Crossbar Dial Telephone Switching System *

By F. J. SCUDDER and J. N. REYNOLDS

This paper describes the crossbar dial telephone switching system recently adopted by the Bell System for large cities where the panel system has been used for nearly twenty years. Central offices of the crossbar type can be introduced in panel areas without changes in existing offices and without changes in existing dial telephone instruments. Crossbar offices and panel offices in the same building will operate on a common power plant and utilize other equipment in common, such as "A" and "B" operator switchboards and outgoing trunks.

The precious metal contact crossbar switches are used for all switching purposes as contrasted with the base metal contact panel switches. The switches operate with relay-like movements under control of common control or marker circuits consisting primarily of multi-contact, *U* and *Y* type relays. The control and marker circuits, which are connected to the switch frames by means of multi-contact relays, perform their operations in a fraction of a second. The switches, the *U* and *Y* type relays and the multi-contact relays are equipped with twin contacts of precious metal. Senders similar to those of the panel system are employed.

The system will be used for new offices in larger cities as manufacturing and plant conditions permit.

Introduction

It is the purpose of this paper to describe briefly the crossbar dial telephone central office switching system which has recently been developed by the Bell System for use in large cities. Sixteen years ago, in February 1923, a paper was read before the Institute, by Messrs. E. B. Craft, L. F. Morehouse and H. P. Charlesworth of the Bell System which outlined the history and the problems involved in telephone central office switching and described the panel dial central office system which had just been developed and was being introduced in the large cities. The first central office of this type was placed in service in December 1921, and since that time 456 panel dial offices serving nearly four and one-half million subscriber stations have been installed in 26 different cities throughout the country. During these years many improvements have been made in the panel system to make it more serviceable to the telephone public and to meet the new

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problems which have arