TELEPHONE THEORY AND PRACTICE

MANUAL SWITCHING AND SUBSTATION EQUIPMENT

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TELEPHONE THEORY AND PRACTICE

BY

KEMPSTER B. MILLER

THEORY AND ELEMENTS

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AUTOMATIC SWITCHING AND AUXILIARY EQUIPMENT

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PREFACE

The title "The Telephone Exchange," originally intended for the second volume of this series, was found to be too comprehensive for a single volume of reasonable size. It was necessary, therefore, either to condense the subject matter logically coming within that title to a degree that seemed undesirable or to present it in two volumes. The latter course was adopted, resulting in the two volumes now presented, this one, "Manual Switching and Substation Equipment," and its companion, "Automatic Switching and Auxiliary Equipment." Although closely related as parts of a whole, each is fairly complete in itself in covering the branch of the subject to which it relates. As the titles indicate, the general dividing line between the two is that between manual and automatic or machine-switching systems. Parts of each, however, such as "Substation Equipment" of this volume and "Auxiliary Equipment" of the companion volume, cover matter in large measure common to both types of system.

This, then, is the second volume of "Telephone Theory and Practice." It relates almost exclusively to the subscriber's station equipment and the central-office switchboards employed in *manually* operated exchanges. Based on the foundation of elementary theory and with the historic background furnished by the preceding volume, "Theory and Elements," it takes up in considerable detail, first, the talking and signaling equipment and circuits at the subscriber's stations and, then, the switchboard equipment and circuits at the central office. Such auxiliary equipment as protective apparatus, distributing frames, power plants, private branch exchange and toll switching apparatus, which is used with suitable variations in both manual and automatic exchanges and which could be better dealt with only after both types of exchange equipment had been discussed, is left for the concluding portions of "Automatic Switching and Auxiliary Equipment," the third volume of the series.

I am glad to acknowledge the generous cooperation of the American Telephone and Telegraph Company, the Automatic

Electric Company, the Bell Telephone Laboratories, the Kellogg Switchboard and Supply Company and the Stromberg-Carlson Telephone Manufacturing Company in furnishing their literature, illustrations, and often matter specially prepared in response to my requests for information. To the officers and others in each of these companies who made this policy of cooperation possible my thanks are extended.

Among the many friends who, as individuals, have assisted in one way or another and to whom my acknowledgment and thanks are due are Mr. W. E. Darrow and Mr. G. H. Peterson of the American Telephone and Telegraph Company for their contributions concerning later phases of the Nos. 1 and 11 switchboards with straightforward trunking, Mr. Eugene A. Reinke of the Stromberg-Carlson Company and Mr. P. A. Bolander of the Automatic Electric Company for the information they placed at my disposal concerning the products and practices of their respective companies, Mr. Richard Maetzel of the New York Telephone Company for criticism and helpful suggestions concerning Chapter VIII, Mr. H. H. Lowry of the Bell Telephone Laboratories on whose storehouse of useful information I have repeatedly drawn, Mr. Ned Crawford of Pomona, California, for his many practical suggestions and his critical checking of parts of the text and circuit diagrams and finally, my long-time friend and former partner, Mr. Samuel G. McMeen, who, with his great fund of wisdom and telephonic lore, has always been ready with helpful counsel. Other and more specific credits for sources of information on which I have freely drawn and for courtesy in permission to use illustrations are made throughout the book.

KEMPSTER B. MILLER.

PASADENA, CALIFORNIA.
December, 1932.

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CHAPTER I

TALKING APPARATUS

The term "talking apparatus" applies to those parts of telephone equipment that are used in projecting and receiving speech. It distinguishes broadly from other classes of equipment, such as "signaling apparatus," "switching apparatus," and "protective apparatus."

Ordinarily three pieces of talking apparatus—a transmitter, a receiver, and an induction coil—are associated in a proper circuit to form what is called a "talking set." In a telephone exchange a talking set is found at each subscriber's station and also at each operator's position at the central office.

The study of the vibratory diaphragms employed for picking up the sounds at the transmitting end and for emitting them at the receiving end is deep and those desiring to engage in it may find excellent books treating of it exhaustively.[1] It will suffice here to review briefly the requirements of diaphragms in telephone instruments and to point out a few of their characteristics.

In the chapters treating of sound in the preceding volume of this work[2] we have referred to resonant vibrations as distinguished

[1] KENNELLY, A. E., "Electrical Vibration Instruments," The Macmillan Company, New York, 1923.

CRANDALL, IRVING B., "Theory of Vibrating Systems and Sound," D. Van Nostrand Company, New York, 1926.

RAYLEIGH, LORD, "Theory of Sound," 2d ed., 2 vols., Macmillan & Co., London, 1926.

[2] "Theory and Elements," p. 115.

from forced vibrations. As a rule the vibrations of strings, reeds, and air columns of musical instruments are resonant. That is, they are in accordance with the natural rate or rates of vibration of the sounding bodies. This condition is sought in musical instruments because of the greater amplitude and louder sounds thus secured. In these instruments the problem is one of causing the vibrating member under a given set of conditions to give forth most efficiently a tone of one pitch, the fundamental and harmonics of which are all the result of resonant vibrations.

Quite a different problem is met in connection with the diaphragms of telephone transmitters and receivers. The requirement for an ideal diaphragm[1] would be for a single member that would respond with equal facility to all the frequencies in the entire range of the sounds of speech and the even wider range of the sounds of music, if music also is to be transmitted. In other words, naturalness and intelligibility of transmitted speech and complete faithfulness of reproduction of transmitted music would best be served by reproducing all of the component frequencies of the original sounds, as nearly as possible in proportion to their original amplitudes. Obviously if a transmitter or receiver diaphragm has pronounced resonance at certain frequencies, that is, if it responds to some frequencies much more readily than to others, those frequencies will be unduly accentuated and the resulting sound distorted.

Under a truly ideal condition, therefore, resonance within the frequency range of the sounds to be transmitted would be avoided. This means that forced vibrations would be relied on in order to secure, as nearly as possible, equal facility of response to all frequencies.

It is possible, as will be shown, to approach fairly close to this ideal by so tightly stretching the diaphragm, or so heavily damping it, that its resonant frequencies will lie outside the useful range of telephone transmission. This, however, can be done only at a tremendous sacrifice of vibrational efficiency, which cannot be tolerated in commercial telephony. The amplitude of vibration, that is, the response to sound waves in transmitters or to waves of magnetic force in receivers, is so greatly diminished under these conditions as largely to destroy the

[1] "Theory and Elements," p. 174.

sensitiveness of the instrument. In the diaphragms of transmitters used in radio broadcasting and in public-address systems, for instance, this great loss in sensitiveness may be borne in the interest of nearly distortionless transmission because, in these instruments, the vacuum-tube amplifier is available to magnify the enfeebled output of the transmitter several millionfold, thus restoring it to the required energy level.

In ordinary commercial telephony the requirements, particularly as to naturalness of transmission, are not so exacting as in radio broadcasting and, moreover, it has not yet been found feasible to associate a thermionic amplifier with each transmitter. A narrower band of transmitted frequencies suffices, and somewhat greater distortion within this band is permissible, so that the refinements involved in the uniform-frequency-response diaphragm and in the vacuum-tube amplifier of the broadcasting transmitter are not necessary. In fact they would be highly objectionable in commercial telephony where simplicity and low cost are of fundamental importance.

In order to obtain the required degree of response, therefore, it is necessary in commercial transmitters and receivers to employ diaphragms with some resonant effects inherent in their structure. Naturally, in designing the instruments, these points of resonance are so chosen that they will be as helpful as possible in securing the desired amplitude of response and at the same time as harmless as possible with respect to their effects on naturalness and articulation. As a result, the point of maximum resonance in most telephone diaphragms has been placed at about 1,000 cycles per second, with other minor resonance points at frequencies above and below this value. Most of the commercial transmitters and receivers were developed in this respect by cut-and-try methods, the experimenter altering the diaphragm and its damping until the best results, as judged by listening to the reproduced sounds, were secured.[1] Later analyses, made since more precise means of measurement have been available, have led to about the same conclusion with respect to the proper point of maximum response in the frequency scale. It has been found that shifting the point of maximum response to a lower value made the reproduced sounds "boomy," while shifting it to a higher frequency made them weak and thin.

[1] Martin and Davidson, The Trend in Design of Telephone Transmitters and Receivers, *Bell System Technical Journal*, October, 1930.

With the region of maximum response in the neighborhood of 1,000 cycles, the maximum range has been found to extend about an octave on each side of this point, that is, from 500 to 2,000 cycles, and of course there is minor response to frequencies somewhat below and above this range. A diaphragm with a maximum response at about 1,000 and a range of response extending somewhat more than an octave above and below this point best satisfies, within commercial limitations, the requirements of both naturalness and intelligibility of reproduced speech.[1] It

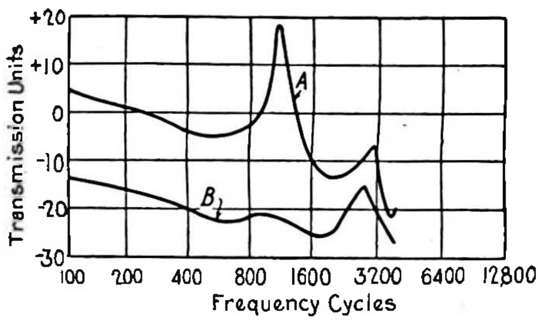


FIG. 1.—Frequency-response characteristics of telephone receivers.

is for this reason that commercial transmitter and receiver diaphragms are made most responsive within this range.

Aside from the vibrational characteristics of the diaphragms themselves, there are other features in the design of transmitters and receivers which in themselves have inherent resonance and which in turn affect the vibrations and the quality of the sounds transmitted. Among these are the enclosed air cavities such as that in the mouthpiece of the transmitter and those in front of and behind the diaphragm of transmitter and receiver. These auxiliary or associated resonances should, of course, without being too pronounced, be made to lie as far as possible within the frequency range just mentioned and thus, without undue distortion, to increase the vibrational efficiencies within the voice-frequency range.

As examples of actual attainment: Fig. 1 shows the relative response of two types of telephone receivers to various frequencies, ordinates representing the degree of response expressed in transmission units (*TU*) or decibels (*db*), and abscissas the frequencies in cycles per second. Curve *A* is that of a com-

[1] "Theory and Elements," p. 184.

mercial head receiver when held to the ear as in use. It will be noted that the response varies widely throughout the frequency range up to about 3,200, and that a decided resonance occurs in the neighborhood of 1,000 cycles.

Curve *B* shows the response of a receiver having a heavily damped diaphragm. Here the response is much more uniform and, it is also to be noted, much smaller throughout the entire range than for the undamped diaphragm. This is characteristic of the difference between damped and undamped diaphragms. As a rule, intelligently applied damping will tend to make resonance at particular frequencies less pronounced but it will also in marked degree cut down the amplitude of response.

The damping of transmitter diaphragms has long been generally employed in commercial instruments. Besides accomplishing the desirable result of so placing the resonant points within the voice-frequency range that they will be most helpful in the matter of efficiency of vibration and least harmful in the matter of distortion, it accomplishes another beneficial result. It renders the transmitter much less sensitive and therefore less responsive to extraneous noises occurring at points more remote than the speaker's voice. It is possible to make transmitters much more sensitive and responsive than those in common commercial use. These have purposely been rendered relatively insensitive so as to respond principally to comparatively strong vibrations of the speaker's voice directly in front of their diaphragms and only slightly to the weaker vibrations reaching them from more remote room noises.

With commercial receivers the case is somewhat different. While proper damping of the receiver diaphragm would, by making its frequency response more nearly uniform, affect a considerable improvement in the matter of articulation, the gain would be at too large a sacrifice in the matter of efficiency. Holding the receiver directly against the ear as in use results in a certain amount of damping. The only energy available for causing the diaphragm to vibrate is that of the incoming voice currents and at times these are so exceedingly feeble that the sacrifice in efficiency that would be caused by additional damping cannot be tolerated. The distortion due to resonance at various points in the frequency range is therefore allowed to remain as the lesser of the two evils.

It may be said further, in regard to this lack of uniform response of transmitter and receiver diaphragms throughout the frequency range, that the marvelous flexibility and adaptability of the human hearing mechanism comes, in large measure, to the rescue. In a telephone system which fails to reproduce equally all frequencies in the speech range by a ratio no greater than 10 to 1, the results cannot be distinguished from the sounds transmitted by a perfect system or, in other words, from those uttered by the speaker himself. Much greater ratios than 10 to 1 in the response along the frequency range may therefore be tolerated without an undue effect on either naturalness or intelligibility of transmission.

Contrast the frequency requirements met in the problems of the alternating-current power engineer with those of the telephone engineer. The power man designs his system for the highest possible efficiency at one particular frequency. This applies to his transmitting device (generator), his induction coil (transformer), his receiving device (motor), and his lines. His whole system is developed for one particular frequency. The telephone man, on the other hand, must avoid just what the power man strives for. He must shun efficiency greater at any one frequency than at others, which means that he must transmit a wide band of frequencies with as nearly as possible equal efficiency. He is not so vitally concerned in mere efficiency as is the power man. He starts with an almost inconceivably small amount of energy but fortunately he has means at hand for supplementing and reinforcing the energy which is originally supplied by the sound waves to be transmitted. Again, the cost of the energy thus supplied for voice transmission is relatively small, so that it does not enter in any major degree into the economic problem. In power transmission it is the mere energy itself which constitutes the commodity that is being sold, and the efficiency of its transmission is therefore of paramount importance. In telephony the commodity being sold is transmitted intelligence rather than mere energy, and the effectiveness of transmission is not measured by power efficiency but by intelligibility.

Transmitters.—The telephone transmitter is the device which converts the energy of the sound waves into corresponding current undulations. How small the amount of energy is which it receives from the voice of an average speaker may be realized from a statement of Fletcher that the average speech power of natural voices is about one ten-millionth of a watt. He translates this into more understandable form by saying that if five million people all talked at once the combined power thus created would be just about sufficient to light an ordinary incandescent lamp.

In so far as they have been put into practical use, transmitters are of three types: magneto, electrostatic, and variable resistance. Types operating on other principles have been proposed, but none of them has met with sufficient success to warrant its becoming a part of the practiced art.

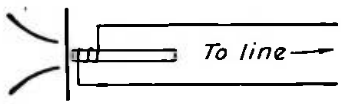


FIG. 2.—Principle of magneto transmitter.

The magneto instrument, as we have seen, was the one first devised by Bell. On account of its feeble output as a generator of undulatory current, it has practically passed from use as a transmitter, but it has survived universally as a receiver. In view of the means now at hand for greatly magnifying the energy of small currents without distorting them, it would not be surprising if, in the further development of telephony, the magneto instrument again assumed an important place as a transmitter. Its simplicity and its faithfulness of reproduction are factors which point in this direction.

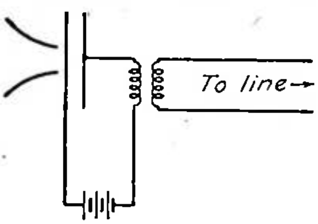


FIG. 3.—Principle of condenser transmitter.

The essential elements of magneto transmitters are a magnet, a coil surrounding its pole, and a light armature of iron adapted to vibrate in close proximity to the magnet pole in response to the sound waves that it is desired to transmit. These elements are indicated in Fig. 2, which will be recognized as the same in substance as Fig. 15 of the preceding volume of this work, there referred to in connection with Bell's development.[1]

Any of the various types of commercial receivers that are dealt with later in this chapter will act as transmitters with fair results in so far as quality is concerned. Feebleness of output is their present disqualifying characteristic. Recently, as will be shown later in this chapter, more powerful magneto transmitters of the moving-coil type, which have a uniform response over a wide

[1] "Theory and Elements," p. 46.

range of frequency, have been developed for radio and motion-picture work.

The electrostatic or condenser transmitter is essentially a condenser whose capacity follows very closely the pressure variations in the sound waves. In its modern form it consists merely of two parallel conducting plates separated by a thin layer of air. One of these plates is fixed, while the other acts as a diaphragm and by its vibrations serves to alter the electrostatic capacity of the two. The principle of its action may be seen in Fig. 3. The condenser, of course, becomes charged from the battery or other constant source of electromotive force connected between its plates. As the diaphragm plate vibrates, it alters correspondingly the capacity of the condenser and therefore the amount of charge it is capable of holding. The corresponding readjustments between the capacity of the condenser and its charge cause currents to flow in the conductors connecting it with the battery and therefore in the primary winding of the induction coil, the secondary of which is connected to the line through amplifiers.

The electrostatic transmitter entered at an early date into the controversy regarding the invention of the telephone, but it never gained a foothold until the advent of radio broadcasting. Like the magneto transmitter, it may act also as a receiver; but, unlike it, it has been even to the present day a negligible factor in ordinary commercial wire telephone practice. Within a few years, however, it has found an important place in radio work. Its action in producing undulatory currents is exceedingly feeble, but the currents that it does produce represent the actuating sound waves perhaps more faithfully than those of any other transmitter. The disadvantage of its feebleness has been overcome by the vacuum tube, which has made it possible to magnify its output some millions of times with but slight distortion. It is now largely used in radio broadcasting, also finding some use in loud-speaking address systems. As a laboratory instrument it is of great value as an aid in studying and measuring sound waves and voice currents. It will be dealt with more fully later.

For commercial telephone-exchange work and for long-distance transmission over wires, the variable-resistance transmitter is now universally employed. It acts not as a current *generator* but as a current *modifier*. As its name indicates, it varies the strength of an otherwise steady current by varying the resistance of the circuit through which this current flows. Its principle is again indicated in Fig. 4.

There are many conceivable ways by which the mechanical vibrations caused by the sound waves might be made to produce corresponding variations in the resistance of a current path. For instance, both Bell and Gray proposed varying the resistance of the path through a conducting liquid by varying the extent to which a vibratory electrode was immersed in it.[1] It was Bell's instrument operating in this way that caused the electric telephone to speak its first sentence. But of all the methods that have been proposed, that of causing the sound vibrations to vary the pressure between two lightly engaging electrodes has proved by far the best for general commercial use. Devices acting on this principle have been found capable, with great simplicity and small cost of construction, of producing more powerful results than the others. Of all the conducting materials that might be used for electrodes, nothing has been found even to approach carbon in effectiveness. It is fortunate that in this one substance should be found those qualifications which make it particularly desirable for microphonic work. It not only produces the desired changes in resistance with changes in contact pressure better than any other known substance but, in addition, possesses the desirable property of lowering its resistance when heated; and it is elastic, non-corrosive, inexpensive, and easily worked.

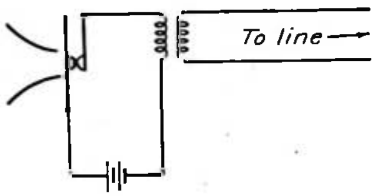


FIG. 4.—Principle of variable-resistance transmitter.

The theory of the microphonic action of carbon contacts and also the reason for the superiority of carbon over all other conducting materials have been subjects of much discussion. At least five different theories of carbon's microphonic action have been put forth as follows:

First, that the specific resistance of the carbon changes with changing pressure. Edison, at an early date, suggested that microphonic action might be due to changes in specific resistance of the material involved in the contact.

Second, that there exists between the electrodes a film of air or gas which prevents actual contact, and that the thickness of

[1] "Theory and Elements," Figs. 11, 12, and 16.

this film is varied by changes in pressure, with resulting changes in resistance. Emile Berliner, to whom the original variable-pressure transmitter is attributed, held this view. A recent extension of this theory suggests that the conduction process may involve the passage of electrons across gaps of molecular dimensions, the emission of electrons from one electrode and their passage to the other being due to the electrostatic field gradient which could exist in such minute gaps with pressures of only a fraction of a volt across them.

Third, that the negative temperature coefficient of carbon—its decreasing resistance with increasing temperature—is in some way accountable for the action.

Fourth, that the change of resistance is caused by variations in the length of electrical arcs between the electrodes. This is, perhaps, but a variation of the second theory above.

Fifth, that the changes in resistance are due to the variations in area of contact between the electrodes—that is, the variations in the number of molecules in actual contact.

The first of these theories now has little support. Ordinary carbon, within its own mass, seems not to change its resistance with changing pressure, at least not to a sufficient extent to account for the action. The writer has made experiments with long carbon rods and with measuring instruments of ordinary sensitivity has been unable to detect any changes in resistance when the pressure was varied from zero to the crushing point. Care was taken that none of the contacts in circuit were subject to the variations in pressure. Professor Bridgman of Harvard, with precision instruments, has tested the specific resistance of carbon through very wide pressure ranges. He found a maximum change in resistance of 12 per cent at 12,000 atmospheres.[1]

The second, or occluded gas theory of Berliner, apparently has been discredited effectively. As long ago as 1897, R. A. Fessenden showed[2] that the resistances of contacts were quantitatively not in accord with those that it was thought would exist were there an intervening layer of gas; also, that the curve formed by plotting resistances against distances was not of the form to be expected for varying lengths of paths through a film of gas or fluid. However, it may be said that at the time of Fessenden's

[1] *Proceedings*, the American Academy, vol. 56, p. 61, 1921.

[2] Fessenden, R. A., Microphonic-Telephonic Action, *American Electrician*, May, 1897.

experiments, knowledge of such phenomena was rather vague. Later, and more conclusively, Holm has shown that when two carbon particles are brought close enough together to conduct electricity, the current flow is directly from carbon to carbon.[1] Holm's conclusion has been borne out by others as will be shown.

As to the third theory, we have seen no reasonable explanation of how the fact that carbon lowers its resistance with rising temperature would serve any useful purpose in causing the resistance of the contact to follow the momentary changes in pressure. True, the heat generated by an increase of current might cause a further decrease of resistance, but this and the reverse action would seem to be of a lagging and cumulative nature not helpful in producing the moment-to-moment variations of microphonic action.

The fourth, or arcing, theory seems to have little validity. Holm's proof that the conductivity is directly from carbon to carbon apparently disposes of it. Moreover, we know that under conditions where arcing is present to any marked extent the transmitter ceases to be effective.

The fifth, or area of contact, theory is undoubtedly the one most nearly accountable for microphonic action. Increase of contact area with increase of pressure is easily understood from the following well-known experiment: If a billiard ball be gently pressed on a smooth marble slab with a thin coating of graphite, the area of contact will be indicated by a small dot of graphite on the ball. If now the ball be dropped from a considerable height, the spot will be much larger, showing that the ball has been flattened to an appreciable extent by the greater pressure at the contact. Of course, if the two bodies had been conductors, the resistance between them would have decreased as the area of contact increased.

In considering the variable area of contact theory, it must be remembered that the surfaces of any single pair of granules in microphonic contact will not be quite analogous to the smooth surfaces assumed for the billiard ball and table top. There will be different orders of roughness resulting in a number of points or small areas of contact instead of a single area. Variations in pressure will not only cause variations in the areas of surfaces already in contact but in the number of contacts as well, new

[1] *Zeitschrift für technische Physik*, vol. 6, p. 166, 1925.

contacts being brought into play by increased pressure and *vice versa*.

Very recently, Dr. Frederick S. Goucher of the Bell Telephone Laboratories has devised an apparatus and developed a technique for studying the behavior of contacts between granules of microphone carbon under very small contact forces (1 dyne or less) and at different temperatures either in high vacuum or in any desired atmosphere of gas.[1]

At the beginning of his paper Dr. Goucher gives an excellent historical *résumé* of recent work and thought on the subject of microphonic action. His principal conclusions from his own experiments are:

First, that the conducting portions of the contact are of the nature of carbon, the temperature coefficient of resistance being negative and the magnitude of this coefficient of the right order and sign as for the same grade of solid heat-treated carbon. Second, that the magnitude of the temperature coefficient of resistance was independent of gas pressure, even though the presence of gas increased the contact resistance. Hence the gas acted as a non-conducting film, limiting the areas of the conducting portion of the contact and not affecting their nature. Third, that the reversible changes of contact resistance with applied voltage—the resistance decreasing with increase of voltage—was due entirely to the heating of the contacts by the passage of current. He concludes that "the conduction process is thus shown to be that which occurs in solid carbon, and no other effects, such as an electronic discharge across small air gaps, can be an important effect."

As a final conclusion he states in part: "All the experimental results are therefore consistent with the theory of area change due to the elastic deformation of the contact material."

While the theory of an intervening layer of gas preventing contact apparently has been disposed of, it would be unsafe to say that the presence of gas either condensed on the surface of the electrodes (adsorbed) or held within their pores (absorbed) does not play an important part in microphonic action and in rendering carbon the most suitable substance for this action. Other experiments have been made in the Bell laboratories to show the effect of gases held on the contact surface of carbon

[1] Microphonic Action in Telephone Transmitters, *Science*, n. s., vol. 72, pp. 467–470, November 7, 1930.

electrodes, those held in the pores opening into the contact, and those held in the body of the material adjacent to the contact.[1] These experiments bring out many facts not before known regarding the influences of gases on the resistance of carbon contacts. Where this new knowledge, or the further information that will undoubtedly be derived from additional scientific research, will lead it is not now possible to state, but it is to be expected that it will result at least in improvement of transmitter design.

To come now to the practical embodiment of the variable-resistance principle in commercial forms of transmitters, reference will first be made to the transmitter devised by Francis Blake, of Boston, in 1878. This, at one time the universal standard of the Bell System, is shown in Fig. 5. It is now mainly of historic interest, for it passed from commercial use during the nineties. It is instructive in showing what the trend of development has been. The general features of the transmitter are sufficiently clear from the illustration, but special attention is called to the vibratory system. The diaphragm was of rather heavy sheet iron, supported in an elastic rubber band stretched around its edge. It was held in place by two damping springs, each bearing on a soft rubber pad resting against it and pressing it against its seat. The front electrode was a small piece of platinum mounted on a light spring and so positioned as to rest against the rear of the diaphragm at its center. The back electrode was a small block of hard carbon, polished on its front face and mounted in a heavy brass block which was supported by a comparatively heavy spring. The light spring carrying the front electrode tended to press away from the diaphragm, while the spring supporting the back electrode had its tension in the opposite direction, and being the stronger it held the front electrode against the diaphragm.

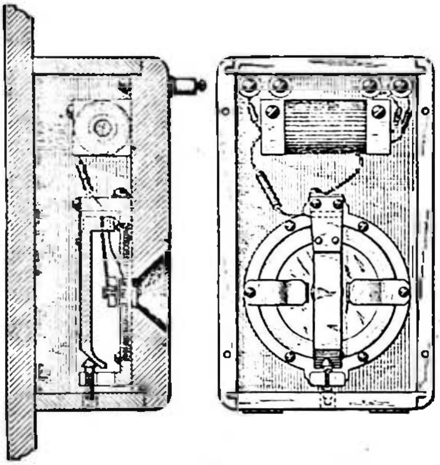


Fig. 5.—The Blake transmitter.

[1] Olmstead, P. S., Effect of Gases on the Resistance of Granular Carbon Contacts, *Journal of Physical Chemistry*, January, 1929.

The two electrode-carrying springs were insulated from each other and each mounted at its upper end on an adjustable lever, hinged at its upper end so that its lower end could be moved back and forth by an adjusting screw projecting from the bottom of the box. Here, instead of having one electrode fixed as is now customary, both were flexibly mounted, but the rear one was so weighted that its inertia rendered it practically fixed against the rapid vibrations of the diaphragm. In this way the initial pressure between the two electrodes was susceptible to very delicate adjustment and, when adjusted, was practically independent of temperature changes.

The Blake transmitter represents probably the highest commercial development of "single-contact" types. It is of further interest because it employed platinum instead of carbon as one of the electrodes. In this particular case that practice proved best. In most transmitters of modern design it has been found best to make the entire variable contact system of carbon, although, as will appear in Fig. 32, for example, there has been a recent tendency to revert to metal-carbon electrode combinations. Even in these cases, however, the principal resistance-varying action is still between carbon and carbon.

The Blake instrument, when properly adjusted, gave excellent quality of transmission but it had two serious faults. It lacked power and it had a tendency to "rattle" or to break contact under the influence of loud sounds. It worked best with a single cell of battery (about 1½ volts). When more battery was applied in attempting to gain transmitting power, it had a tendency to squeal, owing to a vibration set up by the heating of the contact—an action not unlike the Trevelyan effect.

Two characteristic features of the Blake transmitters are conspicuous by their absence in all modern transmitters: first, the employment of but a single contact; and, second, a means of adjustment of the initial contact pressure.

The single-contact transmitter passed out of existence as the result of a demand for greater power, which could be effectively provided only by passing the current through a plurality of resistance-varying contacts. At first the so-called "multi-contact" transmitters used a number of carbon rods, balls, or buttons, resting lightly against other carbon members, so related to the diaphragm as to partake of its vibration. The several contacts were electrically connected in series or in multiple, or in series-multiple relation. The logical outcome of all this multi-contact effort was the adoption of Henry Hunnings' idea of employing a mass of loosely held carbon granules as a resistance-varying medium. Here the multiple-contact idea was attained in maximum degree and with a minimum of inertia, complexity, and cost. In effect, such a mass of granules provides a number of parallel variable-resistance paths, each containing a number of variable-resistance contacts in series. The desired series-multiple arrangement was thus attained automatically.

As to the absence in modern instruments of the adjustable feature of the Blake transmitter, it may be said that the same absence is to be noted in many other kinds of telephone apparatus. During recent years there has been a growing tendency to incorporate the proper adjustment once and for all into the apparatus as a factory operation and, having secured the proper adjustment, to provide no means for subsequently altering it.

Probably as simple a form of granular-carbon transmitter as ever came into commercial use was that shown in Fig. 6. This achieved some prominence in the United States in the late nineties. In this the chamber containing the granular carbon was of the same diameter as the free part of the diaphragm. The diaphragm was a thin disk of hard carbon and served in the triple capacity of diaphragm, front electrode, and enclosing member for the granule chamber. The faulty electrical design is obvious, since the path through the almost inert granules near the edge of the diaphragm forms a shunt for the path through the more active granules near the center. Notwithstanding this and other defects, this transmitter was surprisingly effective.

In practically all later transmitters the carbon chamber has been made smaller so as to occupy an area opposite the central and more active portion of the diaphragm, as is obviously proper. In this form the problem was how best to enclose the granule chamber at its edges, so that the granules might be held in their proper space, and at the same time allow the diaphragm its necessary freedom of movement. One solution, largely used both in this country and in Europe, was to employ a felt washer, the hole of which was filled by the loose mass of granules, the front and rear openings of this enclosure being closed by the front and rear electrodes, respectively. On account of the felt washer, this became known as the "corn-plaster" type of transmitter. Powerful results could be secured with instruments of this general type and they were widely used in both America and Europe. One fault was the tendency of the felt washers to absorb moisture and thus alter the operating characteristics with time. Another was the difficulty of manufacturing a uniform product with this type of construction.

Probably the most serious defect, however, in all these early granular-carbon transmitters, was that due to "packing." At first this trouble was thought to be purely mechanical, due to the granules tending to settle into a compact mass and thus largely losing their ability to change their resistance under varying pressure. We know now, however, that so-called packing may be due to either mechanical or electrical causes. Mechanical packing may be caused by the presence of moisture; the use of granules of varying sizes, so that they tend to arrange themselves in a compact cake; the granules wedging the two electrodes apart and holding them at a greater distance than their normal separation; or variations in the dimensions of the containing chamber due to either heat or mechanical stresses. Electrical packing is due to the coherer action among the granules when subject to a higher than normal voltage, even though the energy involved be exceedingly minute. Electrical sparking, such as may occur upon the breaking of some of the contacts of the telephone itself, may cause the granules to cohere.

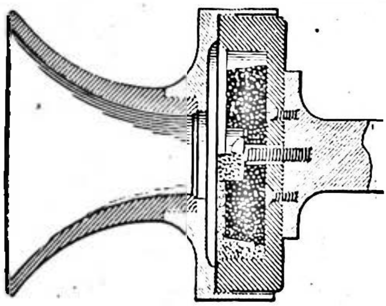


FIG. 6.—Simple granular-carbon transmitter.

Frequently a transmitter when packed may be again put in working condition by a sharp rap from beneath. Before the modern form of transmitter had been evolved, various non-packing, or more properly unpacking, devices were proposed. For instance, the form of transmitter shown in Fig. 6 was at one time so arranged that it could be turned axially by merely twisting the mouthpiece. This would unpack the granules, allowing them freely to rearrange themselves. Another scheme for accomplishing the same result was to provide mechanism for revolving the transmitter, a little at a time, at every stroke of the switch hook. A ratchet was mounted on the periphery of the transmitter casing, which was engaged by a pawl carried by the switch hook. All these devices added unnecessary complexity and have been abandoned. They were based on the principle of correcting an evil rather than preventing it.

It was Anthony C. White, an engineer of the American Bell Telephone Company, who in 1892 showed the way to the modern microphone transmitter. He evolved the scheme of closing the granule cell by a flexible mica washer clamped at its periphery against the rim of the stationary containing cup and at its center against the movable front electrode. In this way the cell was effectively closed against the entrance of moisture and at the same time the required permanency of adjustment, and freedom of movement of the front electrode, was permitted. By the massive construction of the non-vibrating parts of his instrument he allowed the free escape of the heat developed, thus preventing undue heating of the essential parts. The tendency to pack was greatly reduced and, not the least important of all, the mechanical design was such as to permit the manufacture of a uniform product.

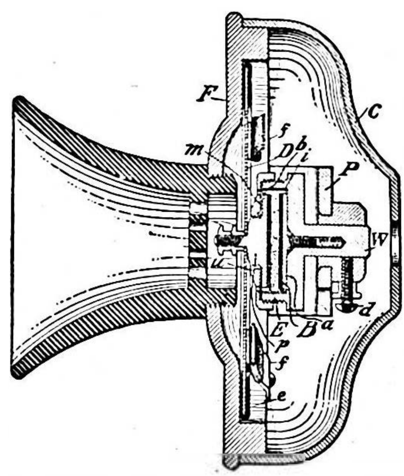


Fig. 7.—White solid-back transmitter.

White's instrument, in the exact form in which it was used for many years by the Bell System, is shown in Fig. 7. Although modern transmitters have departed somewhat from this design, most of them follow closely its principal features. A somewhat detailed description of it will make later types more readily understood.

The front *F* of brass is held in the hollow shell *C*, the two pieces forming a complete metallic casing for the working parts of the instrument. The sound-receiving diaphragm *D*, of hard aluminum, is encased in a soft-rubber ring *e* and held in place by two damping springs *ff*. *W* is a heavy brass cup forming a casing for the electrodes. Its inner circumferential wall is lined with a strip of paper *i*. This block is mounted on a supporting bridge *P*, secured at its ends to the front *F*. The back electrode *B*, of polished carbon, is secured to the face of the enlarged screw head *a*, the shank of which is screw-threaded into the cup *W*. *E* is the front electrode, also of polished carbon, carried on the face of the metallic piece *b*. On the enlarged screw-threaded portion *p* of the piece *b* is slipped a mica washer *m*, held in place by the nut *u*. This washer is of sufficient diameter completely to cover the electrode cup. After the required amount of granular carbon has been put into the cavity, and the front electrode put in position, a screw-threaded clamping ring binds the mica washer securely against the face of the cup, thus confining the granules. The electrodes are of somewhat less diameter than the paper-lined interior of the block *W*, so that there is a considerable space around the periphery of the former, which is filled with carbon granules. This prevents the binding of the free electrode against the edge of its containing chamber and also allows some room for the granules to arrange themselves under the action of heat and vibration. The screw-threaded shank of the front electrode passes through a hole in the center of the diaphragm and is clamped firmly in place by two nuts.

The mouthpiece of hard rubber is screw-threaded into an opening in the front block. The perforated cross-partition in the throat of the mouthpiece guards the interior mechanism against mechanical injury.

The back electrode is in metallic connection with the frame of the instrument, which forms one terminal. The other terminal is mounted on an insulating block carried on the bridge and connected by a flexible wire with the front electrode *E*.

By this design White, for the first time, placed the granular-carbon transmitter on a basis which permitted the manufacture of a uniform product in large quantities. Because its rear electrode was mounted in a heavy block rigidly held, instead of on a flexible spring as in the Blake instrument, it became known as the "solid-back" transmitter. Practically all manufacturers to-day use the solid-back feature.

Before discussing modern commercial transmitters, we may digress to consider briefly the methods by which transmitters are supplied with the direct current which it is their function to vary. It was pointed out in Chap. IV of the preceding volume that in early systems each transmitter was supplied with its own individual battery placed locally at its station. This was the local-battery system. With unimportant exceptions, this practice is now followed only in the telephones of isolated lines and of small exchanges, mostly in rural communities. Modern practice for all larger exchange work is to supply the transmitter current to all stations in each central-office area from a single common source—a storage battery located at the central office. Hence we have two types of transmitter supply—local battery and common battery.

In transmitter operation the two important variable factors, aside from the characteristics of the transmitter itself, are the battery voltage and the resistance of the supply circuit. These two factors, together with the transmitter's own resistance, determine the strength of the current. Obviously the requirements of transmitter characteristics are somewhat different for the two types of supply, and to a certain extent they differ also for lines of different length in the same common-battery system.

In a local-battery system the circuits in which the battery and transmitter work, because they are local and short, are of comparatively low resistance and may be made sufficiently uniform at all telephone stations. This, therefore, practically eliminates one of the variables. The remaining one, battery voltage, must however be contended with. Usually two dry cells are employed with a consequent voltage range from 3 volts down. Within this range marked variations occur, owing, first, to the degree to which the battery has been permanently exhausted by long usage and, second, to the degree of more or less temporary exhaustion during a long conversation.

With the common-battery system, on the other hand, the voltage of the central-office battery is easily kept fairly constant—nominally at 24 or 48 volts, according to the type of system. The length and consequent resistance of the line is, however, a necessary variable because of the different distances of the stations from the central office. Transmitters at stations near the central office will receive greater currents than those at stations more remote. Some difficulty, therefore, is encountered in securing uniformity of transmission for the different zones of a central-office area. Central-office voltage sufficiently high to give transmitters on the average length of line about the desired current is likely to cause the close-in transmitters to receive too much current and those on the outer fringe or zone, too little.

In some exchanges, particularly those of large metropolitan areas, a process called "zoning" is now being resorted to in order to mitigate this difficulty. This consists, in part, of using heavier conductors for the longer subscribers' lines which supply the stations of the outer zones and also, in part, of differentiating between the transmitters that are employed in the different zones. In carrying out the latter feature of zoning, the type of transmitter chosen for the close-in stations is one adapted to work on comparatively heavy currents, while for the outer zones those working best with smaller currents are chosen. Some manufacturers specify the line resistance, or the "loop resistance" as it is called, for which their different types of transmitters are best adapted.

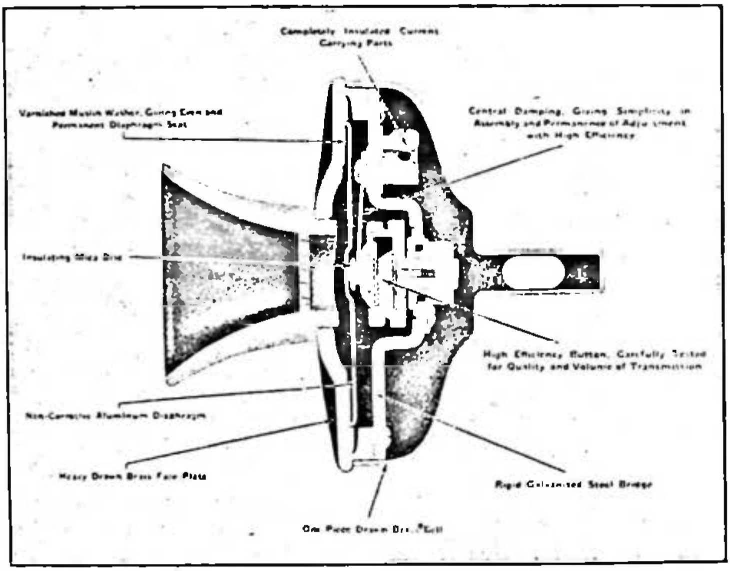


FIG. 8.—No. 323 transmitter of Bell System. (*Courtesy of The American Telephone and Telegraph Company.*)

Of modern transmitters, Fig. 8 shows a cross-section of White's instrument as improved by the late Charles E. Scribner, long chief engineer of the Western Electric Company. This is the present No. 323 transmitter of the Bell System and is undoubtedly the most widely used of any transmitter in existence.

The construction of this instrument is made sufficiently clear by the legends of the diagram. The salient features of White's instrument, that is, the self-contained mica-enclosed carbon cell or "button," and the "solid back," are seen to be present. The rubber gasket supporting the diaphragm and the two eccentric damping springs are, however, absent. Instead, the diaphragm is turned up sharply at its periphery so as to form a circumferential flange which rests against a sheet of varnished muslin.

It is pressed against this sheet by a stud projecting from the front electrode. This stud rests against the center of the diaphragm and is pressed forward by a heavy damping spring which is bifurcated at its free end to engage a groove in the stud. The seat of the diaphragm is made a little larger in diameter than the diaphragm, so that the latter will be free to take its natural position with respect to the button. Another feature of improvement is that all current-carrying parts are insulated from the transmitter casing, thus helping to guard the user against electric shocks when handling the instrument.

This transmitter is one of the present standards of the Bell System, for use on subscribers' loops of small and intermediate length. It has an average direct-current resistance of 35 ohms. With the battery supply obtained on a short loop, it gives an amplification ratio of electrical energy output to acoustical energy input of about 1,000.

In Fig. 9 is shown a cross-section of the No. 337 transmitter of the Bell System. This is due to Mr. J. C. R. Palmer, of the Western Electric Company, and is a Bell standard for use at common-battery sub-stations which are on loops of over 200 ohms resistance. Its average direct-current resistance is 50 ohms and it has an amplification ratio somewhat greater than that of the No. 323 transmitter.

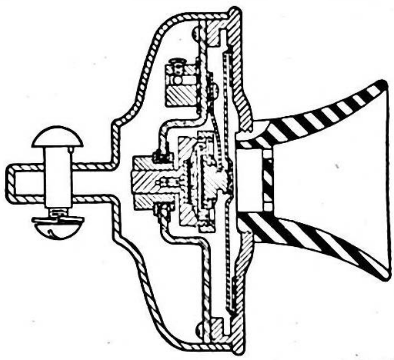


FIG. 9.—No. 337 transmitter of Bell System.

Structurally the No. 337 is the same as the No. 323, except that the granule chamber is tapered from front to rear so as to form the frustum of a cone. The rear electrode is of considerably smaller diameter than the front and completely occupies the smaller end of the cup. By making the chamber of this form, the inactive portions of the mass of granules lie principally at the edge of the larger front electrode and at a distance more remote from the rear electrode than that of any point on the exposed surface of the front electrode. The inactive shunt path, which must always exist to some extent through the granules, is thus made longer than the active path and therefore less effective in reducing the desired current variations.

The standard transmitter of the Automatic Electric Company is shown in cross-section and elevation in Fig. 10. The general features of this instrument are sufficiently clear from the figure, in view of what has already been said, but a few points of special interest may be noted. The auxiliary diaphragm 4, instead of being made of insulating material (mica) as in other transmitters, is here made of a thin flexible metal. Being a conductor, it is used to connect the front electrode 5 through the body 6 of the cup, to the associated cord terminal 14. The chamber 6 is mounted on a back bridge 8 but is insulated from it. It is held in place by the stud 9 projecting from the rear electrode, this

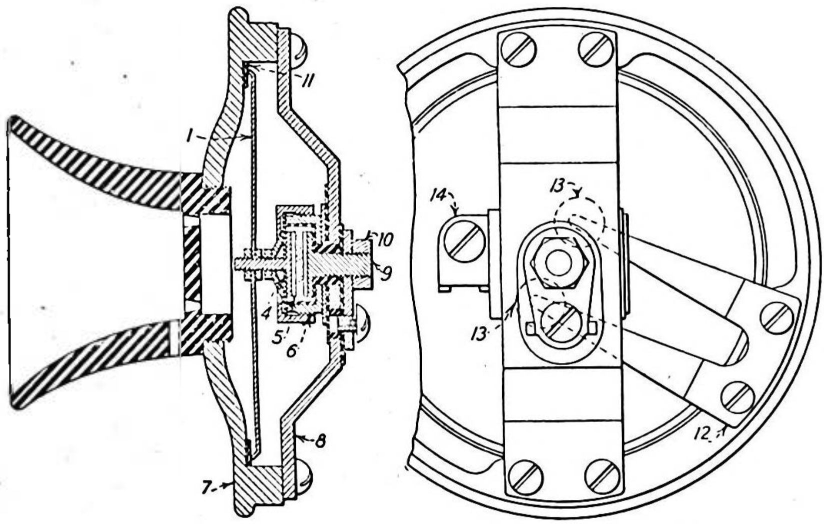


Fig. 10.—Automatic Electric Company transmitter.

being engaged by the lock nut 10. The damping spring 12 is mounted on the rim of the front plate and has two parallel members extending inward and pressing against small insulating disks 13 resting against the diaphragm near its center. The diaphragm is thus bowed outward slightly. As in the later Bell instruments, the entire working parts and terminals are insulated from the front plate and the back containing shell.

The Automatic Electric Company makes this instrument for three different zones of common-battery current supply, adapted for maximum currents up to 60, 125, and 250 milliamperes, respectively. The 250-milliampere type is the one ordinarily used on average subscribers' lines—the two weaker-current types being recommended for unusual or special cases.

The general construction of the transmitters made by the Stromberg-Carlson Telephone Manufacturing Company is shown in Fig. 11. This company standardizes two different types of resistance-varying button. One of these is made along orthodox lines, one electrode being held stationary in the back of the cell and the other occupying the front of the cell and so associated with the diaphragm as to vibrate with it. The other type is unique in that the front carbon disk which vibrates with the diaphragm is split, the two halves being insulated from each other. There are thus two movable electrodes instead of one, each in active connection with the front face of the mass of

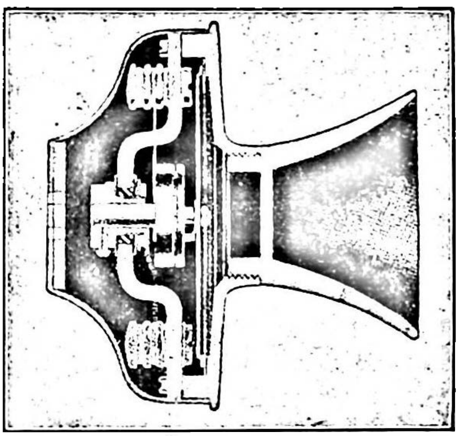


Fig. 11.—Stromberg-Carlson transmitter.

granules. In this case the stationary carbon plate at the back of the cell merely serves as a backing for the granules and is not directly connected in the circuit, the transmitter connection being made to the two movable electrodes. This split-electrode type of transmitter is used by the Stromberg-Carlson Company in its common-battery telephones. The other, or solid-back, type is employed for local-battery telephones.

The split-electrode type is particularly interesting and its principle seems sound. The makers claim that since both of its electrodes vibrate with the diaphragm they are able to obtain almost twice as much resistance-varying effect as those with but one movable electrode. They claim that the microphonic effect of the transmitters takes place mainly in the contacts at, or close to, the movable electrode and that this effect gradually diminishes toward the rear of the mass until there is practically none adjacent to the stationary electrode.

This split-electrode transmitter is made for two zones of exchange service, one, the No. 7-CW, having an average resistance of about 30 ohms, designed for subscribers' loops up to 250 ohms. This is capable of withstanding current up to 280 milliamperes without burning. The average talking resistance of this instrument for various amounts of current is indicated in the curve of Fig. 12.

The other Stromberg-Carlson type, No. 7-C, is designed for use on loops of over 250 ohms and is, therefore, made more efficient

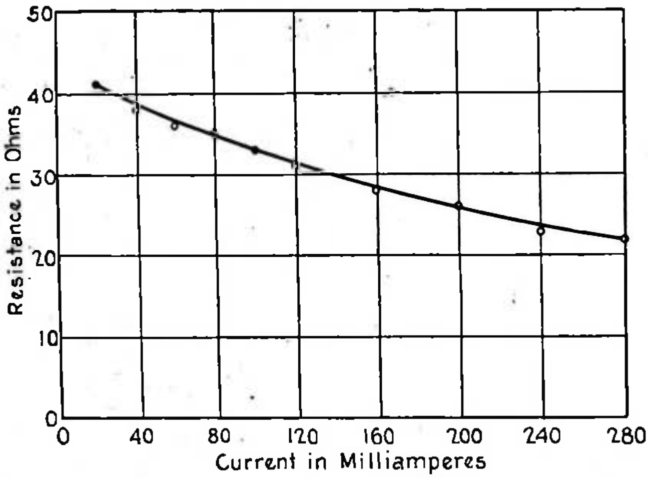


FIG. 12.—Average talking resistance of Stromberg-Carlson short-loop transmitter.

on lower current values. The average talking resistance is approximately 75 ohms, resistance range for various amounts of current being shown on the curve of Fig. 13. While this curve indicates a current range up to 280 milliamperes, 120 milliamperes is about its safe limit.

The local-battery transmitter of the Stromberg-Carlson Company is more nearly of the orthodox solid-back type, the path through the cell being from the movable front electrode to a stationary rear one. It is made, however, with higher resistance than is ordinarily found in instruments for local-battery use. This in itself is a good feature for local-battery telephones, since with the higher resistance there is less drain on the local battery.

Another interesting transmitter is that of the Kellogg Switchboard and Supply Company, designed by Mr. W. W. Dean about twenty-five years ago. It is shown in its original form in Figs. 14 and 15, which disclose its salient features more clearly than any of the available cuts showing it in its exact present form. In its modern form the front is of drawn metal instead of being cast, the rubber gasket surrounding the diaphragm has been done away with, and a more modern form of diaphragm

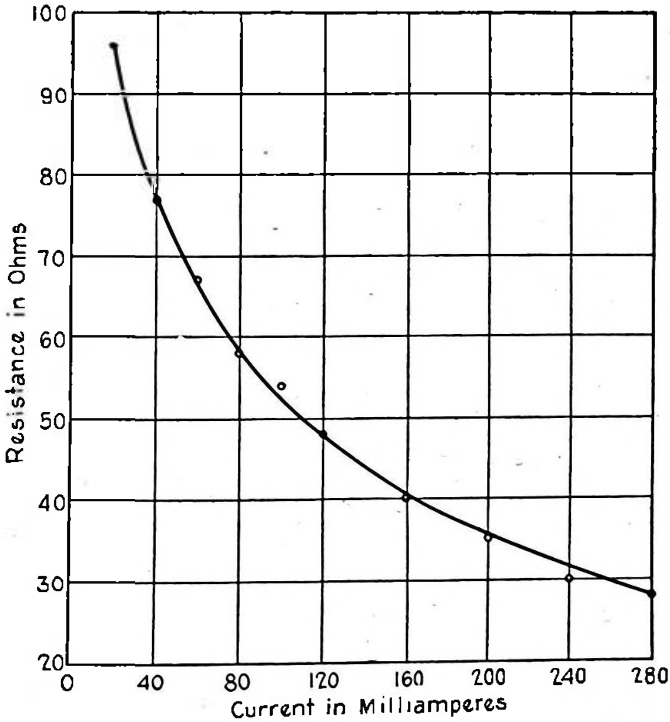


Fig. 13.—Average talking resistance of Stromberg-Carlson long-loop transmitter.

mounting adopted. Also, the modern practice has been followed of insulating all current-carrying parts from the outer shell. The salient parts, however, are as shown in the figures.

The diaphragm *B* is of aluminum and differs from that of other transmitters in that, instead of being substantially a plane, it has a cup-shaped recess *b* in its center, which contains the electrodes and granules. The front electrode *C* is of carbon soldered to a brass plate in the front of this cup. It therefore partakes directly of the movement of the diaphragm. The rear electrode *D* is similarly made up of a carbon disk soldered to the brass disk *d* which has a prolonged screw-threaded shank. This shank passes through a mica washer *E* and a heavy brass bushing *F* which has an enlarged face so as to clamp the mica washer securely against the rear face of the electrode when these parts are drawn together by the nut *f*. After the parts are assembled thus far, the granular carbon is poured into the chamber on top of the front electrode, after which the rear electrode with the mica washer is put in place. This mica washer is then firmly riveted to the diaphragm by means of the aluminum ring *G* and the small rivets *g*. The diaphragm of the transmitter is thus made to carry with it, as an integral part, the entire resistance-varying button. In final

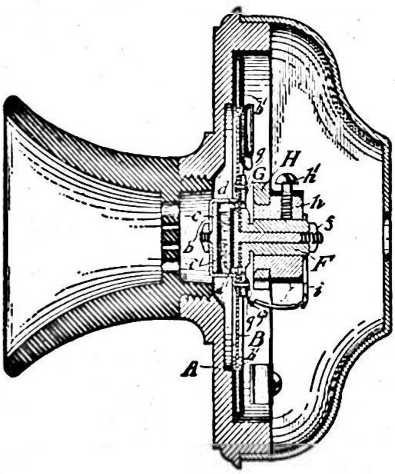


Fig. 14.—Kellogg transmitter.

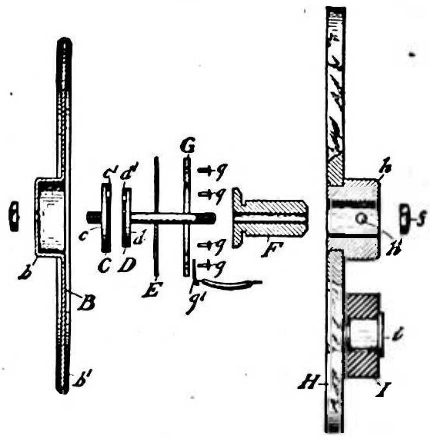


Fig. 15.—Working parts of Kellogg transmitter.

assembly, the rear electrode is held rigidly against vibration by means of the stud *F* which is locked in the bridge *H* by a set screw *h*.

In this instrument the so-called "piston action" between a fixed and a vibrating electrode occurs as in the ordinary solid-back types, the required relative movement being permitted by the flexibility of the mica. The manufacturers claim also that an additional microphone effect takes place on account of the fact that the entire granular-carbon mass is subject to agitation by the vibrations of the diaphragm. There is some question as to whether this latter feature is of sufficient advantage more than to counteract the increased weight which this form of construction imposes on the vibratory member, but, however this may be, this type of transmitter has proved very successful throughout a long period of commercial use.

The Kellogg Company gives the following information about the allowable resistance limits for its common- and local-battery instruments. The resistance is measured with a voltmeter and milliammeter, a constant potential being applied across the transmitter while it is actuated by a tone having a pitch corresponding to a frequency of about 179 cycles. When the current value becomes constant, the meter readings are taken and the resistance computed. The allowable limits under these conditions are: local battery, Type 22-L, minimum 15 and maximum 25 ohms; common battery, Type 22-C, minimum 35 and maximum 55 ohms.

Further examples of present-day commercial transmitters will be given in later portions of this chapter.

It must not be supposed that in any case a mere mechanical design is sufficient to produce a good transmitter. The requirements are so exacting and the number of possible variables sc great that knowledge based on specific experience is required; and this must be coupled with eternal vigilance in order to produce and maintain satisfactory output. In a recent article, Mr. L. C. Pocock, of the engineering department of Standard Telephones and Cables, Ltd., points out some of these requirements and difficulties.[1] In the "solid-back" transmitter the diaphragm movement may be of the order of 10^{-5} centimeter or 0.00004 inch. This small amplitude does not differ greatly from the changes of dimensions that occur in the instrument itself, due to expansion or contraction under temperature changes of a few degrees. It is also comparable to the dimensional changes that may be produced by minute mechanical stresses. When, in addition to these considerations, it is realized that slight variations in the quality of the carbon used for electrodes and granules may produce changes in efficiency and in other required characteristics, the necessity for skill, experience, and watchfulness in the production of transmitters may be appreciated.

The best carbon for microphone transmitters is made from a high quality of anthracite coal carefully selected piece by piece. The selected lumps are subjected to successive crushings, roastings, washings, and siftings. Samples of each lot are subjected to various mechanical and electrical tests. As a final test of

[1] *Electrical Communication*, July, 1929.

fitness a number of transmitters are filled with carbon from each batch and these are tested in various ways. If found unsuitable with respect to any of the necessary characteristics, such as efficiency, resistance, freedom from burning, or uniformity, the entire batch is rejected.

The matter of slow changing with age is one of the most difficult with which the transmitter manufacturer has to deal. It has spelled the doom of a number of promising designs and it has caused unlimited trouble in cases of good design where the manufacturing processes were not carried out with the necessary skill or vigilance.

Receivers.—To construct a receiver that will reproduce speech after a fashion is a very simple matter—in fact nearly any small electromagnet with a light armature, such as is commonly used in electric bells or in telegraph sounders, may be made to speak if only a sufficiently powerful transmitter is used with it. It has proved more difficult, however, to construct a receiving instrument that will produce speech effectively and at the same time successfully meet the practical requirements of everyday service. It has required a vast amount of scientific research and practical development work to bring the receiver from the point where Bell left it to its present stage of perfection. Only recently, in spite of fifty years of effort in this direction, changes have been made in its design which have greatly increased its efficiency, and we have reason to think that this progress is not at an end.

Aside from its electrical efficiency, many considerations of a purely mechanical nature enter into the design of a good telephone receiver. The acoustical design of the chamber in which the diaphragm vibrates should be such as to conduct the sound waves to the ear with minimum distortion and loss. The receiver as a whole must be durable and capable of withstanding the rough usage to which it will surely be subjected by careless or ignorant users. It must be of such construction that its adjustment will be as nearly permanent as possible, which means that it must be rugged enough to withstand all ordinary shocks and of such design as not to be materially affected by changes of temperature or humidity. It must be of such external configuration as to make it attractive in form and convenient for use. Its electrical parts should be so disposed as to make it unlikely that the user will receive electrical shocks from it.

Finally, its construction should be so simple, and its parts so interchangeably built, as to make easy the replacement of any damaged part.

As pointed out in Chap. III of the preceding volume,[1] the first receiver devised by Bell derived its steady magnetic field from an electromagnet energized by battery current. Later Bell substituted a permanent magnet and until recently all receivers have been so constructed. Within recent years, however, there has developed a tendency toward a reversion of type, as a result of which electromagnetic receivers without permanent magnets are in some cases coming into favor. We have then to consider among modern forms two different types, the "permanent-magnet receiver" and the "direct-current receiver," the latter being so called because it derives its steady field from the flow of direct current through its coil.

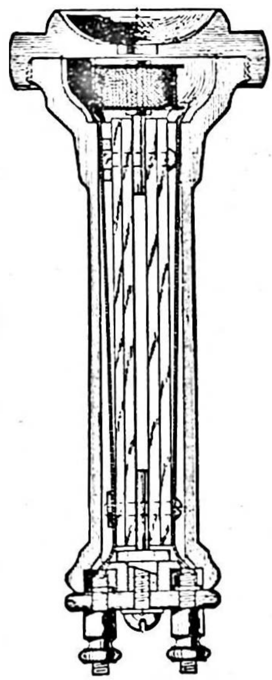


FIG. 16.—Old Bell single-pole receiver.

Each of these types occurs in two forms, quite different as far as outward appearance is concerned: the ordinary bell-shaped hand receiver and the watch-case or head receiver. The hand receiver is the form principally used in subscribers' sets in the United States. The watch-case type, on account of its small size and light weight, is nearly always used by switchboard operators. Of late it is also finding increased favor for subscribers' use in the so-called "microtelephone" or "hand set," where transmitter and receiver are conveniently combined in a single piece of apparatus.

The single-pole receiver as it was early standardized and widely used by the Bell companies in the United States is shown in section in Fig. 16. While it is no longer in commercial use, it may be briefly discussed here to call attention to the faults in its design which have been largely eliminated in modern practice.

In this figure, a compound bar magnet is composed of two pairs of separately magnetized steel bars arranged with like

[1] "Theory and Elements," p. 45.

poles together. Between the pairs of bars at one end is clamped a soft-iron pole piece and at the other end a similarly shaped iron block. These parts are rigidly held together by two machine screws. On the end of the pole piece is slipped a cylindrical coil of wire, wound with two parallel No. 38 B. & S. gage silk-insulated copper wires to a combined resistance of about 75 ohms.

The magnet structure is encased in a shell of hard rubber composed of two pieces which screw together and clamp between them the diaphragm of thin sheet iron. The inner side of the cap is recessed so as to provide free space in which the diaphragm may vibrate, and its outer face is so formed as to fit conveniently and comfortably against the user's ear.

A hard-rubber tailpiece carrying two binding posts fits over the other end of the shell and is held in place by the screw which engages the block at the rear of the magnet structure. This screw serves to hold the tailpiece in place and also to bind the magnet structure securely to the shell. Soldered to the binding posts are heavy lead-in wires, which pass along the sides of the magnet and are soldered at their other ends to the coil terminals.

The diaphragm of this receiver is about 0.01 inch in thickness and 2¼ inches in over-all diameter, the diameter of its free portion being 1¾ inches. It is interesting to observe that none of the standard hand receivers of the present time has departed very widely from these dimensions which were determined by Thomas Watson in the very early days of telephony.

The principal faults of this receiver, as viewed from present-day knowledge, were: first, that the magnet structure presented only one pole to the diaphragm; second, that the magnet structure was attached to the shell at the end remote from the diaphragm; and, third, that its terminals were exposed.

It was later found that the very much more powerful magnetic field which could be secured by bringing the two magnet poles close together, so that they both could be presented to the central zone of the diaphragm, gave much better results. This led finally to the abandonment of the single-pole type.

The securing of the magnet to the shell at the end remote from the diaphragm was objectionable principally because of the variation in adjustment caused by temperature changes or by mechanical shocks. Any difference in the coefficients of expansion of steel and hard rubber caused each change of temperature to alter the length of the air gap between the pole piece and the diaphragm. A broken or cracked receiver shell generally made the receiver unworkable. Modern practice is to support all the working parts of the receiver by an inner metallic cup independent of the shell, so that the shell itself forms no part of the working structure. In this way there is little tendency toward an alteration of adjustment due to changes of temperature, and the likelihood of derangement by mechanical shocks is greatly lessened. Often a broken receiver shell will impair only the appearance of the instrument, its working condition remaining as good as before.

The present practice of putting the terminals within the shell has the advantages of protecting them and of safeguarding the user against electric shocks. The external binding posts were perhaps the most vulnerable parts of the instrument. Their rough usage generally resulted in a broken shell or a broken connection or both. As to the danger of the user being shocked, it is true that voice currents are not harmful. The currents sometimes used in signaling, however, may be of sufficient intensity to cause disagreeable shocks. Aside from the unpleasant effect of these on the user, they may cause him to drop and injure the instrument. But the currents principally to be guarded against are not those normally belonging to the telephone system, but those that may find their way into it accidentally, as when a "cross" occurs between a telephone line and high-tension wires. Such reasons have now led to the general practice, in the case of any instruments that are to be handled by the public, of either putting all metallic parts within the insulated casing of the instrument or insulating exposed metallic parts from all current-carrying circuits.

Before discussing modern types, we may give some general consideration to the electrical characteristics of receivers, particularly with respect to their resistance, reactance, impedance, and efficiency. The subject of receiver action is one to which whole books might be devoted. Much has been written on it, a few examples of which are given below.[1] Only brief rudimentary discussion may be attempted here.

[1] Kennelly, A. E., "Electrical Vibration Instruments," The Macmillan Company, New York, 1923.

Wegel, R. L., Theory of Magneto-Mechanical Systems as Applied to the Telephone Receiver and Similar Structures, *Journal of the American Institute of Electrical Engineers*, pp. 791–802, October, 1921.

The elemental impedance triangle for alternating-current circuits is again shown in Fig. 17. In the case of a simple magnet coil with no armature, such a triangle represents a comparatively simple set of conditions. The reactance X will depend principally on the frequency, since the coefficient of self-induction L is practically a constant of the coil. Likewise the effective resistance R will increase somewhat with the frequency, being the sum of r, the constant direct-current resistance, and r', the various other current-opposing factors caused by hysteresis and eddy-currents, which rise with frequency.

But in the telephone receiver the situation is not so simple. The reactance, for instance, will be different for each different position of the diaphragm because the inductance coefficient L varies with the reluctance of the magnetic circuit and that in turn varies with changes in the air gap. The effective resistance R will also be largely influenced by the movements of the diaphragm, for, although the ohmic resistance r will remain essentially constant, the other part r' of the effective resistance will be subject to wide variation not only with the frequency but with respect to the freedom of movement of the diaphragm. The variable component of the effective resistance is due to the various energy expenditures other than that spent in the mere heating of the conductor.

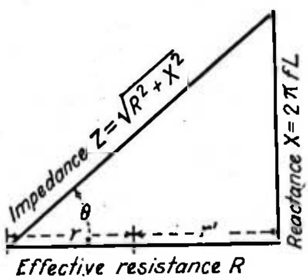


FIG. 17.—Impedance triangle.

Each such expenditure of energy contributes an element of obstruction to the current, which may be expressed in terms of ohmic resistance—that is, in ohms. That this is so we may see from the general power equation $P = I^2R$, in which R is not the ohmic but the total effective resistance. We may thus express the total effective resistance of the receiver in terms of the total power consumed and the current flow. Thus:

CRANDALL, IRVING B., "Theory of Vibrating Systems and Sound," D. Van Nostrand Company, New York, 1926.

MILLS, JOHN, "Radio Communication," McGraw-Hill Book Company, Inc., New York, 1917.

WRIGHT and PUCHSTEIN, "Telephone Communication," McGraw-Hill Book Company, Inc., New York, 1925.

TAYLOR, H. O., Telephone Receivers and Radio Telegraphy, *Proceedings*, Institute of Radio Engineers, February, 1918.

$$R = \frac{P}{I^2}.$$

Of the total power P, a part is expended in producing the movements of air in front of the diaphragm that constitute the desired sound waves. This is the only useful power. The balance, owing to a number of different causes, all is wasted in heat. These losses may be enumerated as follows: first, those spent in heating the conductor on account of its ohmic resistance; second, those due to magnetic hysteresis in the cores, magnets, and diaphragm; third, those due to eddy-currents in the cores, spool heads, diaphragm, and other metallic parts; fourth, those spent in friction in the mechanical movements of supposedly fixed parts due to the variable mechanical stresses imposed; and, fifth, those spent in causing movements of air that do not contribute to the sound.

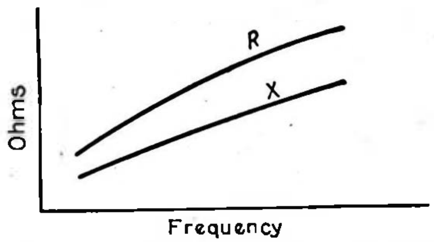


FIG. 18.—Variations of effective resistance and impedance with frequency for blocked diaphragm.

From the equation just given, we see that for a given strength of current the effective resistance varies directly as the power consumed. Neglecting the effects of diaphragm movements, as by assuming that the diaphragm is clamped, it is evident that the effective resistance will increase somewhat with the frequency because the power losses due to eddy-currents and hysteresis increase with frequency.

Thus with the diaphragm blocked, both of the components of impedance increase with the frequency, as indicated by the representative diagram of Fig. 18. These are the values of R and X that for any specific frequency combine, as shown in Fig. 17, to make up what is called the "damped impedance" of the receiver. By damped here is meant that the diaphragm is damped to the extent of completely blocking its movements.

Consider now the case where the diaphragm is not blocked but is free to vibrate. Just as an electric motor will develop a counter electromotive force by the rotation of the armature, so will a receiver by the vibration of its diaphragm. This counter electromotive force is proportional to the velocity of the diaphragm and therefore to the current driving it at any frequency.

It opposes the flow of current, and this opposition constitutes another element of effective resistance, and therefore another component of the impedance of the receiver. With the diaphragm in motion the reactance also will change, not only because of the changes in reluctance of the magnetic circuit, but also on account of its interaction between the eddy-currents in the diaphragm and the currents in the coil.

So for an unblocked diaphragm, both the components R and X of the impedance of the receiver are different from those in the case of the blocked diaphragm. We have, therefore, for any given frequency a damped and an undamped impedance. The difference between the two is called the "motional impedance," since it is wholly that part of the impedance that is due to the motion of the diaphragm.

There is another variable element besides frequency itself that enters largely into the undamped impedance of a receiver—that is, the varying degree of motion of the diaphragm according to whether its vibrations are forced or resonant. In Fig. 1, curve A showed the response of the diaphragm to currents of different frequencies within the ordinary speech range. This shows that, as the frequency of current approaches the natural rate of vibration of the diaphragm, there is a sharp increase in the velocity of the diaphragm. This increases the counter electromotive force and therefore the effective resistance of the instrument at resonant frequencies.

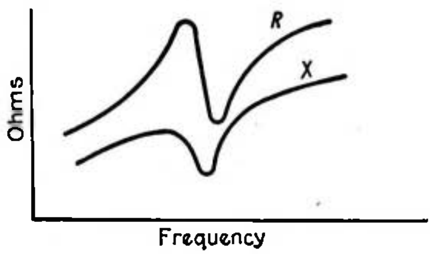


FIG. 19.—Variations of effective resistance and impedance with frequency for unblocked diaphragm.

As a result of these and other causes, the changes of effective resistance and reactance that occur with changes of frequency in an undamped receiver are shown in typical fashion in the two curves of Fig. 19.

From the foregoing it is seen that in order that the impedance value of telephone receivers may mean anything, it is necessary to know whether it is for a damped or an undamped diaphragm, and also at what frequency it was taken. The values ordinarily employed in specifying the impedance of receivers are for the damped diaphragm, and for frequencies of either 800 or 1,000 cycles per second.

For instance: the characteristic data for the standard hand receiver, No. 27-A, of the Stromberg-Carlson Company, as given by its engineering department, are:

D. C. resistance....................	Total, 80 ohms Per coil, 40 ohms
Turns per coil, minimum............	600
Size of wire.........................	No. 37 B. & S., S.S.C.
Effective a. c. resistance at 1,000 cycles	162 ohms
Reactance at 1,000 cycles...........	200 ohms
Impedance at 1,000 cycles...........	258 ohms
Phase angle θ......................	51° 0′

It will be seen that if any two of the last four items of this tabulation are given the other two may be determined by means of such a diagram as that of Fig. 17.

Contrary to general belief, the telephone receiver is an inefficient instrument when measured by the ratio of its output to its input energy. Common belief has confused extreme sensitivity with efficiency. Fleming calculated the ratio of the watts input of electrical energy to the watts output in sound energy to be in the neighborhood of 1 per cent, the efficiency being greater at resonance frequency than at others. As against all the losses enumerated, all wasted in heat, we have only the useful energy spent in producing the desired sound waves.

The inefficiency of the receiver is not of such serious moment as it would be but for the marvelous sensitiveness of the human ear in detecting and interpreting sounds. Many startling figures have been given to illustrate this, but a single one will here suffice. Sir William H. Preece determined in 1887 that a Bell receiver (single pole) will respond audibly to a current of "six ten-thousand-millionths of a milliampere."

In order that the receiver may produce intelligible speech, we have seen that its diaphragm must be subject to the constant pull of an initial magnetic field, in addition to the variable pull due to the field set up by the voice currents. The initial steady pull is thus modified by the incoming voice currents, which act first in one direction and then in the other to alternately strengthen and weaken it. The initial field is usually furnished by a permanent magnet, but it may be caused by a steady direct current flowing through the receiver coil. In the latter case no permanent magnet is required.

Let us inquire as to why this initial field is necessary. Assume first that it does not exist and that the diaphragm is subject only to the magnetic field set up by the voice current, which at any instant has a value i. Under these circumstances the pull at any instant will be proportionate to the square of this variable current, that is, to i^2. There will be two of these pulls for each cycle of current, one for the positive half cycle and one for the negative, but since the squares of both negative and positive quantities are always positive, it follows that each of these pulls will be positive—that is, in the same direction. The diaphragm would thus vibrate with double frequency. If therefore the permanent magnet of an ordinary receiver is removed, the pitch of tone produced by a given frequency of current is raised an octave. Obviously this is not what is required for intelligible speech.

Let us now supply an initial field by causing a constant direct current I, many times as large as i, to flow through the magnet coil. The pull of this field will, as before, be proportional to the square of the current, or to I^2. If now the alternating voice currents i are superposed on this direct current I, the total current flowing at any instant will be $I + i$ and the pull exerted on the diaphragm will be proportional to the square of this current, or to

$$(I + i)^2 = I^2 + 2Ii + i^2.$$

We see from the right-hand member of this equation that the total pull on the diaphragm has three components. The first of these, I^2, is evidently constant and is therefore useless in so far as speech vibrations are concerned. The third member i^2 is undesirable, for, as we have just seen, it acts with double frequency. It is to the second member $2Ii$ that we must look for the varying pull necessary to produce speech. No second powers are involved in this and, since $2I$ is constant and very much larger than i, the total pull due to this component will vary from moment to moment in direct proportion to the voice current and will be very much more powerful. Of the three components of the total power, therefore, $2Ii$ is the useful one, I^2 being harmless and i^2 being harmful. Fortunately the usual conditions are such that the harmful portion i^2 is insignificant in comparison with the useful portion $2Ii$, so that it may be ignored. To illustrate: suppose that on some unit basis the value of the voice current i is 1 and that of the steady current 100. The ratio of the useful pull $2Ii$ to the harmful double-frequency pull would then be as 200 to 1. In practice the disparity in size is usually very much greater than this.

Exactly the same reasoning applies if the initial steady field is set up in the receiver by a permanent magnet, instead of by the steady current in the receiver coil.

Of modern receivers, Fig. 20 shows the No. 144 receiver of the Bell System. It is the usual companion piece of the No. 323 transmitter; and there are probably more of them than of all

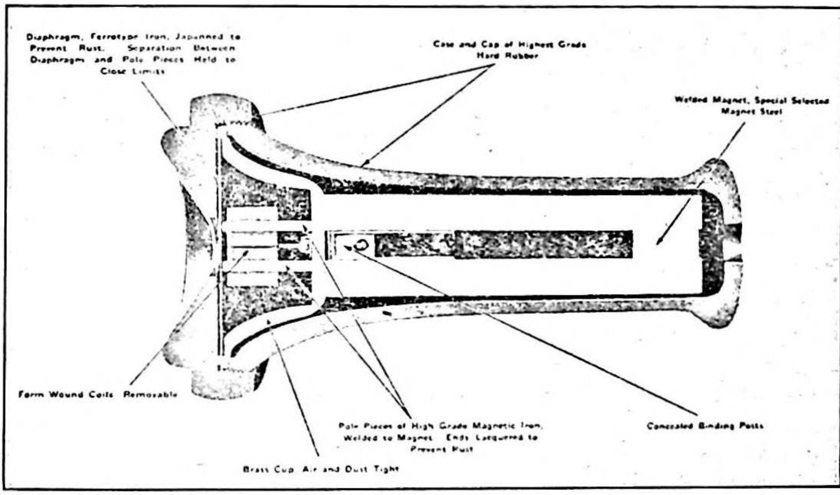


Fig. 20.—No. 144 Bell hand receiver. (*Courtesy of the American Telephone and Telegraph Company.*)

other receivers in the world combined. The construction is sufficiently clear from the diagram and its legends. Special features to be noted are, first, that all of the working parts except the diaphragm form a single unitary structure. The diaphragm is clamped against its seat between the rubber shell and cap. This clamping action also secures the entire mechanism in place within the shell. The welding of the soft-iron pole pieces to the forward ends of the permanent magnet, and of the magnet bars to each other at their rear ends, secures a magnetic circuit of minimum and constant reluctance. Means of adjustment are carefully avoided, the plane of the pole faces being properly related to that of the diaphragm seat in the process of manufacture. The binding posts, as well as other metal parts, are concealed within the shell. This is the standard Western Electric hand receiver for common-battery and magneto subscribers'

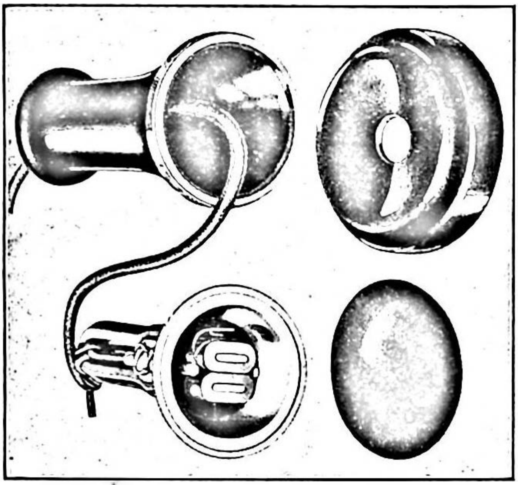


Fig. 21.—Automatic Electric Company hand receiver—permanent-magnet type.

stations. Its winding is of No. 37 B. & S. gage, single silk-and-cotton-covered wire. The direct-current resistance is 84 ohms and the damped impedance at 800 cycles is 215 ohms with a phase angle of 50 degrees. The weight of the receiver is 13½ ounces.

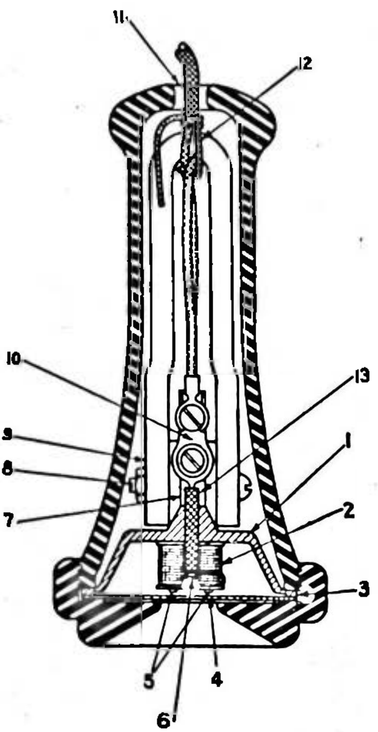


Fig. 22.—Automatic Electric Company hand receiver—permanent-magnet type.

The Automatic Electric Company manufactures two types of hand receivers, one with permanent magnets and the other without. The permanent-magnet type is shown in Figs. 21 and 22. As in the Western Electric instrument just described, there is no dependence on the receiver shell for the relationship between the diaphragm and the pole pieces. The permanent magnet 9 in this instrument is bent from a single bar of tungsten steel. The assembly of the cup 1, pole pieces 5, and coils 2 are clamped between the poles of this U-shaped magnet by a brass bolt 8. In this particular type of design, the diaphragm faces of the pole pieces are ground to a true plane before being attached to the permanent magnet, thus greatly reducing the possibility of metal grindings adhering to the pole pieces after assembly.

The terminals 10 are mounted on and insulated from the projecting lug 7 of the brass cup, one on each side of the receiver. They carry binding screws for the cord terminals, and from each of these a long tongue 6 extends through the base of the cup and into the coil chamber where the wires of the magnet coils are attached to them by solder. Insulating bushings 13 prevent the tongue 6 from coming into electrical contact with the cup where they pass through it.

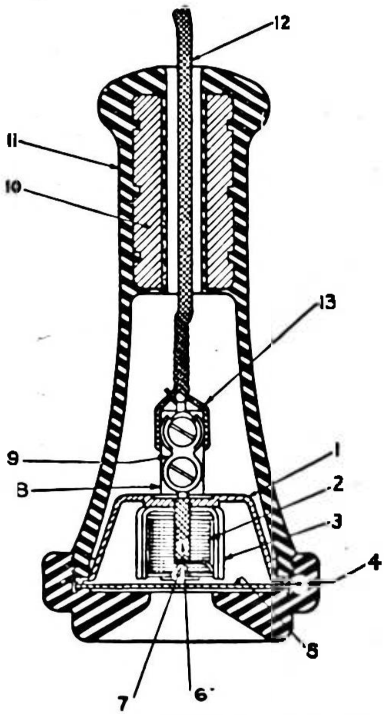


FIG. 23.—Automatic Electric Company hand receiver—direct-current type.

The receiver shell and earpiece are of molded Bakelite with no metal reinforcements. The method of attaching the cord is clearly illustrated, a strain loop 12 being secured to the magnet in such way as to relieve the terminals from strain.

The manufacturers give the following data as to the electrical characteristics: The magnet coils are wound with black enamel magnet wire and are connected in series. The direct-current resistance of the two is 75 ohms. The damped impedance at 1,000 cycles is approximately 270 ohms; and the phase angle, 57 degrees.

The direct-current hand receiver of the Automatic Electric Company is shown in section in Fig. 23. This derives its steady polarizing magnetic field from direct current coming over the line and passing through the magnet coil. The permanent magnet is therefore eliminated. Both poles of the magnet core are in effect presented to the diaphragm, one end of the core being held adjacent to its center and the other end being extended magnetically through the two arms of a U-shaped soft-iron pole piece 3, in which the magnet coil 2 is seated. The two members of this U-shaped pole piece extend on opposite sides of the coil to points immediately adjacent to the diaphragm, so that the only air gaps in the magnetic circuit are those across which the attraction of the diaphragm takes place.

Unless additional weight were provided, the absence of the permanent magnet would leave a receiver of the direct-current type with insufficient weight to depress the hook switch on which it is normally supported. As in the case here shown, this deficiency in weight is made up by the addition of a lead weight 10 molded into the upper end of the receiver shell. This receiver has a direct-current resistance of 53 ohms.

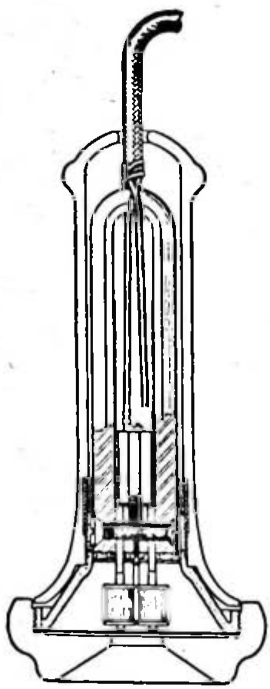


Fig. 24.—Stromberg-Carlson permanent-magnet receiver.

The permanent-magnet type hand receiver of the Stromberg-Carlson Company is shown in cross-section in Fig. 24. This method of mounting the working parts within the shell differs from the types already considered. An internal screw threading of the receiver shell engages an external thread on the shank of the metal cup in such a manner as to hold the magnet, coils, and cup in place within the shell. There is no screw-thread engagement between the cap and the shell, the cap instead engaging an external screw thread on the brass cup which contains the coils. This relieves the ear cap of all strains except those incurred in clamping the diaphragm in place. The electrical characteristics of this receiver have been given in the earlier part of this chapter (page 35).

The direct-current receiver of the Stromberg-Carlson Company has a single cylindrical coil with no permanent magnet, other structural features being similar to those of its regular permanent-magnet type. This company employs this receiver only in interior common-battery systems where lines are short and where no induction coils are used, the transmitters being connected directly in series with the receiver in the line.

All of the receivers so far considered are of the so-called "hand type," this being most used at subscribers' stations in America. As distinguished from the hand receiver, there is the head receiver, so called because it is adapted to be clamped on the head against the ear by means of a head band. Because of this method of use, light weight and small size are desirable. On account of their size and shape they are often called "watchcase" receivers.

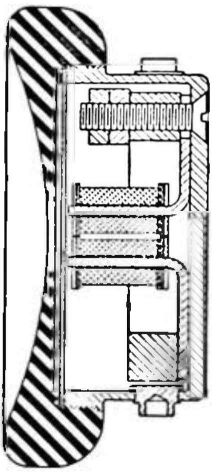


FIG. 25.—Bell head receiver. (*Courtesy of The American Telephone and Telegraph Company.*)

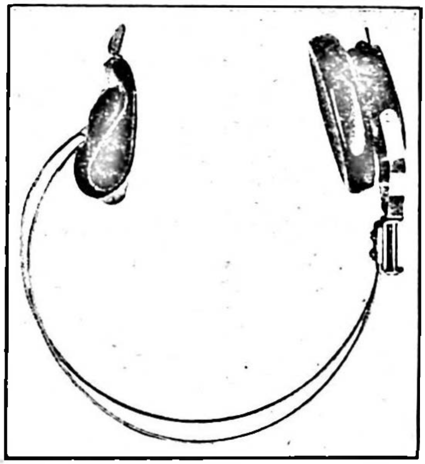


FIG. 26.—Bell head receiver and head band. (*Courtesy of The American Telephone and Telegraph Company.*)

A single example, typical of many, will suffice to illustrate the general design of these. Figure 25 shows the No. 528 head receiver of the Western Electric Company. This is the standard receiver of the Bell System for central-office operators at common-battery and magneto switchboards. In this a ring-shaped permanent magnet lies at the bottom of an aluminum cup which forms the casing of the instrument. L-shaped pole pieces engage, at their outer ends, the opposite poles of this magnet. These pole pieces carry the usual flat-type coils with metal heads so that, except for the shortness of the permanent magnet, the magnetic structure is quite similar to that of the hand receiver. An assembled view of this receiver with its head band for operators' use is shown in Fig. 26.

The electrical characteristics are: winding, two spools No. 38 black enamel wire connected in series; direct-current resistance, 60 ohms; damped impedance at 800 cycles, 260 ohms; and phase angle, 66 degrees. The weight, complete with head band, is 3.8 ounces.

Still other examples of modern commercial receivers are given in later sections of this chapter, relating to combination hand sets and to the loud-speaking instruments used in radio reception and public-address systems.

The material of which receiver diaphragms are made is usually "ferrotype metal." This is a soft sheet iron lacquered on both sides. It derives its name from the fact that in the early days of photography it was employed in making ferrotype or "tintype" photographs. A thickness very close to 0.010 inch is employed in practically all commercial types of receivers, this having proved about right from both the acoustic and the magnetic standpoints. If diaphragms are made too thick, they are not flexible enough, and if too thin they are likely to become magnetically saturated and thus lose efficiency. Moreover, if too thin they are not sufficiently rugged to withstand the rough handling to which they are subjected in public use.

Diaphragm diameters do not vary widely among different makes. The diameter of the free portion in the No. 144 Bell hand receiver, for instance, is $1\frac{15}{16}$ inches and the over-all diameter $2\frac{1}{8}$ inches.

The choice of material for receiver shells and earpieces has been the subject of much experimentation. Two different materials, hard rubber and Bakelite, have proved their fitness by long usage. The Bell System has consistently adhered to hard rubber, and this means that by far the greatest number of all the receivers in the world to-day employ that material. The independent manufacturers have now generally adopted the Bakelite. This is a strong, hard material with very high insulating properties and is impervious to moisture. Bakelite has the advantage that it may be accurately molded, requiring no subsequent machine operations to bring it to the desired shape. Hard rubber, on the other hand, after being molded to approximate shape is readily brought to final dimensions by turning or other machining. Both materials will take high polish and are of attractive appearance, but hard rubber has the disadvantage that it is subject to slight discoloration with age.

Telephone Induction Coils.—All local-battery telephones and most common-battery telephones employ induction coils. It was pointed out in Chap. III of the preceding volume[1] that the use of the induction coil in connection with a local-battery telephone is advantageous in that it allows the changes in the resistance of the transmitter to bear a much larger ratio to the total resistance of the circuit in which these changes occur, than would be the case were the same transmitter placed directly in series in the line. Further, since the coil is used as a step-up transformer, the energy delivered to the line is of higher voltage and therefore better adapted to overcoming the resistance of long lines.

In common-battery telephones the induction coil is used in a variety of ways. In most cases it serves a similar purpose to that of the local-battery coil, in that it provides a local circuit in which the transmitter produces current variations which are repeated by the coil into the line circuit, thus augmenting or "boosting" the variations which the transmitter produces by direct variation of the line resistance. In common-battery instruments also the induction coil usually serves the additional purpose of enabling the receiver to be put in a local circuit where it is not subject to the flow of direct current passing over the line. These functions of induction coils in substation circuits will be treated more fully in Chap. IV. The quality and dimensions of the iron core, the resistance of, and the relation between, the number of turns in the primary and secondary windings and like matters of general design are important but, on account of the highly complex nature of the mathematical reasoning that would be involved, their determination has largely been made by cut-and-try methods.

Some early coils had cores in the form of a cylindrical bundle of soft-iron wires, sometimes 6 inches long and ¾ inch in diameter. Modern practice tends toward the use of silicon steel instead of soft iron, on account of its high permeability and resistivity. Also instead of employing a bundle of wires of this material, the core is made up of thin strips crowded into the tube of insulating material on which the coil is wound. Modern practice has also tended toward smaller and shorter cores. These give better results, the smaller core losing, perhaps, a little in intensity but gaining perceptibly in clearness and crispness.

[1] "Theory and Elements," p. 54.

The use of two fine wires in parallel, instead of a single wire as found in some early coils, is illustrative of a worn-out fallacy. This practice was once quite commonly resorted to in various coil windings for telephone use, on account of some fancied theoretical gain in efficiency. The gain, however, was not real and the practice was undesirable, expensive, and useless: undesirable, because two small wires are more easily injured mechanically

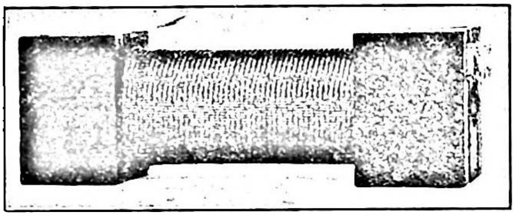


FIG. 27.—Bell induction coil. No. 46. (*Courtesy of The American Telephone and Telegraph Company.*)

than one large one of the same carrying capacity; expensive, because the labor in winding is considerably greater than in the case of a single wire, as is also the first cost of the finer wire; and useless, because no better results were secured.

In Fig. 27 is shown the No. 46 induction coil of the Western Electric Company, which is the Bell standard for common-battery subscribers' sets. The two wooden spool heads are mounted on opposite ends of a thin insulating tube. On this tube a wind-

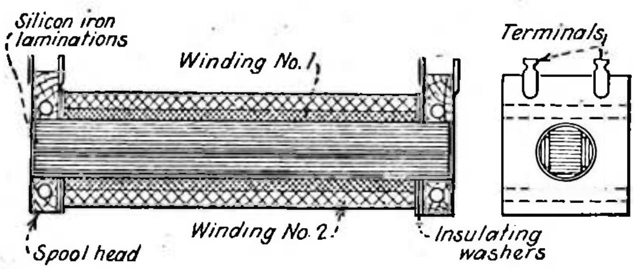


FIG. 28.—Automatic Electric induction coil.

ing of 1,600 turns of No. 28 black enamel cotton-covered wire is wrapped. The inner and outer ends of this winding are brought out and permanently attached respectively to terminals numbered 1 and 2 on the spool head. A sheet of insulating material is placed around the outside of this winding, after which a second winding of 1,025 turns of No. 26 black enamel cotton-covered wire is wrapped on. The inner and outer ends of this winding are brought out and permanently attached respectively to terminals 4 and 3 on the spool head. These terminals serve as soldering clips for the attachment of the circuit wires. The direct-current resistance of the 1-2 winding is 14 ohms and of the 4-3 winding, 9 ohms. The tube on which the coils are wound is filled with narrow rectangular strips of thin silicon steel.

A cross-section of a somewhat similar coil, the standard type of Automatic Electric Company for its substation telephones, is shown in Fig. 28. The two wooden spool heads having numbered terminals are mounted on opposite ends of an insulating tube into which strips of silicon iron are driven. The first winding begins on terminal 1 and finishes on terminal 2, the second beginning on terminal 3 and finishing on terminal 4. In general, it may be stated that this practice is followed where there are more than two windings; for instance, a third winding would begin on terminal 5 and end on terminal 6. In this coil the 1-2 winding consists of 1,400 turns of No. 31 enamel copper wire having a resistance of 27 ohms. The 3-4 winding has 1,700 turns of No. 26 enamel copper wire having a resistance of 14 ohms.

Combination or Hand Sets.—In the United States the almost universal practice until recently has been to make the transmitter and receiver of a talking set as separate units. The transmitter is permanently supported either on an arm projecting from the wall or on a portable stand adapted to rest on a table or desk, while the receiver is hung on a separate hook from which it is removed for use. In foreign countries another plan has more often prevailed: that of combining the transmitter and receiver in a unitary structure adapted to be held in one hand by the user. In these combined talking sets the effort has been to so relate the parts that when the receiver is held in proper position against the ear, the mouthpiece of the transmitter will naturally and conveniently fall into proper position before the mouth. The instrument shown in Fig. 29, while of American make, may be taken as typical of the combination sets as they were once commonly used abroad and to a limited extent here.

Americans who traveled abroad often enquired why the European type, which seemed to them more convenient, was not more commonly used in this country. The answer to this question is somewhat involved. It is principally to be found in the fact that the old-style combination instrument, with its long curved mouthpiece, had certain inherent disadvantages from the standpoint of both operation and maintenance. The American operating companies, more highly standardized along lines of more exacting requirements, felt, I think properly, that it would not be wise to accept these sacrifices, which cut rather deeply into both transmission efficiency and maintenance economy, at the price of what appeared to many to be a somewhat more convenient type of instrument. There had also probably been some inertia on the part of American manufacturers and operators about striking at the root of the question and curing the fundamental defects in the combination type of instrument as it then existed: but in this regard it must be said that there has not always been a unanimity of opinion as to which type of instrument is, all things considered, the more convenient from the users' standpoint.

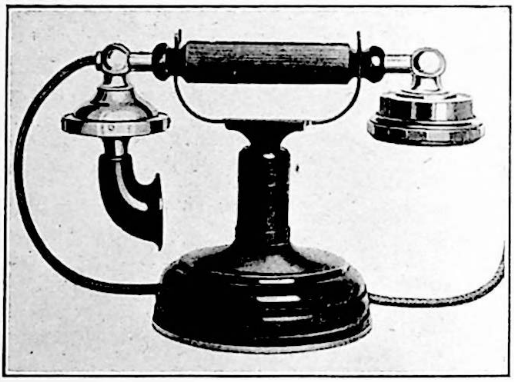


FIG. 29.—Old-style microtelephone set on desk pedestal.

The objections to the older form of combination set were:

First: in spite of all efforts to prevent it, users often assume such positions in talking that the diaphragm of the transmitter would be held in other than vertical or nearly vertical positions. The ordinary type of carbon transmitter loses greatly in efficiency when so held and in fact is likely to open its circuit entirely. Aside from the loss of efficiency, the accidental opening of the circuit during conversation is a thing not to be tolerated in a common-battery system where the opening and closing of the line circuit are employed to give signals or perform other functions. If the system is manual, opening the line signals the central-office operator to disconnect. If it is automatic, it actually brings about the disconnection.

Second: the close mechanical coupling between transmitter and receiver is likely to cause the instrument to howl. The phenomenon is exactly the same as that which sometimes occurs when the receiver of a telephone is held close to the mouthpiece of its transmitter. Vibration of the receiver diaphragm is taken up by the transmitter which in turn reacts on the receiver, and so on in recurring cycles. In the case of the combination set, the rigid mechanical connection between the two instruments accentuate this effect. The more powerful the transmitter and the more sensitive the receiver, the greater likelihood of the occurrence of this trouble.

Third: quite obviously this old type of combined instrument is less rugged and therefore less capable of standing the rough usage of commercial service than is the hand receiver. The long curved mouthpiece of the combination set is a principal offender in the matter of breakage, and this is the more serious because it affects the efficiency of the transmitter more than the breakage of a mouthpiece in the detached type of transmitter.

We may summarize these difficulties in the old-style combination set as (*a*) those due to transmitter position, (*b*) those due to the mechanical coupling between transmitter and receiver, and (*c*) those due to lack of ruggedness of the instrument.

These combination instruments have been called by a variety of names. Perhaps the most common is "microtelephone." There seems to be no logical reason for this name but it is certainly much better than that atrocity in trade names, the "grabaphone," which one American company has long applied to its combination instrument. As applied to their recently standardized set the Bell Companies use the term "hand set," while Automatic Electric Company has adopted the trade name "monophone." We shall here refer to instruments of this general type as "combination hand telephone sets" or merely as "hand sets."

Within the past four or five years, the Bell Telephone Laboratories and some of the independent manufacturing companies in this country have done much development work looking toward the overcoming of the difficulties inherent in the old type of hand sets. As a result the Western Electric Company is now producing a set which the Bell Companies have standardized for common-battery use at those stations where subscribers prefer it, and other manufacturers are offering sets somewhat similar in external appearance for both magneto and common-battery use.

The external appearance of the Western Electric Company's hand set resting in its supporting cradle on the pedestal of a dial telephone desk set is shown in Fig. 30. It is being favorably

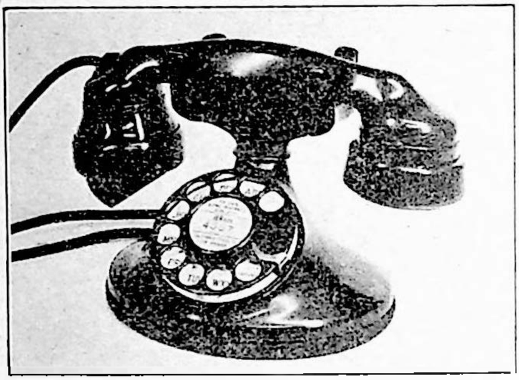


FIG. 30.—Western Electric hand set on desk pedestal. (*Courtesy of The American Telephone and Telegraph Company.*)

received by the public for both manual and automatic service. A cross-section of the hand set alone is shown in Fig. 31 and of its transmitter in Fig. 32.[1]

Chief interest in this instrument centers in the transmitter as it is a radical departure from earlier commercial types. Among the

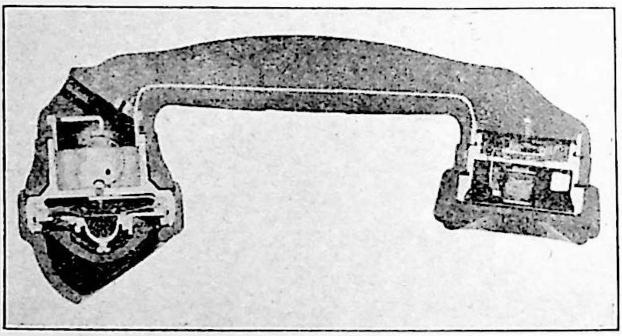


FIG. 31.—Cross-section of Western Electric hand set. (*Courtesy of The American Telephone and Telegraph Company.*)

principal differences from usual practice to be noted in its design are: that the carbon chamber is in front of the diaphragm; that the

[1] Since this chapter was written this hand set has been described and many of its operating characteristics given by Messrs. W. C. Jones and A. H. Inglis in a paper before the American Institute of Electrical Engineers, January, 1932. This paper contains much information in addition to that here given.

electrodes are both of metal and have no movement with respect to each other; that the carbon chamber is hemispherical in form and is practically filled with carbon granules; that the resilient mica enclosing diaphragm is dispensed with, the granules being retained within the chamber by a pile of loosely mounted paper rings; and that the diaphragm is not clamped but is flexibly mounted between the free edges of two opposing piles of paper rings.

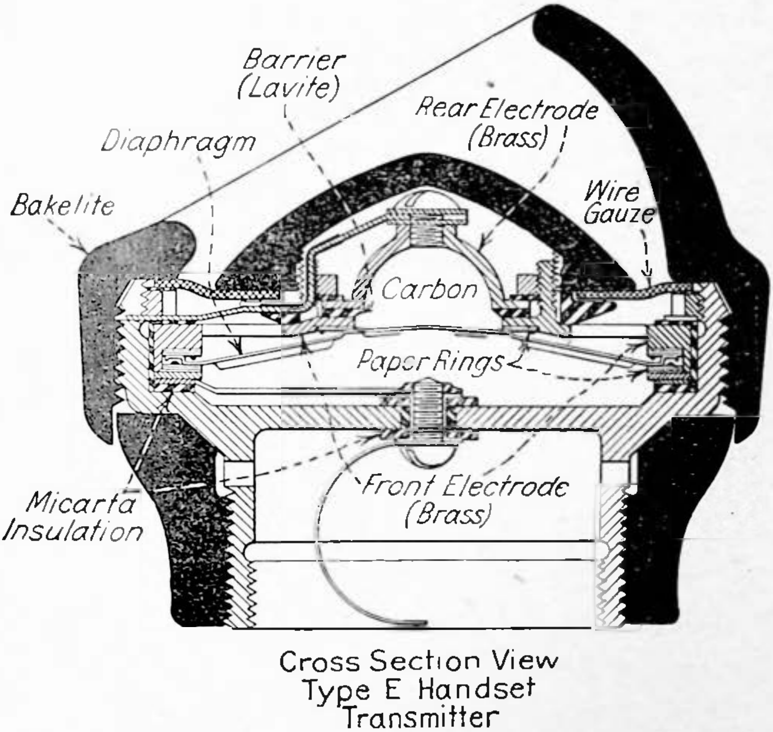


FIG. 32.—Cross-section of Western Electric hand-set transmitter.

As will be seen in the drawing (Fig. 32), the front electrode surface is formed by the inner edge of a brass ring that is fixed with respect to the inner surface of the hemispherical brass cup which forms the rear electrode, the two being separated by an insulating ring or "barrier." The carbon chamber is closed by the center portion of the diaphragm and by the inner edges of a pile of thin paper rings secured at its outer edge to the front electrode. The spreading action of these paper rings at their free inner edges serves as a resilient cushion between the diaphragm and the fixed portion of the granule cell, permitting the free vibration of the diaphragm and at the same time effectively retaining the granules within the cell.

The diaphragm is not tightly clamped at its edges but is resiliently mounted between two sets of paper rings as shown. The diaphragm, while in contact with the granules, forms no part of the variable-resistance circuit. Its function, therefore, is purely mechanical. The sound waves of the speaker's voice pass through the wire-gauze screen, which surrounds the central sound-deflecting dome, and impart their vibration to the diaphragm. This, in turn, by agitating the granules, affects the resistance of the path through them from one fixed electrode

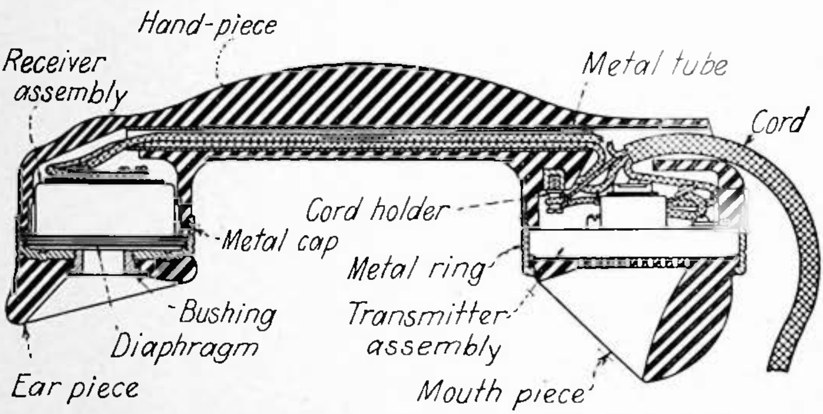


FIG. 33.—Cross-section of Automatic Electric Company hand set.

to the other, the resistances at the numerous points of contact varying with the variations of contact pressure.

This transmitter meets in remarkable fashion the very exacting service requirements imposed upon it. Its performance characteristics are but little affected by the wide range of positions in which it must operate and by the motions to which it is subjected.

A longitudinal cross-section of the Automatic Electric Company's recently developed hand set is shown in Fig. 33. This instrument is made with two types of receivers—one with a permanent magnet and the other with an electromagnet for furnishing the steady field.

The permanent-magnet type is shown in Fig. 34, which requires little explanation in view of what has already been said about watchcase receivers. The permanent magnet is in the form of a nearly closed ring and the pole pieces are clamped against its ends by means of a brass bushing or "pole-piece clamp" which is forced between the flat sides of the pole pieces. A magnet retaining ring secures these parts to the brass cup.

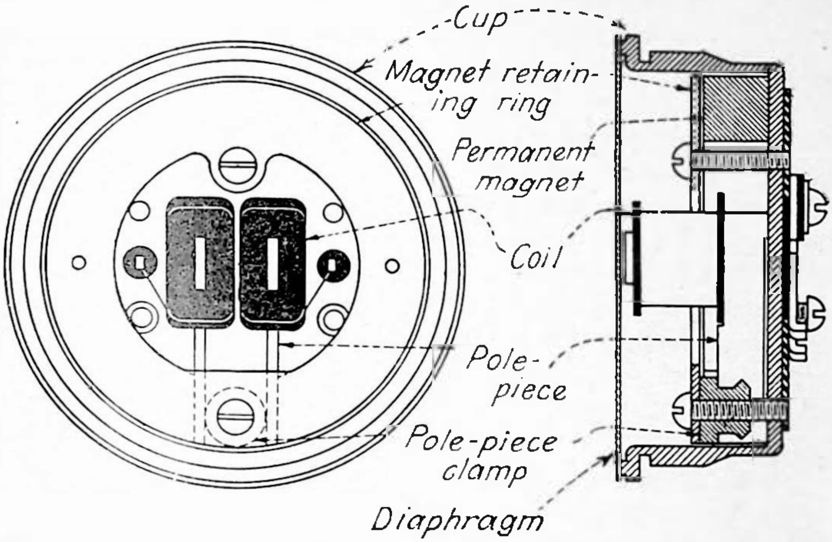


FIG. 34.—Permanent-magnet receiver of Automatic Electric Company hand set.

The direct-current receiver of the Automatic Electric Company's hand set, shown in Fig. 35, presents several features of

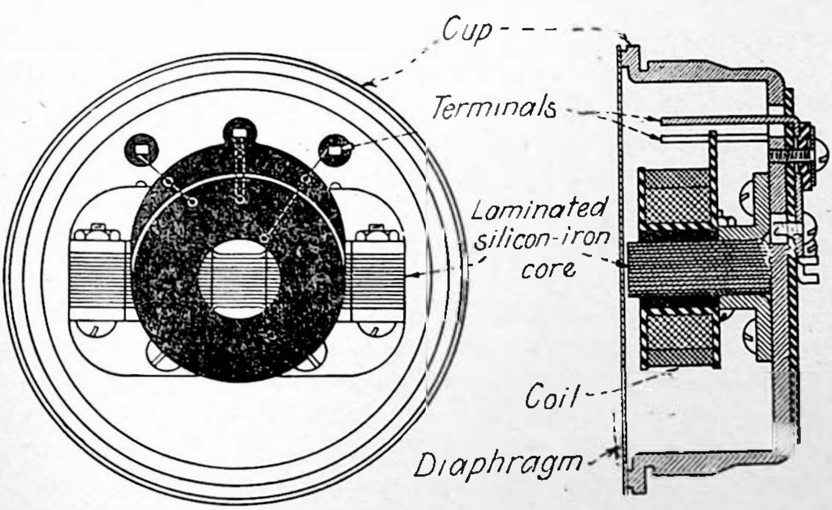


FIG. 35.—Direct-current receiver of Automatic Electric Company hand set.

interest. Like the direct-current receiver of this company shown in Fig. 23, the transmitter supply (direct current) is utilized to give the magnet core its initial polarity. The receiver has two windings on the same core, which are made to serve the triple purpose of furnishing the initial field, acting as an ordinary receiver coil with respect to voice currents, and serving as an induction coil. This special action will be described in greater length in Chap. IV, dealing with complete telephone sets. The electromagnet is of E-shaped laminations of silicon iron. Upon the center branch of this the two coils are wound, the two outer branches being brought close to the plane of the diaphragm so as nearly to complete the magnetic circuit.

The transmitter is of essentially the same design as the transmitter used by the Automatic Electric Company for desk and wall sets already described in connection with Fig. 10, with the general exception that it is somewhat smaller in over-all diameter and that it is not fitted with a front plate or conventional mouthpiece. The mouthpiece is of special design, intended to deflect the sound waves directly against the diaphragm, and is attached to the set by means of a threaded metal cap as shown in Fig. 33. This, like the standard transmitter of this company, is produced for three zones of common-battery supply, for currents up to 60, 125, and 250 milliamperes, respectively.

The transmitter and receiver are assembled in a hand piece of molded Bakelite of the form best shown in the cross-section of Fig. 33. A metal tube extends through the handle for carrying the necessary conducting cords between the transmitter and receiver.

The tendency to howl in this combination hand set is taken care of principally by a special circuit arrangement, which will be discussed in Chap. IV. Briefly, the function of this arrangement in this regard is to make the receiver comparatively insensitive to the current variations of its own transmitter.

Referring now to the hand sets of both the Western Electric Company and Automatic Electric Company it is claimed by each company that the three disadvantages heretofore considered inherent in combination hand sets have been in large measure eliminated.

a. As to the difficulties arising from position, it is claimed that a design of transmitter has finally been achieved which alters its efficiency only in slight degree regardless of the position in which the diaphragm is held; and that it is impossible to break the circuit through the transmitter by holding it in any position whatever. Apparently, instead of there being a loss in transmitter efficiency, there is a gain when average conditions of use are considered. This arises from the fact that in the hand set the transmitter is necessarily held closer and in more uniformly proper relationship to the lips of the speaker than was ever possible of attainment with the average person using the separately mounted transmitter.

b. In overcoming the second or howling difficulty, the Automatic Electric Company seems to have relied principally upon its circuit design, by which the receiver is made insensitive to the transmitter. It is understood that the Bell instrument has relied not only on this "anti-side-tone" feature of its circuit, but also on the acoustical design of the handle by which the coupling is made inherently non-resonant to any frequency of vibration likely to be set up by mutual action between the transmitter and receiver.

c. The third difficulty has been to some extent met in both instruments by increased ruggedness of construction, particularly with respect to the mouthpiece, earpiece, and the general configuration of the structure.

As sometimes occurs in setting out to overcome a difficulty, the difficulty not only disappears but an actual advantage takes its place. So with the efficiency of these new designs of hand sets. There has always been trouble in the case of the separately mounted transmitter to train the public to hold the lips close enough to the mouthpiece. In spite of all efforts, no uniformity in this respect has ever been attained, and this accounts for many complaints of poor transmission. It has been found that with the new designs of hand sets any comparative deficiencies inherent in the transmitter or receiver are somewhat more than counterbalanced by the increased output of the transmitter, owing to the fact that the speaker's lips are automatically brought more nearly into proper relationship with the mouthpiece than has even been possible of general attainment with the separately mounted transmitter.

Any argument as to the relative convenience of the combination or detached types will gradually be settled by the test of actual use by the public. It seems probable, however, that the convenience arguments are principally in favor of the hand set. It can be conveniently used in almost any position, either sitting or standing. It requires the use of but one hand, leaving the other free for writing or other purposes. When used in a standing position the user is not compelled to hold up the complete instrument, as is the case of a desk set with hand receiver.

The relative advantages of the two types from the maintenance standpoint, that is, from the standpoint of repairs and deterioration, seem to be somewhat in favor of the separately mounted type, but it is yet too early to be sure of this.

BROADCASTING TRANSMITTERS AND LOUD-SPEAKING RECEIVERS

While the transmitters and loud-speaking receivers used in radio broadcasting and reception, in public-address systems,

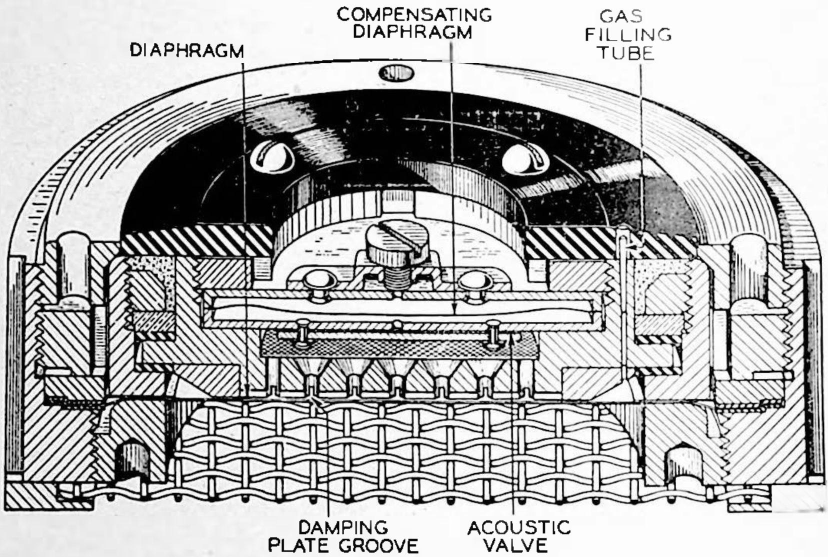


FIG. 36.—Western Electric No. 394 condenser transmitter. (*Courtesy of Bell Telephone Laboratories.*)

and in talking moving pictures find little use in commercial telephone-exchange practice to which this volume is principally devoted, a few representative examples of these may be considered here to round out this chapter on Talking Apparatus.

The Condenser Transmitter.—This, as stated before, is essentially a condenser, one of whose plates is formed by the sound-receiving diaphragm, and whose capacitance varies with the vibrations of this diaphragm and therefore with the pressure variations constituting the sound waves to be transmitted. A constant electromotive force connected across the condenser plates will cause a current closely conforming to the pressure of the sound wave to flow as the result of the condenser charge adjusting itself to the varying capacitance.

A highly developed form, as used in radio broadcasting and moving picture recording, is the No. 394 type condenser transmitter of the Western Electric Company, shown in Fig. 36. The sound-responsive diaphragm is of aluminum alloy, 0.0011 inch in thickness, stretched to raise its natural or resonant rate of vibration to 5,000 cycles. The front face of the stationary member or rear electrode of the condenser lies parallel to the diaphragm and only 0.001 inch from it. This surface is made plane within 8×10^{-5} inch. The thin film of air between the diaphragm and the stationary electrode, or "damping plate" as it is called, serves to increase the stiffness inherent in the diaphragm itself. The required amount of damping at the resonant frequency, without unduly impeding the movement of the diaphragm at other frequencies, is secured by cutting grooves at right angles to each other across the face of the damping plate. This has been found to reduce the stiffness introduced by the thin air film back of the diaphragm and to decrease certain irregularities of response that were found at lower frequencies. Holes bored through the damping plate at the intersections of the grooves form connecting passages between the air film and the cavity at the rear. These holes are tapered at their rear ends to reduce resonance effects.

In order that the performance characteristics of the transmitter may not be affected by changes of barometric pressure, it is necessary to provide for an equalization of pressure on the two sides of the diaphragm. This requirement, of itself, could best be met by permitting a free interchange of air on its two sides. To allow the free entrance of atmospheric air back of the diaphragm would, however, be objectionable in that its moisture content might cause corrosion and destroy the high degree of insulation that is required between the two plates of the condenser. Accordingly a loose compensating diaphragm of animal tissue is stretched across the rear chamber to prevent the entrance of air and moisture, and the chamber between the two diaphragms is then filled with nitrogen, this gas being used on account of its non-corrosive effects.

A more extended description of this transmitter and of its performance characteristics, together with a bibliography containing many references relating to the development and use of transmitters for sound recording in the moving picture industry, is given in a recent paper by W. C. Jones, entitled "Condenser and Carbon Microphones."[1] It is perhaps to be regretted that Mr. Jones in this excellent paper has adopted the vernacular of the radio and the "movies" in so far as he applies the name "microphone" to this transmitter. In radio parlance, the instrument into which one speaks, regardless of

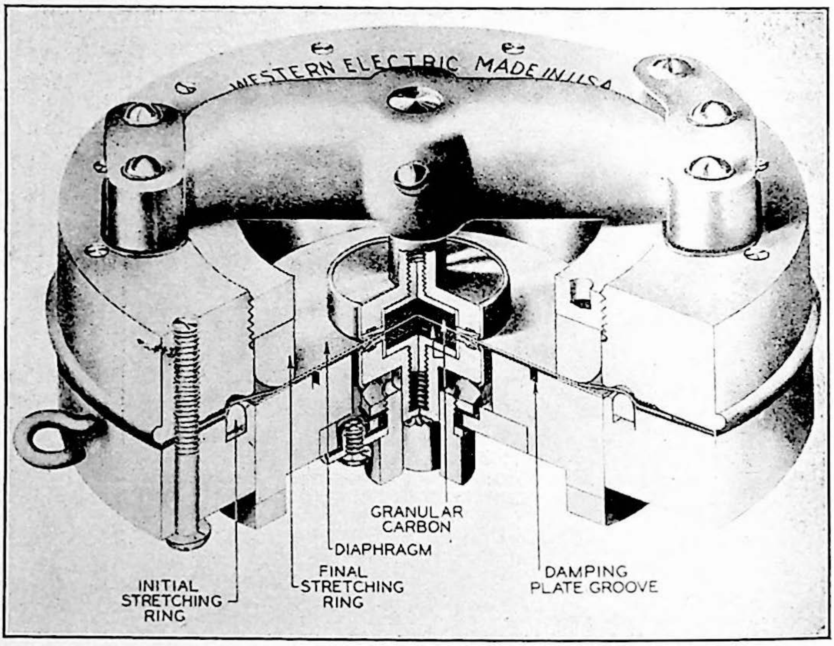


FIG. 37.—Western Electric No. 387 push-pull microphone. (*Courtesy of Bell Telephone Laboratories.*)

its type, is the "microphone" or "mike." Probably this usage has become so well established that it will survive, but in the older telephone art the word microphone has always been used to designate specifically the kind of transmitter which operated on the "loose-contact" principle, both the name, in this connection, and the application of the principle having been due to Prof. David E. Hughes in 1878.[2]

[1] "Condenser and Carbon Microphones," presented before Society of Motion Picture Engineers, October, 1930.

[2] *Telegraph Journal and Electrical Review*, London, July 1, 1878. *Nature*, London, June 27, 1878.

The Push-pull Carbon Microphone.—The idea of having two variable-resistance elements so related in a transmitter that the vibration of the diaphragm would act to pull on one and push on the other while moving in one direction, and *vice versa* while moving in the other direction, is very old, but it never found wide application in commercial telephony because the simpler and more rugged "single-button" transmitters were better adapted for general public use. The more exacting requirements of radio broadcasting and moving picture recording with respect to uniformity of response through a wide range of frequencies has, however, recently called for the development of the push-pull type of carbon microphone to a much higher degree of perfection than it ever attained before. An outstanding example is shown in Fig. 37 which is a cross-sectional view of the No. 387 type microphone of the Western Electric Company.

As in the case of the condenser transmitter, just discussed, the approximate uniformity of response through a wide range of frequency is obtained by the use of a stretched and air-damped diaphragm. The diaphragm is of an aluminum alloy (duralumin) 0.0017 inch thick. It is clamped at its periphery between corrugated surfaces and emery-cloth gaskets to prevent slipping. Its stretching is done in two steps: first, the initial stretching ring is advanced by means of six equally spaced screws (not shown) until all wrinkles are removed, and then the final stretching ring is adjusted until the diaphragm is brought to a resonant frequency of 5,700 cycles. Air damping is accomplished by a grooved damping plate which lies parallel to, and 0.001 inch from, the diaphragm, a spacing washer of that thickness assuring that separation.

The granular-carbon buttons, exactly alike in size and shape, lie on opposite sides of the diaphragm center. The stationary electrodes are of conventional type—a polished carbon disk secured to a brass stud—but the movable electrodes are formed of thin films of gold deposited on the front and rear surfaces of the diaphragm by "cathode sputtering."

The classic mica-washer method of closing the carbon chamber, introduced by White and until recently used in practically all commercial service transmitters, is not found in this instrument. Instead, the granules rest directly against the gold-faced surfaces of the diaphragm and are confined peripherally, in the case of each button, by a pile of 27 rings of very thin paper (0.0004 inch thick) which are clamped tightly together at their outer edges. The spreading inner edges of these rings form a cylindrical surface which confines the granules but offers practically no impedance to the vibration of the diaphragm.

The granules are of such size as to pass through a screen of 60 meshes to the inch and be retained by one of 80 meshes. Each button contains 0.060 cubic centimeter of carbon granules —about 3,000 granules.

The bridge supporting the front button is of massive construction to resist vibration and is given a stream-line configuration so that it may offer as little impedance as possible to the sound waves reaching the diaphragm.

The performance characteristics of this instrument are given in some detail in the paper last referred to.[1]

Loud-speaking Receivers.—In all of the receivers used in commercial exchange and toll service so far considered, the driving element which sets up the sound waves is in the form of a moving iron armature—the diaphragm itself. In loud-speaking receivers the driving element may be a moving iron armature, usually a separate piece of iron mechanically connected to the diaphragm, or it may be in the form of a moving coil connected to the diaphragm and vibrating in an intense steady magnetic field. In either case, since the receiver is not to be held directly against the ear, some more effective form of coupling between the moving element and the surrounding air is necessary. This coupling may take the form of a horn, as in the older phonographs, or of a large moving disk, as in the cone-type loud speakers, so that, in either case, the vibrations of a comparatively small driving element may be effectively imparted to a large body of air. Both the cone type and the horn type of loud speakers are effective with either the moving-iron or moving-coil type of drive and both are largely used. The cone type has the advantage of being more compact than the horn type and of presenting a more pleasing appearance. On the other hand, the horn type, where size and appearance are of less importance, has the advantage of being able to project its sound more effectively in desired directions.

The moving-iron armature type of drive has proven satisfactory for loud speakers where small amplitudes and power

[1] Jones, W. C., "Condenser and Carbon Microphones."

are involved. Where large power and greater amplitudes are involved, however, the moving-coil type of drive is more easily adaptable to a design that will respond uniformly to a wide range of frequencies.

The recently designed horn-type loud speaker of the Western Electric Company for large theatres and auditoriums employs the moving-coil type of drive and is chosen for description here because of its remarkable power, efficiency, and uniformity of response through a wide frequency range.[1]

The form of the diaphragm and that of the air chamber at the throat of the horn are shown in Fig. 38. The throat of the

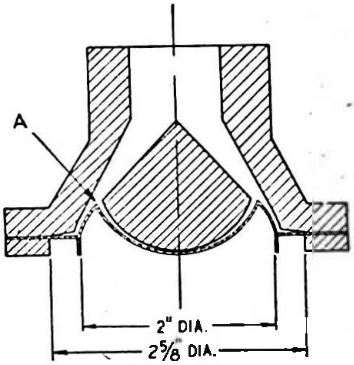


FIG. 38.—Diaphragm and air chamber of Western Electric loud speaker. (*Courtesy of Bell Telephone Laboratories.*)

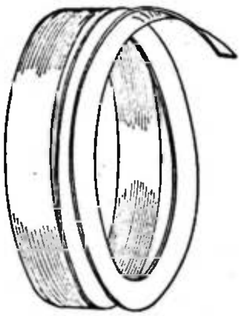


FIG. 39.—Driving coil of Western Electric loud speaker. (*Courtesy of Bell Telephone Laboratories.*)

horn, pointing upward as seen in this figure, is flared annularly from the cuspidal edge *A* of the diaphragm, and, with the exception of the very high frequencies, disturbances from the outer and inner portions of the diaphragm enter the horn in phase. The diaphragm is of aluminum alloy 0.002 inch thick, its central area being drawn into the shape of two reentrant spherical shells. By this formation the central portions of the diaphragm vibrate as a unit, with piston-like action.

The driving coil, in shape a thin cylindrical shell, is fastened directly to the rear surface of the diaphragm at the junction of its plane and spherical sections, as shown in Fig. 38. It has a resistance of 15 ohms and consists of a single layer of aluminum ribbon 0.015 inch wide and 0.002 inch thick, wound on edge as shown in Fig. 39. The coil is bound into a compact

[1] WENTE and THURAS, High Efficiency Receiver of Large Power Capacity, *Bell System Technical Journal*, January, 1928.

rigid mass and its turns insulated from each other by a film of insulating lacquer about 0.0002 inch thick, the whole mass being baked after winding and coating. In this way a coil of great rigidity is formed without a spool. About 90 per cent of its volume is of conducting metal; and since the metal is continuous between its inner and outer cylindrical surfaces, it has a maximum capacity to dispose of its internal heat. Further, this method of forming the coil permits great accuracy of construction, so that very small clearances between the movable coil and adjacent stationary surfaces may be employed. This feature further contributes to the dissipation of heat and also to the low reluctance of the magnetic circuit of the field coil.

The magnet which furnishes the powerful magnetic field in which the driving coil vibrates is shown in Fig. 40. The diaphragm (Fig. 38) lies close to the upper plane face of this magnet, so that its driving coil lies in the annular air gap. Across this air gap a powerful magnetic field (20,000 gausses) is maintained by a flow of direct current in the field coil. Of course the variations in the telephonic currents flowing in the driving coil lying within this powerful field will, by ordinary motion action, tend to cause to and fro movements of the driving coil and corresponding movements of the diaphragm. This is the principle upon which all of the moving-coil or "dynamic" receivers work.

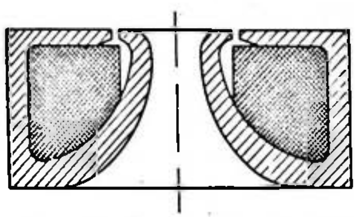


Fig. 40.—Cross-section of field magnet of Western Electric loud speaker. (*Courtesy of Bell Telephone Laboratories.*)

The power, efficiency, and frequency range of this loud-speaking receiver are remarkable. To quote from the synopsis of the Wente and Thuras paper just referred to:

"Its design is such as to permit of a continuous electrical input of 30 watts as contrasted with the largest capacity heretofore available of about 5 watts. In addition the measurements show that the receiver has a conversion efficiency from electrical to sound energy varying between 10 and 50 per cent in the frequency range of 60 to 7,500 cycles. Throughout most of this range, its efficiency is 50 per cent or better. This contrasts with an average efficiency of about 1 per cent for other loud speakers of either the horn or cone type. Combining the fiftyfold increase in efficiency with a five- or sixfold increase in power capacity, a single loud speaker unit of the type here described is capable of two hundred and fifty to three hundred times the sound output of anything heretofore available."

As pointed out in the chapter on Sound,[1] a transmission system that would reproduce, with a fair degree of uniformity, a range of frequencies from 100 to 5,000 cycles without introducing harmonics of its own would meet fairly well the requirements of high-grade music transmission. It is found, however, that the suppression of frequencies above this range causes an appreciable change in the character of some sounds. This is particularly true of many common sounds of an impulsive nature like the clapping of hands, footsteps, and the jingling of keys, where cutting out the higher frequencies may cause the reproduced sound to bear little resemblance to the original. Moreover,

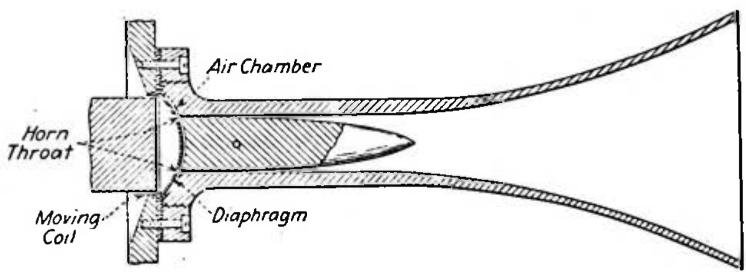


FIG. 41.— Western Electric high-frequency loud speaker. (*Courtesy of Bell Telephone Laboratories.*)

it is found that extending the frequency range to include frequencies well above this range not only makes these common impulsive sounds more natural but appreciably improves the naturalness and brilliance of reproduced speech and music.

The low-frequency requirements of a loud speaker are, in many respects, adverse to high-frequency requirements, particularly on account of the disparity of the masses involved. The Bell Telephone Laboratories have met this difficulty by employing a separate loud speaker specially designed for high frequencies to supplement the loud speaker just described and extend the range of reproduced sound up to 12,000 cycles.[2]

[1] "Theory and Elements," p. 189.

[2] BOSTWICK, L. G., An Efficient Loud Speaker at the Higher Audible Frequencies, *Journal of the Acoustical Society of America*, October, 1930.

BOSTWICK, L. G., A Loud Speaker Good to Twelve Thousand Cycles, *Bell Laboratories Record*, May, 1931.

This loud speaker is constructed along the general lines of the one just described (Figs. 38, 39, and 40) but on a much smaller scale. A cross-section of its diaphragm, air chamber, and horn construction, only slightly less than full size, is shown in Fig. 41. The diaphragm is of duralumin, 0.002 inch thick, about 1 inch in diameter, and with a spherically embossed center

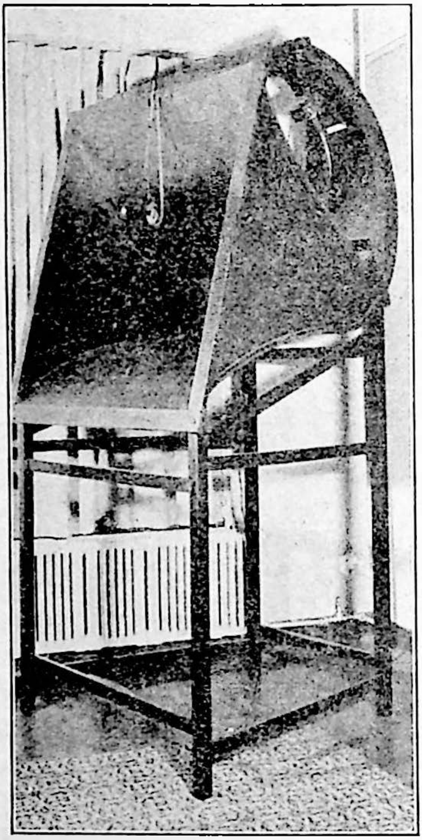


FIG. 42.—Combined loud speakers having frequency response from 60 to above 10,000 cycles. (*Courtesy of Bell Telephone Laboratories.*)

portion. The driving coil is of the edgewise ribbon-wound type shown in Fig. 39, but of much smaller dimensions. The normal thickness of the air chamber in front of the diaphragm is 0.01 inch. The flux density across the air gap in which the driving coil lies is about 18,000 gausses. The horn is of the exponential type with a mouth slightly over 2 inches in diameter and is designed for frequencies above 2,000 cycles. Its throat is in the form of an annular slit to minimize high-frequency resonance effects within the air chamber.

This receiver is efficient for frequencies from 3,000 up to 12,000 cycles per second, but, of course, it is very inefficient for low frequencies. Its purpose, therefore, is to extend the range of response beyond that which the loud speakers designed for the lower and more important range of frequencies are capable of achieving. It may be mounted with its horn mouth extended through the baffle board of one or more cone-type loud speakers or it may be suspended in the mouth of a large horn-type loud speaker. Figure 42 shows one of them so suspended within

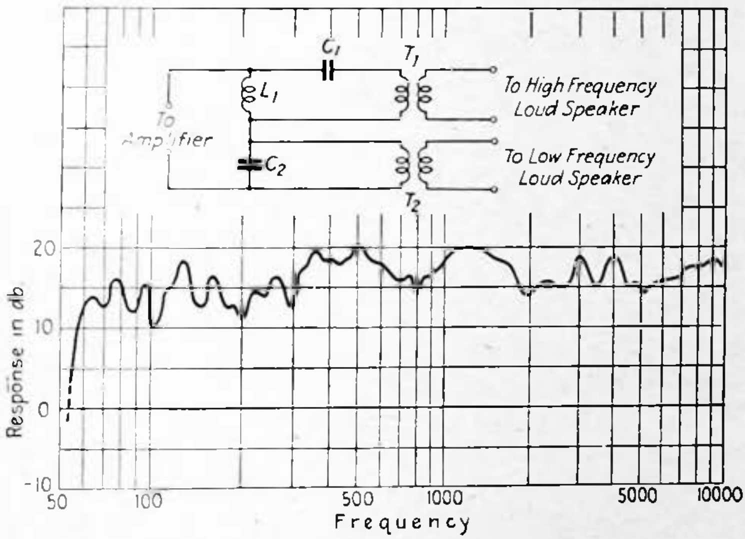


FIG. 43.—Response-frequency curve of combined loud speakers and combining circuit. (*Courtesy of Bell Telephone Laboratories.*)

the large 60-cycle cut-off exponential horn of the standard Western Electric theatre speaker, the working parts of which have already been described.

The curve of Fig. 43 shows the frequency response for the combined receivers for the range from 60 to 10,000 cycles. The circuit network connecting the amplifier to the two loud speakers is shown in the inset of this figure. This is so designed as to deliver most of the electrical power above 3,000 cycles to the high-frequency loud speaker and most of that below 3,000 cycles to the low-frequency speaker. While the curve of Fig. 43 extends only to 10,000 cycles, the real range throughout which this combination is effective is from 60 to 12,000 cycles.

CHAPTER II

SIGNALING APPARATUS FOR SUBSCRIBERS' SETS

Broadly, the signals employed in telephony are of two kinds: audible and visual, adapted respectively to be sensed by the ear and by the eye. As a rule, audible signals are better adapted for the telephone-using public than the visual, since they require neither the immediate presence nor the continuous attention of the persons who are to respond. For this reason they are used at subscribers' stations. Visual signals, on the other hand, are used principally where there are attendants specifically engaged in watching them, as at telephone switchboards. As this chapter deals only with the signaling apparatus that forms an essential part of the subscriber's set, it will treat only of audible signals.

It is not surprising that, when telephone engineering began, the apparently economical expedient of making the telephone receiver serve also as a calling device should have been resorted to. The simplest possible embodiment of this idea was employed on the first outdoor telephone line. This was between the office of Mr. Charles Williams at 109 Court Street, Boston, and his home in Somerville. To call on this line one merely thumped with a lead pencil on the diaphragm of the instrument, which served as both transmitter and receiver, and the thump was feebly repeated by the distant similar instrument.

One must admire the stark simplicity of this first "telephone set." After a fashion it accomplished, with the simple piece of apparatus we now call a receiver, the quadruple functions of transmitting speech, receiving speech, transmitting signals, and receiving signals. There was no battery or other auxiliary source of power and no switch to make and break contact. But, in telephony as in biology, the course of development is from the simple to the complex.

One of the earliest steps toward greater complexity was the addition of a small lever which, when actuated by a push button, struck on the rear edge of the transmitter-receiver diaphragm.

This accomplished the desired thumping more effectively and with less danger of injury to the diaphragm. This instrument, known as "Watson's thumper," is shown in Fig. 44. Two such instruments formed the complete equipment on the line of the first commercial telephone subscriber Mr. Russell C. Downer, in Somerville, Massachusetts. This was in May, 1877. Such simplicity could not survive. The magnetic telephone could produce neither strong enough signaling currents nor loud enough sounds. Moreover, the thumping injured the receiver, which by the nature of its speech-receiving functions was necessarily a delicate instrument.

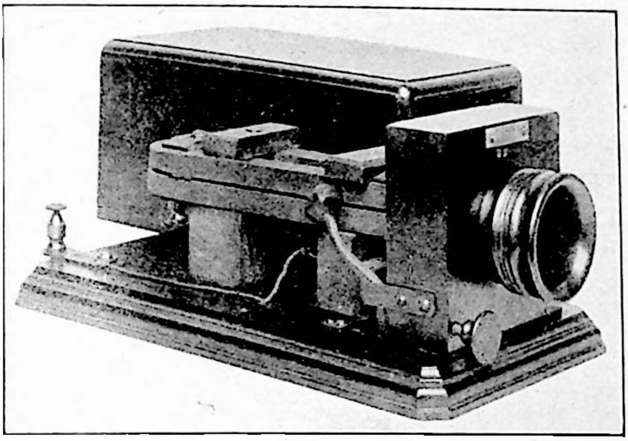


FIG. 44.—Watson's thumper. (*Courtesy of Bell Telephone Laboratories.*)

The ordinary battery bell, working on the principle of the Neff hammer and now generally employed for door bells in residences, attracted early attention as a possible signaling device at subscribers' stations. The fact that at an early date a battery was associated with every telephone for operating the transmitter added to the apparent feasibility of this idea. It was never extensively practiced, however, because a better form of signal bell was devised.

As a result, the battery bell and its near relation the buzzer, important signaling devices in other arts, have always occupied positions of minor importance in telephony. They are employed to some extent for auxiliary local-circuit signals and warrant brief description. Their principle is shown in Fig. 45. The spring-mounted armature carries a tapper adapted to strike the gong when the magnet is energized. Normally the armature is retracted by its spring, so that it rests against its back contact and keeps the circuit closed at that point. When the push button, or other switch, is operated to close the circuit, the armature is attracted, causing the tapper to strike the bell. In doing this, however, the armature is drawn away from its back contact, thus breaking the circuit and de-energizing the magnet. Upon falling back, it again closes the circuit and so repeats the operation, causing a rapid succession of taps on the gong as long as the push button is held down.

The buzzer has no gong or tapper rod but works on exactly the same principle. It produces a sustained rattle or buzz and is commonly used where a less penetrating sound than that of a bell is desired.

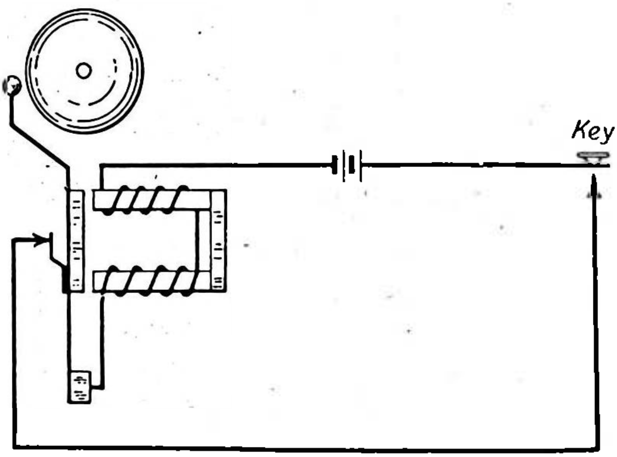


Fig. 45.—Ordinary battery bell.

The principal use of battery bells and buzzers at subscribers' stations is for auxiliary signaling purposes to meet special local requirements. A common one is to enable one who has responded to the ring of the regular telephone bell to summon another not within reach of its sound.

The device that has been found superior to the battery bell for signaling on telephone lines, and generally adopted for that purpose, is the polarized bell or "ringer." This in the general principles of its design is due to Watson as far back as 1878. One is shown partly, in diagram, in Fig. 46. The two electromagnet cores are permanently joined together at their upper ends, by a soft-iron yoke so as to form a horseshoe magnet. A soft-iron armature *A-B* is pivoted at its center so as to lie in front of the poles of this magnet, nearly but not quite completing the magnetic circuit. This armature carries a tapper rod and tapper which play between the two gongs.

The direction of the windings on the two coils is such that when a current passes through the coils in one direction, one of the poles will become north and the other south. With a reversal of the current the polarity will be reversed. With the device so far described, currents passing through the coil in either direction would not cause the armature to vibrate but would merely tend to bend it, because the two ends of the armature would be equally attracted by either polarity developed in the adjacent core ends. This condition is altered, however, by the presence of a permanent magnet *N*-*S*. This, in the form of a shallow U, has one of its ends secured to the magnet yoke, the other end being bent around so as to lie adjacent to, but not touching, the center of the armature.

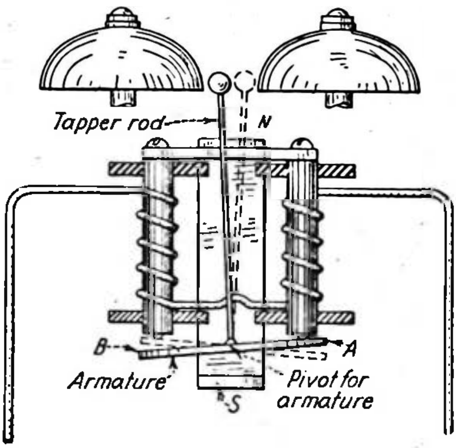


FIG. 46.—Diagram of polarized bell.

This permanent magnet gives the cores and armature a normal magnetic polarity, so that the effect of current in the coils is not to create magnetism in normally neutral iron but to alter the magnetism in iron that is already magnetized. If we assume that the upper end of the permanent magnet has north and the lower end south polarity, then the two free core ends will have normally north, and the two armature ends south, polarity. If now a current flows through the coils in such direction as to make the left-hand pole north and the right-hand pole south, then the left-hand or north pole will attract the south-polarized armature and the right-hand or south pole will repel it. The armature will thus be drawn into the position shown in dotted lines, causing the tapper to strike the right-hand gong. The next current impulse, being in the opposite direction, will reverse the polarities of the magnet cores but not of the armature, and the armature will then be drawn in the other direction, causing the left-hand gong to be struck. In this way the successive impulses of the alternating ringing current cause the tapper to vibrate between the two gongs.

Small pieces of non-magnetic material, brass or copper, are placed between the core ends and the armature to prevent actual contact and consequent "sticking" due to residual magnetism. These the layman often calls "residuals." In all polarized bells the proper design and adjustment call for the stoppage of the armature at a point somewhat short of that where the tapper touches the gong, depending on the flexibility of the moving system to allow the inertia of the tapper to carry it farther into contact with the gong. This gives clearer ringing, since the tapper upon striking the gong immediately rebounds from it and is thus started on its return movement after a single clean stroke.

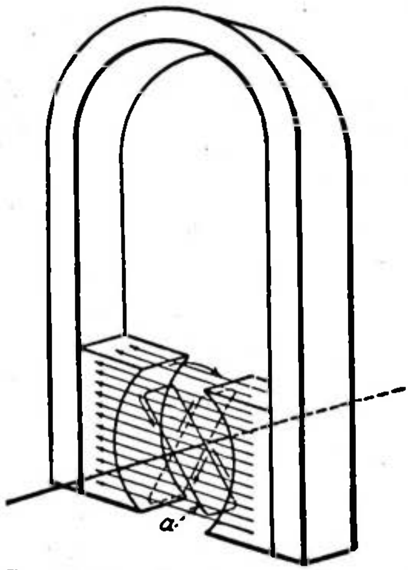


FIG. 47.—Principle of magneto generator.

The ordinary polarized bell operates on alternating currents of comparatively low frequency—usually in the neighborhood of 19 or 20 cycles per second. For some classes of service, notably in magneto exchanges, it is desirable that the bells be responsive to a rather wide frequency range, because much of the signaling current is produced by hand generators, the current frequencies thus being dependent on the rate at which the subscriber turns his generator crank.

In the magneto telephone set, the companion piece of the polarized bell is nearly always the "magneto generator" or "hand generator." This is about the simplest form of dynamo electric machine. It consists of an armature of the Siemens type, wound with many turns of fine wire and so mounted as to enable it to be revolved rapidly between the poles of a permanent horseshoe magnet. Its theory of action is simple and depends directly upon the principles of magnetic induction. It may first be considered in connection with Fig. 47, The loop of wire *a* is supposed to be revolving on its axis in the field of a permanent magnet whose lines of force are represented by the horizontal arrows. In tracing a cycle of operation, it is to be remembered that the electromotive force induced in a conductor moving in a magnetic field will depend on the rate at which the lines of force are being cut; and that the direction of the electromotive force will depend on the direction of the field and on the direction of motion of the conductor through it. When the coil is in its vertical position, the electromotive force will be zero because the conductors are moving parallel with the lines and not cutting them at all. As the loop revolves in the direction of the curved arrow, the rate of cutting, and therefore the electromotive force, will increase, until the coil is in a horizontal position. At that point, the rate of cutting, and therefore the electromotive force, will be maximum. Both will decrease from that point on until the vertical position is again reached, when there will be no cutting and the electromotive force again will be zero. The same sequence of events will be repeated during the next half-revolution, the electromotive force starting at zero, rising to a maximum when the horizontal position is reached, and then decreasing to zero as the coil passes from the horizontal to the vertical position. In this second half of the cycle, however, the direction of motion of the conductors through the field will be the reverse of that during the first half-revolution, with the result that the electromotive force in this half of the cycle will be of opposite sign from that in the first half. Each revolution of the loop thus generates one cycle of alternating electromotive force and, if the loop be closed, one cycle of alternating current.

In practice, the single revolving loop of Fig. 47 is replaced by a coil of many turns. In order to obtain as great a flux as possible through this coil, it is wound on an iron core, the coil and core together forming the armature. This armature is journaled in suitable bearings so as to permit it to revolve freely between the pole pieces of the strong permanent magnet. In the hand generator, the turning of the armature is accomplished by means of a hand crank, the shaft of which carries a driving gear meshing with a pinion on the armature shaft. The arrangement is suggested in the diagram of Fig. 48, which shows also the commonly employed method of leading the current from the revolving coil to the circuit with which the generator is connected. It also indicates the action of an important adjunct, the "generator switch," which in this case keeps the generator normally shunted but acts automatically to break the shunt and switch the coil into circuit whenever the crank is turned. In this diagram, the U-shaped permanent magnets are removed and only their pole pieces indicated.

To provide for the external connection of the armature winding, one of its ends is permanently connected to the body of the core of the armature, and the other to an insulated pin *R* projecting axially from the end of its shaft. The frame of the generator, through the bearing *W*, thus forms one external terminal, and the spring *L* resting against the insulated pin *R*, the other.

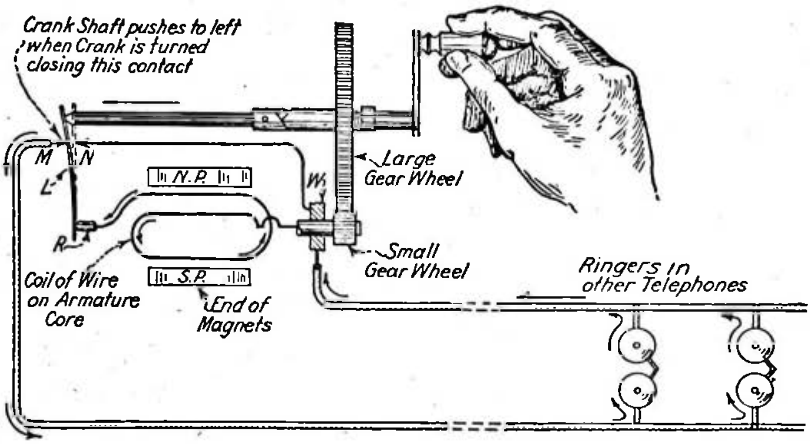


Fig. 48.—Operation of magneto generator.

The automatic generator switch, sometimes called the "generator shunt" or the "generator cut-in," according to the function it is to perform, as shown in Fig. 48, comprises the spring *L*, adapted to engage alternately the contacts *N* and *M*. Normally the movable spring *L* rests against the back contact *N*, thus closing a shunt or short-circuit path *RLNW* about the armature coil and at the same time breaking the circuit to one side of the line at the contact *M*. In its alternate position, the switch spring breaks the shunt and establishes the path across the line through the armature. By thus keeping the armature normally short-circuited, it is afforded substantial protection against damage from high-tension currents that might arise from lightning strokes or from crosses between the line and power circuits. Keeping the generator bridge normally broken prevents the armature coil from acting as a shunt for voice or signal currents passing over the line.

Figure 49 shows the relation between the magnet ends, pole pieces, and armature core in a common form of magneto genera-

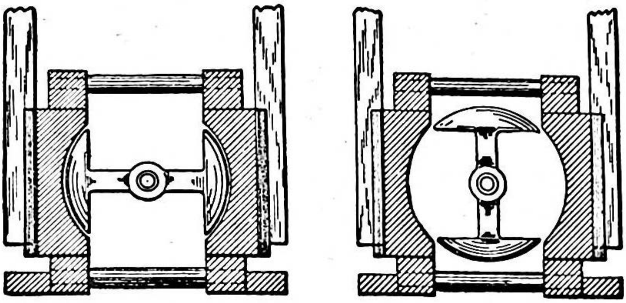


FIG. 49.—Generator pole pieces and armature core.

tor construction. Here the pole pieces are of cast iron rigidly held together by shouldered brass rods. After they are so secured, the space between them is bored out to form accurate cylindrical surfaces between which the armature may revolve. This form of construction gives a substantial base upon which to

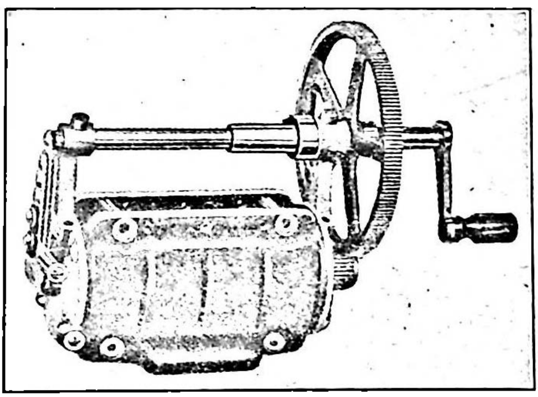


FIG. 50.—Kellogg generator partly assembled.

mount the end plates in which the armature and the crank shaft are journaled. The assembly, in this respect, and that of the generator-switch springs, are clearly shown in Fig. 50.

The general form of armature core is shown in Fig. 51, the cross-section perpendicular to the shaft being as in Fig. 49. The ends of the shaft are turned down to form cylindrical bearing surfaces as at 1 and 2. The outer surfaces 3 are likewise accurately turned to cylindrical form, so as to permit them to revolve freely but with small clearance between the pole faces. Only a few turns of the winding are indicated, but in practice the winding space between the cheeks 4 and the shaft are filled with as many turns of the desired size of insulated wire as can be put on without danger of their rubbing against the stationary pole faces when the armature is turned. After the surface of the winding space is carefully insulated, one end of the wire is soldered to the small pin 6 which projects laterally from the pin 7, projecting axially from the end of the armature shaft. These two pins are connected electrically to each other but carefully insulated from the core. The wire is then wound on the core in the spaces on each

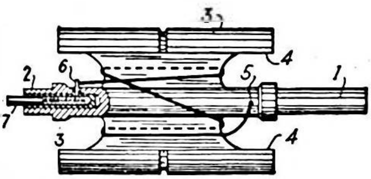


Fig. 51.—Armature core of hand generator.

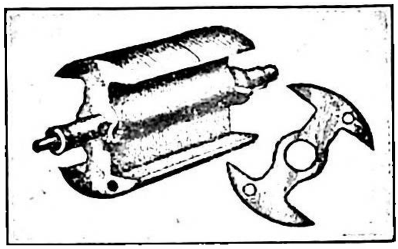


Fig. 52.—Laminated armature core.

side of the shaft, until the winding, with the core faces, assumes a substantially cylindrical form. The free end of the wire is then soldered to the pin 5, which is driven into and electrically connected with the core. The core itself thus forms one terminal of the armature winding and the insulated pin 7 the other.

Sometimes, in order to secure greater magnetic permeability in the armature core than is possible with cast iron, the armatures are built up of laminations. Punchings of silicon steel, of such form as to give the required cross-section of armature, are strung on the central shaft and clamped rigidly together, resulting in a structure indicated in Fig. 52.

Another form of magneto armature assumes the form shown in Fig. 53. In this the advantage of a single rigid shaft extending from one end to the other is sacrificed for the advantages of increased winding space and a more evenly laid winding. The cross-section of the armature core is of H form and the spaces between the cheeks are taken up entirely by the winding instead of being partially occupied by the shaft, as in the older form of armature. Two cylindrical studs, projecting from the brass disks rigidly secured to each end of the core, form the journals on which the armature turns. This modified form of construction has been widely used, and when proper provision is made to secure accurate alignment and sufficient rigidity, it has been entirely successful.

From what has been said in Chap. V of the preceding volume[1] concerning simple harmonic motion, it will be clear that if the armature coil revolves at a uniform rate under conditions as simple as those indicated in Fig. 47, a sine wave of electromotive force will be generated. This form of wave would probably best serve the purposes for which these generators are used, but it is not the form actually generated. The principal reason for the difference is that the uniform field assumed in Fig. 47 does not exist. Instead, the field is greatly distorted by the presence of

FIG. 53.—H-type armature.

the iron core of the armature. Owing to the greater permeability of iron than of air, practically all the lines of force pass through the armature core. When the web of the core is horizontal, as in the left-hand cut of Fig. 49, practically all of the flux passes through all of the turns. This condition exists for a considerable angular distance on each side of the horizontal web position. During this part of the rotation, there is relatively small change in the flux through the coil and therefore relatively small electromotive force. There is an abrupt change, however, just as the armature passes into the position shown at the right of Fig. 49, for then the two cheeks of the armature form parallel paths from one pole piece to the other and the flux does not pass through the coil at all. During the part of the rotation in which it is approaching and leaving this position, the flux changes very rapidly and as a consequence there is an abrupt peak in the electromotive-force wave corresponding to this portion of the armature travel. Variations in the relative widths of the armature cheeks, with respect to the gaps between the pole pieces, have a marked effect

[1] "Theory and Elements," p. 91.

on the wave form generated. The relative proportions shown in Fig. 49 are about representative of common practice.

Too abrupt a peak in the electromotive-force wave is to be avoided in generator design. Such a peak may add little to the mean effective pressure and yet be so high as to break down the insulation of apparatus or cable that is subjected to it.

Sometimes it is desirable that magneto generators be made to send out pulsating instead of alternating currents and that polarized bells be made responsive to certain kinds of current and unresponsive to others. These matters have principally to do with selective ringing on party lines, and in so far as they affect the design and construction of the signaling apparatus itself, they will be dealt with here.

An ordinary magneto generator may be made to deliver pulsating current, that is, current in which all the impulses are in the same direction, by providing a simple commutator on the end of the armature shaft. Such an arrangement is indicated in Fig. 54. Here one end of the winding is brought out to a commutator segment 3, mounted on but not insulated from the shaft, and the other end to the axial pin 1, as usual. The two terminal springs 2 and 5 bear respectively against the pin 1 and the segment 3 and form the means for connecting the armature winding with the external circuit. The spring 2 will make contact throughout the complete revolution, but on account of the insulating segment 4 carried on the commutator, the brush 5 will connect with the armature winding only through about half of each revolution. It is obvious that, if the brush 5 is so disposed as to make contact with the conducting segment only during the half-revolution in which positive impulses are generated, positive impulses only are sent out. In this case, the negative impulses will be suppressed because the circuit is open during the negative half of the revolution.

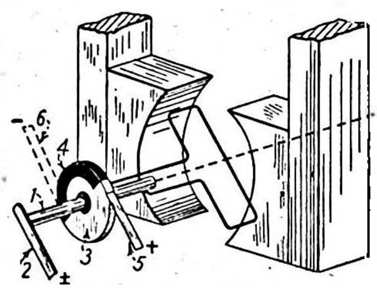


Fig. 54.—Commutator for pulsating current.

In an exactly similar manner, if another brush 6, shown in dotted lines in Fig. 54, be made to engage a point on the segment just opposite to that engaged by the brush 5, it will form a terminal for the generator which would receive only negative impulses. A magneto generator so equipped is thus capable of sending out positive or negative pulsating current, according to which of the brushes, 5 or 6, is used. Or it may be made to send out ordinary alternating current if the two brushes 5 and 6 are connected together and used as one terminal.

With regard to their responsiveness to different kinds of current, we may classify polarized bells in three groups: First, the ordinary alternating-current ringer adapted to respond indiscriminately to alternating current of a comparatively wide range of frequency. Second, the biased ringer which will respond to pulsating current in one direction but not in the other. Third,

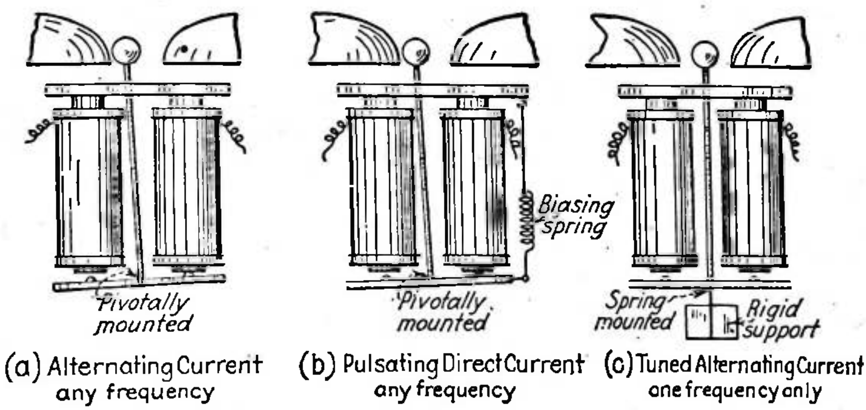


FIG. 55.—Three types of ringers.

the harmonic ringer which has a sharply tuned armature so that it will respond only to one frequency of current. These three groups are typified respectively in Diagrams *a*, *b*, and *c* (Fig. 55). The permanent magnet required for each of these types is not shown in these diagrams.

The principle of the ordinary polarized bell, Diagram *a*, has been dealt with in connection with Fig. 46. The biased bell, Diagram *b*, acts on exactly the same principle, except that the armature is normally drawn toward one magnet pole by a so-called "biasing spring," as indicated. The action of this is readily understood. If the spring holds the armature in the position toward which it would be drawn by negative impulses, then the bell will respond only to positive impulses. Negative impulses are powerless to move the armature, because the spring already holds it in the position to which they would draw it.

The theory of the harmonic bell indicated in Diagram *c* is somewhat more complex and will be dealt with more fully elsewhere. It is easily understood, however. Instead of mounting the armature and tapper on trunnions or pivots, as in the ordinary ringer, the whole moving system of the bell is mounted on a fairly stiff spring which tends to hold it in median position, but which, when sufficient force is applied, permits it to be moved to strike either gong. These vibrating members, comprising the spring, armature, tapper rod, and tapper, are literally tuned each to a given frequency of vibration. Each bell will then respond readily to currents of its particular frequency but with difficulty

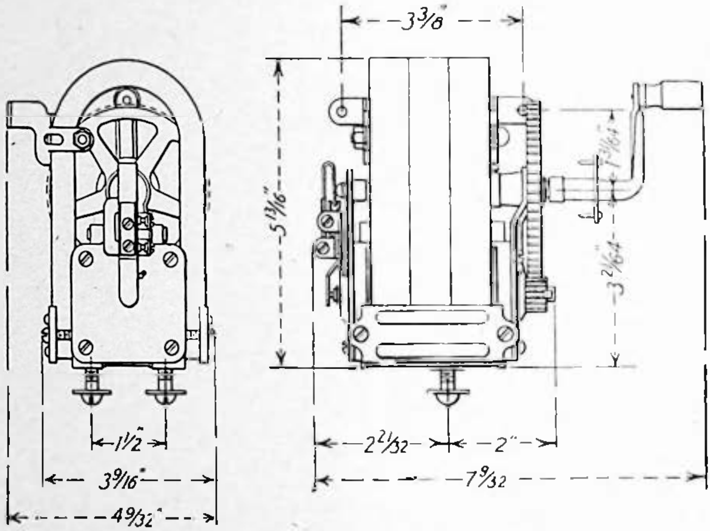


Fig. 56.—Western Electric three-bar generator.

to currents of any other frequency. The tuning as between the several desired frequencies is usually accomplished by employing tappers of different weights, aided in exact tuning by sliding the tapper along the rod or by making adjustments in the stiffness of the spring, or both.

Considering now a few commercial designs of generators and ringers as employed in subscribers' sets, Fig. 56 shows one of the standard magneto generators of the Western Electric Company. This is the No. 22 type for non-selective ringing on short magneto lines. The principal dimensions are indicated. This employs three permanent-magnet bars and is therefore called a "three-bar" generator. Its output is alternating current at a pressure of about 60 volts. It may, however, be provided with a commutator adapting it to produce pulsating current at about 43 volts.

Sometimes, where the generator is required merely to throw a switchboard drop on a short exchange line, the center bar of this No. 22 type generator is omitted, saving weight and expense and at the same time providing ample generating capacity for the duty imposed.

For heavier duty, as on bridging party lines, generators having four or five bars are sometimes employed. In these cases the armature and frame are lengthened to accommodate the greater number of magnets. In Fig. 57 the five-bar generator of the Kellogg Company is shown, some of the details of this having been shown in Fig. 50. In addition to the more powerful field furnished by the greater number of magnets, the winding space on the armature is made as large as possible and wound with comparatively large wire for greater current output.

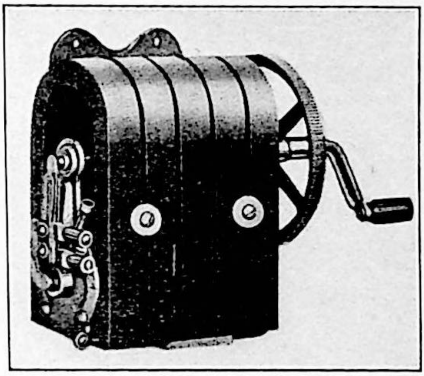


FIG. 57.—Kellogg five-bar generator.

Heavier generators, such as this, are, if required, provided with commutating devices adapting them for pulsating current of either polarity, as well as for alternating current according to which of the terminals are employed. The generator switches may be variously arranged to open and close a generator shunt, or to open and close the bridge circuit across the line, or to perform both functions. The alternating-current output is usually at a voltage of about 80, and the pulsating output at about 56. The usual gear ratio is about 5 to 1, giving a frequency at the ordinary rate of hand turning of about 20 cycles per second.

The kind of duty requiring these generators of larger output is that found on long, heavily loaded rural lines. Sometimes as many as forty or fifty telephones are served by a single line. These are perhaps extreme cases and are not to be recommended, but lines with from ten to twenty telephones are common. On such lines the generator at ony one station is required to ring the bells of all the other stations in multiple. This requires relatively large current output and high voltage. The problem becomes more exacting as the number of stations and the length of the line are increased—particularly so if the line conductors are of No. 14 B.W.G. iron wire, as is often the case.

Obviously such heavy-duty generators should have as great electrical output as is consistent with the small muscular effort available for turning them. The output is largely dependent on the strength of the permanent magnets, but even with an adequate set of magnets much depends on the design, workmanship, and materials used. Obviously the smaller the clearance between the armature and pole pieces and the more permeable the

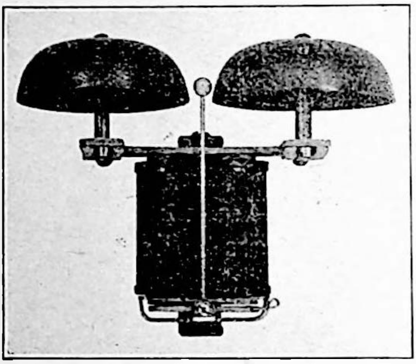


FIG. 58.—Western Electric alternating-current ringer. (*Courtesy of Bell Telephone Laboratories.*)

armature core, the greater will be the flux through the winding. It is important that the magnets do not slowly lose their strength with age.

Mechanically a good hand generator should run quietly, smoothly, and with little wear. Wide, accurately cut gears and pinions, and long, well-fitted bearings with ample provision for oiling, are important in this respect. The structural requirement for air gaps means small clearance between armature and pole pieces, but this must not be carried so far as to allow the armature to scrape on the pole pieces after a little wear, this being fatal to smooth operation. The provision against rust is also an important one. The armature and pole pieces, necessarily of iron, should be given a durable rust-proof treatment.

Figures 58, 59, and 60 show respectively the ordinary unbiased bell for use at magneto stations, the biased bell for use at common-battery stations, and the harmonic ringer, all manufactured by the Western Electric Company and used by the companies of the Bell System.

In Fig. 58, the cross-piece in which the armature is pivoted is carried directly on the lower ends of the magnet cores. The

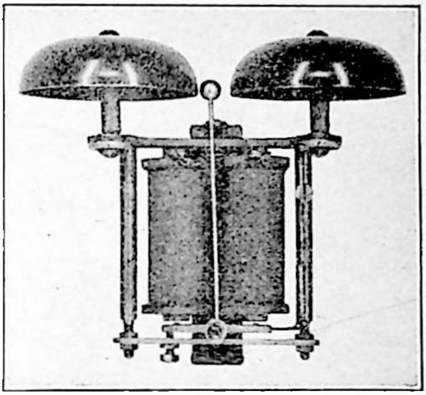


FIG. 59.—Western Electric biased ringer. (*Courtesy of Bell Telephone Laboratories.*)

permanent magnet is secured at its upper end by a screw engaging the center of the soft-iron yoke. Extensions of this yoke form supports for the gong standards. The permanent magnet passes down behind the ringer coils and is then bent forward, so that its

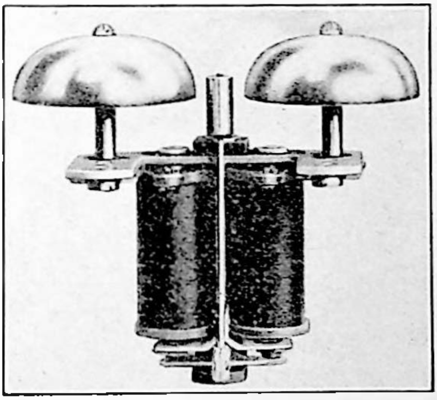


FIG. 60.—Western Electric harmonic ringer. (*Courtesy of Bell Telephone Laboratories.*)

lower end lies just under but not touching the armature. In this ringer the adjustment of the armature with respect to the pole pieces is done by means of a screw not shown in the figure. This adjusting screw passes through the center of the yoke in which the armature is pivoted, through a large hole in the armature, and is threaded into the cross-bar which is supported on the lower ends of the cores. Turning it bends the yoke and thus moves the armature carried by it toward or away from the pole pieces. Screw terminals are provided for the coil, these being located on extensions of the upper spool heads, as shown. This is the Bell standard ringer for magneto service.

In the biased bell of Fig. 59, the armature is supported on a separate framework, as indicated. Its adjustment is by means of the nuts on the lower screw-threaded ends of the two brass supporting standards. The armature is normally held in such position that the tapper will almost touch one of the gongs, by the coiled bias spring. This is attached at its lower end to an eyelet projecting from the armature and at its upper end to a thread which winds around an adjusting screw projecting from the right-hand standard. By turning this screw the tension on the bias spring may be altered at will. The stroke of the armature in the direction in which the bias spring pulls it is limited by an armature stop screw, which permits the adjustment of the position in which the bias spring normally holds the armature. In these ringers, which are used at common-battery stations in the Bell System, the wire ends of the coil terminate in soldering terminals for the attachment of external circuit wires.

The harmonic bell of Fig. 60 resembles more nearly the unbiased bell in its general construction, but, instead of the armature's being pivoted between trunnion screws, it is carried by a stiff spring held between the two halves of the core yoke. The armature and tapper are thus held normally in a median position. From this position they are pulled by magnetic impulses in either direction, if they occur at just the frequency to which the vibrating system is mechanically attuned.

Two views of the untuned ringer of the Automatic Electric Company are shown in Fig. 61. This is used for alternating or pulsating current, according to whether the bias spring is present or absent. The features of interest in this ringer are the methods of mounting and adjusting the armature. Instead of being mounted between pointed pivots as is usual, this armature is journaled on a shouldered stud at one side and a shouldered screw on the other, these constituting in effect a pin bearing. The adjustment of the armature with respect to the pole pieces is accomplished through the medium of an armature retaining spring which serves to connect the armature with the bearing studs and permits the raising and lowering of the armature by means of an adjusting screw. The permanent magnet is made of

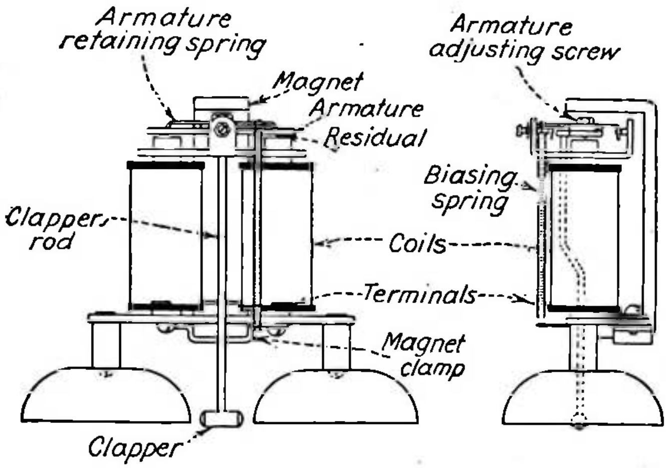


FIG. 61.—Automatic Electric Company untuned ringer.

tungsten steel and is fastened to the magnet yoke by means of a clamp instead of being perforated and attached by a screw.

The harmonic or tuned ringer of this company, shown in Fig. 62, is of similar general construction but differs in the method of mounting the armature and bell tapper. Instead of being

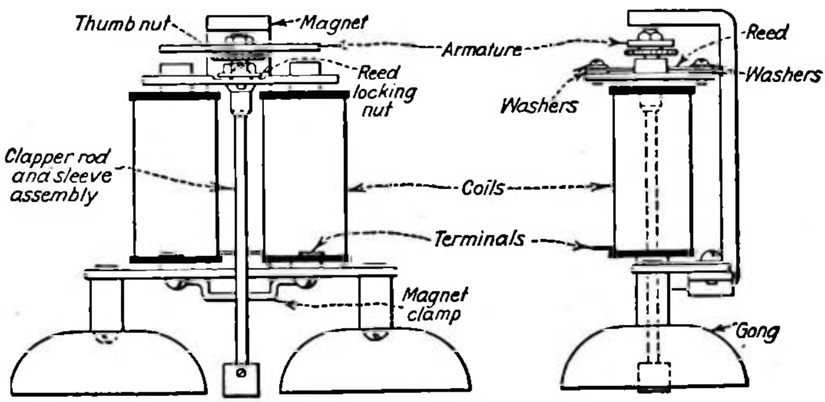


FIG. 62.—Automatic Electric Company tuned ringer.

journaled in bearings carried by the frame, as in Fig. 61, this armature is carried by a flat spring or reed, mounted crosswise to the armature and in a parallel plane. The two ends of this flat reed are fixed to the frame of the ringer by means of screws and washers. Vibration of the armature and tapper is permitted by flexing the center part of the spring with respect to its two fixed ends.

The principal tuning is effected by variations in size of the tapper. Figure 63 shows four of the armature assemblies as

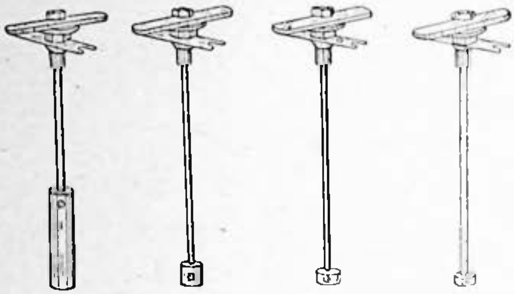


FIG. 63.—Tuned armature rods of Automatic Electric Company ringer.

they are employed for the principal four-party frequencies, 16⅔, 33⅓, 50, and 66⅔ cycles per second, respectively. Finer tuning is accomplished by a slight movement of the tapper along the tapper rod, which thus effectively alters the length of the vibrating member. Adjustment of the air gap is provided for in

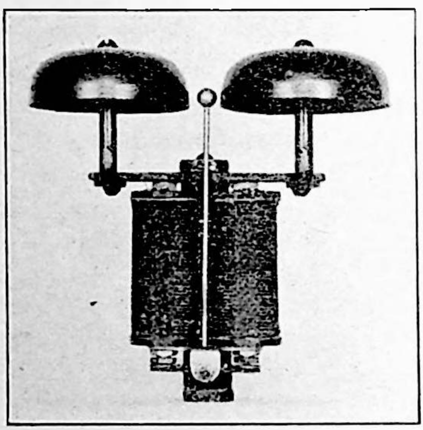


FIG. 64.—Kellogg ringer.

the thumb nut and lock nut which clamp the armature between them on the short end of the tapper rod.

One of the polarized bells of the Kellogg Company is shown in Fig. 64. The point of special interest in this design is the method of adjusting the air gap. Here the pole pieces of the magnet are not the cores themselves but soft-iron screws threaded into the cores. By turning these screws, the effective length of the cores may be shortened or lengthened and thus moved toward or from the armature. In a later type of ringer manufactured by this company, the relationship of armature to pole pieces is fixed in manufacture, means for subsequent adjustment being purposely avoided.

In the various makes of ringers, whether tuned or untuned, two different plans are employed for adjusting the gongs laterally with respect to the tapper. One of these, perhaps the most common, is to mount the gong standard on a lever or adjustable member so as to facilitate its lateral movement. This method is employed in the ringers of the Western Electric and the Kellogg companies, for instance. The other method is to definitely fix the gong posts with respect to the ringer frame and provide for the adjustment of the gong by making the screw hole through it eccentric. In this case the adjustment of the gong with respect to the tapper is varied by merely turning the gong on its support. This practice is followed by the Automatic Electric Company and the Stromberg-Carlson Company.

Ordinarily ringers should be so adjusted that, when the armature is drawn as far as it can go in one direction, the tapper will not quite touch the gong that it is to strike in that direction. Ringers work best under this adjustment, for the resiliency of the tapper rod permits the inertia of the tapper to move it beyond the position to which the armature can draw it. When it strikes the gong, it immediately rebounds, thus acquiring a start on its return journey.

Actual contact between the iron of the armature and of the pole pieces is always to be avoided in polarized ringers, whether biased or unbiased, tuned or untuned. This is because even the best qualities of soft iron used in cores and armatures possess some coercive force and retentivity. Were the armature allowed to come in actual contact with the pole pieces, the residual magnetism would tend to cause them to stick together and this tendency would have to be overcome by the pull in the opposite direction before the armature could move. Iron-to-iron contact is usually prevented by the simple expedient of placing a small bit of non-magnetic material, such as copper, brass, or bronze, on the armature or pole pieces at the points where they would otherwise touch. These "anti-sticking" pieces often take the form of thin copper rivets, as shown in Fig. 59, and sometimes of thin sheets of copper applied to one surface or the other, as shown in Fig. 64.

The windings of ringer magnets must be designed not only with respect to the ringing currents employed to the end that they may produce the required magnetic pull on their armatures but also with respect to the voice currents, since the ringer coils are usually left connected with the line during conversation.

Before the effects on voice currents of electromagnetic reactions had been fully appreciated, it was customary, where more than one telephone was served by the same line, to arrange them in series in the line circuit. It was an easy matter to relieve the talking circuit of the impedance of the generator armature in such cases, for the automatic shunt kept the generator effectively short-circuited when it was not in use. The ringers of the stations not involved in the conversation had to be left in circuit, however, so as to be ready to respond to calls. As a result, the voice currents between the two stations that were talking had to pass through the ringer coils of all of the stations not talking. In order that they might do as little harm as possible it was customary to wind these ringer coils on short spools of as low resistance as was consistent with their ringing functions. This was usually about 75 ohms for the pair. These were called "series ringers" and they were a necessary part of every telephone manufacturer's output. Except perhaps for special uses, the series ringer has now passed out of existence, because of its reactance to the passage of voice currents through it seriously interfering with transmission.

Present practice, as will be shown, requires ringer coils, where left connected with the line, to be connected in bridge across it instead of in series in it. They therefore offer shunt paths across the line for the voice and signal currents to follow. In order that the voice currents may not be shunted out of their intended channels, the ringer coils are wound on long cores, with many turns, so as to give them as high impedance as possible to the voice currents. The low-frequency ringing currents pass through them with greater freedom, sufficiently so to allow them to exert their intended ringing functions.

Modern ringer coils are variously wound to resistances of from 500 to 2,500 ohms for the pair. The mere ohmic resistance, as far as talking currents are concerned, is of little significance. What is important is the impedance of the coil, which on account of reactance is very much higher to voice frequency currents than the ohmic resistance. However, as the winding space of most ringer coils is about the same, and, as it is the winding space that determines the number of turns that can be placed on a coil with a given size of wire, the specifying of the resistance to which coils are wound is a convenient and satisfactory designation of the winding.

CHAPTER III

TELEPHONE SYMBOLS AND CIRCUIT DIAGRAMS

At this point we may profitably digress to consider what has been called the "sign language of telephony"—that is, the system of symbols and conventions used by telephone men in their "circuit diagrams." These circuit diagrams give information as to how the various minor units of telephone apparatus, such as transmitters, receivers, drops, and bells, are combined, physically and functionally, into comprehensive units, such as complete telephones, switchboards, and exchange systems. The beginner need not be disturbed by the fact that, sometimes, quite dissimilar symbols are used to represent the same thing. A really good telephone symbol should be suggestive, in either form or function or both, of the thing it is intended to represent, and little confusion should be caused if different persons adopt dissimilar symbols to represent the same thing. Language presents the same difficulty—if it is a difficulty—since entirely different words are often used to express exactly the same thought.

In the circuit diagrams prepared for this book, no attempt has been made to adhere to any single set of symbols. A manufacturer, in his drafting-room practice, may find it advantageous to do this, but, since telephone men in general persist in using a diversity of forms, it is thought better not to standardize too sharply here but to make the reader generally familiar with the great diversity of symbols that he is sure to find in dealing with telephone circuits.

The symbols and conventions in the two-page collection of Fig. 65 have been chosen as typical. These are the ones chiefly employed in the many circuit diagrams of this and the following volumes. Some of the symbols relating to the more highly specialized apparatus of machine-switching systems have been purposely omitted from this general collection with the thought that they can best be dealt with, and if necessary explained, in the portions of the text treating of these systems.

Telephone-circuit diagrams fall, more or less sharply, into two classes—"wiring diagrams" and "schematic diagrams." The distinction is briefly this: A wiring diagram is intended primarily to show how the wires are run between the various apparatus terminals. In a sense it is structural since it indicates the relative positioning of the apparatus units and shows the kinds of wires and how they are run between the apparatus terminals. It usually gives the color code of the wires and such information as whether they are to be laid up singly, in twisted pairs, or in other specified groupings and whether in cable or in open wiring. It has no regard to affording an easy understanding of the functioning of the circuit. The schematic diagram, on the other hand, ignores structural details in order to make the functioning as clear as possible. It has little regard to the relative positioning of the apparatus units unless there is some mechanical interaction between them which affects the functioning. Instead, the various symbols are arranged on the diagram with the principal idea of showing their electrical connections with as little confusion as possible. Most of the circuit diagrams in this work are of the schematic type.

The following comment on the main groups of the symbols and conventions of Fig. 65 may be helpful in their interpretation and use.

Conductors.—Since most circuit diagrams are on paper, they are limited to two dimensions. It is inevitable, therefore, that lines representing wires must, in crossing, make contact with each other although no electrical connection is intended to be represented. Until recently it was common practice, in such crossing of lines, to indicate that the conductors were not electrically connected by a small jog in one of the lines at the point of crossing. This, indicated at *a*, added to the draftsman's work and sometimes detracted from the clarity of the diagram. Later and better practice is to represent wires which cross without being connected as at *b*. To distinguish from this, where the crossing wires are to be understood as electrically connected, the fact is indicated by a dot at the point of crossing, as at *c*. For branching wires *d*, the dot is used to accentuate the juncture. These are important conventions and once the beginner fixes it in his mind that a dot at the juncture of two lines, as in *c* and *d*, indicates that the wires are conductively joined, while the absence of such a dot as at *b* indicates that the crossing wires are not joined, he will have avoided one element of possible confusion.

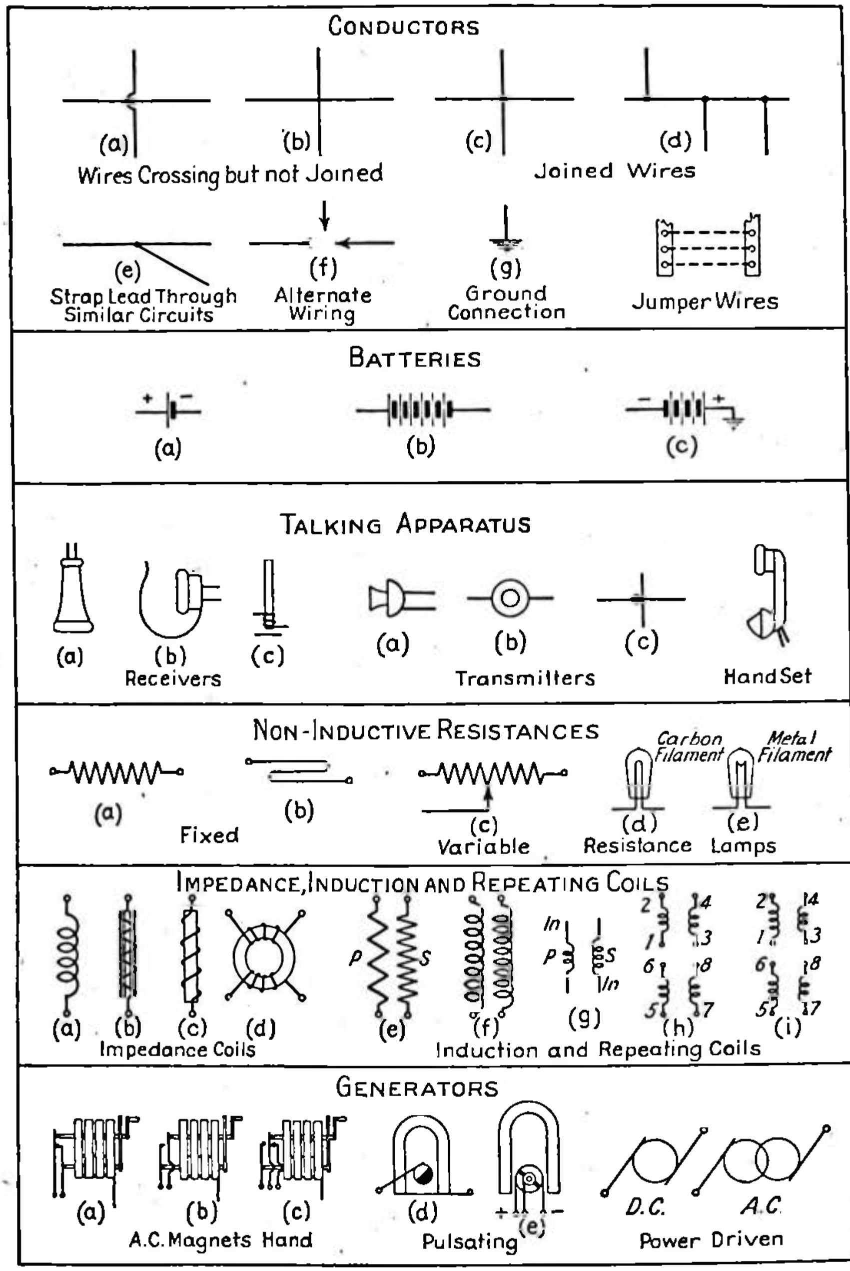


FIG. 65.—Conventional symbols for circuit diagrams.

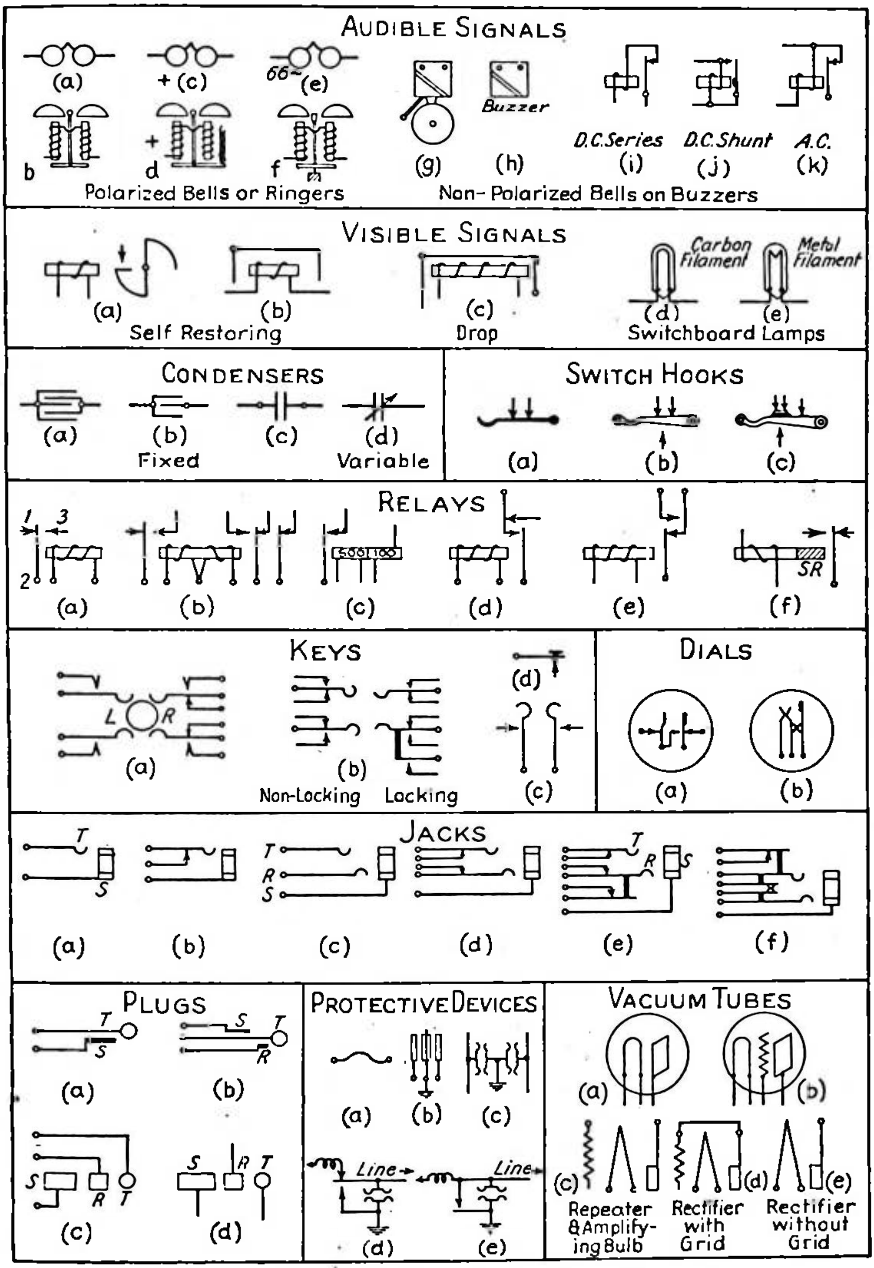


FIG. 65.—Conventional symbols for circuit diagrams.

The strap-lead convention *e* merely means that a number of similar circuits lead off from the point indicated. The alternate-wiring convention *f* indicates that the left-hand wire may be wired to either of the others represented by arrow points. Perhaps the most universally recognized of all the symbols is that of the grounded conductor shown at *g*.

Battery and Ground.—The battery symbols *a*, *b*, and *c* are also well-nigh universal. Each pair of lines supposedly represents a cell of the battery but, as a matter of fact, the number of pairs of lines in a symbol give little indication of the voltage, except in the very general way that the number of pairs is usually greater for a higher-voltage battery than for a lower. Unless there is a positive indication to the contrary, the long thin line is the positive element and the short thick one the negative. Sometimes the plus and minus symbols are applied but more often not.

Usually in common-battery exchange practice one pole of the common battery is grounded, as represented at *c*. Unless indicated to the contrary, it is the positive pole that is grounded. Usually a diagram of a common-battery system uses a number of of battery symbols even though only a single battery is intended to be represented. This avoids the running of lines from all parts of the diagram to a common point, as would be required if only a single battery symbol were used, and thus tends to simplify and clarify the diagram. The same practice is followed with ground connections for the same reason. In tracing the circuits of such a diagram, it is usually well to begin at the negative or ungrounded pole of the battery and to consider that the potential of that point is seeking a path to ground which is, of course, the other pole of the battery. The student should remember that in a diagram of a common-battery system, regardless of how many battery symbols may be shown, all of the ungrounded battery terminals are to be taken as in effect connected together by one common heavy conductor, and likewise all of the grounded terminals as connected by another common heavy conductor. With this in mind, the path of the battery current through the particular pieces of apparatus being considered is to be traced from one of these common conductors to the other.

Talking Apparatus.—Little need be said of the conventional representations of receivers, transmitters, and hand sets.

Receiver symbol *a*, suggestive of form only, is the one most often used for the hand telephone. In *b* the head band of the operator's receiver is suggested. Receiver symbol *c* is sometimes used in elementary diagrams where it is desirable to suggest the function.

Of the transmitter symbols *a* suggests form and *c* function. These are the ones most used. Transmitter symbol *b* has little to commend it, except that it is easily drawn. The hand-set symbol is obvious.

Non-inductive Resistances.—Of the fixed non-inductive resistance symbols, the one consisting of a zigzag line *a* is the oldest and most used. When standing alone, it may usually be taken as a purely ohmic resistance. Unfortunately, however, such a zigzag line forms a part of the most commonly used symbol of induction coils and repeating coils, as will be pointed out presently. It is well, therefore, to scrutinize such a symbol wherever it occurs to determine its true meaning. Possible confusion is avoided if it be marked N.I.

The simple non-inductive resistance symbol *b* has come into favor recently, particularly to represent those coils on relays or transformers that are non-inductively wound, so as to serve a purely resistance as distinguished from a magnetic function. The idea of variability and adjustability of resistance is carried in symbol *c* by the conception that the arrow represents a movable contact, slidable to engage the resistance element at different points along its length.

Lamps, used as non-inductive resistances, may be shown as at *d* and *e*. The differentiation between those having carbon and metal filaments, with their negative and positive temperature coefficients respectively, may be indicated if important in the particular case to which a diagram refers.

Impedance, Induction and Repeating Coils.—Those coils which serve, by inductive action, to react against the passage of variable currents and known variously as impedance, reactance, retardation, inductance, and choke coils are commonly represented as at *a*, *b*, *c*, or *d*. Of these, *a* differentiates sufficiently from a non-inductive resistance by suggesting that the wire is coiled. The three others suggest inductance by the presence of an iron core, in the form of either a bundle of wires or a solid bar.

The ordinary induction coil such as is used in local- or common-battery telephones is most commonly represented as at *e* or *f*.

Of these, *e* is the older form, the primary coil often being represented by a heavier line in such manner as to suggest its coarser wire and fewer turns. In spite of the fact that the zigzag lines of this symbol would, if occurring alone, be taken to represent non-inductive resistances, this is still the most used of all induction-coil symbols. Symbol *f*, however, is technically more correct as suggesting coils of wire with some idea of inductance. Often induction coils, such as those in operator's telephone sets, have three or four windings. In these cases the tertiary and other additional windings may be represented by adjacent similar curls or zigzags.

Where other than a one-to-one transforming ratio is to be indicated for an induction coil, repeating coil, or transformer, it may be done as in symbol *g*. This also designates which end of each winding is the inside end, that is, the end nearest the core, a marking that is sometimes useful when the direction of inductive effects is to be considered.

Symbols *h* and *i* are the ones most often used for the four-winding repeating coils of common-battery systems. The former indicates a one-to-one ratio of transformation and the latter an uneven ratio. The numerals are the terminal markings, and it is usual that the lower numeral of a pair shall represent the inside end of the winding.

Generators.—Symbols *a*, *b*, and *c* are typical of many similar ones used to represent hand magneto generators. The switch springs at the left of these are suggestive of the functioning of the three principal types, *a* maintaining a normally closed shunt about the generator, *b* holding the generator circuit normally open as in modern bridging bell practice, and *c* holding the generator circuit normally open and the bell circuit normally closed but reversing these conditions when the generator is operated. Symbol *d* may be used for a hand generator giving pulsations of current in one direction only, and *e*, where it is provided with a commutator from which positive or negative pulsations as well as alternating current may be drawn.

Audible Signals.—Of the six symbols shown for polarized bells or ringers, the two at the left, *a* and *b*, are for ordinary ringers, responsive to alternating ringing current. The next two, *c* and *d*, are biased ringers, as indicated by a positive sign (+) or a negative one (−) on *c*, or by the similar sign and biasing spring on the armature of *d*. The plus or minus signs are here used to indicate the direction of current, usually from a line wire to ground, to which the bell is responsive.

Non-polarized audible signals are usually in the form of battery-operated bells or buzzers. For these, symbol *g* is most used for the battery bell and *h* for the buzzer. The latter one must be taken largely on faith. Symbols *i*, *j*, and *k* may be used for either bells or buzzers, *i* and *j* for operating on battery, and *k* on alternating current. These are preferable where it is desirable to indicate function rather than form.

Visible Signals.—The two symbols at the left, *a* and *b*, are typical of that class of electromagnetic signals which display their targets when energized and conceal them when de-energized. These are inherently self-restoring. They are commonly referred to in telephony as "visual signals" or "mechanical signals" although they are no more *visual* and no more *mechanical* than the ordinary switchboard drop of which the symbol is shown at *c*. The two symbols for switchboard signal lamps, *d* and *e*, attempt to distinguish between those with carbon and metal filaments, although this distinction is not often important in circuit diagrams.

Condensers.—Most of the condensers used in telephone equipment are of the fixed-capacity type and are commonly represented by any one of the three symbols *a*, *b*, and *c*. Perhaps *c* is the one now most commonly used. The diagonal arrow of the symbol *d* is now generally used to indicate that the condenser is variable, the arrow perhaps being suggestive of the pointer on the dial of variable condensers in radio work.

Switch Hooks.—The three symbols shown are typical and are subject to numerous variations. These are survivals of the old long-lever switch hooks once extensively used in wall sets, but they lend themselves so well to circuit-diagram work that they have been retained in spite of the fact that most switch hooks now, whether on desk stands or wall sets, are of the short-lever type.

Relays.—A few typical examples of relay symbols are here shown. On account of the very great variety of relays that must be dealt with, due to differences of form, windings, and contacts, the subject of their conventional representation in circuit diagrams will be better understood after the general discussion of relays in a later chapter. Of the few shown here, *a* is that of a single-coil relay adapted to break one contact and make another.

The practice of numbering the contacts is frequently followed as an aid in tracing circuits. Symbol *b* shows a differentially wound relay arranged for three breaks and two makes. Another type of relay convention is given at *c*. This like the other may be employed to represent relays having any number of windings or any arrangement of contacts. While somewhat less suggestive, this symbol has the distinct advantage of being easier to draw and of affording convenient space in which to place figures giving the resistance of windings or legends giving other information. Symbols *d* and *e* indicate relays with "make-before-break" or "transfer" contacts, it being clear that in each the normally closed contact will not be broken until after the normally open one is made. The right-hand convention *f* is that of a slow-acting relay. Here a solid or shaded block at one end of the core suggests the copper collar placed on the core for delaying the magnetic action. Sometimes, as in this case, initials such as S. R. are applied to indicate slow release. Other initials may be used to indicate other characteristics.

Keys.—The common form of ringing and listening key is suggested at *a*. The lever represented by the circle acts as a wedge when forced between the two long springs on either side. More often than not, the circle representing the lever itself and the letters referring to the listening and ringing functions are omitted. The same general type of key, with various additional contacts, is indicated at *b* and here a distinction is indicated as between locking and non-locking action of the key lever. In a non-locking key the lever, on being released, returns to its normal position by the action of the springs. The locking key, on the other hand, will remain in its operated position until restored by the operator. The locking action is suggested at the right of symbol *b* by the flat places on the two long springs between which the lever rides. Symbol *c* is that of an order-wire key, the function of which is merely to bridge an operator's telephone circuit across a pair of order wires. These are usually non-locking but may be indicated as locking by flattening the curved portions of the springs as in the preceding symbol. Symbol *d* is often used to represent an ordinary push button or any non-locking key closing a single contact.

Automatic Dials.—Symbol *a* may be used for the type of dial found in most of the subscribers' sets in automatic or machine-switching exchanges of the Bell System. The contact at the left is the one which is made and broken to send the switching impulses as the dial returns to its normal position. Those at the right serve to shunt the transmitter circuit and open the receiver as long as the dial is not in its normal position. Symbol *b* shows the somewhat more simple switching arrangement of the Strowger dial. The two springs at the left cause the required make-and-break impulses while the dial is returning to normal. The off-normal contact, at the right, is the one which shunts the talking apparatus whenever the dial is out of its normal position.

Jacks and Plugs.—The symbols representing switchboard jacks take a great variety of forms, of which a few typical ones are shown. The intent of these is to convey the idea that the insertion of a plug will establish connection between its own contacts and the corresponding registering contacts of the jack. Also, in certain cases, it will move some of the jack springs to make or break contact with other springs with which the plug contacts do not register. Thus in the jack of symbol *a*, the tip and sleeve of a two-contact plug, such as represented by plug symbol *a*, will merely engage the corresponding contacts of the jack, while with jack symbol *b* an additional function is performed, the insertion of the plug not only establishing connection with the jack contacts but also lifting the tip spring of the jack, causing it to break contact with the anvil against which it normally rests. Jack symbol *c* represents the most widely used of all jacks—the three-contact jack used in branch-terminal multiple switchboards. Its corresponding plug is represented by plug symbols *b*, *c*, or *d*. Jack symbols *d*, *e*, and *f* all represent jacks for use with three-contact plugs, all of them carrying auxiliary springs adapted to be moved but not actually engaged by the plug contacts.

Protective Devices.—The ones shown are of three types. At *a* the symbol for a single fuse is given. Sometimes a group of such fuses protecting individual circuits branch off from a common bus-bar.

The "open-space cut-out" or "air-gap arrestor" is represented at *b* and *c*, the two outer conducting blocks or plates being connected with the two limbs of a line and normally separated by short air gaps from the ground blocks or plates between them.

Protector symbols *d* and *e* are those of the combined heat-coil and air-gap protector used at central offices. The circuit of each line wire normally passes through the heat coil to the switchboard apparatus to be protected, but, when this circuit is traversed by a current from without that is too great for safety, the heat generated in the coil releases a spring which automatically acts to ground the line. In the case of symbol *d* the spring also opens the circuit to the switchboard, while in symbol *e* it grounds the line without breaking it.

Vacuum Tubes.—The symbols *a* and *b* for the two-electrode and three-electrode thermionic tubes respectively are self-explanatory, showing the filament and plate in the first case and the filament, grid, and plate in the second. In telephone-system diagrams it is now general practice to omit the circle representing the glass bulb, which perhaps makes it a little more difficult to imagine the vacuum but tends to clarify the electrical connections. The three symbols *c*, *d*, and *e*, at the bottom of the diagram, are typical of this usage.

CHAPTER IV

SUBSCRIBERS' SETS

The terms "subscribers' telephone set," "subscribers' set" or sometimes merely "sub set" designate the combination of apparatus used by a subscriber in sending and receiving both speech and signals. Commonly speaking, it is a complete telephone.

As soon as telephony progressed beyond the point where it attempted to do signaling as well as talking with the single piece of apparatus we now call a receiver (as with Watson's thumper), the need was felt for some sort of a switching device which would connect the talking and the signaling apparatus alternately with the line.

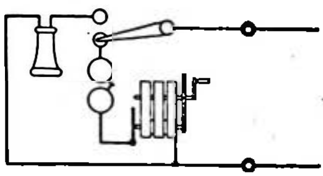


FIG. 66.—Circuit of telephone with hand switch.

At first an ordinary hand switch was used for this purpose, as indicated in Fig. 66. This arrangement was found to be unsatisfactory, not on account of the manual labor imposed on the subscriber but because of the frailty of his memory. Forgetting to move the switch, he would attempt to talk by means of apparatus not connected with the line; or worse, he would leave his instrument in such condition that it could not receive incoming calls.

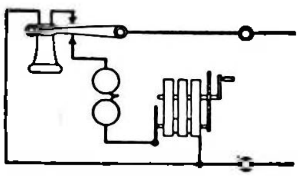


FIG. 67.—Circuit of telephone with automatic hook switch.

This serious difficulty was remedied at a very early date by making the switch automatic—that is, by making its operation incidental to some action which the subscriber would naturally carry out in using the instrument. Accordingly the switch lever was provided at its outer end with a fork or hook adapted to support the receiver and so placed as to form the most convenient, if not the only, object on which to hang it after use. The principle is shown in Fig. 67. The weight of the receiver depresses the lever, connecting the signaling and disconnecting the talking apparatus. When the receiver is lifted, a spring moves the lever into its alternate position. Thus came about the automatic hook switch. One of them now constitutes a part of every subscriber's set.

The advent of the battery transmitter, and slightly later the induction coil, added another function for the hook switch—that of closing and opening of the local-battery circuit during times of use and disuse respectively. To do this, another contact point was added, and arranged in some such manner as indicated in Fig. 68, to control the local circuit. In this way the drain on the battery was prevented during periods of disuse.

This circuit of Fig. 68 is typical of that of the "series magneto telephone," very largely used in early days for both individual and party-line service. The difference between impedance and mere ohmic resistance was not then well understood and it was customary, when a number of such instruments were to be used on a party line, to connect them all in series in the line circuit. With this arrangement it is obvious that the voice currents of any two stations that were talking had to traverse the ringer coils of all the stations that were not talking. In order to make the obstruction to voice currents as small as possible, the ringer coils were wound to as low resistance as their ringing functions would permit, usually about 75 ohms. Of course their impedance to voice currents was very much greater than that. Since the signaling currents had to traverse all the ringer coils in series, the generators were designed to develop high electromotive force and relatively small current.

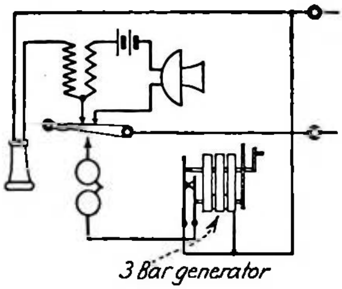


FIG. 68.—Circuit of series telephone.

It was John J. Carty, who later became chief engineer and has only recently retired as vice president of the American Telephone and Telegraph Company, who showed, in 1890, that the connection of telephones in series on party lines was all wrong and that the proper way was to connect them in multiple, each in a bridge across the line. To do this he showed that the ringer coils should be of such high impedance as to offer great obstruction to the passage of voice currents. From his teachings there came about the bridging bell substation circuit like that of Fig. 69.

In this both generator and ringer are usually taken from the control of the hook switch. The ringer is usually bridged permanently across the line and is made with long cores and with a large number of turns, so as to be highly reactive to voice currents. The generator is placed in another bridge across the line, but, since it plays no part in receiving signals, this bridge is kept normally open and is closed automatically by the operation of the generator switch upon the turning of the crank. Thus it remains for the hook switch to control only the circuits of the talking apparatus, connecting the receiver across the line and closing the local circuit only when the hook is raised.

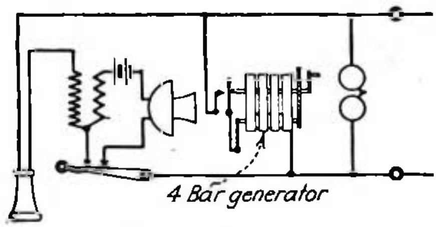


FIG. 69.—Circuit of bridging telephone.

This circuit of Fig. 69 is typical of modern magneto subscribers' sets, although the arrangement is subject to numerous modifications to meet varying service conditions. Some of these modifications will be referred to later in this chapter.

Going a step further in the development of the subscribers' set, the advent of the common-battery system took away from it both the local battery and the magneto generator. This reduced the subscribers' set to the elementary arrangement shown in Fig. 70. In this, the hook switch controls only the path through the talking apparatus. The condenser in series with the bell prevents the flow of battery current through the ringer coils, thus completely opening the line circuit when the hook is depressed. With respect to the flow of direct currents, the fundamental requirements of a common-battery substation set are that the circuit of the line shall be held open during periods of idleness and closed during periods of use. Only when its hook is up, is direct current allowed to flow from the central-office battery for its twofold purpose of supplying the substation transmitter and operating the central-office signals. These

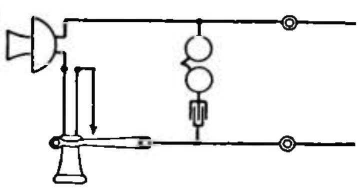


FIG. 70.—Circuit of common-battery telephone.

requirements are met in the circuit of Fig. 70, but many modifications of this simple arrangement have been found advisable in order to improve the talking efficiency and to remove certain objectionable features.

The necessity which brought about the hook switch may be used to illustrate a principle that should be followed as far as possible in the design of all telephone apparatus that is to be placed in the hands of the general public. This is that the acts which a person must obviously perform in the use of his instrument shall, as far as possible, bring about other necessary functioning of which he may know nothing. Thus in the case of a hook switch in a common-battery manual system, for instance, the user is aware that he must hold the receiver to his ear and in order to do so he must take it from its support. When through talking he hangs it up as the easiest way of getting rid of it. The simple act of taking up the receiver accomplishes, with no further care on his part, the connection of his talking set with the line, the supply of his transmitter current, and the display of a signal to the operator at the central office. Again, without his further concern, hanging up the receiver disconnects his talking set, stops the flow of transmitter current, and displays another signal at the central office calling for disconnection. In an automatic or machine-switching system, the acts of lifting and hanging up the receiver each automatically brings about a very much more complex chain of functioning.

Types of Telephone Sets.—Before discussing specific designs and details of subscribers' sets, we may consider briefly the general types of telephones to which they apply. Broadly, subscribers' sets are of two types, local battery and common battery, according to the kind of exchange system for which they are adapted.

Because the "local-battery telephone" is usually provided with magneto generators, a more common name for it is "magneto telephone." Some care must be exercised in the use of these two terms, for not all local-battery telephones are provided with magneto generators, nor all magneto-equipped telephones with local batteries. These exceptions arise from the fact that in some few cases magneto generators are used for signaling on lines where the transmitters are supplied by a common battery; and in other cases local-battery transmitter supply is used on lines which employ common-battery signaling. In other words, we may have common-battery talking with magneto signaling or, in other cases, local-battery talking with common-battery signaling. These exceptions are rare and usually unimportant, so that generally one is safe in using the terms local-battery telephones and magneto telephones interchangeably.

Common-battery sets are sometimes called "central-energy sets," perhaps a better term because it signifies that all sources of electricity, generators as well as battery, are located at the central office.

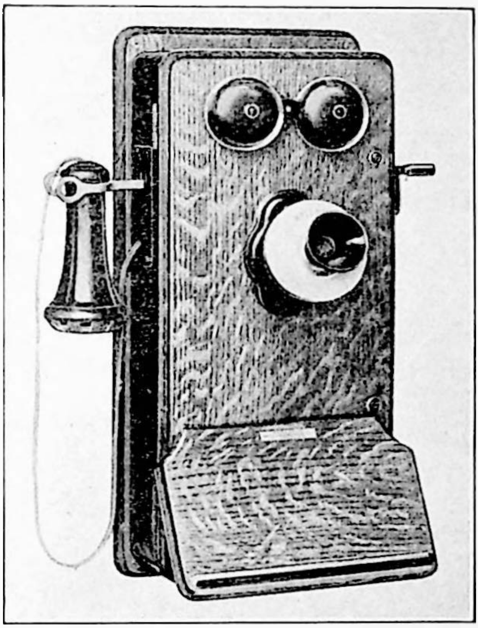


FIG. 71.—Magneto wall set. (*Courtesy of Kellogg Switchboard and Supply Company.*)

From an entirely different standpoint, that is, the standpoint of their general arrangement and assembly, subscribers' sets are of two general types—wall sets and desk sets. Each of these may be adapted either for hand receivers or for combination hand sets.

The following figures show the appearance and arrangement of typical examples of various types of subscribers' sets.

Wall-set Designs.—A modern local-battery or magneto wall set, as manufactured by the Kellogg Company, is shown in Fig. 71. Here the cabinet is of wood enclosing all parts of the instrument except those which are necessarily left outside for use.

The transmitter is mounted on an arm projecting from the front of the cabinet and hinged so as to permit several inches of vertical movement to accommodate it to the height of the user. The generator crank projects from the cabinet at the right and the hook switch from the left. The gongs of the ringer in this case are mounted outside the cabinet. In some makes, however, the gongs also are enclosed within the cabinet, in which case an open grill is provided through which the sound of the gong may emerge.

An interior view of the local-battery or magneto set of the Stromberg-Carlson Company is shown in Fig. 72. This shows the arrangement, nearly always adopted in this type of instrument, of placing the magneto generator on a shelf so that it occupies the upper part of the cabinet. The compartment below this shelf is used for the two dry cells of the local battery. The ringer mechanism is mounted on the inside of the door at its upper end, its tapper rod projecting through a hole in the door so as to engage the gongs outside. The hook-switch unit is mounted on the upper left side of the cabinet, the contact springs and wiring being inside, but the hook lever projecting outside so as to afford a convenient support for the receiver. The induction coil in this case is mounted on the door, though in some other makes it is mounted on the back board of the box. The condenser shown on the lower rear face of the door in Fig. 72 is not always provided in magneto sets of this type. Its use and other special features, such as the wiring of this particular set, will be referred to later.

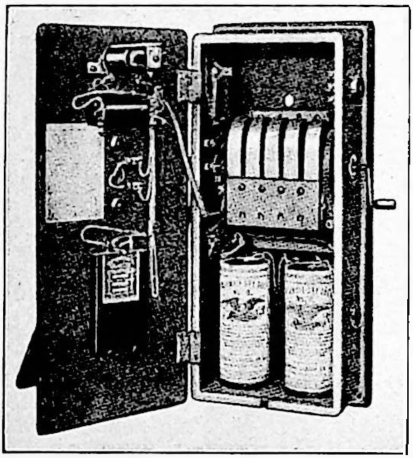


FIG. 72.—Inside view of magneto wall set. (*Courtesy of Stromberg-Carlson Telephone Manufacturing Company.*)

A good example of modern practice in wall telephones for common-battery manual systems is shown in Figs. 73 and 74, which are respectively closed and open views of the Kellogg common-battery wall set. The absence of the battery and magneto generator makes the common-battery set much more compact than the magneto set, and the practice, now adopted by all principal manufacturers, of making the containing box of sheet steel contributes further to compactness. The disposal of the working parts of this instrument is clearly indicated in Fig. 74.

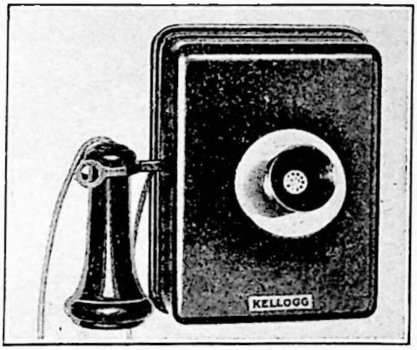


FIG. 73.—Common-battery wall set. (*Courtesy of Kellogg Switchboard and Supply Company.*)

In Fig. 75 are given closed and open views of a magneto wall set arranged for a combination hand set instead of the usual separately mounted transmitter and hand receiver. This is manufactured by the American Electric Telephone Company, a subsidiary of the Automatic Electric Company. The common-battery wall-type instrument for hand sets of this company has the same external appearance, except that it has no generator crank, of course.

Desk-set Design.—Coming now to desk sets, as distinguished from wall sets, two examples of "desk stands," of the general type most used in this country, are shown in Fig. 76. Of these the one at the left is of Stromberg-Carlson make for use in manual exchanges and that at the right of Western Electric make for use in the automatic exchanges of the Bell System. Sets of this general type are adaptable to either local- or common-battery use, the electrical characteristics of the transmitter, receiver, and induction coil being varied according to the type of the system. In stands for automatic service, the pedestal supporting the transmitter and hook switch is usually set back from the center, as in the stand at the right, to afford room for the dial. In case such a stand is used in a manual exchange that is later to be converted to automatic, an apparatus blank is used to cover the dial opening until such time as the dial is required.

In desk sets, the desk stand proper usually carries only the transmitter, receiver, and hook switch, to which is added the dial, if the service is automatic. Sometimes, however, the induction coil also is carried in the base of the stand. In a common-battery set the ringer and terminal strip for the cord, line and ground conductors, and usually the induction coil are enclosed in a separate metal box mounted on the side of the desk

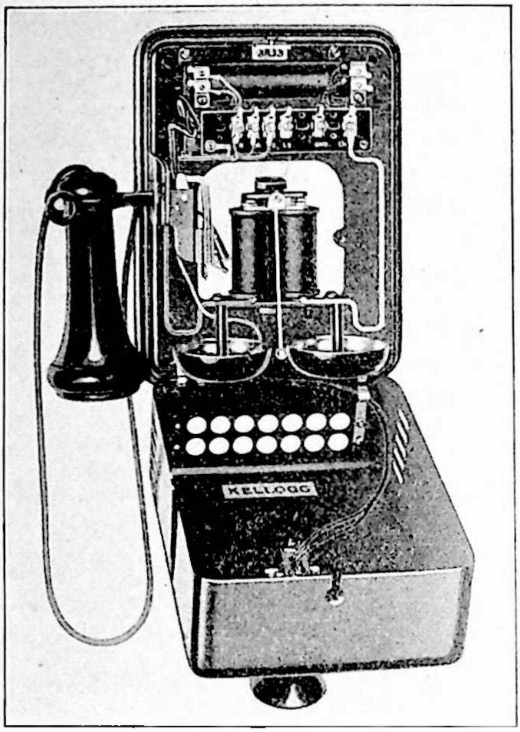


FIG. 74.—Common-battery wall set (open view). (*Courtesy of Kellogg Switchboard and Supply Company.*)

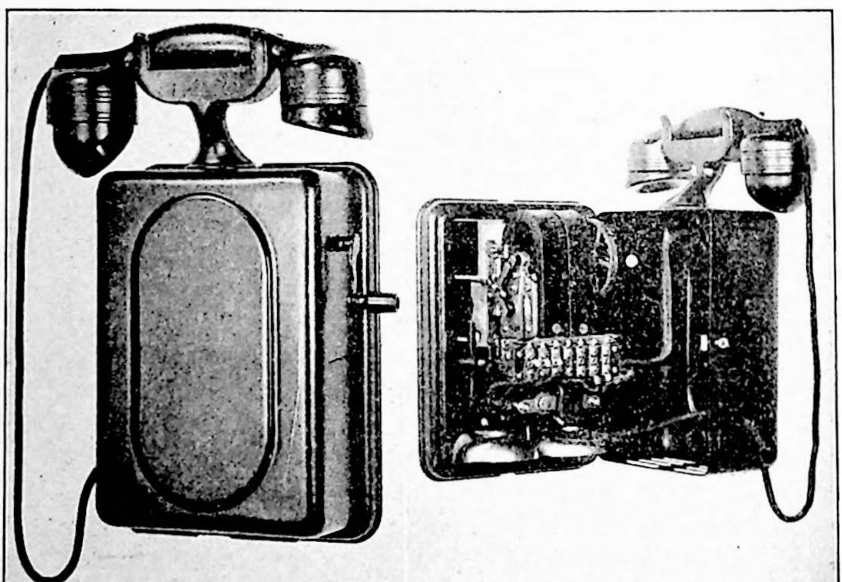


FIG. 75.—Left, magneto wall telephone with hand set. Right, open view. (*Courtesy of American Electric Telephone Company.*)

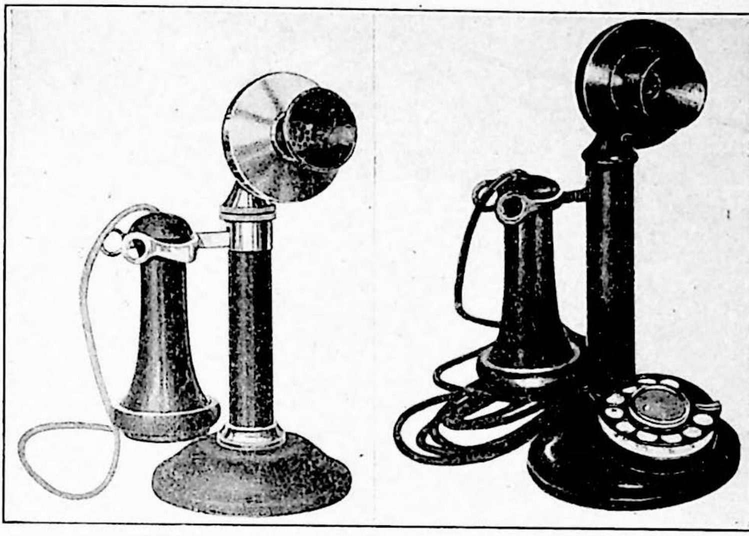


FIG. 76.—Left, Stromberg-Carlson desk stand. Right, Western Electric desk stand with dial.

FIG. 77.—Complete common-battery desk set.

or on the wall within cord length of the desk. Such a complete substation set for a common-battery manual exchange is shown in Fig. 77. In a magneto desk set the local battery is usually placed in some out-of-the-way place within convenient wiring distance of the stand, and the hand generator, usually in the box with the bell, must be mounted within convenient reach of the subscriber.

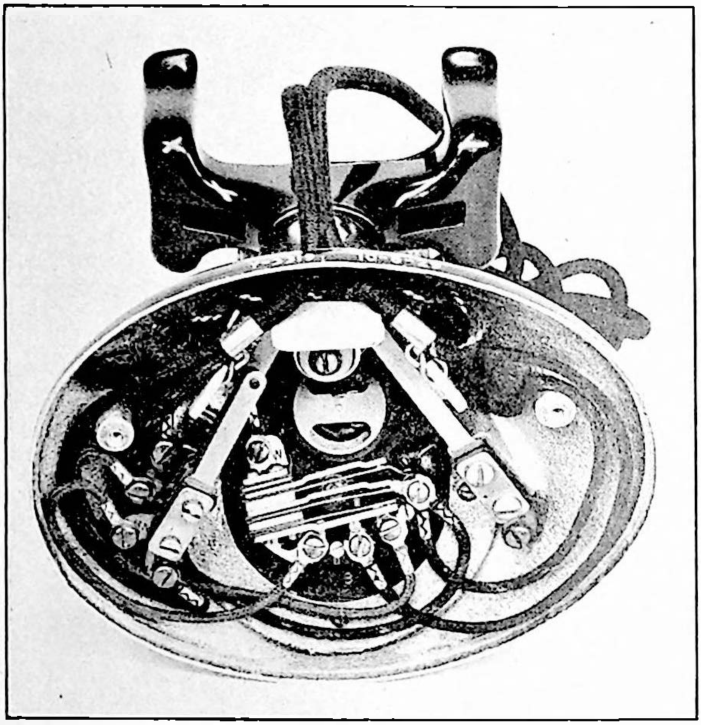


FIG. 78.—Western Electric hand set stand, bottom view. (*Courtesy of Bell Telephone Laboratories.*)

The Bell type of desk stand for use with a combination hand set has already been shown in Fig. 30. Figure 78 is a bottom view of the same stand with its bottom plate removed so as to show the working parts of the dial, the hook-switch springs, and the cord terminals. The cradle for supporting the hand set moves up and down when the hand set is removed or replaced and this, by a vertical push rod, operates the contacts which perform the usual hook-switch functions.

The bell box with its contents for this stand may be the same as for the ordinary common-battery desk stand (Fig. 76). Two recent types of common-battery desk-set bell boxes of the Bell System are shown in Fig. 79. Of these the one at the left is the latest standard type. In this the containing box is of molded insulating material, this feature, and a more compact arrangement of the apparatus within, contributing to a marked reduction in size.

A variety of practices are followed in respect to the flexible cords required to connect the portable desk stand with the fixed parts of the set—that is, to connect the portable talking set with the fixed signaling set. The length of the desk-stand cord depends principally on the range of portability required of the desk stand. Usually it is 6 feet. The number of conductors

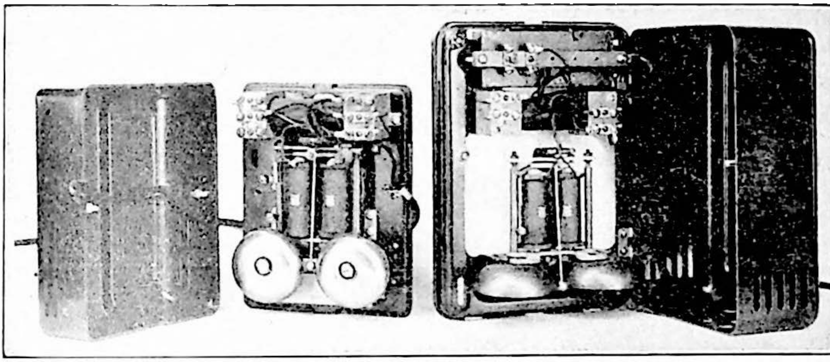


FIG. 79.—Bell box for Western Electric hand set. (*Courtesy of Bell Telephone Laboratories.*)

in the cord depends largely on the circuit employed for the set and also upon whether the induction coil is mounted in the bell box or in the base of the stand. In other words, it depends on how many conductors are required by the circuit to connect the fixed to the movable parts of the apparatus.

Hook-switch Design.—It took a good many years to devise a really good hook switch. The need of complete reliability of contact action was at first not appreciated, nor was there the knowledge for bringing it about. The energy available for the operation of the switch is necessarily limited by the weight of the receiver and the distance of its travel. With our present knowledge, it is easy with only a fraction of this energy to arrange contacts so that they will be positively made and surely broken at the proper times. Then, this problem was not so simple. Although precious-metal contacts were known, the necessity for their use was not appreciated, and, naturally, early attempts sought to avoid their expense. As late as 1887, it is recorded that in the Chicago exchange the phosphor-bronze contact springs "became so caked up with dirt that the trips of the repairman were exceedingly frequent and the annoyance to the subscribers from being cut off, exasperating."

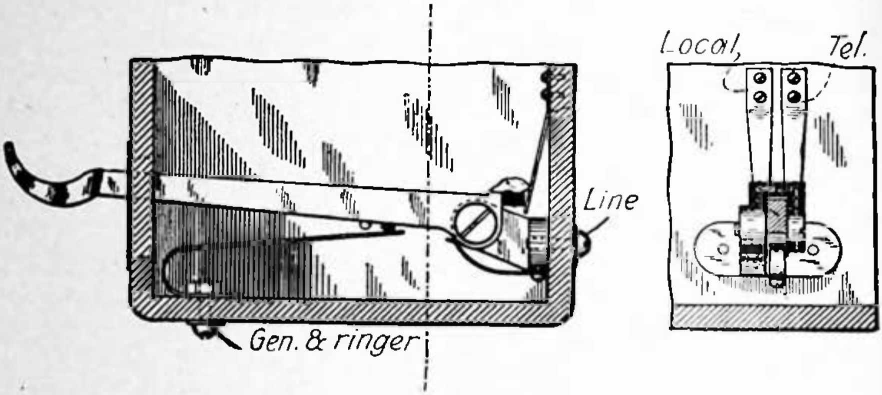


FIG. 80.—Warner hook switch.

Figure 80 shows one of the landmarks of hook-switch progress. This, designed in 1888 by J. C. Warner of the Western Electric Company, was a great improvement over its predecessors and was for many years used in the wall telephone sets of the Bell System. Each of the contact springs alternately bore against a piece of hard rubber or a metal contact carried by the lever. A

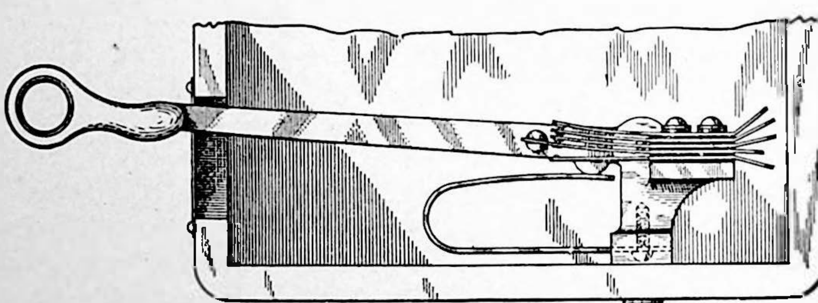


FIG. 81.—Old Kellogg long-lever hook switch.

slight rubbing contact was thus secured, not enough to cause cutting but sufficient to aid in securing good contacts. The various springs were individually mounted on different parts of the containing box instead of all being held together in a self-contained unit as is now usually done. This method is obviously faulty, owing to inaccuracies incurred in mounting and to subsequent changes in the relative position of parts caused by warping or shrinking of the woodwork.

Figure 81 shows an early example more nearly approaching modern hook-switch design. This was used by the Kellogg Company in about 1900 and is typical of the practice of that time. It is entirely self-contained, all of the springs being carried on the same metal base as that upon which the lever is pivoted. The modern form of spring "pile-up" was used and all contact points were of platinum. Also the modern practices were

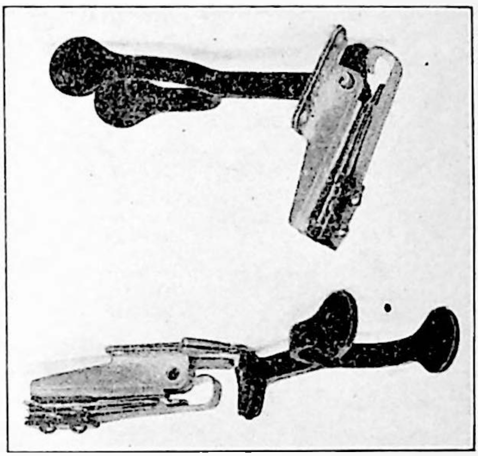


FIG. 82.—Western Electric hook switch for wall telephone. (*Courtesy of The American Telephone and Telegraph Company.*)

employed of insulating the hook lever from all parts of the circuit and of soldering the connecting wires directly to the springs.

In present-day practice, a short bell-crank lever is usually employed for the hook, principally because it is more compact and better adapted for both wall- and desk-set mounting. In Fig. 82 are shown two views of the self-contained hook switch of the Western Electric Company for wall telephones. The frame is insulated from all contacts and is adapted for attachment directly to the metal containing box in such manner that the hook will project through an opening in its side. The lever is readily detachable by the withdrawal of the slotted pin which is normally retained in place by a spring engaging the slot.

This practice of having the hook lever readily removable from wall sets is one now generally employed by all the principal manufacturers. It permits the use of smaller and cheaper packing cases or cartons employed in shipment or storage. It also eliminates one of the most vulnerable points of possible injury to the instrument while it is being handled in transportation or installation. The same reasons have led to the practice of removing the receiver, transmitter, mouthpiece, and the generator crank while in storage or in transit.

In desk stands, some manufacturers mount the entire hook switch within the column of the stand. In this case the requirements for compactness are more exacting than in the wall set. Others mount the switching springs in the base of the stand, actuating them either by a push rod or by a toggle-joint extending from the hook lever down through the column.

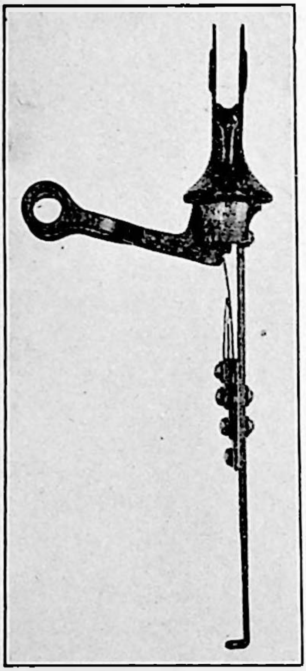


FIG. 83.—Western Electric hook switch for desk stands. (*Courtesy of The American Telephone and Telegraph Company.*)

In the standard desk set of the Bell System, the former practice is followed in a design of great simplicity, as is shown in Fig. 83. The switch springs are carried on the long flat tie-rod which extends down through the column and which serves to clamp the lower member of the transmitter knuckle to the bottom plate of the stand. The whole device is made accessible by the removal of a single screw which passes through the bottom plate of the stand and engages the lower end of the tie-rod. The removal of this screw permits not only the removal of the bottom plate but the withdrawal of the transmitter lug and hook switch bodily from the tube.

A somewhat similar arrangement is employed in the desk-stand and wall-set hook switches of the Automatic Electric Company and shown respectively in the two views of Fig. 84. As in the Bell design, the wiring of the desk stand is arranged with enough slack to allow the withdrawal of the spring assembly from the pillar a sufficient distance for inspection. In the wall

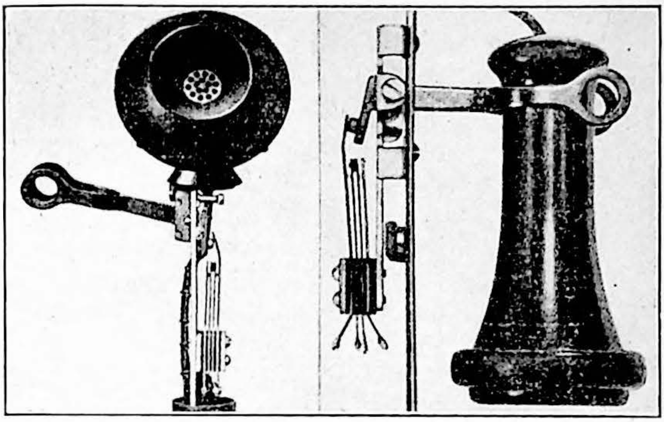


FIG. 84.—Left, Automatic Electric desk-stand hook switch. Right, Automatic Electric wall-type hook switch.

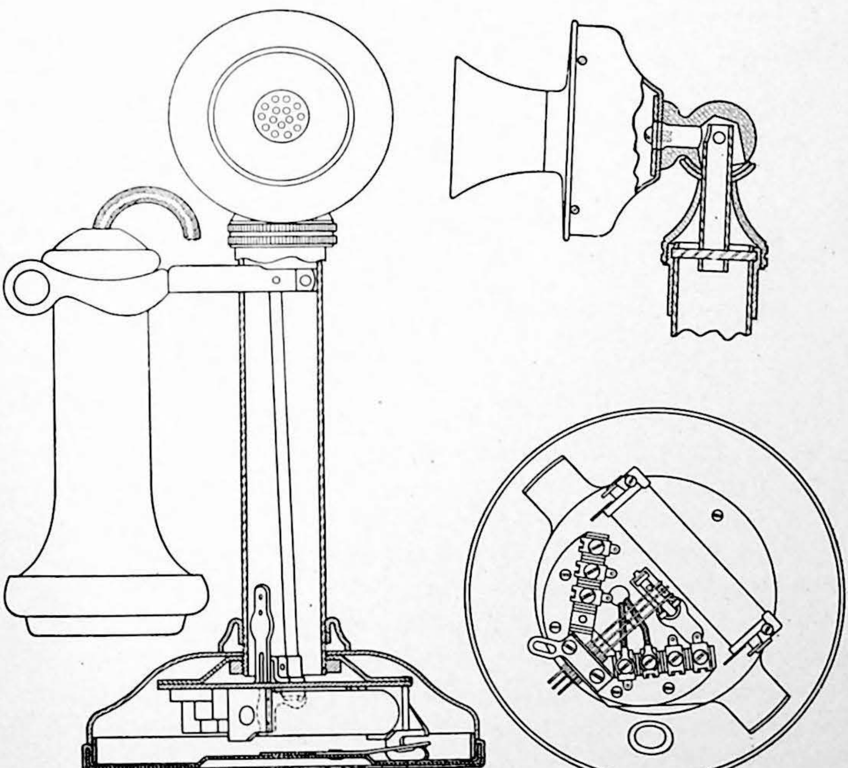


FIG. 85.—Stromberg-Carlson desk-stand details.

set the hook is pivoted to a bracket mounted on the inside face of the metal box cover, as shown at the right in Fig. 84. Here, inspection is allowed by merely opening the box. The lever is removable for transporting or stocking purposes. An interesting feature of desk- and wall-set switches of this company is that they are alike and interchangeable.

The Stromberg-Carlson Company, as shown in Fig. 85, mounts the switching springs of the desk stand in the base of the stand. The springs are actuated by means of a vertical rod extending up through the column and receiving its movement directly from the hook lever. Another interesting feature of the Stromberg-Carlson desk stand is the ball-and-socket hinge joint adjustably mounting the transmitter on the column. The stiffness of action of this joint may be regulated by turning the cap of the column, which varies the tension on the tie-rod, thus altering the pressure between the ball and the socket members. In this stand the induction coil is mounted in the base, as shown. This has the advantage of somewhat simplifying the flexible cord arrangement.

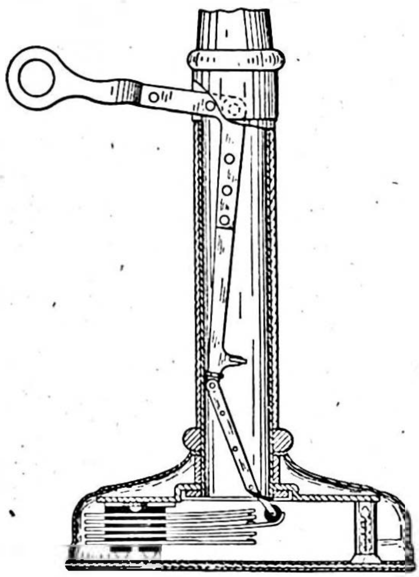


FIG. 86.—Kellogg desk-stand hook switch.

The Kellogg Company also mounts its switch springs in the base of the stand, as shown in Fig. 86. Instead of operating the springs by a direct push-rod action, a toggle-joint is employed, as clearly indicated.

In desk stands where combination hand sets instead of hand receivers are used, a supporting cradle takes the place of the hook as a support for the hand set. A number of principles differing from that employed in the ordinary hook switch have been tried for accomplishing the desired switching action with this form of instrument. In some cases the switch springs have been placed in the handle of the talking set and operated by pressure of the fingers. These efforts have been abandoned and the settled practice now is to operate the switch by the direct action of the weight of the hand set, as in the case of the ordinary hook switch.

One method is to mount the whole cradle on a plunger, as in the set shown in Fig. 29. Later practice is to use a stationary cradle and have the switch springs operated by a push rod extending up into the cradle so as to be depressed by the weight of the hand set. When relieved of this weight the push rod rises by spring action.

Two cross-sectional views of the cradle switch of Automatic Electric Company are given in Fig. 87. The cradle and hand

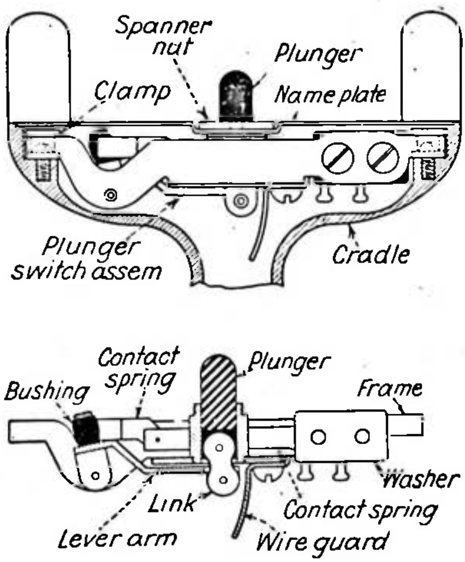


FIG. 87.—Automatic Electric hand-set cradle switch.

set are so shaped that when the hand set is dropped into the cradle it will always slide into the proper position for actuating the plunger. The contact springs are concealed in the base of the cradle and are operated by the push rod through a compound lever. Although the tension on the contact springs is quite heavy to insure positive contacts, only a slight pressure is required on the push rod to operate the springs. The springs are accessible for inspection by removing the name-plate which lies just under the handle of the hand set when resting in the cradle.

Magneto Telephone Circuits and Wiring.—All modern magneto subscribers' sets employ the bridging bell type of circuit, the essential features of which were referred to in connection with Fig. 69. We may now consider somewhat in detail the circuits and wiring of such a set, taking as an example the No. 896 wall telephone of the Stromberg-Carlson Company, of which an open view was given in Fig. 72. As will be noticed from that figure, the ringer, induction coil, transmitter, and a condenser are all mounted on the hinged cover of the cabinet. All of the

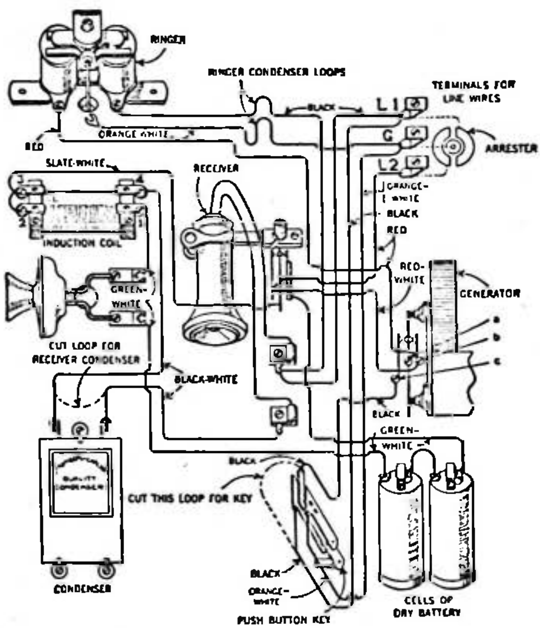


FIG. 88.—Wiring diagram of Stromberg-Carlson magneto set.

other parts, the receiver, hook switch, generator, battery, and line terminals, are mounted in the stationary part of the cabinet, that is, in the box proper.

The details of the wiring connecting these various apparatus elements together in their proper circuits are shown in Fig. 88. While the circuit of Fig. 88 is not precisely the same as that of Fig. 69, a comparison of the two will show the general difference between an ordinary circuit diagram and what is called a "wiring diagram." The circuit diagram, of which Fig. 69 is a typical example, attempts to show, as simply as possible, the circuits. No attempt is made to preserve the relative positions of the different apparatus elements, these being rearranged at will to clarify the essential circuit arrangement. A wiring diagram, however, attempts to give some idea of the relative position of the parts and some details of the wiring, such as the color code. As will be seen in Fig. 88, this is done at some sacrifice of circuit clarity. In this figure the relative positions of the apparatus is shown about as it appears in looking at the telephone in Fig. 72 with the door open. The two line terminals $L1$ and $L2$ are shown in the upper right-hand corner of the diagram, and between them is located the ground terminal G to be used when it is desired to connect some parts of the circuit to ground, as will be described.

In commercial practice a number of variations are frequently met in the service requirements of magneto or local-battery telephones. As a simple illustration, it is sometimes desired that the ringer of a station shall not respond to its own generator, as it does when the ordinary bridging circuit of Fig. 69 is employed. Another modification sometimes desired is that a condenser be placed in series in the receiver circuit. Again, it may be required that the generator or the ringer be connected between either side of the line and ground, instead of across the metallic circuit. None of these modifications mean any very great change in the essential elements of the telephone set, but, taken individually or in various combinations, the attempts to provide for each of them by an individual type of set results in an undue multiplicity of types, undesirable for both the manufacturing and the operating company.

To avoid this as far as possible, some of the principal manufacturers have adopted what they call a "universal wiring," by which they mean a wiring in which is incorporated in permanent fashion all of the wires and connections that may be called for by any of the types of service of which the instrument is capable. The way this plan works out for a few of the more common service variations will be shown for the Stromberg-Carlson set in connection with Fig. 88 and the circuit diagrams immediately following.

The wiring is made up in what is known as a "hand-made cable." That is, all of the wires following a common route are laced together with twine. All of the wires required for all the variations are included, each carrying its designated color code and each cut off to proper length to reach the terminal with which it is to connect. The instrument is ordinarily made up and carried in stock with neither the condenser nor the push-button key that are shown in the diagram, but arrangements are made for readily mounting these if they are subsequently desired.

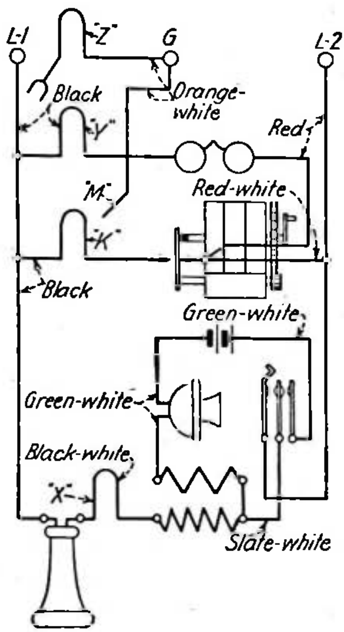


Fig. 89.—Regular bridging circuit.

As thus wired for stock, it is adapted for regular bridging service, and its circuit is shown in Fig. 89.

If it is desired that a ringer shall be unresponsive to its own generator, it is only necessary that the red wire from the ringer be changed from one terminal on the generator switch to another. Figure 90 shows the arrangement of the generator terminals and the connection for both bridged and silent ringer. When the red ringer wire is changed from the terminal *B* to terminal *A*, the circuit of the instrument becomes that of Fig. 91, the only change being that the ringer, instead of being connected permanently across the line, has its circuit opened by the action of the generator crank in ringing.

In many rural districts where a small population is scattered over wide areas, the telephone forms the principal means of social intercourse. Often the telephones of many stations are connected with a single line and it is considered no breach of etiquette for stations not primarily involved to listen in on the conversation of others. This is a well-recognized social feature of rural telephone service. At other times an important feature of rural-line service is the reading of such matter as stock reports to a number of stations at once. As a result of either of these practices, it frequently happens that the receivers of many stations are bridged across the line at once. Where the line is long and heavily loaded, this brings about a serious operating feature. It becomes difficult to ring over such a line while the high-impedance ringers are shunted by so many comparatively low-impedance bridges through the receivers.

The remedy that has been found most practicable for this is to place a condenser of about half-microfarad capacity in series with the receiver and secondary winding of the induction coil at each station. A condenser of this small capacity offers relatively high impedance of the low-frequency ringing currents but slight impedance to the high-frequency voice currents. Consequently its inclusion in the talking bridge at each station prevents the undue shunting of the ringing currents from their intended

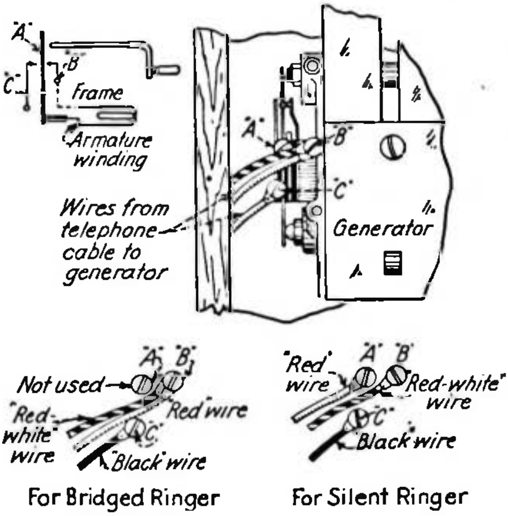


Fig. 90.

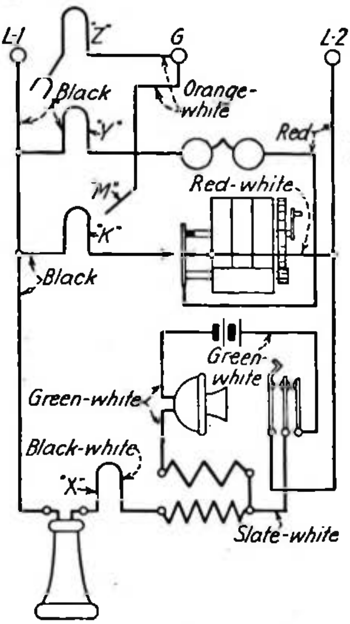


Fig. 91.

Fig. 90.—Generator connections for silent or bridging ringer.
Fig. 91.—Silent ringer circuit.

paths through the ringer, while at the same time they interfere very little with the passage of the voice currents through the receivers.

In order to incorporate this ringing condenser in the bridging set, it is only necessary to secure the condenser in place provided for it on the inside of the door, as shown in Fig. 72, cut the loop in the black-white wire leading from the induction coil to the receiver, as indicated in Fig. 88, and fasten the two wire ends so formed into the terminals of the condenser. The circuit then becomes that of Fig. 92.

As another modification, a condenser in series in the ringer bridge at each station greatly aids the wire chief in testing, for then a normal line will test clear. Evidently the set under discussion shows wiring loops for such purpose.

Sometimes in magneto-exchange service it is found desirable to enable the stations on a party line to call the central office without disturbing the other stations on the same line. To arrange for this, the ringers at all the stations are left bridged across the circuit in the usual way, but the line signal or drop at the central office is connected between one side of the line and ground. The subscribers on the line may thus ring each other as usual, but to call the central office it becomes necessary for each of them to be able to switch his generator to a grounded connection. For this purpose a push-button switch is added to the telephone and so wired as to switch the generator from its normal bridging to a grounded connection. The principle of this is shown in Fig. 93. The provision in the regular wiring of the instrument for the connection of this key is found in the orange-white wire and the black loop extending down to the push button, as shown in Fig. 88. To install the push-button key, it is only necessary to cut the black loop and connect the three wire ends, thus provided, to the terminals of the key. The circuit then becomes that of Fig. 94.

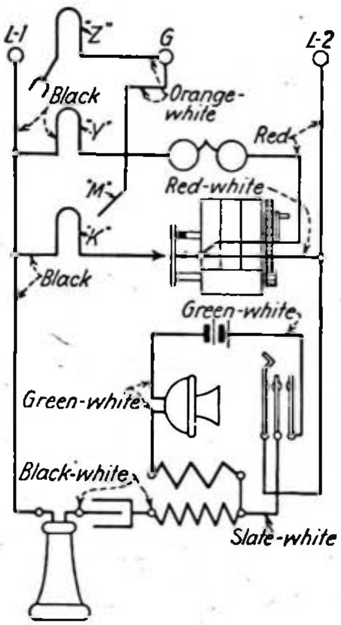


Fig. 92.—Condenser in receiver circuit.

It is possible in magneto-exchange service to so arrange the stations on a party line that only the central-office operator can ring the subscribers, they not being able to ring each other. To call another station, even on the same line, a subscriber must call the central-office operator, who in turn will ring the desired station. For this purpose, the ringers at about half the stations on a line are connected between one limb of the line and ground, those at the other stations being similarly connected between the other limb and ground. This is called "divided-circuit ringing." When ordinary ringers are employed, only half the bells are rung in order to reach any one station. Talking, as usual, is done over the metallic circuit, as is also the signaling of the central office by the subscribers. In this form of service, therefore, the talking set and the generator at each station are connected with the line in the usual way.

In order to arrange the magneto set under consideration (Fig. 88) for divided-ringing service, it is only necessary to change

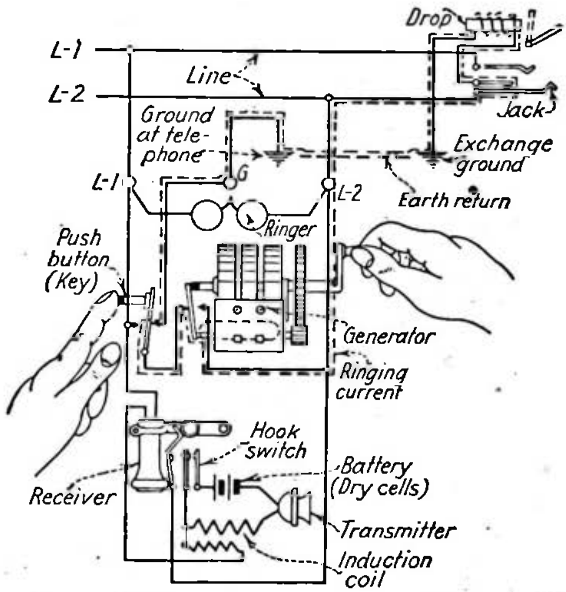
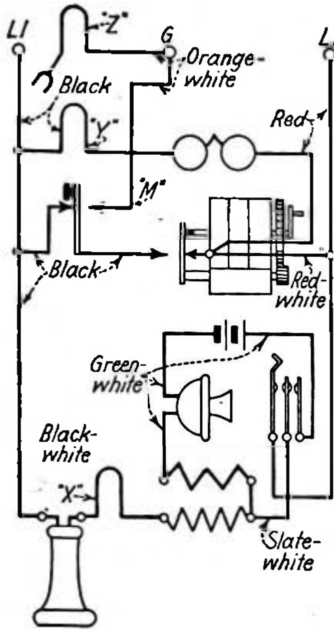


Fig. 93.—Ringing over one side of line.

the ringers from their normal metallic connection to either one of two possible grounded connections. This can be done by altering the connection of the two ringer terminals with respect to three different binding posts. Three wires are brought adjacent to the ringer terminals in the permanent wiring, and the three possible combinations of their connection are indicated in Fig. 95. The circuits resulting from each of the two possible grounded ringer connections are shown in Fig. 96.

The difficulty of ringing on a bridged line with a number of stations listening has been mentioned. Another trouble resulting from this listening-in practice is the useless drain on the local battery at the listening station. As an extreme example, invalids



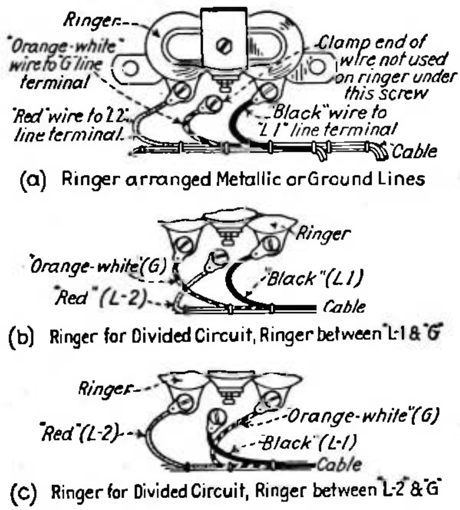


Fig. 94. Fig. 95.

Fig. 94.—Non-interfering push button.
Fig. 95.—Three ways of connecting ringer.

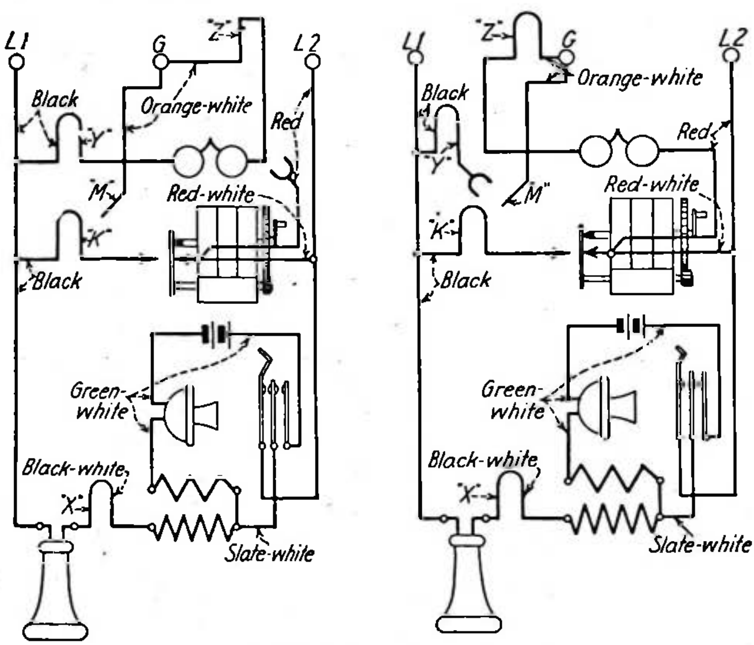


Fig. 96.—Divided-circuit ringer connections.

have been known to have their receivers provided with extra long cords so as to permit their listening in while lying in bed. In order to mitigate this waste of battery, several manufacturers have produced devices by means of which the battery circuit may be kept open even though the receiver is off its hook. One of these, manufactured by the Stromberg-Carlson Company for attachment to its regular magneto wall set, takes the form of a little latch associated with the hook-switch lever. When the latch is thrown, it allows the hook to rise only part way. In this intermediate position the switch closes the receiver circuit but not the battery circuit, as clearly shown in Fig. 97. Hanging up the receiver restores the latch to its normal position, so that when the receiver is again lifted the hook will function in its normal way.

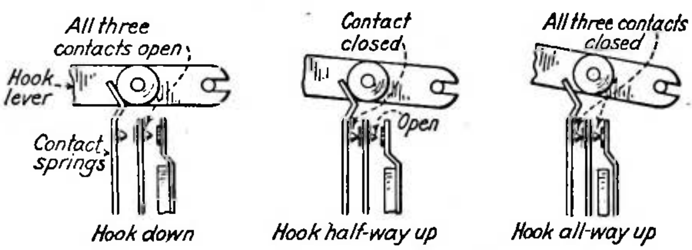


FIG. 97.—Battery-saving attachment.

Common-battery Telephone Circuits.—The simplest possible circuit for a common-battery subscribers' set is that shown in Fig. 70. This meets the fundamental requirements of talking and signaling and has the advantage of simplicity and low first cost. It is not so efficient in voice transmission, however, as other forms of circuit; and, besides this, the flow of direct current through the receiver is found to be an objectionable feature where the receiver is of the permanent-magnet type. This objection arises from the fact that the magnetic flux set up by the current in the receiver coil will either strengthen or weaken the normal flux of the permanent magnet, depending on which way the receiver is connected in the line circuit.

The flow of direct current is usually less objectionable if it tends to strengthen the magnet rather than to weaken it. Increasing the magnetic pull, within limits, would in itself be of some benefit, but it becomes a serious matter if it results in so strong a pull as to bring the diaphragm into contact with the pole pieces. This, of course, would prevent the proper vibration of the diaphragm. The weakening of the field by the direct current is more serious, since by partially offsetting the flux of the permanent magnet it lowers the efficiency of the receiver. In view of these considerations it has been the practice, where permanent-magnet receivers were subjected to the flow of direct current, to connect them in the line circuit in such a way that the pull of the magnet would be strengthened by the line current. This is called "poling" the receiver.

It would seem to be a simple matter so to mark the receiver terminals that by due care the installers might properly connect them. This solution is not so simple as it appears, however, because in various maintenance operations the two wires of the line are sometimes transposed at points between the substation and the central office, this subjecting a receiver, that originally had been properly poled, to current in the wrong direction. Troubles of this nature have led to the general abandonment of any arrangement which involves the connection of a permanent-magnet receiver directly in a common-battery line circuit.

Of course, in the case of direct-current receivers these statements regarding poling do not apply, for these receivers depend on the flow of direct line current through them in order to establish their required steady magnetic field and, having no permanent magnets, the direction of current through them is immaterial.

Many different plans have been proposed for associating the receivers with common-battery line circuits in such manner that the steady battery current necessary for the transmitters would not flow through them. In some of these it was proposed to supply the direct current over a circuit composed of the two sides of the line in parallel, with a ground return. This and other schemes which involved a departure from the fundamental plan of the common-battery system, that is, the furnishing of battery current over the metallic circuit of the line, have never come into general use and need not be described. Only the ones that have been extensively used will be dealt with.

Among these, the very simple one shown in Fig. 98 was for many years the standard of the Stromberg-Carlson Company. This is self-explanatory. The receiver is inductively rather than conductively associated with the line circuit by placing it in a local secondary circuit.

Another circuit, not quite so simple when considered in its entirety, was that of the Kellogg Company shown in principle in Fig. 99. In this the transmitter is connected across the line in series with a coil that is of low resistance but high reactance. Direct current from the central office flows readily through this path for the operation of central-office signals and for the supply of current to the transmitter. Incoming voice currents were

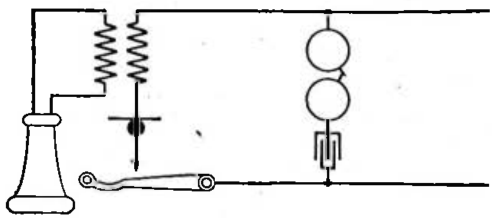


FIG. 98.—Old Stromberg-Carlson substation circuit.

shunted by the high impedance of this coil through the path containing the receiver and the condenser.

An interesting plan, shown in Fig. 100, involved the principles of a Wheatstone bridge. This was devised by Mr. W. W. Dean and was once the standard common-battery substation circuit of a company bearing his name. Its principle is simple. The bridge circuit, while balanced for direct current, was very much out of balance for voice currents. As a result there was no flow

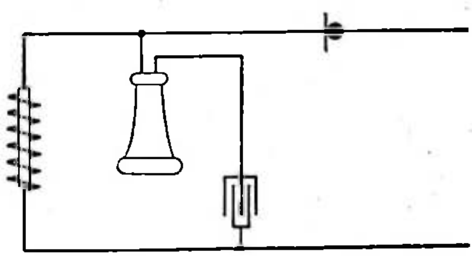


FIG. 99.—Old Kellogg substation circuit (simplified).

of direct current through the receiver because its terminals remained at equal potentials. Voice currents, however, met far greater obstruction in the bridge arms containing the highly inductive coils than in those containing the non-inductive coils, with the result that voice currents followed the zigzag path through the two non-inductive coils and the receiver in series.

While all of these circuits effectively barred direct current from the receiver, most of them have not survived except in so far as they may remain from earlier installations. The reason for this is that a more efficient circuit is available. None of the ones just considered gave better talking efficiency than that of a properly poled receiver directly in series in the line circuit (Fig. 70).

The circuit of Fig. 101 actually improves the talking efficiency and at the same time meets all of the other requirements of

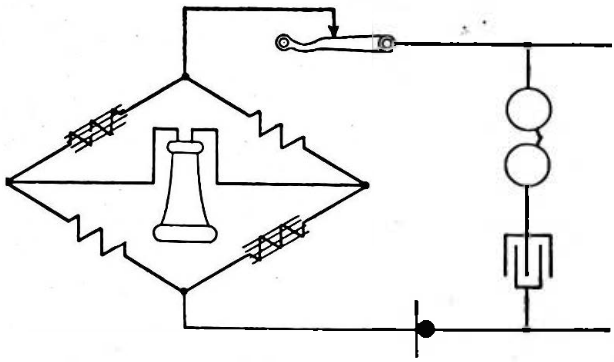


FIG. 100.—Old Dean substation circuit.

common-battery systems. This has long been the standard common-battery circuit of the Western Electric Company and of the Bell System and in recent years has been adopted by other manufacturing companies in this country and abroad. On account of a certain augmenting action which the local

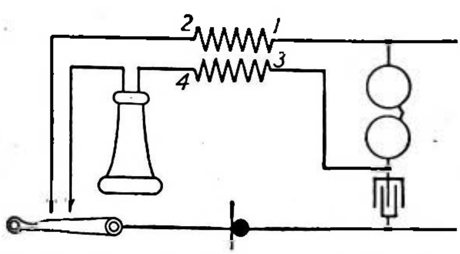


FIG. 101.—Western Electric booster substation circuit.

condenser circuit exerts on the undulations directly produced by the transmitter in the line circuit, this substation circuit is now generally known as the "booster" circuit.

The action of the booster circuit, sometimes a little confusing, may be described in connection with Fig. 102, in which the connections at the substation, as they exist when the hook is raised, are shown at the left, and the connections at the central office for battery supply are shown at the right.

In considering the action during speech transmission, two distinct circuits are to be kept in mind: (*a*) the line circuit over which direct current is supplied from the central-office battery and which includes the two limbs of the line, the transmitter, and the secondary winding 1-2 of the induction coil; and (*b*) the circuit, purely local to the substation, which includes the transmitter, receiver, condenser, and primary winding 3-4.

When talking into the transmitter, two distinct sets of current undulations are set up in these two circuits respectively: (*a*) those directly produced in the line due to the variations in resistance of the transmitter; and (*b*) those produced in the local circuit by the charging and discharging of the condenser,

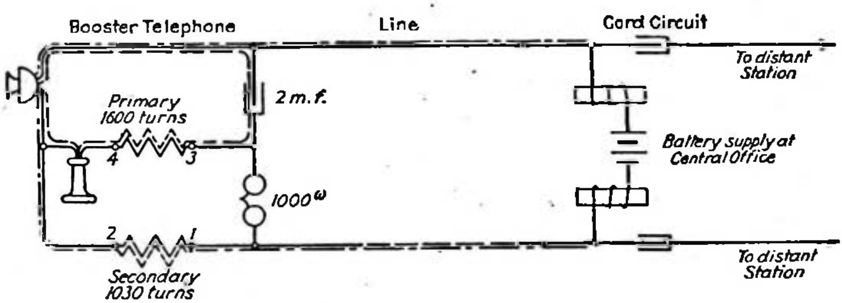


FIG. 102.—Action of booster circuit.

due to the varying potential drop across the transmitter. These local-circuit undulations may perhaps require some further explanation. The matter will be made clearer if it be kept in mind that the condenser is connected across the terminals of the transmitter, directly on one side and through the receiver and primary coil on the other. We may neglect the effect of the small direct current through the ringer and it is evident from these connections that the potential difference across the condenser will be varied by variations in potential across the transmitter. Alternating currents will then flow in the local circuit as the condenser adjusts its charge to the varying difference of potential across the transmitter and across its own terminals. For brevity, we may refer to these two sets of currents as (*a*) direct-line undulations and (*b*) primary-circuit undulations. The path of the direct-line undulations is indicated on the diagram of Fig. 102 by a line of dots and dashes, that of the primary circuit undulations by a line of dashes.

With these two sets of undulations in mind, it is to be remembered that the two circuits in which they respectively flow are inductively related. The primary and secondary windings, instead of being widely separated as was done for circuit clarity in the diagram, are in reality closely associated by being wound on the same core. The currents in the primary circuit will therefore induce currents in the line circuit in much the same manner as is done in a local-battery telephone.

We have then superposed on the direct-line undulations (*a*) another set of undulations induced in the line circuit by the primary-circuit undulations (*b*). If the two windings 1-2 and 3-4 of the coil are connected in proper relation to each other, the induced currents will reinforce or "boost" the directly produced undulations—hence the name "booster circuit."

It will be clear from the last sentence that if either one of the windings of the induction coil is reversed with respect to its proper connection in the circuit, the induced set of undulations will oppose the directly produced undulations, and a loss instead of a gain in transmission will occur. Mistakes, either in the original wiring of the instrument or in connecting the desk-stand cord, sometimes occur and are likely to be overlooked among the many other irregularities that may also tend to reduce the effectiveness of transmission.

In this connection, I am indebted to Mr. E. A. Reinke, of the Stromberg-Carlson Company, for the results of tests to determine the extent of the transmission losses resulting from the more common errors in connecting up the booster type of substation circuit. The correct as well as various wrong connections are shown in Fig. 103. In this, *a* represents the correct wiring; *b* shows the reversal as to position in the circuit of the primary and secondary windings of the coil; in *c* each of the windings is connected in its proper circuit, but the primary winding is reversed; in *d* the windings are transposed as in *b* but, in addition, the primary is reversed in direction; in *e* the windings of the induction coil are correctly connected but the ringer and condenser are transposed in position. With the correct circuit as standard, the losses expressed in miles of standard cable, or transmission units, for both transmitting and receiving, are indicated opposite each of the diagrams.

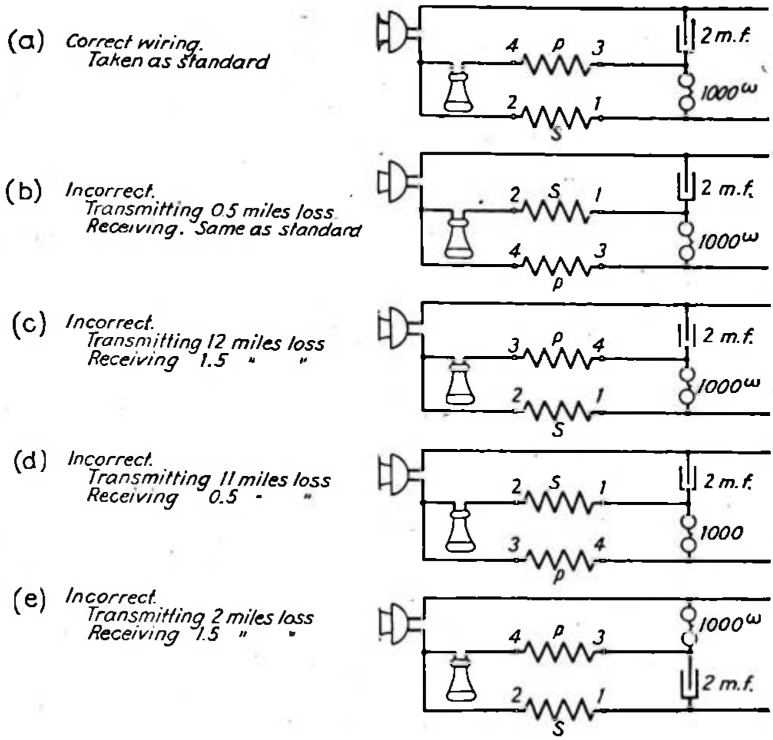


FIG. 103.—Various ways of connecting induction coil in booster-type circuit.

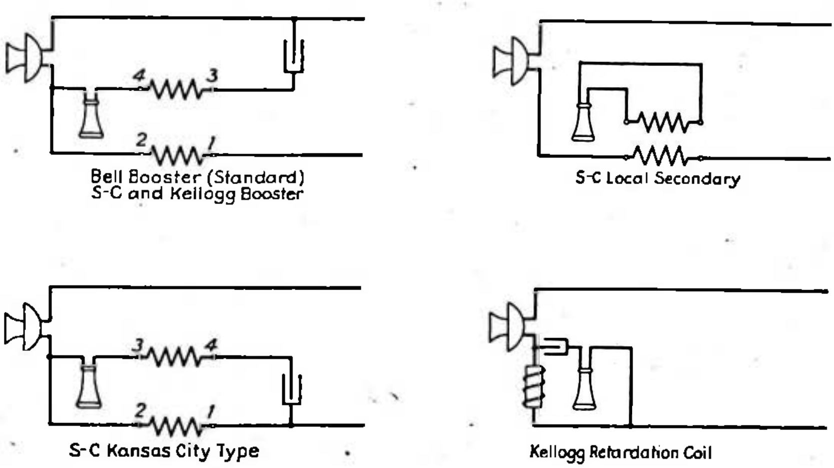


FIG. 104.—Comparative efficiencies of substation circuits.

In comparing the efficiency of common-battery substation circuits, care must be taken to distinguish between the efficiency of transmitting and of receiving. The two may be quite different. This fact is brought out clearly in the following tabulation, which shows the results of tests made in the Stromberg-Carlson laboratories to determine the comparison of various types of common-battery substation circuits. Skeleton diagrams of the four circuits included in this test are shown in Fig. 104. They are the standard booster circuit as used by the Western Electric, the Stromberg-Carlson, and the Kellogg Companies, the Stromberg-Carlson local secondary circuit already described in connection with Fig. 98, the Kellogg retardation coil circuit also shown in Fig. 99, and another type of circuit that has been manufactured by the Stromberg-Carlson Company for use in Kansas City.

Common-battery Substation Circuits Transmission Efficiency

Make and type of circuit	Efficiency, miles standard cable	
	Transmitting	Receiving
Bell "booster" (taken standard).....	Standard	Standard
S-C local secondary No. 39 coil......	3.0 miles loss	1.0 mile loss
S-C Kansas City, No. 11 coil........	2.5 miles loss	1.5 miles loss
S-C booster, new coil...............	Same as standard	Same as standard
Kellogg retardation coil............	4.3 miles loss	Same as standard
Kellogg booster....................	Same as standard	Same as standard

In these tests the transmitter and receiver were the same in all circuits, the difference in results being due to the coils and arrangement of circuits. The transmitter current was taken at 0.075 ampere. The distant station was of standard Bell type.

In all of the foregoing tests the transmission losses were expressed in miles of standard cable instead of in the more recently adopted "transmission unit" TU to which the name "decibel" (db) has recently been applied by international adoption. While the loss through a mile of standard cable is not exactly the same loss as that indicated by the TU or the decibel, the two systems of expression are numerically close enough together to introduce no serious error if the figures just given are considered to be in decibels instead of in miles of standard cable.

The standard circuit of the Bell System for subscribers' stations equipped with hand sets is shown for common-battery manual service in Fig. 105 and for common-battery dial service in Fig. 106. In these the "cradle switch" takes the place of the ordinary hook switch. It will be noticed that these two circuits

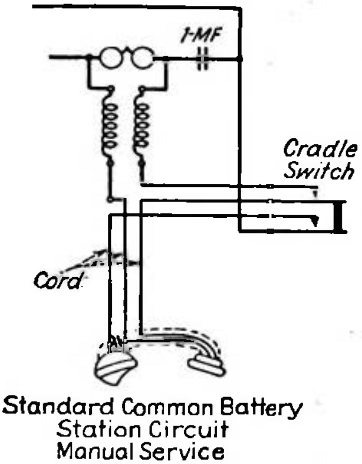


FIG. 105.—Bell hand-set substation circuit—manual service.

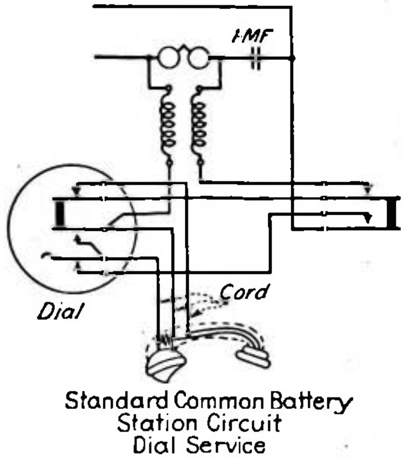


FIG. 106.—Bell hand-set substation circuit—dial service.

are exactly alike when the dial is in its normal position, in which position its contacts are as indicated in Fig. 106. Each will be recognized as of the booster type just discussed.

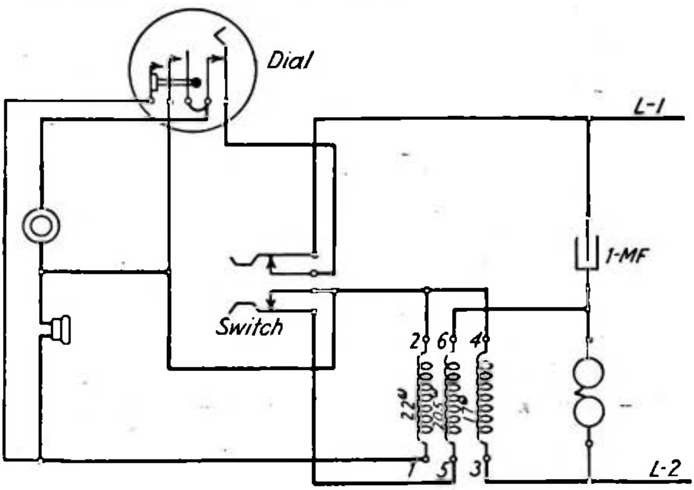


FIG. 107.—Automatic Electric hand-set circuit—permanent-magnet receiver.

The substation circuit of the Automatic Electric Company, where its hand set or "monophone" with permanent-magnet type of receiver is used, is shown in Fig. 107. This is another "booster" type and also is designed with special reference to the suppression or reduction of side tone—that is, the sound produced in the speaker's receiver by his voice acting through his

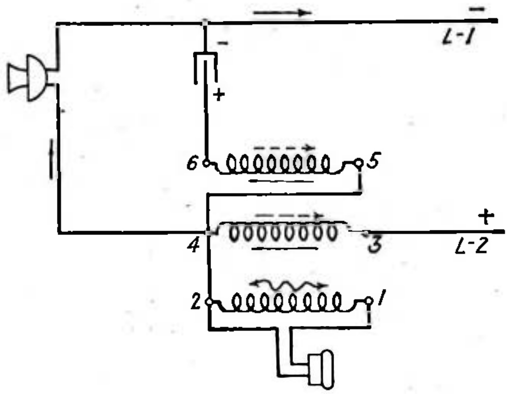


FIG. 108.—Action of permanent-magnet receiver circuit.

own transmitter. Its action may be best understood from Fig. 108, which shows the condition existing when the hand set is removed from its cradle and the dial is at rest in its normal position. The booster action is similar to that of the standard Bell booster circuit, the direct action of the transmitter on the line circuit being reinforced by the inductive action from the local

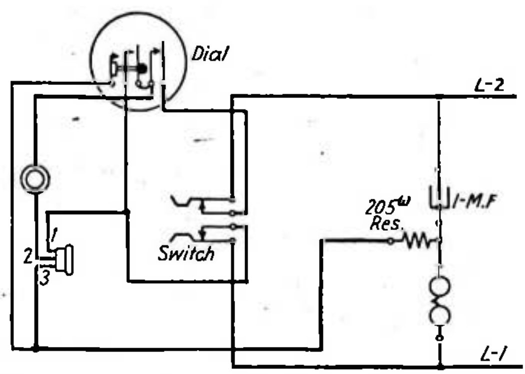


FIG. 109.—Automatic Electric hand-set circuit—direct-current receiver.

condenser circuit from winding 5-6 to winding 3-4. The permanent-magnet receiver is in a local circuit of its own in series with the winding 1-2 of the induction coil—in this respect resembling the old Stromberg-Carlson circuit of Fig. 98. Obviously, direct current is thus prevented from flowing in the receiver.

The reduction of side tone is due to the fact that the variable currents caused by the station's own transmitter are in opposite directions in windings 3-4 and 5-6 and thus tend to neutralize each other in their effect on winding 1-2. The inductive balance required for complete neutrality in this respect is dependent on the relative impedances of the local circuit containing the coil 5-6, condenser, and transmitter and the line circuit containing the coil 3-4. Since the line conditions vary with different lengths of line, the set is balanced for the characteristic impedance of a typical line (19-gage cable, 550 to 600 ohms). As the line departs from this, side tone will increase, but commercial lines are generally within such limits that when connected for talking the side tone is not objectionable.

The substation circuit of the Automatic Electric Company's hand set with direct-current induction-coil type of receiver (Fig. 35) is shown in Fig. 109. The chief purpose of the induction-coil type of receiver, according to its manufacturer, is to make it possible to utilize the hand set with its standard bell boxes containing 1 microfarad or 2-microfarad condensers, the hand set with permanent-magnet type of receiver requiring a special bell box. With the exception that the receiver gets its steady magnetization from the direct current flowing in the line, the action of this circuit is practically the same as that of the permanent-magnet type just discussed and may be more readily understood by considering Fig. 110. The receiver is magnetized by direct line current through the coil 1-2. The current variations set up directly in the line by the transmitter are augmented by those in the local condenser circuit by inductive action from the coil 2-3 to the coil 1-2. These current variations set up by the local transmitter tend to neutralize each other in the two windings of the receiver, thus minimizing the side tone. The non-inductive resistance in the local circuit is for the purpose of balancing the impedances of the local circuit with respect to that of the line circuit to make this anti-side-tone effect more complete.

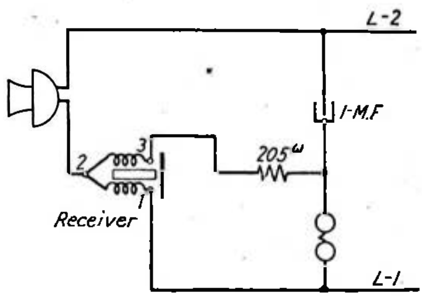


FIG. 110.—Action of direct-current receiver circuit.

CHAPTER V

INDIVIDUAL AND PARTY LINES

This chapter will consider how one telephone line may be made to serve one or more subscribers' stations. It will particularly consider methods of signaling on lines serving more than one subscriber.

Private Lines.—A telephone line with no public-exchange connection is commonly referred to as a "private line." Such a line permits intercommunication among its own telephones only, of which there may be two or many. The terms "private line" and "individual line" should not be confused. Individual line, as will appear, has acquired a definite meaning as referring to a class of public-exchange lines with but a single subscriber each. These, because they terminate in central-office switchboards for connection with other lines, are not private lines under the definition just given.

Exchange Lines.—A line connecting the telephone or telephones of one or more subscribers with a central-office switchboard so as to permit its connection with other lines is characterized as an "exchange line." If it connects only one subscriber with a central office, it is an "individual line." On the other hand, if it connects a number of subscribers with the central office, it is a "multi-party line" or, more commonly, a "party line." It would not be quite proper to make this distinction between individual and party lines on the basis of whether only one or more than one *telephone* is connected with it. Often a line devoted to the service of a single subscriber will be connected to several telephones on his premises. In this case the line is still to be classed as an individual line, one of its telephones being regarded as the main instrument of the line and the others as "extension telephones" or merely "extensions."

There is still another type of exchange line—the *private branch-exchange trunk*. These, as the name indicates, are trunk lines connecting private branch-exchange switchboards with public-exchange switchboards. These trunks, since they ordinarily have no telephone sets directly connected with them, need not be considered here. They will be dealt with in a later chapter on Private Branch Exchanges.

The classification of telephone exchange service based largely on the type of line over which the service is rendered to the subscriber—individual-line service, party-line service, and private branch-exchange service—is an important one. These main classes, with their various subdivisions, indicate the kinds of exchange service offered to the patrons and, entering as they do into the determination of the rates to be charged, they affect largely the revenue of the operating company.

Individual Lines.—The subscriber to individual-line service has the exclusive use of a line to the central office upon which to make or receive calls. On this account individual-line service is a more desirable and more expensive class of service than any of the forms of party-line service. It is more desirable because it is always available for the use of the subscriber in originating calls and because it can be made unavailable for incoming calls from others only when he himself is using it.

Little need be said as to the general method of associating the subscriber's telephone set with an individual line. In modern practice the two wires of a metallic circuit extend directly from the central office to the subscriber's premises and there connect with the terminals of his telephone set. If there are extension sets they are ordinarily connected directly across the same line circuit and may or may not be provided with ringers to receive the incoming signals. No problem of selective ringing as between the main and extension sets is involved, because all of the incoming calls on such a line are supposedly for that station alone. If there are enough extensions to warrant some sort of switching facilities at the subscriber's station for temporarily associating any one of the stations with the central-office line, a switchboard is provided for that purpose, in which case the entire subscriber's installation would be classed as a private branch exchange and the central-office line as a private branch-exchange trunk.

Party Lines.—A party line may have from two to as many as forty or fifty stations. They are not always exchange lines, many being entirely isolated from any central office. We need not accord separate treatment to party lines with and without central-office connections for, as a rule, the central-office equipment, where present, may be regarded merely in the light of another station on the line. Where there are differences in operation on account of the central-office connection, they will be made apparent in the text.

Classification.—Party lines may be either *grounded* or *metallic* according as they comprise one line wire or a pair of line wires. On another basis of classification we have *selective* or *non-selective* lines according to whether their stations are selectively rung or all rung together. On non-selective lines each subscriber distinguishes his own signal from those intended for others by a commonly adopted code of long and short rings. For this reason these lines are often referred to as "code-ringing lines."

As a rule, isolated party lines are magneto-equipped and non-selective. On the other hand, both selective and non-selective methods of ringing are largely used on exchange lines. The better grades of exchange party-line service employ either two or four stations on a line with selective ringing, so that the central-office operator may ring the bell of the party desired without disturbing the others. In non-selective or code-ringing exchange party lines, the operator rings all the bells on a line at once, designating the particular station desired by code.

As a compromise between selective and non-selective ringing, there is the so-called "semi-selective system" wherein the operator may ring either half of the stations on a party line to the exclusion of the other half. In this case the distinction among the parties whose bells respond at any one time is made by code ringing.

Non-selective Lines—General Considerations.—In the case of an isolated party line, since there are no central-office switching facilities available, one line is made to serve its plurality of stations simply because it is the easiest way of providing for their intercommunication. The question of how many telephones may be connected to it, within limitations that will be pointed out, becomes simply one of how many subscribers it is desired to reach. Too great a number of stations tends to make the signaling difficult and the voice transmission poor but, as a rule, the proper limit as to the number of stations is not the number that can be rung by a single generator or the number with which it is possible to transmit speech properly but rather the number of stations that may be employed without causing undue interference between parties desiring to use the line. The question depends principally on two conflicting considerations: on the one hand, the advantages to be derived from being able to reach as great a number of stations as possible, and on the other the disadvantages resulting from the confusion of signals, the lack of privacy, and the greater likelihood that the line will be found busy when one desires to use it.

The number of stations that may desirably be served by a rural line, whether isolated or connected with an exchange, depends on a number of circumstances. The length of the line, the size and kind of its line wires, and the character of its signaling and talking sets of course combine to present rather definite limits. But aside from these physical considerations, the financial necessities of the subscribers and what we may call the "psychology of the community" must be considered. The ability of subscribers to pay for telephone service as well as their willingness to tolerate the lack of privacy, the frequent ringing of their bells for stations other than their own, and the delays involved in the common use of the line by others varies greatly in different communities. To some, otherwise cut off from outside communication, many of the features that would ordinarily be considered objectionable in city service actually appear desirable. Many inventions of so-called "lockout" party-line systems have been made with a view to preventing the listening in of all not properly involved in a conversation. Such systems, however, have generally proven unpopular, if for no other reason, because depriving the subscribers of the opportunity for "sociability" that the open telephone party line affords.

The uncontrolled listening in on rural party lines, however, whether desired by the subscriber or not, carries with it at least two serious disadvantages of a technical nature. One is the undue drain on the local transmitter batteries, and the other is the interference with ringing due to the fact that the receivers of the listening stations form a low-impedance shunt around the high-impedance ringers which deprives the ringers of the current necessary to operate them.

In urban exchange service a single line is shared by a number of subscribers purely as a measure of economy. Exchange party-line service, particularly of the non-selective or semi-selective types, is patronized principally by subscribers whose need for telephone communication is comparatively infrequent and whose affairs and temperaments are of such a nature that they will not be seriously inconvenienced or annoyed by the ringing of bells other than their own and by the occasional delays due to the use of a line by others. For such classes of patrons the party line offers a desirable and generally satisfactory service and to the telephone company it offers the means of securing many patrons to whom the higher grade and more expensive service of the individual line does not appeal.

The economy of the exchange party line reaches further than the mere consideration of the line conductors themselves. Not only is one line shared by a number of subscribers but also the portions of the central-office equipment that are common to that line. If, in a given exchange, there is an average of three stations on each line, a thousand-line switchboard will serve three thousand subscribers instead of one thousand that it would serve on an individual-line basis.

Bridging-bell Lines.—Telephone service in remote rural communities often begins by a few farmers jointly building a

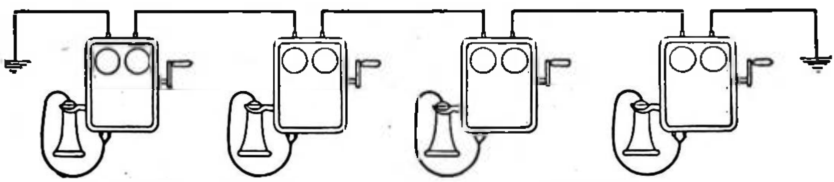


FIG. 111.—Series party line—grounded circuit.

telephone line to connect their several telephones. As the community grows, the line is extended to reach additional subscribers. Since there is no telephone exchange within reach, there is no exchange connection. Many such isolated rural telephone lines began as grounded lines, some of them using the top wire of a barbed-wire fence as the line conductor. While the fence-wire line has almost disappeared, bad insulation in wet weather being one of its principal faults, the grounded rural line is still to be found in many districts in spite of the ever-increasing tendency to cross-talk or inductive noises from neighboring telephone, telegraph, or power lines.

In the early days of telephony the telephones were connected in series on the grounded line as indicated in Fig. 111. Instruments for this use were known as "series magneto telephones." Their ringer coils were made with short cores and wound to low resistance so that they might offer as small impedance as possible to the passage of voice currents. This series plan of connecting party-line telephones was fundamentally wrong because it presented conflicting requirements with respect to signal and speech transmission. For efficient ringing a considerable impedance was necessary in the electromagnets of the ringer, while for efficient speech transmission any impedance in these coils was decidedly detrimental. Later the two requirements were brought into accord by making the ringer coils of very high impedance and

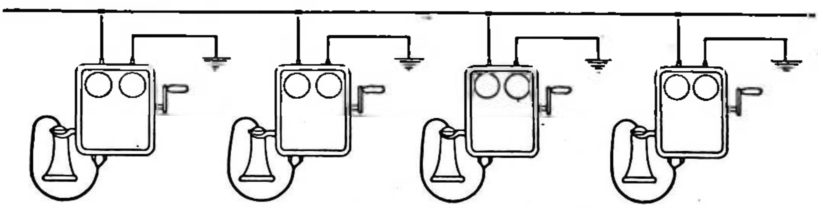


Fig. 112.—Bridging party line—grounded circuit.

by bridging them across the line circuit in accordance with the teachings of the Carty bridging-bell patent already referred to. A grounded line with telephones so connected is shown in Fig. 112, which represents the common present-day practice in those rural districts where single-wire lines are still employed. With the advent of near-by electric power and lighting lines and with the increasing congestion among neighboring telephone lines, the grounded line becomes noisy, often to such an extent as to make it

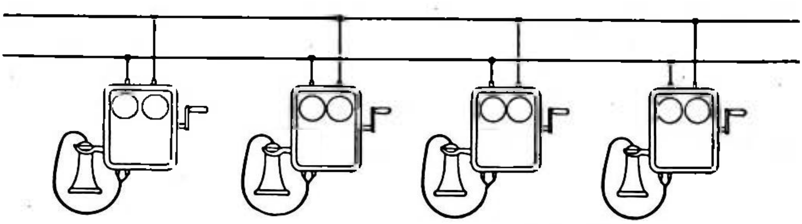


Fig. 113.—Bridging party line—metallic circuit.

unusable. Only by making the line a metallic circuit can this trouble be effectively cured. Figure 113 shows four bridging telephones on a metallic-circuit line. This figure may be considered as representing the line of Fig. 112 after its conversion to a metallic-circuit line.

The circuits, somewhat in detail, of three stations of such a bridging-bell line, in this case including a central-office connection, are shown in Fig. 114. As will be remembered from the consideration of bridging telephone sets in Chap. IV, there are three bridges across the line at each telephone. The first includes the high-impedance ringer and is usually, though not always, permanently closed. The second includes the magneto generator, normally open, and closed only at the time of ringing. The third

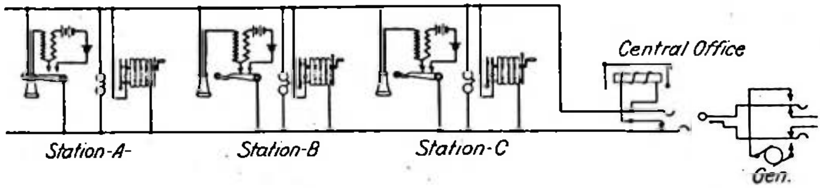


Fig. 114.—Talking and ringing circuits—bridging party line.

is the talking bridge normally open but closed when the hook is up for talking. An additional normally open circuit at each telephone contains the local battery and the transmitter, this also being closed at the switch hook when the telephone is in use. The switch hooks at stations *B* and *C* of Fig. 114 are shown raised as

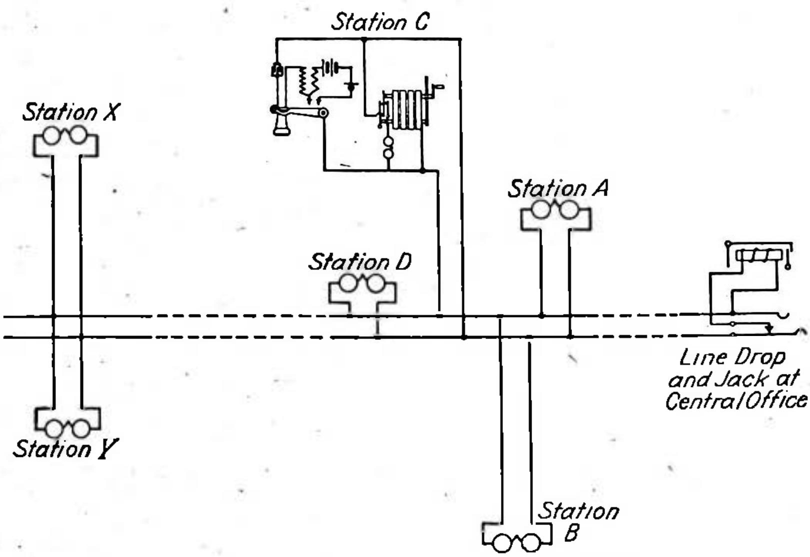


Fig. 115.—Diagram of rural-exchange line.

they would be when these two stations were in communication with each other. The drop of such a line at the central-office switchboard is ironclad and wound for high impedance so that it will not unduly shunt the voice currents when any two stations on the same line are talking with each other. Sometimes these drops, like the subscribers' bells, are permanently connected across the line but, in the case shown, it is so arranged as to be automatically cut out of the circuit when the operator makes connection with the line.

It is seldom that the stations of a rural party line lie directly along the route followed by the pole lead, as a strict interpretation of the figures just preceding would suggest. Figure 115, representing some of the stations close to the pole-line route and others more remote, may be taken as more nearly typical of actual conditions. At each station, whether close to or remote from the main route of the line, the connection is made by a pair of wires branching from the main lead. Only one branch wire is required, of course, in the case of a grounded circuit.

Each subscriber on such a line may ring the other stations, including the central office, by turning his generator handle. He designates the station desired by various combinations of long and short rings. One of many possible codes of signals for distinguishing among fifteen stations and the central office is as follows:

PARTY-LINE RINGING CODE

Station	Rings
Central office	1 long
1	1 short
2	2 short
3	3 short
4	4 short
5	5 short
11	1 long 1 short
12	1 long 2 short
13	1 long 3 short
14	1 long 4 short
15	1 long 5 short
21	2 long 1 short
22	2 long 2 short
23	2 long 3 short
24	2 long 4 short
25	2 long 5 short

This may be extended as desired, preferably avoiding digits higher than five as being more difficult to identify audibly.

The single station of Fig. 115, of which the circuits are given in detail, illustrates two modifications of the original Carty bridging-bell plan that are often found in rural-line practice. One of these is that the generator switch automatically opens the bell bridge when it operates to cut in the generator. As a result, no bell will respond to the generator at its own station. The object of this is merely to lessen the load on each generator by not requiring it to ring its own bell. This practice is advantageous only on lines that are so heavily loaded with stations as to overtax the generator when required to ring them all.

The other modification, shown in Fig. 115, of standard bridging practice is the placing of a low-capacity condenser in the receiver bridge at each station to mitigate the "listening-in" trouble on long heavily loaded lines as already described.

The running down of the local battery at stations much addicted to listening in is relieved by the use of such a "battery saver" as mentioned in connection with Fig. 97 (Chap. IV). This, as there described, consists merely of a special latch which, when set by the subscriber, permits the hook switch to rise far enough to close the receiver circuit but not far enough to close the local-battery circuit. While such devices when properly used serve their intended purpose, the fact that they depend for their effectiveness on the frailty of human memory is an argument against them. If the user forgets to set the latch, battery is not saved; and if he forgets that the latch is set, he will be able to hear but not to transmit.

It was stated earlier in this chapter that the number of stations on a bridging party line might be as high as forty or fifty. The more powerful bridging hand generators may be made to ring that number of bells fairly effectively over a 50-mile metallic circuit that is in good condition and composed of iron wire not smaller than No. 14 B.W.G. Likewise with good transmitters and receivers, and with local batteries in good condition, it is possible to talk over a well-maintained line of this length thus heavily equipped. Little, however, is to be said in favor of the service over such a line on account of the confusion in signaling and the delays involved in obtaining the use of the line when wanted. If it can be afforded, far better results are to be had by limiting the number of stations on a non-selective line to ten or twelve. But, as already stated, this number is often exceeded with fairly satisfactory results where the exigencies of the case demand it.

Sometimes on rural-exchange party lines it is desirable to enable the subscribers on one line to call each other without disturbing the central office or to call the central office without disturbing each other. The simple arrangement of Fig. 116 is one way of doing this. The switchboard drop at the central office, instead of being connected across the metallic circuit, is connected between the "sleeve"[1] side of the line and ground. In each of the substation generator circuits a push button is provided, adapted to connect the generator alternately across the metallic circuit or between the sleeve side of line and ground. The bells at the subscribers' stations are, as usual, bridged across the metallic circuit. When desiring to call the central office, the subscriber presses the push button at his station while turning his generator crank and thus throws the central-office drop over a grounded circuit without ringing the bells on the line. If, on the

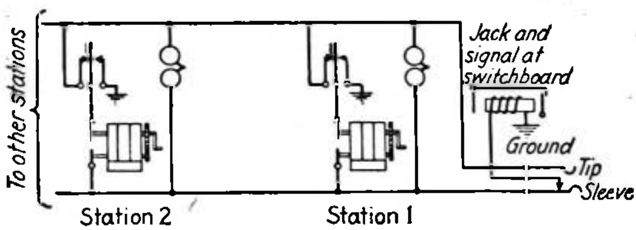


FIG. 116.—Non-interfering ringing.

other hand, the subscriber desires another party on the same line he operates his generator without pressing the push button and thus signals them over the metallic circuit leaving the central-office drop undisturbed. Calls from the central office for any station on the line are, as usual, made over the metallic circuit, the operator designating the station desired by code ringing.

Selective Ringing.—The advantages of being able to call any station on a party line without disturbing the others are obvious. These, in greater or less degree, are counterbalanced by the additional complexity and cost required in the substation appa-

[1] The two limbs of a metallic-circuit line are often designated respectively "tip" and "sleeve" in magneto work or "tip" and "ring" in common-battery work, these terms referring to the corresponding terminals of the jacks and plugs of the central-office switchboard. This use of the word "ring" should not be confused with the verb ring. It refers primarily to the ring contact on a switchboard plug and its meaning has been extended to refer to the spring in the jack with which this plug contact registers and to the limb of the line terminating in this spring. Thus in selective ringing on party lines we may speak of "ringing over the ring side of the line," using the two different meanings of the word.

ratus or in the central-office equipment, or both. Selective signaling on private lines is seldom practiced, code ringing on these lines being generally less objectionable than the intricate provision that would be necessary at all of the stations to enable each of them to selectively ring the others. Practically, therefore, we may limit the discussion of selective party-line ringing to exchange lines. Here the selective ringing is done from the central office, the subscribers being able to call central and not each other.

On magneto-exchange lines, as has been stated, code ringing is the system of ringing most employed. With it the stations on a line may be many without sacrificing the rugged simplicity, hardihood, and reliability under adverse conditions that have been responsible for the long survival of the magneto system in rural districts. Where selective ringing is practiced in magneto exchanges, no attempt is made to deal with the large number of stations on a line that are often found on code-ringing lines. With metallic-circuit ringing, the number on a line is usually limited to four or five, but by making two separate ringing circuits of the line conductors, each comprising one limb with a ground return, these numbers may be doubled, thus making it practicable selectively to ring eight or ten stations on a line. Practically nothing is to be gained by a system that would selectively ring more stations than this, because the objectionable features, already alluded to, involved in placing too many stations on a line would, of themselves, tend to place the limit at about this point.

On common-battery exchange lines, while systems are at hand for selectively ringing eight or ten stations, it is seldom that this number is extended beyond four or five. The principal reason for this is that, as a rule, common-battery systems serve urban communities where the lines are likely to be busier and the standards of service demanded somewhat higher. In common-battery exchanges of the Bell System throughout the United States there are many two-party lines, four-party lines being the generally accepted limit. At present the most commonly used four-party ringing system in Bell exchanges is semi-selective, the full-selective four-party system being used in comparatively few areas.

Three principal methods of selective ringing on party lines have been proposed. These may be referred to as the "step-by-step," the "polarity," and the "harmonic" methods. Of these the step-by-step system, never widely adopted, has fallen into almost complete disuse except in a few highly specialized fields, such as in telephone train dispatching. The polarity and harmonic systems, however, are widely used, the former principally in exchanges of the Bell System and the latter principally in independent exchanges.

Step-by-step System.—On first thought it appears strange that the step-by-step principle of selection, which has been so successfully applied in automatic central-office switching, has found so little success in meeting the comparatively simple requirements of selective ringing on exchange party lines. The reasons, however, are simple. In a step-by-step party-line system the selective switches must be placed at the subscribers' stations where they are required to operate under widely varying conditions and with only occasional expert attention, while in an automatic central office the switches operate under the uniform and favorable conditions of the central office with a competent maintenance force always at hand. But perhaps the controlling reason is that much simpler and cheaper ways are available when the selection is to be made among so few stations. If there has been a widespread need in commercial telephony for selectively ringing, say fifteen or twenty stations on a line, the step-by-step method would undoubtedly have been the one to have been developed for the purpose, as it has been for telephone train-dispatching systems. But the need did not exist and better ways were at hand for meeting the lesser requirements.

The step-by-step plan of party-line operation is based on the general idea of having a switching device at each station that is capable of being moved a step at a time by a pawl-and-ratchet mechanism driven by an electromagnet under control of current impulses from the central office. The switches at all the stations among which the selection is being made are thus moved in unison. Each switch, at some point in its movement, is adapted to close the bell circuit at its station, the point in the movement differing for all of the switches on the line. As the switches are moved in unison, therefore, the bell circuits are closed successively, no two at the same time. In order to call any particular station, therefore, the operator causes all of the station switches to move in unison until the bell circuit at the station desired is closed. She is thus able to apply ringing current to the bell of that station alone

The release permitting all the switches to return to normal is accomplished in a number of ways, usually by withdrawing the actuating and holding pawls from their ratchets. Sometimes the stepping magnet is polarized so as to act as a release magnet upon a reversal of the current. In other cases the release magnet is made too sluggish to be affected by the short stepping impulses but is operated to release the switches upon receiving a long current impulse.

The diagram of Fig. 117 will serve to show only the general principles of one of these step-by-step systems that sought recognition in the United States some years ago. While the switch-stepping mechanisms of four stations only are shown, it will be apparent that the number of stations could be indefinitely extended. The step-by-step mechanism at each station consists of a segment of a ratchet wheel *a*, associated driving and

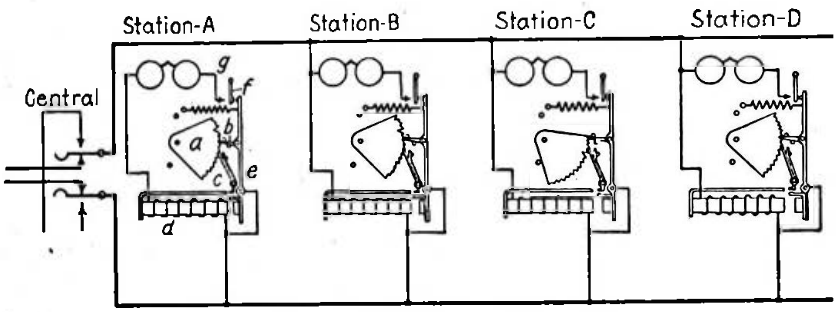


FIG. 117.—Step-by-step lock-out system.

holding pawls *b* and *c* respectively, and an operating magnet *d*. The operating magnet is polarized and permanently bridged across the line circuit. All of these coils receive current impulses from the central office in multiple, and consequently all operate in unison except as one of them may be made inoperative by a calling subscriber. The notches between the ratchet teeth on the periphery of the segment are of three different depths. In each case the first notch (at the top) is of intermediate depth, all of the others except one being shallow and that one being deep. The segments are all exactly alike save in one respect: the deep notch occupies a different position on its segment at all of the stations. Thus, as shown in the figure, the deep notch at station *A* is the third from the top of the segment, the notch at station *B* the fourth, at station *C* the fifth, and so on.

It is the depth of these notches that determines the distance that the driving pawl *b* and the upper end of the rocker arm *e* may be moved to the left. The first or normal notch on each disk allows the rocker arm to engage the contact *f* but not the contact *g*. Contact *f* controls the talking circuit and *g* the ringing circuit, so that normally the talking circuit at each station is closed and the ringing circuit open. The regular stepping notches are so shallow that the pawl *b* will not allow either of these contacts to be closed, while it is only the deep selective notch that permits the closing of the bell circuit. Since no two of the deep notches occupy the same position on their respective segments and since the segments always move in unison, no two of the bell circuits will ever be closed at the same time. In order to select any station, therefore, it is only necessary for the operator to send out the required number of preliminary stepping impulses to bring the deep notch of the segment at that station into the proper position to allow the closing of the bell circuit. Having stepped the switches into this position, the operator then applies ringing current to which only the bell at the selected station responds.

The subscribers call central by magneto hand generators, not shown. These generators do not operate the substation ringers because, with all the segments in their normal position, the ringer circuits are all open. Each subscriber is provided with a push button, not shown, by means of which he may disable his own selective switch during the sending of selective impulses from the central office. He is thus able to maintain his set in talking position when another party on the same line is to be called.

This, it will be seen, is not only a selective ringing system but also a lockout system, for the operator by sending a single impulse may move all of the segments one step and thus open all of the talking bridges without closing any of the ringing bridges.

This and other step-by-step party-line systems have not survived in commercial exchange operation in any large way, if at all. Besides their complexity and costliness they were generally unpopular because depriving the rural subscriber of his much cherished privilege—that of listening in.

The Polarity or Biased-bell System.—The fact that telephone ringers may be biased so as to respond to pulsating currents of one polarity and not of the other was mentioned in Chap. II. The biased-bell method of selective signaling on party lines was first suggested by Mr. George L. Anders, one of the telephone's pioneers. It was later developed into something like its present form by Mr. Angus S. Hibbard, of the Chicago Telephone Company.

As a preliminary to the consideration of the four-party biased-bell system we may consider Fig. 118, which shows a two-party selective-ringing system using ordinary or unbiased ringers. This uses each limb of the metallic circuit as a separate grounded ringing circuit, the choice of the station to be rung being determined by the choice between these two circuits. The two ringing keys are so arranged as to apply ordinary alternating ringing current to either the tip or ring side of the line, according to which key is operated. In each case the ringing key applies a ground to the side of the line not involved in the ringing, this serving to prevent "cross-ringing," that is, the ringing of the wrong party, as might occur if the receiver at some substation

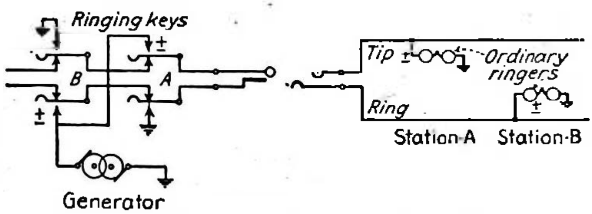


FIG. 118.—Two-party selective system with unbiased ringers.

were off its hook. To illustrate: if it were desired to ring station *B*, the operation of key *B* at the central office would connect the generator with the ring side of the line, the current ordinarily passing to ground through the bell at station *B* only. If, however, some substation hook were up at the time, there would be a connection also to the tip side of the line, so that a part of the ringing current might pass to ground through the bell at station *A*, ringing it also. This bell will not be rung, however, if the ringing key grounds the tip side of the line, because this would afford virtually a short-circuit path to ground around the bell at station *A*. The plan of Fig. 118 is one of the accepted ways of two-party selective ringing in magneto systems. For common-battery systems a condenser is used in each of the ringer taps to ground to prevent the leakage of battery current from one side of the line to the other through the two ringers in series.

Figure 119 shows the polarity system of selective ringing as applied to a two-party line. Here only one limb of the line is involved in the ringing operation. This requires pulsating current and biased ringers instead of alternating current or ordinary ringers as in the system of Fig. 118. The diagram of the ringing generator will be understood when it is stated that the commutator 1 is carried on the generator shaft. Obviously its potential will be alternately plus and minus (±) following the substantially sine-wave potential variations of the generator armature. The

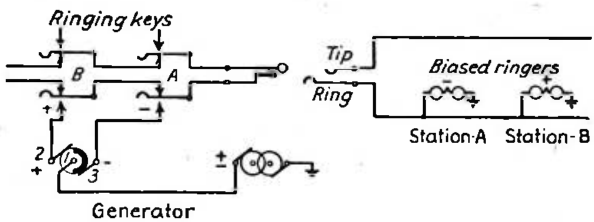


FIG. 119.—Two-party selective system with biased ringers.

brushes 2 and 3 resting on opposite sides of this commutator will then be sources of positive (+) or negative (−) impulses of pulsating current respectively. Ringing key *A*, then, is capable of applying only negative impulses to the ring side of the line, affecting only the biased bell at station *A*, and ringing key *B* only positive impulses, affecting only the bell at station *B*. In this way the two bells are selectively operated over the same ringing circuit.

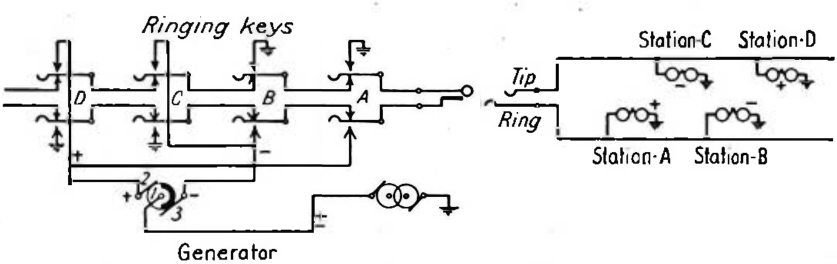


FIG. 120.—Four-party full-selective system with biased grounded ringers.

Obviously, the systems of Figs. 118 and 119 may be combined to form a four-party full-selective system, using the tip side of the line for two oppositely biased bells at two of the stations, and the ring side of the line for the other pair of oppositely biased bells at the other two stations. This is shown in Fig. 120, which needs no further explanation.

To one familiar with the operation of common-battery switchboards it will be evident that the plan of operation shown in Fig.

120 would have a serious fault in common-battery exchange working. As pointed out in Chap. IV, one of the fundamental requirements of a common-battery system is that the line circuit must be held normally open at the substations and closed only when the talking circuit at some station is closed by the raising of its hook switch. It is by the closing of the line circuit when his hook switch rises that a subscriber originates a call. A little thought will show that this requirement of a normally open line circuit is not met in Fig. 120. Regardless of the position of the subscriber's hooks, a path is always closed across the line through the ringers on one side to ground and thence through the ringers on the other side. This direct-current path would cause the operation of the line signal at the central office. One remedy would be to make the biased ringers of such high resistance that

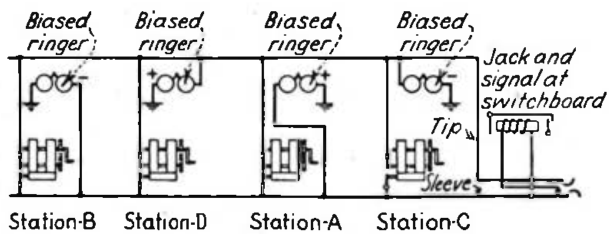


FIG. 121.—Four-party full-selective system on magneto line.

the central-office line relay would not operate through them. At best a makeshift, this would involve a constant leakage and wastage of the common-battery current through the ringers of many lines. The placing of condensers in the bell bridges is not admissible as a cure, because condensers would allow only the passage of the alternating component of the ringing current and this would destroy the selective qualities of the biased bells.

On account of this difficulty the Hibbard system of biased-bell ringing in its original form is now used only on magneto lines where the operation of the central-office signaling is not dependent on the closing and opening of a direct-current path between the two limbs of the line. Such a four-party selective-signaling magneto line is shown in Fig. 121. Here the selection of any station is accomplished by sending positive or negative current over either the sleeve or tip side of the line, exactly as in Fig. 120. The subscribers call the central office by means of their hand generators, in each case bridged across the line during operation. In doing this, there is some tendency to ring the bells on the line by the current passing through the connected bells in series-parallel relation. To guard against this, hand generators of rather low power are desirable and for that reason are shown with but two permanent magnets each. Also, the switchboard drop is made of comparatively low impedance so as to divert most of the hand-generator current from the high-impedance paths through the ringers.

In order to adapt the principles of the Hibbard four-party selective system to common-battery operation, the modification shown in Fig. 122 was devised by Messrs. Thompson and Robes. In this the four biased bells are, as before, connected in pairs of opposite polarity to the two limbs of the line but normally they are not connected with the ground at all. The normal leakage path from one side of the line to the other is therefore absent. A relay in series with a condenser is bridged across the metallic

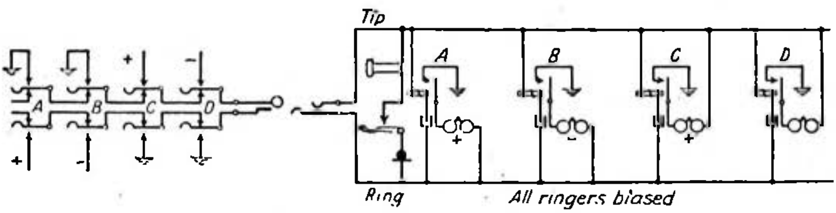


FIG. 122.—Four-party full-selective system with normally ungrounded ringers.

circuit at each station and serves normally to hold open the ground path through its bell. These relays are not polarized and have no selective action. They all operate simultaneously on the pulsating ringing current from any of the ringing keys, the circuit being from the generator lead of any key, over one side of the line, through all the relays in multiple to the other side of the line, and thence to ground at the same ringing key. Upon operating, these relays close their respective bell circuits to ground so that the four bells are temporarily brought into exactly the same relation to the line and the central-office ringing currents as in the system of Fig. 120. The bells are biased and, having no condensers in their circuits, retain their selective action. The result is that only one of them responds to the ringing current from any key, that being the one that is of proper polarity and connected with the side of the line over which the ringing current is sent. This, in principle, is the standard full-selective ringing system for four-party exchange lines in use by the companies of the Bell System to-day.

Superimposed Ringing.—Party-line selective ringing with biased bells involves the use of pulsating rather than alternating ringing current, as already pointed out. In the systems illustrated in Figs. 119 and 120, the ringing machines were provided with commutators adapting them to deliver either positive or negative pulsations of current as required. Later, a better plan of producing the desired positive and negative pulsations of current without using commutators was devised. This plan, known as "superimposed ringing," is shown in principle in Fig. 123. The generator delivers alternating current of ordinary ringing frequency. This alternating current before reaching either ringing key passes through a battery so that the ringing current which

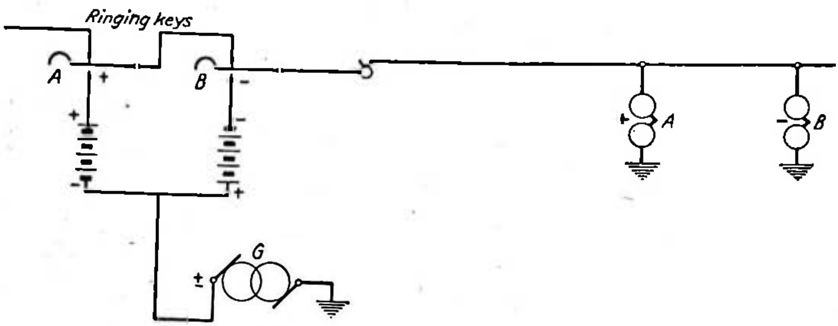


FIG. 123.—Superimposed current ringing—two-party.

flows over the line in response to the operation of any ringing key is in reality a direct current superimposed on an alternating current. The direct-current potential is applied in a positive or in a negative direction, the battery connection being reversed in the two ringing leads. Thus, if the right-hand key of Fig. 123 is used, the negative side of the alternating potential wave will be augmented and the positive wave diminished, resulting in a series of impulses in which the negative half of each wave is highly predominant. Similarly, the left-hand ringing key accomplishes the same result but with the positive halves of the waves predominant.

In superimposed ringing current the alternating component of the wave is not altered but its zero line is shifted in a positive or a negative direction by the amount of the steady battery potential.

Thus, referring to Fig. 124, the alternating component, substantially of sine-wave form, is shown at *a*. Here the potential wave, which is that of the generator alone, extends alternately above and below the axis of zero potential, its crest being alternately positive and negative. Such a current wave is used in ringing ordinary non-biased bells. At *b* (Fig. 124) the whole alternating wave has been shifted in a positive direction by having the steady battery potential superimposed upon it in a positive direction. The result is in effect a series of positive pulsations of current, since the curve lies above the zero axis. At *c* the shift of the alternating wave has taken place in the opposite direction

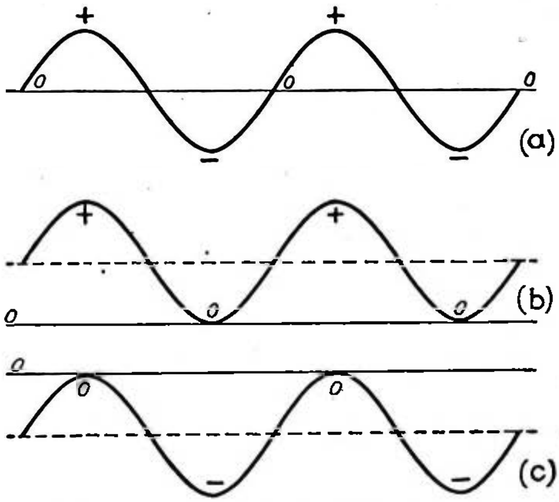


Fig. 124.—Superimposed ringing current.

as by subtracting the battery potential from the instantaneous alternating potential values. Here the wave represents a series of negative pulsations since the curve lies below the zero axis. It is obvious that the biased bells will respond selectively to these two types of impulses in the same way as to the pulsating current waves flowing from the commutator arrangement of Fig. 120.

The application of superimposed ringing current to the ringing keys of a switchboard cord circuit equipped for individual and four-party ringing is shown in Fig. 125. Taking these keys in their order from right to left, as shown in this figure, it is clear that the first two will deliver negative and positive impulses respectively to the ring side of the line, the next two negative and positive impulses respectively to the tip side of the line, and the fifth, or left-hand key, will deliver alternating current from the generator alone. The first four keys are thus adapted for full-

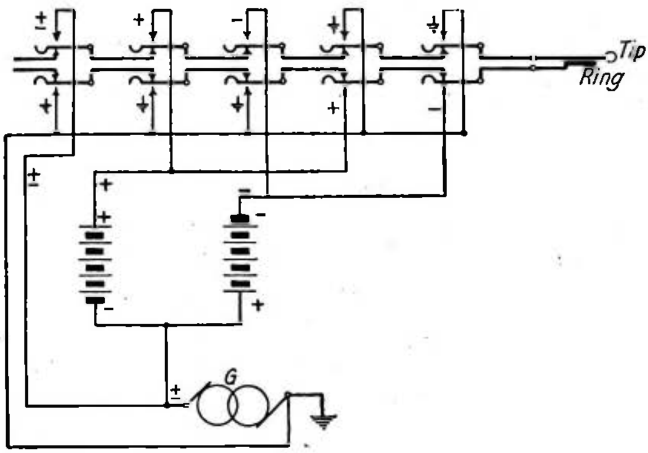


FIG. 125.—Superimposed current ringing—four-party.

selective ringing on four-party lines, while the fifth will be used for ringing unbiased bells on individual lines or on code-ringing party lines.

We may now consider briefly and somewhat more in detail the connection of telephone stations to party lines, with particular

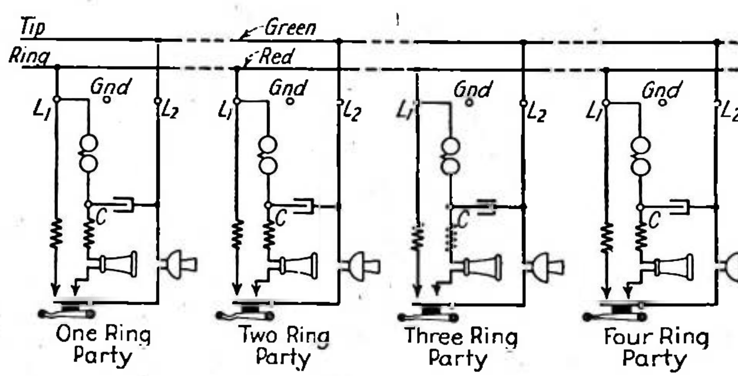


FIG. 126.—Common-battery non-selective line.

reference to the standard practices of the Bell System companies. Figure 126 shows the connection of four stations to a common-battery code-ringing exchange line. Here, since no selective ringing is involved, all of the stations are connected to the line in exactly the same manner. The bells are not oppositely biased and all ring simultaneously. The particular station desired is

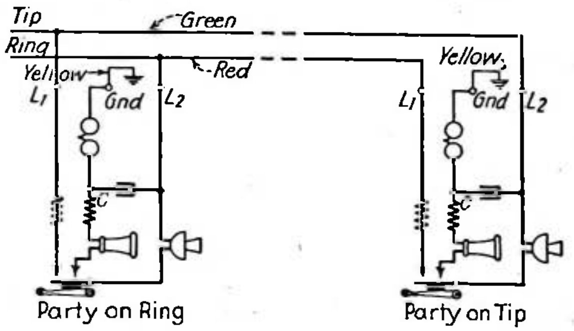


FIG. 127.—Common-battery two-party selective line.

designated by code, the number of rings being indicated below each station. This diagram may be taken as representing also the connections for code-ringing common-battery lines for any other number of stations up to and beyond four, according to the classes of service prevailing in an exchange.

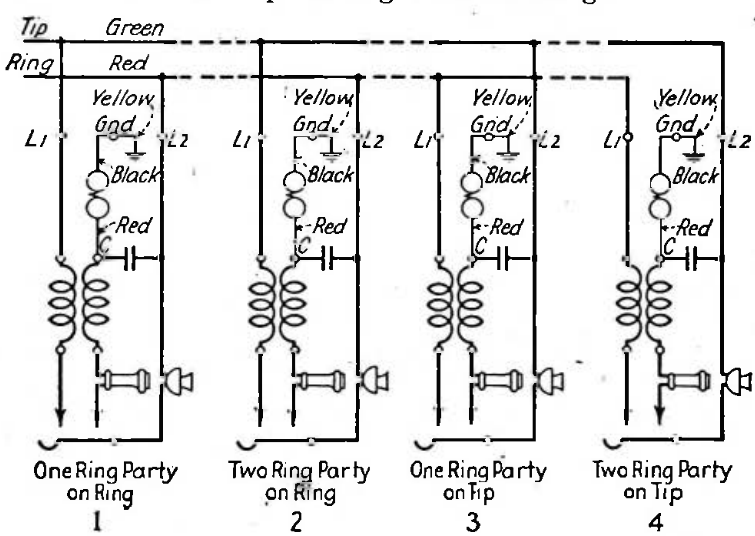


FIG. 128.—Four-party semi-selective line—manual.

The connections of a two-party full-selective common-battery line are made as in Fig. 127. Here the two stations differ only in that their bells are connected to receive ringing current over opposite limbs of the line.

The most commonly used four-party ringing system of the Bell companies is the semi-selective, but in a few areas the full-selective system is used. In the semi-selective system the four ringers, each in series with its condenser, are connected two from each side of the line as shown in Fig. 128. It is seen that the bells of stations 1 and 2 are rung over the ring side of the line, the designation of which of these two stations is desired being indicated by one or two rings respectively. Likewise the bells of stations 3 and 4 are rung over the tip side of the line with the same method of distinguishing between them. The colors of the wires indicated in this and the three diagrams immediately

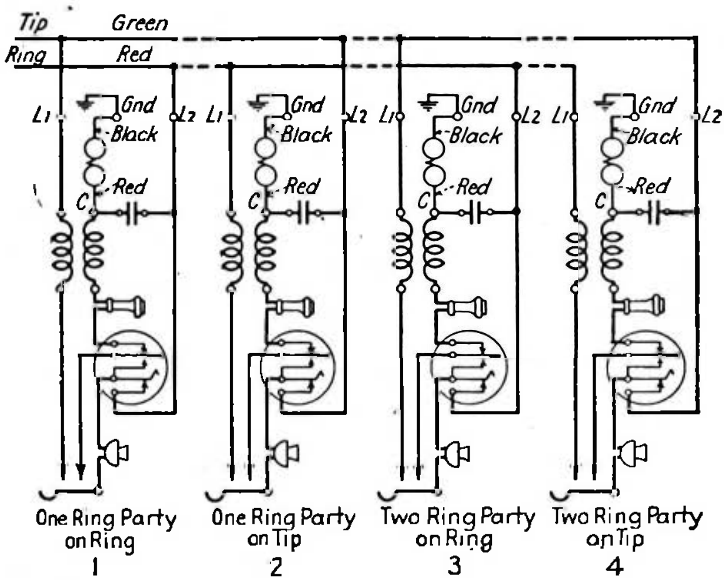


FIG. 129.—Four-party semi-selective line—machine switching.

following are in accordance with the standard color code of the Bell System, in relation to the installation of substation sets in common-battery exchanges.

The connection of the stations on a four-party semi-selective line in an automatic or machine-switching exchange are shown in Fig. 129. This differs from the preceding figure only in the provision for the automatic dial used by the subscribers in controlling the central-office switches.

In Figs. 130 and 131 are shown the station connections on a four-party line with full-selective ringing in manual and machine-switching exchanges respectively. These two figures differ from each other mainly in the provision for the automatic dials on the machine-switching line. It will be seen that the connections of

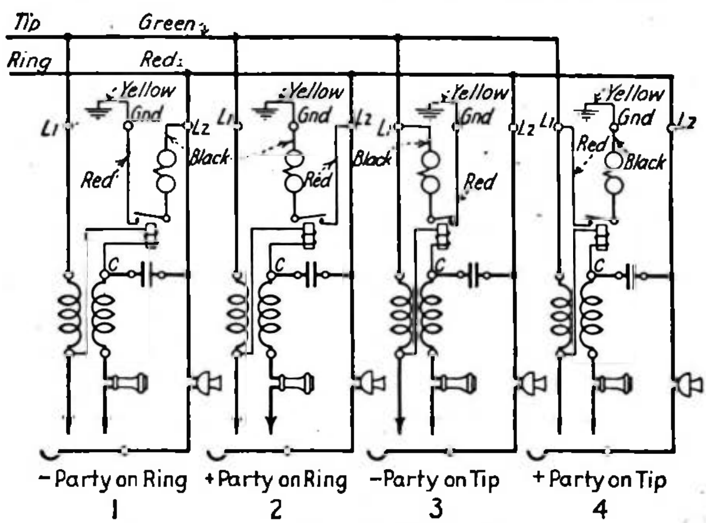


FIG. 130.—Four-party full-selective line—manual.

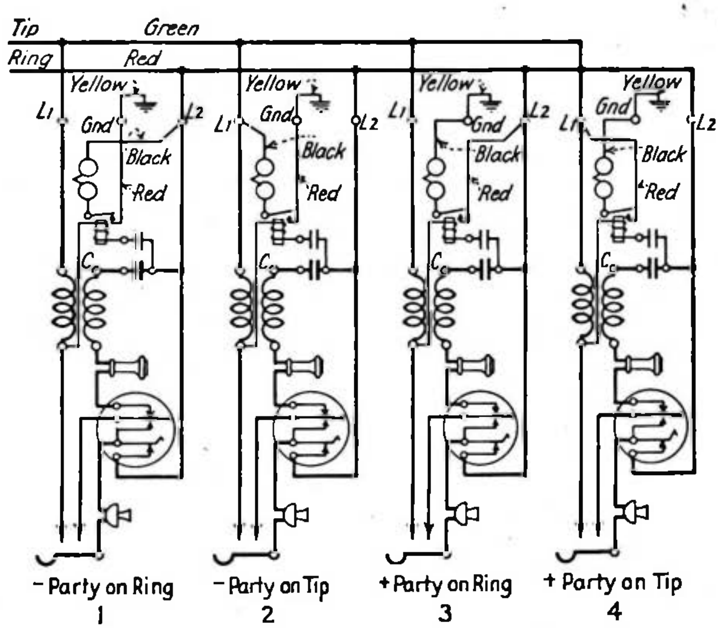


FIG. 131.—Four-party full-selective line—machine switching.

the bells at the different stations to the tip and ring sides of the line, respectively, are brought about in each case by the relay bridged across the line at each station, exactly in accord with the plan of connection shown in Fig. 122. In each of these figures only the bell of the station desired is rung, it being chosen by sending either positive or negative superimposed ringing current over the tip or ring side of the line as the bell connection at that station may require.

Harmonic System.—In the harmonic system of party-line signaling, the bells or ringers at the several stations on a line are each tuned to respond exclusively to a ringing current radically different in frequency from those to which the other ringers on the line are responsive. The bells are bridged across the line so that they each receive a portion of whatever ringing current is sent out from the central office, but only that bell will respond which is tuned to the particular ringing frequency sent.

It was on this principle of selection as between telegraph instruments that both Elisha Gray and Alexander Graham Bell were working just prior to the invention of the electric speaking telephone. The first system of harmonic signaling as between telephone bells of the different stations on a party line was proposed by Jacob B. Currier, an undertaker of Lowell, Massachusetts. Currier's bells were used in commercial exchange service to a considerable extent in New England in the early eighties. A little later on, Mr. James A. Lighthipe, of San Francisco, a power-transmission engineer, produced independently a harmonic selective-signaling system which was put into use on a telephone line paralleling the Sacramento-Folsom power-transmission line and later in telephone exchanges at Sacramento and a few other smaller California cities in that neighborhood. Lighthipe, as in modern practice, used polarized bells with tuned armatures, bridging them across the circuit of the line, each in series with a condenser. The Lighthipe system, while commercially used for a short time, passed out of existence principally because of the difficulties experienced in maintaining a constant speed on the ringing generators driven by the sources of power available in that neighborhood. Variations in speed would, of course, vary the frequency of the ringing current with consequent failures of the tuned bells to respond properly.

In 1903, Mr. W. W. Dean, then with the Kellogg Company, again independently attacked the harmonic selective-ringing problem. The present extensive use of the harmonic system of selection is the direct outgrowth of his work. Dean's first harmonic ringers were of the single-gong type, he having experienced difficulty, as Lighthipe and Currier evidently had before him, in producing a design in which the armature tapper would play between two gongs as in the ordinary ringer. A little later, however, again under Dean's direction, a successful two-gong harmonic ringer was produced and this type has, as far as known, entirely supplanted the single-gong type.

Various present-day commercial forms of harmonic ringers were considered in Chap. II. Their method of use on a four-party full-selective common-battery exchange line is indicated in Fig. 132. The bells are merely bridged across the metallic circuit at their respective stations, each in series with a condenser of sufficient capacity not to obstruct the passage of the required amount of ringing current. The ringing keys shown in connection with the calling plug of the operator's cord circuit are for

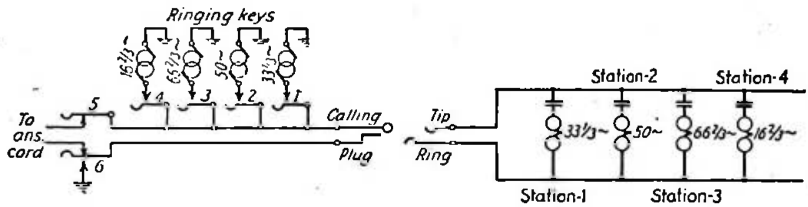


FIG. 132.—Four-party line—harmonic selection.

selectively bridging that one of the sources of ringing current having the desired frequency across the line, this particular set of keys being so arranged that when any one of the springs 1, 2, 3, or 4 is operated the pair of springs 5 and 6 also operate. This cuts off the part of the cord circuit leading to the answering plug and also grounds the sleeve side of the calling cord. Ringing current thus passes from the selected generator over the tip side of the line through all of the bells in multiple to the ring side of line and to ground at the ringing key. The bells at the four stations on the line are each tuned to respond to the frequency of one only of the several generators so that, although all bells receive current when any ringing key is depressed, only that one tuned to the corresponding frequency will respond.

The four-frequency system of harmonic selection is easily extended to give full-selective service on eight-party lines as shown in Fig. 133. Here four differently tuned ringers are connected between each side of the line and ground, and the central-office calling cord is provided with a reversing key so that ringing current may be sent over either tip or sleeve side of the line as required. Similarly, if five ringing frequencies are available, full-selective ringing service may be given on ten-party lines. It is generally considered, however, that four or five stations are enough on city lines, and for that reason the usual practice is to bridge the bells instead of employing the grounded ringing circuits.

The condenser in each ringer bridge in Figs. 132 and 133 is for keeping the line circuit normally conductively open in accordance with the universal requirement of common-battery exchange operation. On magneto lines where harmonic selection from the central office is employed, the condenser is usually omitted.

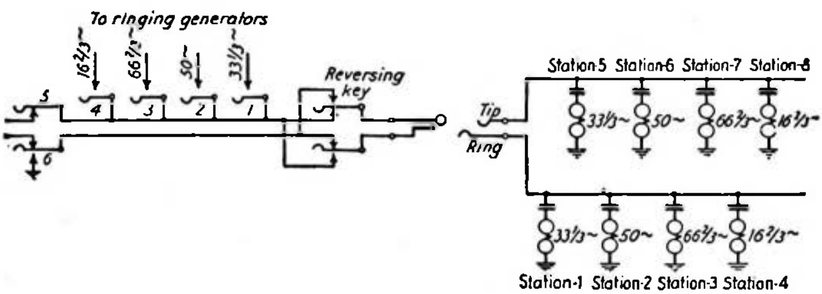


Fig. 133.—Eight-party line—harmonic selection.

The generator frequencies shown in Figs. 132 and 133—16⅔, 33⅓, 50, and 66⅔ cycles respectively—were those originally chosen by Dean and since largely used by the Kellogg Company and some other manufacturers, although in later times a somewhat different set of frequencies has been adopted by others. The reason for this particular set of frequencies was that rotary ringing dynamos were used. The armatures of these were mounted on a common shaft driven at a constant speed of 1,000 revolutions per minute. In order to derive the different frequencies required from four armatures revolving at the same speed, two-, four-, six-, and eight-pole generators were used, giving frequencies of 1,000, 2,000, 4,000, and 8,000 cycles per minute respectively. This generator and the means for keeping its speed constant will be considered in a later chapter on Power Plants as will also the various types of so-called "harmonic converters," which at a later date were designed to generate the ringing currents of the different frequencies required by such systems.

A word further may be said of the action of the harmonic ringer *per se:*

It is found that when the tapper of a tuned ringer strikes its gongs there is a tendency slightly to accelerate the rate of vibration. Expressed in another way, the *natural rate* of vibration of the reed and tapper alone is slightly lower when not striking the gongs than when the tapper is actually striking. The reason for this, of course, is that the rebound from the gongs constitutes one of the factors affecting the natural rate of the vibrating system. Dean, in the development of his first or single-gong ringer, recognized this fact. Accordingly, he purposely *undertuned* his reeds with the thought that they would be slightly accelerated when striking the gongs and brought into proper tune with the actuating ringing current. These undertuned bells, therefore, started their vibration with difficulty, because slightly out of tune but, after striking the gongs, continued more easily because then operating in tune. This proved to be a wrong principle, or at least a better one was soon discovered and has been adopted in all modern two-gong ringers. The armature reeds are tuned accurately to the desired frequencies when not striking the gongs. This enables them to start easily but it results, of course, in a tendency to throw them slightly out of tune on account of the rebound when striking the gongs. With proper design, however, the electromagnet magnetic action is so strong that when in full vibration the armature is forced to keep in step with its actuating current whether quite in tune or not. This so-called "in-tune" system obviously makes for easy starting under influence of the *proper* frequency. This is the condition desired, because at the time of starting the armatures are farthest away from the pole pieces. When in full vibration they come closer to the pole pieces and can be held in vibration although brought slightly out of tune by the action of the gongs.

In this chapter, the ringing current, whether for non-selective or selective ringing and whether for polarity or harmonic selection, has been shown as applied to the line at the central office by manually operated keys. This, of course, is what is done in manually operated switchboards. In automatic or machine-switching systems exactly the same principles of party-line selective, semi-selective, or non-selective ringing are used but the ringing currents are applied to the called subscribers' lines by automatic instead of manual means, as will appear in later chapters.

CHAPTER VI

COMPONENT APPARATUS OF MANUAL SWITCHBOARDS

The apparatus at the central office by which telephone lines are connected for conversation and afterwards disconnected, and by which the various other functions required in giving telephone service are performed, is called the "switchboard." If it is manipulated directly by operators, it is a "manual switchboard." If, on the other hand, the switches are driven by machinery under some form of remote control, it is a "machine switchboard" or an "automatic switchboard." This chapter prepares for the discussion of manual switchboards, by dealing with their component pieces of apparatus. Those pieces of apparatus peculiar to machine-switching or automatic systems will be dealt with in later chapters.

Jacks and Plugs.—The ordinary double-throw switch, as used in power switchboards for instance, performs a very simple switching operation—that of connecting one set of terminals with either one of two other sets. In the manual telephone switchboard the requirement is not so simple. It is necessary to connect the terminals of each line with those of any others served by the switchboard. In a large central office this may mean that the terminals of any one of 10,000 lines may require connection with those of any one of the 9,999 others. Not only this, but many such connections are likely to be required simultaneously.

A combination of jacks, plugs, and flexible cords has been found best to meet this complex switching requirement in manual switchboards. The plug, as the selective member of the switch, is permitted by its flexible cord to move over a large area and to connect with any one of a large number of terminals (jacks) within that area. No other set of instrumentalities has been found even approaching this combination in effectiveness, where a considerable number of lines are involved and where switching operations are to be performed directly by hand under the guiding intelligence of an operator.

The combination of a jack, a plug, and a cord is shown in elementary form in Fig. 134. This is typical of apparatus that was used in early switchboards when grounded instead of metallic-circuit lines were in vogue. While of obsolete form, it illustrates in general principle how jacks, plugs, and cords are used in telephone switchboards.

Normally, the spring of the jack rests on a stationary insulated contact, thus completing the circuit between the subscriber's line and the line signal. When the plug is inserted, the spring is lifted off the pin, thus breaking the circuit to the line signal which is no longer required and which it is better to have disconnected from the talking circuit. The contact between the jack spring and the metal part of the plug extends the circuit of the line to the conductor of the flexible cord, from which it may be still further extended to an operator's telephone or through another flexible cord, plug, and jack to another line.

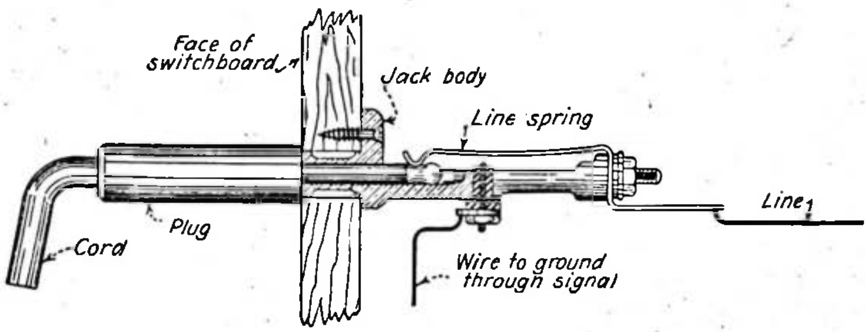


FIG. 134.—Simple jack and plug.

We see that the jack in this case not only serves to extend the circuit of the line to the flexible cord but incidentally performs another switching operation, by which it cuts off the circuit of a piece of apparatus (signal) not used during the connection. Sometimes this and other subsidiary switching operations are done directly within the jack as in Fig. 134, but often they are done outside the jack as an indirect result of contacts that are made or broken within the jack. This will become more apparent when switchboard systems are considered in subsequent chapters, but the point to remember here is that the jack usually has functions beyond that of merely establishing connection with the line and that these incidental functions are important in the general scheme of switchboard operation.

It is of interest to know the origin of the name "spring jack" or "jack." As soon as it was realized that the old telegraph switchboards would not serve the purposes of telephony, the late Mr. Charles E. Scribner, than whom no one did more towards the development of the modern manual switchboard, designed a line terminal provided with a spring blade. This was mounted on the face of the switchboard and provided with a hole for the reception of the plug. When the plug was inserted in the hole, the blade was crowded aside and by its spring action maintained firm contact with the plug. The action of the spring blade in this switch suggested that of an ordinary jack-knife and the device became known as the "jack-knife" switch. As is usual in the development of the nomenclature of a new art, this was shortened and finally became merely jack or spring jack.

The later-developed jack of the type shown in Fig. 134 served its purposes admirably when lines were few and each had but a single line wire. It made strong, firm contact with the plug, and the movement of the line spring was sufficient to make and break with certainty the auxiliary circuit through the signal. It was rugged, and the fact that it was bulky made little difference. The number of lines entering an office was so small that no difficulty was found in getting them all within reach of an operator.

Later, the requirements of jack construction became very different. The number of jacks that had to be placed within the reach of a single operator increased from a maximum of a few hundred to several thousand. Frequently it is over ten thousand. This called for smaller jacks. Working against this requirement for reduction in size was that for a greater number of contacts in each jack. Instead of a single conductor through the jack plug and cord, the usual requirement is for at least three, two for the conductors of the metallic circuit line and one for local purposes. The need also grew for cheaper jacks in order that the great number of them required in a large switchboard might not result in prohibitive costs.

These requirements have been met by better design, more accurate workmanship, quantity production, and the practice of making the jacks in strips, usually of ten or twenty as unitary structures. They are always made in strips where large numbers of jacks are to be placed compactly together. In other cases, however, where only one jack or a few jacks for miscellaneous uses are involved, they are often mounted singly.

Many different arrangements of jack contacts are employed to meet the various circuit requirements, some of which are shown by the suggestive jack symbols of Fig. 65. Of these, symbols *a* and *c* represent respectively two- and three-conductor jacks with no auxiliary make-and-break contacts. Symbol *b* is that of a two-conductor jack arranged to break one auxiliary contact upon the insertion of the plug. Symbol *d* represents a three-conductor jack with two auxiliary break contacts. The jacks corresponding to symbols *e* and *f* are not so common and are given merely

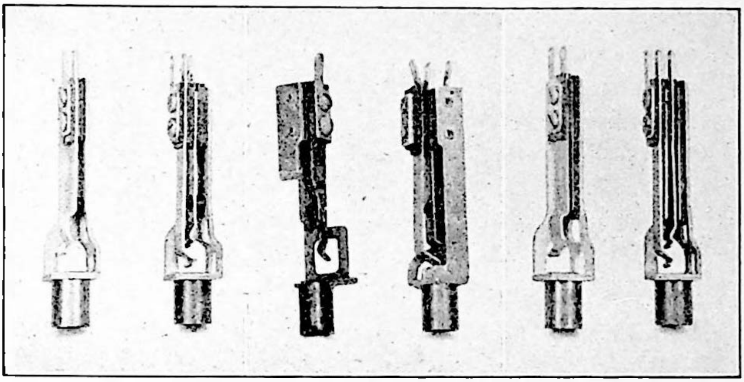


Fig. 135.—Individually mounted jacks. (*Courtesy of Bell Telephone Laboratories.*)

to show how the more complicated forms of jacks may be represented.

The jack of Fig. 134, with its heavy cast frame, is an early example of the singly mounted type. Modern practice in individually mounted jacks is represented by the group of Fig. 135, these being of Western Electric make. They are punched from sheet metal, the contact springs being rigidly secured to, but

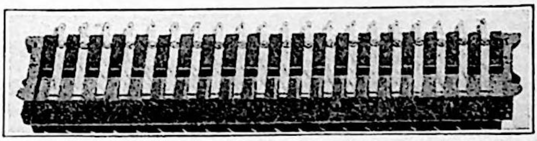


Fig. 136.—Strip of two-conductor jacks. (*Courtesy of Kellogg Switchboard and Supply Company.*)

insulated from, the sleeve which is integral with the jack frame. The two jacks in the center of this group are of an earlier U-frame type, a part of the third one being cut away to show the construction. The others have a later frame design with a right angle, instead of a U cross-section.

Figure 136 shows a strip of twenty jacks of Kellogg make. These are of the simplest type—two conductors without auxiliary make-or-break contacts, corresponding to jack symbol *a* of Fig. 65. Here the twenty-sleeve contacts are mounted in a hard-rubber front strip and the twenty spring contacts are mounted in a back strip of the same material. Each sleeve contact has an integral metal tongue which projects rearwardly through and beyond the back strip. These, and the rearward projections of the tip springs, form convenient soldering terminals at the rear of the jack strip.

Figure 137 shows a strip of twenty No. 92 type jacks of the Western Electric Company which undoubtedly have been made in greater quantities than any other jack in the world, being employed in all large multiple boards of the Bell System. It is of the three-contact type (symbol *c*, Fig. 65) and mounts on 3⁄8-inch centers, horizontally and vertically. The front and back strips are of hard rubber, the front strip being bored to receive the

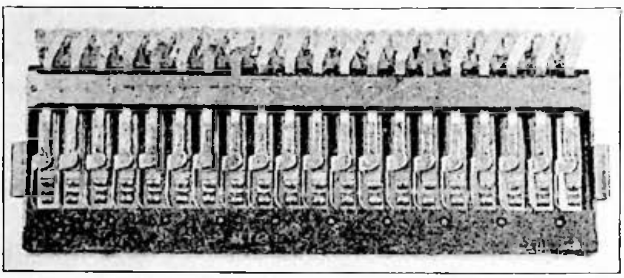


FIG. 137.—No. 92 jack of Western Electric Company. (*Courtesy of Bell Telephone Laboratories.*)

metallic thimbles that form the front or sleeve contact of the jack. The rear strip is milled and slotted to receive the two line springs of each jack and also the terminal of the sleeve contact. This sleeve terminal forms an integral part of the sleeve and extends back through a slot in the rear strip, so as to lie adjacent to the rearwardly projecting tongues of the line springs and with them to form the three soldering terminals of each jack. The face dimensions of the strip whether for ten or twenty jacks are: length, 7 23⁄32 inches, and height, 3⁄8 inch.

Another widely used jack of the Bell System is the No. 49 of which a strip of twenty is shown in Fig. 138. This mounts on 7⁄16-inch centers both ways, the face of the strip of either ten or twenty being 9 3⁄16 inches long. It has the same spring arrangement as the No. 92 jack, but both of the line springs and the sleeve are mounted in a single block of insulating material. This jack is largely used in toll and private branch-exchange services and in small-capacity multiple boards. Its contact arrangement also corresponds to symbol *c* of Fig. 65.

The question of how such jacks are grouped, numbered, and mounted is matter for discussion in subsequent chapters, but it

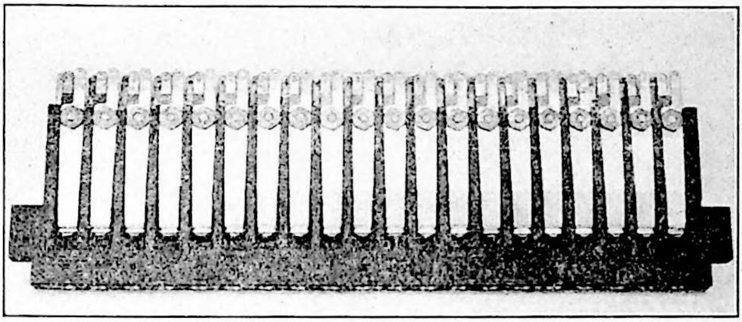


FIG. 138.—No. 49 jack of Western Electric Company. (*Courtesy of Bell Telephone Laboratories.*)

will perhaps serve to emphasize the importance of the spring jack in switchboard construction to state that as many as ten thousand of them are often mounted in a group within reach of a single operator, and that such a group may be repeated many times, resulting in perhaps half a million jacks in a single switchboard.

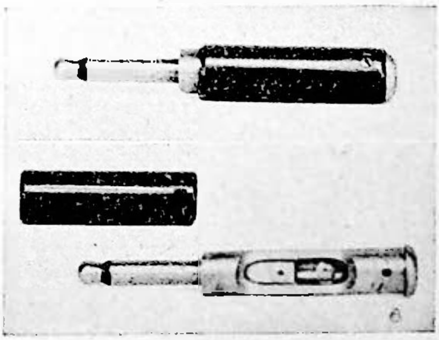


FIG. 139.—Two-contact plug—Western Electric No. 49. (*Courtesy of Bell Telephone Laboratories.*)

The plugs for cooperating with jacks are not so numerous or in the aggregate so costly, but they are none the less important. Figure 139 shows the construction of a two-conductor plug—the No. 47 plug of the Bell System—used in magneto exchanges, test boards, and in other connections where two-conductor cords are required.

The No. 109 plug of the Bell System used in connection with the No. 92 jack is shown in partial cross-section and with its fiber shell or handle removed in Fig. 140. It is to be noted that just back of the tip contact there is a small band of brass, insulated from the central core and from the contacts on each side of it. This "dead collar" is to prevent undue wear on the insulation between the two adjacent "live contacts" and, at the same time, to prevent those two live contacts from being short-circuited by the sleeve of the jack during the entrance of the plug.

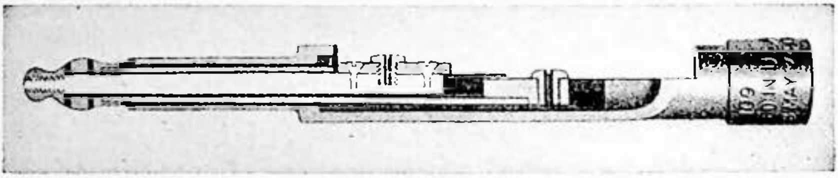


FIG. 140.—Three-conductor plug—Western Electric No. 109. (*Courtesy of Bell Telephone Laboratories.*)

The provision for attaching switchboard cords to plugs is important. The plug of Fig. 140 may be taken as an example. Two of the three cord conductors are provided at their plug ends with small metallic clips. These are fastened respectively to the forward and middle contacts of the plug, by the small hollow machine screws within the handle of the plug. The third conductor of the cord, which connects with the long sleeve of the plug, is merely left bare and, before the cord is attached to the plug, is bent back over the outer cotton braid of the cord so as to come into contact with the metallic body of the plug when the cord is inserted. The heel of the plug has a coarse internal screw thread and the cord is held in place by the tight fit of the braiding in this screw thread. The edges of this internal screw thread are so rounded off as not to cut the cord conductor or the outer braiding. This method of attachment allows stresses on the cord to be borne by the insulating braid rather than by the condensers themselves.

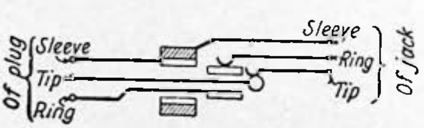


FIG. 141.—Names of jack and plug contacts.

Around the structure of the plug has grown up the nomenclature of the contacts of both plug and jack; and this same nomenclature has been logically extended to the line conductors and to the terminals of distant apparatus. This nomenclature would have no meaning unless its derivation were understood. The forward end of the plug (Fig. 141) is for obvious reasons called the "tip." The live contact just back of it, because it is usually in the form of a ring or short collar, is called the "ring." The rear contact, constituting the shell or body of the plug, is called the "sleeve." We have, then, the names tip, ring, and sleeve applied respectively to the three contacts in order from front to rear. These same names are applied to the contacts of the jack, its sleeve or thimble contact being the sleeve, and the two springs the tip and ring. Therefore, since the two conductors of the line ordinarily terminate in these two springs, the terms tip and ring have been applied to the line conductors, and thus we may have at a distant point, such as within the telephone at a subscriber's station, the tip and ring sides of the line, and we may find terminals of the instrument marked accordingly.

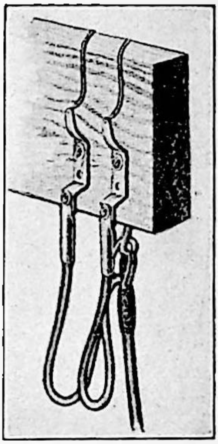


FIG. 142.—Cord rack connectors.

The flexible conductor ends at the other end of the cord require connection with the wiring leading to other parts of the switchboard apparatus. In order to do this effectively and conveniently with respect to the replacement of worn-out cords, a stationary cord-connecting rack, with some such arrangement of terminals as that of Fig. 142, is employed. This shows the terminal arrangement for a two-conductor cord. The switchboard wires, being permanent, are soldered to the rack terminals, while the cord conductors, being relatively short-lived, are screw-connected. A strain loop relieves the cord terminals from danger of possible damage by the direct pull of the cord.

FIG. 143.—Cord weight.

From the cord-terminal rack the cords pass up loosely through holes in the operator's plug shelf, where they end in the plugs. In order that the cord may be held taut and yet allow the plug to be moved freely over the jack field, a cord weight is employed in the bight of each cord. One of these is shown in Fig. 143, this one being composed of a hard alloy of lead cast about the lower portion of a U-shaped brass stirrup in which is journaled the pulley through which the cord runs. Later practice is to make the cord weights of cast iron with a galvanized finish or of a pressed-steel outer shell with a cast-lead filling. They usually weigh about 9 ounces, that weight being required to restore the cords to their places when the plugs are withdrawn from the jacks.

In most manual switchboards the cords and plugs are associated in pairs, each pair, connected together cord end to cord end, forming a possible link adapted to connect two lines for conversation. Each such link of two cords and plugs with the auxiliary apparatus individual to it, all connected in proper circuit relation, is called a "cord circuit." In each cord circuit that plug which is employed in making initial connection with a line in response to its signal is the "answering plug." It is the plug used by the operator in *answering* a call. The other plug, with which the operator establishes the connection with the desired line, is the "calling plug" or the "connecting plug." It is the plug used in *connecting* with the desired line and in *calling* the subscriber on it. Each equipped position on a switchboard is provided with a number of these cord circuits (often seventeen) so that a number of connections may exist simultaneously.

Operator's Talking and Ringing Equipment.—In order that the operator may communicate with the subscribers either before or during connections, and also with other operators, in case the connection requires their services, each operator is provided with a talking set consisting of a receiver, transmitter, and induction coil. These parts have been dealt with in the chapter on Talking Apparatus, but their association with each other and with the other parts of the switchboard requires some attention here.

In order that the operator may have both hands free in the performance of her work, the receiver is held at her ear by means of a head band, of some such type as that shown in Fig. 26 (Chap. I). Practice varies, somewhat, with respect to the support of the transmitter. In small switchboards where wide bodily movement on the part of the operator is not required, it is customary to suspend the transmitter from some part of the switchboard structure in such manner that it will fall into convenient position for her use. In this type, illustrated in Fig. 144, the suspending cords are also the transmitter conductors. A balancing weight in the bight of each cord within the top of the switchboard cabinet, or a vertical movement of the arm itself, permits the up-and-down adjustment of the transmitter to conform to the operator's height and position. This type of operator's transmitter suspension was formerly used on large as well as small boards, but for large multiple boards, where the operator

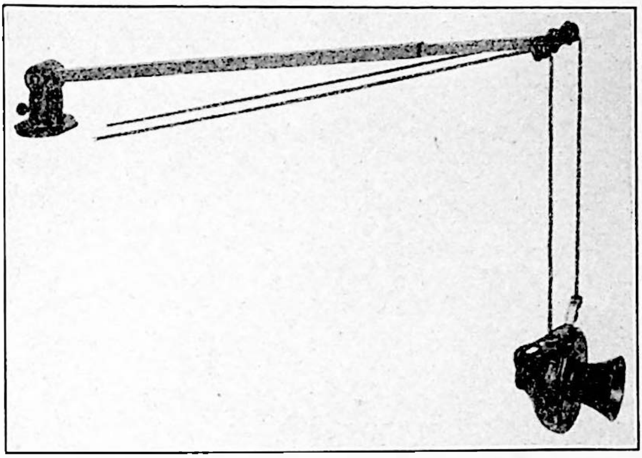


FIG. 144.—Operator's transmitter suspension.

has to reach over a wide jack field, it has been found best for her to wear the transmitter on her chest so that it will follow her bodily movements and always be in correct position for use regardless of her position before the switchboard. Such a form of

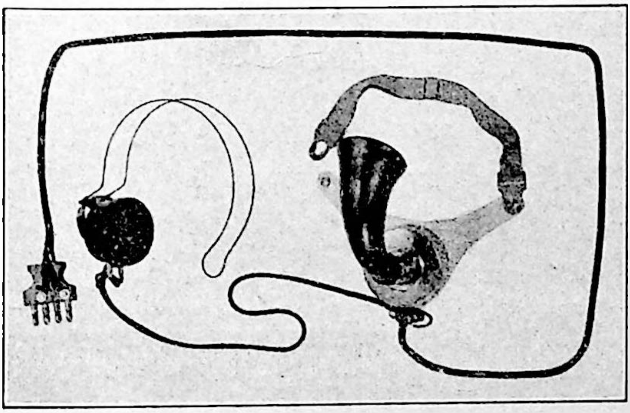


FIG. 145.—Operator's telephone set with breast transmitter.

operator's transmitter and harness, commonly known as the "breastplate" or "chest transmitter," is shown at the right of Fig. 145. This is suspended by a strap or ribbon passing around the operator's neck. The long, curved mouthpiece is adjustable, so that it may assume the required position in front of her lips.

In modern switchboard-operating practice, the induction coil of talking set is attached permanently to the stationary switchboard structure, but each operator carries her own transmitter and receiver, which she takes from the switchboard when off duty. This necessitates ready means for attaching or detaching her transmitter and receiver when her trick on duty begins or ends, or when she changes from one switchboard position to another. For this purpose the permanent wiring of the talking set of each position is extended to a point on the vertical rail of the operator's key shelf and terminated there in an operator's cut-in jack of such type as that shown in Fig. 146. The cooperating plug for this jack is at the end of the flexible cord of the operator's set as shown in Fig. 145. Since, with the breastplate transmitter, the transmitter as well as the receiver is carried on the person of the

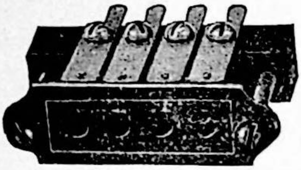


FIG. 146.—Operator's cut-in jack. (*Courtesy of Stromberg-Carlson Telephone Manufacturing Company.*)

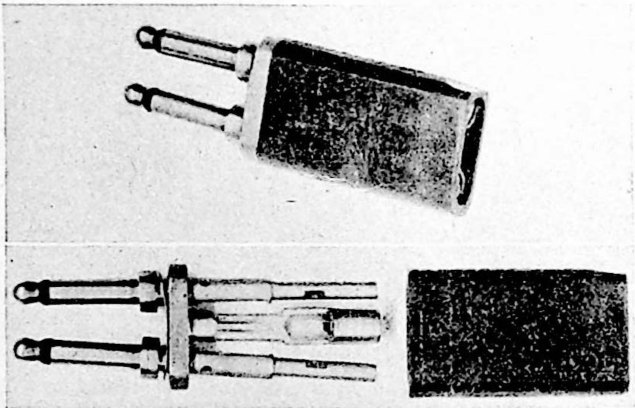


FIG. 147.—Western Electric Company's twin plugs. (*Courtesy of Bell Telephone Laboratories.*)

operator, four conductors are required in the operator's cord and four contacts in the plug and jack. When the operator leaves the switchboard, either temporarily or at the end of her trick, she withdraws the plug from the jack. The relieving operator has only to insert the plug of her set into the jack in order to be in readiness to begin operating work.

Instead of using "four-finger" operator's plugs of the general type shown at the left in Fig. 145 more recent practice in the Bell System is to terminate the portable part of the operator's set in a "two-finger" plug like that shown in Fig. 147. This consists essentially of two No. 47 plugs (Fig. 139) flexibly mounted in a common handle. The flexible mounting of the two plug members or fingers is to permit them to align themselves readily with the operator's cut-in jacks whose spacing is subject to slight variation. These "two-finger" four-conductor plugs are also used on toll test boards and on flexible test cords on main distributing frames.

Every switchboard requires a source of current for ringing the bells at the subscribers' stations. In very small switchboards an ordinary hand magneto generator may be made to serve this purpose. Usually, however, some form of continuously operating machine, such as a motor-driven ringing generator or an automatic "pole changer," is employed, thus providing a source of uniform ringing current continuously available to the operator without muscular effort on her part. Where the hand-driven magneto generator is employed, one of them is provided for each operator's position and so mounted that its crank will be in convenient position for the operator to turn it. Magneto switchboards are usually so equipped even though a power-driven generator is provided, the hand generators serving for emergency purposes in case of the breakdown of the power machine.

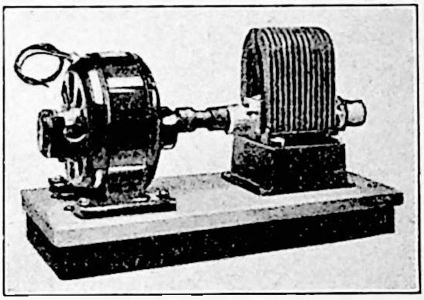


Fig. 148.—Motor generator ringing set.

Figure 148 shows a very simple form of power-driven ringing generator. It is merely a magneto generator direct-connected to a small electric motor. This will serve at this point to typify ringing machines in general, their more complete consideration being reserved for a later chapter.

Keys.—The operator's talking set, as we have seen, is individual to a switchboard position. The ringing machine may be (as with hand generators) individual to the position, but when power-driven it is common to the entire switchboard or to the entire central office. It is necessary to provide some means by which the operator may associate either her talking set or the ringing generator with any one of her individual cord circuits, in order that she may talk with or signal a station on the line with which that cord circuit is at the time connected. For this purpose, except where these functions are done automatically, each cord circuit is provided with a "listening key" and a "ringing key." These are merely hand-operated switches, the movable or switching members of which are operated by a small hand lever, or by a push button or plunger, on the "key shelf" of each switchboard position.

The principal function of the listening key is merely to connect the operator's telephone set across the two talking conductors of the cord circuit. For that reason it has two pairs of normally open contacts adapted to be closed by the operation of the key. It is commonly represented in circuit diagrams as by the left-hand half of key symbol *a* in Fig. 65, which suggests its switching function. The ringing key, on the other hand, must not only be able to connect the ringing generator across the two line conductors of the cord that is connected with a line to be called, but it must also, when ringing, open the normally closed path back of it to prevent disturbing the subscriber on the other end of the connection, usually the one who originated the call. For this reason the ringing key ordinarily requires two sets of make-and-break contacts and is commonly represented as by the right-hand portion of key symbol *a* of Fig. 65. Commonly, each cord circuit has both a ringing and a listening key, often combined in a single unit. This symbol, taken in its entirety, therefore represents a combined ringing and listening key. Often various other spring contacts are added to perform additional, switching functions coincident with the listening and ringing operations.

Listening and ringing keys, individual or in combination, assume a great variety of forms, owing to variation in the designs of different manufacturers, to the different types of service required, to the different methods of mounting, and to the varying space requirements. The principal variations in design occur in the ringing key and are due to the many kinds of ringing service that may be required. The simplest case is that where it is necessary merely to ring over the metallic circuit of one cord with no requirement for selective ringing. For this the functioning suggested in key symbol *a* of Fig. 65 suffices. Sometimes it is desirable to be able to ring back over the answering cord as well as over the calling. In this case, it is usual to provide another set of springs and another lever or push button for operating them. Where the ringing is selective, the key may be required, for instance, to connect any one of four or five different ringing generators of as many different frequencies with the cord circuit; or, in another system of selection, to connect a single ringing generator in any one of four different ways. These different systems of ringing and a number of variations of each bring about many modifications of the simple arrangement suggested in Fig. 65.

Ringing and listening keys may be classified broadly as of two types: those with vertical-spring arrangement and those with

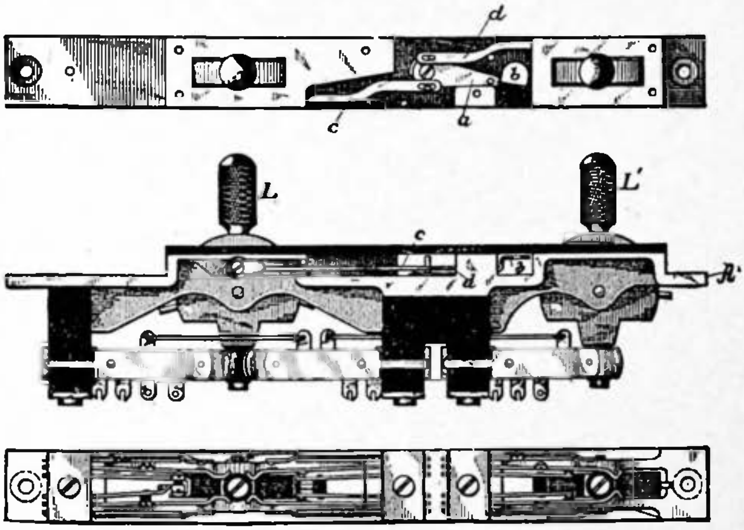


FIG. 149.—Early Western Electric lever-type keys.

horizontal. In the horizontal type, the plane of the metal of the springs should be vertical rather than horizontal, to facilitate inspection of the contacts and to reduce the likelihood of particles of dust lodging between the points and interfering with good electrical contacts. In all cases the contact points should be of some of the precious metals or alloys of proven ability to resist corrosion under arcing conditions. The springs themselves are usually of German silver of such thickness and temper as to retain their form and resiliency after repeated flexing through long periods of years.

A horizontal type of key that, with various minor modifications, has been widely used in the Bell System is one of the early models of the Western Electric Company shown in Fig. 149. The two operating levers L and L' are pivoted in a heavy-brass casting A, upon which the several sets of contact springs are mounted. The button or cam of insulating material carried on the lower end of the lever L plays between the listening group of springs, shown at the left, and a set of ringing springs, which is the middle group on the key. When, therefore, the key lever L is thrown to the right, as seen in the cut, the operator's telephone set will be connected with the cord circuit. When this lever is thrown in the opposite direction, the calling plug is disconnected from the rest of the cord circuit and is connected with the calling generator terminals to effect the ringing of the bell of one of the parties on the line with which the calling plug is connected. The cam of the lever L' plays between one set of springs only, and when thrown to the right is adapted to serve as a ringing key for the other party on the line. The small hook-shaped spring on the inside of the group of listening springs shows how an auxiliary circuit may be controlled as an incident to the listening operation.

The plan view in Fig. 149 shows the top of the key with its upper hard-rubber finishing strip removed. This discloses a top view of a lever a carrying a white-and-red target b. This target is displayed to the view of the operator through a hole in the rubber finishing strip. The lever a is so arranged as to be moved by the slotted link rods c and d, pivoted respectively to the key levers L and L'. By virtue of the pin-and-slot connection between these links and the lever a, the target will be moved into the position shown (and will therefore appear white) when the lever L is thrown into its ringing position. It will not be moved by subsequent operation of this lever; but if lever L' is thrown, the target will be moved by means of link d so as to have its red portion visible to the operator. This target, therefore, always shows the operator which one of the ringing keys was last operated, so that if required to ring a second time she may avoid pressing the wrong key.

It is obvious that this key may be modified to meet the requirements of several types of service. For instance, instead of being used for two-party line selective ringing, it may be so connected with the cord circuit as to ring non-selectively on either cord of the pair. Again, by leaving off the right-hand cam with its group of springs and also the indicating device, the key becomes merely a combined ringing and listening key for ordinary individual line ringing. This key is secured in the key shelf in an iron framework, the various keys being mounted close together side by side and secured in this framework by machine screws. Eighteen of such keys may be placed in an ordinary key shelf unless too much key-shelf room is required for some of the other devices that may be required.

The chief objection inherent in the horizontal type of ringing-and-listening key is the amount of room it requires on the key shelf. To avoid this and at the same time attain what is probably a somewhat cheaper type of construction, the vertical-spring type of key was evolved. A simple design representative of this

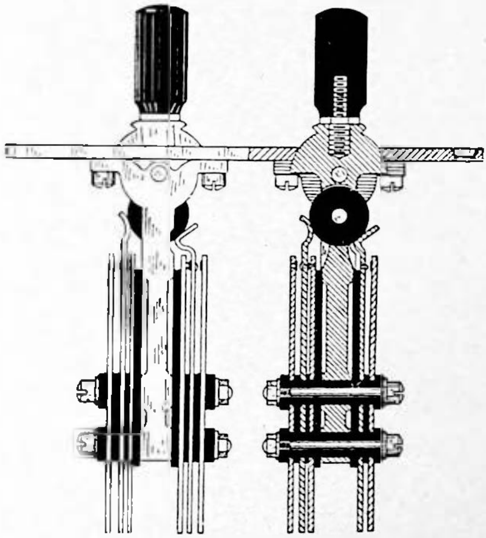


FIG. 150.—Vertical-spring type of lever keys.

type is shown in Fig. 150, in which two double-throw keys are carried on a single mounting strip. Their construction and mode of operation are obvious. The key shown in section at the right is arranged for ringing and listening, the one at the left for such additional ringing purposes as the type of service may require.

This figure may be used to illustrate the difference between locking and non-locking keys. Evidently, when the right-hand key lever is thrown to the left, its cam rollers, moving to the right, will ride upon the right-hand pair of springs in such a way as to lock in that position, the end of the springs being so formed that their pressure will be exerted in the line extending through the pivot and the center of the cam roller. When such a key is thrown into the listening position, therefore, it remains until restored by hand. When the key is thrown into the ringing position (right), the long springs on the left-hand side exert their pressure in such a direction as to restore the cam as soon as the operator releases the lever. Speaking generally, cord-circuit listening keys are usually locking while ringing keys are usually non-locking. Keys for other purposes are made of either variety in this respect, according to the way they are intended to function with respect to the operating routine.

To meet the need of the Bell System for larger possible spring combinations than could be provided for in its older horizontal-type keys, the Western Electric Company produces a vertical type of ringing and listening key, of which that shown in Fig. 151 is typical. In this, as in other vertical keys, what may be called the "unit type" of construction has been adopted. The heavy frame of cast brass formerly used (Fig. 149) is replaced by a channel pressed from sheet steel, to which are bolted subordinate frames for holding the spring pile-ups and the levers or plungers. This permits the production of numberless key arrangements to meet various required functioning by the comparatively simple process of combining standard units rather than the previous course of designing and manufacturing an entirely new key. The fact that the pile-ups run longitudinally instead of cross-wise makes the number of springs in the pile-up independent of the width of the key.

The different shapes of the three long "plunger" springs (Fig. 151) are to be noted. The plunger spring on one pile-up of each pair may be straight to restore the lever or made with a V-shaped crimp for holding the lever until restored manually. In the other pile-up of the pair the motion of the cam roller is taken by a long curved crook in the plunger spring which absorbs the energy of the lever and cam in its rebound from the other direction, before being moved far enough to operate any of the contacts.

A great improvement in the method of mounting in the key shelf also characterizes modern practice. As illustrated in Fig. 152, the key-shelf opening has two pair of parallel steel mounting bars running lengthwise at its front and rear edges. A small post is provided at each end of each key channel (Fig. 151), each post having at its lower end a screw and a narrow flat-sided washer. These posts and washers pass between the pairs of mounting bars and are held in place by turning the washers and tightening the screws. This method allows the mounting of different types

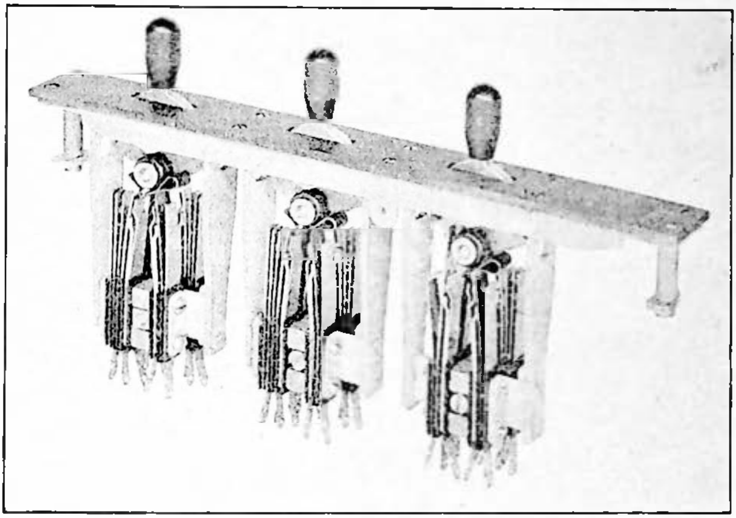


FIG. 151.—A-1 type Western Electric key. (*Courtesy of Bell Telephone Laboratories.*)

of keys without drilling, cutting, or otherwise changing the key shelf.

Figure 153 illustrates another type of ringing and listening key of the Western Electric Company, this one designed for four-

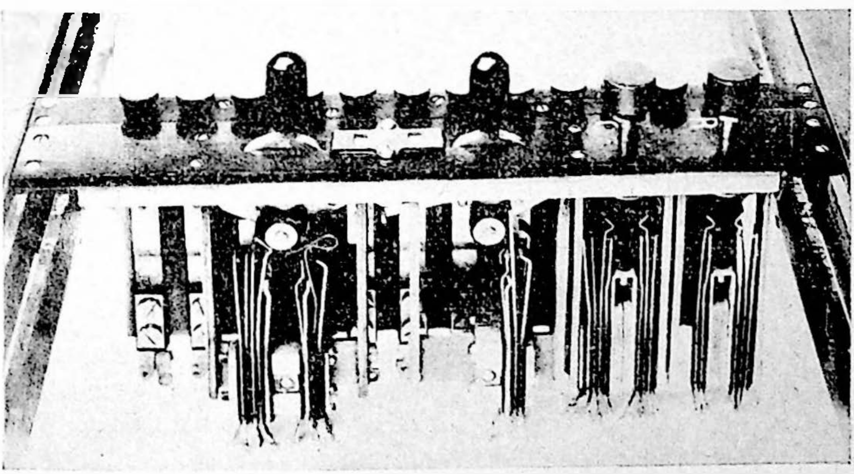


FIG. 152.—Mounting keys in key shelf. (*Courtesy of Bell Telephone Laboratories.*)

party selection on party lines. This is of the so-called "plunger" type. The five ringing keys are non-locking, but the listening key in which the plunger is actuated by a cam lever is locking by virtue of the cam surface. This key, like the one shown in Fig. 149, automatically indicates which of the ringing keys was last

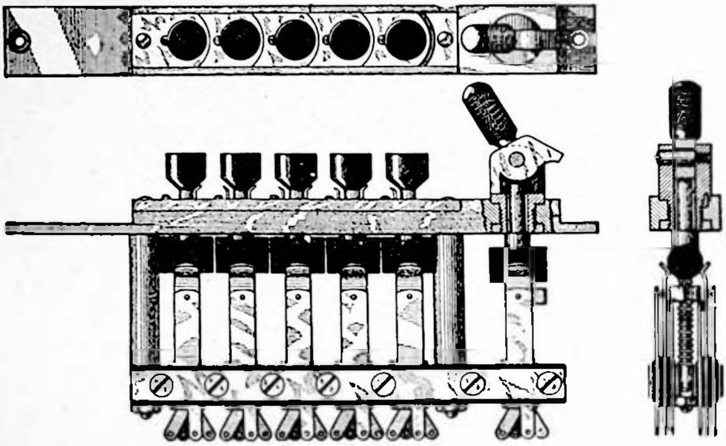


FIG. 153.—Four-party ringing and listening key.

operated. To do this, it is provided with four slidable plates, each adapted to be moved in one direction or the other by the operation of the ringing plungers. These plates all bear against each other except for the slight space that may be left between any pair of them. Since there is only room enough in their slideway for one such space as is produced by the movement of the plunger, it follows that an opening will always be left between the pair of plates corresponding to the plunger last depressed.

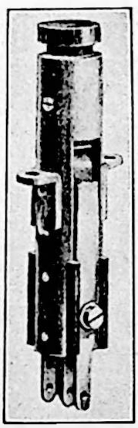


FIG. 154.—Individually mounted plunger-type key.

Aside from their use in cord circuits, keys of various types are required to perform many other functions as component parts of telephone switchboards. Important among these are their use on "order wires" or "call circuits." These are circuits by means of which two operators usually in different offices communicate with each other in establishing a connection. The *order-wire keys* used on these circuits are usually of the non-locking plunger type and may be individually mounted as in Fig. 154, or may be mounted in strips, as in Fig. 155. Usually when used for order-wire purposes, these keys are provided with the simple listening-key combination of springs (key symbol *c*, Fig. 65) but, when used for other purposes, they are often provided with ringing-key combinations, that is, with a pair of make-and-break contacts.

In order-wire work, it is simply necessary for the operator momentarily to bridge her telephone set across the order-wire circuit, which is merely a pair of wires extending to another operator's telephone. The order-wire keys are usually mounted on an operator's key shelf at the left of the cord-circuit keys. In large multi-office exchanges these key shelves become very crowded and economy in the spacing of order-wire keys is thus a matter of importance.

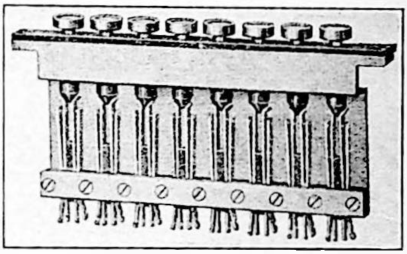


FIG. 155.—Strip of order-wire keys.

Relays.—Where it is not possible, convenient, or desirable to manipulate switches directly by hand as with various types of keys such as those just considered, relays are employed. A relay, in the sense in which the word is generally employed in telephony, comprises an electromagnet, its armature, and a switch controlled by the armature. It is an electromagnetic switching device.

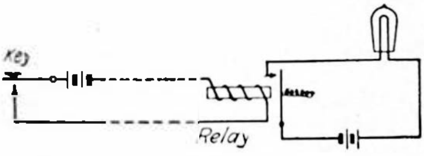


FIG. 156.—Action of simple relay.

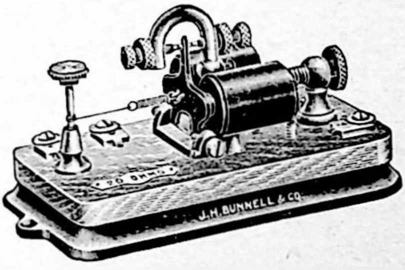


FIG. 157.—Morse telegraph relay.

One is illustrated in elemental form and function in Fig. 156. When the circuit of this relay magnet is closed, as by depressing the key shown at the left, the magnet is energized and attracts its armature. This closes the local circuit at the right and energizes the lamp, or whatever other device may be in this circuit with the local battery or other source of current. Obviously, by rearranging the relay contacts, the attraction of the armature may be made to break instead of make the local circuit, or by providing many contacts, variously arranged in different circuits, it may be made to break some and make others. Again, instead of the relay magnet being controlled directly by the manual operation of a key, as suggested in Fig. 156, it may be controlled indirectly as by a pair of contacts in another relay which may itself be energized as an incident to the operation of some other parts of the system.

An excellent example of simple relay action under direct manual control is that found in ordinary Morse telegraphy. Here the relay winding is directly in the line circuit which is controlled by the keys at the various stations along the line. The relay contacts in this case merely control a local circuit containing a local battery and a telegraph sounder. The common form of Morse relay is shown in Fig. 157. It will be recognized as the embodiment of the relay symbol of the preceding figure. This relay has a single armature pivoted in trunnions below and vibrating at its upper end between a forward and a back contact screw. The Morse relay serves its purpose admirably in telegraphy, where space requirements are not exacting and where the relay is needed to control only a single circuit. In telephony, however, its use is only incidental. One reason for this is that it takes up too much room in the restricted space available in telephone-switchboard work. Again, its design is not well adapted to the carrying of many contacts and to the relatively complicated switching functions which telephone-switchboard relays are often required to perform. Various types have been developed for telephone work that are much more compact and at the same time cheaper and more flexible as to the arrangement of their contacts.

In the switchboard relay, single-core electromagnets are mainly used on account of space conditions and cost. The practice of carrying the movable contact on a pivoted lever, as in the Morse relay, has been largely abandoned in the development of the telephone relay, partly because the carrying of the electrical circuit through the pivots involves some uncertainty of contact unless the pivot is shunted by a light coiled wire to assure continuity, and partly because the presence of trunnions or other pivoting devices causes mechanical complications that are difficult to manufacture and costly to deal with under exacting space requirements. Instead, the practice of using long flexible springs for the movable contact members has been developed. These play between the alternate contacts, also long flexible springs. For reasons already dealt with[1] these flexible springs almost universally carry contacts of some precious metal or alloy at their forward ends. The rear ends of the springs are usually allowed to project beyond their rigid points of support so as to provide suitable soldering terminals for the connecting wires. In this way, all pivots or joints between the movable part of the switch member and its stationary terminal are eliminated, the flexibility of the springs being relied upon to permit the necessary movement.

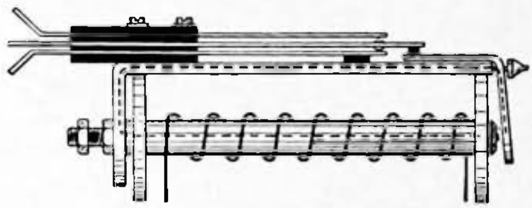


FIG. 158.—Typical switchboard-relay construction.

This general principle of relay construction is shown in Fig. 158. Although a single straight core is used, a magnetic circuit of low reluctance is provided by attaching to the rear of the core a strip of soft iron bent at right angles so that its free leg will extend parallel to the core throughout the length of the coil. Pivoted on the front edge of this strip is an angular armature of soft iron, the lower end of which lies opposite the front end of the core. An almost complete magnetic circuit is thus provided, the only air gap in it being that between the free end of the armature and the core end. Mounted on the back end of the flat core extension are the three contact springs insulated from each other and from the core, each provided at its forward end with a precious-metal contact and each adapted to register with the one on the adjacent spring. The center or longer spring extends over the rearwardly projecting end of the armature. Its contact point normally rests against that of the lower spring; but when the armature is attracted, the long spring is raised, breaking with the lower spring and making contact with the upper. Several such groups of springs may be carried on the top of such a relay.

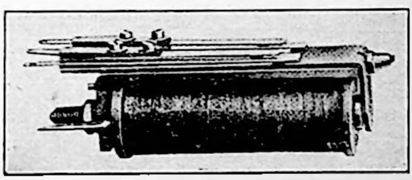


FIG. 159.—Kellogg switchboard relay.

[1] "Theory and Elements," Chap. XVI.

Commercial forms of this type of relay are shown in Figs. 159 and 160. In Fig. 159, which is the standard type developed by the Kellogg Company, the pivot for the armature consists merely of the knife-edge formed by the front edge of the core extension. The relay of Fig. 160 is that of the Stromberg-Carlson Company. In this the angle armature has a wire pivot, as shown.

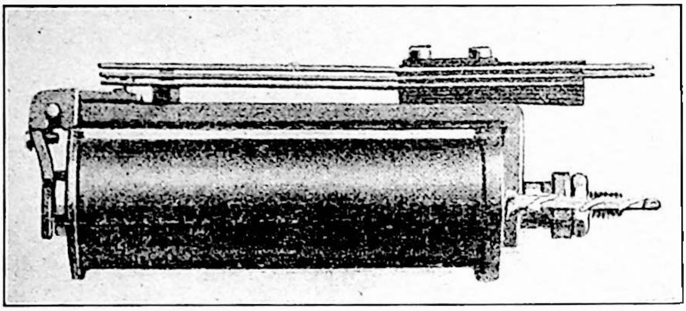


Fig. 160.—Stromberg-Carlson switchboard relay.

In both these types the arrangement of all stationary terminals, both of coil and contacts, at the rear end of the relay and of all the movable parts, such as the armature and contact points, at the front end, is to be noted. This is in accordance with the generally adopted practice. Such relays are usually mounted on heavy sheet-steel mounting plates, the screw-threaded end of the core extending through the plate and secured by the hexagonal nuts.

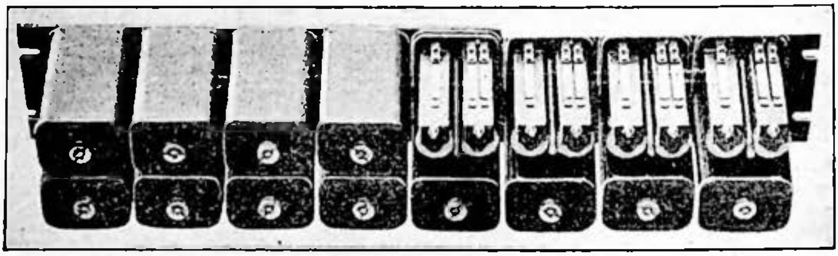


Fig. 161.—Strip of 32 Kellogg relays with enclosing shells.

The rearwardly extending terminals of both coil and springs extend through holes in these mounting plates and project considerably beyond, so as to be available for soldering the connecting wires. Figure 161 shows such a mounting plate carrying sixteen pairs of such relays.

Figure 162 shows one of many general types of relay manufactured by the Western Electric Company, of which Code Nos.

122, 149, and 178 are examples. Relays of this general design were once extensively employed in common-battery switchboards of the Bell System, but since the advent of the flat-type relay, to be described later, their use is now confined to circuits in which special requirements are to be met. The particular relay of Fig. 162 is the No. 122. It has a spool winding and a laminated core. The magnetic circuit is completed through the two L-shaped core extensions and the long flat armature which lies beneath them, the latter, when attracted, completely bridging the gap. One end of the armature is attached by a reed hinge of thin resilient metal to the rear core extension. The forward end, when not attracted, drops down against the adjusting screw which limits its back stroke. When the relay is energized, the end of the armature is drawn up against the under face of the forward core extension and by this movement imparts the necessary movement to the switching springs. Relays of this type are usually provided with individual cylindrical soft-iron dust covers which serve also as magnetic shields.

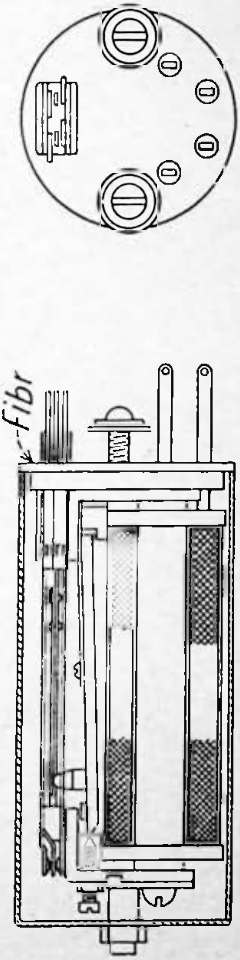


FIG. 162.—122-type Western Electric relay.

Most of the relays so far considered use cores made from round bars of magnetic material, and all of them use cylindrical coils. A type of relay invented in 1910 by the late Edward B. Craft, of the Western Electric Company, employs a flat core punched from sheet metal and a flattened coil. This is called the "flat-type" relay, and in its various forms it is more extensively employed by the Bell System than all other types combined. It is used in vast numbers not only in manual but in machine switching central-office equipments. Aside from its flat form, a distinguishing feature is that practically all its parts are punched from sheet material, a method of construction admirably adapted for very large quantity production.

The structural features of the flat-type relay will be understood from Fig. 163. The core is a T-shaped punching. The cross-bar of the T carries screw holes for mounting the contact springs and lugs for attaching the relay to the mounting plate. The stem of the T carries the winding, through which it projects a considerable distance to form one pole of the magnetic circuit. The armature is a U-shaped punching which lies in such relation to the core that the cross-bar of the T closes the open end of the U and the bottom end of the T overlaps the center of the lower side of the U. These two parts are flexibly held together at the rear by a strip of resilient sheet metal riveted to the cross-bar of the T and the ends of the U, forming a simple reed hinge between them. The center of the U, overlapping the free end of the T, forms the other pole of the magnetic circuit. The two poles are normally held a slight distance apart, but when a current traverses the coil the magnetic attraction draws them together.

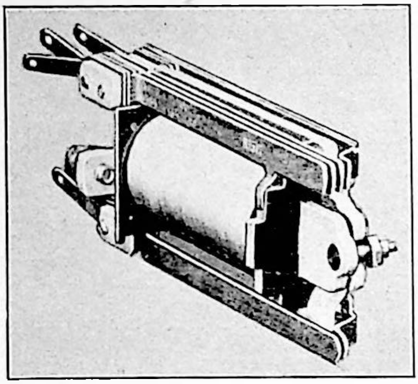


FIG. 163.—Western Electric flat-type relay. (*Courtesy of Bell Telephone Laboratories.*)

The contact springs are mounted on the base of the core punching (cross-bar of the T) and they project forward so that their free ends may be moved relatively to each other by the movement of the armature.

By this design a nearly closed magnetic circuit is secured in a very simple way and with great compactness of form by the use of only two pieces. The flux developed by the coil in the core divides in its return path through the two limbs of the U-shaped armature. On account of its flattened form and the use of both its sides for the purpose, the T-shaped core affords a maximum space for the disposal of contact springs.

Aside from the compactness, cheapness, and high efficiency which are attained by this design and by the choice of proper magnetic materials, this relay has a number of other advantages. Perhaps the principal one is the large number of spring contacts and the wide variety of contact combinations to which it lends itself. The fact that all of the spring contacts and the armature air gap are at the front end of the relay, where they are clearly visible, contributes to ease of inspection and adjustment; and the

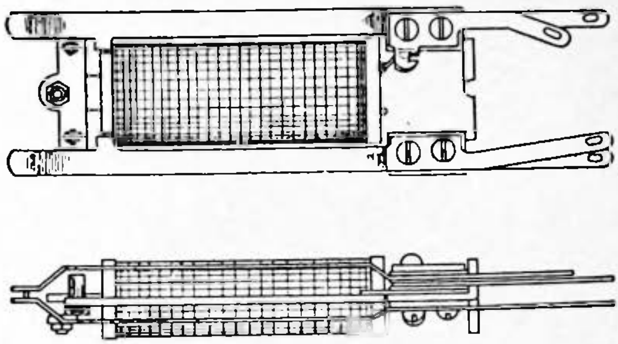


FIG. 164.—A-type relay.

fact that the springs and armature are all vertically disposed tends to allow particles of dust to drop out rather than accumulate on them. Of this general design, the Western Electric Company makes a number of types, some of which have numerous variations in minor detail. The relay of Fig. 163 is an

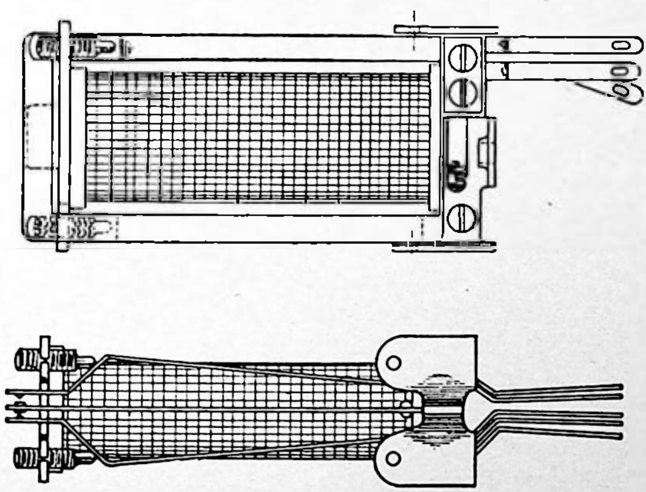


FIG. 165.—B-type relay.

example of the E type, and under this general code there are some three thousand varieties differing from each other with respect to the number and arrangement of spring combinations, the number, resistance, and impedance of their windings, and their speed characteristics. The subjects of spring combinations and speed characteristics (quickness or slowness of action) will be dealt with later in this chapter.

In Figs. 164, 165, and 166 are shown, in comparable form and scale, the general aspects of three of these principal types, the A, B, and E types, respectively. The A type is very compact. It is used in very large numbers in the line circuit of the common-battery manual switchboards of the Bell System. For this

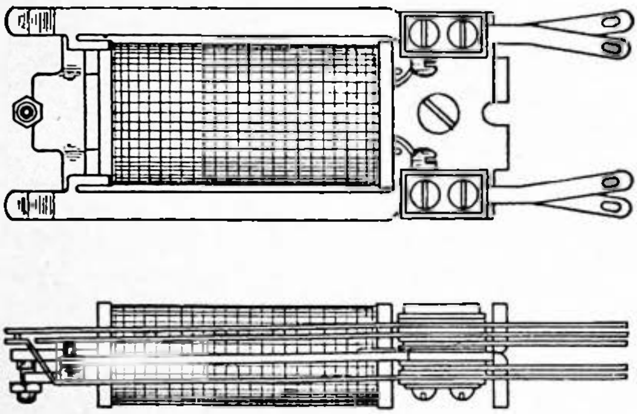


Fig. 166.—E-type relay.

purpose they are usually mounted in strips of twenty under a single dust cover.

The B-type flat relay (Fig. 165) has a micrometer screw adjustment for each group of contact springs, as clearly indicated. This permits of more accurate adjustment of the contacts than the more rough-and-ready method employed in the A type, in which the adjustment is attained by bending the springs. The B type is principally used in the cord circuits of common-battery manual switchboards. Since in this use its winding is associated with the talking circuit, means for preventing cross-talk between adjacent relays in different cord circuits must be provided. For this reason each relay of this type is usually provided with an individual dust cover which acts also as a magnetic shield. On this account it requires more mounting space than the A type.

The E type (Fig. 166) is somewhat more elaborate than either the A or the B type, but of similar mechanical construction. It is especially designed with respect to its adaptability for various combinations of spring contacts. On account of the adaptability in this respect, it is very generally used for a wide variety of purposes in both the manual and the machine-switching central-office equipment. It may be called the general utility relay.

There are a number of other families of flat-type relays. Among these is the H type which is similar to the E type but has laminated cores contributing to higher impedance. The G type also has laminated cores but, like the B type, is capable of more refined adjustment by the provision of micrometer adjustment screws for each set of contacts.

There is one disadvantage of the flat-type relay as it was originally designed. It takes more wire to go around a rectangular core than around a cylindrical one of the same area of cross-section. In later designs the Western Electric Company has avoided this and at the same time retained the advantages inherent in the general flat design by swaging the core after it is punched, so as to give it a substantially cylindrical form with exactly the same amount of metal. This is done while the metal is cold and, as a result, strains are set up in the core which would alter its magnetic characteristics but for the heat treatment that is given it before it is assembled and wound. This swaging of the flat core into a round one has resulted in the R-type relay, which attains the same performance characteristics as the E type, with something like 10 per cent less magnet wire, owing to the shorter periphery of the round core. The cost of the swaging and annealing operations is more than offset by savings in other directions. Besides the saving in wire, there is one of labor because a round core is easier to wind than a rectangular one. Moreover, the danger of injuring the wire on the sharp angles of the flat core is avoided.

The insulation employed in the construction of relays is of course an important element of design. In the flat-type relays of the Western Electric Company the insulation on the magnet wire is enamel. The papers used in the winding and in insulating the core are chosen for their chemical stability as well as their insulating and mechanical qualities. They are practically inert from the standpoint of electrolytic corrosion. After being wound, the coils are covered with a serving of cotton thread which is treated with bleached shellac, this covering forming a protection against abrasion and a seal against moisture. Phenol fiber is used for the spool heads and for the spring insulation. Relays insulated with these materials are able to stand much higher temperature than those insulated with silk, cotton, and hard rubber. Moreover, phenol fiber is much superior to hard rubber in its ability to withstand a wide temperature range without causing trouble due to expansion and contraction.

The contact springs are of nickel silver, often called "German silver." The contact points, of platinum or some of the recognized equivalent precious-metal alloys, are electrowelded to the springs. Two standard sizes of contact pairs have been adopted as shown in Fig. 167. Of these, the lighter ones are principally used in manually operated systems.

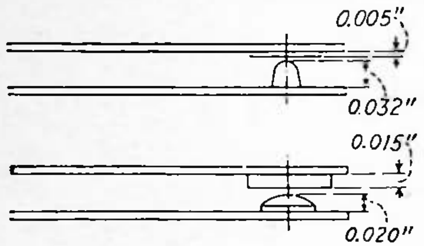


Fig. 167.—Standard sizes of contacts used on flat-type relays. (*Courtesy of Bell Telephone Laboratories.*)

Possible variations in the spring arrangement and contact grouping on relays are practically without number. In addition to the requirement that the relay shall merely make and break its contacts, the added one is often imposed that it shall make and break them in certain sequence, often an important consideration in circuit design. Figure 168 shows a few

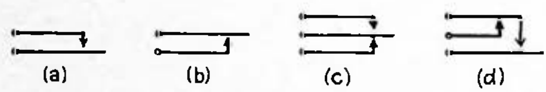


Fig. 168.—Elementary relay spring pile-up symbols.

elementary combinations in a single pile-up. In each case the long spring is the one that is directly moved by the armature. The ordinary designation of these combinations is: (*a*) single make, (*b*) single break, (*c*) single break-before-make, (*d*) single make-before-break.

In Fig. 169 are shown twenty-six of the spring combinations that are used on the flat-type relay. A single relay may carry any one or two of these twenty-six spring arrangements, thus making possible 377 different spring combinations by selection among these particular groups.

Another principal variant by which relays of the same general design may differ from each other is in the winding. Windings may be of few turns or many, of low or high resistance, of low or high inductance, and they may be si gle or plural. If plural, they may be arranged in any of the ways previously discussed.[1] Differential windings may be formed by laying the two wires on the core side by side, or the two windings may be separately wound, one inside the other (concentric) or one at each end of the core (tandem). Where there are two or more windings, one need not necessarily be designed to oppose the other. They

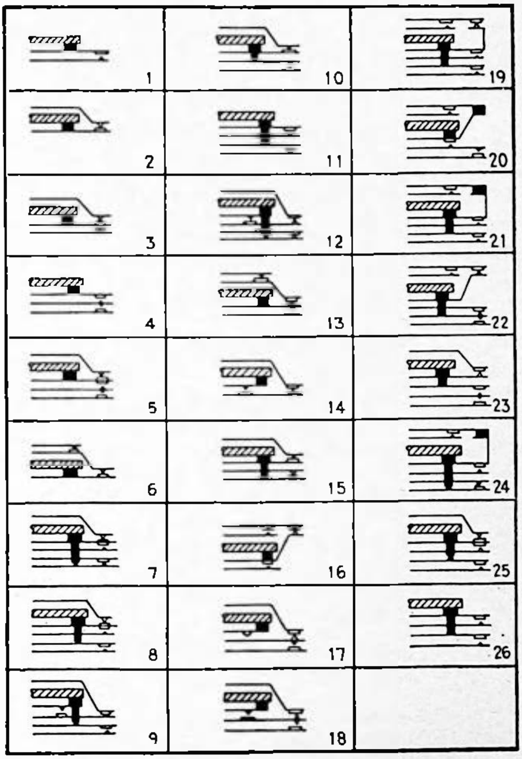


FIG. 169.—Spring combinations—flat-type relay. (*Courtesy of Bell Telephone Laboratories.*)

may act in different circuits or at different times, as when one winding acts to pull up the armature and another to hold it up after the first is de-energized.

Relays are usually made slow acting by placing a heavy copper sleeve over the core or a heavy copper slug on one end of it. In this case the sleeve or slug may be looked on as an additional winding of one turn. Variation in speed of relay action brought about by this means, or by changes in the form

[1] "Theory and Elements," Chap. XII, pp. 394–399.

and material of the magnetic circuit, is an important factor in telephone circuit design.

It is usual to employ direct current for energizing telephone relays, and all of the relays so far considered are adapted for such current. If the coils of these relays are energized by alternating or pulsating currents, their armatures are likely to chatter, particularly if the frequency is low, as in the case of ringing current or ordinary commercial lighting current. There are, however, some conditions under which it is desirable to operate relays by pulsating currents and by alternating currents throughout a wide range of frequencies. A relay

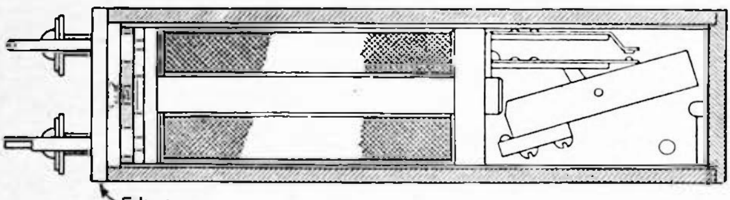


Fig. 170.—87-type relay for alternating currents.

designed for use on a 20-cycle ringing current, either pulsating or alternating, is shown in Fig. 170, this being the No. 87-type relay of the Western Electric Company. The armature consists of a heavy block of iron pivoted near its center so as to be slightly out of balance. When the relay coil is energized, the armature is drawn into a horizontal position in which it presses its two contacts together. On account of its large mass and its being only slightly out of balance, there is little tendency for it to fall back between impulses of current, and the contacts are held together in spite of current fluctuations.

A more modern way of assuring satisfactory relay operation on alternating currents is to bifurcate the pole end of the core and completely to surround one of the core branches with a copper ring. The magnetic flux is thus made to divide between the two core extensions, and on account of the copper ring on one of them the fluxes in the two paths are displaced in phase with respect to each other. This means that their zero values do not occur simultaneously and that, while the attraction due to the flux in either one of the branches is passing through zero, that in the other exists in sufficient degree to hold the armature attracted. This principle has been applied in the design of some of the flat-type relays, with the result that the relays work almost equally well on alternating and direct current.

In some cases it is required that a relay should be responsive to current in one direction only or, in other cases, to be oppositely responsive to currents in opposite directions. The ordinary polarized relay, or polar relay, of Morse telegraph practice, is an example. One of these is shown in Fig. 171, which needs little explanation. The armature plays between two electromagnet poles. A permanent magnet imparts one polarity to the armature and the opposite polarity to the two magnet poles, in much the same manner as is done in ordinary ringers. As a result, the armature will move in such manner as to close its contact only when traversed by a current in the proper direction, current in the other direction serving merely to hold it in its open circuit position: or it may close one contact for current in one direction and another for current in the other direction. Various forms of polarized relays have been devised, all based on this principle and many of them being mere adaptations of the polarized ringer structure.

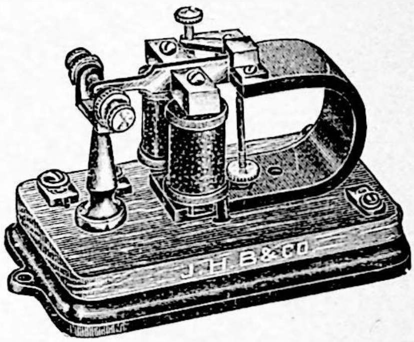


FIG. 171.—Polar telegraph relay. (*Courtesy of J. H. Bunnell & Co.*)

Since telephone lines are largely used also for telegraph purposes, polar relays specifically designed for telegraph purposes are often associated with telephone switching equipment. Since the number of these is much smaller than that of telephone relays, the space requirements are less exacting, and the matter of cost less important.

The small number employed makes it practicable to make these relays more readily interchangeable than in the case of telephone relays, a desirable feature aiding continuity of service under the difficult conditions under which telegraph relays must often work. In Fig. 172 is shown one of the telegraph-type relays of the Western Electric Company. This is merely plugged into a suitable jack or base provided with the necessary contact springs to connect it properly with the terminals of its circuit. The individual dust cover is to be noted.

The method of mounting and of providing dust protection of ordinary telephone relays is important. Figure 173 shows a

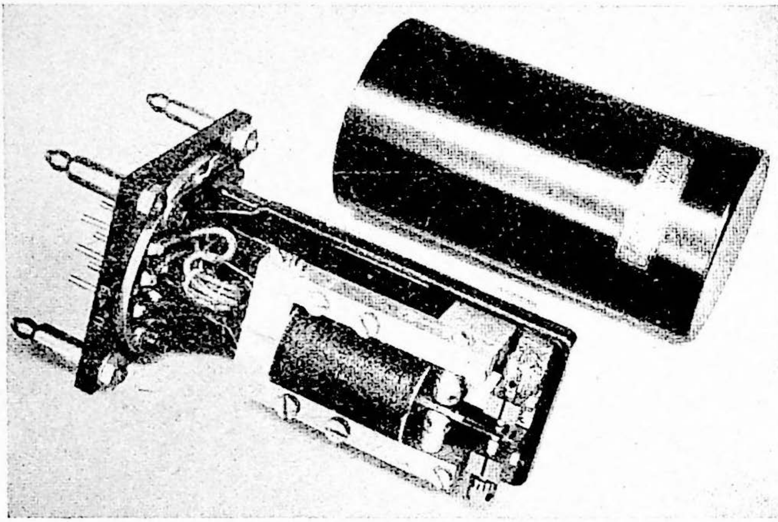


FIG. 172.—Polar relay. (*Courtesy of Bell Telephone Laboratories.*)

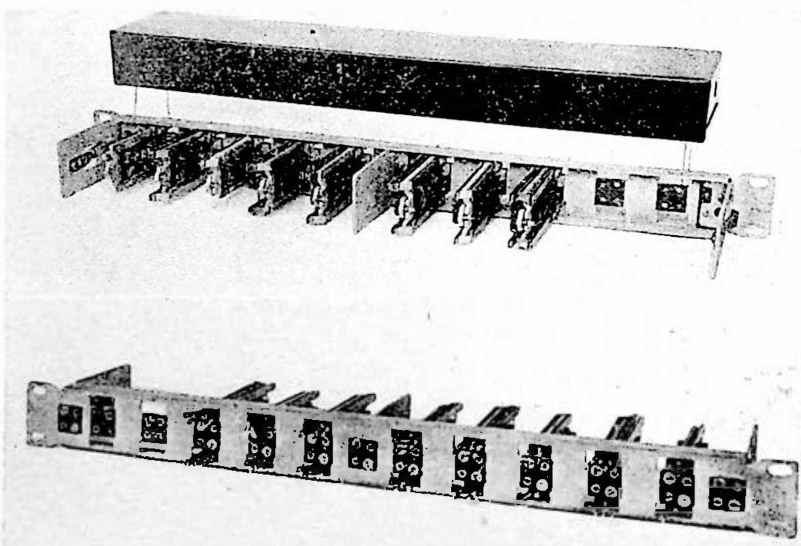


FIG. 173.—Strip of E-type relays with dust cover. (*Courtesy of Bell Telephone Laboratories.*)

strip of flat-type relays, with common dust cover, on a punched steel mounting plate ready for mounting on a switchboard frame or on a relay rack. The feature of design, already mentioned, of having all working parts of the relays on one side of the mounting strip and all wiring terminals on the other, is found here also. By this arrangement, after the relays have been assembled on the relay rack, all wiring is done on the back side of the rack, no wires extending to the front side. This is important from the standpoint of convenience and also because it reduces the liability of drops of solder or shreds of insulation falling into the relay contacts. It permits all inspection and adjustment of contacts and working parts to be done from the front side of the rack. It also makes possible the use of dust covers without interfering with the wiring.

A well-designed relay in good adjustment is an apparatus of remarkable reliability. Under proper environment it will work within its intended range of operation for millions of times without failure. A part of its proper environment, however, is as nearly a dust-free atmosphere as possible. Where dust is present in the atmosphere, some of its particles are likely to lodge between the contact points and prevent the proper closing of the circuit when contact is supposedly made. "Dust trouble" is one of the most elusive of telephone troubles. The practice is growing of using several pairs of contacts in multiple on certain relays which carry particularly heavy responsibility. The North Electric Manufacturing Company does this by bifurcating the free ends of its relay springs, each branch end carrying its own contact point.

The choice of individual covers, as indicated in Fig. 162, or of group covers, such as shown in Fig. 173, depends on considerations of circuit requirements and of cost. Where there is danger of cross-talk between adjacent relays, that is, where the relay coils are left associated with the talking circuit, individual covers are generally employed. They serve the double purpose of cross-talk and dust shields. The individual covers are, however, more expensive and somewhat extravagant of space. Where the cross-talk feature is not of importance, as is the case where the relay coils are cut out of the talking circuit, the group dust cover is advantageous because of its saving of both cost and space.

In cases where it is not necessary or convenient to enclose the relays individually or in small groups, the practice is often followed of mounting an entire bank of many relays in a dust-proof cabinet similar to that of an enclosed bookcase. This method is probably not quite so effective a dust preventive as the others, because larger air spaces involve more circulation of air, and, with any dust at all present, there is some possibility that it will find lodgment between the contacts. This objection is perhaps more theoretical than real, for in many cases relays merely enclosed in comparatively large closed cabinets are effectively guarded against dust.

In concluding this discussion of telephone relays, it is well to emphasize their importance in switchboard work. It may be pointed out, for instance, that in certain typical manual switchboards about 112 switch contacts are made and broken in the completion of a single call, of which number about 70

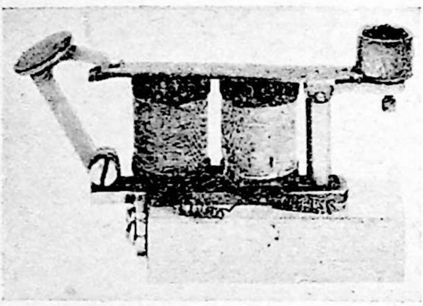


Fig. 174.—Early switchboard drop. (*Courtesy of Bell Telephone Laboratories.*)

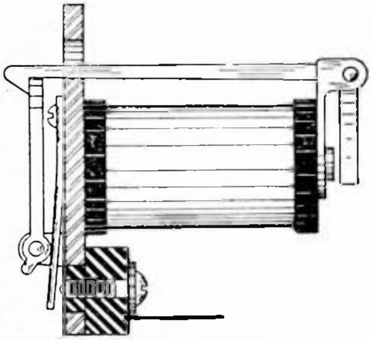


Fig. 175.—Simple switchboard drop.

are relay operated. In some automatic switchboards, as many as 2,000 switch contacts are opened and closed in the completion of a single call, of which about 1,200 are accomplished by relays. The importance of infallibility of operation is apparent.

Electromagnetic Signals.—We come now to the class of component switchboard apparatus that may be designated broadly as signals. These are of two general types, visible and audible. The former are of paramount, and the latter usually of secondary, importance.

Of the visual switchboard signals, the drop or annunciator was of earliest origin. The one shown in Fig. 174, a product of the historic shop of Charles Williams, Jr., in Boston, is of interest as showing how some of the early difficulties in switchboard design were met. The shot pan at the rear of the armature lever served as a variable counterweight to allow the sensitiveness of each drop to be adjusted to the characteristics of its particular line. The simple but antiquated type shown in Fig. 175 illustrates the principle of more modern drops. The armature, when attracted, simply lifts the latch and allows the pivoted shutter to fall forward to attract the attention of the operator. In falling, the drop presses the small spring lying just back of it into engagement with a contact screw and thus closes the circuit of an electric bell common to all the drops. This is the "night alarm" which serves as an auxiliary signal to audibly notify the operator that a drop has fallen. It is used in small exchanges at night, or at other times of little traffic when the operator may be absent from her position at the switchboard. In this arrangement we have a primary

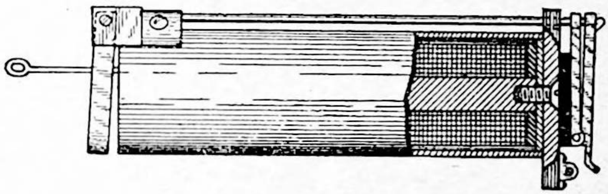


FIG. 176.—Tubular drop.

visual with a secondary audible signal. The drop is typical of a large number requiring manual resetting by the operator. On account of this feature, and also because it takes up too much room on the face of the switchboard, it is now little used.

Another type requiring manual resetting, still used to a considerable extent in small switchboards, is shown in Fig. 176. This is known as the "tubular drop," from the fact that the coil is included in a soft-iron tube which forms the return portion of the magnetic circuit and also serves to shield adjacent magnets from stray fields. Such types of drops are principally used as clearing-out signals in magneto switchboards. Since they are permanently connected in the talking circuit and necessarily mounted close together, the importance of magnetic shielding is evident. Such drops are commonly mounted in strips of five or ten, as shown in Fig. 177.

In order to economize the time as well as the mental and muscular effort of the operators, a type of switchboard signal has been developed by which the target is automatically restored as an incident to some other function necessarily performed by the operator. The function on which the restoring of the drop is usually made to depend is that of plugging into the jack in answer to a call. Two ways have been proposed for doing this—one electrical, the other mechanical. Of the two, the mechanical alone has survived in any considerable degree.

The electrically restored drop (Fig. 178) was provided with two electromagnets. The long one in the rear was responsive to signal currents in the line from the subscriber's magneto generator. When thus actuated, it unlatched a front armature which was heavy enough to displace the shutter by falling against

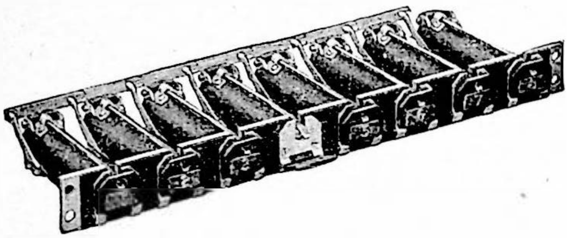


FIG. 177.—Strip of tubular drops.

it. The short magnet in front was in a local circuit, and when energized it drew the heavy front armature into its latched position, allowing the shutter to resume its normal or undisplayed position. An extra pair of contacts was provided on the switchboard jack to close this local restoring circuit when the operator plugged in.

This drop was one of the landmarks of switchboard development. It economized space on the face of the switchboard

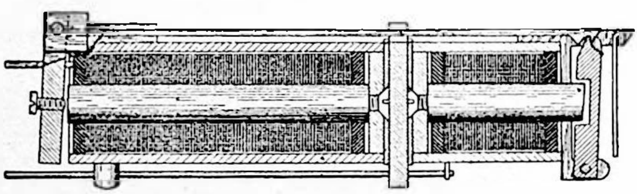


FIG. 178.—Electrically restoring drop.

by permitting the drops to be mounted above the reach of the operator so as to occupy none of the space of the jack field. This advantage, however, has quite disappeared, for the switchboard drop is no longer used except in small magneto exchanges where the number of lines is so small as to leave ample room for both drops and jacks within reach of the operator. Moreover, the removal of the drops to a more remote portion of the switchboard entailed a considerable strain on the operator in shifting her vision from the remote drops to the near-by jacks, and back again. It has been found to be a considerable advantage, where drops are used, to place each immediately adjacent to

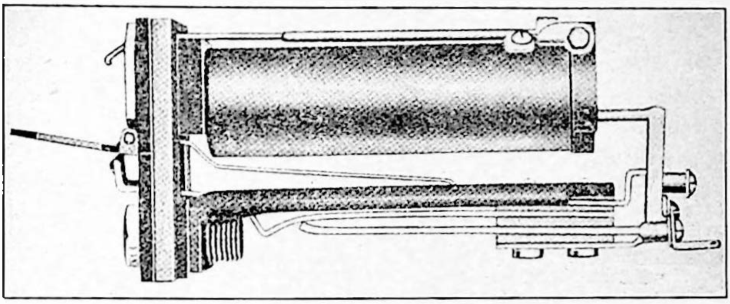


Fig. 179.—Kellogg combined drop and jack.

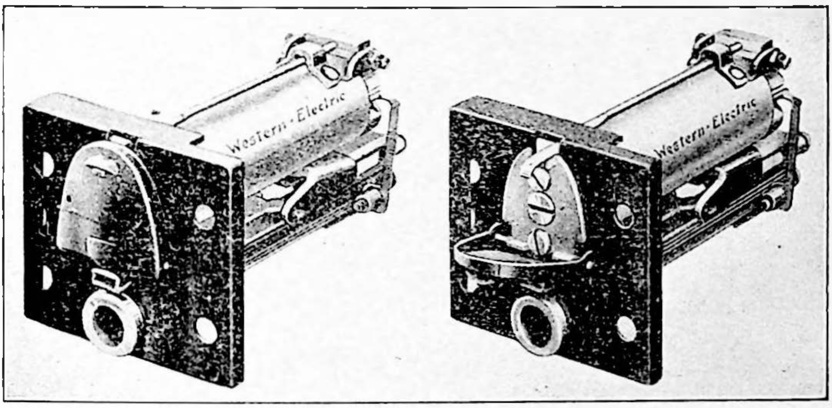


Fig. 180.—Western Electric combined drop and jack. (*Courtesy of The American Telephone and Telegraph Company.*)

its associated jack so that the falling of the drop at once attracts attention to the particular jack involved. This consideration pointed clearly to the mechanical method of restoration, made easy on account of the proximity of drop and jack.

Various methods of mechanical restoration have been proposed, but the principal ones that have survived involve the placing of the drop immediately above the jack in such manner that one of the jack springs, when raised by the insertion of the plug, will engage the shutter and restore it to its latched position. The pioneer combined drop and jack of this type was that of the Kellogg Company, originally designed by the writer. Its operation is made clear in Fig. 179.

Two views of the Western Electric combined drop and jack are shown in Fig. 180, and that of the Stromberg-Carlson Company in Fig. 181. In each of these the same principle of shutter restoration is employed.

This view of the Stromberg-Carlson drop and jack shows well several interesting features that are also to be found in different form in some of the Western Electric and Kellogg apparatus. A pair of contacts, *E* and *C* (Fig. 181), are controlled directly by the armature of the tubular-drop magnet. This provides for what is called a "code alarm" as distinguished from the ordinary night alarm. A bell or buzzer controlled by these contacts will respond to any code signals from the subscriber's generator, whereas the night alarms controlled by the shutter will respond but once and continuously for each falling of the shutter. The sleeve *S* of the jack is readily replaceable when worn out, being held in place by the nut *N*. The drop coil is bodily removable from its tubular iron shell by

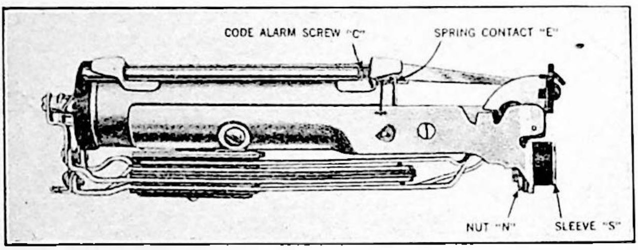


Fig. 181.—Stromberg-Carlson combined drop and jack.

loosening its screw terminal connections and withdrawing it from the rear. This permits the ready replacement of a burned-out or injured coil, or the changing of a coil in case one of different winding characteristics is desired.

Usually the clearing-out drops, associated with the cord circuits for the purpose of indicating the end of a conversation, are of the manually restoring type. One or two of them are permanently associated with each cord circuit and, in order that the signal may promptly identify the associated cord-circuit apparatus, it is customary to mount them in line with and just back of the corresponding cords and keys. The Stromberg-Carlson Company has taken advantage of this proximity by moving the clearing-out signals still closer to the keys and providing a mechanical link between them so that the operation of the listening-key lever will automatically restore the drops. This arrangement is shown in Fig. 182. The two signals and keys are thus built into a unitary piece of apparatus adapted for mounting on the operator's key shelf in the space usually occupied by the keys alone. As shown here, the lever in front controls the listening and the regular ringing key. The push-

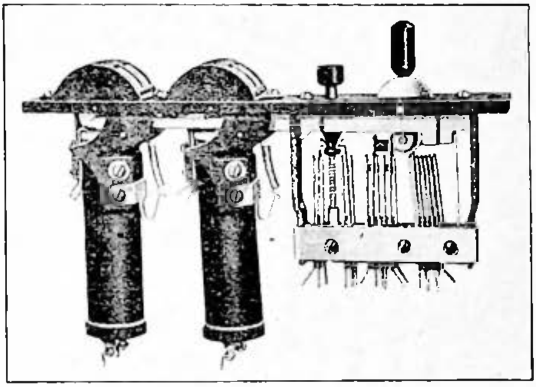


FIG. 182.—Self-restoring supervisory signals and keys. (*Courtesy of Stromberg-Carlson Telephone Manufacturing Company.*)

button key just back of it is the ring-back key, for ringing on the answering cord when required.

A type of visual signal somewhat different from the latched drop consists essentially of a light-weight target carried on the

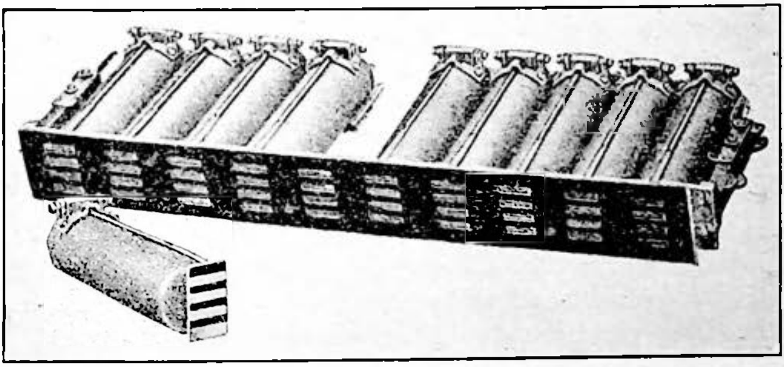


FIG. 183.—Magnetic visual signals. (*Courtesy of Kellogg Switchboard and Supply Company.*)

end of the armature lever, in such manner that the attraction and release of the armature will raise the target into a displayed position and lower it into a concealed position, respectively. This constitutes a self-restoring electromagnetic signal of the simplest type. A strip of them, with one detached, is shown in Fig. 183. In the particular signal here shown, the movable target is given a "gridiron" marking of horizontal stripes alternately of black and white. These register with corresponding openings in the black front strip. When the target is raised, the white strips are brought opposite the openings. In this way a fairly vivid signal is presented with a small movement of the target, but its effectiveness is somewhat marred by parallax.

Figure 184 shows a strip of twenty Western Electric (42-A) magnetic signals of similar type, but here the striped form of target is not used, the vertical movement of the target being equal to the height of the window. These have been commonly used as busy-indicators on Bell System toll switchboards. They mount on $\frac{7}{16}$-inch centers horizontally and are $\frac{7}{8}$ inch high.

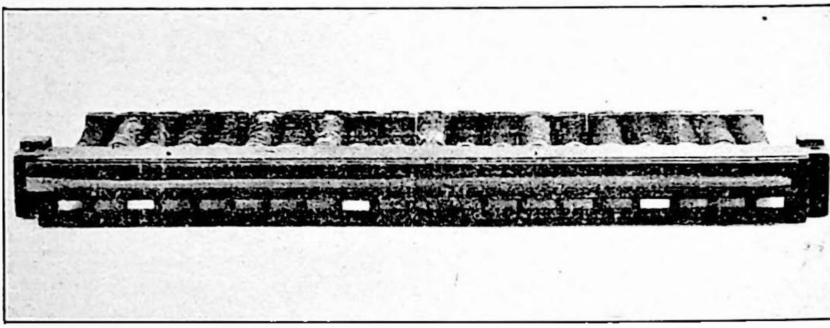


FIG. 184.—Strip of 20 magnetic signals. (*Courtesy of Bell Telephone Laboratories.*)

For some reason without apparent logic, signals of this general type have become known in the art as visual signals. They are, of course, visual signals, but no more so than any of the other mechanical signals that have been discussed or, for that matter, than the lamp signals which will be considered later in this chapter.

Message Registers.—A device, not properly classed as a visible signal but which nevertheless like the drop or magnetic signal gives visual information and forms an important element of switchboard equipment, is the message register. This, as its name indicates, is used primarily for automatically counting and registering the number of completed messages or local-exchange connections made in response to calls on a telephone line as a basis for billing the subscriber on that line. It has however many other uses, such as registering the total number of calls arising in the exchange or at each individual position, or the numbers of various other kinds of happenings, such as calls which fail for different reasons. What it is to count and register depends, of course, on how it is connected into the switchboard circuits.

In Fig. 185 a register is shown with its protecting cover removed and placed at the right. It consists of an electromagnet, an armature, and a train of registering wheels and gears driven by the armature through a ratchet. The armature is normally held against an adjustable backstop by means of a coiled retractile spring. The pawl pivoted to the armature engages any one of the ten ratchet teeth of the first wheel of the counter mechanism,

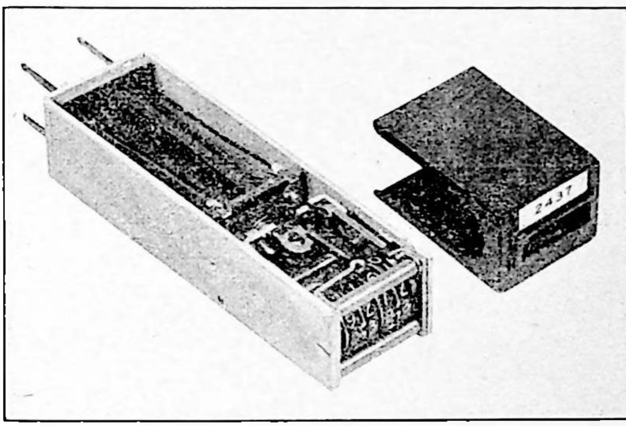


Fig. 185.—Message register. (*Courtesy of Automatic Electric Company.*)

which, upon making one revolution, moves the next wheel at its left one step and so on through the train. It registers up to 9,999. The protecting cover has a glass-faced window in front, through which the numbers on the counter wheels are plainly visible.

Lamp Signals.—The miniature incandescent electric lamp has largely superseded all forms of mechanical signals for attracting the attention of operators in large telephone switchboards. It has the advantage of being compact, cheap, easily installed, and replaced, and of being effectively self-effacing without any mechanical complications whatever. Moreover, being its own source of illumination it presents a more pronounced signal than any of the mechanical devices that have been employed for this purpose.

At first the lamps used for telephone purposes were adapted for screw sockets, the base being threaded after the manner of larger lamps for commercial lighting. It was not long, however, before this form was changed to one in which the lamp was provided with two contact plates arranged on opposite sides of the bulb, these forming the terminals of the filament and being adapted to slide between the cooperating terminals of the socket. On account of the similarity between these sockets and ordinary jacks, these lamp sockets are frequently called "lamp jacks."

Lamps when used as line signals are usually mounted on the vertical face of the switchboard, and when used as supervisory signals, on the horizontal shelf before the operator. In both of these locations, space must be conserved and therefore the lamp bulbs are made of small glass tubes about 5/16 inch in

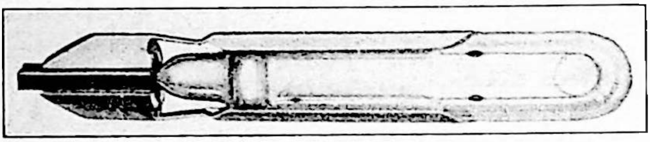


FIG. 186.—Switchboard lamp. *(Courtesy of Kellogg Switchboard and Supply Company.)*

diameter, the whole lamp being about 1¾ inches long. With this size of lamp the lamp jacks may be made small enough to conform to the ordinary jack-spring spacing.

A modern type of switchboard lamp is shown in Fig. 186. In older types the pointed tip, formed in the process of "sealing off" the bulb from the vacuum pump after exhaustion was in front, and tended to interfere with the illumination from that end. The lamp shown, being sealed off at its rear end, presents a smooth rounded front, not subject to this objection.

The external lamp terminals are of thin brass punchings shaped at their forward ends to conform to the cylindrical sides of the bulb. These are cemented in place, and the leading-in wires projecting through the glass are soldered to them. These punchings project considerably beyond the rear end of the bulb, the space between them back of the bulb being filled with a re-inforcing block of wood or lava, or sometimes with a kind of insulating cement that is poured in after the terminals are fastened to the lamp.

The voltages most commonly employed for switchboard lamp operation are 12, 24 and 48, the last two corresponding to the usual battery voltages in common-battery systems. Lamps of lower voltage than 24 are, as a rule, for use in those circuits where the lamp does not receive the full battery voltage owing to its being placed in series with other elements of apparatus.

The following tabulation shows the voltage and corresponding current consumption of some of the No. 2-type switchboard lamps of the Western Electric Company.

Code number	Voltage	Current consumption	
		Minimum amperes	Maximum amperes
2A	4	0.17	0.21
2B	4	0.27	0.31
2C	15	0.09	0.12
2E	20	0.09	0.12
2F	12	0.097	0.12
2G	24	0.075	0.115
2H	6	0.27	0.31
2J	24	0.0225	0.0375
2K	30	0.09	0.12
2L	10	0.24	0.26
2N	6	0.12	0.16
2P	8	0.085	0.10
2R	18	0.09	0.12
2T	35 to 37	0.025	0.0375 (35 volts)
2U	24	0.035	0.045
2W	18	0.035	0.045
2Y	48	0.028	0.036
2AC	18	0.18	0.30
2AD	36	0.18	0.30

While current and energy consumption of switchboard lamps is individually small, it becomes of some importance on account of the very large numbers of them that are used in a large central office.

Like nearly every other phase of telephone practice, the development of the technique of switchboard-lamp manufacture has been a slow and laborious process. Early lamps were erratic in their performance, particularly with respect to life and illumination. Obviously, long life and uniform high illuminating power are desirable. The switchboard lamp may now be counted on for an average life of over one thousand hours of effective illumination. The number of times it is turned on and off apparently has little effect on life. In some tests, switchboard lamps have been flashed some millions of times without serious signs of deterioration.

As in the case of line jacks, lamp sockets or jacks may be mounted individually or in strips. An individual socket is shown in Fig. 187. This passes through the supporting panel or board and is fastened in place by two screws from behind. The lamp is inserted from the front and afterwards covered by a "lamp cap" carrying a lens for diffusing the light. Individual mountings are principally employed on the plug shelves for holding the supervisory lamps associated with the cord circuits, and also on the vertical panels of the switchboard where they are used as "pilot" signals.

Where closer spacing than that permitted by individual sockets is required, lamp sockets are commonly mounted in

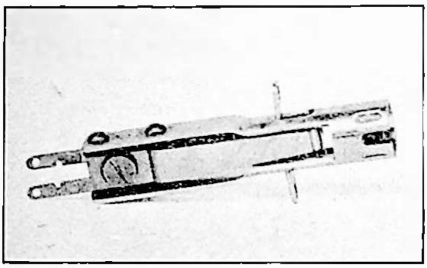


FIG. 187.—Individual lamp jack. (*Courtesy of Bell Telephone Laboratories.*)

strips of ten or twenty. Two types of lamp-socket strip, in each case for twenty lamps, as made by the Western Electric Company, are shown in Figs. 188 and 189. In the former the framework is of hard rubber, in the latter of metal. The rubber mountings are somewhat cheaper than the metal and each lamp, being in a separate compartment by itself, has its light effectively shielded from the openings on each side of it. They are, however, subject to the objection of possible overheating, with softening and warping of the rubber, under conditions where a number of lamps are likely to be burning at once for considerable periods. On the other hand, the metal mountings are not affected by heat and the sockets may be placed closer together. The horizontal and vertical spacing of the sockets in the strips shown is 7/16 inch for the rubber and 3/8 inch for the metal, thus matching the spacings of the No. 49 and the No. 92 jacks respectively.

Strip mounting is always used for line lamps, these appearing on the vertical face of the switchboard. Common practice is to make the spacing for line lamp sockets to correspond to the answering jack spacing, and to mount the answering jack

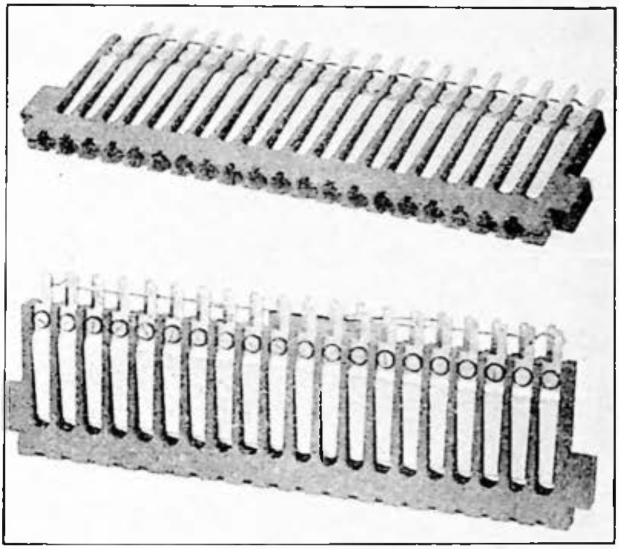


FIG. 188.—Strip of 20 lamp jacks—hard-rubber framework. (*Courtesy of Bell Telephone Laboratories.*)

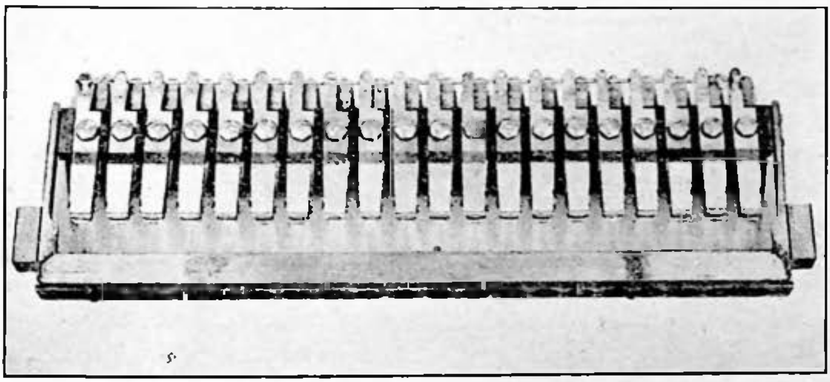


FIG. 189.—Strip of 20 lamp jacks—metal framework. (*Courtesy of Bell Telephone Laboratories.*)

strips and the line lamp strips alternately so as to place each lamp immediately adjacent to its corresponding answering jack. This has the advantage that the lighting of the line lamp will attract the attention of the operator directly to the answering jack into which she is to insert her plug.

In order to prevent direct glare from the light of the signal lamp and also to make the signal visible from a wider angle, an approximately hemispherical lens is, in many cases, placed directly in front of each lamp so as to close its socket opening. The convex side of the lens is outward, as shown diagrammatically in Fig. 190. Such a lens with its supporting metal ferrule is called a "lamp cap." The lenses for line lamps are usually clouded or opalescent, tending further to eliminate glare and also to permit various designating markings to be carried on the face of lens where this is desired. Lenses used in connection with supervisory lamps are commonly small, like those of line lamps, and they may be distinctively colored in case the characteristic nature of the signal is to be further emphasized. The lenses employed in connection with pilot lights are usually made much larger than those of the line and supervisory lamps in order to give them additional prominence. The fact that pilot lamps are few in number, and usually occupy relatively uncrowded space, permits this departure from the usual practice as to the size of the signal lights.

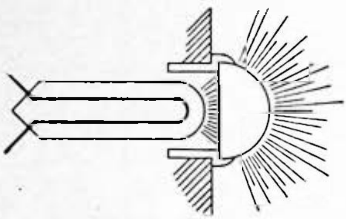


FIG. 190.—Diffusing lens in front of lamp.

In some cases, as in outgoing trunk and toll switchboards for instance, designation cards are associated with the lamp-socket strips. It was the former practice to provide "designation strips" just above the lamps to hold these. These, however, took up as much space on the face of the board as the lamp strips—a serious objection in boards of large capacity. Later a type of card and card holder was developed for mounting directly in front of the lamp strip so that it occupies no additional space in the jack and lamp field. The card is opaque except for small translucent spots spaced according to the lamp-socket openings. The lamps when lighted shine through these spots, instead of through a lens, and their signals are easily associated with the information printed on the cards.

Recent practice of the Bell System in this respect is the use of the combined designation strip and lamp-socket strip shown in Fig. 191. The face plate of the socket strip and the designation strip are the same. It is formed from a thick metal bar, the front of which has a channel with overhanging fins to hold the designating card. The lamps are removable through the front strip by removing its card. The front strip, being 5/16 inch thick, provides lamp compartments deep enough to prevent cross-lighting between adjacent lamps.

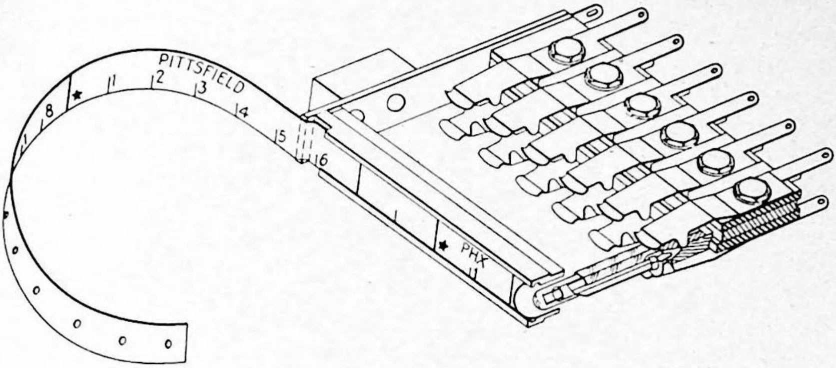


FIG. 191.—Lamp sockets with designation strips combined.

The upper part of Fig. 192 shows two such combined designation strips and lamp sockets mounted with two strips of jacks in the panel of a toll board as in the latest Bell practice. The lower part of this same figure shows, for comparison, the older

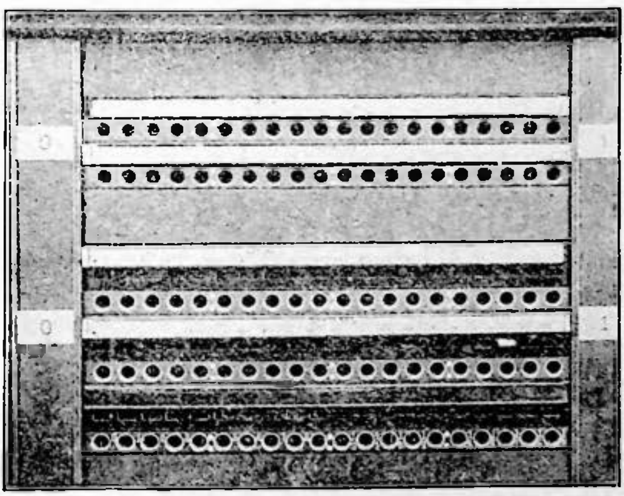


FIG. 192.—Comparative arrangements of jack, signal and designation strips on face of switchboard.

practice of associating jack and designation strips with strips of mechanical signals of the type shown in Fig. 184.

Audible Signals.—Of the audible signals used in central-office equipment, little need be said in addition to the discussion of ringers, battery bells, and buzzers, in Chap. II. Their use in connection with telephone switchboards is only incidental for two reasons: first, their noise, if extensively employed, would be objectionable; and, second, they are not well adapted to pointing out an individual object or happening from among many other similar ones. As an example of this inability to produce a distinguishing signal, it may be pointed out that the average person finds difficulty in distinguishing with certainty the sound of any one ringer in a group of three, even though they may be provided with gongs of radically different tones.

The night alarm, already referred to, is a good example of the use of an audible signal in telephone central-office work. In very small offices it permits the operator to retire during the periods of small traffic at night, relying on the audible signal to attract her attention, which the falling of a drop or the lighting of a line lamp would fail to do. Another use in central-office practice is that of giving an alarm upon the blowing of a fuse or upon the failure of some element of apparatus on which a large number of other elements are dependent. Either battery bells, or buzzers, or polarized ringers may be used, depending on whether the source of current to be employed is a battery or a source of ringing current.

Other important component parts of telephone switchboards, besides those treated of in this chapter, such as flexible cords, wires, cables, condensers, coils, and contacts were considered in the chapters of Part III of the preceding volume,[1] and still others will be dealt with in subsequent chapters relating to the different types of switchboards.

[1] "Theory and Elements."

CHAPTER VII

NON-MULTIPLE MAGNETO SWITCHBOARDS

We may best gain fundamental ideas of manual central-office equipment and methods of working by considering first the *simple* or *non-multiple* switchboards—that is, those switchboards in which each line is provided with but a single point of access or, in other words, a single jack. Such boards are adapted to serve directly only relatively small groups of lines, the reason for this limitation being as follows:

Where the amount of traffic (number of calls in a given time) is greater than can be promptly handled by a single operator, additional operators must be employed; and it is obviously desirable that each operator, without the assistance of others, may be able to complete any connection in response to any call she answers. This means that each operator must be able to reach a terminal for every line; and since each line has but a single jack, it follows that all of the jacks must be placed within an area that can be used in common by all the operators working at the board. The physical dimensions of the human operator not only limit the area over which she can conveniently reach but require that she have a certain amount of space (elbow-room) in which to work. The requirement that all of the operators use a common area, coupled with these physical considerations as to reach and elbow-room, means that not more than about three operators can efficiently work before such a switchboard. Even with this number, some awkward reaching, or passing of plugs, is required by the operator at either of the end positions in gaining access to the jacks at the other end of the jack field. For these reasons non-multiple switchboards are usually not provided with more than three operator's positions—two positions being a more desirable limit.

The number of lines that can be served by such a board depends altogether on the total amount of traffic that originates on them. Obviously the total traffic must be kept within the capability of the group or "team" of operators to attend to it. The limitation in the number of lines is thus due to the limitation in the number of operators that can reach a common jack field, and not at all to the number of jacks that might be placed within that field. Each operator can attend efficiently to only a certain amount of traffic. That is, she can answer and complete the connections for only a certain number of calls in a given time. The maximum traffic within the capability of the group of operators may arise on comparatively few lines having a heavy-average calling rate, or it may originate on a large number of lines having a low-average calling rate. The calling rate for each line will depend on the number of stations on the line and the individual calling rate of those stations. For these reasons no definite statement can be made as to the limiting capacity of a non-multiple switchboard expressed in the number of lines it may accommodate. Sometimes in rural districts with low calling rates as many as one hundred and fifty lines are provided for a single operator's position, and a magneto switchboard of three such positions would constitute about the limit of non-multiple boards under rural conditions.

This chapter treats of non-multiple boards of the *magneto* type, as distinguished from those of the *common-battery* type to be dealt with later. A magneto switchboard is one adapted to serve telephone lines that are equipped with magneto telephones. Since these telephones are provided with magneto generators, from which they derive their name, it follows that the signal-receiving devices of the switchboard must be of a type responsive to the currents of these generators. Also magneto telephones nearly always have their own local batteries and therefore the switchboard serving them needs no provision for supplying current to the substation transmitters. These are the two principal features of the magneto switchboard distinguishing it from the common-battery switchboard. The matter of current supply at the switchboard itself is thus reduced to its simplest possible terms: a small local battery for furnishing current to the operators' transmitters and a source of ringing current for actuating the bells at the substations.

We may consider the circuits of the magneto switchboard under three headings: line circuits, cord circuits, and common or group circuits. The line circuits are those individual to the subscribers' lines. Each usually comprises a drop for receiving the subscribers' signal and a jack for affording means of establishing connection with the line. The cord circuits are the links used in connecting the lines together in pairs for conversation. Usually each cord circuit comprises a pair of cords and plugs with ringing and listening keys and one or more supervisory signals.

Each line circuit and each cord circuit is a unit individual to itself. Associated with groups of each are certain "common" circuits. As examples, the circuit of the night-alarm apparatus is common to a group of lines; and the circuit of the operator's telephone apparatus is common to a group of cord circuits. The night alarm, common to a group of lines, serves to indicate audibly the fact that a signal has been displayed on some one of them. The operator's talking circuit, common to a group

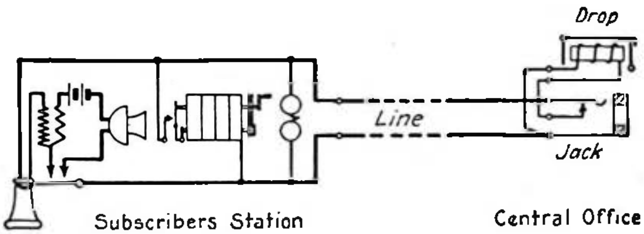


FIG. 193.—Magneto line circuit.

of cord circuits, may be connected with any one of them at the will of the operator to enable her to talk with a subscriber on the line with which that cord circuit is at the time connected. The distinction between individual and common circuits and units is to be kept in mind in the consideration of the circuits and apparatus of all kinds of central-office equipment, whether small magneto switchboards or any of the larger and vastly more complicated central-office switching systems.

A line circuit, stripped of detail, is shown in Fig. 193. The switchboard drop and jack at the right and parts of the complete subscribers' telephone set at the left are represented by their ordinary symbols. In order to simplify the understanding of the functioning of the apparatus, all auxiliary equipment, such as that employed in protection against electrical hazards, has been omitted.

The turning of the generator crank by the subscriber automatically connects this generator across the circuit of the line and sends out ringing current to actuate the drop at the central office. With the connection here shown, it will also incidentally ring his own bell. When the operator plugs into the jack in response to the signal, the lifting of the tip spring by the plug will open the circuit through the drop, thus freeing the line of the bridge circuit through the drop at a time when its signal is no longer required.

Figure 194 shows a typical simple magneto-switchboard cord circuit, comprising a pair of plugs and cords, a ringing key, a listening key, and a clearing-out drop. These parts just mentioned are individual to the cord circuit. The operator's telephone set and ringing generator shown are common to all the

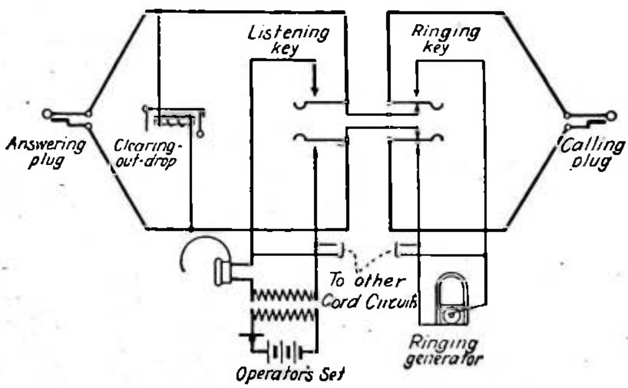


FIG. 194.—Magneto-switchboard cord circuit.

cord circuits of the switchboard position and, by means of the cord-circuit keys (listening and ringing), may be brought into operative relation with any individual cord circuit as required. Normally, the tip and sleeve strands of the two cords are so connected as to form continuous conductors between the two plug tips and the two plug sleeves respectively. The listening key, when operated, has no effect on the continuity of these tip and sleeve conductors, merely serving to bridge the operator's talking set across them. The ringing key, however, severs each of these conductors, cutting off the conductors of the answering plug before bridging the generator across those of the calling plug. The answering plug is the one used by the operator in initially making connection with the line in response to the display of a signal by a calling subscriber. It is the plug by means of which she *answers* a call. The calling plug, often called the "connecting plug," is the one used in connecting with the line of a called subscriber and the one used to send ringing current over his line to call him. One reason for so arranging the ringing key that it will cut off the answering plug before applying generator current to the calling plug is to prevent "ringing in the ear" of the waiting calling subscriber while ringing the bell of the called subscriber.

Bridged directly across the cord circuit is the clearing-out drop. This is for giving the operator a signal for disconnection at the end of a conversation. Since it must always be ready to receive such a signal, it must of necessity be left associated with the cord circuit during the conversation. Since it is bridged across the talking circuit, it is made of high impedance to prevent unduly short-circuiting the voice currents. Also, because it necessarily lies in close proximity to clearing-out drops of other cord circuits, it is made of the tubular type (Fig. 176), so as to avoid cross-talk between adjacent cord circuits. If no magnetic shield were provided in this or some equivalent manner, the magnetic field developed by the talking currents flowing in the coil of one drop would induce similar currents in the coils of adjacent drops, and conversation carried over a pair of lines connected by one cord circuit would be heard on other pairs of lines connected by other cord circuits.

A number of these cord circuits are provided for each operator's position, this number depending upon the number of calls originating on the lines served by the position and the average duration of the connections. Obviously, the number of calls originating on a line will depend on the number of stations attached to it and on the habits of the subscribers with respect to the frequency of their calling. The period of the conversation plus the time required by the operator to answer and complete a call and afterwards to take down the connection constitutes what is called the "holding time." This is one of the important factors in "telephone traffic." It is mentioned here in a preliminary way because it is one of the factors which determine the number of pairs of plugs and cords, *i.e.*, the number of cord circuits that must be provided for a given group of lines. Obviously, the number of cord circuits must be great enough to provide for the maximum number of simultaneous connections; and this in turn is dependent on the average calling rate per line and on the average holding time during the period of maximum activity. It is unsafe therefore to make a definite rule as to the relationship between the number of cord circuits and the number of lines. Frequently, in non-multiple magneto switchboards, cord circuits numbering 10 per cent of the line circuits are found sufficient to provide for the maximum number of simultaneous connections during busy periods. As stated, however, no general rule can be given without knowing the traffic conditions.

Before discussing switchboard circuits and operation in greater detail, it is well to gain some idea of the physical relationship and arrangement of the various apparatus elements in an assembled switchboard. For this purpose Figs. 195, 196,

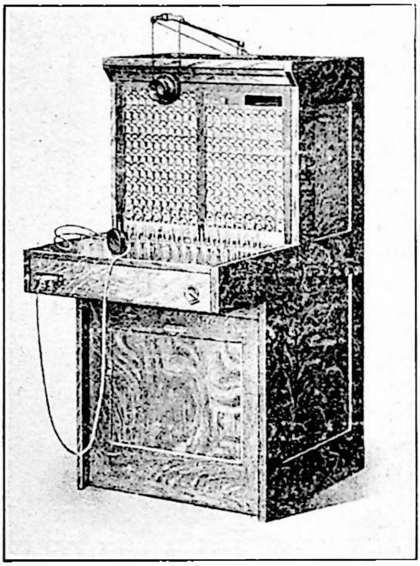


FIG. 195.—Magneto switchboard—general view.

and 197 are given. These are views of a single-position magneto board of the Kellogg Switchboard and Supply Company. Figure 195 is a general view showing the arrangement of the drops and jacks in the vertical face of the board and the plugs and keys on the horizontal shelf or table. The positions of the suspended operator's transmitter, the operator's receiver with its associated plug and jack, and the crank of the operator's magneto generator are clearly indicated. Figure 196 is a more intimate view of the face of the board and of the plug and key shelves. Figure 197 is a rear view of the same board, giving a general idea of the wiring and of the disposal of the switchboard cords and weights. The cords, as will be seen, terminate in a connecting rack back of the key shelf, and by means of the fixed terminals on this rack, the cord conductors are connected to the fixed wiring of the switchboard. From the connecting rack the cords pass down and then up to the plugs through holes in the plug shelf. A cord weight in the bight of each cord serves to hold the cord taut, guarding against their becoming entangled and at the same time allowing for the movement of the plugs over the face of the board. As shown in Fig. 196, two of the plugs are withdrawn from their normal seats for insertion in the jacks.

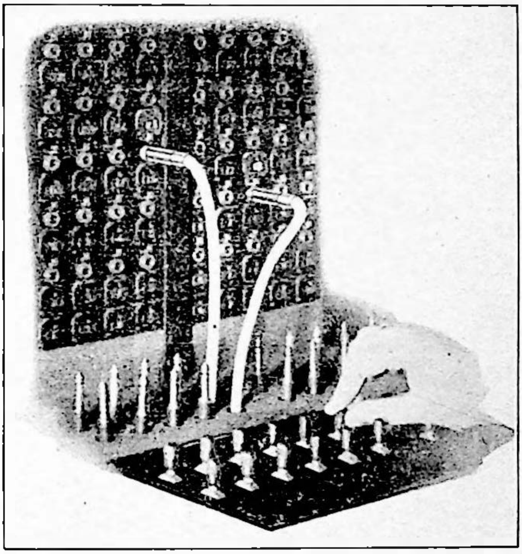


FIG. 196.—Magneto switchboard—face and key-shelf arrangement.

The key shelf is usually hinged at its rear edge, either directly to the plug shelf or to a horizontal rail in front of it, thus permitting ready access to the wiring, the contacts, and the mechanism of the keys. No movement is provided for the plug shelf because of its simple function and its ready accessibility from either the face or the back of the board.

This general arrangement of jacks and signals in vertical panels on the face of the board, and of plugs and keys on horizontal shelves at the base of these panels at convenient height for manipulation by the operator, has been found by long experience and after experimentation with other arrangements to be the most practical. It has now been adopted, with slight variations, in practically all manual switchboards.

To return now to the operation of the circuits of such a board: it has been shown in connection with Fig. 193 how the subscriber, desiring a connection, turns the crank of his generator and causes the corresponding drop on the switchboard to fall. Seeing the signal, the operator inserts the answering plug of an idle cord circuit into the jack. This may or may not restore the shutter, according to whether the drop is of the self-restoring type or not. In any event, it extends the connection from the two conductors of the line to the tip and sleeve strands of the cord

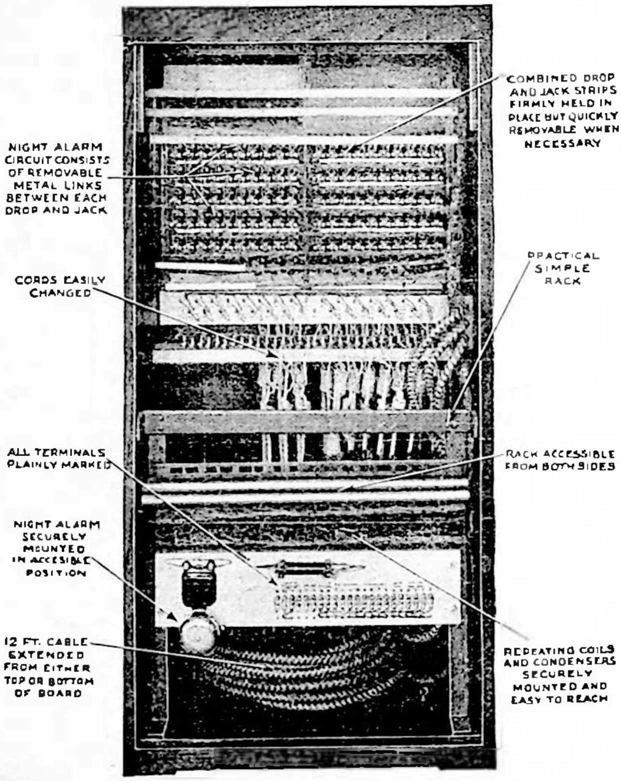


FIG. 197.—Magneto switchboard—rear view.

circuit, at the same time breaking the circuit through the drop The operator, having thrown the listening key of this cord circuit, has thus connected her telephone set across the extended conductors of the line. She is thus enabled to talk with the subscriber, who, after operating his generator, has removed his receiver from its hook. The circuit is now as represented in Fig. 198.

Having learned from the calling subscriber the number of the station with which he desires to communicate, the operator inserts the calling plug of the pair into the jack of the called line and presses the ringing key of that cord circuit. The circuit, with relation to the called line, now becomes that of Fig. 199. The insertion of the calling plug into the jack cuts off the drop of that line as in the case of the calling line. As

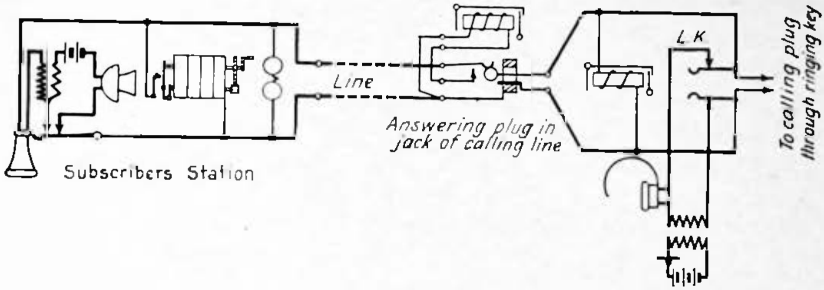


FIG. 198.—Magneto switchboard—operator answering on calling line.

a result, this drop will receive none of the ringing current sent out over the called line, nor will it interfere with the talking circuit later to be established.

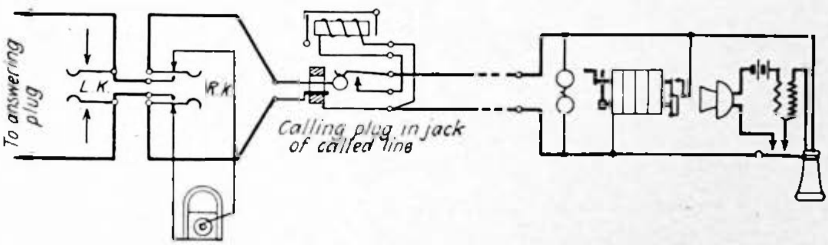


FIG. 199.—Magneto switchboard—operator ringing on called line.

The first thing accomplished by the operation of the ringing key was to cut off the answering end of the cord circuit so that the ringing current would not interfere with the calling

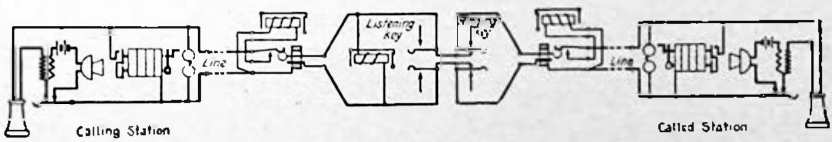


FIG. 200.—Magneto switchboard—two lines connected for conversation.

subscriber, the clearing-out drop, or the operator's telephone set. The further movement of the ringing key bridged the calling generator directly across the strands of the calling cord, thus sending ringing current through the ringer of the called subscriber who supposedly has not yet removed his receiver from its hook.

The release of the ringing key cuts off the calling generator and restores the normal continuity of the cord circuit. The response of the called subscriber by lifting his receiver places his talking apparatus in operative relation with the line. The circuits are now as indicated in Fig. 200. The talking circuit between the two stations is continuous, with no bridges across it at the central office save that through the clearing-out drop, which is left associated with the line to serve as a signal for disconnection.

If at any time while the lines are so connected the operator is in doubt as to whether the subscribers are still talking, or if either of the subscribers indicates that he requires attention, by means of the clearing-out drop, the operator by means of her listening key may bridge her telephone across the circuit and listen or converse with either of the subscribers.

At the close of the conversation, one or both of the subscribers, upon hanging up their receivers, are supposed to turn their generator cranks to display the clearing-out signal. If they fail to do this—which they frequently do—the operator must listen in to ascertain whether the conversation is still going on. Finding by either method that the connection is no longer desired, the operator pulls down the plugs, restoring them to their respective seats. The cord circuit is then available for use in establishing other connections. Also the withdrawal of the plugs from the jacks re-established the connection of the line drops with their respective lines, thus making them again available for indicating subsequent calls.

The line and cord circuits of Figs. 193 and 194, and the method of operation so far considered, while elementary, are typical of modern magneto non-multiple switchboard practice. They are, however, subject to variations, some of which are either necessary or desirable to meet different requirements or refinements of service.

One of the most common variations of the line circuit is that shown in Fig. 201, where both sides of the line drop are cut off by the insertion of the plug into the jack. This merely requires the employment of a double cut-off instead of a single cut-off jack. This complete severing of the drop from the line results in a more perfectly balanced condition of the line. Where one side of the drop is left connected as in Fig. 193, the electrostatic capacities of the two sides of the line are no longer exactly alike—resulting, theoretically at least, in a slight unbalance. This condition is unimportant in ordinary local-exchange service but may become of some moment in long-distance work. Even in local-exchange work, however, the leaving of one side of the drop connected with the line during a conversation may cause cross-talk between lines having adjacent drops unless the drop magnet coils are magnetically shielded. For this reason, and also because of the greater efficiency of the drop, it is now almost universal practice to employ drops of the tubular magnetic-shell type, such as indicated in Fig. 176.

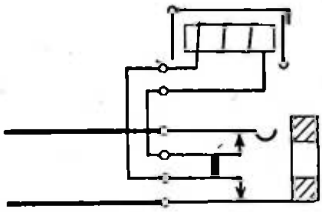


FIG. 201.—Magneto-switchboard line with double cut-off jack.

Other common modifications of the elementary magneto-switchboard circuits so far considered are: the placing of a repeating coil or other inductive separation between the answering and calling sides of the cord circuit, so as to connect them inductively rather than conductively; the employment of two clearing-out drops, one for each end of the cord circuit, responsive to the answering and calling lines respectively; and the employment of a ringing key for each end of the cord circuit, so as to permit the ringing on either of the two connected lines. These and other modifications will be more fully discussed when the details of specific switchboards are considered later in this chapter.

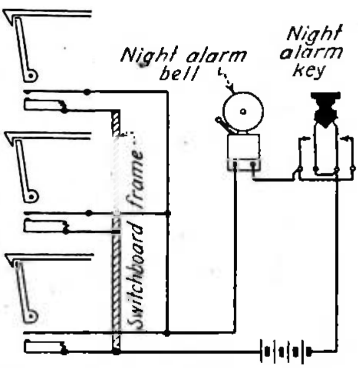


FIG. 202.—Night-alarm circuit.

Of the common or group circuits, the night alarm may be first considered. It is common to a group of lines and, as has been stated, is for the purpose of audibly informing the operator of the existence of a call even though she may not see the display of the visual signal. A common form is shown in Fig. 202. In this the light flexible spring, already considered in connection with Fig. 175, is directly associated with each drop in such manner that it will be depressed by the falling of the drop and thus brought into engagement with a contact connected with some common conductor, such as the metallic switchboard frame. All of these flexible springs of all the drops are connected together with another common conductor, normally insulated from the frame. Connected between these common conductors are the night-alarm bell, a source of current and a switch key. The result is that when any drop falls the two common conductors are electrically connected and remain so as long as the drop is down. As a result, the night-alarm bell is sounded, assuming of course that the circuit is not held open at the night-alarm switch. This switch may be of any type adapted merely to hold a circuit either open or closed, but in practice it is usually some standard form of locking key adapted to remain in either position until moved to the other. It is often mounted on the lock rail of the key shelf or in the upper part of the switchboard frame, and its function is to disable the night alarm during the day time or periods when the operator is seated at the board, and to make it effective during the night when her constant attendance at the board is not feasible.

With the ordinary night alarm just considered, the alarm sounds until the drop is restored and it gives no distinction as between calls intended for the operator and those which may be intended for another party on the same line. As pointed out in Chap. V, the distinctions between calls for different stations on a party line not equipped for selective ringing is ordinarily made by "code ringing"—that is, by a combination of long and short rings. An operator seated at the switchboard can usually distinguish such rings and determine their import by the rattling or buzzing noise made by the armature of the drop in response to the pulsations of ringing current. If the operator is not at her position, she does not have this guide, for the night alarm of Fig. 202 makes possible no such distinction.

To supply this deficiency, a modified alarm circuit is often employed in magneto switchboards. This, called the "code alarm," is shown in principle in Fig. 203. Here the alarm contact is closed by the movement of the drop armature instead of by the falling of the shutter. The drop is thus made to act as an ordinary relay and the bell or buzzer will follow whatever code is being rung by the subscriber.

A code-alarm circuit of somewhat greate refinement is shown in Fig. 204. In this, the local circuit, which is under control of the drop armature, contains a slow-acting relay instead of the bell or buzzer, and this relay in turn controls a second local circuit containing the bell or buzzer. This remedies a defect often found where the alarm circuit is directly controlled by the drop armature, for the drop armature is likely to "chatter" or rattle under the individual impulses of the ringing current and thus not hold its circuit closed continuously during either a long or a short ring. In the arrangement of Fig. 204 this will not occur, because the slow-acting relay will not release its armature during the momentary interruptions caused by the vibrations of the drop

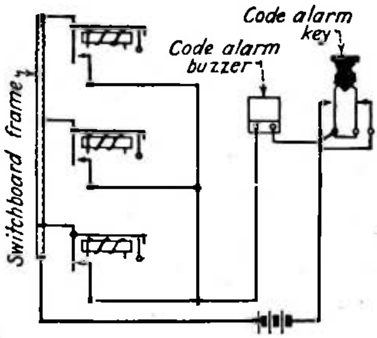


FIG. 203.—Code-alarm circuit.

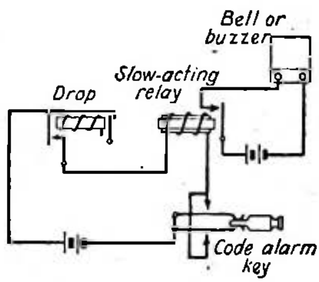


FIG. 204.—Code alarm with slow relay.

armature and will thus hold the buzzer circuit closed until the relatively long pause at the end of each ring.

Of the common equipment specifically related to groups of cord circuits, that for supplying current to ring the bell on the subscribers' lines and that for enabling the operator to talk with the subscribers are the most important. These are referred to respectively as "ringing equipment" and "operator's talking equipment."

Considering first the ringing equipment: the ringing generators shown or suggested in the various cord-circuit diagrams may be of any type producing the desired alternating or pulsating currents of the proper voltage, strength, and frequency for actuating the substation ringers.

In magneto switchboards, a hand-operated magneto generator is usually mounted in each switchboard position, the shaft projecting through the lock rail of the key shelf and terminating in a crank, shown in Fig. 195, conveniently located for hand operation. In very small switchboards, this is sometimes the only source of ringing current, but usually some sort of constantly operating source is provided for regular use leaving the hand generator available for emergencies. Often these constantly operated ringing machines consist of small alternating or pulsating current generators constantly driven by alternating-current motors. In other cases, in magneto exchanges, the common source of ringing current is one of the so-called "pole changers." These derive their energy from primary batteries, a constantly vibrating reed serving to commutate the current in such manner as to produce in it the rapid succession of alternations or pulsations as required by the character of the bells to be rung. This whole question of ringing generators will be more specifically dealt with in later chapters. It will suffice at this point to say that these sources of ringing current in magneto exchanges are common to all positions of the switchboard, where more than one position is involved, and that they are usually provided in duplicate so that if one breaks down the other may be brought into service, thus avoiding as far as possible recourse to the hand generators.

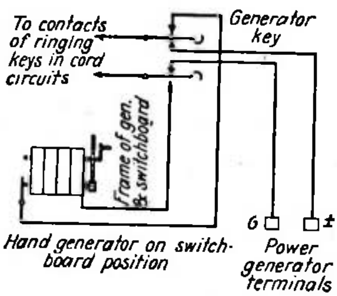


FIG. 205.—Magneto-switchboard generator circuits.

A typical ringing generator circuit is shown in Fig. 205. A generator key, common to the position, affords means for changing from the office power generator to the hand generator of that position. Ordinarily this key is kept in the position shown connecting the terminals of the power generator with the common wires leading to the back contacts of all the ringing keys on that switchboard position, so that the operator need pay no attention to her hand generator. If, however, the power generator is disabled, the generator key is thrown to its alternate position, thus making the hand generator available for use.

Figure 206 shows a typical operator's talking circuit. At the right, the listening key of one of the cord circuits is shown, and it is to be remembered that the common parts of this talking circuit would be wired to each of the other listening keys of the same position in exactly the same manner. The wires branching off to other listening keys are indicated at x, x, and y, y. The operator's talking circuit may thus be brought into proper relationship with any one of the cord circuits by merely throwing the corresponding listening key.

The operator's circuit of this figure is arranged for a breast-plate transmitter and therefore, since the transmitter as well as the receiver is to be carried on the operator's person, the operator's cord, plug, and jack must each have four conductors—two for the transmitter and two for the receiver. If the suspended type of transmitter, like that shown in Fig. 195, were employed, the switchboard ends of the transmitter cord could be attached directly to the fixed wiring of the switchboard, as by connecting them to the points z, z of the local circuit. In this

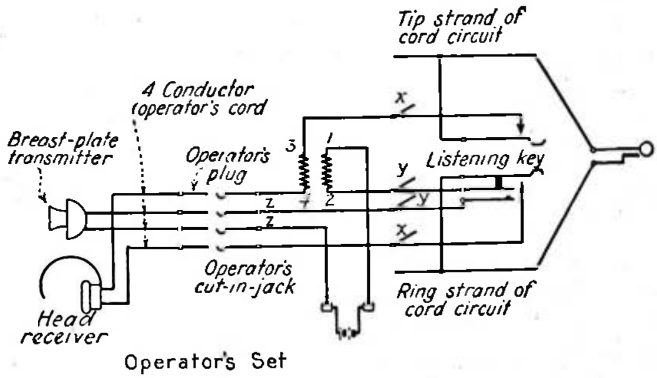


FIG. 206.—Magneto-switchboard operator's circuit.

case a two-conductor cord, plug, and jack would suffice for connecting the portable part of the operator's set.

To avoid constant drain on the operator's battery while her set is attached, each listening key is provided with an additional pair of normally open contacts through which the local circuit of the transmitter extends. As a result, when all the listening keys are open, no current passes through the transmitter. When a large storage battery is available for supplying the transmitter current, this economizing of current by battery contacts on the key is not so essential, but in small magneto exchanges dry cells are usually relied on for operator's transmitter current, and it is only by some such provision that a reasonable life for these cells is to be secured.

Analysis of the operator's circuit will show that, reduced to its simplest terms, it is the ordinary local-battery talking circuit, such as employed in magneto substation sets. The battery, transmitter, and primary of the operator's induction coils are connected in a local circuit, while the receiver in series with the secondary of the induction coils is adapted to be connected across the two sides of the line.

One of the common modifications of the simple magneto cord circuit of Fig. 194 is formed by the addition of a so-called "ring-back key," as shown in Fig. 207. The ring-back key is

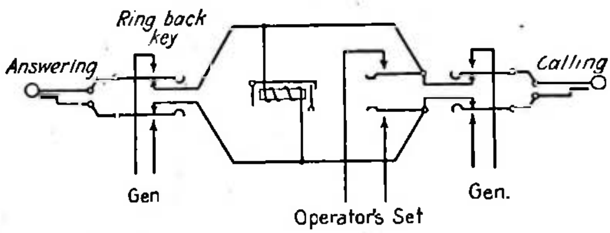


FIG. 207.—Magneto cord circuit with ring-back key.

merely a second ringing key associated with the conductors of the answering cord in exactly the same manner as the regular ringing key is associated with the conductors of the calling cord. This added key enables the operator to ring back on the calling line, as it is sometimes necessary to do. Without it the operator would be required to withdraw the answering plug from the jack of the calling line and insert the calling plug in its place.

In many cases it is desirable to separate the answering and calling ends of a cord circuit by means of a repeating coil, as in Fig. 208. The two ends are thus inductively connected but conductively separated. In this cord-circuit diagram, as in a number of others that will follow, the fairly obvious ringing and listening key and signal connections are omitted for greater clarity of the particular points under discussion.

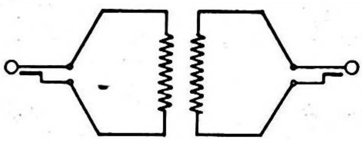


FIG. 208.—Repeating coil in cord circuit.

One use for the repeating-coil cord circuit is found in exchanges serving both metallic-circuit and grounded lines—a requirement still surviving in some rural districts, although fortunately extinct in many. With the repeating coil in the cord circuit, a grounded line may be connected to a metallic line without grounding one side of the latter and throwing it out of balance. A connection between a grounded and a metallic-circuit line in this manner is shown in Fig. 209. Such a connection is not ideal, but it is the best that can be done where grounded lines exist. There is no practical way of freeing a grounded line from inductive noises if it is within the inductive influence of power or telegraph circuits or of other grounded telephone circuits.

Many of the troubles inherent in grounded lines are accentuated when the wires of a number of them are bunched together in a cable. The proximity of the wires greatly increases the likelihood of inductive interference between them. When it is necessary

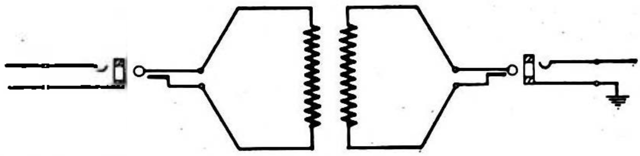


FIG. 209.—Connection of metallic to grounded line through repeating-coil cord circuit.

to place the conductors of grounded lines in cables in their approach to the central office or within the office, each grounded line should be given a separate twisted pair in this cable. This provision is indicated in Fig. 210, the grounded line conductor coming into the office over one wire of a cable pair, the return path being out over the other wire of the same pair to ground at the outer end of the cable. By treating all grounded lines as if they were metallic, in passing through the switchboard and entrance cables, the cross-talk and other central-office inductive

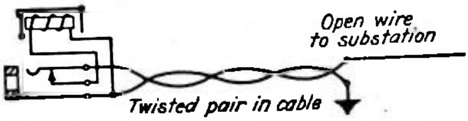


FIG. 210.—Connecting grounded line to switchboard through cable pair.

disturbances which would arise from the congested wires is largely eliminated. The cross-talk arising from the proximity of the single wires beyond the cable and the other noises arising by either conduction or induction along the path of the single-wire line beyond the cable will not, however, be lessened.

The use of the repeating-cord circuit is not restricted to switchboards serving grounded lines. In most magneto offices, even though all the lines are metallic, some of the cord circuits are of the repeating-cord type. The principles governing their use, where metallic-circuit lines only are involved, are the same in kind as those where metallic and grounded lines are to be connected. Either by design or by accident—usually the latter—some of the metallic-circuit lines are likely to be partially grounded—and more so on one side than the other. Or one side of a metallic line may have greater capacity to ground or to other lines than the other side. Such a line is said to be "out of balance." Disturbing effects from outside sources in its two limbs do not exactly neutralize each other as should be the case in a properly balanced metallic line.

The direct conductive connection of an unbalanced to a balanced line serves to unbalance the latter. A long-distance line, passing through highly inductive territory, may be quiet when well balanced but will be noisy when unbalanced. The repeating-coil cord circuit is used when it is necessary to connect balanced lines with lines more or less out of balance and is

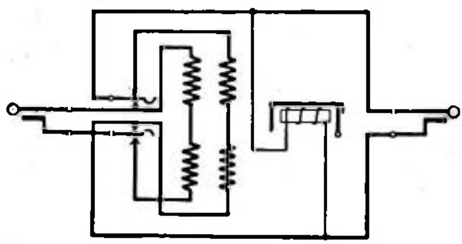


FIG. 211.—Convertible cord circuit.

particularly valuable in connecting long lines that are in good condition with short local lines that are in poor condition or are unbalanced for some other reason.

With all lines metallic and all in well-balanced condition, the simple cord circuit of Fig. 194 is the most efficient as far as the transmission of voice currents is concerned. If, however, the lines to be connected are not in good condition, and particularly if a long good line is to be joined to a poor short one, then the repeating-coil circuit of Fig. 208 is likely to be much better.

In order readily to change from the conductive to the inductive type of connection, the so-called "convertible" cord circuit has been devised and frequently a few of the cord circuits on each position on a magneto switchboard are of this type. The principle of the convertible cord circuit is shown in Fig. 211. A tracing of the circuit will show that when the converting key is in one position the tip and sleeve strands of the cord are cut straight through, forming continuous conductors from one plug to the other. In the alternate position of the key each strand of the cord circuit is severed, the gap thus created being bridged inductively by the induction coil. The condition then becomes that of Fig. 208. The operator when using one of these cords may thus change from one condition to the other without withdrawing the plugs of one cord circuit and inserting those of the other type.

So far, the discussion, with respect to the straight-through *versus* the repeating-coil type of cord circuit, has been with regard to talking conditions. Signaling conditions are also involved in relation to the clearing-out or supervisory signals. The objections with regard to signaling that may be urged against the simple cord circuit of Fig. 194 are, first, that the signaling current sent by one of the connected subscribers may operate the bell or bells at one or more stations on the other line and, second, that since there is but one signal the operator cannot tell which subscriber has sent it and, therefore, which of them desires attention.

With the simple straight-through type of cord circuit, the ring-through difficulty may be lessened by making the clearing-out drop of comparatively low resistance but highly reactive, with the idea that the drop will so shunt the signaling currents as to prevent their passing to the other line with sufficient strength to ring the bell. To make this really effective, however, there is likely to be an undue loss in voice transmission. Moreover, this does not solve the problem of providing two separate clearing-out signals, each responsive to currents from the line with which its plug is connected.

Evidently the requirements for double supervision are the same as those for the avoidance of through-ringing. What is needed is a cord circuit for maximum voice-current transmission and minimum signal-current transmission. The repeating coil lends itself to this purpose, if it is designed for good talking and for poor ring-through efficiency. In the repeating-coil cord circuit of Fig. 208, or the convertible one of Fig. 211, two clearing-out drops may be used, one bridged across each end of the circuit, with the intent that each drop will respond only to clearing-out signals from the line to which its plug is connected. This arrangement, however, is not wholly satisfactory. The shunting of the drops by the repeating-coil windings renders the drops less sensitive. Also, some of the ringing current will be transmitted inductively through the repeating coil which may possibly cause the display of both signals.

Another plan for a double-supervision and non-ring-through cord circuit is to separate the two ends of the cord circuit by small condensers and to bridge a clearing-out signal across the circuit on each side of the condensers, as shown in Fig. 212. This presents about the same objections as the plan just referred to. Unless the condensers are made so small as to interfere with proper talking efficiency, there will be some uncertainty as to whether one or both of the clearing-out drops will fall. This arrangement does not solve the problem of connecting grounded to metallic lines, or faulty lines to good lines, as well as those employing repeating coils.

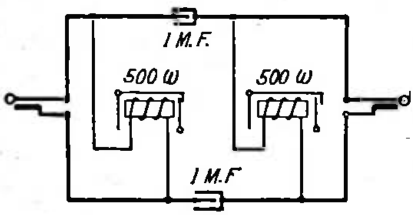


FIG. 212.—Double-supervision cord circuit.

Another cord circuit of the double-supervision and non-ring-through type, shown in Fig. 213, employs a combination of repeating coil and condensers. Here the condensers help to

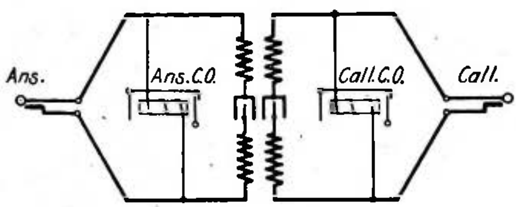


FIG. 213.—Double-supervision cord circuit.

prevent the undue short-circuiting of the drop by the repeating-coil windings, at the same time permitting the voice currents to flow. This circuit meets the requirement for connecting grounded and metallic circuits employing repeating coils.

Another variation using a combination of condensers and repeating coil is shown in Fig. 214. This circuit has been widely and successfully used in the No. 105 magneto switchboard of the Stromberg-Carlson Company. Here all shunting effect of the clearing-out drop winding with respect to the voice-transmission efficiency is avoided, and a drop winding of as low impedance as is necessary for ring-down purposes may be employed without affecting the speech transmission.

It will have become apparent from the foregoing discussion of magneto cord circuits that, even in the comparatively simple conditions of magneto switching, no one type of cord circuit can be considered as best adapted for all purposes. A cord circuit which meets the non-ring-through requirement must inevitably have some loss in voice-transmission efficiency. If the conditions are such as to demand the highest efficiency of voice transmission, then something must be sacrificed with respect to the non-ring-through requirements. As a rule, well-designed cord circuits of the non-ring-through and double-supervision type afford sufficiently good speech transmission for all

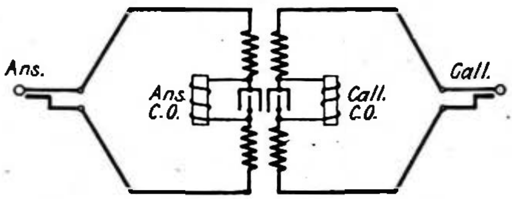


FIG. 214.—Double-supervision cord circuit.

ordinary local connections. But where long-distance connections are involved, requiring perhaps the utmost in speech transmission, then conveniences accessory to the cord circuit may be sacrificed in order to gain the nearest approach to the simple cord-circuit connection of Fig. 194. Accordingly, it is often desirable to provide in each position of the switchboard a few cord circuits of the convertible type, so that in case of long-distance connections they may be changed best to meet the talking requirements of the particular connection involved. In case both of the lines to be connected are well balanced and insulated, the simple straight-through connection without repeating coil is likely to be best; but where one or both of the lines are faulty, the introduction of the repeating coil is likely to improve the connection.

The magneto-switchboard practice of the Bell companies in the United States has tended to follow lines of almost extreme simplicity. That of the independent companies, on the other hand, has tended toward the employment of refinements and labor-saving devices even though it involved a considerable increase in complexity. We may profitably consider a specific example of each of these practices.

Taking first the simpler practice: a general front view of one of the single-position upright magneto switchboards that has long been standard for use in small rural exchanges of the Bell companies is given in Fig. 215. Another view from the side is shown in Fig. 216. The legends on Fig. 215 serve to identify the various parts of the apparatus as they appear on the face and shelf of the board. The face equipment here shown

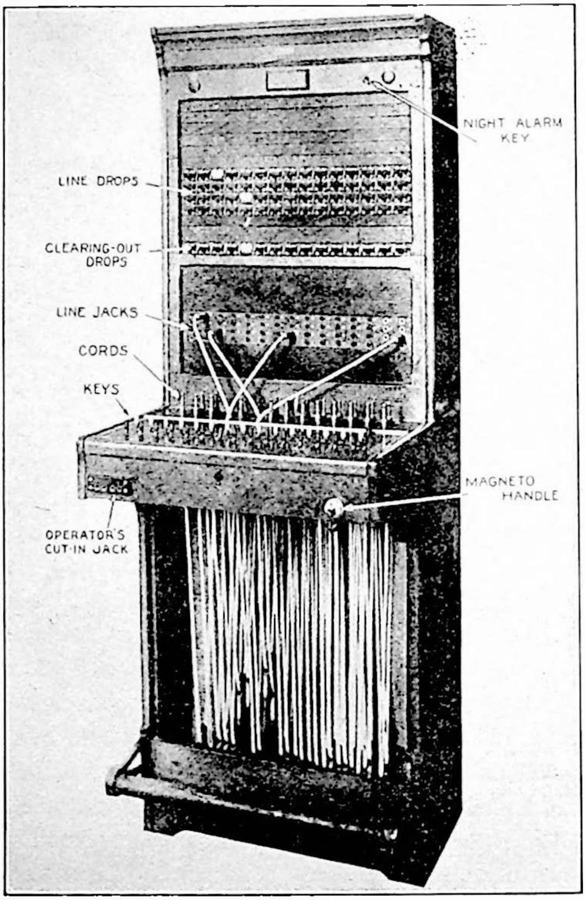


FIG. 215.—Bell-type non-multiple magneto board—front view. (*Courtesy of The American Telephone and Telegraph Company.*)

consists of manually restoring line and clearing-out drops, the jacks and drops being mounted on separate panels. Generally the Bell companies have not extensively employed self-restoring drops in their rural exchanges. However, the type of combined drop and jack manufactured by the Western Electric Company and shown in Fig. 180 may be substituted for the manually restoring drops, if desired.

The board shown in these figures is equipped for sixty lines and fourteen cord circuits. This is nearly a full cord-circuit equipment for a single-position magneto board; but the drop-and-jack equipment, as will be noticed, occupies only a portion of the available space on the face of the board, blank mounting strips occupying the space subsequently to be filled by additional drops and jacks as they are required for future growth. The ultimate line capacity is for about 150 drops and jacks.

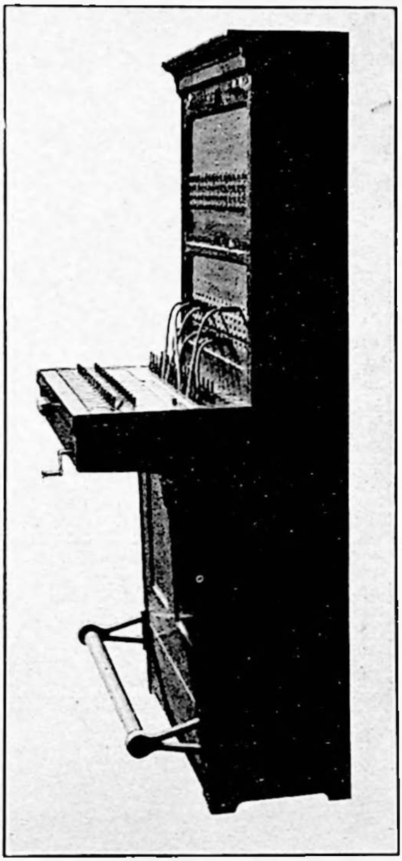


Fig. 216.—Bell-type single-position magneto board—side view. (*Courtesy of The American Telephone and Telegraph Company.*)

The circuits of this board commonly used in the Bell System are shown in Fig. 217. In this, an individual subscriber's line with its single substation is shown at the left and a four-party line at the right. The substation equipment is of the local-battery magneto type. Each of the four stations on the party line is connected alike across the two limbs of the line, this being the ordinary non-selective bridging connection. The cord circuit shown in the lower portion of the figure is provided with ringing, ring-back, and listening keys connected as already described. The listening key, when operated, bridges the operator's telephone set across the cord circuit and also by its extra pair of contacts closes the operator's local-battery circuit, to prevent the waste, as already referred to in connection with Fig. 206. The clearing-out drop as well as the line drops are provided with the contacts for operating the common night-alarm bell. Usually two operator's cut-in jacks, instead of the one shown, are provided on each position to allow a second operator to connect her set with the circuits. This is for purposes of supervision, for use in training new operators, and for facilitating the change of operators. Such double cut-in jacks are shown in Fig. 215. The contacts of the second jack are merely wired in multiple to the one shown in the circuit of Fig. 217.

The method of indicating the ringing generator connection employed in this figure is to be noted, as it is one often employed

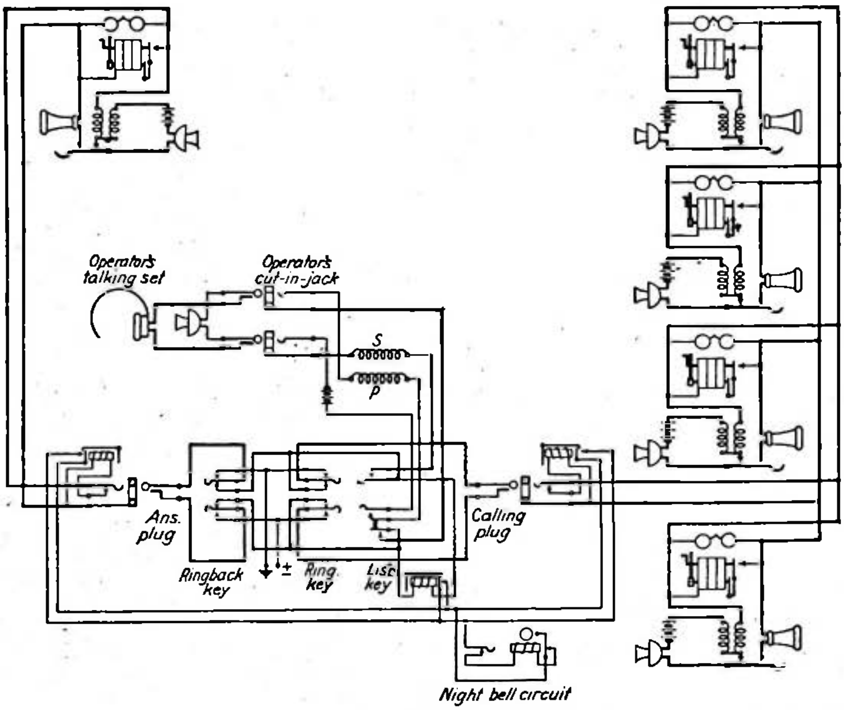


FIG. 217.—Connection between two subscribers through a No. 105-A magneto board.

in circuit diagrams. Usually one or the other terminal of the ringing machine is grounded. The other terminal delivers alternating or pulsating currents, which are indicated by the plus-or-minus sign (±) if the current is alternating, or by a plus (+) or a minus (−) sign if the current is pulsating and positive or negative.

The Bell companies ordinarily employ a few cord circuits of the convertible type shown in Fig. 218 on each magneto board. With the repeating-coil key in the position shown, the circuit is cut straight through as in the regular circuit of Fig. 217. With the key in its alternate position, however, the repeat-

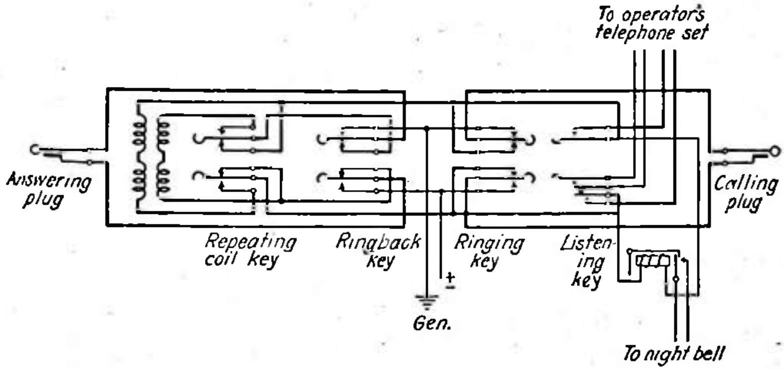


FIG. 218.—Magneto cord circuit arranged to cut in repeating coil.

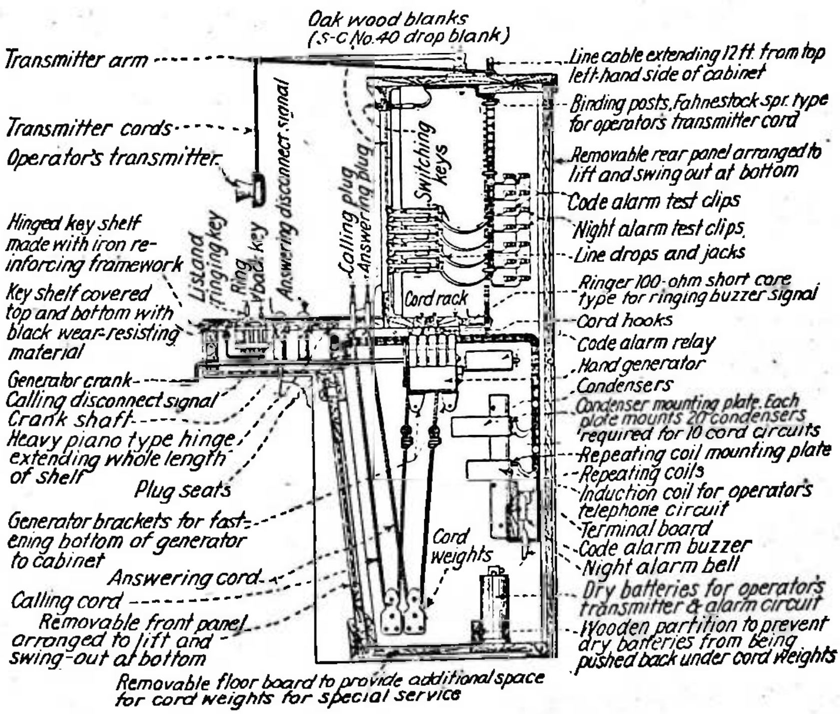


FIG. 219.—Cross-section of Stromberg-Carlson magneto switchboard

ing coil is introduced between the answering and calling cords, thus conductively severing the two connected lines.

We may take the No. 105 magneto switchboard of the Stromberg-Carlson Company as an example of the somewhat more complex magneto-switchboard practice of the independent companies in the United States. A vertical cross-section of one of these is shown in Fig. 219, front and plan views of the face and shelf equipment in Fig. 220, and a rear view in Fig. 221. The notations on these cuts will identify the various parts.

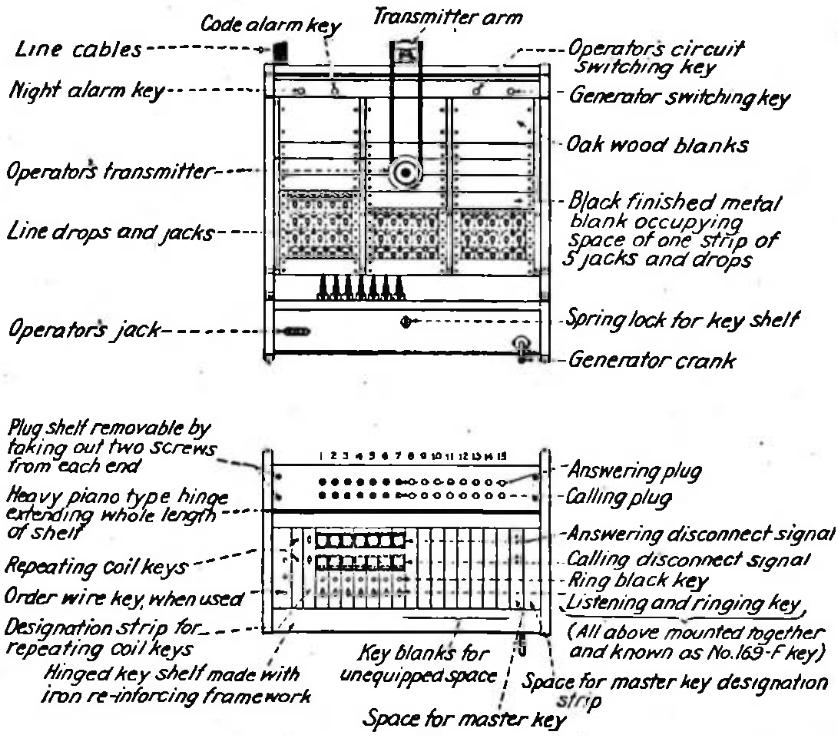


Fig. 220.—Face and shelf equipment Stromberg-Carlson magneto switchboard.

The framework is formed principally of the enclosing hardwood cabinet. The entire rear panel and the front panel under the key shelf are removable to give access to the parts within. The key shelf is hinged to the plug shelf, giving access to the ringing and listening keys, and the supervisory signals.

The board as shown is equipped for fifty lines and seven cord circuits, the ultimate capacity being one hundred fifty lines and fifteen cord circuits. The combined drops and jacks of the type shown in Fig. 181 are mounted—as indicated in Fig.

220—in strips of five in three vertical panels. The keys and supervisory signals are of the type shown in Fig. 182.

The cable bringing the twisted pair line wires into the switchboard enters the top of the cabinet. The individual pairs of wires are taken out of the cable just back of the binding posts of their respective drops and jacks, to which they are led and terminated as best shown in Fig. 221.

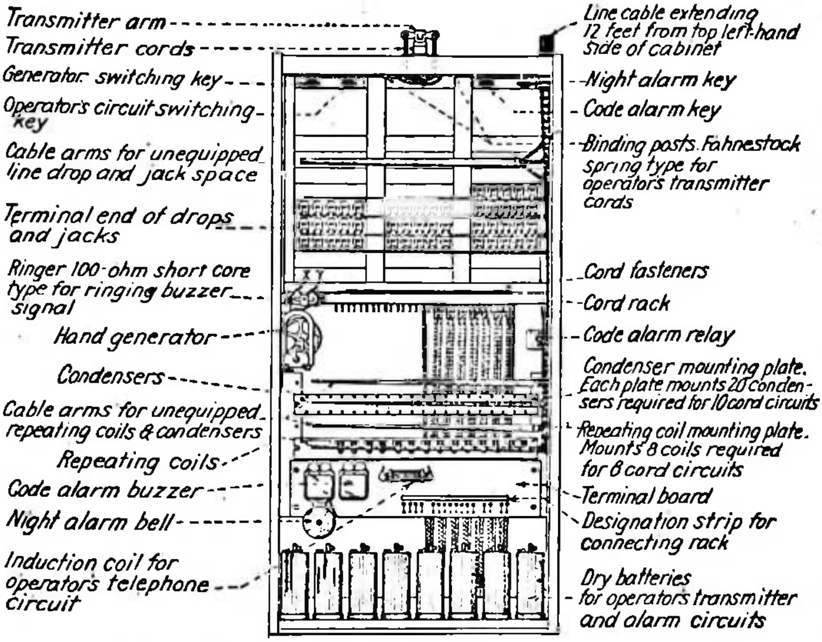


FIG. 221.—Rear view Stromberg-Carlson magneto switchboard.

Generally in magneto switchboards, the key shelf carries only the key equipment, the clearing-out signals occupying the lower portion of the vertical face of the board under the line equipment. The Stromberg-Carlson Company departs from this practice by mounting the clearing-out signals of a cord circuit on the same mounting plate as the keys of that cord circuit. This close association of the two is brought about to permit the mechanical restoration of the clearing-out signals by the movements of the key levers. The method of mounting a strip of keys and signals (Fig. 182) on the key shelf is shown in Fig. 222, while the diagram of Fig. 223 shows how the automatic restoration of the shutters is accomplished by the movement of the listening-key lever.

The relative positions of the two plugs and cords, the disconnect signals, and the keys which belong to the same cord

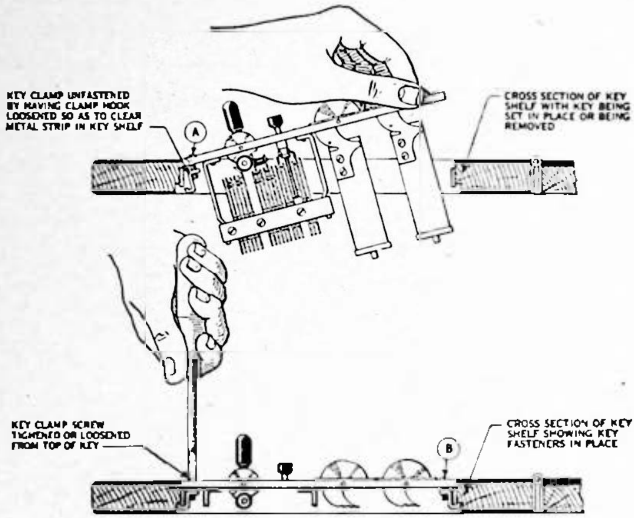


FIG. 222.—Attachment of cord circuit key and signal equipment.

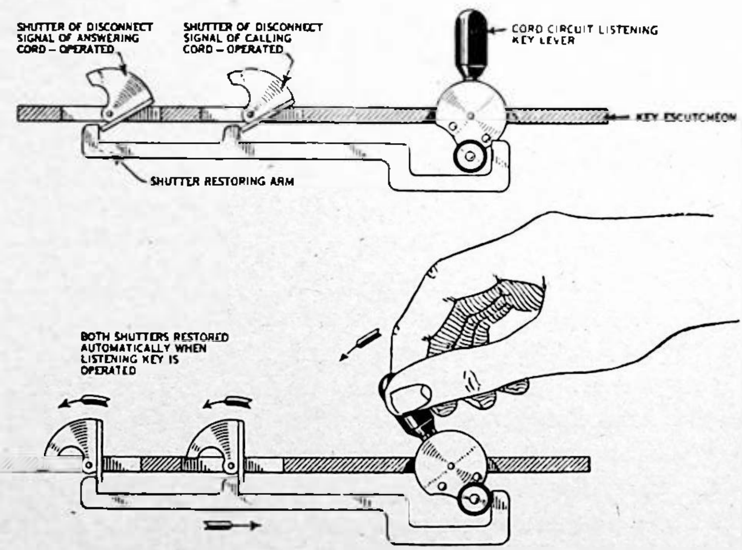


FIG. 223.—Automatic restoration of clearing-out signals.

circuit are shown in Fig. 224, these parts normally lying in a horizontal line at right angles to the face of the board. The rocking lever acts as a listening key when thrown toward the face of the board, and as a ringing key when thrown in the opposite direction. The plunger operates the ring-back key, which is of this type to avoid confusion with the regular ringing key, which of course is used much more frequently.

All of the cord circuits are provided with repeating coils but the two left-hand ones of each position are made convertible

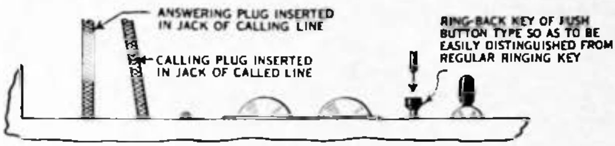


Fig. 224.—Arrangement of keys, signals and cords.

to the straight-through type. Figure 225, a plan view of the left-hand end of the key shelf, shows the location of the repeating-coil cut-out keys for the two convertible cord circuits. The mounting strip immediately at the left of the first cord

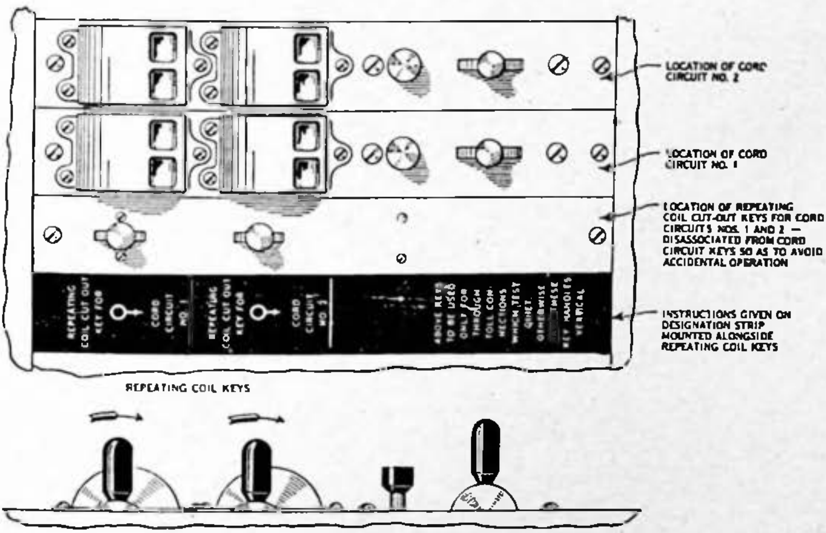


Fig. 225.—Arrangement of left end of key shelf.

circuit contains the repeating-coil keys for these two cord circuits, while the black strip at the extreme left carries no apparatus but only instructions for the proper use of the two convertible cord circuits. The operation of these cut-out keys transforms the corresponding cord circuit from the normal repeating-coil type to the alternate straight-through type.

The talking circuit of two lines connected through any of the regular cord circuits is through a repeating coil as shown in Fig. 214, but when two lines involved in a long-distance conversation are connected by either of the convertible cord circuits after its repeating-coil key has been thrown, the circuit is cut straight through. In this latter case the operation of the repeating-coil key has disconnected one set of repeating-coil windings, one of the clearing-out signals, and both of the condensers. The other clearing-out signal is left bridged across the circuit in series with one set of repeating-coil windings, and the two ends of the cord circuit are conductively connected. This gives a circuit of minimum transmission loss for long-distance connection, but of course it sacrifices the double-supervision and non-ring-through features. The two convertible cord circuits are used only for connecting toll lines or through lines to other exchanges where the greatest transmission efficiency must be attained. If these lines are well balanced and quiet, the repeating coil should be cut out. If, on the other hand, the lines are out of balance and noisy, it is probable that better results will be secured by leaving the repeating coil in the connection.

The line circuit and its associated night-alarm and code-alarm circuits of this board follow the general principles already outlined. Both sides of the drop are cut off at the jack during a connection. The night alarm and the code alarm operate substantially in accordance with the discussion already given in connection with Figs. 203 and 204.

The problem of growth is ever-present in central-office switching equipment. Up to the ultimate capacity of the non-multiple switchboard, growth is provided for by making the switchboard framework of greater line and cord capacity than the immediate needs and later installing additional line and cord equipment in the blank places provided in the original frame. When the frame is full, additional ones are added up to a limit of operator and cord reach—usually not more than three positions and better not over two. Figure 226 shows two positions of Kellogg magneto switchboard of the type shown in Fig. 195. Here the matter of cord reach was provided for by placing the two positions on a common base or pedestal, so as to raise them sufficiently above the floor to permit the use of longer cords than the height of cabinet originally allowed.

The Western Electric Company a few years ago introduced into the small-switchboard business an idea long successfully used by the manufacturers of bookcases. Like the sectional bookcase which is made to grow conveniently with one's library, the sectional switchboard was designed to grow conveniently with its increasing number of lines in a small exchange. The No. 1800 sectional unit type of Western Electric switchboards embodies this idea. An example of it is clearly illustrated in Fig. 227. This type is intended only for meeting the require-

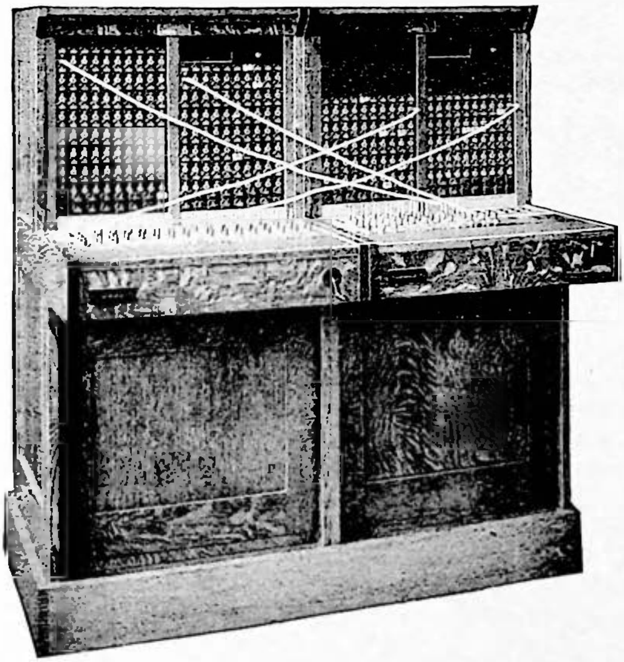


Fig. 226.—Two-position magneto switchboard. (*Courtesy of Kellogg Switchboard and Supply Company.*)

ments of very small exchanges, from their beginning of perhaps ten lines up to a maximum of seventy or eighty lines.

The supporting units are for support only. They may consist of a table, a desk, or merely a wall shelf. The "cord unit" contains the cord-circuit equipment and the operator's telephone-circuit apparatus. The "line units" each contain a maximum of ten drops and jacks—usually of the combined type shown in Fig. 180. Instead of drops and jacks, each line unit may contain a maximum of five ringers and jacks, in which case the ringer takes the place of the usual drop and thus serves the purpose of a code alarm, a convenience where the operator is not always at the switchboard. Each ringer is provided with an indicator to show which bell has rung.

The very simple kind of switching device, of which Fig. 228 is typical, deserves attention as being of value in sparsely settled rural communities. This particular arrangement is

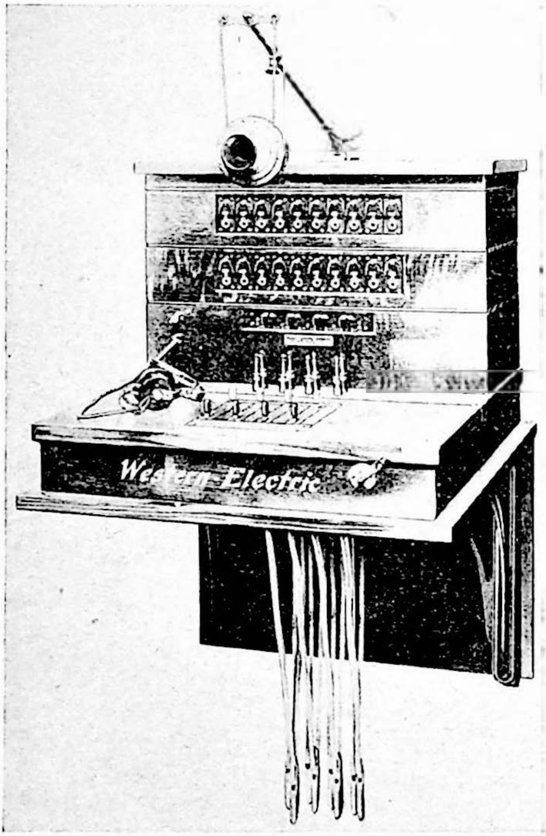


FIG. 227.—Sectional type of magneto switchboard. (*Courtesy of Bell Telephone Laboratories.*)

really a magneto switchboard for two lines and may be used where two lines come to a switching point, or where it is desired to divide a long rural line in order to be able to work either way on it. The entire two-line switchboard consists merely of three double cut-off jacks with a bridging ringer mounted in a small box, and an ordinary local-battery bridging magneto telephone with a plug and cord.

With the plug withdrawn as shown, the two line-sections are connected through with the ringer bridged across them to receive a signal from either end. By plugging into the center

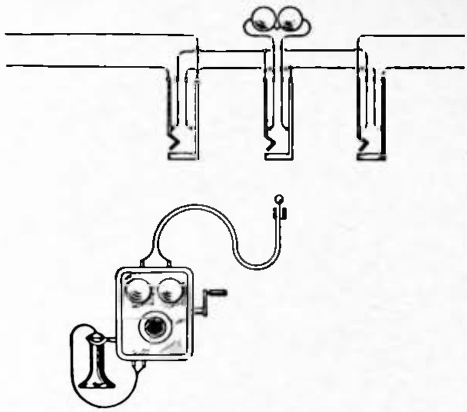


FIG. 228.—Toll cut-in station.

jack, the attendant may listen in without severing the through connection. By plugging into the jack on either side, the attendant may talk on that line-section, leaving the ringer bridged across the end of the other. If desired to separate the two sections for a time, the attendant may leave the plug in either of the side jacks, when, with the receiver on its hook, the ringer of the telephone set will receive signals from that section, the separate ringer receiving those on the other.

When more than two lines are involved in such a rural switching station, a combination of ringers, jacks, plugs, and cords, mounted in a simple wall-type cabinet, may be employed. Such a magneto wall switchboard as made by the Kellogg Company is shown in Fig. 229. This is intended for use in rural exchanges, having fifteen lines or less, where the number of calls is not sufficient to warrant having an operator in constant attendance. In such cases the switchboard may be installed in a farmhouse and

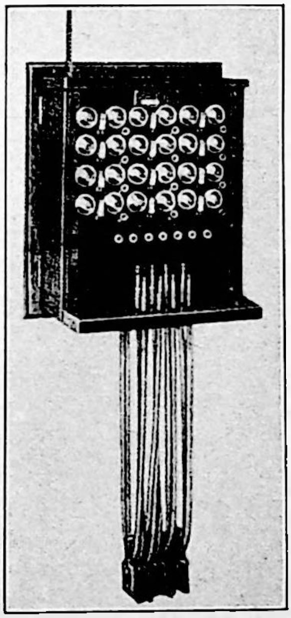


FIG. 229.—Magneto wall switchboard with combined drops and ringers.

operated by various members of the family. Bridged ringers serve as the line signals. Each has a hinged shutter, which falls when released by the first movement of the tapper rod to give a visible signal identifying the bell that has rung. The talking apparatus and the generator, wired as in an ordinary magneto telephone set, terminate in a listening cord and plug. With this the operator may plug into the jack of any line for the purpose of sending a signal or talking. Connections between lines are made with any of the four pairs of cords. Each of these has a listening jack bridged across it, but no other cord-circuit equipment, such as keys and clearing-out signals. The

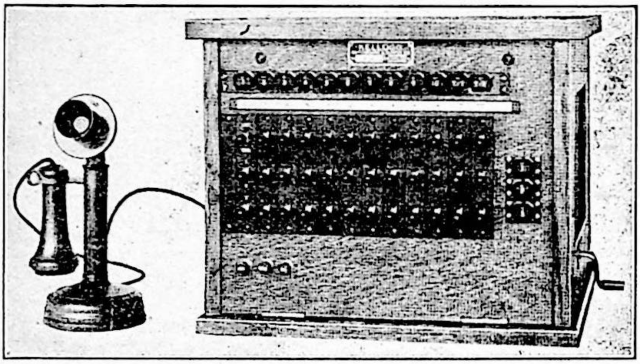


FIG. 230.—Cordless magneto switchboard. (*Courtesy of Kellogg Switchboard and Supply Company.*)

attendant listens in for supervisory purposes by inserting the plug of her telephone in the listening jack of the cord circuit.

For small private exchanges serving but a few lines the cordless type of switchboard merits attention on account of its simplicity, ruggedness, and ease of operation. One of these for magneto operation, with a capacity of twelve lines and three simultaneous connections, is shown in Fig. 230. Each line is equipped with three double-throw keys, arranged in vertical rows, by means of which all listening, ringing, or connecting operations are performed. Extending across these vertical rows of keys are six pairs of horizontal wires, three of which are for operator's talking and ringing purposes and the other three for connections between the lines as required. Across the circuit of each line, represented by a vertical row of keys, is bridged a line drop, these being shown in a horizontal row above the keys. Across each of the three pairs of connecting wires is bridged a clearing-out drop, these being seen in a vertical row at the right of the keys.

The operation will be more easily understood in connection with the circuit shown in Fig. 231. The upper horizontal pair of wires are for the supply of battery to the operator's transmitter, and the second pair from the top lead to the operator's receiver circuit. By raising the upper key lever of any vertical row, the local circuit of the operator's transmitter will be closed and her receiver will be connected across the circuit of the corresponding line. The operator is thus enabled to answer any call or listen in on a connection.

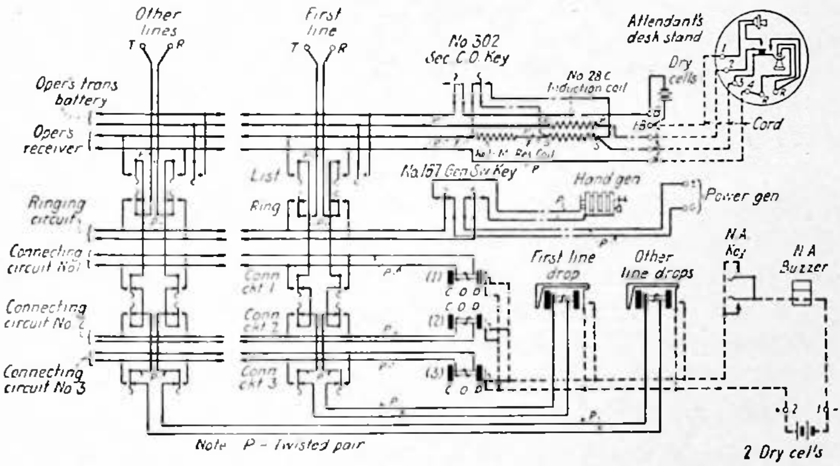


FIG. 231.—Cordless magneto switchboard circuits.

The third pair of horizontal wires from the top are the generator wires which may lead either to the hand generator or to a power generator according to the position of the generator switching key in the upper right portion of the face of the cabinet. By depressing any one of the upper row of key levers, the operator may connect the generator wires to the line wires corresponding to the key and thus call the subscriber on that line.

The three lower pairs of horizontal wires are the connecting wires, acting in lieu of cord circuits to connect any two lines together. Any line may be connected with connecting circuit 1 by throwing its center key lever up, or with connecting circuit 2 by throwing its center key lever down. Likewise by means of the lower row of keys (which in this case are single-throw only) any line may be connected with connecting circuit 3.

To connect any two lines together through any of the three connecting circuits, therefore, the operator has only to throw the two corresponding keys of those lines into position to connect with the desired connecting circuit.

The line signals, it will be noted, are in each case cut off when any key of its line is thrown, but the high-impedance clearing drops are left bridged across the connection as in the cord types of magneto switchboards.

Of recent years there has been some tendency to advocate the use of lamp signals for line and cord circuits in magneto switchboards. The advantages of doing this are, in most cases, not apparent. The necessity for extreme economy of space on the face of the switchboard, which in very large offices constitutes one of the chief reasons for the use of lamp signals, does not exist in exchanges of the size that ordinarily operate on a magneto basis. Again, to operate lamp signals economically requires a storage battery, and often the source of power to charge one is not readily available in small rural centers. Whether or not the requisite charging source is at hand, the added complexity necessarily involved in making line and supervisory lamps responsive to magneto signaling currents does not seem to be warranted in most exchanges that are small enough to operate on a magneto basis.

CHAPTER VIII

CURRENT SUPPLY IN COMMON-BATTERY EXCHANGES

In the common-battery, or central-energy system, as it is sometimes called, the local batteries and hand generators, which the magneto system requires for all subscribers' stations, are replaced by a single larger source of current, located at the central office. The advantages to be gained by thus centralizing and unifying the numerous and widely scattered current sources are many and far-reaching: The cost of each subscriber's set is reduced by about that of the generator and local battery. The labor and expense of visiting the substations for repairs are reduced, and those for battery renewals are avoided. The subscribers' sets are made neater, simpler, and more compact by the absence of the batteries and generators. The electrical efficiency of the plant is greatly improved by having one large secondary source of power in constant operation, instead of a great number of small primary sources, each idle most of the time. The gradual decrease of power in speech transmission due to the slow deterioration of local batteries and the disruption of service due to their failure are avoided.

Perhaps of more importance than all of these foregoing advantages, which bear principally on first cost, maintenance expense, and continuity of service, are the advantages which arise from the fact that a sufficiently large source of electrical energy always stands ready at the central office to be drawn upon by the subscribers. This affects primarily the convenience of use of the system by both subscribers and operators and contributes to celerity of operation and lower operating costs. Primarily it makes possible the automatic sending of signals, such as the display of a signal at the central office when the subscriber removes his receiver from its hook and of another when he hangs it up after use. These signals the subscriber sends unconsciously as a mere incident of his taking the receiver in his hand for use and of his getting rid of it after use. As a result, they are more dependable than those he sent—or was supposed to send—by turning his generator crank.

All things considered, under the conditions for which it is adapted, the common-battery system is capable of rendering more uniform and prompter service with greater convenience to the subscriber, with less effort on the part of the operator, and with less expense to the owner, than the older system employing local batteries and hand generators at the substations. Except for small rural communities and for certain special conditions of minor importance, telephone exchanges now operate quite universally on the common-battery basis. This is true of not only manual-switching but automatic or machine-switching systems as well.

This chapter will deal with the general principles of common-battery supply as a preliminary to the more detailed discussion of actual switchboard systems. While here illustrated particularly in connection with manual switching, it will be recognized that essentially the same considerations will apply to automatic or machine-switching.

Some of the advantages of the common-battery supply were appreciated long ago, and several early attempts were made to realize them in practice. In April, 1881, Charles E. Scribner, than whom no one has done more in the development of telephone switching systems, proposed to furnish transmitter current from a central battery, by sending it over an extra or supply wire leading from the central office through all the subscribers' stations in series. The battery-supply wire led through a balanced Wheatstone bridge at each station, the transmitter being in one arm of the bridge and the primary of the induction coil in the cross-wire. The secondary of the induction coil and the receiver were placed in the regular line circuit of each station. This was a "common"-battery system and now has no other than historical interest. Another early plan was proposed in 1881 by George L. Anders, of the London and Globe Telephone Company. This used a separate battery in each cord circuit of the switchboard so connected as to supply current in series to the two connected lines. This was a "centralized"- but not a "common"-battery system, because a separate battery was required for each cord circuit.

As long as these ideas of supplying transmitter current over a separate wire or of connecting the batteries in series in the cord circuits prevailed, no practical advancement was made, and the local transmitter battery at each substation remained firmly entrenched. In the early nineties, however, when the effects on voice currents of resistance, inductance, and capacitance were beginning to be appreciated, the idea of furnishing transmitter current from a single battery of large current capacity, bridged in common across all the connected lines, was evolved. Then began the rapid progress in the development of the common-battery system.

In 1891, John J. Carty, who as we have seen was the pioneer in connecting telephone sets in multiple across the line instead of in series in it, proposed also to supply current to a number

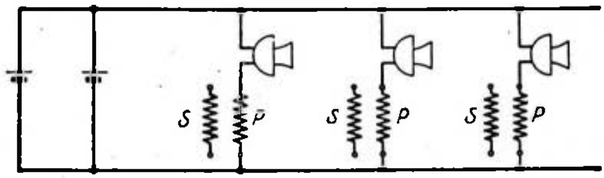


FIG. 232.—Common supply to switchboard transmitters.

of operators' transmitters by connecting them in multiple across the terminals of a single battery. His purpose was to avoid the use of a separate battery for each of the operator's transmitters in a central office, as had been done up to that time. His arrangement is shown in Fig. 232. He used secondary cells, partly on account of their having lower resistance than primary cells, and he still further contributed to the low resistance of the source by using several cells in multiple. He also used very heavy supply leads so that the whole common-supply circuit would be of extremely low resistance.

Earlier efforts to supply operators' transmitters in multiple from a single source had resulted in serious cross-talk between the operators' sets. Any variation in current due to the action of one of the transmitters would affect the potential across the common-supply leads and thus affect the current through the primary coils of all the other transmitters. Carty found, however, that, if he made the resistance of the common-supply circuit—including that of the battery—very low, he could practically avoid the troublesome cross-talk. From the standpoint of ohmic resistance alone, it is clear that the potential across the terminals of any of the transmitter bridges would be that of the battery less the *IR* drop through the common-supply circuit. If the resistance of the supply circuit were zero, then the product *IR* representing this drop would be zero, so that the potential across the terminals of the transmitter bridges would remain constant, regardless of any variations in current flow produced by the action of any of the transmitters. Of course, a supply circuit without resistance is an impossibility, but by employing very large and short conductors and a battery of large capacity, a sufficiently close approximation to the ideal condition for practical purposes is attainable.

As will be shown later, low ohmic resistance alone does not constitute the ideal condition for the common-supply circuit in order to guard against cross-talk between parallel branches. Low reactance also is needed so that this, combined with low resistance, may result in low impedance to the rapid variations of current.

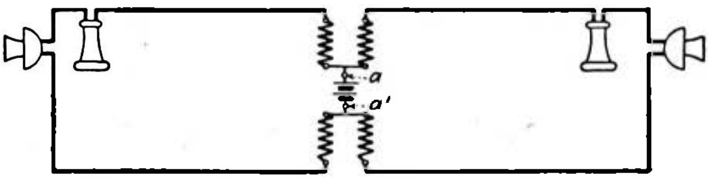


FIG. 233.—Repeating-coil method of common-battery supply.

In 1892, Mr. Hammon V. Hayes, later chief engineer of American Telephone and Telegraph Company, and Mr. John S. Stone, of the American Bell Telephone Company, proposed and patented two plans of feeding transmitter current to the subscribers' stations of all connected lines from a common battery located at the central office. In each of these plans the common battery was bridged in a common path across all the cord circuits so that current was supplied in multiple to all the lines that were connected for conversation. The Hayes plan and the Stone plan differed only in the manner of bridging the battery across the cord circuit, Hayes doing so through the windings of a "split repeating coil" and Stone through a pair of impedance or retardation coils. The two methods are known respectively as the "repeating-coil" and the "impedance-coil" methods of common-battery supply and both are widely used today.

The principle of the Hayes repeating-coil method is shown in Fig. 233. In this, two telephone lines, each for simplicity of illustration terminating in a simplified subscriber's talking set, are inductively connected for conversation through a split repeating coil. A storage battery connected between the two pairs of windings of the repeating coil furnishes direct current to the two lines in multiple. Current variations caused by the transmitter in one of the lines will act inductively through the two repeating-coil windings in that circuit on the two windings in the circuit of the other line and cause corresponding fluctuations in that line.

The Stone or impedance-coil plan is similarly shown in Fig. 234. Here, as before, current is supplied to the two substations over the two lines in multiple. The retardation coils offer comparatively low resistance to the steady battery currents supplied to the two lines, but on account of their reactance they offer high impedance to the passage of voice currents

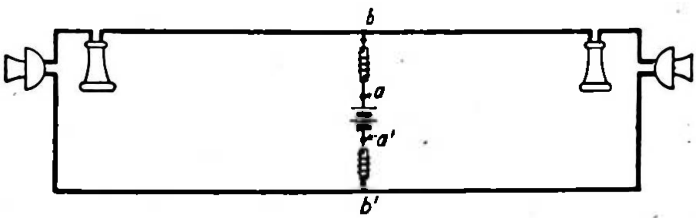


FIG. 234.—Impedance-coil method of common-battery supply.

through the bridge. The bridge, therefore, while permitting free passage of direct current to the lines, has little shunting effect on the voice currents. As a result, current variations caused by the transmitter action in one line pass by the bridge and on to the other line as if the bridge were not present.

With minor modifications, one or the other of these two plans of common-battery supply forms the basis of all modern common-battery systems, whether operating on the manual or the machine-switching basis. One practical difference between the repeating-coil and the impedance-coil type of supply is due to the fact that in the repeating-coil type the portion of the path *a-a'* (Fig. 233) that is common to the two lines is of very low resistance, while in the impedance-coil type the path common to the two connected lines is *b-b'* (Fig. 234) and includes the impedance coils. It therefore has considerable resistance. With the repeating-coil connection, therefore, the current supplied to one line is not affected by that supplied to the other, since the

IR drop across *a-a'* is practically zero; but with the impedance-coil circuit, the *IR* drop across the path *b-b'* common to the two lines may be of considerable moment. As a result, with the impedance-coil connection one line may tend to "rob" the other of its due amount of transmitter current. Thus when a long line is connected to a short one, the latter on account of its low resistance takes a comparatively large current, thus causing a considerable drop in potential through the two coils and reducing the potential between the points *b*, *b'*. As a result, the long line gets less current while the short one, which needs less, gets more.

The modified form of retardation-coil supply shown in Fig. 235 completely cures the foregoing fault of the simpler circuit of Fig. 234. The two lines are inductively united but conductively separated by the two condensers. The common-

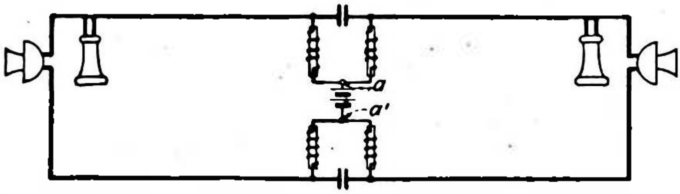


Fig. 235.—Condenser-impedance-coil method of common-battery supply.

supply path is thus brought back to the very low resistance path *a-a'*, avoiding all tendency of one line to affect the current supply of the other. In this respect it is on an equal footing with the repeating-coil circuit of Fig. 233.

Of these three general types of battery-supply circuit, the repeating-coil type (Fig. 233) has been most widely used in the manual-exchange switchboards of the Bell companies. The single-impedance bridge type (Fig. 234) is very effective and largely used by both Bell and independent companies in small switchboards, such as those in private branch exchanges, where there is not likely to be great disparity in the lengths and resistances of the various lines. The combined impedance-coil and condenser type (Fig. 235) is principally used in the manual-exchange switchboards of the independent companies of the United States and also finds wide use in automatic or machine-switching equipment of all makes. The choice among these types lies very largely in their relative adaptability to the particular conditions under which they are to operate.

A further modification of the combined impedance-coil-condenser circuit is shown in Fig. 236. This deserves passing attention only because it was once rather widely used in certain independent exchanges in the United States. It differs from the circuit of Fig. 235 only in that it employs two batteries instead of one. With the lines connected in pairs for conversation, this arrangement resulted in all the calling lines receiving their transmitter current from one battery and all the called lines from the other, no two of a connected pair receiving current from the same source. The reason for the use of two batteries instead of one was involved in the patent situation of that time rather than in any inherent merit of the plan.

Figures 233, 234, and 235 each show merely the principle involved in supplying transmitter current to a single pair of lines that have been connected, without regard to the switching

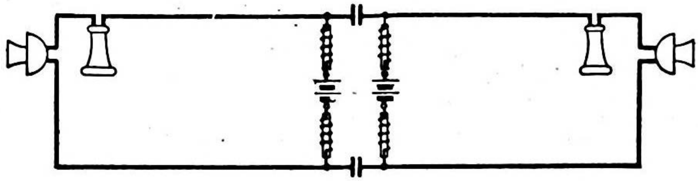
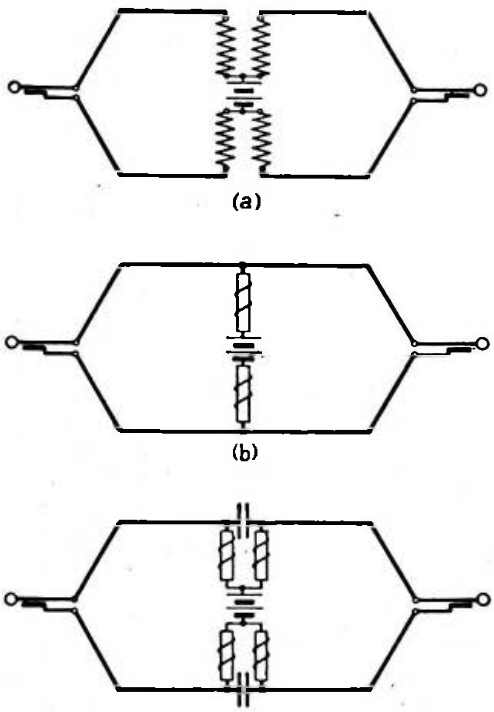


Fig. 236.—Two-battery current supply.

devices by which the connection between them was effected. Each of these figures may thus apply to the furnishing of transmitter current to the subscribers of either manual or machine-switching systems. In considering specifically manual-switchboard practice, the plan almost universally used is to place the battery-supply bridge directly across the talking strands of each switchboard cord circuit. Thus the establishment of the connection between two lines also sets up the proper condition for the supply of transmitter current to their substations. The three diagrams of Fig. 237 show respectively: (*a*) the repeating-coil, (*b*) the impedance-coil, and (*c*) the condenser-impedance-coil methods as applied to manual-switchboard cord circuits.

All of the similar cord circuits in a central office are connected to the common battery in exactly the same way. This is illustrated in Fig. 238 for three cord circuits of the repeating-cord type, and in Fig. 239 for three cord circuits of the single-bridge retardation-coil type. The connections for common supply to condenser-retardation-coil cord circuits like those shown in Fig. 237*c* will be obvious from Figs. 238 and 239.

The choice among the foregoing systems of common-battery supply depends not only on the conditions that might affect talking efficiency, as in the matter of the relative battery feed to long and short connected lines, but also on the system of signaling or of switch operation employed. As an illustration with respect to signaling in manual switchboards, the system



(a)

(b)

(c)

FIG. 237.—Three principal types of common-battery supply through cord circuits.

of supervisory signals in the common-battery switchboards of the Kellogg Company employs four relays for each cord circuit. The coils of these relays are associated with the conductors of the answering and calling cords in exactly the same manner as the four retardation coils of Figs. 235 and 237*c* are associated with their cord-circuit conductors. The same four coils are therefore made to serve the double purpose of retardation coils for the common-battery supply and of relay coils for the supervisory signals. As another example, the system of supervisory signaling in most of the large common-battery switchboards of the Western Electric Company employs relays that are independent of the

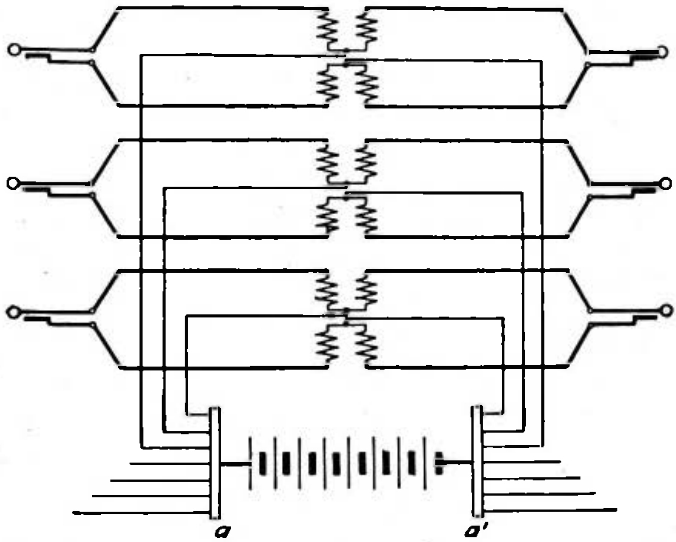


FIG. 238.—Connection of several cord circuits to same battery—repeating-coil method.

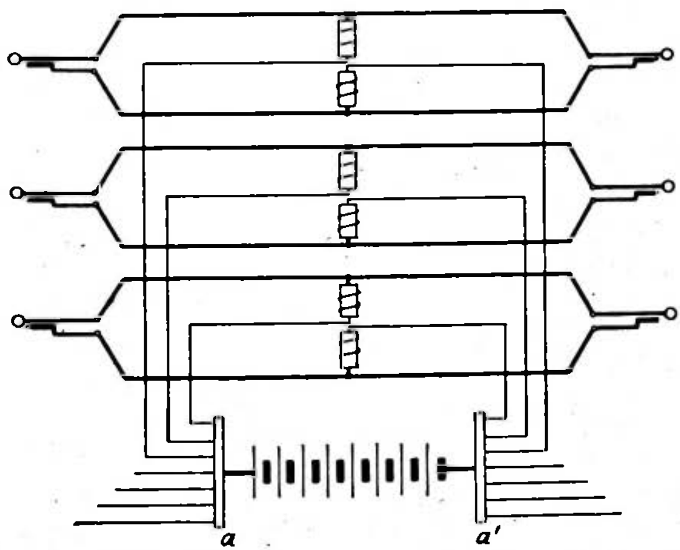


FIG. 239.—Connection of several cord circuits to same battery—impedance-coil method.

voice-current translating devices in the cord circuit. This permits the use of the repeating-coil type of circuit, since the current-supply coils have no relay-coil functions to perform.

As we have seen, it is a fundamental condition of any of the common-battery systems of modern practice that all of the talking circuits, each comprising a pair of connected lines, are bridged by a common path containing the battery which supplies their transmitter current. All of the talking circuits are thus conductively tied together, and this, obviously, is a condition that would ordinarily contribute to cross-talk between them.

The danger of cross-talk is not the only one involved in this common connection that must be guarded against. Another is that arising from the various dynamo electric machines or other sources of current used in charging the battery or furnishing ringing and other kinds of current to the exchange. Small undulations or ripples in the supposedly constant electromotive force of the charging machines may cause by direct conduction corresponding fluctuations in the potential across the battery terminals; or rapid variations in the magnetic fields surrounding any of the machines, whether connected to the battery or not, may cause by induction corresponding electromotive forces in the common supply circuit. Rapid undulations in the common circuit produced in either of these ways are likely to produce noises in the connected talking circuits. These noises from the machines usually occur as a hum. They may be classified as "machine noises."

A third kind of disturbance that may have its cause in the common supply is due to the fact that the common battery furnishes direct current for many other exchange purposes than that of transmitter supply. The draft on the battery for some of these purposes is of a decidedly "jerky" nature, occurring in a succession of sudden impulses. This is particularly true in machine-switching offices where the switching operations are often performed by series of rapid impulses through relays or motor magnets. These tend to cause fluctuations in the potential across that part of the circuit that is common also to the talking circuits, and therefore noises in those circuits. These, usually a rapid succession of clicks, may be called "switching noises" to distinguish them from cross-talk and machine noises.

In this chapter dealing particularly with the supply of transmitter current from a common source, it is pertinent to consider somewhat more in detail these three kinds of disturbances that may arise by virtue of the fact that a portion of the supply circuit is necessarily common to all talking circuits. We may refer to these collectively as "common-supply disturbances" to distinguish them from others, such as those caused by railway, lighting, and power-transmission circuits, or by telegraph or other telephone lines.

An idea of the general conditions surrounding this problem may be gained from Fig. 240. The bus-bars *a*, *a′* are the ones referred to by the same letters in the preceding figures. They are commonly placed on the "coil fuse panel," so called because in addition to being the distributing point for all the individual supply wires to the cord-circuit coils, it also carries fuses for guarding these circuits from abnormal currents.

These bus-bars are connected by relatively short, heavy conductors to the terminals of the common battery. The

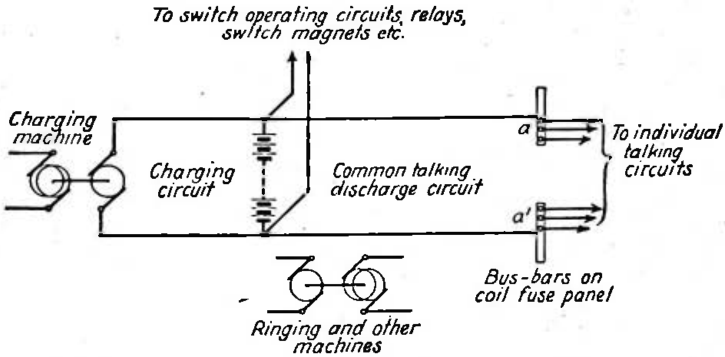


FIG. 240.—Possible sources of noise in common conductors.

wires leading from these bus-bars carry transmitter current to the repeating coils or impedance coils of the individual talking circuits, as shown in Fig. 238 or 239. The charging dynamo delivers its current directly to the storage battery. It is usually driven by an electric motor operating on either alternating- or direct-current circuit, according to the source of power available. The other machines shown, not connected with the talking circuits, are to be considered as typical of any dynamo electric machines, such as the ringing motor generators for instance, which may affect the conductors of the common circuit by induction. The discharge conductors leading from the upper portion of the diagram are those feeding circuits other than the ones involved in talking, such as the circuits of the various switching relays and signal lamps in a manual switchboard or those to the relays, lamps, and switch-operating magnets in an automatic switchboard.

With these conditions in mind, we may consider the three classes of common-supply disturbances—cross-talk, machine noises, and switching noises—in this order.

Cross-talk.—Here the disturbing sources are the transmitters in the different talking circuits drawing their current from the common battery. For simple analysis, we may consider merely two cord circuits, each connecting a pair of lines for conversation, as indicated in Fig. 241. The transmitter at substation *A* will be taken as the disturbing source and its effects on the receivers at stations *B*, *C*, and *D* considered. A

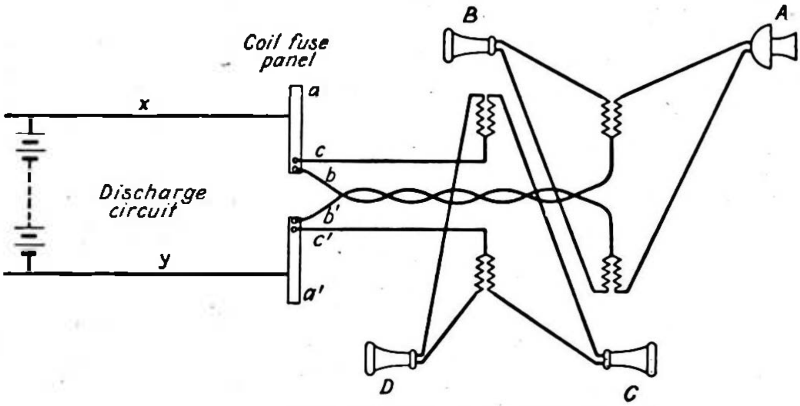


Fig. 241.—Analysis of cross-talk conditions.

prime requisite of the system is that the transmitter at any one station (*A* in this case) shall have its current variations transmitted efficiently to the station (*B*) on the line with which it is connected; and it is of scarcely less importance that they shall not be transmitted at all to any of the other stations (*C* or *D*). Evidently the first requirement is met, for current variations produced by the transmitter in the line of station *A* will pass through the two windings of the repeating coil in the circuit of that line and will induce corresponding currents in the other pair of windings of that coil which will pass over the line of station *B* and affect the receiver of that station. But the current variation produced by the transmitter at *A* will necessarily pass though the individual feed wires *b*, *b′* to the bus-bars *a*, *a′* and through the common wires *x* and *y* and the common battery. If these current variations through the common path produce variations in potential across the bus-bars a, a', then it is obvious that the receivers at stations C and D will also be affected, since they also are directly connected across those bus-bars.

Clearly, if the impedance Z of the common path from a to a' through conductors x and y and the battery were zero, then these current variations produced by the transmitter at A would cause no fluctuations in the voltage across the bus-bars. If we let I represent any change in current produced by the transmitter in the common path from a to a', then the product IZ will represent the corresponding voltage change across those bars. As the impedance Z approaches zero, this voltage change produced by the transmitter will approach zero, no matter how large the current change may be.

For many years it seems to have been tacitly assumed that the reactance of such short, straight conductors as those employed in the common circuit was so low as to be of no considerable moment and, therefore, that ohmic resistance alone was the determining factor. Early writings, my own included, treated of the subject in this way,[1] and common-battery supply circuits were designed with the sole idea of keeping the ohmic resistance as low as possible.

It was Richard Maetzel, power plant engineer of the New York Telephone Company, who showed that, for voice-current frequencies, the reactance of the common path often assumes major proportions in comparison with its ohmic resistance and that the real desideratum, in order to secure freedom from cross-talk, is low *impedance* rather than low resistance.[2] He showed experimentally that, when the self-induction of the common conductor was increased without increasing the resistance, the amount of cross-talk was made considerably larger. This was to have been expected, but what was not expected was that even with the straight, short, heavy conductors commonly employed the impedance of the common path to voice-current frequencies was sometimes as much as a hundred times

[1] J. J. Carty, U. S. Patent 518394, April 17, 1894; also "American Telephone Practice," 3d ed., p. 247, McGraw-Hill Book Company, Inc., New York, 1900.

[2] Maetzel, Richard, "Inductive Disturbances and Cross Talk," a paper read before the Telephone Society of New York, June, 1906, and the Telephone Society of Philadelphia, February, 1908.

that of its pure resistance. As an example, he cited an actual installation where the coil fuse panel (bus-bars a, a' of Fig. 241) was about 8 feet from the battery. Each of the bus-bars was connected to its battery terminal by two 800,000 circular-mil copper cables in parallel. (A bare copper-wire cable of 800,000 circular-mil cross-section is slightly over an inch in diameter and has a resistance of 0.0135 ohm per 1,000 feet.) For this circuit the ohmic resistance R between the bus bars was 0.0003 ohm. The calculated self-induction $X = 2\pi fL$ for a frequency of 500 cycles was 0.03 henry.[1] The impedance $Z = \sqrt{R^2 + X^2}$ at the same frequency was therefore slightly over 0.03 ohm or about one hundred times the pure resistance. Under these circumstances some cross-talk was noticeable in a receiver bridged directly across the bus-bars, but none in objectionable degree beyond the repeating coils.

This calculated impedance ignored the mutual induction[2] between the positive and negative discharge leads because they were so widely separated as to make that negligible. Maetzel reasoned that by bringing the two sides of the discharge circuit close together he could reduce the impedance, since the mutual induction between the two sides of the loop would act in opposition to the self-induction of the single conductor. He therefore constructed an experimental cable for the battery discharge leads (x and y, Fig. 241) in which there would be high mutual inductance between the positive and negative leads. To do this he took a piece of standard 600-pair lead-covered, paper-insulated telephone cable and, taking one wire of each pair, he bunched them together to form the positive lead x. The remaining wire of each pair he similarly bunched together to form the negative lead y. The arrangement is suggested in Fig. 242. This 600-pair "split cable" was installed between the battery and the coil fuse panel in a large central office, and suit-

[1] The coefficient of self-induction of the conductor, considered straight, was taken as

$$L = 2l\left(\log_e \frac{2l}{r} - \frac{3}{4}\right),$$

in which l is the length and r the radius of the conductor.

[2] The mutual induction between two parallel wires was taken as

$$M = 2l\left(\log_e \frac{2l}{a} - 1\right),$$

where l is the length and a the distance between the parallel conductors.

able switches were provided so that either the regular leads or the split-cable leads could be thrown into service.

The substitution of the split-cable leads for the regular ones resulted in a reduction of about 70 per cent in the cross-talk observable at the coil fuse panel, in spite of the fact that the ohmic resistance of the split leads was about twice that of the regular ones. Important results with respect to machine noises were also noted.

Further experimentation showed that such a high degree of subdivision as that involved in the use of a 600-pair cable was not necessary. Usually the splitting of the leads into two, three, or four pairs will suffice. It was determined that the impedance at 500 cycles of the common-supply circuit should in all cases be kept below 0.075 ohm. It was also determined that,

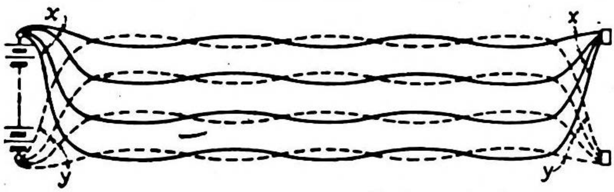


FIG. 242.—Split cable for discharge leads.

where the length was such that a single pair of the required carrying capacity gave a higher impedance than 0.075 ohm, the conductors should be subdivided or split as in Fig. 242, until the resulting impedance was somewhat below that allowable maximum. There are numerous cases where it was found necessary to split the feeders into eight and even a greater number of pairs. More will be said of this in the chapter on Power Plants.[1]

The use of the split cable for the talking-circuit feeders is now general in common-battery offices. It not only has made possible better results with respect to the avoidance of disturbing noises but has largely removed the limitations formerly existing with regard to length of the common-supply leads. It has made it practicable, for instance, to put the battery and in fact the entire power plant in the basement of a building and the coil fuse panel on some floor above and some hundreds of feet away. This has resulted in a decided economy in building construction for, if it were necessary to locate the power plant in close proximity to the coil fuse panel, as was formerly the case,

[1] "Automatic Switching and Auxiliary Equipment," Chap. VII.

additional floor space, often with larger floor-load capacity, would have to be provided on the upper floors to accommodate it.

In concluding, regarding cross-talk, we have seen that the principal requirement, as far as the common supply is concerned, is that the impedance at voice-current frequencies of the common path through the battery be kept very low and that this can be done either by making the talking-circuit feeders very short and heavy or by installing split cables of the required current-carrying capacity. Another requirement is that the repeating coils or retardation coils be magnetically shielded from each other so that there can be no induction between them. Still another is that individual supply wires from the battery bus-bars to the coils (b, b' and c, c' of Fig. 241) be twisted together in pairs so as to render each pair non-inductive with respect to all the others. In fact, as everywhere else throughout the telephone system, great care must be taken that each individual talking circuit be non-inductive with respect to all the others.

Machine Noises.—These are always objectionable. Besides being a source of annoyance, they exert a masking effect on the listener's ear, thus interfering with the intelligibility of the transmitted sounds, as pointed out in the preceding volume.[1] We may first consider those machine noises caused by currents that are introduced into the common-supply system by direct conduction.

For many reasons of practical operation and economy, a secondary or storage battery is used as the source of talking current. Some primary source of direct current, such as a dynamo electric machine, is thus required for charging the battery in order to replace the energy drawn from it by the exchange circuits. The electromotive force of these charging dynamos, or other sources of charging current, is seldom constant enough, that is, "smooth" enough, to insure an absolutely "quiet" charging current. Usually there are slight periodic variations in it, quite unimportant in power and lighting work but sufficient to cause a hum or buzz in telephone receivers. It is usually necessary to charge from some such source while the battery is connected with the talking circuits, so that the charging machine is in effect supplying the direct-current energy used by the

[1] "Theory and Elements," Chap. VI.

exchange while the battery is "floated" on the supply circuit. These conditions are represented in Fig. 243.

The lack of smoothness in the charging current may be understood in part by a consideration of the way in which the commutator of a direct-current dynamo rectifies the alternating currents that are generated in its armature coils. If the dynamo

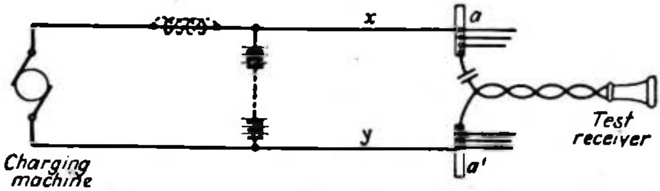


FIG. 243.—Machine noises—conductive.

had but a single coil terminating in two commutator segments, the current would be in one direction, but with an electromotive force wave form something like that shown at *a*, Fig. 244. If there were two coils and four commutator segments, the wave form would be considerably smoother with doubled frequency somewhat as indicated by curve *b*. As the number of coils and

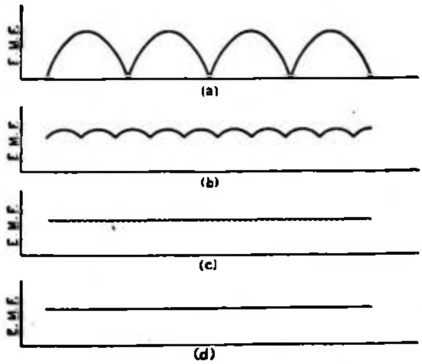


FIG. 244.—Ripples on charging-machine current.

segments are increased, the variations in electromotive force are still further reduced in amplitude but increased in frequency, until a condition roughly indicated in curve *c* is reached. Theoretically the ideal, perfectly smooth electromotive force indicated in curve *d* would be attained only in an armature having an infinite number of commutator segments and in a machine that was in all respects symmetrical and running at perfectly constant speed.

As will be shown in the chapter on Telephone Power Plants, the charging machines designed especially for telephone-exchange purposes have been brought to a high degree of refinement in the effort to produce as nearly noiseless a current as practicable. Although these special machines are much more costly than the ordinary commercial power machine, it has, until recently, been considered necessary to incur this expense in order to reduce as far as possible the amount of machine noise directly resulting from the charging current. Even with these refinements, however, some very small ripples remain on the supposedly smooth current from such a machine.

It is clear from an inspection of Fig. 243 that any variation of potential from the charging machine will tend to cause corresponding fluctuations in voltage across the bus-bars, a, a', and corresponding noises in a test receiver bridged across these bars and in all of the talking circuits deriving current from them. Of course the very low effective resistance of the path through the battery tends to short-circuit these fluctuations so that those reaching the coil supply wires will be very minute; but, on the other hand, the marvelous sensitiveness of the telephone receiver must be kept in mind.

Where necessary, a heavy retardation coil may be placed in the charging leads between the generator and battery, as indicated in dotted lines in Fig. 243. Such coils must be of massive construction, involving a large amount of iron in the core and a large amount of copper in the winding to secure the desired high reactance, low ohmic resistance, and large heat-radiating capacity. Until very recently the general practice has been to secure the required smoothness of current by refinements in the charging machines themselves and to employ the choke coil only in case a further reduction of machine noise from this source demanded it. Later practice, already referred to, attacks the problem in a radically different way by filtering out the objectionable noises from the discharge leads.

Before discussing this filtering method of eliminating noises arising from the common-supply circuit, we shall consider the other possible sources of such noises. Maetzel pointed out that, in a power plant equipped with the specially designed smooth-current charging machines and with the ordinary arrangement of separate, low-resistance discharge leads, the largest part of the machine noise is attributable to the stray magnetic fields from the various machines of the power plant. The current variations are thus introduced inductively, instead of conductively. The source of this disturbance may be the charging machine itself, or the other various auxiliary dynamos or motors not connected with the talking circuits at all. The ringing machines are examples of this latter class.

The stray field from a dynamo electric machine, whether acting as a motor or a generator, is that portion of the magnetic flux which fails to follow the intended magnetic circuit of the machine and instead seeks a path through the surrounding air. Fluctuations in the strength of the stray field may be due to a number of causes—such as variations in the primary or secondary

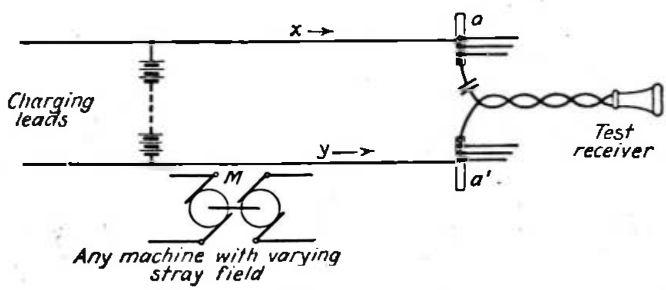


FIG. 245.—Machine noises—inductive.

voltages, unbalanced windings, poor commutation, or machine vibration.

In considering machine noises arising from varying stray fields, we may refer to Fig. 245. If the conductors x and y of the discharge circuit lie within the stray field of the machine M, any variation in the strength of the field will induce electromotive forces in them which will be superimposed on the constant electromotive force of the battery. With the relative positions as they are shown, the induced electromotive force in y would be greater than that in x, y being the nearer. They would be in the same direction, however, at any instant and would therefore tend to neutralize each other, the effective changes in the desired constant potential across the bus-bars being the difference between the two.

Obviously, since these induced electromotive forces are introduced into the common discharge circuit in series with the battery, the low impedance of the battery path does not tend to short-circuit and minimize them as it does with respect to cross-talk and the noises due to ripples on the charging circuit, both of which are introduced into the common circuit in multiple with the battery. In the case of stray-field noises, the most effective remedy lies in bringing the two sides of the discharge circuit close together and, as nearly as possible, in the same average relationship with respect to the disturbing field. By twisting them together, the opposing electromotive forces induced in each of them are made exactly equal so as completely to neutralize each other. This is exactly what is done, in effect, in the split cable illustrated in Fig. 242 and already discussed in connection with the reduction of cross-talk. The split discharge-lead cable has therefore proved a complete remedy not only for cross-talk but also for the machine noises arising from the action of stray magnetic fields on the common-supply circuit.

Switching Noises.—The common battery furnishes not only the current required by a central office for talking purposes but also most of that used in switching and signaling operations as well. The battery discharge for these other purposes is subject to rather violent and sudden changes caused by the opening and closing of circuits for the operation of relays, switching magnets, signals, and other devices involved in the switching operations of the system. In automatic systems, particularly in those operating on the "step-by-step" plan, the current in many of the switching circuits flows in a series of sudden impulses occurring in rapid succession. These variations in the discharge current are generally of a rather gross nature and occur at low frequencies in comparison with either voice currents or charging machine ripples.

Referring again to Fig. 240, it is evident from what has been said that these "jerky" switching currents will produce variations in potential across the talking-circuit discharge leads unless the effective resistance of the battery bridge to the switching currents is kept very low. This is effected by connecting the switching discharge leads as close to the battery terminals as possible and using very heavy conductors in the battery bridge. Noises due to switch operations are usually in the nature of clicks rather than the sustained tone which characterizes machine noises.

Filter Method of Common Supply.—The advent of automatic or machine switching greatly increased the power consumption required of central offices. The current consumption for talking purposes remained about the same as in manual offices, but that for other purposes was increased several fold. All direct current for these various purposes could most economically be supplied from the same source and this meant that all of the direct-current energy had to be supplied by the very costly smooth-current charging generators, even though only a small portion of it was subject to the exacting smooth-current requirements.

The cost and size of these highly specialized charging machines were more than double those of regular commercial machines of equal output. Moreover, their efficiency was lower and their maintenance expense higher. These disadvantages became much more burdensome with the larger amounts of energy required by machine-switching systems, and this naturally stimulated the effort to devise some plan permitting the use of regular commercial types of charging machines.

The plan finally evolved, and now generally adopted in new offices of the Bell System, is to use ordinary charging machines as the primary source of direct current and to give "special treatment" to only that portion of the discharge current that is consumed by the talking circuits. For the major portion of the discharge, used for other than the talking circuits, the lack of smoothness of the ordinary charging machines presents no difficulties. The special treatment for the talking supply consists merely in placing a low-pass filter in the common talking-current discharge leads. This allows the required direct current, that is, the current of zero frequency, to pass freely from the battery to the talking circuits but filters out the ripples on this current, which of course are in the nature of alternating currents of frequencies producing the objectionable machine noises.

The principles involved in this plan may be discussed briefly in connection with the diagram of Fig. 246. Four different sources of noises or disturbance—charging machine ripples, stray-field induction, switching-circuit variations, and voice-current variations—are indicated by N_1, N_2, N_3, and N_4, respectively. The charging machine N_1 is of ordinary commercial type with no special smooth-current features. No provision is made to keep charging-machine ripples or other minor variations out of the purely switching circuits, because any fairly close voltage regulation meets the requirements of those circuits. In the common talking discharge circuit is included a heavy retardation coil L, and across the discharge leads x and y between this coil and the talking circuit bus-bars is bridged an electrolytic condenser C of large capacity.

The reactance coil and condenser, connected in this way, together with the resistance of the battery circuit, form a low-pass filter with respect to currents flowing from the common-supply circuit to the talking circuits—that is, a filter which will permit direct currents and very low frequency currents to pass freely and will effectively bar the passage of higher-frequency noise-producing currents. This filter, which is primarily furnished to eliminate machine noise produced by

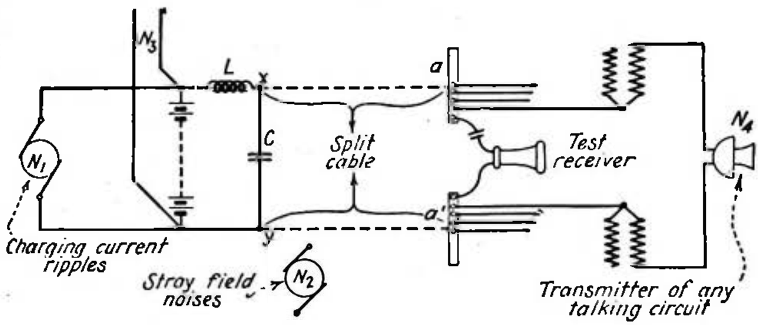


FIG. 246.—Filtering out machine noises

generators of the commercial type, is located as near as possible to the battery terminals, the condenser usually being placed in the battery room. The discharge feeders provided for talking circuits are of the split-cable type, extending between the terminals of the filter equipment and the coil fuse panels.

The cut-off point of this filter, that is, the point in the scale of frequency at which the filter begins to act as a bar, depends on the product of the capacitance C and the reactance L. Any pair of values giving this required product would suffice as far as the mere cut-off characteristic is concerned, but other considerations point toward as high a capacity as practicable with a correspondingly relatively low reactance. Very high capacitance at C is required in order that a path of practically zero impedance may be afforded for voice current. As discussed in connection with the battery bridge of preceding circuits, it is only when the impedance to voice currents between the bus-bars a, a' approaches zero that the transmitter N_4 of any connected talking circuit will fail to act as a disturbing agent to other talking circuits drawing current from the same source. Again, relatively low-resistance value in the coil L is desirable on account of cost considerations. It must carry heavy current and this requires short conductors of large cross-section to limit the losses. Under these requirements the cost of the coil increases very rapidly as the reactance is increased and soon becomes prohibitive.

Fortunately the electrolytic condenser provides the necessary high capacity at reasonable cost and in compact space, thus affording the required low-impedance path for the voice currents and at the same time permitting the desired relatively low-reactance value of the coil L.

CHAPTER IX

NON-MULTIPLE COMMON-BATTERY SWITCHBOARDS

The last chapter considered the principles involved in supplying transmitter current from a single battery to all the subscribers' stations of a central office without causing cross-talk or troublesome noises due to the common connection of all the lines. The present chapter will show the application of these principles to a small switchboard of the simple or non-multiple type. In this way a working idea of the circuits and routine operation of common-battery manual switching practice in small offices may be obtained without the confusing complications involved in multiple boards which are required for larger offices.

The principal field of usefulness of the non-multiple common-battery switchboard is in private branch exchanges. It is, however, often used in small public exchanges, but its field for this purpose is restricted, because most manually operated public exchanges, too small to require multiple switchboards, are operated on the magneto plan. The private branch exchange, commonly abbreviated "P. B. X.," may be best discussed after an understanding of the various kinds of larger public-exchange equipment has been obtained, since an important feature of its operation is that involved in the trunk lines connecting it to the main office. For this reason the discussion of P. B. X. switchboards, as such, will be deferred for another chapter, and the non-multiple common-battery switchboard will be considered here only as it would be employed in a small isolated exchange of from a few up to perhaps three or four hundred lines.

Line Circuits and Line Signals.—It is to be remembered that an essential feature of the common-battery subscribers' station equipment is that the metallic circuit of the line is held open to direct current while the receiver is on its hook, and closed while the receiver is removed for talking. Since the control of the switchboard signals by the subscriber depends on this feature alone, we may, for the purposes of switchboard discussion, represent the substation circuit in the very simple form shown in Fig. 247.

The simplest type of common-battery line circuit at the switchboard may be called the "lamp-in-line circuit" and is shown in Fig. 248. Here the line lamp is normally included directly in the metallic circuit of the line in series with the common battery, so that when the subscriber's receiver is lifted the line current will flow through the lamp. Both sides of the circuit pass through normally closed contacts of the line jack, in such manner that, when a plug is inserted, the connection of the lamp and battery with the line will be severed.

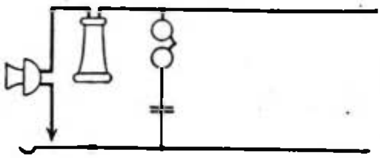


FIG. 247.—Simplified common-battery substation circuit.

Obviously, while this method may accomplish the desired display of the line signal in the simplest way, it has some limitations. It is desirable in practical switchboard operation that all the lamps be alike, particularly as to external form and current consumption, so that they may be readily interchangeable. In this line circuit the amount of current received by the lamp

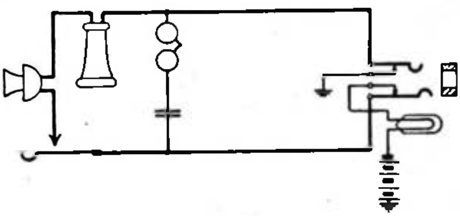


FIG. 248.—Lamp-in-line line circuit.

depends on the resistance of the line and it is clear that, unless all the lines have about uniform and proper resistance, the illumination of the lamps will be neither uniform nor proper. A line of too low resistance may subject the lamp to such a current as to burn it out, while a line of too high resistance may not allow it to be illuminated at all. One must keep well inside the range between these two extremes in line resistance in working with this kind of circuit. Of course, the shorter the line the greater will be the proportion of the total resistance of the circuit residing in the lamp itself. This, for short lines, tends to minimize the variations in current caused by different lengths of line.

For city exchanges the lamp-in-line circuit is not at all adapted because of the wide variation in the lengths and consequent resistances of the subscribers' lines. On the other hand, for small exchanges where the lines are all short, and of nearly uniform resistance, it is well adapted and is often used. Such conditions of low, uniform line resistance may occur where all the stations are within a single building or a compact group of buildings.

A number of proposals have been made to widen the range of variation in line resistance within which the lamp-in-line

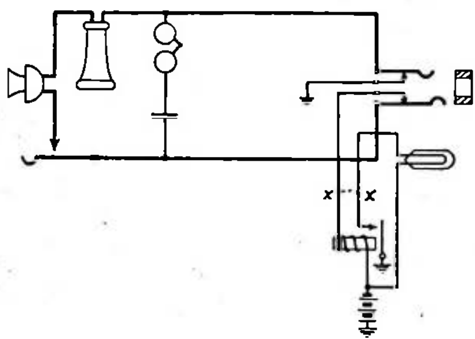


Fig. 249.—Relay line circuit.

type of line circuit may be used advantageously. One plan has been to use lamps of high resistance adapted to be fully illuminated at considerably less than the full battery voltage and to place compensating resistances in series with the lamps to reduce the current to the required value for proper illumination. A modification of this plan has been to make the compensating resistance in the form of a negative-temperature-coefficient resistor, like an iron-wire ballast or a ballast lamp, so that the variable heating effect of the resistor would, in itself, tend to compensate for the differences in resistance of the lines and thus tend to equalize the currents in the lamps. None of these plans, though no doubt some of them are capable of practical development, have come into general use, because a line relay with the lamp in its local circuit completely solves the problem of uniform current supply to the lamps, entirely independent of the length and resistance of the lines with which they are associated.

The relay type of line circuit is shown in Fig. 249. Here the relay coil is placed directly in the normal path of the line circuit in series with the common battery. It will operate over a wide range of line resistances, being effective from the smallest amount of current which will cause it to attract its armature to the largest which it may carry without danger of overheating its coil. Unlike the direct-line lamp, the maximum current it receives on very short lines may, without danger, be several times greater than the minimum it receives on the longest exchange line. The lamp, which in this case is so chosen as to operate on the full voltage of the battery, is placed in the local circuit of the relay. As all of the local circuits are practically alike and of negligible resistance, each lamp is subject to its proper working voltage when its relay is energized by the closing of the line circuit at the subscriber's station. As before, the insertion of a plug into the line jack cuts off the line circuit at the jack and, in this case, de-energizes the relay and extinguishes the lamp.

There are many variants of these typical line circuits of Figs. 248 and 249. Sometimes a mechanical signal of such types as shown in Figs. 183 and 184 is substituted for the direct-line lamp of Fig. 248. The mechanical signal has some advantages for direct-line use because it is not so closely tied to a given operating current as is the incandescent lamp. For this reason, and because it requires less current, the mechanical signal is often used in small common-battery switchboards where the talking current is furnished over a pair of wires from a distant central office, or where a reliable local source of approximately constant voltage is not available. On the other hand, the use of the mechanical signal is at a sacrifice of the simplicity afforded by the direct-in-line incandescent lamp which has no moving parts. Moreover, it does not display so good a signal as a properly illuminated lamp.

Another variation in types of line circuit is caused by the use of cut-off relays instead of cut-off jacks. Where this is done, the normal circuit of the line, instead of passing to the line-signaling equipment through a pair of contacts in the jack, passes through a corresponding pair of normally closed contacts on an extra relay called the "cut-off relay." The coil of this relay is so connected that it will be energized when a plug is inserted in the jack of its line. When energized, therefore, the cut-off relay performs exactly the same function with respect to the line signal as that performed by the pair of cut-off contacts in the jacks of Figs. 248 and 249. When there is but a single jack for each line, the simplest way of disconnecting the line signal while the line is switched for use is by means of the cut-off jack, and for that reason the cut-off relay type of circuit is little used in non-multiple switchboards. It is now almost universally used in multiple switchboards, as will be seen in subsequent chapters.

From the single-line diagrams of Figs. 248 and 249, the method of connecting all the lines with the common battery may not be altogether clear to the beginner. Figure 250 will convey the idea by showing the normal battery-supply connections for three lines. This also shows the addition of an important feature, the line pilot lamp with its controlling pilot relay. The line pilot lamp is common to a group of lines. In a small switchboard this group may be all of the lines; in larger switchboards it may be all of the lines on a single switchboard position. The pilot relay, as shown in Fig. 250, is of low resistance and is wired in the common-supply lead to all the line lamps. When, therefore, any individual line lamp receives current in response to the energizing of its relay, this current will energize the pilot relay and cause it to light the pilot lamp, which is usually provided with a large lens and mounted in a prominent place on the face of the switchboard so as to display a conspicuous signal.

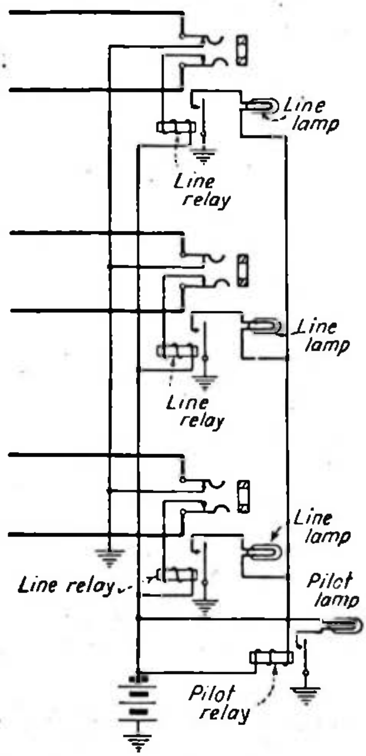


FIG. 250.—Normal battery supply to lines.

We have now seen how the subscriber by means of his switch hook may control his line lamp as a signal to the operator as long as there is no connection with his line at the central office.

We may now show how the subscriber is enabled to signal the operator during the time of a connection.

Cord Circuits and Supervisory Signals.—The clearing-out drops of the magneto switchboard have given place in common-battery practice to what are termed "supervisory signals." Two of these, usually lamp signals, are associated with each cord circuit, one for each plug of the pair. These are called respectively "answering" and "calling" supervisory signals, corresponding to the answering and calling plugs respectively. During a connection, each of these lamps is under the control of the subscriber with whose line the corresponding plug is connected. In this way the operator is enabled to "supervise" the connection, the lamps keeping her informed whether the receivers of the connected subscribers are on or off their hooks.

For controlling the local circuit of each of these lamps, there is always a supervisory relay which is responsive to the action of the hook control at the station of the connected subscriber. The requirements are not quite so simple, however, as in the case of the line lamps, for it is clear that the subscriber's control of the supervisory lamp cannot become effective until the operator has made the connection with his line. Clearly, for purposes of current economy as well as for obtaining the proper significance of the signals, the supervisory lamps should be out when the cords are idle, at which time there is no flow of current in the cord circuit and none through the supervisory relays. This requirement alone would indicate that the lamps should be lighted only when current flows through the supervisory relays. But when the cord is connected with a line, the supervisory relay is to be under the control of the subscriber, and here the requirement is that the lamp shall be lighted only when the subscriber's receiver is on his hook. This means that, for an ordinary relay, the condition with respect to the lighting of the lamp is the reverse of that before the plug was inserted in the jack. In other words, the lamp must be lighted only when no current flows through the supervisory relay.

Broadly there are two ways of meeting these apparently contradictory requirements. The first method, now generally used, is to have the local circuit of the lamp controlled at two points: one at the contacts of the supervisory relay and the other at contacts controlled by some function necessarily performed by the operator in making connection with the line—

usually the act of inserting the plug into the line jack. This usually, though not always, requires a third conducting strand in the cord and corresponding contacts in the plug and jack through which the local circuit of the supervisory lamp must be extended before it can be closed at all. Under this plan the supervisory lamp cannot be lighted until the plug has been inserted in a jack, regardless of whether the supervisory relay is energized or not. Under the second plan, now little used, the local circuit of the lamp is controlled only by the front contacts of the supervisory relay, but this is of the differential type, remaining de-energized either when there is no current flow through its two coils or when there are equal currents through them in opposite directions. Thus the lamp remains out while the cord is idle, for then there is no current flow; and it remains

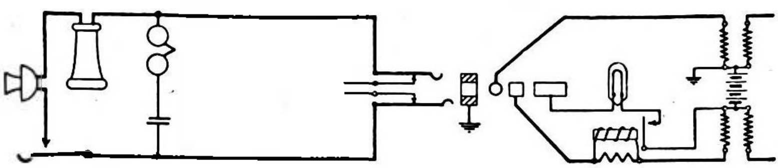


FIG. 251.—Supervisory-lamp control—lamp in sleeve strand of cord.

out while the cord is in use as long as the subscriber's receiver is off its hook, for then the transmitter current flows over the metallic circuit, traversing the two windings oppositely. This relay, however, attracts its armature and lights its lamp when only one of its coils is energized, as when current flows through one side of the line over a ground return circuit closed by the hook switch when the subscriber hangs up his receiver.

Two examples of the first and one of the second of these methods of supervisory-lamp control will suffice, although there are numerous variants of each, as will appear when multiple-switchboard circuits are considered.

Figure 251 shows an example of supervisory-lamp control through a third strand of the cord and extra contacts in the plug and jack. This, with minor modifications, is the one most used in large switchboards, its place in small switchboards being less important. The local circuit of the lamp cannot be closed at all until the connection is made with the line. Then the illumination of the lamp is controlled by the position of the relay armature. In the particular form shown, the lamp is lighted when the relay is de-energized, its armature falling back to close the circuit. In a modification of this, the relay contacts are not in the lamp circuit but they control a shunt around the lamp which, when closed, prevents its lighting. In this case, when the supervisory relay is de-energized, its armature falls back to break the shunt and light the lamp.

Considering the circuit in the form in which it is shown in Fig. 251, it is clear that the lamp cannot be lighted at all until the plug is inserted in a jack. Then its illumination will depend on the position of the substation hook switch which controls the flow of transmitter current in the metallic circuit of the line, a part of this current energizing the supervisory relay.

Were it not for the non-inductive resistance shunting the coil of the supervisory relay, a serious objection could be urged against this type of cord circuit. The inductive reactance

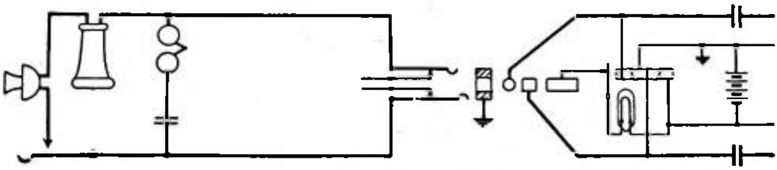


FIG. 252.—Supervisory-lamp control—lamp in sleeve strand of cord.

of the relay magnet coil would offer too high impedance to the passage of voice currents. This objection is practically overcome by the non-inductive resistor around the relay coil. This resistor offers little obstruction to the alternating component of the current and yet forces enough of the current through the relay coil to assure the operation of the relay. Of course, this reduces the sensitiveness of the relay and also, it cannot be denied, the placing of the relay and resistor in one side of the cord circuit with no compensating element in the other results in a slight unbalancing of the talking circuit. These objections, however, have not proved serious enough to prevent this general type of supervisory control from being more widely used than any other, as will be seen when common-battery multiple switchboards are considered.

The type of cord circuit shown in Fig. 252 is one largely used in non-multiple common-battery switchboards in both Bell and independent fields. This employs the condenser-impedance-coil type of battery supply instead of the repeating-coil type used in the circuit of the preceding figure. When the cord circuit is idle, the local circuit of the supervisory lamp is open at the sleeve contact of the plug. It is closed to ground at this point, however, when a connection is made with a line, so that the lamp is then subject to the control of the supervisory relay. The two windings of this relay are alike and form the impedance coils of the battery feed to the two talking strands of the cord circuit. They are so connected that their magnetic effect on the relay core is cumulative rather than differential. The operation of the relay thus depends on the flow of battery current to the substation transmitter when the subscriber's receiver is off its hook. When so energized, it attracts its armature to extinguish the supervisory lamp. This circuit leaves both of the talking conductors entirely free from either series resistances or retardation coils and, moreover, gives a properly balanced talking circuit.

Both of the cord circuits of Figs. 251 and 252 require an extra strand in the switchboard cord and extra contacts in the plug and jack. The third strand of the cord terminates in the sleeve contact of the plug, which is adapted to register with a grounded sleeve contact in the jack. The sleeve strand with its corresponding sleeve contacts in plug and jack are spoken of as "extra" because they are in no wise a part of the talking circuit. It is not surprising therefore that attempts have been made to do away with these extra strands and contacts and accomplish the supervisory signaling as well as other functions over the two sides of the circuit necessarily involved in the talking circuit. A number of plans have been applied to this end, resulting in the so-called "two-conductor" switchboard circuits but, for reasons that will appear, they have generally been abandoned in favor of some of the "three-conductor" circuits like those just discussed.

One of these two-conductor cord circuits is shown in Fig. 253. Here the grounded sleeve contact of the jack is dispensed with as is the third contact of the plug and the third strand of the cord. Connected in series in the two strands of the cord circuit are the two equal windings of a differential supervisory relay. The battery current fed to the line through the cord circuit passes in series through these relay windings, but, since the windings are differential, the relay remains unenergized. The supervisory lamp is thus not lighted either when the cord is idle (because of no current through the relay windings) or when the cord is in use with the subscriber's receiver off its hook (because of equal currents in opposite directions passing through its windings). The lamp is lighted, however, when the subscriber of the connected line hangs up his receiver, for then a circuit is established from the ungrounded pole of the battery through the ring side of the cord and one limb of the line to ground through the substation ringer.

A number of these differential-relay two-conductor cord circuits came into commercial use early in the present century. They have not generally survived, however, for two principal reasons: First, the use of a ground return circuit between the central office and the outlying subscriber's stations in a city exchange area was objectionable, differences between the earth potential at the central office and that at the outlying points

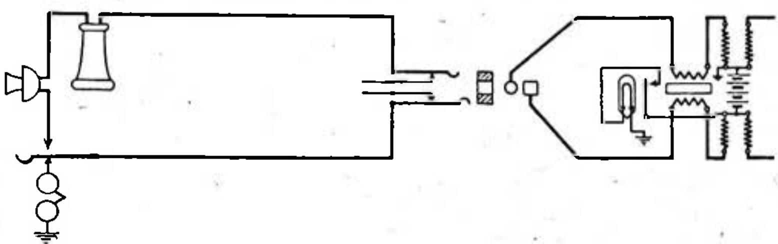


FIG. 253.—Supervisory-lamp control—differential relay.

sometimes affecting the reliability of the signals. Second, while it was easy enough to make the relay windings neutralize each other with respect to the direct component of the current involved in signaling, it was not so easy to do so for the alternating component involved in voice transmission. The ordinary "sandwich" differential winding (Fig. 205, "Theory and Elements") proved "neutral" enough for the direct signaling currents but it left much to be desired in respect to the impedance it offered to the passage of voice currents. To cure this would involve the employment of some such differential winding as that suggested in Fig. 203 ("Theory and Elements"). This, besides other objections, would involve placing the two wires so close together for such a length that they would act as a condenser bridged across the talking circuit of the cord, thus introducing a transmission loss not to be tolerated.

The Common Battery in Circuit Diagrams.—Before discussing the joint operation of such line and cord circuits, we may call attention to two different methods, each often employed, of representing the common battery in telephone-circuit diagrams. These two methods are illustrated in the diagrams of

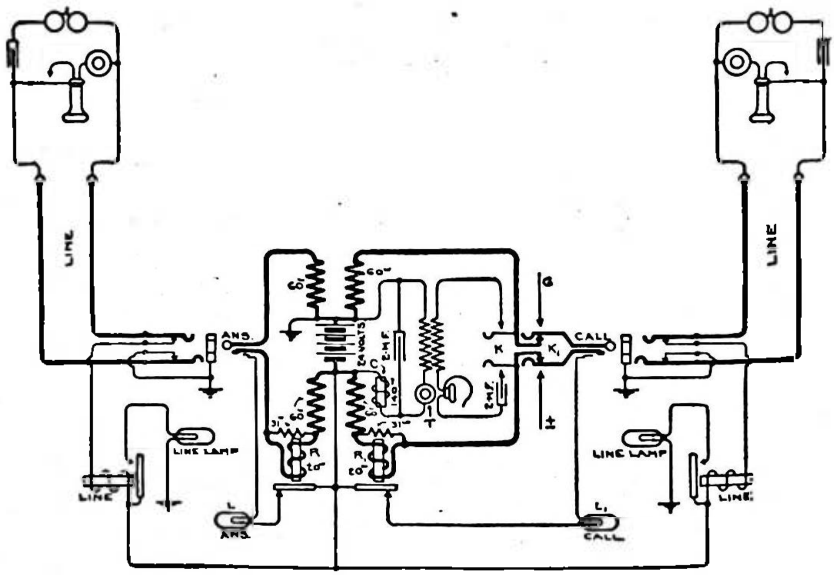


FIG. 254.—Typical circuits small common-battery switchboard.

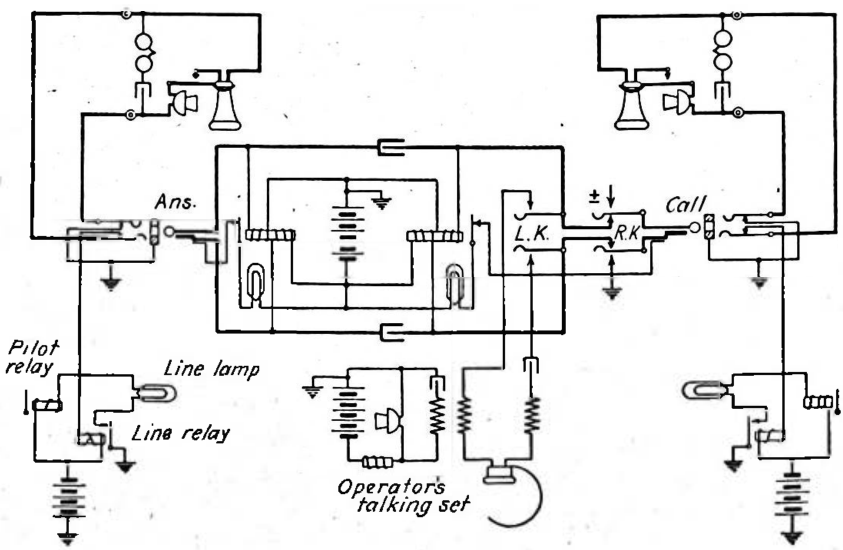


FIG. 255.—Typical circuits small common-battery switchboard.

Figs. 254 and 255, presently to be described. In the diagram of Fig. 254 the battery symbol is shown but once. Where this is done, all connection with the ungrounded or negative side of the battery must be indicated by lines running to the single-battery symbol. In the other method, employed in Fig. 255, the battery symbol is shown several times, although, as before, only a single battery is referred to. This practice, sometimes a little confusing to the beginner, obviously saves the running of many lines across the diagram to a common point and often prevents much crossing of lines and consequent confusion. In each of these diagrams the several ground symbols may all be taken as representing a common grounded conductor to which the positive pole of the common battery is connected.

Operation of Switchboard.—From the foregoing description of various types of line and cord circuits, considered separately, the details of their operation when combined to form complete switchboards will be fairly obvious. We may, however, briefly consider the routine operation of two typical examples. In Figs. 254 and 255 are shown the circuits of two simple common-battery switchboards, represented in each case by two lines and a single cord circuit.

The line circuit of Fig. 254 is essentially that of Fig. 249, and the cord circuit that of Fig. 251. The routine operation is as follows: The subscriber at the left of the diagram, desiring a connection, removes his receiver from the hook, thus energizing the line relay and lighting the line lamp. In response to this the operator inserts an answering plug into the jack of that line, thus cutting off both sides of the normal line signal circuit at the jack and establishing connection between the line and the cord circuit instead. Since the calling subscriber's receiver is off its hook at this time, the answering supervisory relay receives current through the talking circuit and thus prevents the lighting of the answering supervisory lamp. Having thrown her talking key K, the operator's telephone is bridged across the cord circuit and she is thus enabled to receive the number desired from the calling subscriber. Learning this, she inserts the calling plug into the jack of the called line and operates the ringing key K_1 to ring the bell of the called subscriber. The insertion of the calling plug into the jack of the called line causes the calling supervisory lamp L_1 to light, because the called subscriber's receiver is still on its hook. As soon, however, as the called subscriber responds, the calling supervisory relay is energized by the flow of current over the line and the lamp is extinguished. After conversation, when either subscriber hangs up his receiver, the corresponding supervisory lamp will be lighted by the falling back of its relay armature. The lighting of both the lamps serves as a signal to the operator to take down the connection..

The operator's telephone circuit brought into connection with the cord circuit by the listening key *K* of Fig. 254 deserves attention. Current from the 24-volt common battery is supplied to the operator's transmitter *T* through an impedance coil of high reactance. This, in connection with the primary of the operator's induction coil, has enough ohmic resistance to limit the direct-current flow to the amount required by the transmitter. A 2-microfarad condenser is bridged across the primary circuit in such manner as to shunt the primary coil in series with the transmitter. There is thus formed, in effect, a local circuit, of low impedance to voice currents, in which the transmitter may act to vary the current through its primary coil. The fluctuations thus produced act through the induction coil to induce currents in the secondary circuit in the usual manner. The operator's receiver and the secondary of her induction coil are associated with the primary circuit in the same manner as in magneto boards, with the exception that a condenser is placed in series with the receiver. The purpose of this is to prevent the operator from receiving an undue click in the ear when she operates her talking key.

In Fig. 255 the two line circuits are of the same type as Figs. 249 and 254. The cord circuit, however, is of the condenser-impedance-coil type shown in Fig. 252. The routine operation of this circuit will be clear from what already has been said.

In either of these complete switchboard circuits it will be understood that the lamp-in-line type of line circuit may be substituted for the line-relay type. By referring again to Fig. 249, it will be seen that, if the two wires leading from the jack and lamp to the line relay are cut at the points x and x and their upper ends joined together, the circuit will be converted to the lamp-in-line type of Fig. 248. Some small common-battery switchboards are made so as to facilitate this change so that the short lines may be of one type and the long ones of the other.

It will also be understood that, instead of the simple one-party ringing key shown on the calling cord only, keys for various kinds of party-line ringing may be provided, and on the answering as well as the calling cord if so desired.

Operator's Telephone Circuit.—The general subject of the operator's talking set merits somewhat more extended attention than has been given in the description of the foregoing switchboard circuits. We have already seen in Chap. IV that the "side tone" heard in one's own receiver as the result of the operation of his own transmitter may be objectionable from two different standpoints. First, the comparatively loud tones resulting from the action of the transmitter of the same set tends to lessen the sensitiveness of the ear of the person talking to the more feeble incoming currents from the distant station. Second, the loud tones he hears from his own transmitter are likely to make him speak more softly, and thus not loud enough to produce the desired effect in the receiver at the distant station. These considerations, for obvious reasons, are particularly pertinent to switchboard operators' telephone sets and

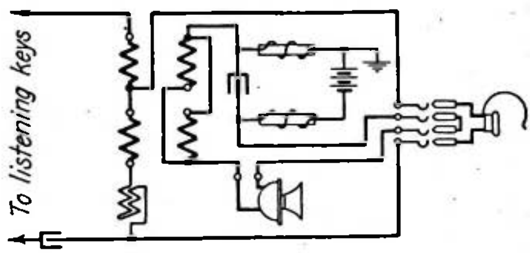


FIG. 256.—Anti-side-tone operator's circuit.

have led to much effort toward the development of efficient "anti-side-tone sets" for operators' use.

A good example is the standard operators' circuit of the Stromberg-Carlson Company, shown in Fig. 256. This employs two induction coils mounted side by side on a single base. One of the secondary windings carries an additional non-inductive winding connected in series with it as shown. The circuit as shown is for a suspended type of transmitter, the head receiver only being carried on the cord terminating in the operator's cut-in plug. Obviously, if a breastplate transmitter is desired, the usual breastplate set may be substituted by connecting its transmitter across the two inner contacts of the operator's plug.

The point of real interest about this circuit is its anti-side-tone feature. We may consider this more easily in connection with Fig. 257 which shows exactly the same circuit connections stripped of detail. The two primary windings, of about 15 ohms resistance each, are connected in parallel in a local voice-current circuit containing the transmitter and a condenser in series. Battery current is fed to this circuit through two reactance coils connected on opposite sides of the condenser. Variations of resistance in the transmitter disturb the normally steady voltage across the condenser terminals and cause fluctuations in the otherwise steady current through the primary windings. These induce corresponding currents in the two secondary coils, of about 91 ohms resistance each, which are connected in series. When the talking key is thrown, these currents pass over the line to the receiver at the distant station.

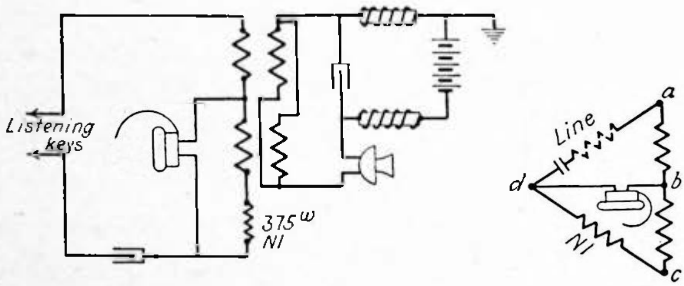


FIG. 257.—Anti-side-tone operator's circuit—simplified diagram.

Let us see how these induced currents affect the receiver of the operator whose voice is thus being transmitted to the distant station. The small diagram at the right of Fig. 257 will be found correctly to represent the secondary-coil connection when the listening key is thrown. Since the two secondary coils are alike, it is evident that at any time the potential generated in *ab* will just equal that in *bc*. In other words, point *b* is the point of mid-potential. Now let us assume that the coil in the branch *cd* has the same impedance to voice currents as that of the subscriber's line and condenser in the branch *ad*. Then the drop from *a* to *c* through the path *adc* would be equally divided between the branches *ad* and *dc*, so that point *d* is the point of mid-potential in this path. Under these assumed conditions there would be no flow of current through the operator's receiver in the branch *bd*, because the terminals of that branch would be at the same potentials.

Now the conditions just assumed cannot be realized in practice because the lines vary in length and resistance, and also because the impedance of the line would vary for different frequencies while that of the non-inductive coil would remain the same for

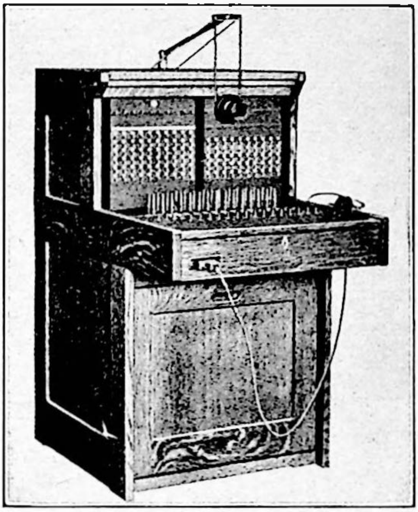


Fig. 258.—Small common-battery switchboard—front view.

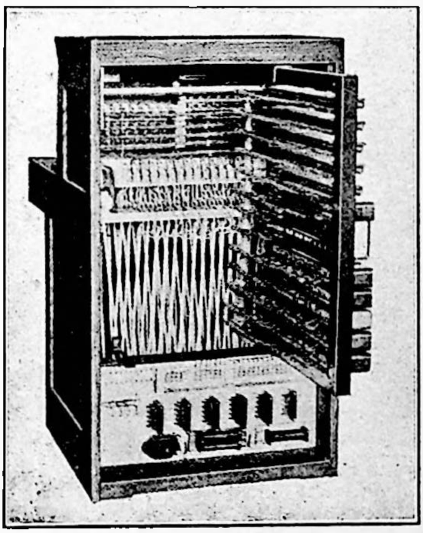


Fig. 259.—Small common-battery switchboard—rear view with apparatus gate open.

all frequencies. However, by giving the coil a resistance approximating the impedance of the average line to voice currents, it is evident that the effect of the action of the operator's transmitter on her own receiver, while not completely neutralized, will be greatly reduced. No such neutralizing action is experienced for incoming voice currents from the distant station. Here, referring to the small diagram of Fig. 257, the branch *ad* generates the varying currents. These pass through the secondary coil *ab* in series with the receiver, the latter being shunted by the other secondary coil *bc* and the non-inductive resistance in series.

This operator's telephone circuit is typical of many employed in common-battery switchboards where it is desired to suppress the side tone.

Switchboard Cabinet and General Assembly.—Two views of a Kellogg single-position common-battery switchboard are shown in Figs. 258 and 259. These illustrate modern practice in the general assembly and mounting of the various switchboard parts in relation to the supporting and enclosing cabinet. In large switchboards, of the types to be considered later, the relays are mounted on racks separate from the switchboard and usually in another room. In such small boards as here considered it is feasible to mount the relays within the cabinet, thus comprising the entire switchboard within a single compact unit. The mounting of the relays on an iron rack or "gate" adapted to swing outwardly, so as to allow access to both its sides and to the jacks, lamps, and cords attached to the stationary part of the cabinet, marks a distinct advance, contributing to both compactness and accessibility.

As stated at the beginning of this chapter, the non-multiple common-battery switchboard finds its greatest use in private branch exchanges and will be considered at greater length in a chapter relating to that subject.[1] It has been given preliminary treatment here in order to discuss common-battery switching practice in its simpler phases and thus serve as an introduction to the more complicated phases to follow.

[1] "Automatic Switching and Auxiliary Equipment," Chap. X.

CHAPTER X

GENERAL FEATURES OF MULTIPLE-SWITCHBOARD PRACTICE

Limitations of Non-multiple Switchboard.—When the number of calls arising on the lines of a central office during the busiest period of the day is so small that a single operator can handle them all without undue delay, a single-position switchboard suffices. When the calls occur at a faster rate, either because more lines are added or because their average busy-hour calling rate increases, another position of the same sort of switchboard may be placed alongside the first to enable a second operator to share the load. The line jacks and signals, one of each for each line, are then divided between the two positions and each position is given its quota of cord-circuit equipment. The space occupied by the jacks (jack field) is in this case so small that each operator may reach all over it and thus without aid establish a connection between any two lines. Since each line has but one point of access (one jack), there is no danger that the two operators may establish duplicate connections with the same line.

To provide for the second operator, the width of the switchboard, or more properly its length, has thus been increased, but not to such an extent as to place any of the jacks beyond the reach of either operator. With ordinary width of switchboard position (in the neighborhood of 24 inches) an operator may easily reach over the entire jack field of an adjacent position on either side of her. In a two-position switchboard, therefore, no problem of reach is encountered. Either operator, after answering a call, usually though not necessarily originating at her own position, may complete the connection with the jack of the called line, even though it is located on the remote edge of the other position.

When the traffic grows beyond the capacity of two operators, the mere addition of a third position does not afford quite so satisfactory a solution. The operator at the center position has no difficulty in reaching the entire jack fields of the two others, but the operators at either of the end positions cannot so easily reach into the fields of the other end positions. Connections might be made, of course, by an end operator passing the calling plug of the pair she used in answering to the center operator who could then reach the required jack on the remote position. This, however, evidently is not a clean-cut solution, even for a limit of three positions. Beyond three positions it is easy to see that the procedure of merely adding new positions to provide for growth brings about unworkable conditions. Among other things it entails cords of impracticable length.

The Transfer Switchboard.—One way of solving the problem of increased switchboard capacity was found in the so-called "transfer boards" which were quite extensively used in some early central offices of considerable size. In these, the connections between two lines terminating on portions of the board remote from each other were completed by means of auxiliary links extending between the various positions. These were called "transfer circuits" and would now be called "local trunk circuits" or merely "local trunks." In some systems the transfer circuits terminated in a jack at each end, in others in a plug at each end, and in still others in a jack at the originating end and a plug at the distant end. The last was the most common and probably the best arrangement. However the trunks terminated, the operator who answered a call, after finding that the jack of the called line was not within her reach, would extend the calling line through a trunk to a position within reach of the called line jack. Then, by telephoning over the trunk circuit or over a separate circuit ("order wire"), she would give the second operator the required information so that she in turn could connect the other end of the transfer circuit with the required called line.

The principal advantage of the transfer switchboard was its low initial cost and the comparative ease with which it could be expanded to meet the requirements of growth. One of its disadvantages was that, even in medium-sized offices, most local connections required the attention of two operators. It was given a thorough trial and, while some central offices serving several thousand lines were operated by it with apparent success, it could not survive in any large way because the multiple switchboard offered a better solution.

It must not be supposed, however, that the requirement of two operators to complete a connection disappeared with the passing of the transfer switchboard. Obviously, in multi-office manual exchanges an operator in each of at least two offices will be involved in every connection between lines terminating in different offices. Also, as will be shown, in very large manual exchanges the practice is often followed of employing two operators for every connection even though the two lines terminate in the same office.

Lines versus Traffic.—The practical limit of the simple non-multiple switchboard is ordinarily reached at a few hundred lines, but this is not because the space is lacking for a very much greater number of line terminals within the direct reach of an operator. It is an easy matter, for instance, to place several thousand line jacks and lamps within a field over which an operator may readily reach. It is well to appreciate at the outset, therefore, that the requirement which makes the multiple switchboard necessary in manual-switching practice is the *amount of traffic to be handled* rather than *the mere number of lines*. If the total number of calls arising on all the lines in a given time were so few that one or a few operators could attend to them promptly, a very large number of lines could be served by a non-multiple board. Regardless of the mere number of lines, as the traffic increases, the number of operators required to handle it increases. It is primarily the necessity of providing working space for this increased number of operators that calls the multiple switchboard into being.

To show more clearly that it is the amount of traffic instead of the mere number of lines that is the controlling factor, we may consider several different cases, each with the same number of lines but with widely differing volumes of traffic. We may take an assumed office serving, say, 5,000 lines. Practically there would be no difficulty in placing 5,000 jacks and line lamps, within the reach of a single operator. Now if the subscribers on this group of 5,000 lines called only twice a week and at such times as to spread the calls uniformly throughout the entire period there would result only about 60 calls an hour. A single operator could handle this with ease. Under such an assumption, which is extreme in several respects, a simple non-multiple board would suffice.

As a second case, let it be assumed that the calling rate is two a day instead of two a week and, as before, that the calls are distributed uniformly over the 24-hour period. The resulting traffic would be something like 416 calls an hour, probably beyond the capacity of one operator, but well within that of two. Again, there would be no difficulty, for each of the two operators required could reach all over a common 5,000-line jack field, each completing herself the calls she answered, and together handling all the traffic.

Now, from the standpoint of actual practice, there are two things wrong with each of the foregoing assumptions: first, lines have very much higher calling rates and, second, the calls are not distributed uniformly throughout the twenty-four hours but are largely concentrated within short periods of relatively intense activity. We may, therefore, take our third case more in line with practical conditions. Let it be assumed that *during the busy period* the 5,000 lines originate calls at the rate of two per line per hour. Thus, instead of 60 or 416 calls per hour, as in the first two cases assumed, we would have to provide for their occurrence at the rate of 10,000 per hour. If we assume that in this particular office the conditions are such as to make it possible for the operators to attend to an average of 200 calls an hour, 50 operators would be required to handle the busy-hour traffic. With still heavier traffic or with conditions making for lower average operators' loads, the number of operators required and the *number of switchboard positions* would be correspondingly increased.

For actual traffic conditions the problem evidently takes on an entirely different aspect from that of the first two cases assumed, although the total number of lines remained the same in all three cases. The physical dimensions of the human operator evidently enter as a controlling factor, for each operator requires a certain amount of space (elbow-room) in order to do her work comfortably and efficiently, and each has a fairly well defined reach. It is obviously impossible to crowd fifty operators within a space small enough for each of them to reach over.

The Multiple-switchboard Idea.—The width of jack field over which the average operator may comfortably reach is in the neighborhood of six feet, and within such a width not more than three operators can conveniently work. The multiple switchboard meets this space problem by the simple expedient of placing a complete quota of jacks (one for each line) within a unit jack field small enough to be easily reached over by an operator and then repeating this unit jack field along the length of the board as many times as it is necessary to afford working room for the required number of operators. In this way the basic requirement is met: There is provided the necessary equipment and associated working space to accommodate the number of operators required to take care of the traffic during the busiest period. This, of course, greatly multiplies the number of jacks but it attains the important result that, no matter where an operator is working on the board, she has within her reach a terminal for every subscriber's line in the office.

The jacks in these fields that are thus repeated at regular intervals along the board are termed "multiple jacks," and the entire aggregation of them with their connecting wiring is referred to as the "multiple." Evidently, each line has as many multiple jacks as there are sections of the multiple.

The arrangement of the multiple jacks is exactly alike on each section of the multiple and, therefore, with as many as three operators' positions to each section it follows that, except for the two end positions of the switchboard, an operator at any position can reach the equivalent of an entire multiple section. An operator at the center position of a section, for instance, can reach all over it; one at a right-hand position can reach about two-thirds of the jacks in that section and the remaining third in the section at her right; and similarly for the operator at a left-hand position. The positions at the extreme ends of the multiple are usually left blank, as far as cord circuits and operators' equipment are concerned, so that the end operators may each have a full multiple available without undue reach.

The Busy Test.—Further thought will show that while this arrangement of multiple-line terminals accomplishes the purpose of permitting every operator to reach all the lines of an office, it creates another problem—the avoidance of different operators making more than one connection at a time with the same line. This would cause confusion that could not be tolerated. To guard against it, the "busy test" is provided. By it, as soon as a connection is made with a line at any section, the electrical condition of all the jacks of that line is so altered that an operator at any other section, in attempting to make a connection with the line, will be warned that a connection already exists. This warning is usually given by means of a click in the operator's head telephone when she starts to thrust a plug into the multiple jack of a busy line.

Multiple-switchboard Terminology.—Having established the basic principle from which the multiple switchboard derives its name, that is, the repeating or "multipling" of the jack groups along the face of the board so that each operator may have within her reach a terminal for every line in the office, we may now mention a broad classification of multiple switchboards according to whether they are designed directly to handle calls originating on subscribers' lines or those coming over

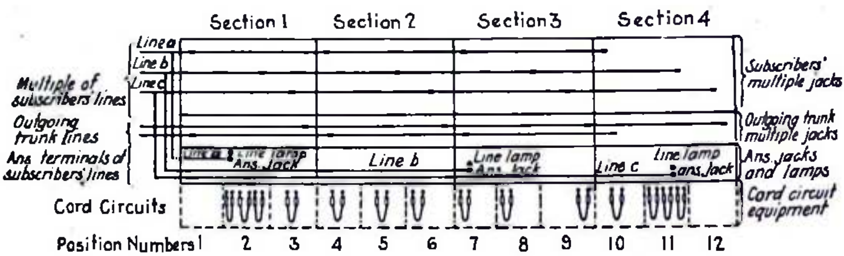


FIG. 260.—General arrangement of subscriber or "A" multiple switchboard.

trunk lines from other offices. Those switchboards, sections, or positions at which subscribers' calls are answered and either completed in the same office or extended to other offices are called "subscriber," or "A," switchboards, sections, or positions; those at which calls trunked from other offices are received for completion in that office are called "incoming trunk," "trunk," or "B," switchboards, sections, or positions. These names have been extended to the operators themselves, so that we have well established the terms "subscriber operators," or "A operators," and "trunk operators," or "B operators."

Evidently in a single-office exchange there will be only a subscriber, or "A," switchboard for no trunking will be required on exchange calls. In multi-office exchanges both subscriber, or "A," and trunk, or "B," switchboards (or at least some sections or positions of each) will be required at each office in order to make inter-office connections.

Subscriber, or "A," Switchboards.—Figure 260 attempts merely to suggest the general arrangement of the face equipment of a comparatively small "A" board with four sections and ten working positions. Except in the recently adopted "multiple-line lamp" switchboard which will be considered later, the multiple jacks of the subscribers' lines are used only for completing connections with *called* lines. For establishing the initial connection with *calling* lines, another set of jacks is provided. These are called "answering jacks" to distinguish them from the multiple jacks, and for the present discussion we may consider that there is but one of them for each line.

Each answering jack is directly associated with a line signal by placing the two in immediate proximity, so that the display of the signal will at once indicate the corresponding answering jack. These are apportioned among the operators' positions in such manner that the number of calls likely to arise on each position during the busy hour will constitute as nearly as possible a proper operator's load. In this way each operator has assigned to her a comparatively small group of lines, the calls of which she is to attend. The answering jacks and line signals usually occupy the space at the bottom of the vertical face of the switchboard just above the plug shelf. The line signals are thus in the direct field of vision of the operator, and the answering jacks in the position most easily reached.

Between the subscribers' multiple and the answering jacks on the face of the board is the "outgoing-trunk multiple." This consists of multiple jacks, multipled throughout the sections, for each trunk line extending from this switchboard to the "B" board of some other office.

A number of cord circuits are provided for each position. The operator at any position, in response to a call indicated by one of her line signals, inserts one plug of a pair into the corresponding answering jack and, having ascertained the number of the line desired and found that it is not busy, inserts the corresponding plug of the pair into the multiple jack of the line called for, whether it be a subscriber's line or a trunk line. She is thus enabled, without assistance from any other operator, to complete a connection with any line in the office in response to the request of any one of the comparatively small group of subscribers whose lines she attends.

The underlying plan of the subscriber, or "A," switchboard is thus very simple: operator's positions are provided and equipped in sufficient number to accommodate the number of operators required during the busiest periods promptly to answer the calls and make the connections and disconnections; the answering jacks and line signals are distributed among these positions in such manner as properly to apportion the load among the operators; and the multiple jacks for both subscribers' lines and trunks are repeated along the face of the board in such manner that each operator always has within her reach a jack for every line of the office. The apparent complexity of the multiple switchboard is due mainly to the great number of repetitions of a few different circuit units—each, in itself, comparatively simple.

The connection of two subscribers in the same office area through a subscriber, or "A," switchboard is indicated in

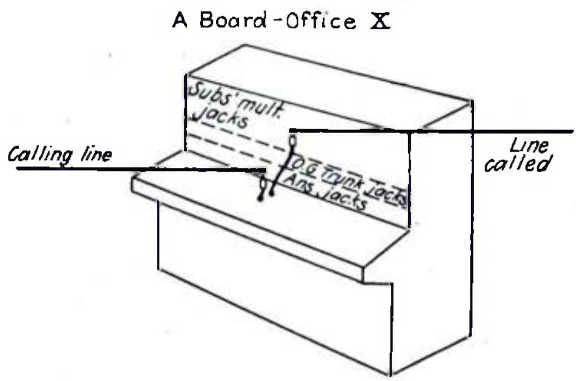


FIG. 261.—Simple connection through "A" board only.

Fig. 261. Had the subscriber called for been in another office area the right-hand plug of this diagram would have been inserted in an outgoing-trunk jack in order to extend the connection through a trunk to the other office, as will be described later.

Sometimes more than one answering jack is provided for each line. The additional ones, connected in multiple with the first, are called "ancillary" answering jacks and are usually placed on adjacent sections. The purpose of thus providing a plurality of answering jacks for each line is to aid in "team work" among the operators. Under the laws of chance calls do not arrive before the different operators at uniform rates, so that from moment to moment some operators are too busy while others are comparatively idle. The provision of ancillary jacks tends to equalize the load by enabling the operators to help each other more effectively than if each line had but one point of answering access.

Inter-office Trunking.—As a preliminary to the consideration of the trunk, or "B," switchboard we may consider briefly a few of the broader phases of inter-office trunking. If it were possible to build switchboards of unlimited size, it would, at least theoretically, be possible to serve all the lines even in the largest exchange from a single central office. It would probably not be economical to do so, however, for several reasons, among which is that the cost of running all the subscribers' lines to a common center serving the whole area would be very much greater than that involved in running them to a number of centers each serving its particular smaller area.

As will be shown later, the consideration of all factors in exchange design has led to fixing the maximum capacity of central-office switchboard units in the neighborhood of ten thousand subscribers' lines. Very often, however, it is found advisable to subdivide an exchange area into smaller central-office areas with smaller-capacity switchboards than would be the case if this limitation in switchboard size were alone considered. In fact, in many American cities where the total number of subscribers' lines is less than ten thousand, and therefore within the capacity of a single multiple-switchboard unit, several central offices with trunking between are employed instead of a single office with no trunking.

One-way and Two-way Trunks.—As in railroad practice, the trunk system may operate on a "single-track" or a "double-track" basis. The single-track inter-office trunk plan necessarily employs "two-way" trunks. This means that each trunk may be used in establishing connections in either direction according as the call originates in one office or the other. Two-way trunks are used only where there is a very small amount of traffic between the two offices they connect. As a rule, they are terminated in jacks at each end, multipled throughout the sections where multiple boards are employed, and each has a drop or equivalent ring-down signal. When an operator at either end receives a local subscriber's call for someone in the distant office, she merely inserts her calling plug into the trunk jack and rings as she would on a local line. An operator at the other office answers in the usual way and receives the number from the first operator over the trunk line. She then completes the connection with the calling plug of the pair used in answering. Connections in the opposite direction are made in exactly the same way. Such two-way trunks are often called "ring-down" trunks. Their operation is relatively slow and also inefficient in respect to the number of calls they can carry in a given time. For these reasons they are little used in inter-office exchange trunking where considerable amounts of traffic are involved.

The double-track plan employing one-way trunks is much more rapid in its operation and also more economical in the use of trunks where there is enough traffic to justify its use. To illustrate this plan, consider any two central offices, X and Y, in a city exchange with enough traffic between them to call for more than a very few trunks between them. These trunks

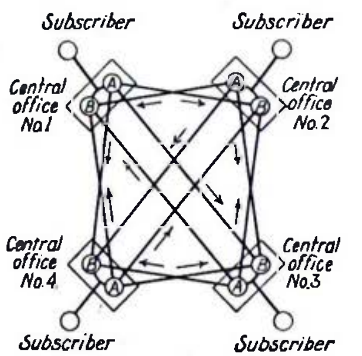


FIG. 262.—Direct trunks in multi-office system.

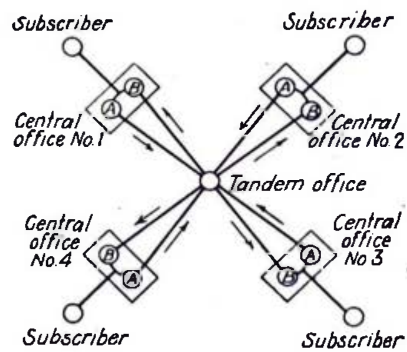


FIG. 263.—Tandem trunks in multi-office system.

are divided into two groups, one for calls originating in office X, the other for those originating in office Y. Each trunk has an "outgoing" and an "incoming" end, and it is evident that the outgoing trunks of office X will be the incoming of office Y, and *vice versa*. For reasons that will presently appear, the incoming and outgoing trunks of each office terminate on separate switchboards—that is, on the "B" and "A" switchboards respectively as already defined.

Direct and Tandem Trunking.—It is desirable, of course, in order that not more than two operators shall be required in the completion of a trunked connection, that a group of trunks extend from each office to each other office in the exchange area. Such a "direct-trunking" plan for four offices is indicated in Fig. 262, the arrow indicating in each case the direction of the traffic from the outgoing terminals on the "A" board at one office to the incoming terminals on the "B" board at the other.

Direct trunks, though always desirable, often cannot be justified between every pair of offices in a large multi-office exchange. In order to economize in trunks and obtain the higher efficiency of larger trunk groups what is called "tandem trunking" is employed for widely separated offices between which the traffic is relatively small. This gain in trunk efficiency is, of course, to be weighed against the disadvantages of requiring three operators in each call completed through tandem trunks.

The general scheme of tandem trunking for four offices is illustrated in Fig. 263. Here two groups of trunks, incoming and outgoing, are run from each office to the centrally located tandem office through which all trunked calls are routed. The gain in the size of trunk groups is seen by comparison with the preceding figure, all the trunks to and from each office being embraced in two groups instead of six. It must not be inferred, however, that even in the largest exchange areas tandem trunking is ever employed to the exclusion of direct. Adjacent offices or offices between which there is heavy traffic are nearly always connected by direct trunks, so that in a large exchange area a combination of the two plans would be employed.

Incoming Trunk, or "B," Switchboards.—The reasons for the segregation of equipment as between subscriber, or "A," boards and trunk, or "B," boards may now be made clearer. Obviously, the outgoing trunks must be made readily available to the "A" operators who answer the calls of the local subscribers, so that they may connect a calling line to a trunk leading to a distant office when so required. Also, since the "A" operators do not know at the time they answer calls whether they are to be for the line of a local subscriber or for one at a distant office, it is highly desirable that they be able to complete the trunk connections with the calling plugs of the same pairs used in answering. These considerations rather definitely demand that the outgoing ends of the trunks shall terminate in jacks that will cooperate with the calling plugs of the "A" operators' cord circuits. Also since the outgoing trunk must be available to all the "A" operators in the office, its jacks, like those of a subscriber's line, must be multipled through the sections of the "A" board. We have already seen in the discussion of the "A" board (Figs. 260 and 261) how these provisions for the outgoing ends of the trunks are carried out on that board.

Consider now the other ends of these trunks, the incoming trunks at the terminating office. A little thought will show that there is no need for their equipment to be associated at all with the "A" operators' position equipment. The "A" operator makes verbal contact with the subscribers and, in the case of trunked calls, performs the initial acts involved in the connection. Moreover, after the connection is established, she presides over it and finally initiates its taking down. The "B" operator, on the other hand, makes no verbal contact with the subscribers and presides solely over the incoming ends of the trunks, acting always under instructions (verbal or

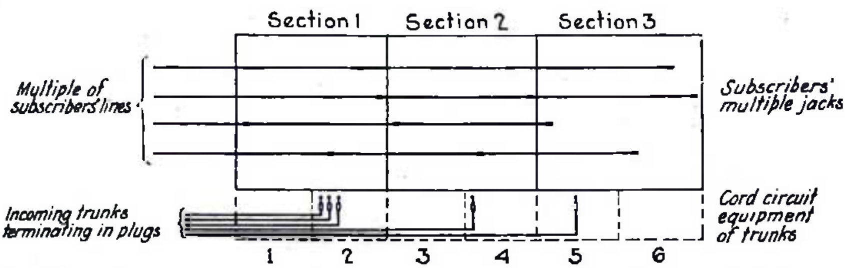


FIG. 264.—General arrangement of incoming trunk or "B" multiple switchboard.

signaled) of the "A" operator. For these reasons the incoming trunks are terminated on "B" positions which are entirely distinct from the "A" positions and presided over by a different set of operators who are skilled in this particular work.

These incoming trunk ends at the "B" positions of an office have to do only with calls that have been directed to this office for completion. This presents definitely the requirements that a complete subscribers' multiple be available to each "B" position and that the incoming trunks at these positions be so terminated as to permit their being connected with the jacks of this multiple with the greatest facility. This connection requirement is best met by terminating each incoming trunk in a single plug. The plugs of different trunks are distributed among the "B" positions in such manner as properly to apportion the incoming trunk load among the "B" operators.

It is feasible to terminate the incoming trunks in this way because the average number of calls per trunk is so great that relatively few trunks supply a "B" operator's load. From thirty to forty-eight trunks ordinarily furnish enough traffic to keep a "B" operator busy and no difficulty is experienced in finding room on each "B" position for that many plugs and cords.

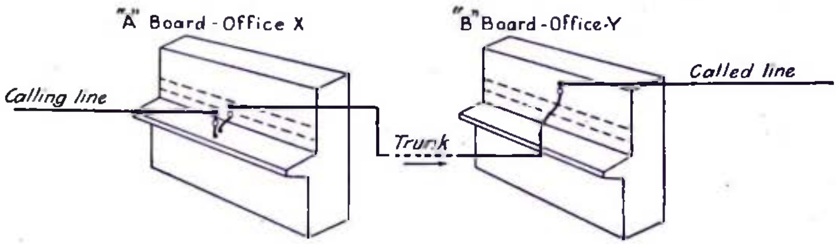


FIG. 265.—Trunked connection through "A" and "B" boards.

The arrangement of the "B" switchboard is suggested in diagram in Fig. 264 where three two-position sections are indicated. As a rule incoming trunk sections are of the two-position type, unless the "A" and "B" boards are in one continuous line in which case the "B" sections usually have three

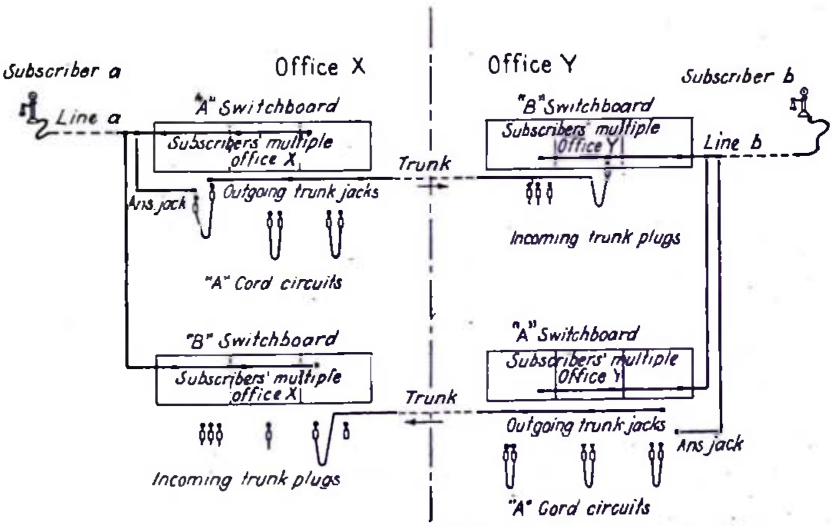


FIG. 266.—Relationship of "A" and "B" switchboards in two offices.

positions each, if that is the type of the "A" sections. In broad outline, each section carries a full multiple of all the subscribers' lines of the local office. Each position carries its operator's telephone set and in addition the equipment for from thirty to forty-eight plug-ended incoming trunks. Any

"B" operator may complete a connection between any one of her trunks and any subscriber's line in the office by merely inserting the plug of that trunk into a multiple jack of that line.

The connection of a calling subscriber's line in office X to a called line in office Y through the two switchboards and an intervening trunk is indicated in Fig. 265, while the provision for the connection in both directions is outlined in Fig. 266.

So far in this very general outline of direct-trunk operation no consideration has been given to the way in which the two operators at the respective ends of a trunk communicate with each other in furthering the progress of the connection desired. Two general methods of doing this require consideration. The

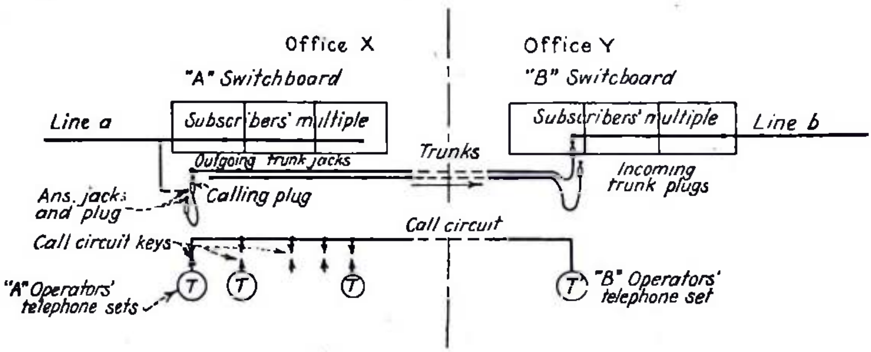


FIG. 267.—Call-circuit or order-wire trunking.

first is the "order-wire," or "call-circuit," method, in which the necessary verbal communication between the two operators is carried on over a talking circuit (order wire or call circuit) entirely separate from the trunk. The second is the "straightforward" method which involves the use of no order wires or call circuits, all verbal communications between the two operators being carried on over the two wires of the trunk itself.

Call-circuit Trunking.—Remembering that each group of one-way trunks (Fig. 266) is available at its outgoing end to a number of "A" operators and at its incoming end to one particular "B" operator, we see that the need of a call circuit, as far as a given group of trunks is concerned, is to provide facilities for any of the "A" operators to whom the trunks are available at one office to communicate with the "B" operator at the other office. Taking two offices X and Y, as before, the arrangement of a single call circuit leading from the "A" operators' telephones T, T, T, etc., of office X to a single "B" operator's telephone T' at office Y is suggested in Fig. 267. The two trunks indicated are representative of a group or groups leading to this particular "B" position. The call circuit is permanently connected to the "B" operator's telephone but at the other end it is normally open, being connected to any "A" operator's telephone set only when she presses her call-circuit key. By this means any "A" operator may place herself in communication with the "B" operator on that call circuit.

In considering the routine of operation under the call-circuit plan, it should be kept in mind that the "A" operator at office X, upon receiving a call for a subscriber in the distant office Y, knows which group of outgoing trunk jacks she is to employ, because the various groups are designated in the outgoing multiple according to the distant office in which they terminate. She has no means of knowing, however, which individual trunk of the group to employ, because any of them may be busy by virtue of connections made with them at other sections of the "A" board. On the other hand, the "B" operator at office Y can always ascertain at a glance whether any trunk is busy or idle, any plug remaining in its seat being idle.

The routine operation under the call-circuit plan of trunking is about as follows: An "A" operator at one office (X, Fig. 267), having received from a calling subscriber a request for a connection in a distant office (Y), depresses a call-circuit key that bears the designation of the desired office. This act connects her telephone T to the call circuit leading to the "B" operator's set T' at office Y and enables her to communicate with that operator. She then tells the "B" operator the number desired and that operator in turn tells the "A" operator what trunk to use. Each operator now has the necessary information to complete the connection. The "A" operator releases the call-circuit key and inserts the calling plug of the pair she used in answering into the designated outgoing-trunk jack. Simultaneously the "B" operator, who has taken up the plug of the designated trunk, proceeds to test the multiple jack of the called line and, if not busy, completes the connection by inserting the trunk plug into the jack.

No further verbal communication is required between the two operators in connection with this call. A complete set of signals keeps the operators informed as to subsequent developments leading to the taking down of the connection. After it is established, the supervision of the connection falls entirely on the "A" operator who originated it. The two supervisory lamps of her cord circuit are controlled respectively by the two connected subscribers. The "A" operator thus initiates the taking down of the connection, and the withdrawal of her calling plug from the trunk jack conveys the necessary signal for disconnection to the "B" operator.

Straightforward Trunking.—This method of trunking, which is rapidly superseding the call-circuit method just outlined, involves the use of no supplementary order wire or call circuits, all the verbal communication between the two operators being carried on over the trunk circuit itself. On its face, this would

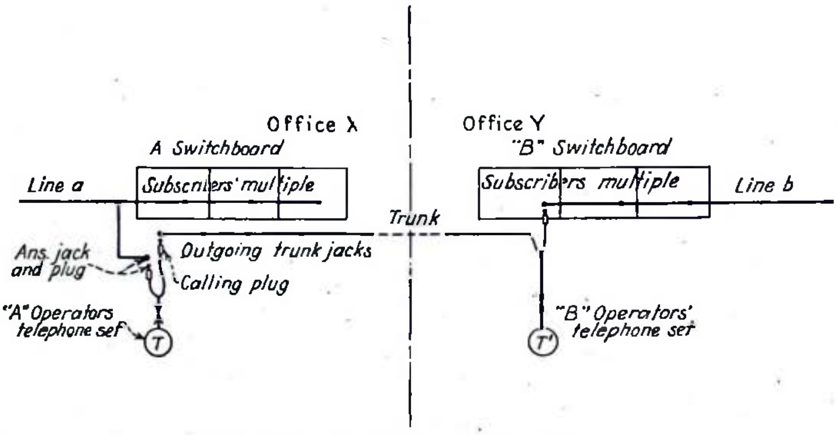


FIG. 268.—Straightforward trunking.

seem to be the logical and "straightforward" method, since, instead of employing a separate system of circuits for communication between the operators, it makes use in each case of a circuit that must be established for the two subscribers to talk over. The two operators involved in setting up a connection merely make temporary use of the trunk already extending between their respective switchboard positions over which the subscribers themselves are later to talk. Strange as it may seem, this plan of using the trunk itself for communication between the operators is about as old as trunking itself and has long been used on ring-down trunks and toll lines and in some cases on automatic trunks, but, until recently, it has not played any important part in manual inter-office trunking. It was only when the call-circuit system became a serious burden, and in fact showed signs of breaking down in very large multi-office systems, that the straightforward method began to come into general use.

Referring to Fig. 268, the general routine of operation in straightforward trunking may be outlined as follows: An "A" operator at one office, having received a request for connection to a subscriber in a distant office, herself selects an idle trunk to that office. She may do this in several ways. One is by running the tip of her calling plug along the sleeves of the row of jacks which bears the designation of the office desired. Busy trunks will have their sleeves grounded and each time the plug tip touches one, a click will be heard by the operator in her head telephone. She plugs into the first jack that produces no click, knowing that no connection exists with that trunk at any other section. The telephone set of the distant "B" operator attending this group of trunks then becomes connected with the trunk selected. This may be done automatically, as the result of the "A" operator's plugging in, or manually by the "B" operator in response to a signal on that trunk. As soon as the "B" operator's telephone is so connected with the trunk, a tone signal is conveyed to the "A" operator to indicate that the "B" operator is connected and that she is ready to receive the number. The "A" operator then gives the number of the desired line to the "B" operator, omitting the office name, because the proper office has already been selected by the choosing of the trunk group leading to it. As soon as the "B" operator receives the number she disconnects her telephone from the trunk and inserts the trunk plug into the jack of the called subscriber's line, completing the connection.

The significance of the name "straightforward trunking" is apparent from the mode of operation just described. Instead of the verbal instruction between the two operators being first in one direction and then in the other, as in the call-circuit system, it—and in fact the whole procedure of establishing the connection—proceeds straightforwardly from the calling to the called end.

The Tandem-trunking Switchboard.—The tandem switchboard for handling the traffic through such offices as that at the center of Fig. 263 has plug-ended trunks from the "A" boards at the originating offices and jack-ended trunks leading to the "B" boards at the terminating offices. A connection from calling to called line involving such a board is shown in Fig. 269.

As operated on the straightforward basis, the routine of establishing such a connection is about as follows: The "A" operator at office X receiving a call for a subscriber in office Y selects an idle trunk to the tandem office. As soon as the tandem operator's set is connected to this trunk, the "A" operator receives three short high-pitched tones in her head set as a signal to proceed. The "A" operator passes only the name of the called office to the tandem operator. Receiving this the tandem operator extends the connection by inserting the tandem trunk plug into a jack of an idle trunk leading to the terminating

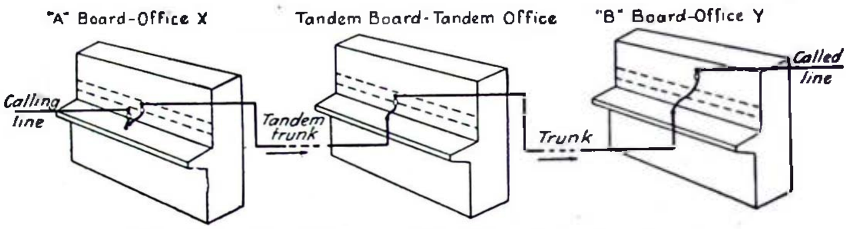


FIG. 269.—Trunked connection through tandem board.

office Y, this act automatically disconnecting her telephone set. The "A" operator then passes the number desired to the distant "B" operator at office Y who proceeds to complete the connection with the called subscriber's line. The tandem operator, having put up the connection, has no further duties in connection with this call until a disconnect lamp tells her to take it down.

General Arrangement of "A" and "B" Boards.—Regardless of the kind of trunking employed, the "A," or subscriber, board and the "B," or incoming-trunk, board constitute two major divisions of the switchboard directly serving subscribers' lines of each office in a multi-office exchange. These two may be placed in the same line and form one continuous structure, the subscribers' multiple extending in an unbroken line through both, as is a common practice in smaller offices. Or, as in larger offices, the "A" and "B" boards may be entirely separate, in separate lines, or sometimes even on separate floors.

The dividing of a switchboard into positions concerns mainly the key- and plug-shelf equipment. Each operator has her own set of cords, plugs, and keys, these being assigned specifically to her individual use while at a given position. She may use them in connection with any of the jacks on the face of the switchboard that she is able to reach. It is well to bear in mind, therefore, that what is called the "position equipment," that is, the cords, plugs, keys, and other equipment associated with the key- and plug-shelf of a position, are normally for the individual use of the operator at that position; and that the equipment on the vertical face of the switchboard consisting, in the "A" board, of the answering jacks, line signals, subscribers' and trunk multiple, and, in the "B" board, of the subscribers' multiple, are in the nature of "common property," to be used by any operator who can reach it.

The beginner is apt to think of the answering jack and line signals as being definitely assigned to the individual operators before whose positions they occur. This is a wrong conception, for, while it is true that an operator will naturally give primary attention to the line signals immediately before her, she will give secondary attention to those in front of the positions on her right and left. She is thus able to help out either of the adjacent operators at times when they are overloaded.

With respect to the subdivision of the common-property part of the switchboard, the face of each section is divided into vertical panels, which are arbitrary divisions, often quite irrespective of the positions. Thus, as an example, the Western Electric No. 1 switchboard when equipped with the No. 92 jack (Fig. 137) has eight panels per 3-position section in the "A" board and seven panels per 2-position section in the "B" board. The dividing lines between the panels are in each case the vertical stile strips upon which the jacks are mounted. The width of the panel is, therefore, primarily a matter of the length of the jack strip, and this in turn is a function of the horizontal distance between jack centers.

Numbering Plan in Subscribers' Multiple.—As the multiple jacks are almost universally mounted in strips of twenty, a group of five strips laid together constitutes a bank of one hundred. A single bank is shown in its relation to its two supporting strips in Fig. 270, which shows also the plan of numbering employed. The jacks in each strip are numbered respectively from 0 to 19, 20 to 39, and 40 to 59, etc. These numerals constitute the units and tens digits of the subscribers' directory number; the hundreds and thousands digits are placed on the stile strip immediately at the left of each hundred bank. Thus, in the figure, the directory numbers of the jacks shown would be from 3100 to 3199, inclusive. Thin horizontal strips of white holly are used to separate each hundred bank from those above and below it. One hundred such banks would constitute one section of a ten-thousand-line multiple, in which the jacks would be numbered from 0 to 9999.

Considerations of "A" Board Multiple.—In an "A" board of a large multi-office exchange having both subscriber and outgoing-trunk multiple, the outgoing-trunk multiple is likely to be used very much oftener than the subscriber multiple,

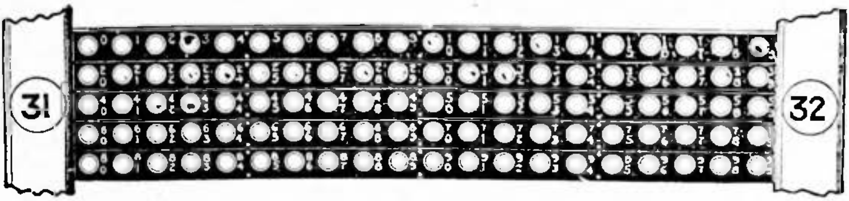


FIG. 270.—Numbering of multiple jacks.

because in such an office most of the originating calls are likely to be for other offices. This makes it advisable in some cases to multiple the outgoing-trunk jacks more frequently than once on every section. We sometimes find, therefore, an "A" board in which the subscribers' lines are multipled on an eight-panel basis, and the outgoing trunks on perhaps a six-panel basis. The purpose of this is merely to make the trunk jacks somewhat more readily accessible to the "A" operators. Whether or not this is done usually resolves itself into the amount of available space on the face of the switchboard. The more frequent multipling of the trunk jacks means, of course, that more of them must be provided, with correspondingly less available space for subscriber multiple and answering jacks. This is an important consideration where a board is approaching its ultimate capacity.

In very large multi-office exchanges, such, for instance, as that of the metropolitan area of New York, it is found that as many as 90 per cent of the calls originating in one office are for subscribers in other offices, which means, of course, that 90 per cent of the connections must, in any event, be completed through the outgoing-trunk multiple. This naturally raises the question as to whether the provision of a subscriber multiple can be justified at all for the small percentage of calls that are completed through it. The answer to this question in many cases has been to omit the subscriber multiple from the "A" boards, with the consequent trunking of 100 per cent of the calls. When this is done, calls for the subscribers in the same office must be trunked through the "B" board of that office and completed through the multiple there in the same manner as an incoming call from any distant office would be completed. This means, of course, an increase of traffic through the "B" board, for which additional "B" board positions must be provided. The saving of investment by eliminating the "A" board subscribers' multiple is not, therefore, clear gain, for against it must be weighed, among other things, the cost of the additional "B" positions required to handle the traffic local to that office.

The elimination of the "A" board subscriber multiple, under such circumstances, does two things besides the avoidance of the large investment required for its installation. It provides room on the face of the board for the more economical arrangement of the outgoing-trunk multiple, and, of more importance, it affords room not otherwise available for ancillary answering jacks. The purpose of multiple answering jacks on the "A" board is, as before stated, to balance the traffic on the various switchboard positions and thus increase the load the operators can carry. This, of course, is of considerable moment, since a single answering jack is accessible to only three operators, whereas two are accessible to six and three to nine operators. As an example, it has been found in No. 1 Western Electric switchboard installations in the Bell System that the provision of one additional answering jack results in the operators being able to carry a 6 per cent increase in load, while the provision of two additional answering jacks results in a 9 per cent increase. It has not been found economical in this type of board to associate more than three answering jacks with a subscriber's line, even under the most favorable conditions for multipling, but, as will be shown in the next chapter, modern tendency in switchboard practice is to associate the line lamps directly with the multiple jacks, doing away with the separate answering jacks entirely. Each multiple jack which has a line lamp immediately adjacent to it then becomes in itself an answering jack. With this arrangement as many as five line lamps are advantageously used on each line.

Factors Limiting Switchboard Capacity.—Obviously in multiple switchboards the number of subscribers' lines that can be served by an "A" or a "B" board depends on the number of multiple jacks that can be placed within reach of an operator, and this in turn depends on the face dimensions of the multiple jack itself.

As a specific instance, the No. 92 jack of the Western Electric Company mounted twenty per strip, which is used in the large-capacity multiple switchboards of the Bell System, has a horizontal and vertical spacing between jack centers of $\frac{3}{8}$ inch. This, considering the extra space necessarily occupied by the vertical stiles and horizontal strips dividing the jack field, makes possible the placing of a maximum of from 9,600 to 10,500 jacks within a section of multiple. In the "A" board the number is somewhat restricted by the number of answering jacks, line signals, trunk jacks, and designation strips that must occupy space on the face of the board in addition to that taken by the multiple jacks. Smaller jacks than the No. 92 have been used, resulting in a correspondingly larger possible number of lines which the switchboard might serve as a maximum. For instance, jacks with a horizontal and vertical spacing of $\frac{3}{10}$ inch have been used in switchboards having possible ultimate capacities of 18,000 lines, under conditions where there were comparatively few outgoing trunks to other offices. In European practice there was at one time a tendency toward the use of very small jacks and switchboards of very much larger line capacity than this. As an extreme case, a switchboard manufactured by the L. M. Ericsson Company of Sweden and installed in Stockholm was designed for an ultimate capacity of 60,000 lines.

Other ways than that of reducing the size of the jack have been proposed for increasing the capacity limit of multiple switchboards. One of these, the "divided multiple board"[1] was invented by the late Milo G. Kellogg and manufactured by the company bearing his name. It provided four separate divisions of the subscriber multiple, each containing jacks for but one-quarter of the lines. The line-signaling system was so arranged

[1] "American Telephone Practice," 4th ed., McGraw-Hill Book Company, Inc., New York, 1904.

that each subscriber could selectively initiate a call in the division of the board containing the multiple of the line desired. Two installations of this board with ultimate capacities of 24,000 lines each were made in St. Louis, Missouri, and Cleveland, Ohio, in about the year 1904. After several years of operation on regular exchange service both were replaced by straight multiple boards. Such radical departures from the straight multiple idea have not been generally successful.

In the United States, several installations of straight multiple boards with $\frac{3}{10}$-inch jacks, designed for ultimate capacities of 18,000 lines, were made by the Kellogg Company, but owing to other considerations, not involved in the design of the switchboard, none of them ever grew to more than about half that capacity. While these were in regular exchange service for a number of years, the consensus of opinion seems to have been that a $\frac{3}{10}$-inch jack is somewhat too small, all things considered, and that the $\frac{3}{8}$-inch jack with the consequent limitation of about ten thousand lines in a single office is better.

One of the considerations which has led to this conclusion regarding the size of jack below which it is not advantageous to go is the degree of ruggedness required of both jacks and plugs, in order that they may withstand the wear and tear of use through long periods of time. Another is that they must not be so small and so closely grouped as to unduly increase the liability of error on the part of the operator in selecting one of them from among many others. Again, considerations of wiring enter into the determination of the practical minimum size of switchboard jacks. If they are made too small and too great a number of them crowded into a given space, then the difficulties of installing the connecting wiring without reducing the size of the wire beyond a practical limit assume importance.

The foregoing factors tending to limit the number of lines to be served by a single multiple switchboard unit we may call "mechanical limitations." They relate to the size of the section and the number of jacks that may be placed within it. But the element of cost also enters as a limiting factor. A little consideration will show that, under a given set of conditions, the number of multiple jacks required will increase approximately as the square of the number of lines. Doubling the line capacity of the board, for instance, quadruples the number and cost of the multiple jacks and has the same effect, approximately, on the multiple cabling. This cost comparison applies, of course, only to two boards engineered on exactly the same basis.

Looking broadly at the cost situation then, we see that as far as the switchboard itself is concerned, where the average traffic conditions per line remain the same, the costs connected with its multiple increase roughly as the square of the number of lines served. Other costs relating to what is called the "position equipment"—that is, to the answering jacks and line signals, cord circuits, operators' equipment, and other elements which grow with the number of positions—increase roughly in direct proportion to the number of lines.

Thus, both the mechanical and the cost considerations tend to place a limit on the number of lines to be served by a single switchboard unit beyond which it is inadvisable to go. Experience in this country of both Bell and independent companies has placed this limit in the neighborhood of ten thousand lines.

Factors Determining Central-office Capacities.—This approximate limit of switchboard capacity establishes a limit beyond which a single manually operated central office does not ordinarily go, for it is not usually considered advisable to assign more than one multiple-switchboard unit to a single central office, even though, in cases of extreme congestion, a small area may require switchboard facilities for several times ten thousand subscribers' lines. When such is the case, as many multiple-switchboard units as may be required to serve the total number are employed, and, even though several of them are installed in the same building, they are treated and designated as separate central offices. Such conditions exist only in the intensely congested districts of large metropolitan exchange areas like those of New York and Chicago. These extreme cases, as far as manual switching is concerned, are gradually passing away, for in such areas all new installations, as far as known, are now being made on a machine-switching rather than a manual basis. Here again, though for somewhat different reasons, the limit in the number of subscribers' lines in a single central-office unit is usually placed at about ten thousand.

As a more typical case we may consider a manual exchange with an ultimate of, say, ten thousand lines, the stations of which are scattered over a wide area. From the standpoint of switching alone it would be desirable to serve this area from a single central office having a full multiple-switchboard unit of ten thousand lines. But other factors than those of switching enter the problem. Important among these is the cost of the outside wire plant. It is clear that, for a given exchange area, the average length of subscribers' line will be a maximum when all the lines are run to a single office, and much less if the whole area is divided into districts each served by its own central office. The lowering of the line costs by thus subdividing the area will not be clear gain, however, because of the trunk lines necessary for establishing inter-office connections. In determining the relative outside plant investments, the sum of the costs of the subscribers' lines and the trunks required in the multi-office plan must be weighed against the costs of subscribers' lines alone in the single-office plan.

Many other considerations than those of first cost must also enter into the problem of the division of a large exchange area into smaller central-office areas and the determination of the proper capacity of each office. Relative operating costs, risks of property damage, risks of service breakdown, transmission, and accuracy of service are all matters to be weighed. This is one of the important problems with which the telephone engineer has to deal.

CHAPTER XI

MULTIPLE SWITCHBOARDS

Early Multiple Switchboards.—The broad idea of the multiple switchboard, conceived by Firman in 1879, did not find general acceptance until about 1884. The first multiple boards were adapted only for grounded lines. They disappeared after a struggle, having served to accentuate the troubles inherent in single-wire circuits and thus to hasten the inevitable general adoption of metallic circuits.

The grounded-line boards and the early metallic-circuit boards which followed them all operated on the magneto plan, their line signals being annunciators or drops responsive to the magneto generators at the subscribers' stations. Their period, of course, antedated any successful plan of common-battery current supply.

Some of the early forms of magneto multiple-switchboard sections serve to illustrate the difficulties that were experienced in the quest for the best general section arrangement—that is, the arrangement of the drops, jacks, cords, and plugs on the section that was best adapted to the efficient working of the operator in setting up and taking down connections.

In the type shown in Fig. 271, the plugs were arranged in an inverted shelf at the roof of the section so as to point downward from a horizontal plane immediately above the multiple jack field. The cords in this case extended over and behind the multiple wiring. The line drops were placed below the jack field just above the key shelf.

In the radically different arrangement shown in Fig. 272, the line drops were placed on each end of the section, the multiple jack field lying between them. Here the plugs and cords were disposed on a plug shelf just back of the key shelf as later became common practice.

The section shown in Fig. 273 came a step nearer to the finally adopted arrangement in that the answering jacks and line signals were placed below the multiple jack field and just above the key shelf. An intermediate plug shelf for the calling plugs alone was provided below the multiple jack field, leaving the answering plugs only to be carried on the lower plug shelf

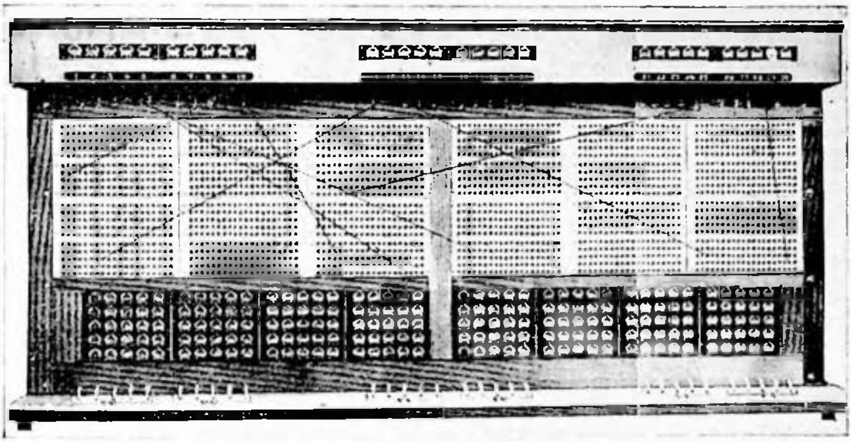


FIG. 271.—Early type of section with plugs in roof.

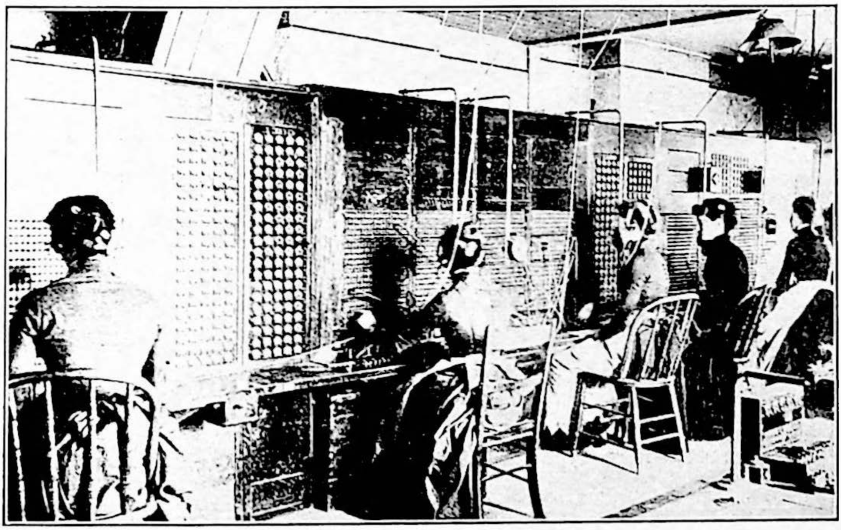


FIG. 272.—Early arrangement with drops at ends of section.

just back of the key shelf. This plan, in addition to placing the line signals conveniently within the operator's reach and vision, tended to avoid confusion among the cords, the set of plugs on the upper shelf being used in the multiple above, and those on the lower shelf in the answering jacks below. This minimized the crossing and tangling of cords and also prevented the line signals' being obscured by the presence of cords in front of them. Whatever advantages there were in thus segregating the answering and the calling cords did not prove to be great enough to counteract the difficulties involved in having the calling cords hang down behind the answering-jack and line-signal wiring.

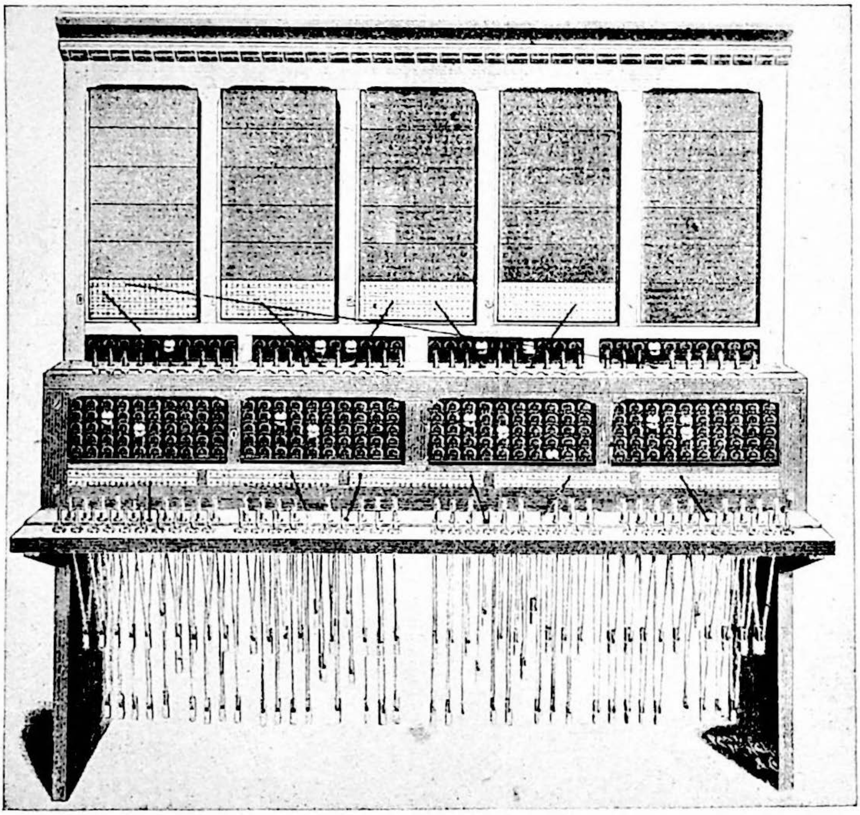


FIG. 273.—Early type of section with extra shelf for calling plugs.

The problem of avoiding the undue curtailment of the multiple jack space, owing to the large size of the drops and the necessity of placing them within reach of the operator, was first solved successfully by employing electrically restoring drops that could be placed out of reach of the operators. This, however, as will be shown, presented disadvantages. Later, the use of incandescent lamps as switchboard signals offered a much more satisfactory solution.

We may dismiss the multiple magneto switchboard with scant further attention, since it has practically passed out of the art as far as new installations are concerned. While there are a considerable number surviving in the United States and one is still included among the standard equipments of the American Telephone and Telegraph Company, the fact is that, as a general rule, an exchange large enough to require a multiple board is usually large enough to justify common-battery working on its city lines. One or two phases of multiple magneto-board development may be referred to, however, to illustrate steps in the progress toward more modern types.

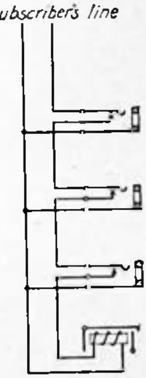


FIG. 274. — Series line circuit—magneto multiple board.

When it was realized that metallic circuits were necessary, the line circuit of the multiple board soon took the form shown in Fig. 274. One of its sides passed in series through a break contact of each jack of the line and thence to the drop. The return side was permanently continuous but was tapped to the front contact of each jack. The insertion of a cord-circuit plug into any jack would thus establish the connection between the cord circuit and the line, at the same time cutting off the drop at the break contact of the jack.

Aside from the expense involved in making all the jacks of the cut-off type, this type of line circuit was objectionable for two principal reasons: First, the talking circuit was unbalanced. This was principally because the drop circuit was cut off from only one side of the line, the portion beyond the break in the jack remaining permanently connected with the other side. The electrostatic balance of the circuit was thus disturbed, resulting in cross-talk and inductive noises from other circuits. Second, make-and-break contacts were not so reliable then as now, and the long row of jack contacts in series in each line circuit was a prolific source of trouble.

The principles first clearly pointed out by Carty, which led him to produce the "bridging bell" for party lines,[1] also pointed the way to the next and final major step in the development of the magneto multiple board. This is shown in Fig. 275, which illustrates a single-line circuit in a "branch-terminal"

[1] John J. Carty, U. S. Patent 449106, March 31, 1891.

magneto multiple board. Both the main troubles of the series multiple board were eliminated by the simple expedient of making the line coil of the drop of such high impedance as to permit its being left permanently connected across the line circuit. This at once did away with the necessity for cut-off jacks and gave a perfectly balanced line circuit, but, incidentally, it introduced another feature of faulty design in that the contacts between the plug and the two non-flexible sleeve contacts of the jack were not altogether reliable. However, the talking circuit of the line through the switchboard became one of maximum simplicity, extending in unbroken conductors through the switchboard, with taps to the tip and ring contacts of each jack.

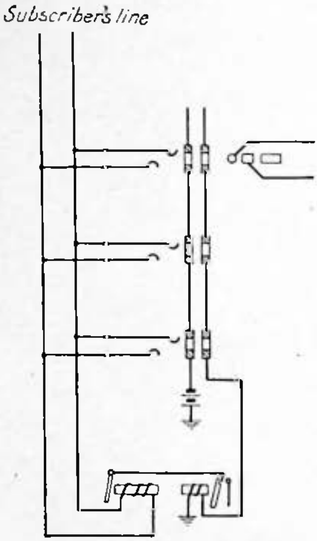


FIG. 275.—Branch-terminal line circuit—magneto multiple.

The drop used with this line circuit was of the electrically self-restoring type, shown in Fig. 178. The restoring coil mounted just in front of the line coil was connected, as shown, between ground and the front or test contacts of the jacks. Normally, therefore, the test contacts of the jacks were held at ground potential. When a plug was inserted into a jack, its two forward contacts, tip and ring, registered with the two line springs of the jack, while its long dead sleeve served to connect the two sleeve contacts of the jack together, thus completing the circuit through the restoring coil of the drop. This acted not only to restore a fallen drop upon the insertion of a plug, but also to prevent the line drop from falling in response to clearing-out signals sent by the subscribers or to ringing current sent out by the operators. At the same time it raised the potential of all the test contacts of the line for busy-test purposes. A two-conductor cord circuit was used with bridged clearing-out drop.

Magneto multiple switchboards of the branch-terminal type were made by the Western Electric Company during the nineties. Some of these were of large capacity, notable examples being those in the Cortlandt Street office of the New

York Telephone Company and in one of the large central offices in Paris, France. The latter was equipped for nine thousand lines and at the time of its installation was the largest multiple switchboard in existence. A front view of slightly more than one of its sections is shown in Fig. 276. Immediately above the key shelf are the answering jacks, and above these a row of out-

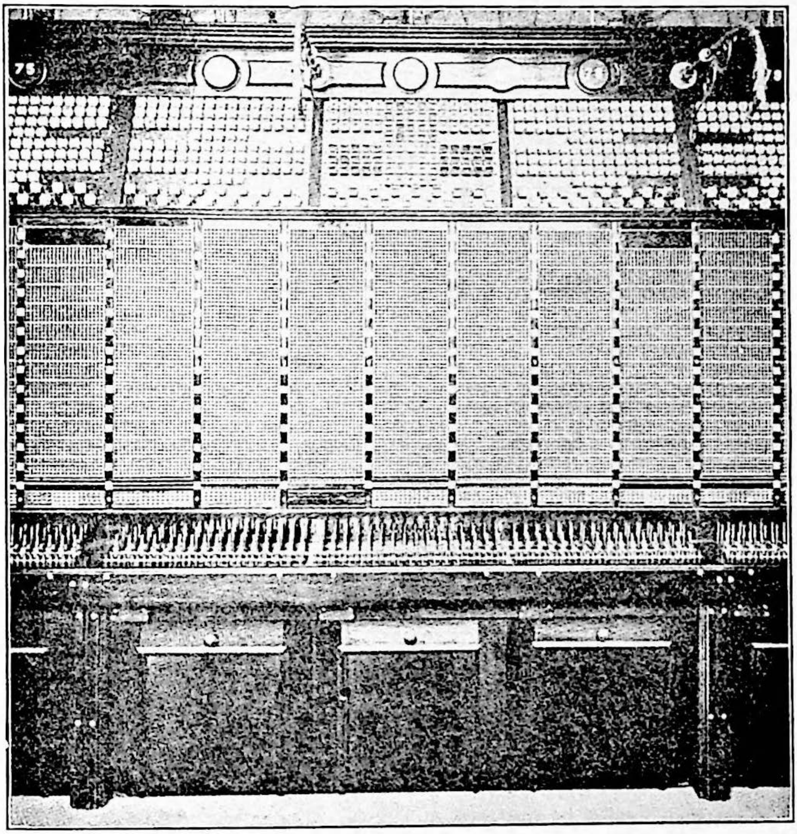


FIG. 276.—Old magneto multiple board—Paris, France.

going-trunk jacks for establishing connections with subscribers in distant offices. Above these, and occupying by far the greater portion of the jack field, are the multiple jacks, nine thousand in number on each section. Above the multiple jacks and entirely out of reach of the operators are the line and clearing-out drops.

This picture shows that even before the beginning of the present century the multiple switchboard had assumed rather imposing proportions. We may use it also to illustrate some of the difficulties inherent in large magneto multiple boards, which the common-battery board, with its lamp signals, has been able to overcome in large measure. In order to place as many as nine thousand of the half-inch jacks within the reach of an operator (and, incidentally, the reach in this board was greater than is now considered practicable for economical operation), the line and clearing-out drops had to be placed above the multiple and thus far removed from the answering jacks. The operator had first to look up above the jack field to note the number of the signal displayed and then look down below the jack field to pick out the answering jack corresponding to that number. This contributed not only to errors but also to the fatigue of the operator. In the common-battery system the small size of the line lamps permits their being mounted each immediately adjacent to its answering jack, without taking up too great a space in the jack field. The lighting of a lamp thus immediately identifies the answering jack to be used with a minimum of mental or physical effort on the part of the operator.

Again, the comparatively large size of the magneto line signals made it necessary to place them out of reach of the operators, and, since they were out of reach, a system of electrical restoration was required. This was expensive, since it involved extra contacts and wiring for every jack, but, of greater importance, it contributed to the difficulty of making smaller jacks of a sufficiently rugged nature. The self-effacing feature of the lamp signal used in the common-battery system at once removed all necessity for a specific signal-restoring system.

THE NO. 1 SWITCHBOARD WITH CALL-CIRCUIT TRUNKING

The essential features of the No. 1 common-battery multiple switchboard, as manufactured by the Western Electric Company for the Bell System, had been developed and put into use in several large central offices at the beginning of the present century. It became the standard switchboard for large and medium-sized central offices of the Bell System, and, while numerous improvements have been made from time to time in its component apparatus and in the details of its circuits, its really basic features stand unchanged to-day.

We may well use this classic switchboard as our example in obtaining a grasp of the fundamental principles of common-battery multiple-switchboard operation, as there are many times as many positions of No. 1 switchboard in operation as of all other types of Bell System common-battery multiple-switchboard positions combined. In doing so, it is best to consider it in its relatively simple form—that is, without any of the confusing details involved in the various special features that are often incorporated in it with the main object of facilitating the work of the operators. With the fundamentals thoroughly in mind, the way is paved for an easier understanding of the innumerable variations in form and function that occur in practical exchange operation in order to effect economies, to improve service, to meet some particular requirement of service, or to conform to the practices of different manufacturers.

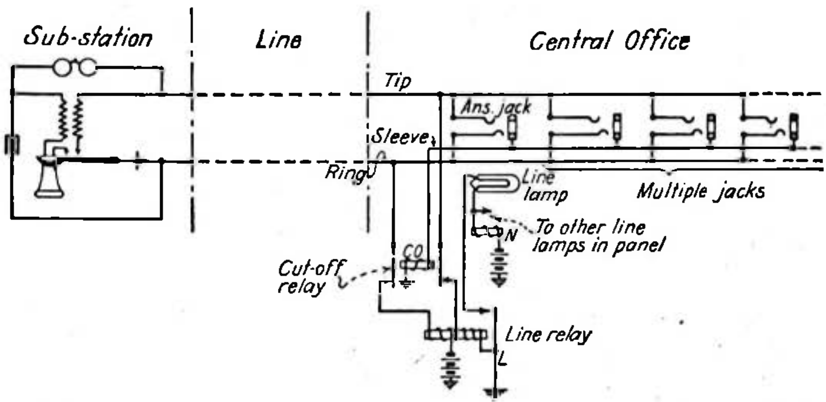


Fig. 277.—Line circuit of Western Electric No. 1 common-battery multiple switchboard.

Subscriber's Line Circuit and Connections.—Except for improvements in the apparatus involved, the line circuit of the No. 1 board has remained essentially the same for over thirty years. The circuit *per se* leaves little to be desired in manual-switchboard work and has been quite generally adopted by other manufacturers of common-battery multiple switchboards. Its elements are shown in Fig. 277. It will be recognized that the branch-terminal feature of the earlier magneto multiple board survives in this and that the objectionable feature of the double-sleeve jack has been avoided. The two sides of the line run as continuous conductors through the board, being tapped at the tip and ring contacts respectively of a jack on each section. The third wire, or "sleeve wire," for each line is tapped to the front, or "sleeve contact," of each jack, this like the others being a permanently continuous conductor throughout its length. There is a complete absence of the series jack contacts that characterized the earlier magneto multiple boards and that are still successfully employed in some smaller common-battery multiple boards and generally in non-multiple boards.

There is a line relay *L* and a cut-off relay *CO* for each line. The line relay has two windings, about alike in resistance but one of them practically non-inductive. The active winding is the one normally connected between the ring side of the line and the live pole of the battery, while the inactive one is similarly connected between the tip side of the line and ground. This relay thus receives current through both its windings when the line circuit is closed by the lifting of the substation receiver. When calling is done by grounding the ring side of the line at the substation (as in the case of a coin-box paystation), only the active winding of the line relay receives current. In either case the relay acts to close the circuit of its line lamp as a signal to the operator. This winding arrangement permits uniform adjustments of the active winding of the line relays for both coin and non-coin substation lines. In the case of the former the 1,000-ohm coin-box magnet takes the place in the circuit of the non-active or tip winding of the line relay.

The two branch wires from the tip and sleeve sides of the line to the line relay pass each through a pair of normally closed contacts on the cut-off relay. These contacts are opened when the cut-off relay is energized, thus completely detaching the line relay from the line. The coil of the cut-off relay is connected, as shown, between the test or sleeve conductor of the line and ground, and, as the sleeve strand of each cord circuit is connected with the live pole of the common battery, this relay will be energized whenever and as long as any plug is inserted in any jack of the line. The line relay is thus cut off from all connection with the line, and potential of all the test or sleeve contacts of the jacks is altered from their normal ground potential, as long as a connection exists with the line at any section of the switchboard.

The central-office part of this same line circuit is shown in Fig. 278, which goes into sufficient detail to give an idea of the wiring and includes several features that, for the sake of simplicity, were omitted from Fig. 277. These are the two distributing frames and the common auxiliary line signals including the line pilot lamp and the night bell.

Distributing Frames.—Speaking generally, the principal function of the distributing frame in telephone central offices, as will be pointed out in a later chapter, is to provide means for

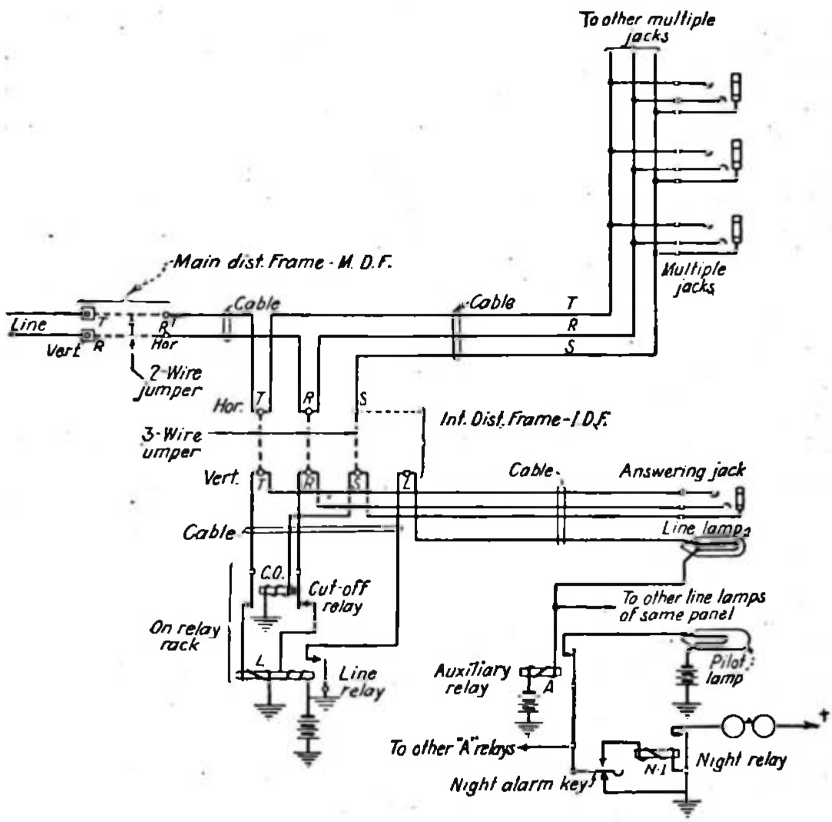


FIG. 278.—Line circuit with distributing frame connections—No. 1 switchboard.

terminating the wires of the line and switchboard circuits within the office in permanent and orderly fashion and, at the same time, to provide facilities for changeably interconnecting these permanently terminated wires among themselves by means of jumper or cross-connecting wires. Another important function is to afford convenient points of access to the circuits for testing purposes. Some distributing frames also carry the central-office protective devices for guarding the apparatus and the circuits themselves against dangerous currents which might be brought into the office over the outside lines.

Two such frames are indicated diagrammatically in Fig. 278—the "main distributing frame" usually abbreviated "M.D.F." and the "intermediate distributing frame" or "I.D.F." In Bell practice the terminals on one side of the frame are arranged in horizontal rows and on the other side in vertical rows. The open space within the frame between the horizontal rows on one side and the vertical rows on the other is conveniently divided into horizontal and vertical runway to facilitate running the "jumpers" or "cross-connecting" wires which may connect any set of terminals on one side with any set on the other side. The vertical side of the main frame carries the protector strips, which are always equipped with contact springs to facilitate opening the line for testing at that point, and which may or may not carry protectors for each line according to the requirements of the case. This equipment will be considered more in detail in the next volume,[1] in chapters on Distributing Frames and Protective Apparatus respectively.

As shown in Fig. 278, the subscriber's outside line terminates at protectors on the vertical side of the M.D.F., and is continued by jumper to the horizontal side. This is in accordance with the present usual Bell practice.[2] From the horizontal or switchboard side of the main frame the two sides of the line are continued to the horizontal side of the I.D.F. These two line-wire terminals on the I.D.F., together with the corresponding sleeve-wire terminal for each line, are cabled to the respective contacts of the multiple jacks as indicated. On the other (vertical) side of the I.D.F. four terminals for each line are cabled to the answering jack and lamp on the switchboard positions, and the same four terminals are also cabled to the line and cut-off relays located on the relay rack. In this way, each answering jack and lamp is permanently associated with

[1] "Automatic Switching and Auxiliary Equipment," Chaps. VIII and IX.

[2] In older offices of the Bell System the outside line wires were commonly terminated on the horizontal side of the frame, and the wires leading to the switchboard on the vertical side which carried the protectors. This was done principally on the theory of economizing in protectors, there being fewer switchboard lines than cable pairs entering the office. While somewhat less expensive, this older practice left the main frame itself, including the jumper wires, without protection. Moreover, it was less convenient in testing those outside lines which were not connected by jumpers to the protector side.

the relay-rack line equipment. It may be mentioned here that in modern practice one 24-volt battery lead is provided for each group of 120 line relays at the relay rack.

The distributing frame connections shown in Fig. 278 are as they would be in a No. 1 switchboard serving an exchange having but a single office. In a multi-office exchange the "B"-board multiple may be merely a continuation of the "A"-board multiple, as when the "A" and "B" boards are arranged in the same line as one continuous structure. More often, however, the "B" board is a separate structure, in a different line, perhaps on another floor. In all such cases, the tip, ring, and sleeve wires of the "B"-board multiple are tapped to the

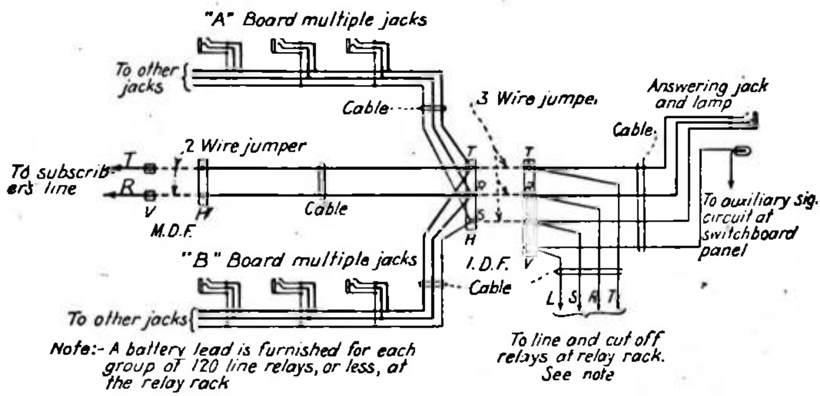


FIG. 279.—Connections of subscriber line through main and intermediate distributing frames.

same terminals on the horizontal side of the I.D.F. as the "A"-board multiple.

A schematic diagram of the distributing-frame connections in offices having both "A"- and "B"-board multiples is shown in Fig. 279. In multi-office exchanges, equipped with No. 1 boards, the "B" board always has a full subscriber multiple, but the "A"-board subscriber multiple is sometimes omitted, for the reasons mentioned in the last chapter. In this latter case, the distributing-frame connections are the same as those of Fig. 279, except for the omission of the multiple jacks on the "A" board and the cables connecting them to the horizontal side of the I.D.F.

The solid lines of Figs. 278 and 279 represent permanent connections, not intended to be changed, and the dotted lines extending across the two distributing frames represent jumper or cross-connecting wires, which are of a less permanent nature and intended to be changed as occasion requires. With this in mind, it will be seen that any subscriber's outside line may be cross-connected at the main frame to any line number as identified by the fixed numerical sequence of the multiple jack numbers. Also the cross-connection facilities at the I.D.F. permit any answering jack, with its permanently associated line and cut-off relays, to be assigned to any set of multiple jacks and thus to the subscriber's outside line to which the multiple jacks are at the time connected at the main frame. The main frame, therefore, permits any outside line to be assigned to a particular switchboard number, while the intermediate frame allows the proper distribution of the traffic loads and classes of service throughout the "A"-board panels.

These frames are purely static, playing no active part in the regular switchboard functioning. They may be regarded as belonging to the switchboard wiring. Aside from the protective equipment on the main frame, they function only in testing and in facilitating changes in the connection of subscribers' lines with respect to the multiple or in the distribution of answering jacks with respect to the "A" operators.

Line Pilot and Night Alarm.—The auxiliary circuits shown in the lower right corner of Fig. 278 relate to the line pilot lamp and the night alarm. There is a line pilot lamp on the bottom of each switchboard panel common to all the line lamps in that panel. This glows when any line lamp on its panel lights. Its function is to give a more conspicuous signal than that of the individual line lamp, and for this reason it has a much larger lens. A pilot or auxiliary relay *A*, having a low-resistance winding, is placed in the battery-supply lead that is common to the line lamps of that panel. This relay controls the pilot lamp of its panel in an obvious manner. Also, if the night-alarm key has been operated, the night-alarm relay *N*-1 is included in the local circuit of the auxiliary relay and operates to close a ringing-current circuit through the night bell.

It is the present practice in No. 1 boards to make the line pilot common to the line lamps of one panel, and the night bell common to six switchboard positions. The night-alarm key, however, has another set of springs besides the one shown, controlling another night-bell circuit, so that each night-alarm key, when operated, connects the night-alarm circuit for a total of twelve subscriber positions, rather than only six.

Line Wiring.—The line wiring from the main frame is usually carried out in units of 20 lines, corresponding to the number of multiple jacks in a strip. The wires of each unit of 20 that follow a common path are bunched into a cable. Switchboard cable of the type, and with the color code, described in Chap. XI of the preceding volume "Theory and Elements" is used for the purpose. Thus, referring to Fig. 278 or 279, besides the outside line cables terminating on the vertical side of the main frame, we have the following principal cables: Main to intermediate frame, 21 pair; intermediate to multiple, 63 wire; intermediate to answering jack, 84 wire, and intermediate to relay rack, 84 wire. The terminals on the main frame are designated in pairs, "tip" and "ring" (*T* and *R*), and those on the multiple side of the intermediate frame in triplets "tip," "ring," and "sleeve" (*T*, *R*, and *S*), taking these names from the corresponding jack contacts. On the relay-rack side of the intermediate frame there are four terminals in each set, *T*, *R*, *S*, and *L*, the *L* standing for "lamp" and referring to the local-line lamp circuit. This *L* terminal on the I.D.F. is not intended for jumper connection and, therefore, has no corresponding terminal on the other side of the frame.

Ancillary Answering Jacks.—Where space on the face of the "A" switchboard permits, it has been found advantageous to provide one or two additional answering jacks and lamps for each line. These are connected in multiple with the regular answering jack and lamp and are located on different sections of the "A" board. They are called "ancillary" answering jacks and make it possible for a greater number of operators than those within reach of the regular answering jack to answer calls on a given line. The use of more than one answering jack on a line tends to balance or equalize the load among the operators. More will be said of this later in this chapter.

Basic "A"-board Cord Circuit.—The cord circuit shown in Fig. 280 is what we may call the basic or fundamental cord circuit for "A" positions in No. 1 switchboards. That is, it is the "A" operator's cord circuit reduced to its simplest terms by omitting all of the complications that would be involved in such features as "flashing recall," "automatic ringing," "automatic listening," and others that are sometimes added. The connections and general mode of operation of this cord circuit will require little explanation in view of what has already been said of common-battery cord circuits of non-multiple switchboards. A few of its characteristic features may, however, be referred to.

The answering and calling supervisory relays *A* and *C* are included in the ring strand of their corresponding cords, and, in order to avoid the retarding effect of their active windings on the talking circuit, each is shunted by a low non-inductive resistance which is wound on the relay core and is a part of the

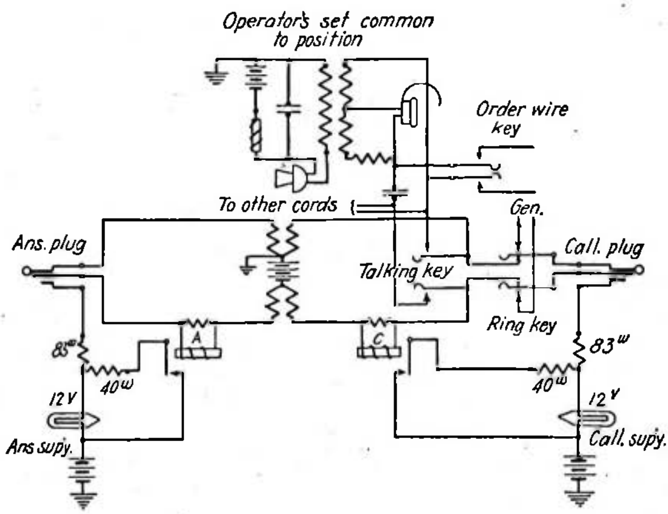


FIG. 280.—Basic subscribers' cord circuit—No. 1 switchboard.

relay itself. The supervisory lamps are connected each in the sleeve strand of its cord, but, in this case, the supervisory relay does not act to make and break the circuit through the lamp but exerts its control on the lamp by opening and closing a 40-ohm shunt around it. By shunting the lamp to extinguish it, rather than breaking its circuit, the lamp filament is kept hot as long as the cord is up, thus permitting its more rapid response to the switch hook. This arrangement does not break the continuity of the sleeve strand of the cord which must serve other functions in addition to that of supervisory-lamp control. It furnishes current to operate the cut-off relay of a line when a plug is inserted into one of its jacks, and the flow of this current serves also to alter the potential of all the sleeve contacts of the jacks of that line for busy-test purposes. Both these conditions must continue while the plug is inserted, and therefore the breaking of the sleeve conductor by the supervisory relay must be avoided.

The supervisory lamp is adapted for normal illumination at 12 volts. The normal common-battery voltage is 24, but the 83-ohm resistance in the sleeve strand in series with the 34-ohm resistance of the cut-off relay coil serves to reduce the voltage across the lamp to the amount required for its proper illumination. The 40-ohm shunt when closed around the lamp lowers the current through it to a point just below that required for its illumination. The lamp is thus kept "warm" while a cord is up, whether it actually glows or not. Other features of the cord circuit will be brought out in describing its operation in the course of connecting two subscribers' lines through it.

The operator's circuit of Fig. 280 will be recognized as being of the same general anti-side-tone type that was discussed in connection with Figs. 256 and 257 (Chap. IX). In other words, the operator's receiver is so connected as to be sensitive to incoming voice currents arriving over a line or call circuit, but comparatively insensitive to voice currents sent out by the operator's own transmitter.

The Busy Test.—With the possible exception of the busy test the operation of the cord circuit of Fig. 280 in connection with the line circuit shown in Figs. 277 and 278, will be readily understood from what has already been said. Having answered a call and received the instructions of the subscriber as to the number of the line desired and having taken up the calling (front) plug of the pair used in answering, the operator proceeds to pick out the multiple jack, within her reach, of the line desired. If a plug is found to be in that jack, she will know that the line has already been connected with and will inform the calling subscriber that the line is busy. It is more likely, however, that if the called line is busy it will be by virtue of a connection made at another section of the board and therefore not visible to the operator now in question. To ascertain whether a connection exists at some other section, she touches the tip of her calling plug to the sleeve or test contact of the jack of the called line.

We have already seen that the sleeve contacts of all jacks of a non-busy line are held at ground potential and that those of a busy line are held at different potential. The tip of a calling plug engaged in making a test is normally at ground potential, by virtue of the tip strand of the cord being connected to the grounded pole of the battery through its repeating-coil winding. Therefore, in testing a line that is not busy, no click will be heard in the operator's head telephone, because the bringing together of two points of equal potential causes no disturbance in a circuit network. On the other hand, the touching of the grounded plug tip to a jack sleeve of a busy line will alter the potential of the tip strand of the cord circuit used in making the test and, since the talking key is closed at the time, will cause a slight current to flow through the operator's head set, resulting in a warning click. In this case, the operator tells the calling subscriber that the line is busy and does not complete the connection. The purpose of the condenser in the ring side of the operator's talking circuit is to prevent false busy tests. Without this "ring" condenser there would be a flow of current from ground on the sleeve contact of an idle line being tested through the tip of the plug and the operator's set to battery on the ring side of the cord. This would result in a false busy-test click.

Interpretation of Supervisory Signals.—The answering supervisory lamp does not light upon the operator's plugging in, because, the calling subscriber's receiver being off its hook, causes the supervisory relay *A* to be energized, which closes the 40-ohm shunt around the lamp. The calling supervisory lamp, however, lights on plugging in and remains lighted until the called subscriber responds. Then, his line circuit being closed through his transmitter, the calling supervisory relay *C* is energized by the flow of current. This closes the 40-ohm shunt about this lamp extinguishing it, as a signal to the operator that the subscriber has responded. Both supervisory lamps of the cord circuit remain extinguished as long as the two subscribers are in conversation, but as soon as either hangs up, the corresponding lamp will be lighted by the release of its supervisory relay armature and the consequent breaking of the shunt. The lighting of both lamps of a cord circuit is a signal to the operator to take down the connection.

"A"-board Cord Circuit with Flashing Recall.—The basic "A" operator's cord circuit of Fig. 280, with modifications such as those necessary to provide for selective ringing on party lines or for operation in connection with coin-box and message-register lines, was standard in the Bell System for many years. Another cord circuit that later, with similar variations, became standard for "A" positions in No. 1 boards is shown in Fig. 281. This differs from the basic cord circuit just considered in two principal features, termed respectively "flashing recall" and "audible ringing signal."

Flashing Recall.—The cord circuit of Fig. 280 left something to be desired in regard to the interpretation of signals in those cases where the calling subscriber desired to initiate another

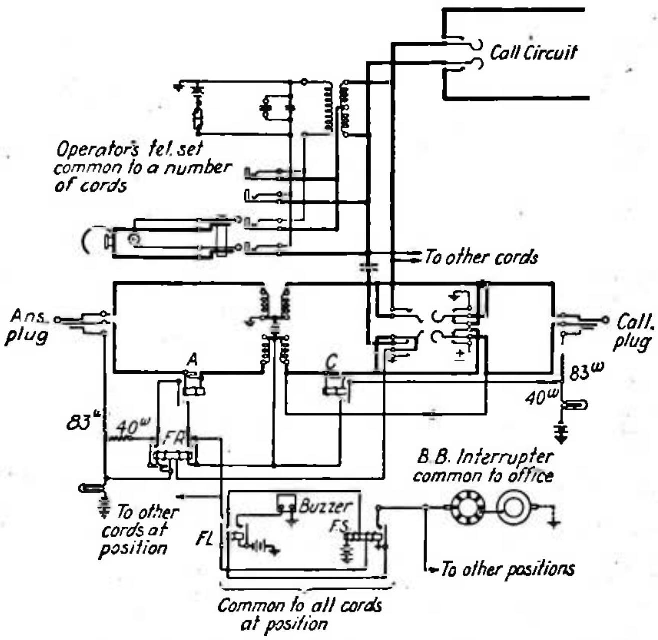


FIG. 281.—"A"-board cord circuit with flashing recall.

call immediately upon the conclusion of a previous one. Of course, hanging up his receiver lighted his supervisory lamp, which, in connection with the lighting of the calling supervisory lamp, the operator would take as a signal to disconnect. After she did so, his own line lamp would be available for re-calling, but this involved the time necessary for the operator to take down the connection, during which the subscriber had no means of knowing whether the disconnection had been made. If he lifted his receiver before the disconnection was made, it merely extinguished his supervisory lamp again, withdrawing the signal to disconnect. Of course, the method commonly employed was for the calling subscriber desiring to make another call to "flash" his hook, that is, to move it up and down, causing his supervisory lamp, or his line lamp if disconnection had been made, to flash intermittently. This method worked perfectly if the subscriber was properly educated in the routine of it, but if he was not his failure to flash his hook when desiring a recall sometimes resulted in some lost time and lost motion for subscriber and operator.

Thus, while the practice of having the answering supervisory lamp flash intermittently to indicate a recall had long been in vogue, it was felt that some improvement would result if this flashing were brought about automatically as a result of the subscriber's momentarily hanging up his receiver. This the cord circuit of Fig. 281 does, the rhythmically flashing lamp constituting an insistent signal to the operator, indicating that the subscriber has "hung up" to conclude his first conversation and that he has again taken up his receiver to initiate another call. She thus avoids the needless motion of withdrawing her answering plug and inserting it again upon seeing the line lamp lighted. Instead, she merely leaves the plug in the answering jack and throws her talking key to obtain the subscriber's new order. The operation of this key stops the flashing of the lamp.

This flashing-recall feature requires the addition of one relay to the answering side of each cord circuit and two relays common to the seventeen cord circuits of a position. The flashing-recall relay *FR* is individual to the cord circuit, while the "flashing-start" relay *FS* and the "flashing" relay *FL* are common to the position. Also, a regularly interrupted current is required. This is secured by means of a power-driven commutator geared to one of the ringing generators, or to some other constantly operating machine, in such manner as to interrupt a direct-current circuit at the required intervals. This is generally a part of the "busy-back" interrupter. The primary purpose of the two positional relays *FL* and *FS* is to reduce the current to be broken by the interrupter, from the heavy current required to light the cord lamp to the weak current required for relay operation, thereby reducing brush wear.

When the operator in response to a call inserts an answering (back) plug into the answering jack of a line, the cut-off relay of that line is operated, and the line lamp extinguished, in exactly the manner already described. The answering supervisory relay *A* also operates as before over the metallic circuit of the line, the calling subscriber's receiver being off its hook. The operator in answering has her talking key closed. This causes the flashing-recall relay *FR* to operate over a circuit from battery through the right-hand winding of the *FR* relay to ground at the talking key. This relay on operating establishes a locking path for itself as follows: from battery through the right-hand make contact of the *FR* relay, closed contact on the supervisory relay *A*, left-hand make contact on the *FR* relay, through the left-hand winding of this relay, and thence to ground over the sleeve of the cord and the cut-off relay of the line. This locking path holds the *FR* relay operated after the talking key is restored. The left-hand or locking winding of this relay has a resistance of 40 ohms. It will be noticed that, when the *FR* relay is operated, this locking winding is shunted around the answering supervisory lamp, this acting instead of the other 40-ohm resistance shown to keep the lamp extinguished.

The flashing relay *FR* originally energized by closing a contact in the talking key can only be de-energized by breaking its locking circuit, and this is held closed as long as the answering supervisory relay *A* remains energized. The circuit will remain in this condition, therefore, during the conversation.

If at the close of the conversation the calling subscriber does not desire another connection, he will merely hang up. This will release his supervisory relay, thus opening the shunt around the supervisory lamp and permitting its illumination in the ordinary manner. The breaking of this circuit also unlocks the flashing-recall relay *FR*, which assumes its normal position.

If, however, the calling subscriber desires to make another call, he will flash his receiver hook once, this being sufficient to establish the flashing-recall condition. This momentarily releases the supervisory relay *A*, thereby opening the locking path described for the *FR* relay. The relay *FR* is thus released and does not operate again in response to the re-operation of the supervisory relay which immediately follows on account of the rising of the subscriber's receiver hook. The periodic flashing of the supervisory lamp is now brought about in the following manner:

The flashing-start relay *FS* operates over a circuit traced from battery, through the left-hand winding of the *FS* relay, back contact of the *FL* relay, right-hand back contact of the *FR* relay, make contact of the *A* relay, left-hand back contact of the *FR* relay, 40-ohm resistance to the sleeve strand of the cord and ground through the cut-off relay of the line circuit. The resistance of the winding of the *FS* relay involved in this operation is approximately ½ ohm and it will be seen that the supervisory lamp is now shunted by another circuit of approximately 40 ohms and, therefore, for the moment remains extinguished.

The operation of the *FS* relay as just described closes the path for the flashing relay *FL* to the busy-back interrupter, energizing this relay at regular intervals as the grounded segment of the interrupter comes into contact with its brush. At each stroke, the flashing relay *FL* does three things: First, through its left-hand break contact, it opens the 40-ohm shunt circuit around the supervisory lamp, allowing it to light to its full brilliancy. Second, through its right-hand contact, it operates a single-tap buzzer, thereby giving an audible signal to the operator. Third, at its left-hand make contact, it establishes a holding path for the *FS* relay, this leading from battery through the left-hand winding of the *FS* relay, make contact of the *FL* relay, and right-hand winding of the *FS* relay to ground. This prevents the flashing-start relay from releasing during the break interval in the 40-ohm lamp-shunt path. As soon as the grounded segment of the busy-back interrupter has passed beyond the brush, the *FL* relay releases, thereby restoring the shunt around the lamp and extinguishing it.

The flashing of the lamp and sounding of the audible signal continue under control of the busy-back interrupter until the operator responds to the subscriber's call by throwing her talking key (Fig. 281). This energizes the flashing relay *FR* which locks up as already described, keeping the supervisory lamp shunted and extinguished during the ensuing conversation. The energizing of this relay also releases the *FS* relay, which, in turn, breaks the circuit from the busy-back interrupter to the *FL* relay.

Audible Ringing Signal.—It has proved to be a desirable feature so to arrange the cord circuit that the calling subscriber will be automatically informed when the ringing of the called subscriber is in progress. To accomplish this, two condensers of small capacity are bridged around the normally closed contacts of the ringing key, as shown in Fig. 281. In this way, when the ringing key is operated, a small current from the ringing generator is allowed to leak back over the calling subscriber's line. Hearing this in his receiver, he feels that the operator has done her work and that he only awaits the coming of the called subscriber to his telephone. Condensers of about 0.02-microfarad capacity each are used for the purpose, this small capacity assuring that the waiting subscriber will not receive too loud a tone and that none of the apparatus on his line, or on the answering side of the cord circuit, will be disturbed.

Inter-office Trunking.—So far we have considered only such circuits of the No. 1 switchboard as are concerned in the "A" board. The connection described has been that between two subscribers whose lines terminate in the same office, no trunking being involved. It is a connection between two lines in the same office such as would occur in a single-office exchange, or in an office of a multi-office exchange which had an "A"-board multiple.

We have now to consider a connection that must be trunked from an "A" to a "B" board in a multi-office exchange. Such a connection will, in most cases, be between two subscribers' lines terminating in different offices, the connection being made over an inter-office trunk extending from the "A" board in one office to the "B" board in another. In cases where the "A" board multiple is omitted, we may have a trunked connection between two lines in the same office, in that case from the "A" board to the "B" board in the same office.

In practically all multi-office systems employing large manual multiple boards, the outgoing ends of the trunks appear in jacks multipled throughout the "A"-board sections. At the distant office the incoming end of each of these trunks terminates in a single plug, these plugs being distributed among the "B" or "incoming-trunk" positions at that office. These are "plug-ended trunks." Sometimes, in trunking to small offices, the incoming end of the trunk may terminate in a jack. In this case we have "jack-ended trunks."

In the preceding chapter, attention was called to two quite different methods of communication between "A" and "B" operators, in furthering the progress of a trunk call—the call-circuit method and the straightforward method. The No. 1 switchboard arranged for call-circuit operation will now be considered.

Call-circuit Trunking with No. 1 Switchboard.—In the very old No. 1 installations, manual ringing by means of ringing keys was employed at the "B" as well as the "A" positions. At an early date, however, the "B" cord circuits were equipped for "machine ringing." In this, the ringing *starts* automatically when the "B" operator plugs into the jack of the called subscriber and *stops* automatically when that subscriber responds by lifting his receiver. If the type of service is such as to require selective or code ringing on party lines, the proper polarity in the full-selective offices or the proper code (one or two rings) in semi-selective offices, as well as setting the circuit for tip or ring side ringing, is accomplished manually by depressing the proper ringing key. This key once set remains locked mechanically in its operated position until one of the other buttons is subsequently depressed. Hence if the key is already properly set (as for individual-line ringing), subscribers can be rung on call after call without touching the key until a different code or polarity is ultimately required. This is "key machine ringing." In offices where the service requires no selection on party lines, the ringing of the called subscriber from the "B" board is made entirely automatic, the ringing current being applied automatically when the "B" operator plugs in and stopped automatically when the subscriber responds. This is called "keyless machine ringing."

Figure 282 shows the circuits involved in establishing a connection between two subscribers through No. 1 "A" and "B" switchboards by the call-circuit method and with keyless machine-ringing trunks. The "A"-board cord circuit is the one just considered in connection with Fig. 281, having flashing recall, audible ringing signal, key listening, and key ringing for all calls completed through the "A"-board multiple.

The circuit of the calling subscriber's line is shown at the extreme left and that of the called subscriber at the extreme right. That portion of the central-office equipment at the left of the vertical dot-and-dash line belongs to the "A" board of the originating office, that at the right of this line to the "B" board at the terminating office. The two line circuits and the "A"-board cord circuit at the originating office will be recognized as the same as those already discussed.

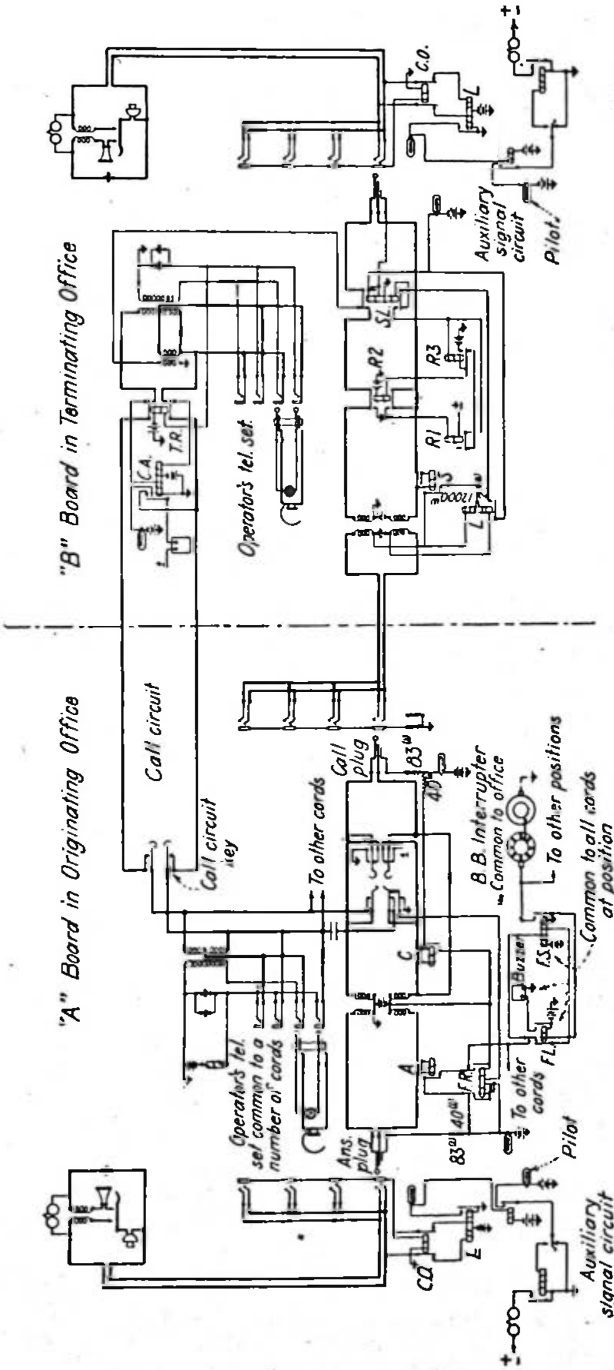


FIG. 282.—Connection between two subscribers through No. 1 "A" and "B" switchboard.

The "A" operator, in response to a call originating on the line at the left of Fig. 282, answers by inserting the back plug of a pair into the answering jack of that line. The operation of the line and answering supervisory signals, up to the time the operator throws her talking key and receives the number from the subscriber, are exactly the same as already described in connection with a purely local call. Also, if the call is for a subscriber in the same office, and if the "A" board is provided with a full multiple, the "A" operator tests and, if the called line is not busy, completes the connection in the multiple. In this case the operation of the ringing key and of the calling supervisory signal is exactly the same as already considered.

In the present case, however, it will be assumed that the line of the subscriber called is in another office. The directory designation used by the calling subscriber will, of course, give the "A" operator the office in which the called line terminates and its number in that office. Learning these, the "A" operator presses a call-circuit key bearing the name of the office desired. This connects her telephone set with that of a "B" operator at the desired office, at whose position a group of trunks from the originating office terminates. Communication between the two operators being thus established over the call circuit, the "A" operator passes the number of the subscriber desired to the "B" operator, who in turn designates to the "A" operator the particular trunk to be used.

The "A" operator thereupon inserts the calling (front) plug of her cord pair in the outgoing jack of the trunk assigned. This action causes the *L* relay in the incoming trunk at the terminating office to operate over a circuit from battery and ground at the originating office through the repeating coil and calling supervisory relay *C* in the "A" cord circuit, over the metallic circuit of the trunk, through the two windings of the repeating coil and of the *L* relay at the incoming end of the trunk. The supervisory relay in the calling cord does not operate at this time because of the high resistance 12,027 ohms of the *L* relay, both of its windings being in series in this circuit. The 40-ohm shunt provided for the calling supervisory relay in the "A" cord is, therefore, open at the contacts of the supervisory relay *C*, and this lamp, therefore, is lighted. It will be remembered from what was said in Chap. X that the calling supervisory lamp in the "A" cord is intended to be under the control of the called subscriber at the terminating office. Therefore, as will be shown, it will not be extinguished until that subscriber responds.

If the "B" operator has not plugged up the cord of the trunk, the lamp associated with this trunk at the "B" position is lighted, the path being from battery through the lamp, make contact of the *L* relay, back contact and lower winding of the *SL* relay to ground. The lower winding of the *SL* relay has very few turns, so that this relay does not operate at this time.

The "B" operator tests the multiple jack of the called line to determine if it is busy. The test circuit may be traced from the tip of the trunk plug through the upper back contact of the *SL* relay to ground through one winding of a separate busy-test repeating coil in the operator's telephone set. As in the case of the test on the "A" board, the test contacts or sleeves of an idle line will be at ground potential, and, therefore, the operator will hear no click in making the test. If, on the other hand, the called line is busy, by virtue of its being plugged at another section, all its sleeves will be at other than ground potential, which will result in a flow of current through the test circuit to ground on the operator's set, and the resulting click will inform the "B" operator that the line is busy. In this latter case the "B" operator will not complete the connection but will insert the trunk plug into a busy-back jack, not shown, which carries a characteristic tone from the busy-back interrupter. This tone will be transmitted back over the talking circuit to the calling subscriber to inform him that the called line is busy. The busy-back circuit at the "B" board also applies intermittent ground to the ring of the trunk plug which, through the action of the trunk relays *S* and *L* and the calling supervisory relay of the "A" cord circuit at the originating office, will cause the calling supervisory lamp at that office to flash intermittently.

Upon finding that the line is not busy, the "B" operator inserts the trunk plug into the subscriber's multiple jack. This operates the sleeve relay *SL* from battery through the trunk lamp, upper winding of the *SL* relay, sleeve circuit of the trunk cord to ground through the cut-off relay of the subscriber's line. The current already flowing through its lower winding also assists in operating the *SL* relay. The cut-off relay in the subscriber's line is also operated over the sleeve circuit just traced and, as in the case of the "A" board, serves to disconnect the line signaling apparatus from the called line and renders the line busy to other calls.

The talking strands of the trunk circuit are thus connected with the metallic circuit of the called subscriber's line. It will be seen that, on plugging in, the *SL* relay disconnected the normal test circuit from the tip of the plug and closed the talking circuit on the tip side of the trunk cord.

The contacts of the relay *R*-2 in the trunk bear about the same relation to the trunk cord circuit as those of an ordinary ringing key bear to the calling plug of an ordinary cord circuit. Thus, when operated, this relay serves to disconnect the tip and ring of the trunk plug from the circuit leading back to the trunk line and to connect them instead to a source of ringing current. The relay *R*-2, therefore, takes the place of a ringing key, but its action is automatic rather than manual, as will now be described.

The operation of the *SL* relay on plugging in, in addition to the functions already described, closes a circuit for the *R*-2 relay from battery through the winding of that relay, back contact of the *R*-3 relay, back contact of the *R*-1 relay, lower make contact of the *SL* relay, make contact of the *L* relay through the upper winding of the *SL* relay to the sleeve of the plug and to ground through the cut-off relay of the subscriber's line. Incidentally, the resistance of the *R*-2 relay is 40 ohms, and its winding, it will be seen, is shunted around the trunk lamp, thereby extinguishing it. Also, that part of the above path just described over which the *R*-2 relay was operated, namely, the back contact of the *R*-3 relay and back contact of the *R*-1 relay, constitutes a short circuit around the *R*-3 relay, preventing it from operating. The operation of the *R*-2 relay automatically applies ringing current to the line, the path being from the ringing generator lead (±) through the coil of the *R*-1 relay, lower make contact of the *R*-2 relay, thence out over the subscriber's line through his ringer, and back to ground at the upper make contact of the *R*-2 relay. The impedance of the subscriber's ringer and condenser is so high that the *R*-1 relay does not operate by the current which is thus caused to flow through it.

By means of a constantly driven commutator, resembling the busy-back interrupter, ringing current and 48-volt battery current are alternately applied to the ringing lead (±), the "ringing" periods being of 2 seconds duration and the intervening "silent" periods 4 seconds. With the relay *R*-2 energized, this ringing lead and its associated ground are, as just shown, connected across the circuit of the called line.

The resulting alternating application of ringing current and 48-volt battery current continues until the called subscriber answers. His answer places his transmitter and induction coil across the line, and, as this constitutes a low impedance path, the *R*-1 relay operates to remove the short circuit from the *R*-3 relay. This relay then operates from battery through the *R*-2 relay, winding of the *R*-3 relay, lower make contact of the *SL* relay, make contact of the *L* relay, and to ground through the sleeve circuit of the trunk and cut-off relay of the subscriber's line. The *R*-3 relay, in operating, short-circuits the *R*-2 relay and also locks itself from battery through its own make contact and coil to ground through the cut-off relay over the path just described. This short-circuiting of the *R*-2 relay permits its release, thereby stopping the ringing. The *R*-3 relay also keeps the lamp extinguished since its resistance also is 40 ohms, and it takes the place of the *R*-2 winding in the circuit.

The application of the 48-volt battery during the interval between the ringing intervals permits the operation of the *R*-1 relay to bring about the consequent cessation of ringing, either during the ringing interval, when it operates on ringing current, or during the silent interval, when it operates on battery current. There is thus no delay in breaking the ringing circuit and restoring the talking circuit of the trunk, whether the called subscriber responds during the silent or the ringing interval.

The called party's answer also causes the supervisory relay *S* in the trunk to operate. This, in turn, short-circuits the 12,000-ohm winding of the trunk line relay *L* and permits the supervisory relay in the "A" cord circuit to operate. This extinguishes the calling supervisory lamp in the usual manner. In this way, the response of the called subscriber in the terminating office is signaled to the "A" operator in the originating. It will be noted that the "B" operator receives no signal from the called subscriber—her trunk lamp responding only to the "A" operator's taking down the connection at the originating office. This is in accordance with the customary plan of supervisory signaling in "A" and "B" trunking—that the "A" operator shall supervise the connection and the "B" operator respond only to signals from the "A" operator.

When the conversation is completed, the hanging up by the called subscriber releases the supervisory relay in the trunk, thereby removing the short circuit from the 12,000-ohm winding of the *L* relay, which causes the supervisory relay in the "A" cord to release. This gives the "A" operator a disconnect signal. The disconnect by the calling subscriber releases the other supervisory relay and lights the answering supervisory lamp. The "A" operator then takes down the connection. The withdrawal of her calling plug from the trunk jack releases the *L* relay in the trunk, which opens the path of the *R*-3 relay which has been shunting the cord lamp, thereby permitting this lamp to light and giving the "B" operator a disconnect signal. The "B" operator disconnects, restoring the *SL* relay to normal.

Two relays, it will be noted, are provided in the "B" operator's telephone set, namely, the *TR* and the *CA* relays. The purpose of these is to give a signal at the "B" position, in case that position is vacated when an "A" operator depresses the key of a call circuit terminating at this "B" position. Under this condition, the *CA* relay operates, lighting a lamp and ringing a bell. When the "B" operator's set is connected at the operator's jack of the position, the *TR* relay operates on the current supplied to the operator's transmitter. This disconnects the *CA* relay and connects the call circuit to the telephone set.

The circuits just described, and shown in Fig. 282, remain typical of present No. 1 switchboard practice in the Bell System, with the exception that straightforward trunking is now more extensively used than the call-circuit method there illustrated.

Two other of the older Western Electric boards, the 1-C and the 1-D deserve brief attention as modifications of the No. 1 board that have been standardized for the use of the Bell System.

The No. 1-C Board.—This was designed principally for use in single-office exchange areas, where there would be no inter-office trunking, or for use in offices from which the total percentage of trunking would be small. Where conditions are such that but few of the calls, if any, require to be completed through the local multiple, the use of machine ringing on the "A" cords cannot be justified. On the other hand, in offices of the type for which the 1-C board was designed, most, if not all, of the calls are completed through the local multiple, so that the added expense of equipping the calling cords for machine ringing is warranted. The real difference between the No. 1 and the No. 1-C board was based on this distinction—that is, on the "A" cord circuits. The former provides for manual ringing and the latter for machine ringing on the calling cords and manual ringing, if required, on the answering cords.

The No. 1-C board employs the framework units of the standard No. 1 subscriber, or "A," sections with No. 92 jacks.

The No. 1-D Board.—This was standardized for use in the Bell System in communities where an ultimate capacity of not more than three thousand lines was expected during the life of the board. It replaced the No. 10 board[1] which employed cut-off jacks rather than cut-off relays and which had a capacity of sixteen hundred lines. It also met the requirements of offices of considerably larger size in which a No. 1 board would previously have been required, even though the ultimate requirements were considerably short of the capacity of the larger board.

A board of this character is generally used in single-office areas where toll and trunk positions or other special positions are likely to form a part of the main switchboard line-up. On account of this consideration, the section of the No. 1-D board is constructed in such a way that its lower portions containing the position equipment can be removed bodily, in single-position units, from the line-up without disturbing the upper portion containing the line multiple equipment. This marked a real advance in switchboard construction, particularly useful in offices where toll, rural, or other special types of positions are in the same line-up with the local subscriber positions. It permits the addition or substitution of positions for any class of service without disturbing the upper portion of the board containing the multiple. This feature is also found in the No. 11 board of the Western Electric Company, to be referred to later in this chapter.

The line circuit of the 1-D board is of the branch-terminal type with line and cut-off relay quite similar to the line circuit of the No. 1 board. The cord circuit is also similar to that of the No. 1 board except that the control of the supervisory lamp is effected in a slightly different manner to cut the lamp out instead of shunting it. Manual ringing only is employed.

Trunk equipment when required in connection with the 1-D switchboard is generally located in a special position, either with or separated from the toll-switching trunks. As a rule, the trunks are equipped for manual ringing but some of these switchboards have been provided with machine-ringing trunks.

[1] McMeen and Miller, "Telephony," American Technical Society, Chicago, 1912.

The 1-D position unit is made equal in length to two panels of the jack-field equipment and the jack-field framework is furnished in units of two or six panel lengths, so as to cover either one or three positions. The distributing frame used with the 1-D switchboard is of the combination main and intermediate type. The trunk positions, whether for manual or for machine ringing, have a capacity of thirty-eight plug-ended trunks.

KELLOGG TWO-WIRE MULTIPLE SWITCHBOARD

This board is now mainly of historic interest, although a number of them are still rendering good service. It will be given brief attention here, however, as illustrating perhaps as great a degree of simplicity of design as has yet been attained and, further, as showing that it is mechanically possible to make practical switchboards of much greater line capacity than has been found to be desirable when all phases of the problem are taken into account.

About the year 1902 the Kellogg Switchboard and Supply Company found itself with orders for several multiple switchboards with ultimate capacities ranging up to eighteen thousand lines. For such large capacities, the high prices then prevalent for multiple jacks would have made the ultimate cost almost prohibitive under conditions then existing. Moreover, in order to get as many as eighteen thousand multiple jacks in a single section, a smaller jack than any then being manufactured in this country was required.

With these two principal considerations in mind, Mr. F. W. Dunbar and the writer, both then in the employ of the Kellogg Company, set about designing a multiple-switchboard system that would have a jack of the greatest possible simplicity so that it could be made within the desired limitations of cost and size. The Kellogg two-wire multiple switchboard was the result of these efforts. It became the standard of that company and found rather wide use among independent companies in the United States as well as in a few European exchanges. That it did not survive in any important degree is due mainly to the fact that there has been found no economic demand for switchboards of larger capacity than about ten thousand lines, and therefore no need for the smaller and frailer jack.

The outstanding feature of the two-wire multiple board is indicated by its name. Only two wires for each line extend through the multiple, so that two-contact jacks and two-contact plugs with two-conductor cords suffice for all purposes. The two conductors were designated "tip" and "sleeve" respectively, there being no "ring" conductor. Figure 283 shows one of the cord circuits connecting a calling line on the left with a called line on the right.

Referring to the line circuit, it is seen that the tip and sleeve of the line terminate respectively in the two springs of the cut-off relay. Normally, when this relay is not energized, it connects the sleeve of the outside line to ground and the tip to battery

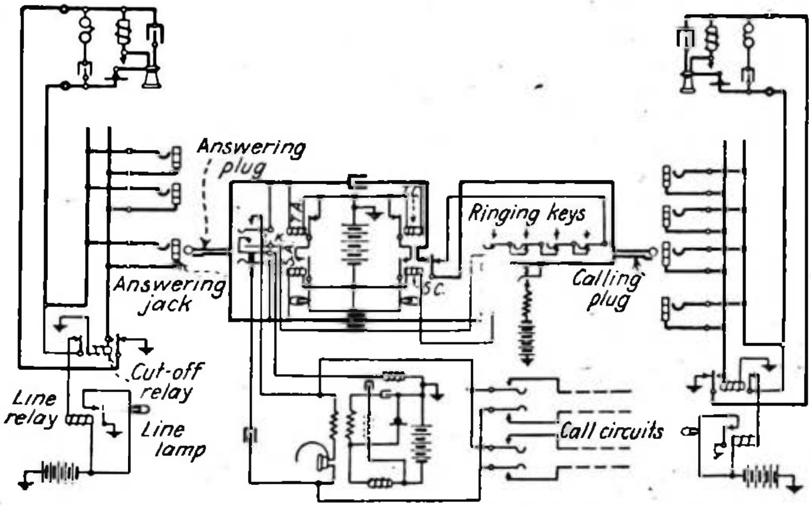


Fig. 283.—Connection of two subscribers through Kellogg two-wire multiple board.

through the coil of the line relay, thus placing the line relay and its lamp under control of the subscriber's switch hook, as usual.

The wires of the pair running through the multiple are tapped respectively to the tip and sleeve contacts of a multiple jack on each section. The tip wire of this pair is, in the later installations of this board, connected permanently to the tip side of the outside line. The sleeve wire of the multiple runs permanently to ground through the coil of the cut-off relay and is normally disconnected from the sleeve conductor of the outside line at the front contact of the cut-off relay.

The sleeves of all jacks of an idle line will, by virtue of the connection to ground through the cut-off relay, be held at ground potential. When, however, a plug is inserted into one of the jacks, the battery potential carried by the sleeve strand of the cord will result in a flow of current to ground through the cut-off relay, accomplishing two purposes: first, it will energize the cut-off relay which in turn will disconnect the line relay and bring the multiple jacks into operative relation with the outside line; and, second, it will alter the potential of all the test contacts of the multiple jacks for busy-test purposes.

The cord circuit furnishes talking current from the common battery[1] to the two connected subscribers by means of the condenser-retardation-coil plan (Fig. 235, Chap. VIII). The pair of relays associated with each cord serves the double purpose of acting as the retardation coils in the talking-current supply circuit and of controlling the supervisory lamp of that cord. Obviously the sleeve relay *SA* or *SC* of each cord, being on the live side of the battery, will be energized through a cut-off relay whenever its plug is inserted into a jack. This relay, therefore, serves to prepare the local circuit of its supervisory lamp whenever its plug is connected with the line. The tip relay *TA* or *TC* of each cord, however, being on the ground side of the battery, can only be energized by current flowing over the metallic circuit of the line to which its plug is connected. It is therefore responsive to the movements of the subscriber's switch hook, keeping the supervisory lamp extinguished as long as the subscriber's receiver is off its hook but allowing it to light as soon as he hangs up.

The method of answering a call will be clear from what has already been stated. The test of the called line is, of course, made with the listening key thrown, the test circuit being from the tip of the calling plug through the back contact of the calling sleeve supervisory relay *SC*, thence through the back contacts of the four-party selective-ringing keys and through an extra pair of contacts on the listening key to ground through a retardation coil in the operator's set. If the line is idle, the test circuit is from ground to ground and no click will result. If, on the other hand, the line is busy, the test contacts of the called line will be held at a different potential, owing to the drop through

[1] For reasons wholly pertaining to the then existing patent situation, all of the earlier installations of this type of switchboard employed two batteries, one common to all the answering cords and the other to all the calling cords (Fig. 236).

the cut-off relay, and the resulting flow of current through the test circuit will result in a click in the operator's head set.

The ringing key shown is for four-party selection among harmonic ringers, each responsive to a different frequency of ringing current. The single ringing-key spring connected with the sleeve side of the calling cord operates whenever any one of the four selective keys is depressed. Pressure on any one of these selective keys, therefore, serves to connect battery with the sleeve side of the calling cord and ringing potential of the desired frequency with the tip side. One side of each ringing generator is grounded, and the connection from its live terminal, after extending through the selective keys, passes through the back contact of the sleeve supervisory relay *SC* to the tip of the calling plug. When any ringing key is depressed, therefore, the ringing current passes from the ungrounded pole of the corresponding ringing generator out over the tip side of the subscriber's line, through the bells at the substations in multiple, and back over the sleeve side of the line through the common spring of the ringing key to ground through a non-inductive resistance coil and the central-office battery. The purpose of including the battery and coil in the sleeve side of the ringing circuit is to prevent the cut-off relay of the called line from falling back when the ringing key breaks the normal connection of the battery with the sleeve side of the cord.

LATER MANUAL MULTIPLE-SWITCHBOARD FEATURES

With minor modifications manual common-battery multiple-switchboard practice, such as has been discussed in the foregoing portions of this chapter, involving simple double lamp supervision, manual listening, and manual ringing on "A" boards and with machine ringing, either key or keyless, on "B" boards, has long been and still is widely used in the United States.

Statements have often been made by a certain class of critics to the effect that the manual switchboard was allowed to stand still for twenty-five years and that the failure to adopt in practice many of the "labor-saving and service-improving features" as soon as they were put forward resulted in "losses to the operating companies with consequent injury to the public." There is much to be said on the other side of this proposition. There was, it is true, a long period without radical change in manual-switchboard circuits or in their underlying methods of operation, but during this time there was a constant improvement in the design of apparatus, in the quality of the workmanship and materials involved, and in the service rendered. The switchboard of about 1925 showed a decided improvement over the ones of about 1900, and marked changes for the better occurred from time to time throughout the intervening period. One has only to examine installations made at different dates within this period to be convinced of the truth of this statement.

The period in question, involving roughly the first quarter of the present century, may be regarded, as far as the manual multiple switchboard is concerned, as one of cautious, painstaking, and intelligent development work, directed toward the perfecting rather than the revolutionizing of manual-switching practices. The time had come for telephony to grow up to what it had learned. A thoroughly sound basic plan of central-office operation had been found and it was wisely felt to be better for all concerned to perfect this plan to its highest degree rather than to subject the industry to the further disquieting effects of frequent radical changes. The automatic or machine-switching system was on the horizon, but during the earlier part of the period it was clearly not ready for general adoption. The same is true of the so-called automatic "features" that have since been successfully introduced into the manual switchboard. Most of these had their origin in the machine-switching development, and the condition of the industry was not yet ripe for their general adoption even in manual-switching systems.

In retrospect now, one can see clearly the disastrous effects that would have followed the premature general adoption either of machine switching as a whole or of the machine-switching ideas that later were applied to manual switchboards. The telephone art had gradually to grow up to the point where it could assimilate, in any wholesale way, the greater refinements necessarily involved in these improvements. Neither the equipment nor the trained personnel required to handle it was ready for such a step until the period in question was well advanced. Even then, the transition had to be made gradually and, at the present time, is still in progress.

As an example of this conservatism with regard to making radical changes in manual switchboards before the art was sufficiently advanced, it was apparent as early as 1904 that listening keys in the "A" cord circuits could be dispensed with and the connection of the operator's telephone be made automatic, by employing one relay to cut in the operator's telephone when she plugged in and another to cut it out when she completed the connection. In this way, the connecting and disconnecting of the operator's telephone circuit could have been made to follow automatically as a result of the acts she necessarily performed in setting up a connection. This idea was then rejected for the very good reason that both manufacturers and operating companies were striving to keep their cord circuits as simple as possible in the interests of reliability of action with the apparatus then available and of its easy understanding and proper maintenance by the forces then available to keep it in order.

Meanwhile the development work that was being done on machine-switching systems of both automatic and semi-automatic types was doing much toward providing the equipment and personnel needed for incorporating automatic functions in manual switchboards. This pioneering work, primarily directed toward another objective, paved the way for much that has since been done toward the improvement of manual switchboards. As a single instance, the feature of automatic listening by the operator was carried much farther in the semi-automatic system of the North Electric Company than has ever been done in manual systems and at an earlier date. In this case, an operator's telephone became connected with the calling line without any act whatever on the part of the operator, such as plugging in or manipulating a key. It soon developed that this particular instance of automatic functioning was faulty because too speedy. The operator would frequently request the number of the subscriber before his receiver reached his ear. This was remedied by introducing a manual function, making it necessary for the operator to press a button before her telephone became connected with the calling line, which is the practice in this system to-day. Thus the coming of machine switching, which carried automatic features far beyond what was ever dreamed of in manual operation, not only gave telephony several radically different kinds of automatic switching systems but also gave the older manual switchboard a number of labor-saving and service-improving features which, later, it might adopt with safety.

Multiple Line Signals.—The idea of making each call on a line available for answering at a number of points along the face of the switchboard instead of at one only is by no means new, as shown by the old ancillary answering-jack plan already referred to. Multiple line lamps directly in the multiple have been used in the Bell System throughout practically the entire period that separate multiple answering jacks were used. In small installations, such as the larger private branch exchanges where only a few appearances of each line were required, multiple line lamps directly in the multiple were used; while in larger installations requiring many appearances of each line, the separate answering jacks prevailed.

The present tendency of manual multiple-switchboard practice is toward the direct association of the multiple line lamps with the multiple jacks. The separate answering jacks and lamps, formerly used only for answering calls, are dispensed with and instead a line lamp is associated directly either with each multiple jack of the line or, if the board is a large one, with a portion of them. Each line lamp occupies a position on the face of the board immediately adjacent to its multiple jack and all of them belonging to a line are controlled in multiple by the line relay which occupies its accustomed place in the circuit.

The advantage of any multiple line-lamp arrangement is that it tends to distribute the load evenly among a large team of operators. A single answering jack and line signal is available to three operators at most. With the multiple line-signal arrangement, however, each of the multiple jacks with which a signal is associated becomes potentially an answering jack, each available to perhaps three operators. Thus any call may be answered by any one of many operators distributed along the board. As was found with ancillary answering jacks, a considerable increase in operator's loads is secured, owing to the more even occurrence of the calls before each operator and the consequent absence of idle periods interspersed with those of more intense activity. Contrary to what might be expected, the average answering time has not been found to be shortened by any appreciable amount. This is probably because as much advantage as possible is taken in the increase in operator's loads.

In the case of ancillary answering jacks, we have seen that providing two points of answering access instead of one increases the operator's loads about 6 per cent, while three points of access gave an increase of about 9 per cent. Smaller gains result from some further increase in the number of answering jacks, but it has been found that no substantial gain is made by increasing the number beyond five. For this reason and because there are certain inherent disadvantages involved in a multiplicity of line signals, it is usually found inadvisable to employ more than five multiple signals on a line, even though there may be a much larger number of multiple jacks. In this case, those multiple jacks which have line signals may be used for answering as well as for completing calls, while those without the line signals are available only for the completion of calls as in the case of the ordinary multiple jack.

One of the principal disadvantages inherent in rural line signals in offices of large capacity is that the ultimate capacity of the multiple board is materially cut down on account of the space taken up in the multiple jack field by the additional line lamps. A line lamp occupies as much room on the face of the board as a multiple jack. Therefore, on account of this consideration alone, if every multiple jack were provided with a line lamp, the ultimate capacity of the multiple would be just halved. But there is another consideration which works for a still further reduction in capacity. The fact that each multiple jack becomes a potential answering jack means that the multiple jack field must be confined to an area that is within the range of easy vision of the operator. It has been found that the range of easy vision is somewhat less than the range of easy reach, and this, with jacks and lamps on 3/8-inch centers, practically limits the capacity of a straight multiple line-lamp board to about four thousand lines where a signal is provided for each jack.

These considerations involved in the mere matter of jack-field space point to the desirability of limiting the number of line signals for each line in the case of large multiple boards. Certain features of operating efficiency point distinctly in the same direction. If too great a number of line signals are employed, there is a tendency toward confusion among the large number of operators who may strive to answer the same call. In other words, there results too much competition among the operators in the answering. It is obvious that any effort which an operator may make to answer a call which has already been answered by another operator is wasted effort. All of these considerations involved in the economy of space on the face of the switchboard and in economy of effort on the part of the operator have shown it to be advisable to limit the number of line signal appearances to not more than five for each line.

Answering Busy Test.—It has been found desirable in multiple line-lamp boards to provide some sort of an automatic busy test to prevent more than one of two or more operators, who may be striving to answer the same call, from actually gaining access to the line. This must be looked upon as another inherent disadvantage of the multiple line-lamp system because it tends to complicate the cord circuit. This answering busy test has been called the "operator's bar" because it acts automatically to bar an operator from making a connection with a line that has already been connected with by another operator. It offered essentially the same problem that had already been solved in the development of automatic systems where, for instance, one selector switch is automatically prevented from establishing connection with a trunk or a line that had already been seized by another switch. In either case, it is the switch or the operator that "gets there" first that gets the connection.

Automatic Listening.—Whether with or without the multiple line-lamp feature just discussed there has been a growing tendency in recent years to adopt automatic listening on "A" boards. This involves the return to the plan already referred to of having the operator's talking set become automatically connected with the cord circuit as a result of her act of plugging in in response to a call and of becoming automatically disconnected as a result of some act on her part involved in the final completion of the connection with the called subscriber. The advantages of this practice, which is variously called "automatic listening" or "keyless listening," probably reside less in the actual saving of labor on the part of the operator than in certain features of service which rather naturally flow from it. One of these is so-called "secret service" which, if listening keys are omitted, makes it difficult for the operator to listen in on a connection.

Another incidental feature of automatic listening is that it compels the operator to answer calls one at a time rather than answering a number in rapid succession, carrying the called numbers in her mind and then plugging them up one after another in the multiple, as was often done with key listening. While experienced operators achieved remarkable skill in the matter of holding a number of subscribers' calls in mind before she completed the connection with any of them, there can be no doubt that this practice was accountable for many wrong-number connections.

As a refinement of the automatic listening feature in this respect, one company has so arranged its keyless cord circuits that the calling supervisory lamp will be faintly illuminated to indicate to the operator the particular cord circuit with which her telephone set is connected. This partial illumination of the answering supervisory lamp persists until the operator's set is disconnected, which automatically occurs when the ringing button is depressed. This arrangement permits the operator to plug in on a second call while still engaged in answering a previous one but her telephone set is not cut in on the new call until the previous one has been disposed of.

Secret Service.—The main idea back of this term as it has been used among independent telephone manufacturers is the inability on the part of operators, when not provided with listening keys, to listen in on completed connections between subscribers. With automatic listening and non-interfering answering (operator's bar) it is practically impossible for the "A" operator to connect her telephone set on a connection that has been completed unless specific means are provided to enable her to do so.

There are conflicting opinions regarding the desirability of this feature. Some of the independent manufacturers make much of its advantages from the secrecy standpoint and provide no means to enable the operator to listen in. The Bell people, on the other hand, apparently feel that it is desirable for the operator to be able to listen in, so as to be able to aid the subscriber when required. For this reason they provide keys in each subscriber cord circuit.

Machine Ringing.—Automatic or machine ringing, wherein the operator pressed a key associated with the cord circuit to start the ringing which continues intermittently until automatically stopped by the response of the called subscriber, was, I believe, first proposed by Mr. W. W. Dean, while with the Western Electric Company early in the first decade of this century. This form of ringing has been largely used by that company in its "B" boards from about that time. Later, as we have seen in the discussion of trunking with No. 1 boards, keyless ringing was sometimes used. In this no key and no action on the part of the operator was required to start the ringing. In other cases, where the service demands selective ringing on party lines, the nearest approach to keyless ringing requires a single selective-ringing key common to the entire position. With this, the operator merely depresses one of its buttons in order to determine which station on the called line shall be rung.

It has generally been considered inadvisable to provide machine ringing on "A" boards in multi-office exchanges where a large proportion of calls are necessarily trunked to other offices. Here such a small proportion of the called subscribers are rung by the "A" operators that the expense and complexity involved in equipping their cord circuits for automatic ringing are not justified. On the other hand, in single-office exchanges where there is no trunking or in those multi-office areas where the percentage of trunking from a given office is small, the provision for automatic ringing on the "A"-board cords is often warranted. Where this is done, the same general principles as in the older "B"-board practice apply.

There are a number of advantages to be derived from machine ringing in its various forms whether applied to "A" or "B" boards, assuming of course that it is justified at all on the "A" board. The fact that the called subscriber's bell, once started, continues to ring intermittently until he answers, or until the operator disconnects[1] tends to promote greater promptness in the response of the called party. The insistence of the regularly ringing bell and the knowledge that the calling subscriber rather than the operator is in control of the duration of ringing are probably accountable for this result. Again, by means of the revertive ringing tone, by which the calling subscriber is made aware that the called subscriber's bell is ringing, the calling subscriber is relieved of doubt and is more content to wait a reasonable length of time without venting his impatience on the operator. Moreover, the ringing once having been started, the operator is relieved of all further responsibility with respect to supervising the called subscriber's response and re-ringing him. All re-ringing is done for her automatically.

[1] In the later systems of the Stromberg-Carlson and the Kellogg Company, the ringing also stops when the calling party abandons the call.

The Dark Key Shelf.—This latter advantage of machine ringing has led the Stromberg-Carlson and the Kellogg Company to modify the former method of operating the calling supervisory lamp and of interpreting its signal. With the older system of double-lamp supervision, the calling supervisory lamp remained lighted until the called subscriber responded, and it served then merely as an indication to the operator that the called subscriber had not responded and as a reminder to ring him again at intervals as required. With key-started machine ringing on the "A"-board cords, these companies thought it desirable to extinguish the calling supervisory lamp when the operator depresses the ringing key. Under this plan, as long as this lamp remains lighted, therefore, it serves as a guard lamp to prevent the operator's forgetting to start the ringing; and, in connection with a calling supervisory pilot lamp sometimes provided, it serves to show the supervisor when the ringing has been neglected on some connection on that position. This modified arrangement of supervisory signals made possible by machine ringing on "A" boards has been termed the "dark key shelf." The significance evidently intended to be conveyed by this name is that any light appearing on the normally dark key shelf calls for some definite action by the operator. The Bell practice, I believe, is to allow the calling supervisory lamp to remain lighted, as before, until the called party responds, to assist in preventing the registration of abandoned calls.

Automatic Disconnect.—In the various machine-switching systems, whether automatic or "automanual," the disconnecting of the subscribers at the close of a conversation is accomplished automatically as a result of the subscribers' hanging up their receivers, this mode of operation being inherent in the system. This is a feature which it has been difficult for tne manual systems to adopt in its entirety, for in the machine-switching system the connection between the subscribers is not only severed but is actually taken down as the direct result of the subscribers' hanging up. In manual systems, on the other hand, it has been found possible automatically to sever the connection when the subscribers hang up, leaving the operator to take it down later by pulling the plugs out of the jacks and restoring them to their seats. In this case, relays in the cord circuit are employed automatically to break the connection between each plug and the balance of the cord circuit when the corresponding subscriber hangs up. This results in leaving the plug dead in the jack, but being entirely severed from the cord circuit this dead plug has no power either to make the line with which it is connected test busy or to maintain the operation of the cut-off relay. As a result, the line in question may immediately originate another call or, on the other hand, it is available immediately to receive a call from some other line. With this arrangement, the two lines involved in a previous connection need not wait until the operator pulls down the plugs before they can either originate or receive new calls. This, of course, accomplishes the thing that the flashing recall was primarily designed to do, that is, to enable the calling subscriber to signal to the operator of his desire to make another call. Some systems employing the automatic-disconnect feature still retain the flashing recall, however, to associate the subscriber with the operator who put up his original connection.

Automatic Peg Counts.—The peg count in telephone operation is a count of the number of calls answered or of other traffic functions performed at various divisions of the switchboard during definite periods of the day and on various typical days. Its purposes are threefold: to improve the service, to improve the economy of rendering the service, and to provide the data required in engineering new central-office equipments or enlarging existing ones. This was formerly done by means of a small manually operated counting register placed at each position of the switchboard and manipulated by the operator at each completion of the function that was at the time being counted. The manual peg count always involved a considerable amount of trouble on the appointed peg-count days and being dependent on human action in the midst of other pressing duties was subject to considerable error. The machine-switching system naturally accomplished the counting automatically, employing mechanical counters which registered at the proper time in the progress of each call or of each connection. By thus removing the human element, greater accuracy in counting was attained.

An accurate knowledge of the performance of the various human operators in a manual system is even more important than a corresponding knowledge concerning the "machine operators" in an automatic system, and it is not surprising therefore that this feature of machine-switching practice should also find its way into manual practice. With one or more automatic counting registers for each switchboard position, the management not only is able to ascertain the total number of calls, connections, or failures in a desired period but also is enabled to compare the efficiencies of the different operators with respect to each other.

Not only may the registers record calls answered or calls completed but, by altering their circuit connections, they may be made to show such other information as the number of calls that failed because the line wanted was busy or did not answer.

Straightforward Trunking.—As stated in Chap. X, in straightforward trunking the "A" operator selects the trunk and passes the call over it to the "B" operator, instead of using a separate call circuit to do so. This method of trunking is probably older, at least in its basic features, than the call-circuit method. It is natural that this should be so, for it seems in every way more logical for the operators in different offices to communicate with each other over the trunk circuits themselves rather than over an entirely different set of call circuits provided for inter-operator communication alone. Each trunk circuit about to be involved in a connection necessarily stands ready for such communication between the operators who are to establish the connection and it has always seemed to the writer a wasteful procedure not to so use it. Notwithstanding this, the use of call circuits was well-nigh universal in multi-office practice until, with the enormous growth of telephone traffic in certain metropolitan districts, the call circuits themselves became a serious burden. Perhaps two considerations were principally influential in starting the movement toward the abandonment of call circuits and the adoption of the straightforward method. One was the lack of room on the "A"-board key shelves, in certain offices, for the very large number of call-circuit keys required. The other was the low operating-experience factor at the time, owing to war conditions.

After this very general discussion of some of the later features of manual multiple-switchboard practice, we may return to a consideration of actual switchboard systems in which they have been incorporated in greater or less degree.

THE NO. 1 SWITCHBOARD WITH STRAIGHTFORWARD TRUNKING

This is the latest Bell System standard with respect to the No. 1 switchboard. The line circuits stand unchanged, as do also the basic features of the cord and trunk circuits. The principal differences are those growing out of the change from call-circuit to straightforward trunking.

General Statement of Straightforward Operation.—With the straightforward method of operation the "A" operator, instead of obtaining a trunk assignment from a "B" operator over a call circuit, tests and selects an idle trunk to the terminating office "B" position and passes the called number directly to the "B" operator over the trunk circuit which is subsequently to be used for conversation between the subscribers. This method of operation is particularly advantageous as compared to call-circuit trunking, in that there is less likelihood of operating errors, and operators' loads are increased, particularly so at "B" positions having trunks from more than one office. Furthermore, the straightforward method in large measure relieves the "A" operator's key shelf of the call-circuit buttons, an important advantage in very large multi-office exchanges where the congestion on "A"-board key shelves was becoming more and more acute on account of the large number of call circuits required.

In some cases, it is found desirable to provide supplementary means at the "A" position to facilitate the selection of an idle trunk to the "B" position. For this purpose, group busy tones are often employed to furnish an indication to the "A" operator when all of the trunks of a subgroup of trunks (usually five) are busy simultaneously. This avoids the necessity of testing them individually. Another method of expediting the selection of an idle trunk requires the provision of an individual lamp for each trunk circuit to a terminating office. In this case, the lamp associated with one idle trunk of each group to the terminating office will light, giving an indication to the operator of the trunk to be used and avoiding the necessity of making a busy test. When the trunk is selected, the lamp associated with the next idle trunk will light.

When the "A" operator has selected an idle trunk to the "B" position, the front or calling cord of the pair used in answering will be connected in the usual manner, thus lighting a guard lamp at the terminating office. In response to the lighted guard signal, the "B" operator will become connected to the incoming trunk, either automatically or manually. If the "B" operator's set is connected automatically, no act on her part is required to bring it about. If, however, the connection of the "B" operator with the trunk is done manually, it may be by depressing an associated trunk key or by connecting an incoming plug-ended trunk to a jack or by connecting a cord to an incoming jack-ended trunk. Regardless of the particular means employed at the "B" board for connecting an operator to the trunk, an *order* tone consisting of two short impulses of high pitch will be transmitted to the "A" operator as a signal that the "B" operator is available and that the called subscriber's number may be passed to her. Only automatic listening will be considered here in connection with straightforward trunking. On obtaining the called number from the originating operator, the "B" operator at an automatic-listening straightforward position will disconnect from the incoming trunk, either by connecting to a jack of the called subscriber's line or by depressing a common release key at the "B" position.

Description of Circuits.—This description of the modern No. 1 "A" and "B" switchboard system, arranged for straightforward trunking and automatic listening, will be made in connection with Figs. 284, 285, 286, and 287. The description will, in general, indicate the method of operation but will not trace the circuits in detail, as has heretofore been done in most cases.

Figure 284 is in three sections, 1, 2, and 3. The circuits are similar to those of Fig. 282, except that a straightforward trunk and associated circuits have been substituted for the call-circuit trunk of that figure. It is to be understood that these circuits, as well as their descriptions, are based on local manual trunking only and include no reference to other forms of trunking, as, for example, from a subscriber position to tandem or toll offices. Even though all the features which are commonly furnished in local No. 1 offices are not illustrated or specifically described, an attempt is made at least to mention the more important ones that are not specifically dealt with, in order to indicate, in general terms, the usual arrangements that are typical of No. 1 board practices. The trunking between manual and automatic or dial offices cannot be considered at this time. Although this is an important feature in multi-office exchanges, particularly during the period of conversion from manual to dial operation, it cannot well be described until after the broad subject of automatic or machine switching has been discussed.

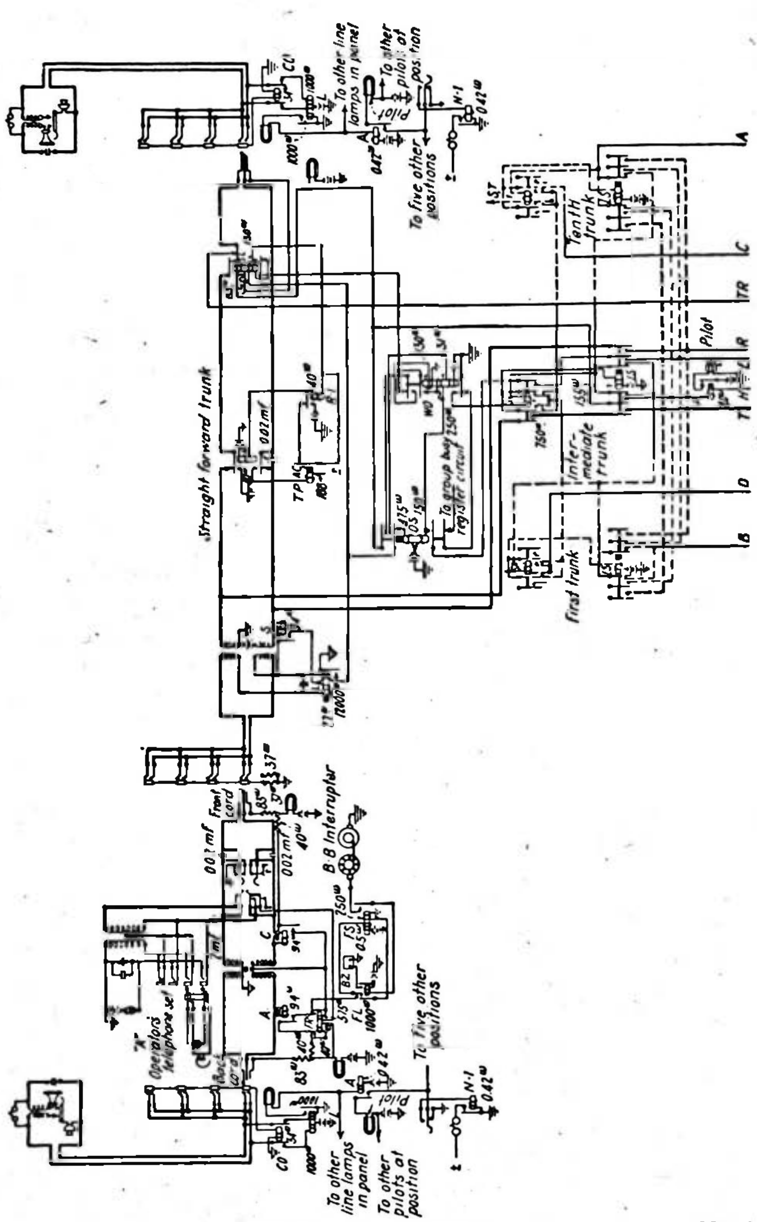


FIG. 284.—Section 1—Connection between two subscribers through a No. 1 "A" and "B" switchboard with straightforward trunking.

Subscriber Line and Associated Auxiliary-signal and Night-alarm Circuits.—It will be understood that the line circuits shown schematically at the extreme right and left of Fig. 284 (Section 1) are connected through main and intermediate distributing frames, as shown more in detail in Fig. 279, for the purposes already discussed.

These line circuits show no facilities for use on coin-box or message-register lines, or for use with rural lines, whether of the magneto or common-battery type. The differences in the line circuits required for these classes of service are not major and have not, therefore, been specifically illustrated.

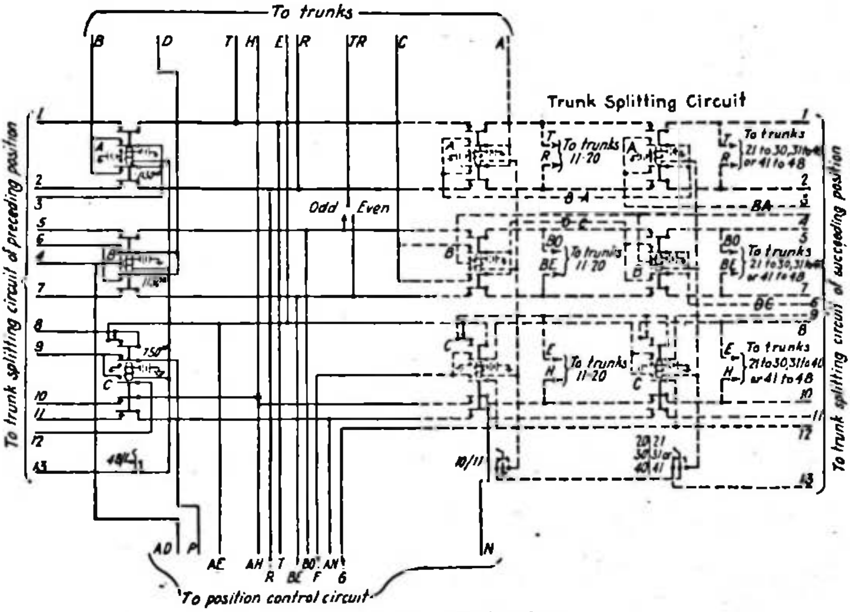


Fig. 284.—Section 2.

In the No. 1 board, as previously pointed out, the answering jacks and line lamps are not associated in position directly with the multiple jacks. Only a single answering jack is shown, but it will be understood that when more than one is provided for each line, in order better to balance the operators' loads, the ones added are connected in multiple with the one shown and placed on adjacent sections.

The possible omission of the entire subscriber multiple from the "A" board in order to provide space for more multiple answering jacks and outgoing trunk jacks has already been

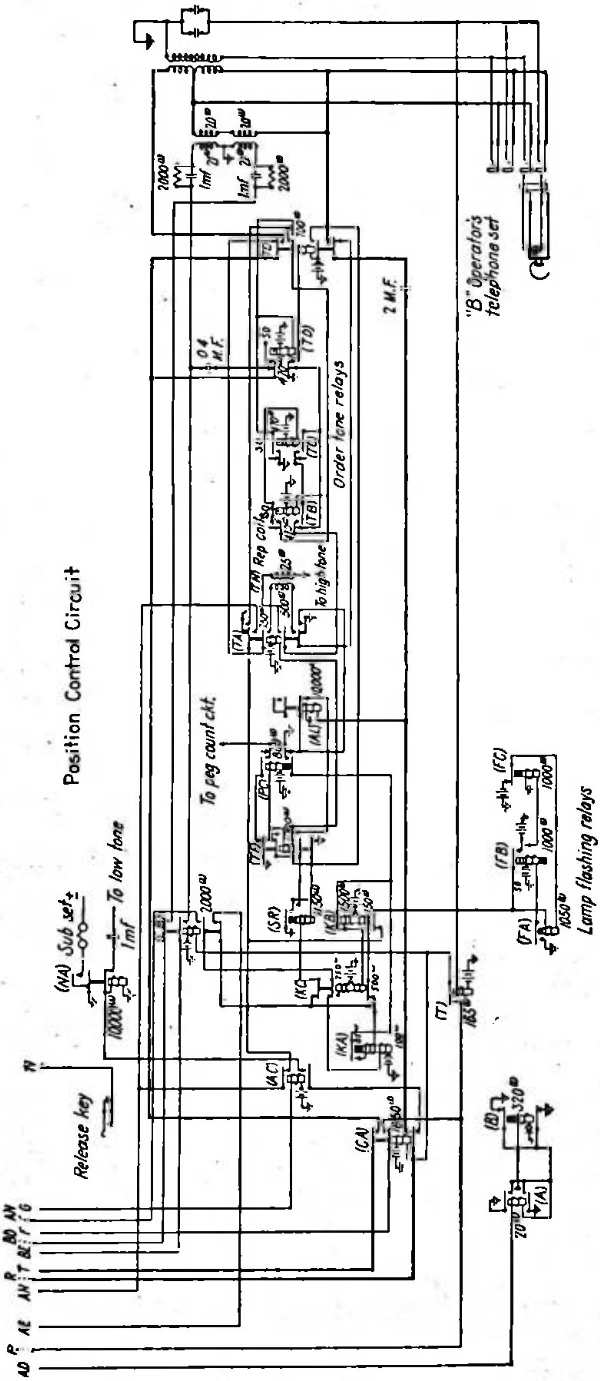


FIG. 284.—Section 3.

discussed. In determining whether or not this omission is warranted, it is necessary, among other things, to compare the operating savings incident to multiple answering jacks with the equipment and operating costs involved in providing additional "B" positions.

When a calling subscriber (at the station indicated at the left of Fig. 284, Section 1) initiates a call, the associated line relay *L* operates, bringing about the lighting of the line and pilot lamps and the ringing of the night-alarm bell if the night-alarm key has been operated. The arrangement of the line and auxiliary signals will be understood from the diagram and from what has been said regarding the No. 1 board with call-circuit trunking. When, in responding to the lighted signal, the "A" operator connects a back cord to the answering jack, the cut-off relay *CO* operates and disconnects the line relay. The release of the line relay extinguishes the line lamp and pilot and disconnects the night-alarm bell.

"A"-board Cord Circuit with Flashing Recall and Operator's Telephone Circuit.—The subscriber cord circuit, with flashing recall and revertive ringing tone, and the operator's telephone circuit are similar to the corresponding portion of the circuit of Fig. 281. The call-circuit key is, of course, omitted. Here again only a relatively simple cord circuit has been chosen for illustrative purposes. Features relating to coin and message-register line operation are not included, nor are facilities shown for "A" cord teaming and dialing, nor for operation in conjunction with rural magneto lines.

In noting a lighted line lamp, the "A" operator connects the back cord to the answering jack, operates the associated cord talking key, and obtains the called number from the subscriber. The operation of the answering supervisory lamp and of the flashing-recall circuit has already been described in connection with Fig. 281. The answering supervisory lamp merely lights steadily when the calling subscriber hangs up, or, if he "flashes" his hook, it lights intermittently at busy-back speed and at the same time causes a single-stroke buzzer to sound.

Obtaining the called number from the subscriber, the "A" operator selects an idle trunk to the terminating office. She does this either by making a busy test by running the tip of the calling plug along the strip of jacks or by observing a lighted lamp associated with an idle trunk to an available "B" position in the terminating office. Having selected an idle trunk, the "A" operator inserts the front plug of the pair used in answering and waits until the order tone, consisting of two short impulses of high pitch, is transmitted, as a signal that a "B" operator is available to receive the order. After passing the called number, the "A" operator restores the talking key to normal. The front cord supervisory lamp, which, as will be explained, lighted when the "A" operator plugged into the trunk, remains lighted either until the called subscriber in the terminating office responds or until the trunk at the "B" board is connected to a busy-back jack, as an indication that the called line is busy. In the latter case, the lamp flashes.

Straightforward Trunk to a No. 1 "B" Switchboard with Associated Splitting, Control, and Operator's Telephone Circuits. We may well subdivide this part of the discussion by considering first the outgoing end of the trunk, then the incoming end, and then the associated "sequence," "trunk-splitting," "position-control," and operator's talking circuits, in the order mentioned.

Outgoing Trunk.—In Fig. 284 (Section 1) a relatively simple outgoing-trunk circuit is illustrated, consisting merely of multiple outgoing-trunk jacks and an associated sleeve resistance. As already stated, it is the practice in some cases to furnish auxiliary means for facilitating the selection of an idle trunk by the "A" operator. This is of minor importance in small exchanges, where the trunk groups are small. Where large trunk groups are involved, however, the process of testing each individual jack to determine an idle one becomes burdensome.

One method for expediting the selection of an idle trunk consists in providing outgoing-trunk sleeve relays with their contacts wired in series, so that a tone may be connected to the sleeve of a designated master jack when all the individual jacks in the subgroup are busy. With this arrangement the test of the first jack gives an immediate audible indication to the "A" operator when all the individual jacks of the subgroup are busy. Receiving this, the "A" operator tests the first jack of the next subgroup and so on until one with an idle trunk is found.

A more expensive form of supplementary equipment for expediting the selection of an idle trunk consists of idle trunk and position indicating apparatus. This arrangement requires furnishing an individual lamp for each outgoing trunk together with collateral relay equipment. As regards a particular group of trunks to a terminating office, the idle trunk and position indicating equipment is arranged to light the lamp associated with only one trunk at a time, provided the "B" operator and trunk are idle. This more expensive form of equipment is ordinarily justified only in large trunk groups.

Only calls which are trunked to local No. 1 "B" positions are here considered. As a matter of general experience, however, "A" operators are required to trunk calls to terminating offices other than local manual offices, such as calls to tandem switchboards, to toll switchboards, and to dial-system offices.

Incoming Trunk.—The incoming straightforward trunk shown in Fig. 284 is arranged for automatic-listening straightforward operation. Although this arrangement is typical of trunk circuits now provided in No. 1 switchboards arranged for straightforward operation, it may be mentioned that other forms of straightforward trunks are sometimes employed. With the automatic-listening type, the operator's telephone circuit and the associated control circuit are connected automatically to incoming trunks and in a predetermined sequence, if calls are waiting on more than one trunk at a given time.

In other forms of straightforward trunking, the operator's telephone and control circuits may be connected manually to the incoming plug-ended trunk by depressing an associated trunk key or by connecting the incoming trunk to a listening-jack circuit. In the case of incoming jack-ended straightforward trunks, the position circuit may be connected by means of an associated cord.

The automatic-listening straightforward trunk, shown in Fig. 284, is similar to the call-circuit trunk already described, in that it is arranged for automatic ringing and is provided with a single lamp which is arranged to light on selection and also to light on a disconnection. The straightforward trunk has four additional relays not used in call-circuit trunks, namely, the *DS*, *WO*, *LS*, and *ST* relays, which furnish features essential to straightforward operation. With straightforward operation, the associated trunk lamp lights as a guard signal when the trunk is selected at the "A" board. When it flashes at the rate of approximately sixty interruptions per minute, it serves as a signal to the "B" operator that the trunk is connected to the control circuit and should be identified with the called number passed by the "A" operator.

When the trunk is selected at the "A" board, the trunk-line relay *L* operates over the trunk conductors as in the case of call-circuit trunking. The operation of the *L* relay operates the *WO* relay through its 250-ohm winding. The *WO* relay locks through its 31-ohm winding in series with the *DS* relay, which also operates. The associated guard lamp lights steadily, as a signal that the trunk has been selected and a call is waiting. The circuit for the lamp includes the 130-ohm non-inductive winding of the *WO* relay. Incidentally, the *DS* relay locks to the line relay through its 475-ohm winding and is arranged to be slow releasing, to guard against displaying false disconnect signals as a result of the possible momentary release of the line relay *L*.

Trunk-sequence Chain.—Up to this point we have the trunk lamp glowing steadily to show that it has been selected at the "A" board. There may be several such trunks waiting the attention of the "B" operator. The operation of the *WO* relay connects ground to the winding of the associated *ST* relay and, if no other calls are waiting or being handled, causes the operation of the *LS* relay, thereby connecting the incoming trunk to the position control circuit. In case, however, another call is being handled at the position and other calls are waiting, the trunk relays *ST* and *LS* will not operate until all calls waiting to the left of the particular trunk are connected in turn to the control circuit and subsequently released. A description of the operation of the trunk-sequence relays *ST* and *LS* may be facilitated by reference to the schematic diagram of Fig. 285.

This shows the *WO*, *ST*, and *LS* relays of a group of trunks arranged in order from left to right. The *ST* and *LS* relays of the incoming trunks are those which determine the order or sequence in which the "B" operator will dispose of calls. It will be seen that the trunk *ST* relays are equipped with transfer-spring combinations, which are connected in sequence in such manner that the operation of any *ST* relay disconnects ground from the armatures of all the *ST* relays to the right. In practice, duplicate sets of springs are furnished on these relays to insure reliability of operation. It will also be seen that the *LS* relays include back-contact spring combination (also paired for reliability) which connect a common-battery supply to the windings

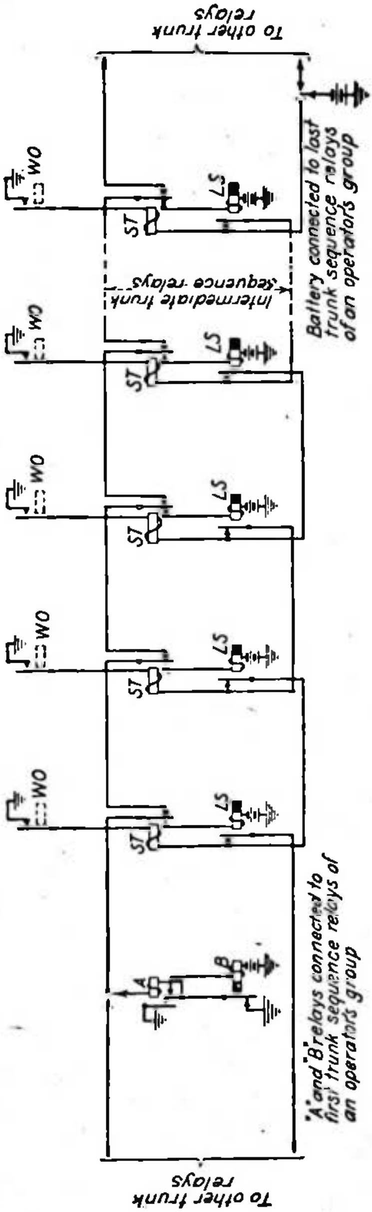


FIG. 285.—Schematic—automatic listening straightforward trunk sequence relays.

of the associated trunk *ST* relays. Since the common-battery lead is connected to the last *LS* relay in the group, the operation of any *LS* relay disconnects battery from the windings of all *ST* relays to the left. Only one *LS* relay at a position operates at a given time, and this relay is effective in associating a particular trunk with the position circuit to the exclusion of all other trunks.

Assuming that the first three consecutive *WO* relays illustrated on Fig. 285 are operated simultaneously by virtue of incoming calls being waiting on each of the three trunks, it may be noted that all of the three *ST* relays will be operated simultaneously. The operation of the first *ST* relay to the left, however, connects ground to the winding of its associated *LS* relay, causing its operation, and disconnects ground from the armatures of all the other *ST* relays in the group. The operation of the *LS* relay associated with the first trunk connects the particular trunk to the position circuit.

It should be observed that, when an order has been obtained, the "B" operator releases the associated control circuit, thereby causing the trunk *ST* and *LS* relays to release. In the same manner as described above, the *LS* relay associated with the next waiting trunk to the right operates and at the same time disconnects battery from the windings of all *ST* relays to the left. Should, therefore, any trunk to the left be selected before all calls are handled on the trunks to the right which are waiting, the associated *ST* relays cannot operate and cannot, therefore, disconnect ground from the armatures of the *ST* relays to the right. The *LS* relays are made slow releasing to assure the left to right progression in handling calls.

When waiting calls have been connected in a definite sequence from left to right, the first waiting call to the left will then be given preference. The auxiliary relays *A* and *B* are employed to insure that the sequence resumes at the extreme left, thus permitting the handling of calls in a definite sequence without involving abnormal delays on any one call. In this connection, when any trunk relay *LS* operates, the positional relay *A* also operates in series with the trunk *LS* relay. The *A* relay locks to ground on its own contacts as long as any *LS* relay remains connected and energizes the *B* relay, which disconnects the operating ground for the first relay. When the last waiting call to the right has been completed, battery from the trunk

LS relays is momentarily disconnected, causing the release of the *A* relay. The release of the *A* relay, in turn, releases the *B* relay which, owing to its slow-releasing characteristics, holds ground disconnected from the *A* relay and, therefore, from the armatures of the trunk *ST* relays for a brief interval. This interval is sufficient for the trunk *ST* relays to operate and thereby establish definite sequence, since the extreme left relay operated will be given preference as regards operating the associated *LS* relay.

When the incoming-trunk circuit is connected through the sequence circuit to the control circuit, the associated guard lamp flashes as a distinctive signal for identifying the trunk involved. The trunk guard lamp is caused to flash, owing to its regular momentary shunting by the 40-ohm pilot relay *P* (Fig. 284, Section 1). One pilot relay is provided for each group of ten trunks and lights an associated pilot lamp. The pilot relay is slow releasing in order that the associated pilot lamp may light steadily, even though the associated relay is energized momentarily at a predetermined rate. When the "B" operator has obtained the called number from the "A" operator, the trunk may be disconnected from the control circuit, either by depressing a common release key or by connecting the associated trunk to a multiple jack.

In case the trunk is disconnected by depressing a common release key, ground is connected to the armature of the *DS* relay, thereby placing a short circuit across the 31-ohm winding of the *WO* relay. The *WO* relay releases and causes the release of the *ST* relay and in turn the *LS* relay. Should the trunk be disconnected by plugging the associated cord into a multiple jack, the *WO* relay releases, owing to the opening of its 31-ohm winding at the bottom transfer spring of the sleeve relay *SL*.

On connecting the trunk cord to a multiple jack, machine ringing is started automatically and continues until the called party answers, as in the case of regular call-circuit trunking. When the called party answers, the 12,000-ohm winding of the line relay *L* is short-circuited, thereby permitting sufficient current to flow over the trunk loop from the "*A*" cord repeating coil to operate the front cord supervisory relay. The operation of this relay extinguishes the associated front cord supervisory lamp as an indication to the "A" operator that the called party has answered.

Trunk-splitting Circuit.—The incoming trunks at a straightforward position are ordinarily connected to the position-control circuit by way of a trunk-splitting circuit. The trunk-splitting circuit is designed to permit grouping varying numbers of trunks to a particular control circuit, thereby facilitating operation under light load conditions. In a No. 1 switchboard the trunk circuits are associated with splitting circuits in groups of ten trunks. A control circuit is commonly provided for each physical switchboard position, although fewer control circuits than positions may be furnished, if conditions require more trunks for each operator during the busy hour than can be accommodated on one physical position.

The splitting circuit includes three relays for each group of ten trunks, together with an associated locking-type key for operating the relays. The key is located in the key shelf between the trunk cords affected. If all the splitting keys in a "B" board are normal, all the associated trunks will be connected together and may, in turn, be connected to any control circuit by an operator's connecting her telephone set to the corresponding position. To eliminate the possibility of interference which might otherwise result on connecting two operators' sets to a large group of trunks, facilities are included to give preference to the particular telephone circuit in the group which is located to the extreme left.

The function of the trunk-splitting circuit in combining groups of ten trunks with associated control circuits is illustrated in Figs. 286 and 287. Figure 286 shows, in simplified form, that portion of the splitting circuit which is required for grouping trunk-sequence relays in a continuous chain, so that the arbitrary sequence of handling calls from left to right is maintained regardless of the number of trunks combined. It may be noted that the splitting circuit connects *A* and *B* relays to the left of the sequence chain established and battery to the right. Figure 287, in a similar manner, indicates the arrangement of the splitting circuit for combining other trunk leads to the control circuit and the arrangement whereby the extreme left telephone circuit of a group of trunks may be effective in preference to other telephone circuits connected to the right.

The splitting circuits illustrated in Fig. 284 and in schematic diagrams of Figs. 286 and 287 are arranged for grouping automatic-listening straightforward positions only. Some additional

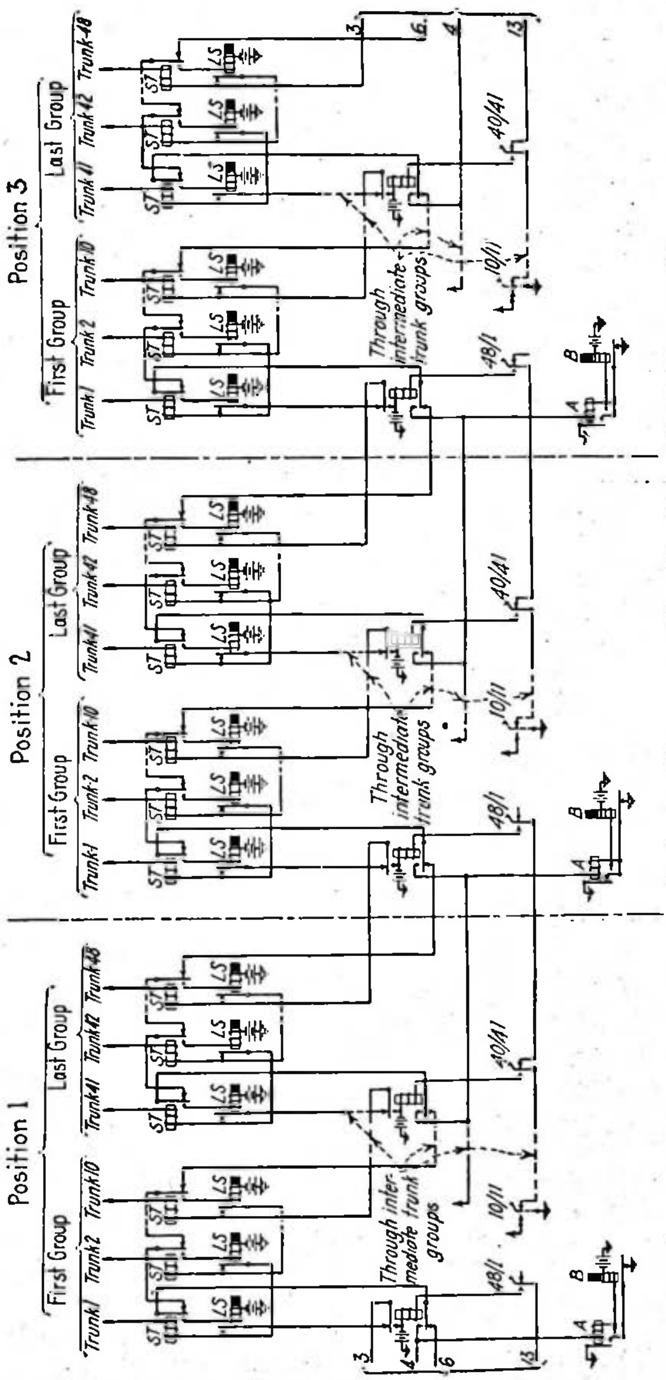


FIG. 280.—Schematic—automatic-listening straightforward position trunk-sequence relays and splitting circuit.

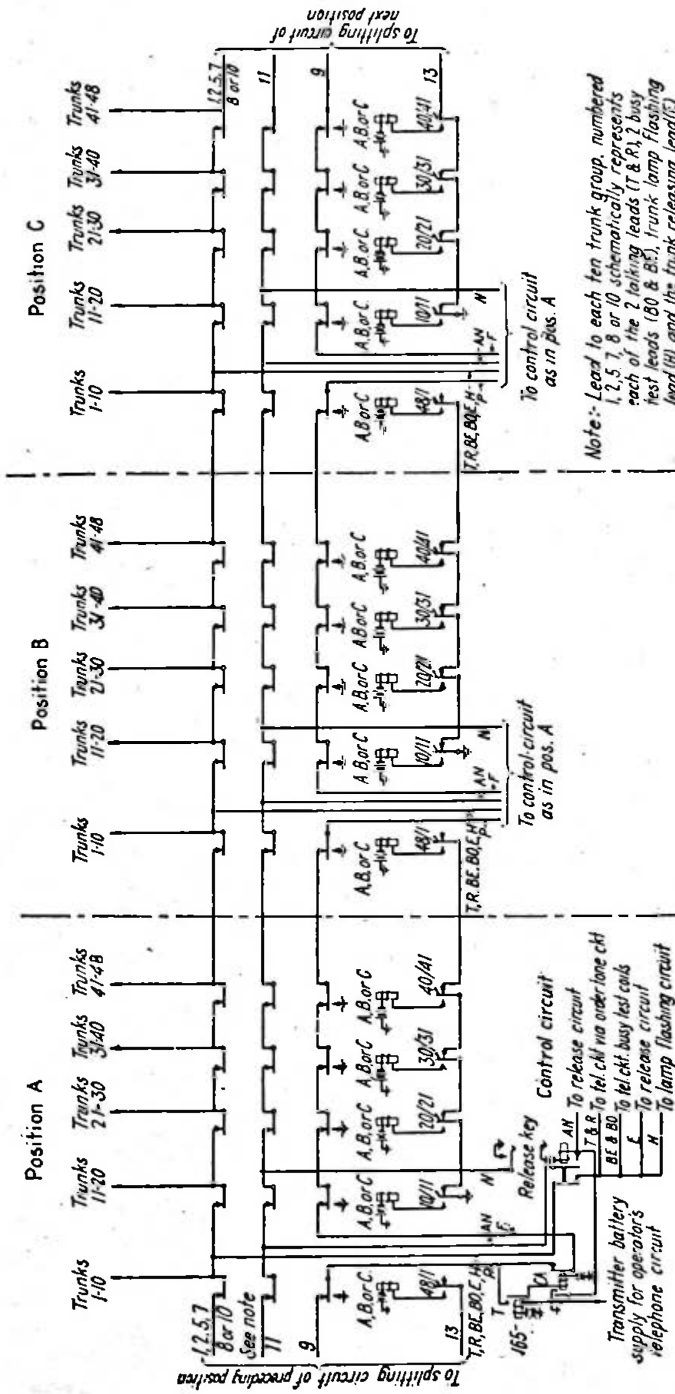


FIG. 287.—Schematic—automatic-listening trunk-splitting circuit (excepting sequence-relay grouping leads).

complications are ordinarily involved in order to provide for the grouping of these positions with call-circuit type positions and call-indicator positions. The latter requirements do not, however, introduce circuit arrangements which differ materially from the fundamental arrangements illustrated.

Position-control and Telephone Circuit.—Referring to Fig. 284, it may be noted that the control and telephone circuit is connected to the splitting circuit, provided the operator's telephone set is connected and the set has preference over other telephone circuits which may inadvertently be connected. In this case, the *CA* and *CB* relays operate and thereby connect the talking leads to the order-tone circuit and the busy-test leads to the telephone circuit. In addition, leads for flashing the trunk lamp and for releasing the trunk from the control circuit are also connected. The alarm relay *NA* is disconnected.

When a trunk is connected to the control circuit, relays *FA*, *FB*, and *FC* operate in a definite sequence such that battery is connected momentarily to the *FL* lead for flashing the trunk lamps. A relay flashing circuit of this character is employed, in order to avoid the possible failure of trunk lamp to flash, which might be experienced if a common flashing circuit or a common busy-back interrupter were used.

The order-tone circuit, consisting of relays *TA*, *TB*, *TC*, *TD*, and *TE*, is arranged to transmit an order tone consisting of two impulses of high pitch to the "A" operator as a signal that the called number should be passed. The order tone is also transmitted to the "B" operator at a lower level, owing to the connection of the 0.04-microfarad condenser from the tip of the circuit to the busy-test lead. The operation of the last order-tone relay *TE* disconnects the talking leads from the order-tone circuit and connects them to the operator's telephone circuit.

The operation of a common release key operates the release-key relays *KA*, *KB*, and *KC*, causing ground to be placed on the winding of the trunk *WO* relay, thereby causing its release. The control circuit is arranged to provide a count of all calls handled and also to provide for night-bell operation in case a call is completed to the position when the operator's set is not connected. Under this condition the *CA* relay is non-operated and, if a call is completed to the control circuit, the night-alarm relay *NA* operates. While the "B"-board night bell sounds, a continuous low tone is connected to the originating "A" operator as an indication that the "B" operator is not connected to the position. The "A" operator, therefore, waits until the continuous tone is disconnected and a regular order tone transmitted. In certain cases, as in night operating, this continuous tone will indicate that the position has been permanently vacated,

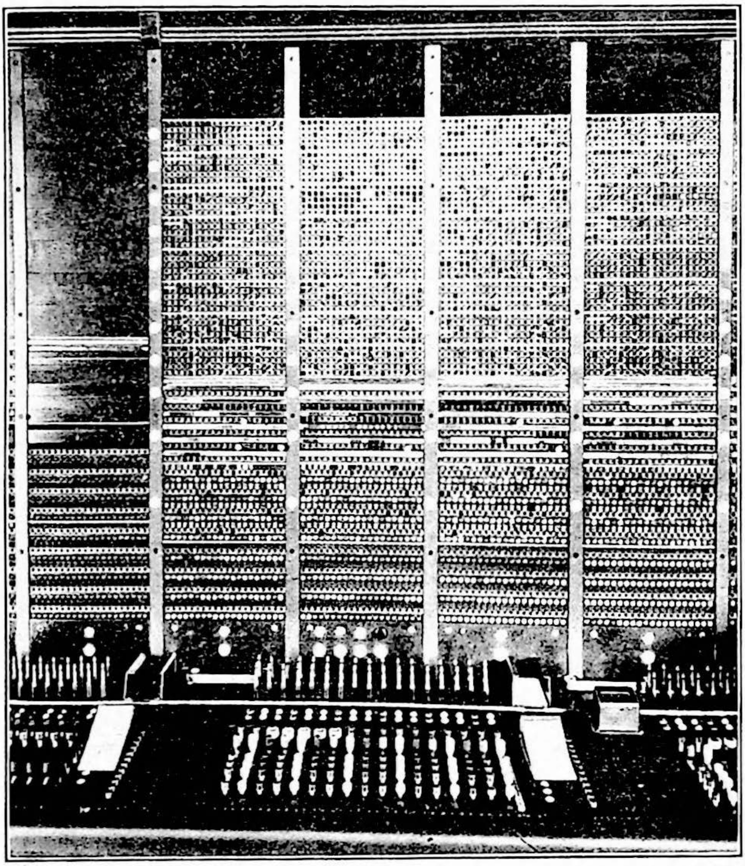


FIG. 288.—No. 1 switchboard—portion of "A" or subscriber section. (*Courtesy of The American Telephone and Telegraph Company.*)

and the "A" operator will, therefore, select a trunk to another position.

Dimensions and Capacities of Sections.—The frameworks for the sections of No. 1 switchboards are essentially the same whether for call-circuit or straightforward trunking. No major changes are required in either subscriber or trunk sections as a result of the introduction of straightforward trunking. In fact most of the No. 1 switchboards that to-day are operating on the straightforward basis were originally designed for use with call-circuit trunking.

Subscriber or "A" Section.—In general, the only changes in the "A" sections which straightforward trunking has brought about relate to the reduction or elimination of call-circuit key buttons at the subscriber-position key shelf and, in some cases, to the association of lamp equipment with the outgoing-trunk

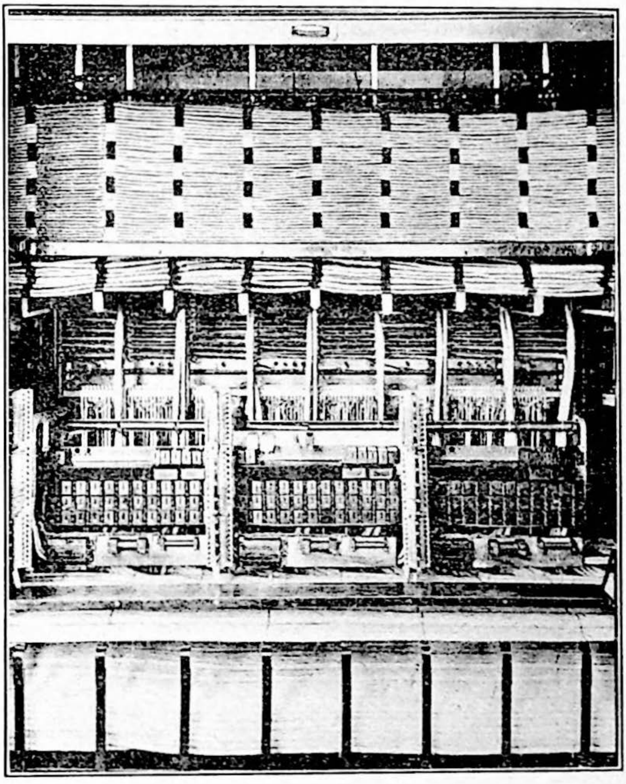


FIG. 289.—No. 1 switchboard—rear of "A" or subscriber section. (*Courtesy of The American Telephone and Telegraph Company.*)

jacks to facilitate the selection of an idle trunk to a terminating office, as before mentioned.

A typical arrangement of an eight-panel, ninety-two-jack subscriber section is shown in Fig. 288. The rear of the section, with the enclosing curtain raised, is shown in Fig. 289.

The present standard No. 1 subscriber section is a three-position eight-panel, ninety-two-jack section. The panels are on 8½-inch centers, thus involving an over-all section length of 68 inches. The jack opening in each panel is 34½ inches high. The number of subscriber-line multiple jacks that can be furnished is variable, depending upon the number of outgoing trunks and answering jacks equipped, and in practice is limited so that the total height from the key shelf does not exceed approximately 34 inches. The table on page 373 gives various capacities based on this limitation, it being noticed that the trunk jacks are multipled on a six-panel basis, as against the eight-panel basis of multipling for the subscriber's jacks.

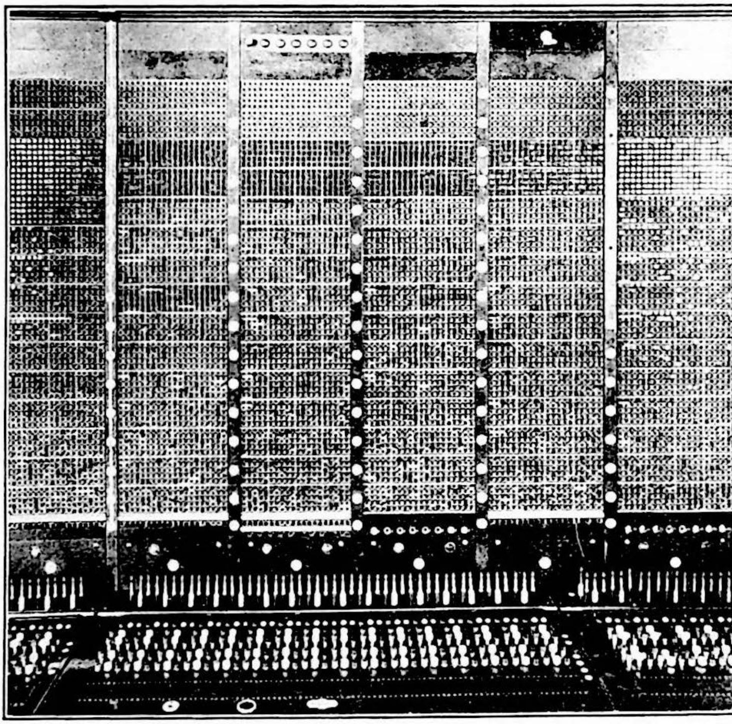


FIG. 290.—No. 1 switchboard—"B" or trunk section. (*Courtesy of The American Telephone and Telegraph Company.*)

Many of the older No. 1 sections employed the larger No. 49 jacks. These have not been considered standard equipment for new installations in the Bell System for a number of years, but a considerable number of them are still in service.

Trunk Sections.—As in the case of the subscriber section, the introduction of straightforward trunking necessitates no major modification of the trunk section. The only difference to be noted in a trunk key shelf, when changed from call-circuit to straightforward operation, is the addition of a common release key and five trunk-splitting keys.

The standard No. 1 trunk section has two positions, and seven panels and uses the No. 92 jack. It is 59½ inches

No. 92 Jack, Three-position, Eight-panel Subscriber Section

Subscriber multiple (8-panel)	Trunk multiple (6-panel)	Total answering jacks per panel	
		(10 per strip)	20 per strip
9,600	120	80	100
8,000	600	80	100
7,200	840	80	100
8,800	120	100	120
8,000	360	100	120
7,200	600	100	120

long and has a jack opening 36½ inches high. A typical front view is shown in Fig. 290.

The number of subscriber and trunk multiple jacks may be varied, as indicated by the following cases:

No. 92 Jack, Two-position, Seven-panel Trunk Section

Subscriber Multiple	Trunk Multiple
10,500	280
10,500	420
9,800	560
9,800	700

THE NO. 11 SWITCHBOARD OF THE BELL SYSTEM

An essential feature of this switchboard is the use of multiple line lamps associated directly with the multiple jacks. It is this feature which principally distinguishes it from the No. 1 switchboard, although there are many other minor differences. Owing to its range of capacities and to the variety of features it may embrace, the No. 11 switchboard has replaced, as standards in the Bell System, the Nos. 1-C, 1-D, and 9-C switchboards and to a large extent the No. 1 switchboard, although the last is still considered standard. It may be variously equipped but will be described here with flashing recall, straightforward trunking, automatic listening on both subscribers' and incoming-trunk cords, and with machine ringing started by common ringing keys at both subscribers' and trunk positions.

Equipment Arrangement.—As in the case of the No. 1-D board, the No. 11 section is made up of separate upper and lower units, permitting the lower units to be interchanged without disturbing the upper. The upper units are in either one-position or three-position lengths, extend from the key-shelf level to the roof, and include the rear-door or rear-curtain assembly. The lower units are in single-position lengths and extend from the key shelves, which they include, to the floor. They are

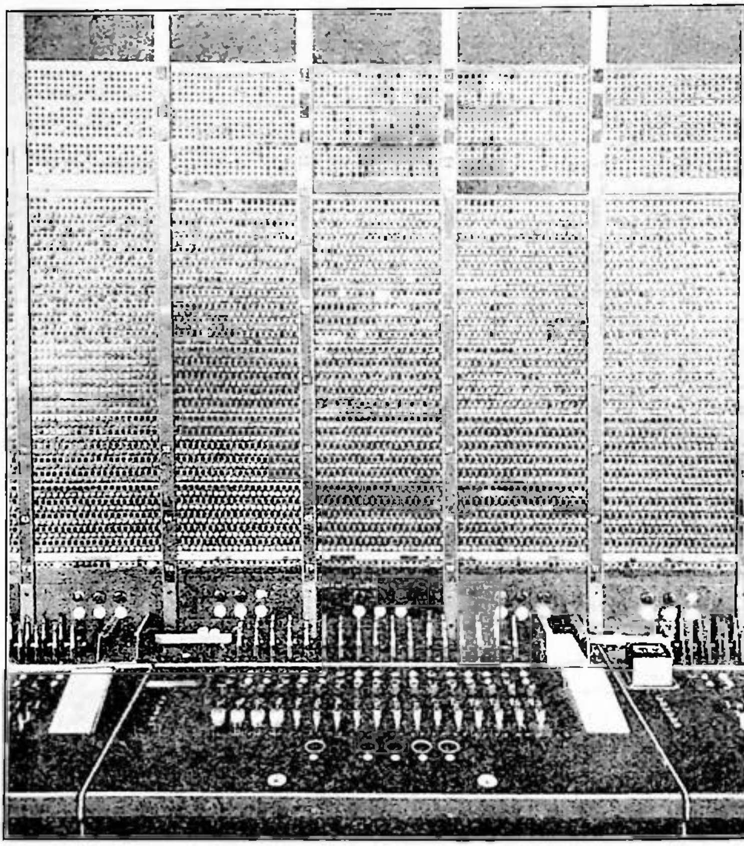


FIG. 291.—No. 11 switchboard—"A" or subscriber section. (*Courtesy of The American Telephone and Telegraph Company.*)

designed to be removable from the switchboard line-up in order to facilitate changes in the locations of positions as required by growth and the redistribution of classes of service. For this reason, the lower-unit frameworks for subscriber, trunk, and toll positions are mutually interchangeable.

Subscriber-position Unit.—The subscriber-position unit includes the subscriber cords and position circuits which are arranged for automatic listening, flashing recall, and machine ringing on a common ringing-key basis. Either four-party selective or four-party semi-selective ringing may be furnished. In this connection it may be observed that a universal tripping relay is employed, thus facilitating the application of a common-position unit for use in either a selective or semi-selective ringing area. The apparatus associated with the cord and position circuits is mounted in the rear of the unit. Front and rear

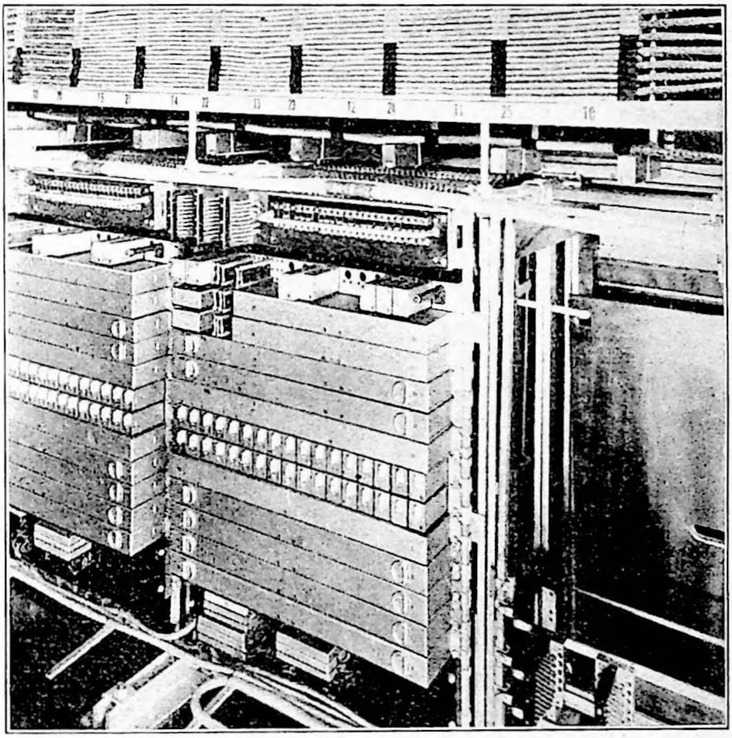


FIG. 292.—No. 11 switchboard—rear view "A" section. (*Courtesy of The American Telephone and Telegraph Company.*)

views of portions of a No. 11 subscriber-switchboard section are shown in Figs. 291 and 292 respectively.

Trunk-position Unit.—For trunk positions that are to be in line with subscriber positions, a lower unit is provided which can be associated with the upper units in the same manner as a subscriber-position unit. This trunk unit is equipped with forty straightforward automatic-listening trunk circuits arranged for machine ringing on a common key-ringing basis. The trunk circuits are similar to the automatic-listening No. 1 trunk circuits already described, except that ringing is controlled by a common-position key rather than by mechanically locking keys individual to each trunk circuit. A front view showing the arrangement of face and key-shelf equipment on somewhat more than one trunk-position unit is shown in Fig. 293. Figure 294 is a rear view.

As will be shown, a separate line of trunk positions may be used in large No. 11 installations. In this case the standard two-position, seven-panel, 92-jack, No. 1 trunk section is employed, but key shelves arranged for common-key ringing are used in place of the usual No. 1 key shelves. Owing to the provision of common-key ringing rather than individual-key ringing,

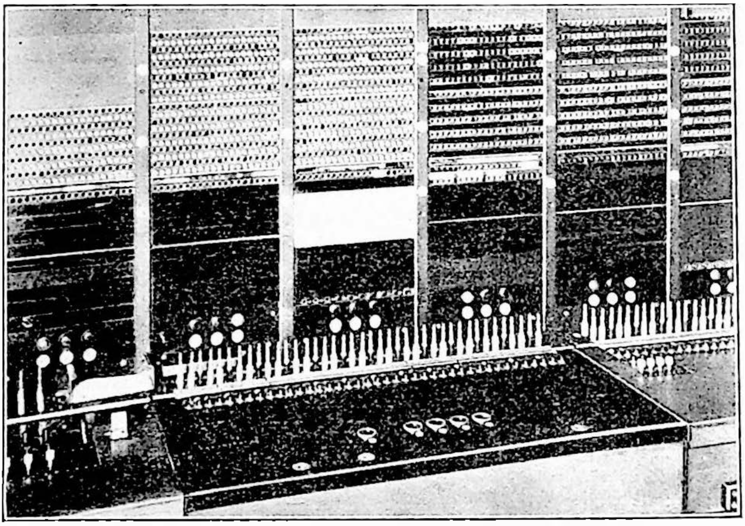


FIG. 293.—No. 11 switchboard—"B" or trunk section. *(Courtesy of the American Telephone and Telegraph Company.)*

a total of fifty trunks may be furnished at each position in place of the forty-eight trunks usually furnished with four-party No. 1 installations.

Method of Operation.—When an "A" operator answers a subscriber line signal by connecting her back cord to one of the multiple line jacks, her telephone circuit is automatically connected unless the call has already been taken up by another "A" operator. In this latter event, her telephone set will not be connected and a warning tone will be given her as a signal that the call has already been answered and that her cord may be withdrawn.

The subscriber call may be completed directly through a multiple jack at the "A" position or, if it is required to trunk the call, through a "B" position by way of a straightforward trunk in a manner similar to that employed in No. 1 switchboards. When the "A" operator has tested or otherwise selected an idle trunk to the "B" position, the front cord is connected to the associated trunk jack and the order passed. When the

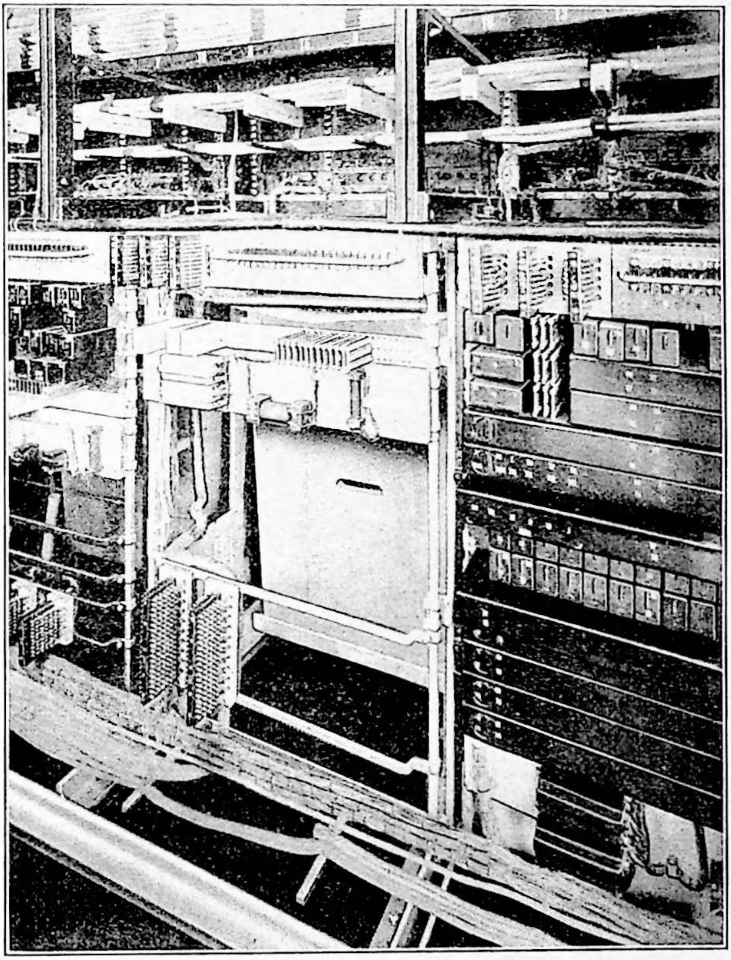


Fig. 294.—No. 11 switchboard—rear view. (*Courtesy of The American Telephone and Telegraph Company.*)

called number has been passed to the "B" operator, the "A" operator releases her telephone circuit from the cord pair by depressing the common-positional *TRK* key. The operation of the key releases the telephone circuit without applying ringing current.

The subscriber cord is equipped with a talking key in order to permit an "A" operator to connect her telephone circuit to the cord pair manually in case a subscriber recalls. The recall equipment provides for a flashing-back cord signal in a manner similar to that described for No. 1 switchboards.

The No. 11 automatic-listening straightforward trunk operates substantially in the same manner as the corresponding circuit used in No. 1 offices, except for differences resulting from the use of a common-positional ringing key. When the "B" operator obtains the called number from the "A" operator, one of the buttons of the common ringing key is depressed to establish conditions in the associated trunk for ringing the proper party. In addition, the operation of the ringing key is effective in releasing the trunk from the positional-control circuit.

Description of Circuits.—Figure 295, in four sections, includes the circuits which are involved in straightforward-trunk connections established between two subscribers served by No. 11 switchboards. The circuits involved include two individual subscriber lines, a flashing-recall machine-ringing "A" cord, an automatic-listening straightforward trunk circuit with associated position-control and telephone circuits. This represents the fundamental circuit arrangements required for such a connection, the circuits being typical of the present No. 11 switchboard practices. A number of different circuit arrangements are also required in a No. 11 switchboard to provide for operation in conjunction with prepayment-coin, message-register and rural lines, interconnecting circuits to dial-system offices, and to furnish auxiliary service features, such for example as intercepting, service observing, information, testing, and similar arrangements.

The descriptions included in the following sections do not trace in detail the operating or releasing paths for the various relays. However, the descriptions indicate the general method of operation and should facilitate an interpretation of the circuit drawing.

Subscriber-line Circuits.—As in the case of the No. 1 switchboard circuits, the line relay operates when the subscriber initiates a call and is disconnected when an operator responds, owing to the operation of the cut-off relay. Unlike the No. 1 switchboard circuits, the No. 11 line circuit employs lamps normally connected to ground instead of to battery. One auxiliary-signal relay is provided for each group of forty subscriber lines. One night-alarm relay is furnished in each office for all subscriber lines.

The fact that in the No. 11 switchboard the line lamps are associated directly with the multiple jacks avoids the necessity of an intermediate distributing frame for providing cross-connection facilities. The cabling of the multiple jacks and lamps to the horizontal side of the M.D.F., as well as the connection of the subscriber line to the protectors on the vertical side of the frame, is illustrated in Fig. 296.

The provision of four answering jacks and lamps offers an increase of 11 per cent in operator's loads, owing to the more even distribution of the calls. Should a greater number of multiple line lamps be furnished, the theoretical slight increase in load would be more than offset by the increase in the number of cases where an operator needlessly attempts to answer calls which have already been taken up at other positions. In view of this, it is ordinarily the practice to furnish only four appearances of the line lamps even though lamp sockets are equipped for the entire line multiple. Line lamps are "pulled" at the other appearances of the line multiple. As an exception, however, a complete line-lamp multiple is frequently furnished at designated positions to facilitate night operation and this results in a partial fifth appearance.

Although the arrangements are not illustrated, line circuits are provided in No. 11 offices arranged for common-battery or magneto rural-line operation and for prepayment-coin or message-register operation. With the exception of the obvious differences which would obtain on handling these services, the line circuits operate substantially in the same manner as the simple fundamental arrangement described.

Subscriber Cord Circuits.—The subscriber cord circuit shown on Fig. 295 (Section 1), together with the associated positional circuits for flashing recall, non-interfering answering, and for common-key ringing operation, provides a number of operating features not incorporated in No. 1 switchboard cord circuits. Included among these improvements is automatic listening on the back cords with relay equipment to prevent interference in case more than one operator should answer the multiple line signals. Flashing recall is obtained on the back-cord lamp in a manner similar to that provided for No. 1 switchboard cords.

The No. 11 cords are arranged for machine ringing and, in place of furnishing individual keys for each cord circuit, relays are equipped in the cords and are operated by a common ringing key in order that proper ringing current may be connected to

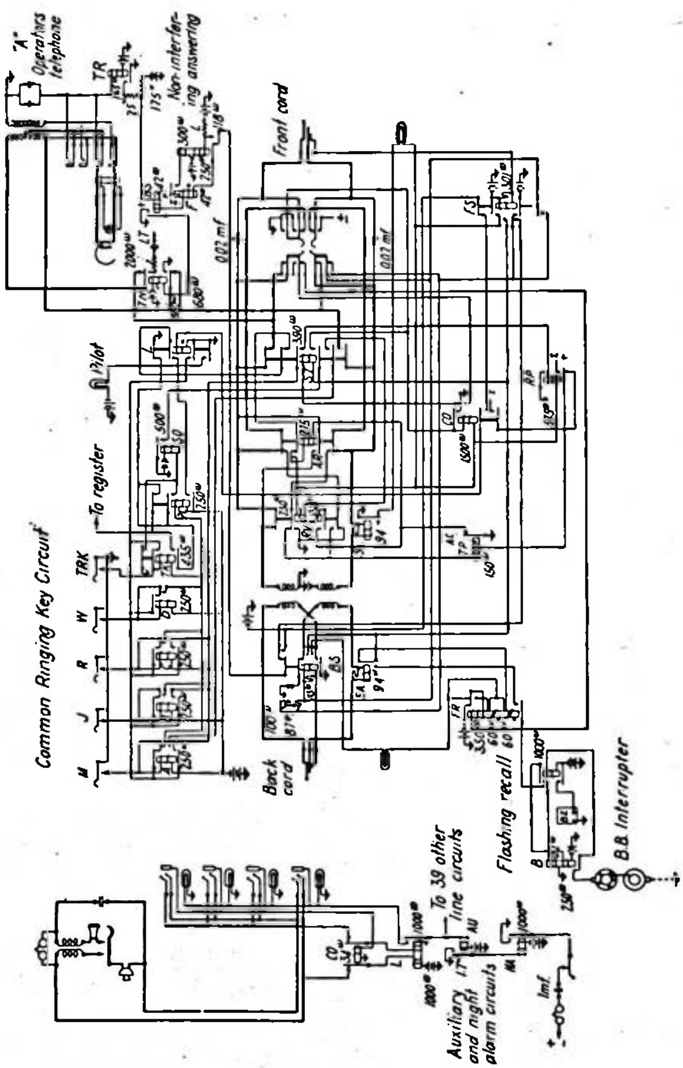


FIG. 295.—Section 1—Connection between two subscribers through No. 11 "A" and "B" switchboards.

either the tip conductor or the ring as required for ringing the called party's bell selectively.

When the "A" operator connects the back cord to a subscriber line jack in response to a lighted line lamp, a circuit is closed through the back-sleeve relay *BS* and the *F* and *BS* relays of the operator's telephone circuit. If no other cord has been connected to the subscriber line in the meantime, the *F* relay will operate and lower the resistance of the circuit in series with the back-sleeve relay *BS* sufficiently to allow the latter

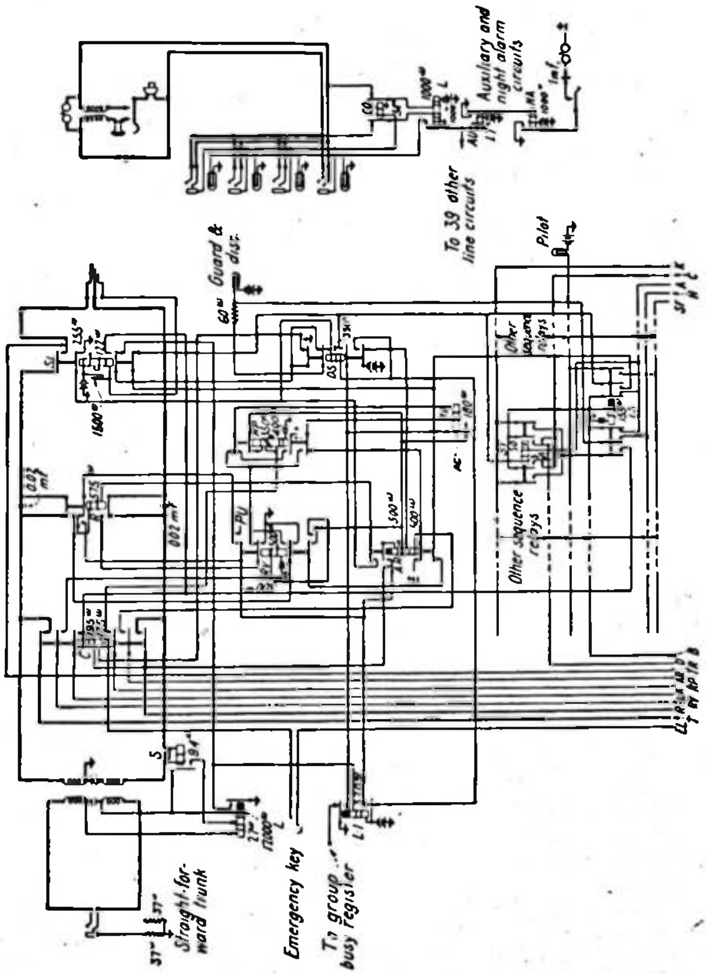


Fig. 295.—Section 2.

relay and the line cut-off relay to operate. If, however, the line has been taken up by another "A" operator, the two subscriber cords in conjunction with the operator's telephone circuit and subscriber-line circuit form an unbalanced Wheatstone bridge causing a reversal of current through the *F* and *BS* relays of the second operator's telephone circuit. Owing to this reversal, the *F* relay remains normal but the *BS* relay operates and in turn operates an auxiliary relay *TN*, which applies a tone to the second operator's telephone circuit as a warning that the "A" cord should be withdrawn. It should be noted that until the back-sleeve relay operates, the cord circuit to the subscriber line remains open. thus avoiding clicks

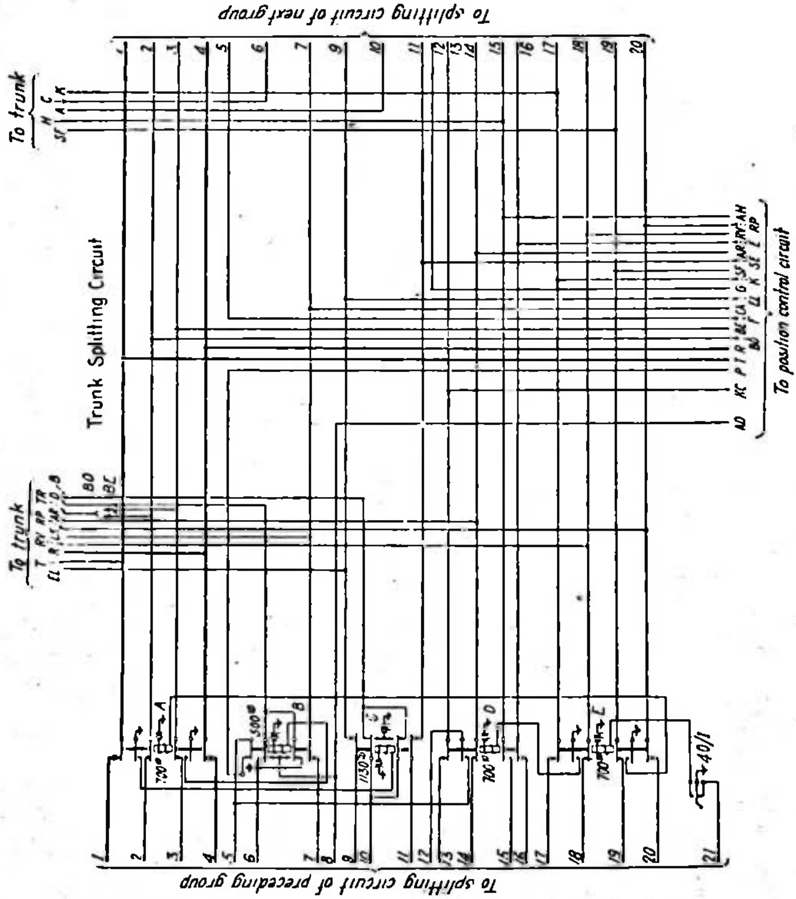


Fig. 295.—Section 3.

or other service disturbances due to the second operator's answering a call which is being completed.

Assuming that the operator has connected the cord to the line before any other operator may have answered the signal, the back-sleeve relay *BS* operates together with the line cut-off relay. Subsequently, the start relay *ST* also operates, thus connecting the cord circuit to the position equipment.

On obtaining the desired number from the subscriber, the "A" operator connects the front cord to the called subscriber

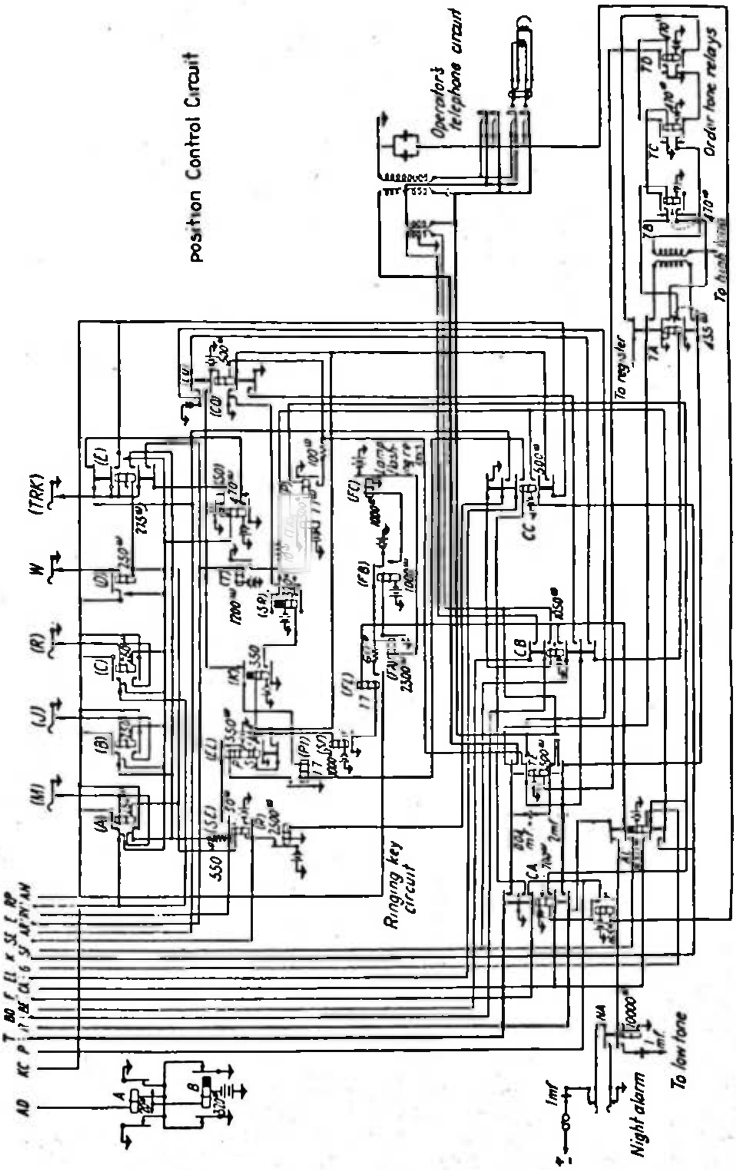


FIG. 295.—Section 4.

jack or to a trunk jack and proceeds to establish circuit conditions within the cord for ringing the called subscriber's bell, if the connection is to be completed to the local multiple, or to release the cord circuit from the position equipment without establishing conditions in the cord for ringing, if the connection is to be extended over a trunk. To provide for the release of the cord equipment in either of these two ways, five non-locking flush-type key buttons are furnished with the ringing-key circuit at each position. Four of the non-locking buttons, *M*, *J*, *R* and *W*, are designated to correspond with the station designation of a four-party line. The fifth button is designated *TRK* and is employed on trunked connections in which ringing conditions should not be established in the cord circuit.

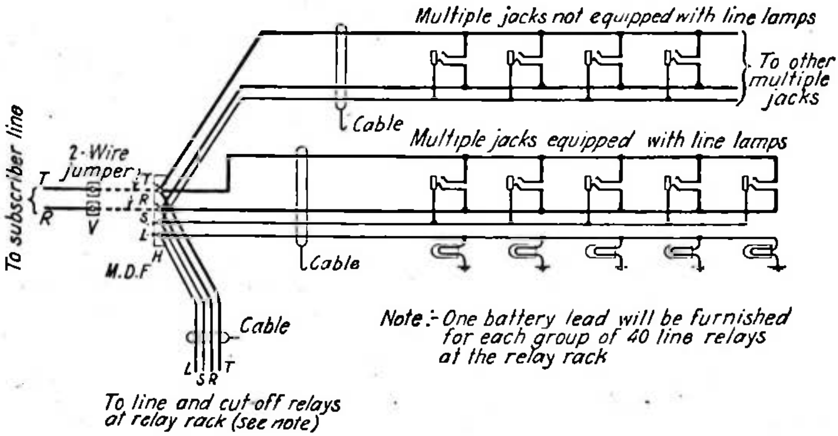


FIG. 296.—No. 11 switchboard—line-circuit connections through main distributing frame.

It will be noted from the ringing-key circuit that the operation of any of the five key buttons energizes auxiliary relays which are furnished to provide additional contacts for circuit operation and to simplify the cabling. The operation of the *R*, *J*, or *M* key connects ground to either or both the windings of the *RV* and *RP* relays in the cord circuit. The operation of the *W* key is ineffective as regards connecting ground to either the *RV* or the *RP* relay. If the *RV* and *RP* relays of the cord are normal at the time the cord is released from the position circuit, negative superimposed machine-ringing current is connected to the ring conductor of the line. If the *R* key is depressed, the *RP* relay operates, and positive superimposed machine-ringing current is connected to the ring side of the line. In a similar manner, the operation of the *J* key effects the operation of the *RV* relay, which causes negative superimposed machine ringing to be applied to the tip conductor of the line. Finally, the operation of the *M* key connects ground to both the *RV* and *RP* relays, in order to set the cord circuit for applying positive ringing current to the tip conductor. It will be noted that the *RP* relay selects the polarity of ringing current and the *RV* relay selects between the tip and ring conductors.

The operation of any party-line ringing key closes the circuit to a slow-operating relay in the ringing-key circuit, so that ground is placed on the winding of the *CO* relay a short interval after the *RV* and *RP* relays have been allowed sufficient time to operate. The *CO* relay of the cord circuit operates and disconnects the cord from the position equipment. Owing to the slight delay interval introduced, the *RV* and *RP* relays are given an opportunity to operate and lock before the cord is disconnected from the position circuit.

Should the *TRK* key be depressed, ground is connected to the *CO* relay for releasing the cord circuit, without operating the *RV*, *RP*, or *AR* relay. This prevents applying ringing current to the trunk.

As soon as the front cord is connected to a multiple jack or outgoing-trunk jack, a pilot lamp associated with the ringing-key circuit is lighted as a positive signal that one of the five ringing keys should be depressed. The tripping relay *TP* operates when the called party answers and in operating is effective in releasing the *AR* relay, thus disconnecting machine ringing from the line and connecting the cord through for talking.

Supervisory relays *SA* and *SC* are furnished in the answering and calling cords respectively, as in the case of similar No. 1 switchboard cord circuits. A flashing-recall relay is also equipped in the back cord for providing flashing-recall signals from the calling subscriber. Unlike the No. 1 switchboard arrangement, the No. 11 switchboard flashing-recall relay is normally non-operated and operates if the calling party should disconnect. If the flashing-recall relay is operated and the supervisory relay re-operates (as in the case of a recall), the answering cord lamp flashes at a regular rate, owing to the momentary and regular connection of a 60-ohm shunt across the lamp. The auxiliary flashing-recall relays *A* and *B* operate in conjunction with the flashing-recall relay of the cord in substantially the same manner as the similar No. 1 switchboard arrangement.

It is sometimes necessary to furnish subscriber cord circuits arranged for handling coin- and message-register calls and for dialing on trunk connections to machine-switching offices. The circuit arrangements required for these additional features are relatively minor and do not effect major modifications of the fundamental cord arrangement described above.

Straightforward-trunk and Associated Splitting, Control, Operator's Telephone, and Common Ringing-key Circuits.—The No. 11 automatic-listening straightforward-trunk circuit shown on Fig. 295 (Sections 2, 3, and 4) is similar to the arrangement described for the No. 1 switchboard with the exception that the trunk is arranged for four-party selective ringing on a common-key ringing basis. As in the case of the No. 11 subscriber cord, two relays *RV* and *RP* are furnished with each trunk circuit and are operated by common-positional ringing keys in a manner such that positive or negative superimposed ringing current is connected to either the tip or the ring conductor in accordance with the setting of the ringing key. It should be noted that the *RV* and *RP* relays are operated momentarily from the ringing-key circuit and remain locked locally to the trunk after the ringing key has been disconnected. The other relays required for machine ringing include the *AR*, *TP*, and *R* relays. The *R* relay is a ringing relay and is employed for connecting ringing current to the subscriber line and further is wired to serve as a "pick-up" relay. In the capacity of a pick-up relay, the *R* relay is operated after a predetermined delay interval in case it is necessary to connect ringing current to the tip conductor of the line. This provision is required to avoid the possibility of ringing the bells on the ring side of the line falsely when the tip of the plug passes the ring spring of the line jack during plug-in.

Trunk-sequence Chain.—The No. 11 automatic-listening straightforward trunk includes a relay sequence-chain circuit which operates in a manner similar to that already described for the No. 1 switchboard. Owing to the fact that common-position leads to the trunk-ringing relays are required in addition to talking leads and other control leads, it is necessary to provide an auxiliary cut-in relay *C* which operates when the *LS* relay operates. It may also be observed that the *C* relay may be operated by an individual non-locking trunk key independently of the sequence-chain relays, thus providing means for operation on an emergency basis as well as for resetting trunk ringing if required on an intercepted call.

A further difference noted in the No. 11 straightforward trunk as compared with the No. 1 switchboard trunk relates to the disconnect relay *DS*. The *DS* relay of the No. 11 trunk operates after the "A" cord is disconnected, provided the trunk plug is connected to a multiple jack. The *DS* relay causes the trunk to remain in a disconnect condition until the associated plug has been withdrawn from the subscriber-line jack. The trunk may, however, be reselected by an "A" operator while the cord is in a multiple jack and, in case the trunk has preference over other waiting trunks, may be connected to the "B" operator's telephone circuit. The trunk cannot, however, be released from the control circuit and machine-ringing current cannot be started until the trunk cord is released from the line jack.

Trunk-splitting Circuit.—As in the case of No. 1 switchboard practices, groups of straightforward trunks may be combined and connected to the control circuit at a particular position by means of trunk-splitting circuits. In No. 11 trunk positions, which are installed in line with subscriber positions, only two splitting keys and associated relays are furnished at each position, thus allowing for the grouping of the trunks in units of twenty trunks each. Although, as compared to No. 1 splitting circuits, additional splitting relays and leads are required, owing to the differences in No. 11 trunk circuits, the two splitting circuits are substantially identical. A simplified schematic of the splitting circuit is shown on Fig. 297.

Position-control Circuit.—The No. 11 straightforward-trunk control circuit (Fig. 295, Section 4) includes facilities for connecting the order-tone and common-key ringing control leads to a group of trunks, provided the position is occupied and, in case of possible interference, provided the operator's position has natural preference due to its location at the extreme left of the group. The control circuit also includes two sequence-control relays *A* and *B* which are furnished to insure that the trunk sequence resumes at the extreme left, after all waiting calls to the right have been handled.

The tone relays *TA* to *TE*, inclusive, operate in sequence and are effective in transmitting two short impulses of high pitch to the originating operator, and in reduced volume to the "B" operator, as a signal that the called number may be passed. Flashing relays *FA*, *FB*, and *FC* also operate in sequence at a regularly recurrent rate and are effective in causing a connected trunk lamp to flash, as a signal that the order received should be associated with that particular trunk.

The common ringing-key circuit furnished at a No. 11 trunk position is arranged to establish conditions in the trunk circuit for ringing a called subscriber station. In addition, the circuit shows a considerable amount of apparatus which is used for emergency listening operation.

When a trunk circuit is connected to the control circuit through the contacts of the chain *LS* relay, the trunk *C* relay

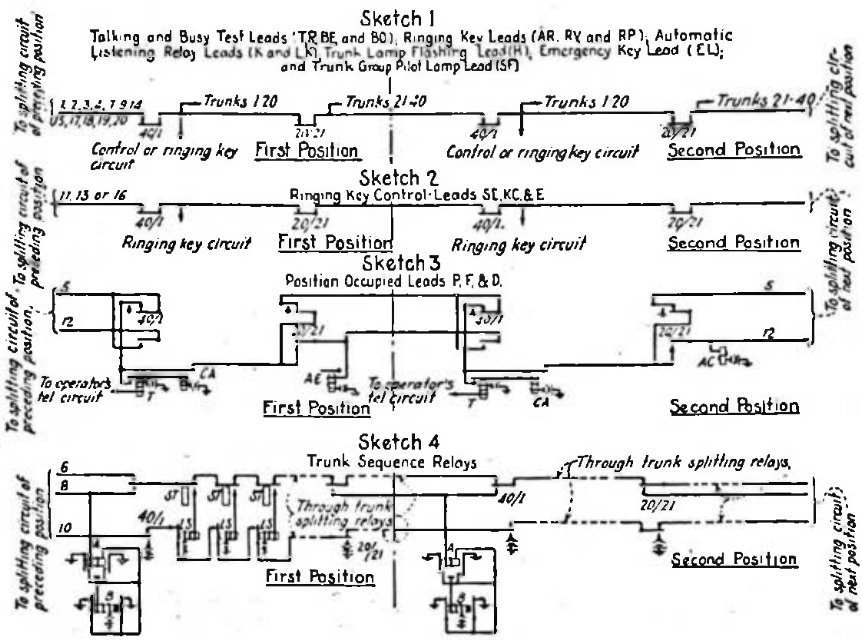


FIG. 297.—Schematic of trunk-splitting circuit No. 11 switchboard.

operates to the ringing-key circuit and is effective in connecting the trunk talking leads and ringing leads to the control circuit and to the common ringing-key circuit. When the "B" operator obtains the called number from the "A" operator, one of the four ringing-key buttons is depressed. The depression of the ringing-key button operates or avoids operating the *RV* and *RP* relays in the trunk circuit, as required, to ring the called party station. A short interval after the *RV* and *RP* relays have been operated, ground is connected to the *AR* relay and the *T* and *TK* relays of the common ringing-key circuit operate. The operation of the latter relays causes the release of the trunk from the common ringing-key circuit and from the control circuit. (The *TRK* key is depressed only occasionally, in case a call is to be connected to an automatic trunk to a near-by manual- or dial-system office.) The trunk plug is then connected to the called subscriber's jack. It will be noted that the ringing is preselected, that is, the ringing condition is set up before plug-in rather than after plug-in as in the case of "A" cords.

In addition to the relatively simple functions of the common ringing-key circuit as enumerated above, features are incorporated to guard against irregular operating conditions which might be experienced and to include facilities for emergency operation.

Section Arrangement.—The upper units of the No. 11 switchboard are made in two sizes termed respectively large- and small-capacity sections. These, whether of the three-position (nine-panel) type or the single-position (three-panel) type, are arranged for No. 92 jacks. The jack opening is slightly over 35 inches high for the large unit and 31 inches for the small. The large-capacity upper unit is made in three-position lengths, the small capacity in one. The lower unit, whether equipped for subscriber, trunk, or toll use, is three panels or one position long and may be used with either the large- or small-capacity upper units.

Based on the usual limitations of the operator's reach, a single line of the No. 11 switchboard will accommodate 4,000 subscriber lines and 720 outgoing trunks. Where a larger capacity than this is required, two separate lines of sections are established. The first line will be equipped with multiple line lamps for part of the lines, the remainder of the lines appearing in multiple jacks only. The second line will be similarly equipped, except that the lines having lamps in the first line-up will be equipped with jacks only in the second line-up, and *vice versa.* It is possible to provide the switchboard sections in two separate and distinct lines or in one continuous line with an intervening cable-turning section. In the latter case, the cable-turning section is employed for the inversion of the multiple. In the first line of switchboards, the lower-numbered subscriber lines will be equipped with multiple answering lamps and the higher numbered lines equipped with multiple jacks only for the completion of calls. In the second line of boards, this plan is reversed, the higher-numbered subscriber lines being equipped with multiple answering lamps and the lower-numbered subscriber lines with multiple jacks only. This arrangement permits extending the capacity of the No. 11 installation without exceeding the permissible limits of reach which have been established for subscriber answering and multiple jacks.

The inversion of the subscriber multiple to exceed the capacity of a single section as described above permits the large No. 11 section to take care of a maximum of 6,400 to 7,200 subscriber lines and the small No. 11 section a maximum of 5,600 subscriber lines.

The multiple capacities of the large and small No. 11 switchboard sections for two lines of positions are shown below in tabular form. These capacities are based on a maximum reach of 30 inches above the key shelf to the line lamps and a maximum reach of 34 inches for completing calls in the multiple. They also assume an eight-panel subscriber multiple and a six-panel outgoing-trunk multiple.

Multiple Capacities of No. 11 Switchboard Sections

Description	Small section	Large section	
		7,200 total	6,400 total
Subscriber multiple jacks with lamps	4,000	4,000	3,200
Subscriber multiple jacks only	1,600	3,200	3,200
Total subscriber multiple, two lines of board	5,600	7,200	6,400
Total outgoing-trunk jacks	720	240	720

The large No. 11 switchboard may also be furnished in an area which requires as many as 10,400 subscriber lines. In this case, it is necessary to establish three separate lines of subscriber sections and ordinarily these line-ups will be arranged for 3,200, 3,200, and 4,000 lines, respectively. With this plan it is necessary to furnish a separate trunk switchboard containing a complete three-wire multiple of all the lines in the office. Local trunks are terminated at this "B" board from the three separate subscriber-switchboard line-ups, as well as from distant offices.

The separate trunk board for use in such an office is essentially the standard No. 1 switchboard two-position, seven-panel, 92-jack section which has been described previously. The only change in the section arrangement applies to the key shelf and the rear equipment. Since regular No. 11 switchboard automatic-listening straightforward trunks are used in this case, the key shelf furnished at the trunk board is designed to accommodate common-key ringing straightforward trunks as used in a No. 11 office, rather than individual ringing-key trunks which are ordinarily used in No. 1 switchboards. This permits a key-shelf capacity of fifty trunks per position instead of forty-eight where individual trunk ringing keys must be provided.

For smaller offices, involving but a few hundred lines initially and within the range formerly served by the No. 9 switchboard,[1] a modification of the small-capacity manual ringing No. 11 switchboard is used. The principal changes from the larger board just described are a six-panel instead of an eight-panel subscriber multiple, the omission of those features needed only with larger ultimates, and the adoption of certain fixed floor-plan arrangements designed to simplify the engineering, manufacture, and installation of the boards.

Subscriber-position Equipment.—The lower unit for use at subscriber positions is wired for seventeen subscriber cords arranged for four-party selective or semi-selective ringing. The cords are equipped for flashing recall and include wiring for coin- and message-register operation and for dialing on connections to panel or step-by-step offices. All the apparatus associated with the cord and position circuits is mounted in the rear of the position unit.

The key-shelf equipment is arranged in a manner similar to that of the No. 1 switchboard except that individual gang-type cord ringing keys are replaced by a common-position ringing key consisting of five flush-type push buttons. A two-way lever-type key for each cord is also furnished for manual ringing on rural lines and for connecting the operator's telephone circuit on subscriber recalls. The cord equipment employs short-base keys thereby allowing additional wiring space and mounting space for the common ringing keys.

[1] The No. 9 switchboard of the Bell System had a two-panel single-position framework and used magnetic signals instead of lamps. The signals were placed in the upper portion of the section above the jacks. It was originally designed for a limit of 800 lines but later was so modified as to have an ultimate capacity of 1,200 lines.

Trunk-position Equipment.—The trunk position includes forty automatic-listening straightforward trunks which are similar to the No. 1 switchboard trunk circuits with the exception of the differences resulting from the use of common-key ringing as compared with individual-key ringing. A minor difference may also be noted with respect to an individual non-locking key which is provided for each trunk circuit for use under emergency conditions. The rear of the trunk-position unit accommodates the apparatus associated with the operator's telephone circuit. The apparatus of the trunk circuits is mounted on ten trunk units at the relay rack.

In No. 11 offices having a separate trunk board and using the No. 1 type trunk section, it is possible to furnish fifty incoming trunks at each position instead of forty-eight ordinarily used on No. 1 sections. This is because the individual trunk ringing keys are omitted. As in the case of No. 1 switchboard circuits, five splitting keys are mounted in the key shelf and are designed to group the incoming trunks by units of ten trunks each.

STROMBERG-CARLSON MULTIPLE SWITCHBOARD FOR LARGER OFFICES

Recent large multiple switchboards of the Stromberg-Carlson Telephone Manufacturing Company have used the "A" operator's cord circuit shown in Fig. 298. This is of the keyless-listening machine-ringing type, employing a single master ringing key, common to all cords on a position, by which selective ringing on party lines is accomplished. This cord circuit is designed for operation with the type of three-wire line circuit already discussed, wherein a grounded cut-off relay is operated over the sleeve conductor of the cord and line upon the insertion of a plug, and when so operated serves to disconnect the line relay and extinguish the line signal or signals. The line may have only a single answering jack and signal, or it may have multiple answering facilities in the form either of ancillary answering jacks and signals or of multiple line signals directly associated with the regular multiple jacks.

An interesting structural practice employed in this switchboard is that of carrying all the relays, resistances, and condensers belonging to a cord circuit together as a unit on a single mounting plate individual to the cord circuit. These elements on each plate are wired together in proper relation among themselves, the plate wiring being brought to screw-type terminals on the ends of the plate and thence connected by cable with appropriate terminals on the switchboard sections. This arrangement facilitates the mounting of the cord-circuit relays

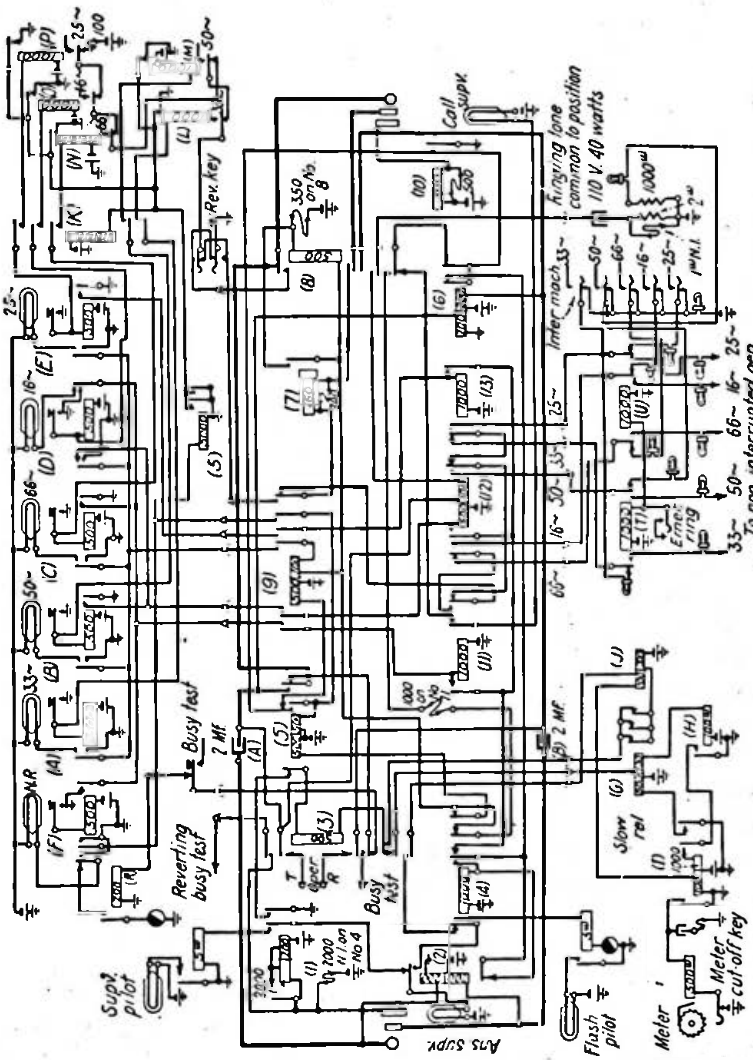


FIG. 298.—Subscribers' cord circuit—Stromberg-Carlson multiple-switchboard system.

entirely outside the switchboard section—preferably on a relay rack in the terminal room where their identification, inspection, and repair may most conveniently be accomplished.

Of the relays shown in Fig. 298, thirteen are individual to a cord circuit and twenty are common to a position. On this diagram and the ones following relating to this system, the individual relays are designated by numbers and common relays by letters.

This circuit may best be analyzed by considering it in sections, each section embracing those elements involved in some particular function or closely related group of functions. Thus the automatic-listening function may be considered in connection with Fig. 299. Because almost the same apparatus is involved, we may also use this figure in describing such features as the arrangement which permits advance plugging in, the operator's bar, the operator's listening indication, and the metering of answered calls.

Automatic Listening and Operator's Bar.—When the operator plugs in, relay 1 (Fig. 299) is energized over the third, or sleeve,

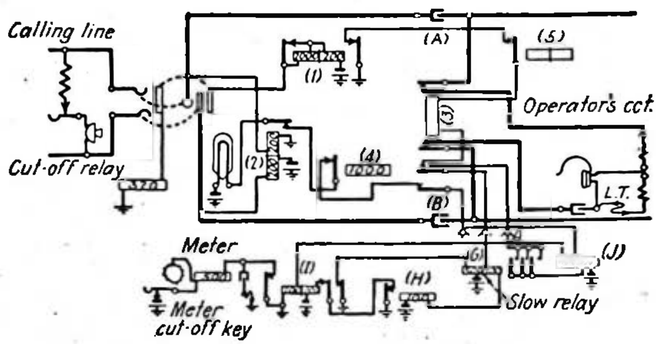


Fig. 299.—Portion of cord circuit showing keyless listening function.

strand of the answering cord to ground through the cut-off relay. The operation of the cut-off relay disables the line relay and extinguishes the line signal or signals in the usual way. At first both coils of the sleeve relay 1 are included in series in the circuit but, by closing its left-hand contact, its 2,000-ohm coil is short-circuited, leaving the 200-ohm coil to hold during the entire time of the connection. This makes effective the operator's bar for, should any other operator attempt to answer the same call by plugging in to another jack of the line, its sleeve-strand relay 1 with its total resistance of 2,200 ohms would not be able to pull up because of its being shunted by the 200-ohm coil of the cord circuit that made the original connection as just described.

Returning to the original operator, the pulling up of her sleeve relay 1 closed a circuit for energizing the operator's cut-in relay 3, traced from battery, through the 200-ohm winding of common coil *J*, normally closed triple contact of common relay *G*, normally closed contact and coil of relay 3, back contact of relay 5 to ground through the front contact of relay 1. The relay 3 is thus energized and acts as a listening key to cut in the operator's telephone set, bridging it across the cord circuit as indicated by the heavy lines of Fig. 299.

Operator's cut-in relay 3 cannot be energized originally except through the three multiple contacts of the common relay *G* as just noted. Once operated, however, it closes an alternate holding circuit for itself which also serves to energize the common relay *G*. This is traced from battery through the coils of common relays *H* and *G*, make-before-break contact of relay 3, coil of relay 3, back contact of relay 5 to ground through the front contact of relay 1. Relay *G* is thus operated to open its triple contacts which serves to prevent the operation of the cut-in relay 3 of any other cord circuit of this position. The connection of the operator's set with more than one cord circuit at a time is thus definitely prevented.

This arrangement also provides for "advance plugging in," that is, the insertion of an answering plug of one other cord circuit of the position into the jack of another line on which a second call has originated. The operator's set will not be cut across this second cord circuit, however, until the call "in hand" is disposed of because the common relay *G* is holding the circuits of all the cut-in relays open. As soon as the operator presses the ringing key in completing her work on the first call, the relay 5 of that cord circuit will be energized, as will be explained later, and this will break the holding circuit for relays 3 and *G*, freeing the operator's set from the first cord circuit and making possible the operation of the cut-in relay 3 of the second cord circuit, the answering plug of which has already been inserted into another jack preparatory to answering the second call. No more than one answering cord may thus be successfully plugged in in advance of the release of the operator's set from the first cord circuit. If more than one is plugged up in advance, neither of them can cut in upon the release of the original cord. This is due to the fact that relays 3 are given a stiff adjustment so that, when two or more of them are fed in multiple through the 200-ohm winding of the starting coil *J*, none will receive enough current to operate.

Operator's Listening Indication.—When the operator plugged in to the calling line, the answering supervisory relay 2, through the two coils of which talking current is supplied to the calling subscriber, was energized over the metallic circuit of the line. This resulted in the partial illumination of the answering supervisory lamp, over a local circuit from battery through the lamp, contacts of relays 2, 4, and 3, starting coil *J*, and coil of common relay *I* to ground. The 200-ohm resistance of these two coils in series with the lamp permits the lamp to be faintly illuminated as an indication to the operator that her telephone set is cut in on that particular cord circuit.

Metering of Answered Calls.—The operation of relays 1, 2, and 3 caused the operation of common relay *I* over the supervisory lamp circuit as just described. This relay closed the

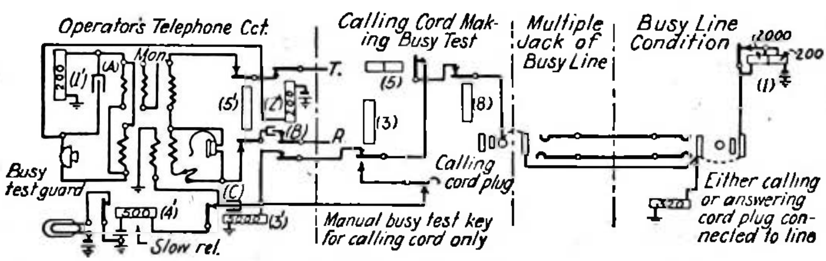


Fig. 300.—Portion of circuit used in testing a called line.

local circuit of the call-registering meter (Fig. 299) in an obvious manner. Common relay *H* was also operated at the same time in series with the operator's cut-in relay 3 and common relay *G*. The operation of relay *H* established a local locking circuit for the meter relay *I* which prevents its release and subsequent re-operation on this call. When the ringing key is depressed, the relay 5 operates as before stated to break the control circuit for relays 3, *G*, and *H*. The release of this latter relay breaks the locking circuit for the relay *I*, thus leaving it ready to register the next call answered by this operator. The relay *G* is made slow acting so that a sufficient interval will occur before its release to allow the relays *I* and *H* to restore. Since the common relay *G* cuts off battery from all of the cut-in relays 3 of a position other than the one that is actually operated, it follows that it is impossible to operate the meter by plugging another answering cord into and out of a live jack. The condenser and resistance bridged around the meter contact of relay *I* are merely for the prevention of sparking at the contacts of the meter-controlling relay.

Busy Test.—The parts of the cord circuit involved in testing the called line before completing the connection are shown in Fig. 300. At the extreme right is indicated the condition which may exist at another section by virtue of a connection already established there. Such a connection would, of course, make a line test busy because of the battery potential it places on all its test contacts. At the extreme left is shown the telephone circuit of the operator making the test.

When the testing operator touches the tip of her calling plug to the test sleeve of a called line, circuit is established from the test sleeve through the tip of the plug, contacts of relays 8, 5, and 3 of the cord circuit and 2′ of the operator's telephone circuit to ground through the 5,000-ohm coil of the test relay 3′ of the operator's telephone circuit. The operation of this last relay closes a local circuit through the coil of the relay 4′ and the test winding of the operator's induction coil. This produces a click in the operator's head set, indicating the busy condition. The operation of relay 4′ in this local test circuit lights a busy-test guard lamp, which serves not only as a visual indication of the busy condition but also as an automatic indicator of some kinds of trouble on the cord circuits of this position, such, for instance, as a cross between the tip and the sleeve of the calling cord.

If the line tested is idle, then the test circuit is from ground at the cut-off relay to ground at the relay 3′, with resulting silence in the operator's set. The condenser *C* in the test circuit of Fig. 300 serves to allow the passage of various special tone signals to the operator's head set.

In case it is desired to make a busy test when the answering cord is not up, the manual busy-test key associated with the calling cord may be depressed, so as to complete the continuity of the test circuit without the relays 2′ and 3 being operated.

Flashing Recall.—As this cord circuit does not provide for the automatic disconnection of the subscribers when they hang up, the intermittent flashing of the answering supervisory lamp to indicate a recall becomes desirable. Figure 301 shows the portions of the circuit involved in this function. Relays 1, 4, and 10 are shown operated and relay 6 in its normal position, which is the condition existing when both plugs are up but with the called subscriber's receiver on its hook as before his response. Should the calling subscriber hang up and immediately lift his receiver, the relay 2 would respond by releasing and again attracting its armature. This momentary release of relay 2 closes its contact X, which causes the operation of relay 4 through contacts of relays 6 and 10. Relay 4 does not release, however, when relay 2 immediately afterward operates to break the contact X, because it has established its own locking path through contacts of relays 6 and 10. Relays 2 and 4, now both energized, establish the condition for the intermittent flashing of the answering supervisory lamp, over a circuit from battery through this lamp, contacts of relays 2 and 4, coil of

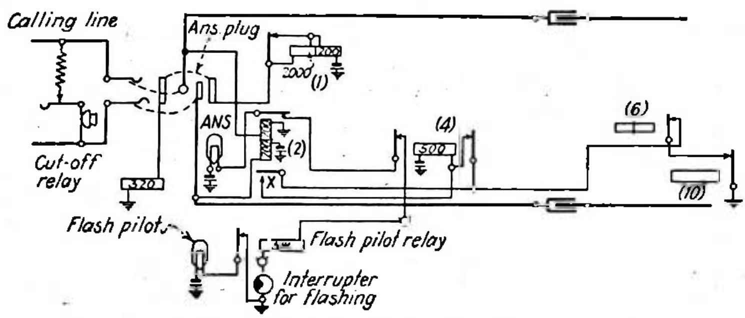


FIG. 301.—Portion of circuit involved in flashing recall.

the flashing pilot relay and power-driven interrupter to ground. Since the supply of talking current to the called subscriber is through the relay 6, it is apparent that this flashing condition cannot exist while the called subscriber's receiver is off its hook. If, therefore, the calling subscriber had attempted to initiate another call because the called subscriber did not respond promptly enough and, meanwhile, before the operator had withdrawn the calling plug, the subscriber originally called should respond, the flashing would cease, and the calling subscriber would be connected with the subscriber he originally desired. An even more important feature of this arrangement is that, should the calling subscriber during a conversation accidentally depress his hook switch momentarily, the flashing condition will not be established and the conversation interrupted, because, the called subscriber's hook being raised, the relay 6 would be energized and prevent the operation and locking of the relay 4.

Operator's Ringing Control.—The cord circuits have no individual ringing keys but in order to provide for five-party harmonic selective ringing a single five-button master key common to all the cord circuits of a position is provided on each key shelf. This common ringing key or master key becomes momentarily associated with a cord circuit that is about to be used in ringing upon any one of its buttons being depressed. The ringing button actuated sets up a condition within the cord circuit which determines which one of the ringing frequencies shall be used. The condition thus set up locks itself during the ringing operation and at the same time disengages the

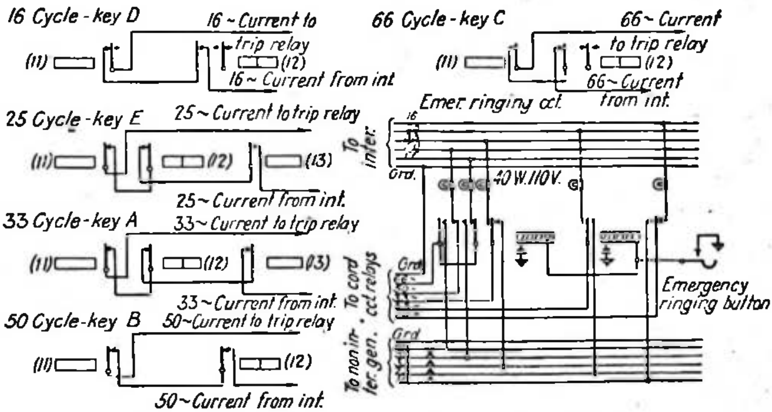


FIG. 302.—Portion of circuit involved in selection of ringing frequency.

common ringing key from the cord circuit, so that it is available for use on another cord circuit.

The selection of the ringing frequency to be used to ring the desired station depends entirely on the combinations in which the relays 11, 12, and 13 of Fig. 298 are operated, or not operated, under control of the common or master ringing-key buttons *A*, *B*, *C*, *D*, and *E*. This frequency-selecting function will be made clearer by reference to Fig. 302. Master-key button *D* energizes both relays 11 and 12 and brings the 16-cycle generator into the ringing circuit. Button *E* energizes relay 13 alone, leaving 11 and 12 normal and applies the 25-cycle current. The 33-cycle ringing current corresponding to ringing button *A* is the one most often used and is applied through the back contacts of relays 11, 12, and 13, requiring the operation of none of them. Similarly, button *B* energizes relay 12 alone and button

C relay 11 alone, applying the 50-cycle and the 66-cycle currents, respectively.

The sixth button *F* on the master ringing key (Fig. 298) is used on all connections which require no ringing current to be sent from the "A"-board cord circuit, such as on one trunked to a "B" board in the same or a distant office. The operation of the circuit when this button is depressed will be referred to further on in the discussion of ringing control.

The emergency ringing key controlling relays *T* and *U* (Fig. 298) is for enabling uninterrupted ringing current of the various frequencies to be substituted for the interrupted current normally supplied through the ringing interrupter. As

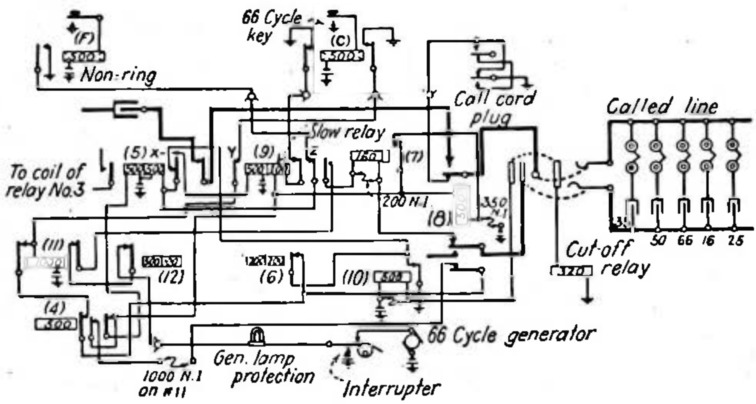


FIG. 303.—Portion of circuit used in master ringing-key selection.

shown more clearly in the diagram of Fig. 302, this button controls two relays which act in effect as a five-pole double-throw switch to make this substitution. The emergency button is used only in case of failure of the interrupter, or when it is purposely desired to signal with continuous ringing.

The control of the ringing function, that is, of the actual starting and stopping of the ringing, will be considered in detail only with respect to the 66-cycle frequency, it being remembered that the choice of this or other frequencies is determined by which of the relays 11, 12, and 13 are operated. The portions of the cord circuit involved are shown in Fig. 303, it being assumed that ringing button *C* has been depressed to select the 66-cycle current by energizing relay 11, relay 12 remaining normal. The condition represented in Fig. 303 is that existing when the calling plug has been inserted in the multiple jack of a called line preparatory to ringing. The sleeve relay 10 of the calling cord has pulled up and with it the cut-off relay of the called line. The relay 10 closes a circuit traced from battery through the 500-ohm coil of relay 9, contact *X* of relay 5 (not yet opened) to ground through the contact of relay 10. Relay 9, thus operated, is the master-key control relay and serves to associate the master ringing key temporarily with the cord circuit that is about to be used in ringing. This connection of the ringing key with the cord circuit is brought about only upon plugging into a called line at a time when ringing has not yet started. It can occur only on a cord on which the relay 10 has been energized while relay 5 is yet normal.

When the 66-cycle key is depressed, it energizes common relay *C*. This establishes two ground connections through the now closed contacts of relay 9, which, besides the selection of the proper frequency through the relays 11 and 12, performs several other functions in connection with the starting of the ringing. The relay 5 is operated over a circuit from ground at the left-hand contact of relay *C*, contact and the 100-ohm winding of relay 9, contact of relay 4, left-hand winding of relay 5 to battery. Relay 5 is thus operated. The same ground through the 100-ohm winding of relay 9 is simultaneously applied to relay 8, causing its operation. The right-hand grounding contact of relay *C* closes a circuit passing through the contact *Y* of relay 9 and to battery through the winding of relay 11. Relay 11 is thus operated leaving 12 unoperated—the condition necessary for the selection of 66-cycle current.

Thus the operation of the relay *C*, caused by depressing the 66-cycle button of the master key, brought about the simultaneous operation of relays 5, 8, and 11, this all being accomplished through the connection established with the master key by the relay 9, which was operated at the time of plugging into the called line.

Relay 5, thus energized, locks through its own contact and through the contact of relay 10. It will remain energized until relay 10 releases upon the withdrawing of the calling plug. Relay 5 closes the tip side of the cord circuit and, as we have already seen in connection with Fig. 299, it causes the release of the relay 3 and the disconnection of the operator's circuit. Relay 8 is also held locked over a circuit from ground at relay 10 through contacts of relays 10, 6, and 8, and through the

1,000-ohm non-inductive resistance of relay 11, contact of relay 4 and coil of relay 8 to battery. Relay 11 is also held locked over a circuit through back contacts of relays 4 and 6 to ground through the contact of the relay 10. Thus the relays 5, 8, and 11, all originally operated through the contacts of relay 9 and of common relay *C*, are all locked and remain so upon the release of the relay 9, which occurred as another result of the operation of the relay 5. Relay 9 is of the slow-release type so as to allow a short time interval to permit the operation and locking of the relays it controls, before it itself releases to disconnect the master key.

Ringing current now passes from the 66-cycle generator through the ringing interrupter, contacts of relays 12 and 11 in series, back contact of relay 9 (now released), coil of tripping relay 7 to the ring side of the cord circuit, thence to line through all of the substation harmonic bells in multiple, and back over the tip side of line to ground through the closed front contact of relay 8.

Tripping relay 7 is shunted by a non-inductive resistance. The high impedance of this relay causes most of the ringing current to pass through this non-inductive shunt and therefore, on account of its low sensitivity, it is not operated by the ringing current. When, however, the called subscriber lifts his receiver, a low-impedance path is established for direct current from the battery that is applied in series with the generator during the ringing interval or directly through the commutator during the silent interval. Owing to its relatively low resistance, most of this direct current passes through the coil of the tripping relay 7, which is thus operated as soon as the called subscriber responds.

The operation of the relay 7 short-circuits the ringing relay 8, thus permitting it to release. Ringing current is thus instantly cut off from the cord circuit and at the same time the talking circuit is re-established through the tip and ring sides of the cord circuit.

The foregoing regarding the ringing control has all been based on the assumption, as stated, that button *C* of the master ringing key was used to ring the subscriber whose bell was tuned to 66-cycle current. The action would have been the same for any of the other ringing buttons *A*, *B*, *D*, or *E*, except that a different frequency would have been chosen, owing to the operation or non-operation of different ones of the relays 11, 12, and 13.

The sixth or non-ring button *F* on the master key remains to be considered: This, as stated, is used on trunked calls or other connections where no ringing current is to be sent from the "A"-board cord circuit. When the non-ring button is depressed, relay *F* is operated. This closes a circuit for the relay 5 but does not apply ground to operate the ringing-control relay 8. Relay 5, as before, causes the release of relay 3 to free the operator's telephone from the cord circuit, but owing to the non-operation of ringing relay 8, no ringing current is applied to the calling plug.

Calling Subscribers' Ringing Control.—The calling subscriber can stop the ringing by merely hanging up his receiver, which he does, of course, upon the non-response of the called sub-

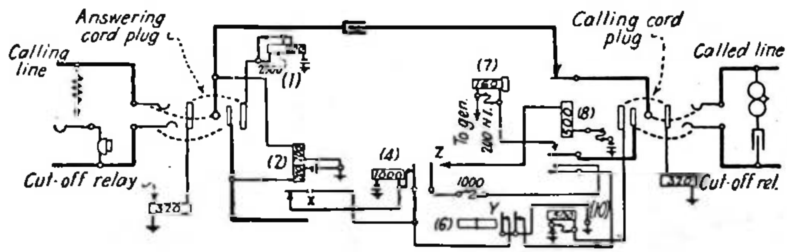


Fig. 304.—Portion of circuit showing control of ringing by calling subscriber.

scriber. The parts of the circuit involved in this control of the duration of ringing by the calling subscriber are shown in Fig. 304. When, after ringing has been started, the calling subscriber decides to wait no longer and hangs up, relay 2 releases, closing its contact *X*. Since the called subscriber's receiver is still on its hook, relay 6 is not operated and the release of relay 2 causes the operation of relay 4 through contacts of relays 2, 6, and 10. Relay 4, by opening its contact *Z*, de-energizes relay 8, which by its release stops the ringing.

Revertive Ringing Tone.—The source of the ringing tone heard by the calling subscriber is the reverting tone transformer shown in the lower right-hand corner of Fig. 298. The 1,000-ohm primary coil of this transformer receives the periodically interrupted current from the 50-cycle ringing generator. The secondary current producing the tone flows from the 0.2-ohm secondary of this transformer through the 2-microfarad condenser, front contact of relay 8 (closed during ringing), winding of relay 12, spring of relay 3 to the tip side of the cord circuit just back of the condenser *A*, thence over the tip side of the line and the calling subscriber's receiver, back over the ring side of the line, and to ground through one winding of relay 2. This tone is, of course, cut off at the ringing relay 8 when the called subscriber responds.

Talking Circuit.—The talking circuit between the two subscribers is shown in Fig. 305. This is established when the called subscriber responds, the ringing relay 8 releasing its armature to close the gaps in the tip and ring sides of the calling end of the cord circuit. It will be seen that the battery supply is of the condenser-impedance-coil type, the two coils of relay 2 being bridged in series with the common battery across the answering

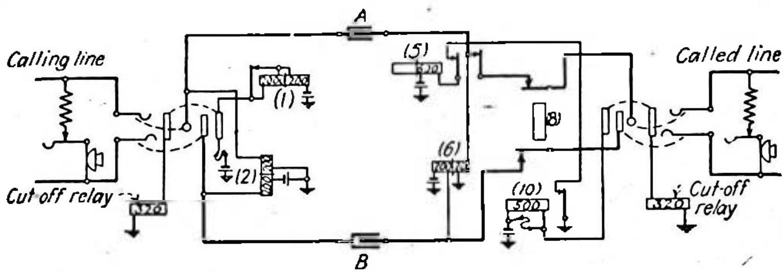


FIG. 305.—Talking circuit Stromberg-Carlson multiple board.

cord to furnish transmitter current to the calling subscriber, while the two coils of relay 6 serve a similar function for the called subscriber. Incidentally, these two relays bring about the lighting of their respective supervisory lamps at the close of the conversation, as will now be shown.

Action of Supervisory Signals—Dark Key Shelf.—Referring to Fig. 306, it has been shown that the answering supervisory lamp was dimly lighted upon the operation of the cut-in relay 3 as an indication to the operator that her telephone set was connected with that cord. Upon the release of this relay at the beginning of the ringing operation, this lamp was extinguished. The calling supervisory lamp was lighted upon the insertion of the calling plug over a circuit from battery through the lamp, back contact of relay 11, back contact *X* of relay 8, back contact of relay 6 to ground through the front contact of relay 10. Under the old method of operation this lamp would have remained lighted after plugging in until the called subscriber responded, but in this case it goes out at the beginning of the ringing operation because the contact of relay 8 is always opened at that time. Both answering and calling supervisory lamps remain extinguished, therefore, during the ringing period, this being in accordance with the so-called "dark key shelf" method of operation.

When the calling subscriber hangs up, the circuit of relay 2 is broken at his hook switch. The release of this relay causes the answering supervisory lamp to light, from battery through the lamp, back contact of relay 2, front contact of relay 1 to ground through the supervisory pilot relay. Similarly, when the called subscriber hangs up, relay 6 is released, causing the calling super-

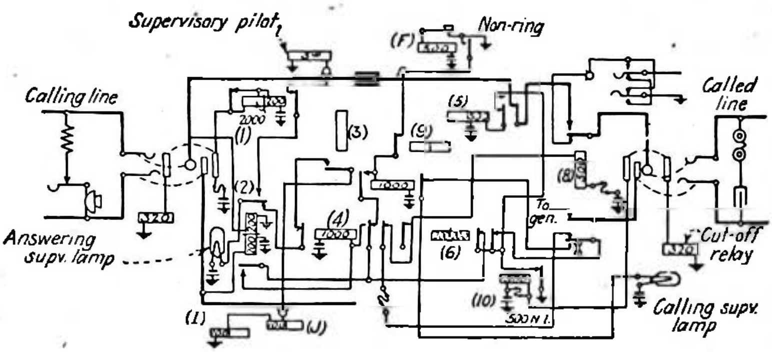


FIG. 306.—Action of supervisory signals—dark key shelf.

visory lamp to light, from battery through the lamp, back contacts of relays 11, 8, and 6 and front contact of relay 10.

When the operator in response to the signals pulls down the connection, the sleeve relays 1 and 10, both of which were operated on plugging up, release, thus extinguishing their respective lamps.

Straightforward Trunking.—The circuits of the Stromberg-Carlson multiple-switchboard system so far considered have been those involved in a purely local connection, that is, a connection through the "A" board between two subscribers' lines terminating in the same office. For connections between subscribers' lines terminating in different offices this company, like others, has adopted the straightforward method of trunking. This, as before stated, requires that means be provided at the "A" board for enabling the operators there to determine whether an outgoing trunk is available or not. In cases where the interoffice trunks occur in large enough groups to warrant its use the plan of "idle-trunk and idle-position indicating" is employed.

A lamp is provided for each appearance of each trunk on the face of the "A" board, the arrangement being such that a lighted lamp indicates not only that the associated trunk is the first one in its subgroup that is idle but also, in most circumstances, that the "B" operator at whose position the trunk terminates is also available. In other words, a lighted lamp *always* gives

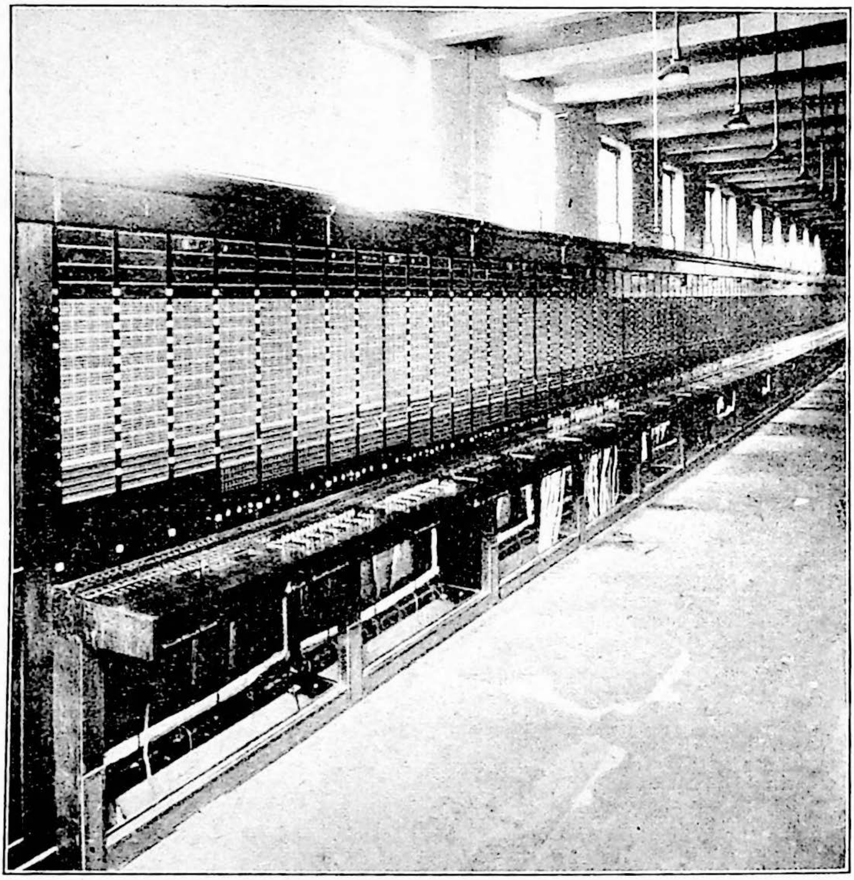


FIG. 307.—Subscriber or "A" switchboard—Monroe Office, Rochester exchange.

indication that the corresponding trunk is idle and *usually* that the "B" operator is ready to handle the connection. The exception as to the idle-operator or idle-position indication is that, if all "B" positions reached by the entire group of trunks are busy, the idle-position indication becomes ineffective and the lamps then indicate idle trunks as if all the "B" positions were idle. In this case, the "A" operator plugs into the trunk and waits until the "B" operator is ready.

Structural Features.—Some of the structural features of the Stromberg-Carlson switchboard system as exemplified in the Monroe office, one of the largest of the seven offices in the Rochester, N. Y., exchange, are of interest. General views of the "A" and "B" boards taken at a time when their installation was not quite completed are shown in Figs. 307 and 308 respectively.[1] The section framework of both the "A" and "B" boards is

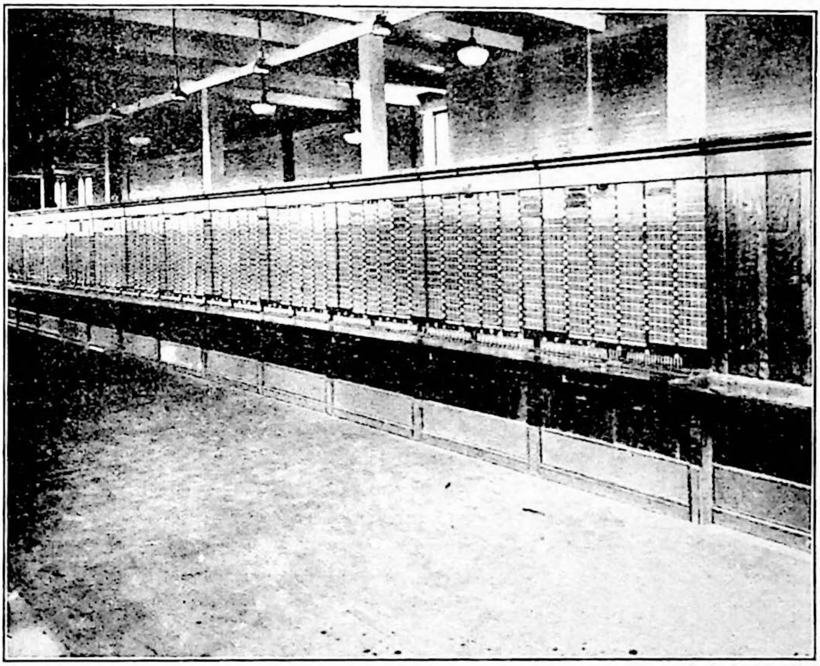


Fig. 308.—Trunking or "B" switchboard—Monroe Office, Rochester Exchange.

arranged on a two-position six-panel basis. The multipling on the "A" board, however, is done on an eight-panel basis, which means that the multiple jack field is repeated every two and two-thirds positions. The "B" board is multipled on a six-panel basis. On these bases the "A" board has an ultimate capacity of 8,000 subscribers' lines after making due allowance for outgoing-trunk jack capacity on the face of the board below the line multiple field. The "B" board has an ultimate capacity of 10,200 lines. It is estimated that ultimately this office will be required to serve a greater number of lines than its "A"-board multiple

[1] The photographs and drawings for Figs. 307 to 319 inclusive are reproduced by courtesy of the Stromberg-Carlson Telephone Manufacturing Company.

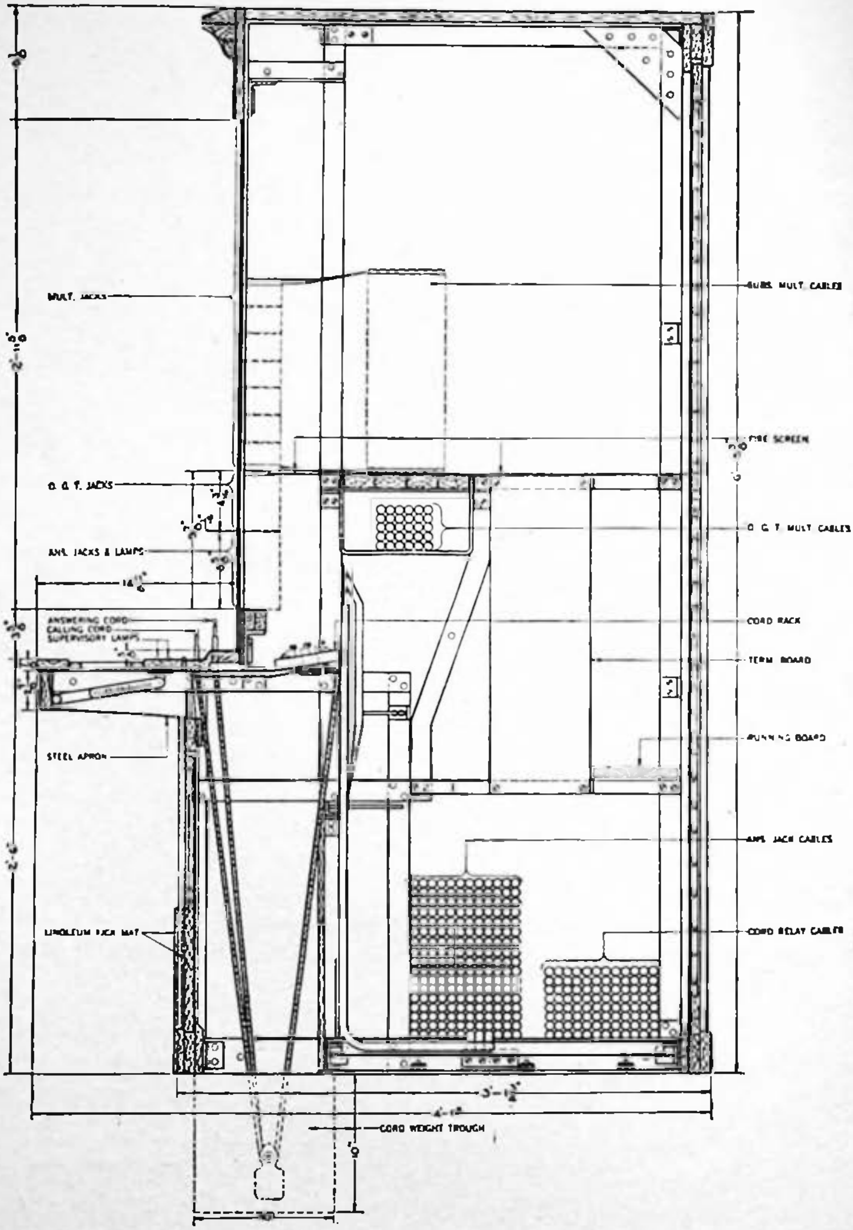


FIG. 309.—Cross-section of "A" switchboard section.

capacity of 8,000. For a considerable time, therefore, or until the limit of 8,000 lines is reached, each call originating in the Monroe district and intended for a subscriber in the same area will be handled through the "A" board alone by the operator who answers it. After the capacity of 8,000 lines is exceeded, calls for higher numbers within the same area will be trunked to the "B" board in this office in the same manner as if they were for subscribers in other offices.

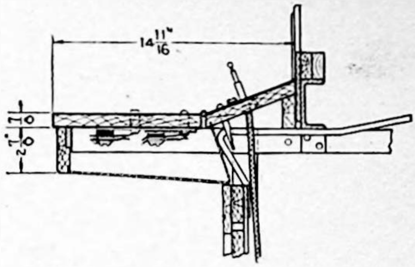


Fig. 310.—Key-shelf design of "B" switchboard.

In the "A" board the calling-plug rail is on the same level with the shelf containing the supervisory lamps and keys but the answering-plug rail is slightly elevated to give better access to the back row of plugs. This arrangement is better shown in the cross-sectional drawing of Fig. 309, showing the arrangement and principal over-all dimensions of an "A" section in this same office.

In the "B" board (Fig. 308) the rear edge of the rail containing the single row of forty trunk plugs and the trunk supervisory lamps is elevated somewhat above the level of the key shelf as shown in Fig. 310. This tilting of the lamp and plug rail somewhat facilitates the handling of the trunk plugs and also brings the lamps more directly into the line of vision of the operator.

As was mentioned while discussing the circuits of this board, the absence of individual ringing and listening keys minimizes the number of wires required to connect the cord-circuit relays and condensers with the keys, lamps, and other equipment that must of necessity be mounted within reach or sight of the operator. This facilitates the placing of the cord-circuit relays, and such other cord-circuit equipment as it is not necessary for the operator to see or handle, on a separate rack in the terminal room, where it may be most effectively inspected and maintained. Such a unit of cord-circuit equipment for one operator's position is shown in Fig. 311, this being for an "A" position equipped with only seventeen cord circuits instead of twenty or twenty-two as in the Monroe office installation now being discussed. The same practice is followed in mounting the cord-circuit apparatus of the "B" position. The resulting absence of cord-circuit relays and associated cord-circuit equipment from the rear of the switchboard sections is to be noted from Fig. 312, which is a rear view of the "B" board taken before the installation was quite complete.

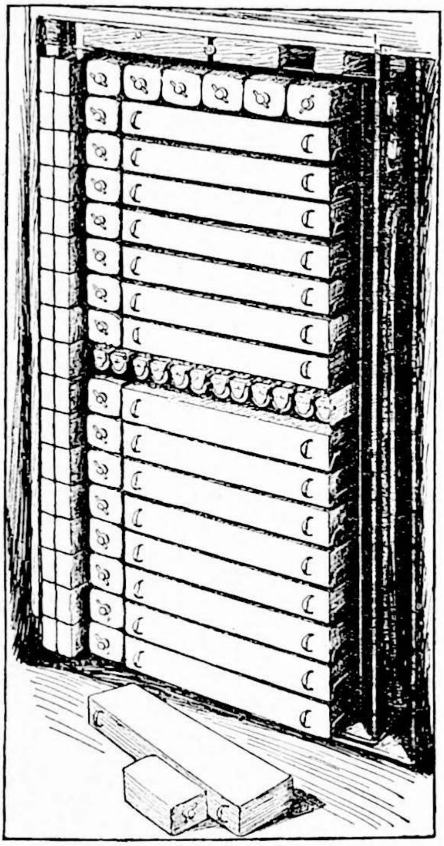


FIG. 311.—Condenser, relay and miscellaneous coil unit for operator's position.

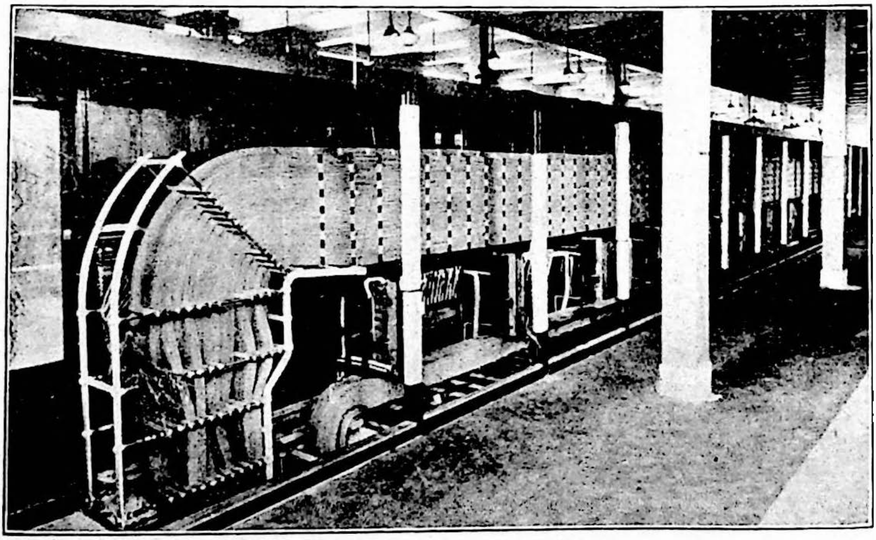


FIG. 312.—Rear view of "B" board—Monroe Office, Rochester Exchange.

A "running board" placed just above the answering jack and cord relay cable runway is to be noted in Fig. 309, and in Fig. 312 in all sections beyond the first. This provides a convenient place on which maintenance men may stand when inspecting the multiple or sit when replacing cords. It also has the advantage of protecting the lower cable runs (principally trunk or answering jack cables) from mechanical injury. Sheet-iron fire screens placed just below the multiple cable run, as indicated in Fig. 309, serve as a preventive against the communication of fire from the lower parts of the section into the main mass of cables above.

As shown in Fig. 309, a trough is constructed below the normal floor level in which the cord weights may hang. This allows room for the required length of cords with lower sections, and it also permits the use of lower operator's chairs with their greater convenience and comfort.

The precaution here adopted to hold the heavy run of multiple cables securely in position as it enters the switchboard sections may be seen in Fig. 312, the cables being clamped and lashed to an iron framework in the turning section. The unusually long horizontal distance in the multiple run between the first multiple jacks and the downward sweep of the cables is to allow room for the "wedging up" of the multiple cable run back of the first multiple jacks without subjecting the wires to undue tensile stress.

With reference to Fig. 307, in which the positions are numbered from left to right, position 1 is a trouble position where preliminary trouble tests may be made. This has a purely maintenance rather than an operating function. Positions 2 and 3 are equipped to handle paystation lines, while position 4 is equipped for message rate service. The remaining positions are devoted to flat-rate local service, with the exception of the last equipped position which is provided with trouble and test cords.

The face and shelf equipment of one of the regular "A"-board positions is shown in Fig. 313. Each of these is wired for an ultimate of twenty-two cord pairs and equipped for twenty. The space at the right of the position for the additional two cord pairs is bored and blanked and the wiring provided, so that the twenty-first and twenty-second pairs may be conveniently added if required.

There are 180 answering jacks terminating on each regular operator's position, but this number, of course, is subject to adjustment downward by changes at the intermediate distributing frame in accordance with variations in traffic load from position to position or from time to time.

These regular "A"-board positions, as already stated in the discussion of circuits, are equipped for various so-called "features" of which the more important are operator's bar from busy lines, automatic listening, flashing recall, master ringing-control key, revertive ringing tone, automatic-call registration, and straightforward trunking. These features result in the absence

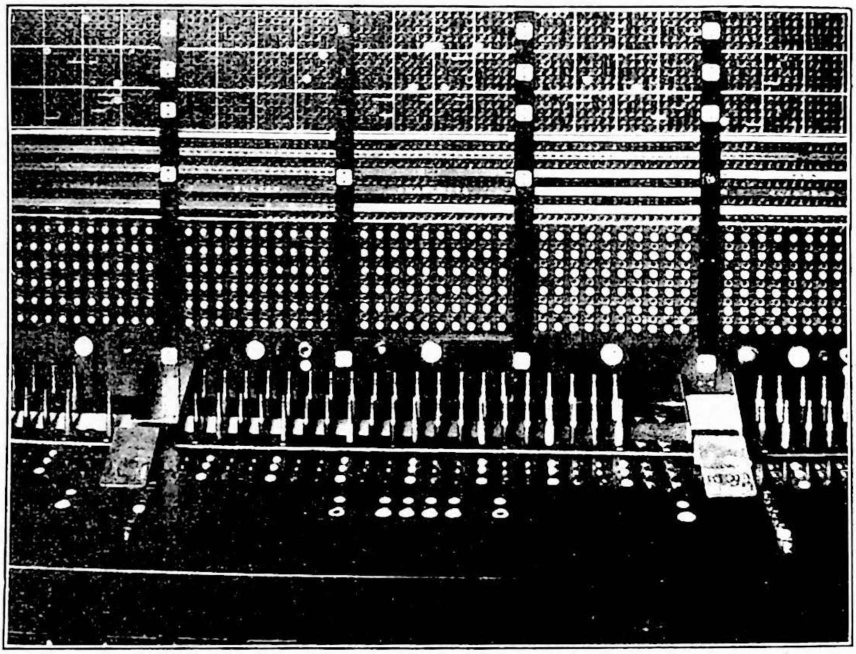


FIG. 313.—Face and shelf equipment of "A" board—Monroe Office, Rochester Exchange.

of all individual ringing and listening keys and also of all call-circuit keys, excepting a few for cooperation with distant offices not provided for straightforward trunking, or for communication with desk operators. As a result, both the top and the under sides of the key shelf, as shown in Figs. 314 and 315, present a strikingly vacant appearance to one accustomed to the older forms of "A"-board equipment.

With reference again to Fig. 313, the outgoing trunk jacks, arranged twenty per strip and multipled throughout the "A" board, are shown immediately above the answering jacks and lamps and below the subscribers' multiple. Each strip of these trunk jacks is provided with a strip of lamp indicators which serve to eliminate the need of making busy tests in establishing

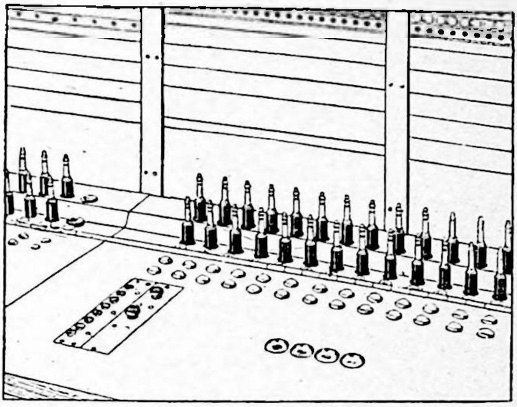


FIG. 314.—Keyboard and plug-shelf arrangement.

outgoing-trunk connections, since they always indicate an idle trunk and usually an idle "B" operator at the distant office. These lamps lie directly behind the outgoing-trunk designation

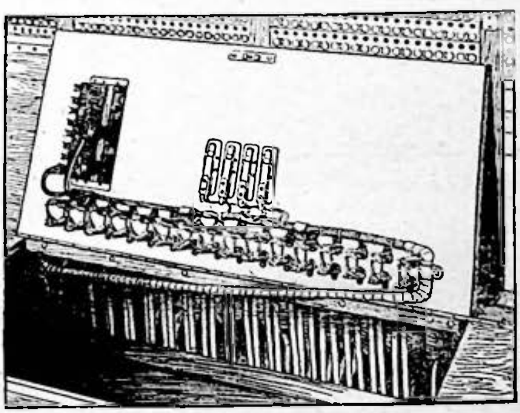


FIG. 315.—Under side of keyboard.

strips which are of translucent material. In this way the indicator lamps take up no more room on the face of the board than was formerly taken by the designation strips alone.

At the "B" board (Fig. 308) different positions are provided for handling toll trunking, inter-office trunking, and trouble. Of the equipped positions, numbered from the right to left in this figure, the first and last are trouble positions, the second and third handle the incoming trunks from the toll board, and the remaining ones the inter-office trunks. The face and shelf equipment of one of the local trunking positions is shown in Fig. 316. Each trunk position, such as the one here shown, is wired and equipped for forty trunks, terminating in a single row of plugs

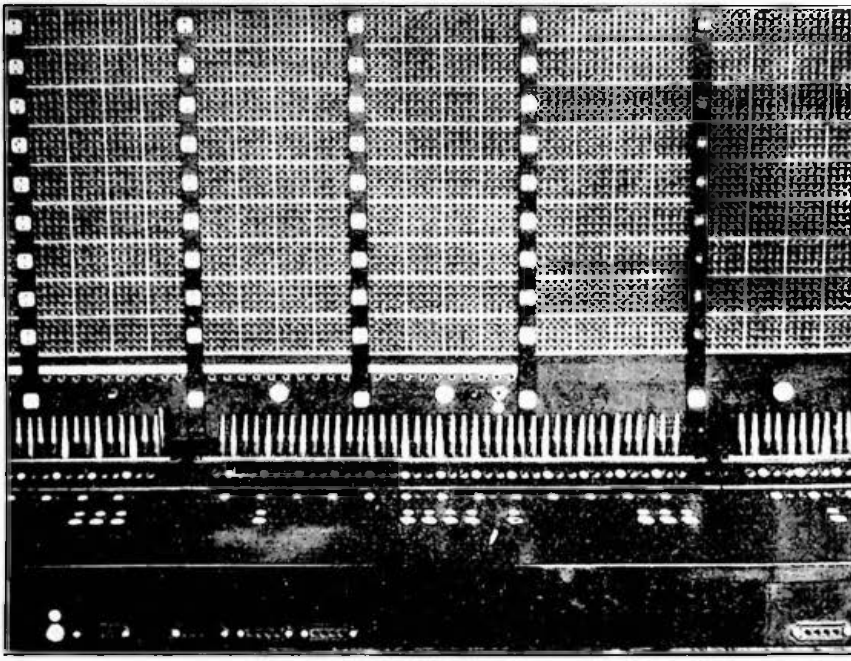


Fig. 316.—Face and shelf equipment "B" board—Monroe Office, Rochester Exchange.

as shown. The trunk cords, plug shells, and lamp caps are distinctively colored to facilitate tracing disconnects.

MULTIPLE SWITCHBOARDS FOR SMALL EXCHANGES

It was stated in the last chapter that there is now little need in telephone-exchange operation for the magneto multiple board. As a rule, an exchange large enough to warrant a multiple board is large enough for common-battery equipment. This is not to say, however, that the need of handling some magneto lines in multiple boards is entirely eliminated by the adoption of the common-battery system. There are many exchange areas, served principally by common-battery equipment, in which the outlying rural districts are best served by means of magneto lines, and often these magneto lines may be best handled by bringing them directly into the common-battery multiple board.

Ordinarily the regular common-battery cord circuits are not adapted to work with magneto lines, and, therefore, for connections involving magneto lines it becomes necessary either to provide a few special cord circuits on each position of the multiple board or else to terminate the magneto lines on one position only and connect them with the common-battery lines by trunking. Neither of these plans is altogether satisfactory for obvious reasons, and a better way, where the ratio of magneto to common-battery lines is large enough to warrant it, is to make all of the cord circuits of the convertible type, that is, of such type as will permit them readily to be converted to adapt them for either magneto or common-battery service. This conversion of the cord circuit is often done manually by the operator as occasion requires, a key in each cord circuit serving, when in normal position, to establish the conditions for common-battery service and, when in its alternate position, to bring about those for magneto service. More recently it has become common practice, where the proportion of magneto connections is large enough to warrant it, to arrange the cord circuits so that they will automatically adapt themselves to the type of line (magneto or common battery) with which they are, at the moment, connected. Cord circuits in which the conversion is thus made automatic are often called "universal."

When a magneto exchange reaches the point where it becomes economical to change to a common-battery basis, it is often desirable to make the change gradually, first equipping the more congested areas for common-battery operation and later the more remote areas out to the ordinary limit of common-battery working.

Switchboards with either manually or automatically convertible cord circuits naturally find use, therefore, in small exchanges that have just outgrown or are in the process of outgrowing their former magneto equipment and which, by the nature of their communities, have little expectancy of ever requiring switchboards of very large capacity.

Stromberg-Carlson Small Multiple Board.—Typical of such small multiple boards is the "junior multiple" switchboard, of the Stromberg-Carlson Company, which provides the essential elements of modern common-battery service in so far as they are

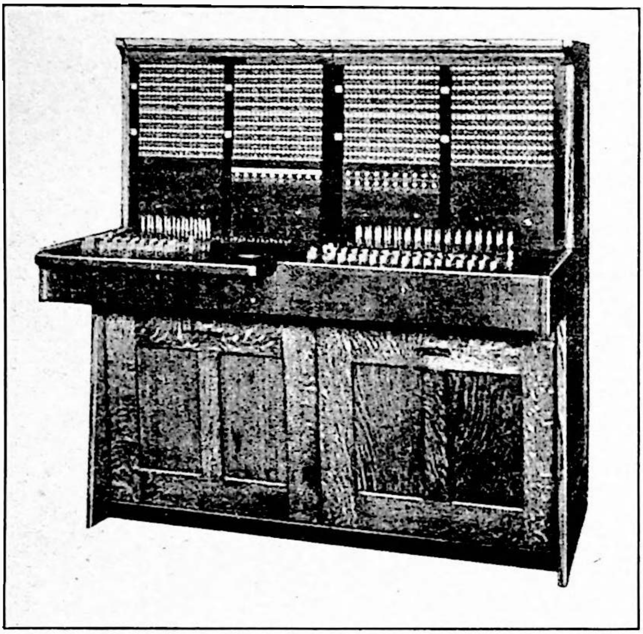


FIG. 317.—Two-position Stromberg-Carlson junior multiple switchboard.

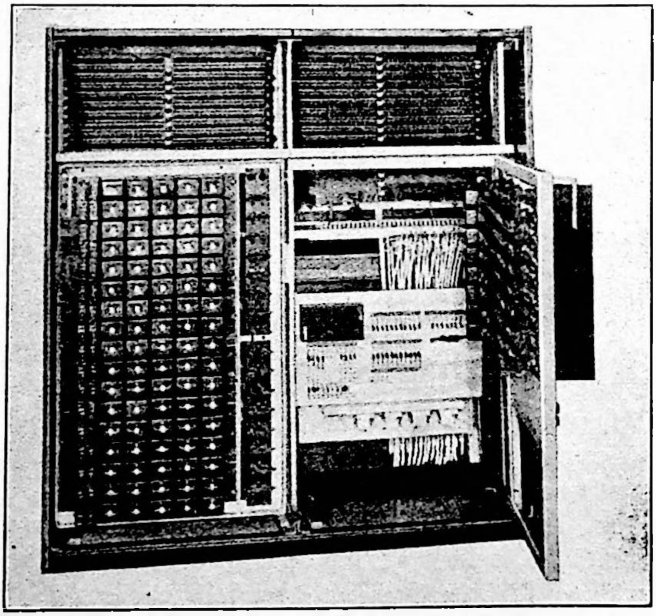


FIG. 318.—Rear view junior multiple switchboard.

thought economically applicable to small-exchange operation. A feature of this board is its automatically convertible cord circuits, "universally" adaptable for connecting magneto and common-battery lines. Figures 317 and 318 show front and rear views, respectively, of a two-position switchboard of this type.

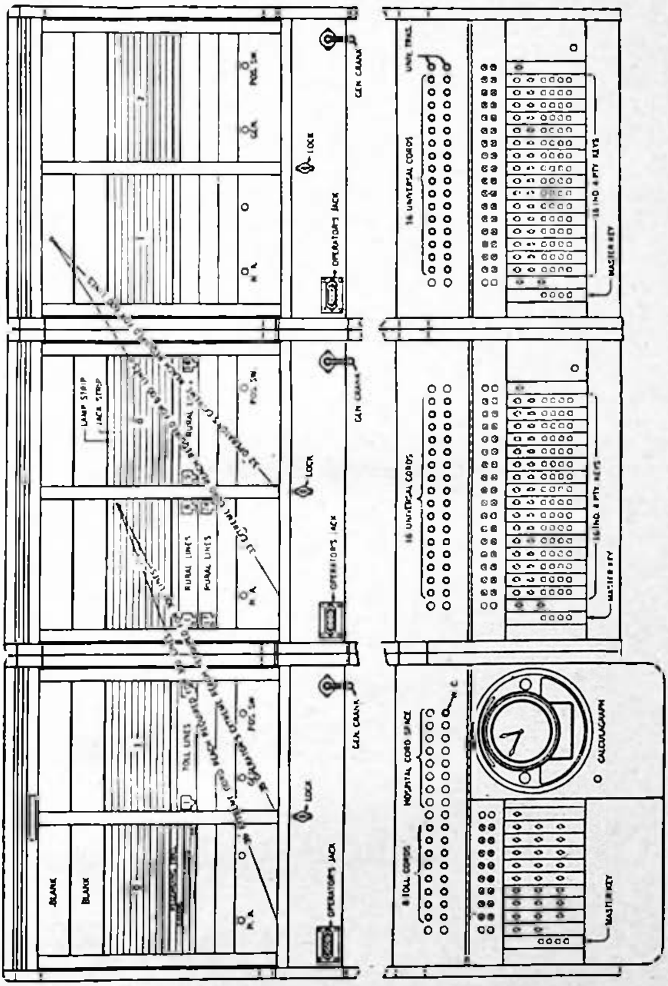


FIG. 319.—Face and keyboard layout junior multiple switchboard.

Figure 319 shows the arrangement of the face equipment and also of the key- and plug-shelf equipment on a three-position switchboard of the same type. It also indicates the reaches required of the operator in covering 300- and 600-line multiple jack fields respectively.

The framework is of steel with hardwood encasement and is in single-position lengths. Special toll sections are made with wider key shelves to provide room for calculagraph mounting, the positions at the left of Figs. 317 and 319 being of this type.

The condensers, relays, and repeating coils belonging to each position are mounted on a swinging gate so as to give access to both sides of the relay equipment for inspection of wiring and

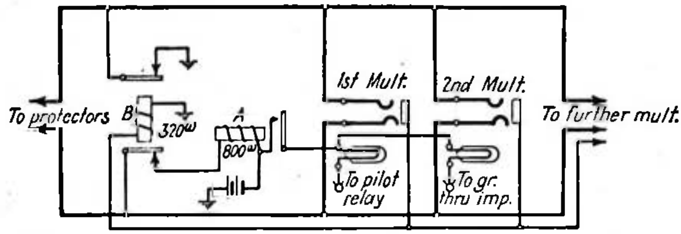


FIG. 320.—Common-battery line circuit—junior multiple switchboard.

contacts and also to the cords and other equipment carried on the stationary parts of the board.

Each regular position is arranged for an ultimate capacity of sixteen universal cord circuits and the toll positions for eight cord circuits. The multiple field has an ultimate capacity of 600 lines,

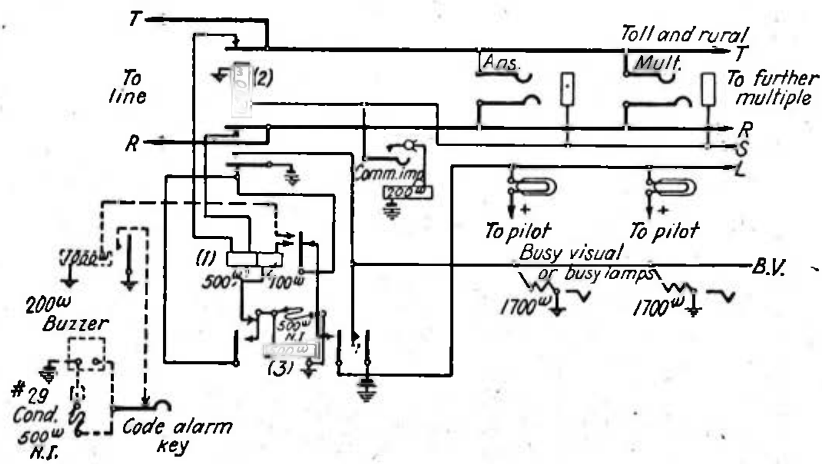


FIG. 321.—Magneto line circuit—junior multiple switchboard.

when the multipling is done on a three-panel basis, or for 800 lines when on a four-panel basis. Below the multiple field, space is available for the installation of magneto lines or trunks.

Common-battery Line Circuit.—The circuit of a common-battery line, for stations within the common-battery area, is shown in Fig. 320. This, as will be seen, is of the multiple line-lamp type, a line signal being directly associated with a multiple jack on each section of the multiple. The operation of this circuit will be clear from what has gone before.

Rural- and Toll-line Circuit.—The line circuit for use with magneto-equipped stations, either toll or local, is shown in Fig. 321 and is not quite so simple. The subscriber on such a line or the operator at a distant exchange signals by means of alternating current such as that from a magneto generator. This flows over the metallic circuit of the line through the 500-ohm coil of the line relay 1. This relay, by closing its front contact, causes the operation of relay 3, over a circuit traced from ground through the inductive and non-inductive windings of relay 3 in multiple, normal make-before-break contact of relay 3, 100-ohm winding and make contact of relay 1, to battery through the break contact of relay 2. The flow of current in this circuit through the 100-ohm winding of the relay 1 tends to stabilize the action of that relay during the time while relay 3 is pulling up. The 500-ohm non-inductive winding on the relay 3 provides a path of comparatively low impedance for the alternating current set up in the 100-ohm winding of relay 1 by the transformer action from the line coil of that relay.

As the relay 3 pulls up, it first closes its own locking circuit from battery through the back contact of relay 2 and then breaks the holding circuit through the 100-ohm winding of relay 1. As a result, when the subscriber ceases to turn his magneto generator, relay 1 releases, while 3 continues to hold. Relay 3 causes the illumination of the line lamps over a circuit traced from battery, back contact of relay 2, back contact of relay 1, front contact of relay 3, line lamps in multiple, to ground through the line pilot relay.

The break contact on relay 1 is provided in order that the operator may distinguish a code call intended for another party on the same bridged magneto line from a call for the central office. During code ringing, the line signal lamp goes out each time the line relay pulls up and a signal buzzer gives an audible reproduction of the code-ringing signals. The circuit for controlling the buzzer is from ground through the 1,000-ohm buzzer-controlling relay, make contact of relay 1, and back contact of relay 2 to battery. At the completion of code ringing, the operator may release relay 3 by pressing a line-signal restoring key associated with that position. This momentarily operates the cut-off relay to break the holding circuit of relay 3.

When the operator, in answer to a call intended for the central office, inserts an answering plug in the jack associated with the lighted line lamp, the cut-off relay 2 is energized over the sleeve strand of the cord circuit as in the case of a common-battery line. The action of the cut-off relay 2 breaks the circuit of the line signals, extinguishing them, and also releases relay 3. It also transfers the battery connection to the visual busy signals associated with the line lamps and operates each of them to show that the line is busy. It also cuts off all of the signaling bridges across the line circuit, avoiding transmission losses through them.

Universal Cord Circuit.—Each of the sixteen cord circuits on regular positions is of the universal type, which makes it unneces-

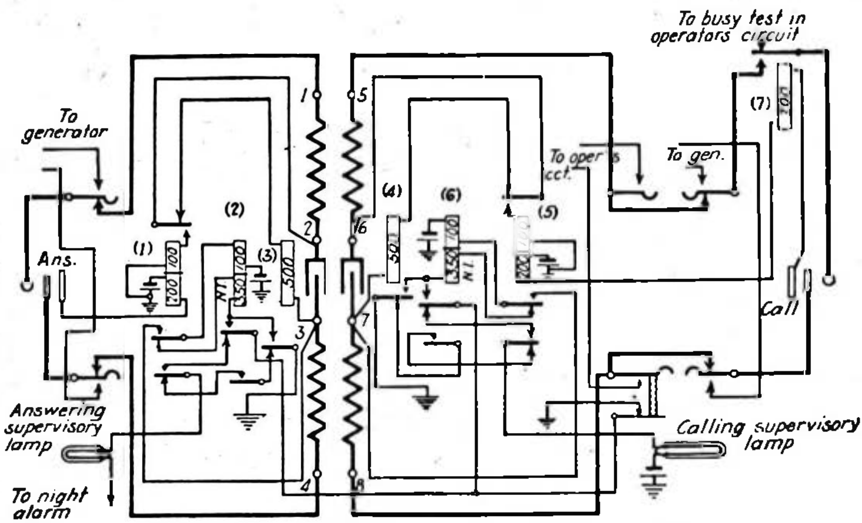


FIG. 322.—Basic cord circuit—junior multiple switchboard.

sary for the operator to perform any act in order to adapt any cord circuit to the type of line that is being connected. Key listening and key ringing are used throughout, the complications involved in keyless operation being thought unwarranted in exchanges of the size for which this board is adapted. The complete cord circuit equipped for manual ringing on both answering and calling cords is shown in Fig. 322, this being the basic circuit from which those required for other types of service, such as selective ringing on party lines, may be secured by simple, easily understood modifications.

The feature of particular interest in the universal type of cord circuit generally is the method by which each end of the cord distinguishes between magneto and common-battery lines. The point of difference between the two types of lines, upon which the cord, as it were, bases its decision, is that the resistance of the cut-off relay on a magneto line is made relatively high, and that on a common-battery line relatively low. In the present instance, as shown in Figs. 320 and 321, the cut-off relay coils have resistances of 320 and 1,500 ohms, respectively. The

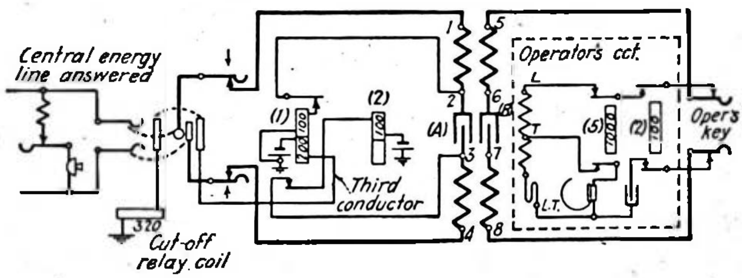


FIG. 323.—Portion of circuit used in answering on a common-battery line.

relay in the sleeve strand of each cord (1 and 5, Fig. 322) are the ones which make the choice, refusing to pull up over the higher resistance but doing so readily over the lower.

The basic difference between common-battery and magneto operation, as far as transmission requirements are concerned, is that in the common-battery system talking-battery current is supplied from the cord, while in the magneto system it is supplied

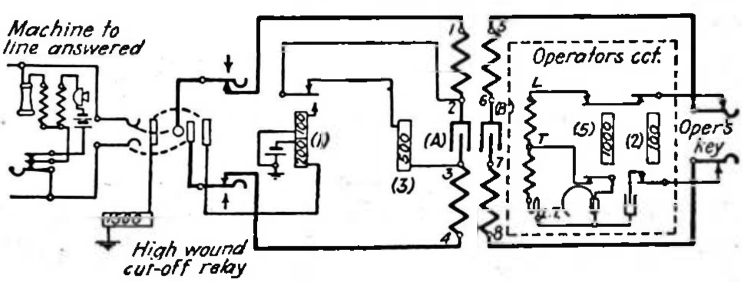


FIG. 324.—Portion of circuit used in answering on a magneto line.

from the subscriber's station. A comparison of Figs. 323 and 324 shows how the answering end of this cord circuit automatically adapts itself to either condition. When the operator, in answering, plugs in on a common-battery line (Fig. 323), relay 1 is operated over the sleeve strand of the cord in series with the low-resistance cut-off relay, as usual. When so operated, it establishes the circuit for the supply of battery current to the calling subscriber through the 100-ohm windings of relays 1 and 2 in series and through the two windings of the repeating coil. When, however, connection is made with a magneto line (Fig. 324), no such battery supply is needed. The relay 1 of the cord circuit does not pull up because of the high resistance of the cut-off relay with which such lines are provided. As a result, the battery-supply bridge is left open. In either of these cases the operator upon throwing the listening key is enabled to talk with the calling subscriber through the inductive action between the windings of the repeating coil.

In similar manner the calling end of the cord circuit distinguishes between a common-battery line and a magneto line, the relay 5 (Fig. 322) operating over the sleeve strand of the calling

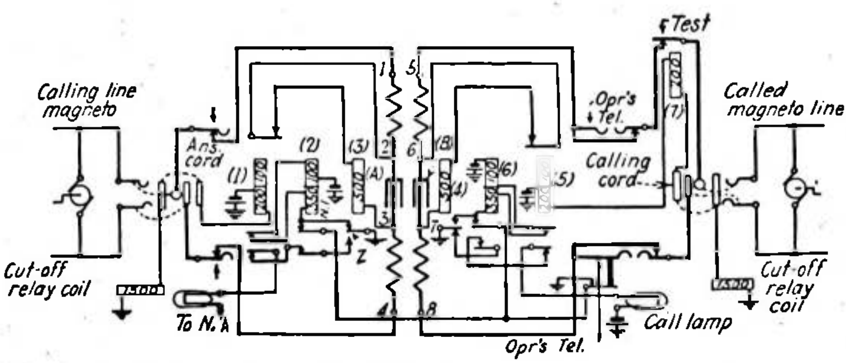


FIG. 325.—Portion of circuit involved in magneto supervising.

cord in series with the low-resistance cut-off relay of the common-battery line, but failing to operate over the high-resistance cut-off relay of the magneto line.

The action of the supervisory signals of this cord circuit in connection with common-battery lines will be understood readily by studying Fig. 322. It is practically the same as in the four-relay cord circuits already described. Thus, on the answering end, relay 1, operated on plugging in, serves to prepare the local circuit of the answering supervisory lamp, while relay 2, responsive to the movements of the subscriber's hook switch, serves to close it when that subscriber hangs up.

When the connection is with a magneto line, an entirely different mode of supervisory signaling must be relied on, because in this case the subscriber must turn his generator crank to send a clearing-out signal. By considering the answering side and referring to Fig. 325, it is seen that the relay 3 is in position to receive the alternating ringing current of the calling subscriber's generator. Relay 3, in pulling up, causes the operation of relay 2 over a circuit from battery, 100-ohm inductive winding of relay 2, back contact of relay 1, 350-ohm non-inductive winding of relay 2 to ground at the contact of relay 3. Relay 2, thus energized, locks to ground through a normally closed contact on the listening key. Relay 3 released when the subscriber ceased to turn his generator, so that of the three relays 1, 2, and 3, only 2 is energized. This closes a circuit for the steady illumination of the answering supervisory lamp as a clearing-out signal. The lamp burns until the operator listens in, in finally supervising the connection, which act breaks the locking circuit of relay 2, allowing it to release and effacing the signal. The action of the calling supervisory signal on a magneto line connection is exactly like that on the answering cord.

Kellogg Small Multiple Board.—Another common-battery multiple switchboard designed for small exchanges wherein some provision is necessary for magneto lines is the so-called "universal" board of the Kellogg Company. In this, as in the one just described, the sections are in one-position units, so that the board may be added to one position at a time. An equipped two-position board of this type is shown in Fig. 326. A box panel at one end affords entrance room for the cables from the main distributing frame and also houses the relay rack carrying the line and cut-off relays. Lift-out panels, front and rear, give access to both sides of this part of the equipment.

The ultimate capacity of this board when the multipling is done on a four-panel, two-position basis, with jacks and lamps each mounted ten per strip, is 800. Space below the multiple jacks and signals is afforded for magneto lines, either of the self-restoring drop type, as shown in the lower part of the right-hand panel, or of the lamp-signal type, as shown near the bottom of the second and third panels.

Each position has provision for seventeen pairs of cords and plugs and it is the more common practice to equip these for key ringing and listening, although they are sometimes equipped for automatic ringing on common-battery lines.

Three types of line circuit may be used interchangeably in this board: (*a*) common-battery multiple with multiple line-lamp signals, (*b*) magneto multiple with multiple line-lamp signals, and (*c*) magneto multiple with a single self-restoring drop signal, The operation of the common-battery line circuit needs no explanation, it being practically the usual two-relay line circuit with multiple line-lamp signals. The magneto line circuit with lamp signals has almost the same wiring but the winding of the cut-off relay is made of such high resistance that the sleeve relay of the cord circuit will not operate through it. The cut-off relay, however, operates in the usual manner to disconnect the

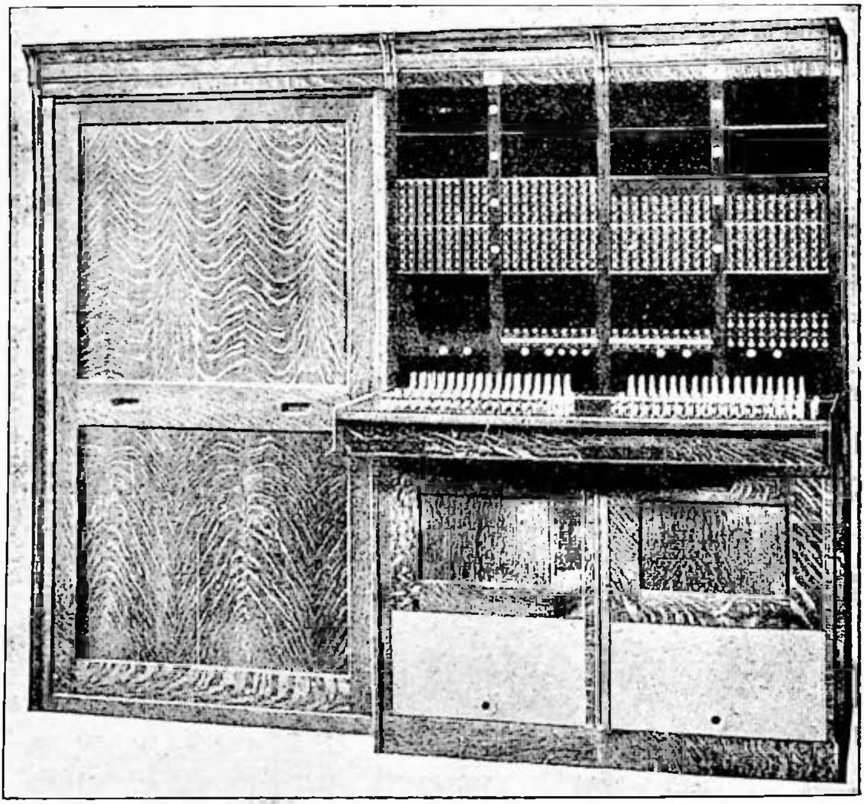


FIG. 326.—Two-position Kellogg universal switchboard. (*Courtesy of Kellogg Switchboard and Supply Company.*)

line relay and lamps. The subscriber signals by means of his magneto generator, its current passing through the coil of the line relay. When thus energized, the line relay locks from the common battery and thus causes the line lamps to glow steadily. When the operator plugs in, the cut-off relay is operated over the sleeve circuit, thus severing the connection between the line and the line relay and at the same time breaking the locking circuit of that relay. The magneto line circuit with self-restoring drop employs cut-off jacks and but a single line signal. The line is accessible from every section of the switchboard through its multiple jacks, the sleeve contacts of which are connected together for busy-test purposes.

The cord circuit for use interchangeably with these line circuits is shown in Fig. 327. It is adapted for key listening and ringing and is of the universal type; that is, it automatically adapts itself to either common-battery or magneto operation or to both, according to the type or types of lines involved in the connection. This automatic adaptation as between common-battery and magneto lines is brought about as in other so-called "universal" cord circuits by the marginal action of the sleeve relays 3 and 1 on the answering and calling sides respectively, these relays being so constituted that they will pull up through the high-wound cut-off relays of common-battery lines but not through the higher-wound cut-off relays of magneto lines.

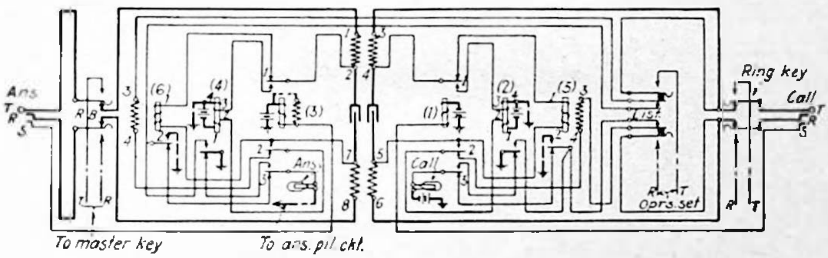


Fig. 327.—Universal cord circuit, Kellogg small multiple switchboard.

With this preliminary explanation, the operation of this cord circuit may be considered more in detail. Let it first be assumed that the answering plug is inserted into the jack of a magneto line. Under this circumstance, the sleeve relay 3 of the cord will not be energized and talking battery will not be supplied to the line through the windings of relay 4. Also, the relay 6 is left bridged around the condenser on the answering side of the cord, so that it is in a position to receive clearing-out current from the generator at the calling station at the close of the conversation. The path of this clearing-out current is over the two sides of the line, the two repeating-coil windings and the coil of relay 6 in series. Relay 6 thus intermittently energized by the slow alternating current attracts its armature and, upon the first closure of its make contact, energizes the relay 4 over a circuit traced from battery, lower winding of relay 4, back contact of relay 3, resistance 4-3, closed contacts on listening key to ground through the make contact of relay 6. Relay 4 immediately locks over the circuit just traced continued to ground through its own make contact. Upon the cessation of the clearing-out current, relay 6 falls back, thus lighting the answering supervisory lamp, from battery through the lamp, back contact of relay 3, back contact of relay 6 and front contact of relay 4 to ground. The answering supervisory lamp, therefore, glows continuously until the operator, in supervising the connection, operates her listening key. This breaks the locking circuit for the relay 4 which, upon releasing, extinguishes the supervisory lamp.

Upon inserting the answering plug into a jack of a common-battery line, the sleeve relay 3 is operated in series with the low-resistance cut-off relay of the line. This bridges the talking-battery supply circuit through the two windings of relay 4 between the tip and ring sides of the answering cord, placing the relay 4 under control of the calling subscriber's switch hook. The operation of the relay 4 prevents the lighting of the answering supervisory lamp, the circuit of which was prepared by the operation of relay 3. When the subscriber hangs up, relay 4 is de-energized, which completes the circuit of this lamp.

The operation of the calling end of this cord circuit, in so far as it relates to its automatic adaptation to magneto or common-battery lines and to the operation of the supervisory signal in connection with either type of line, is exactly the same as that of the answering end, it being noted that the operating and holding circuit for the relay 2 in a magneto line connection passes through another set of normally closed contacts on the listening key.

The cord circuit, as shown, is equipped with a ring-back key on the answering end. If selective ringing is desired, it may be done either by individual selective-ringing keys on each of the cord circuits or by a master selective key common to all circuits of the position.

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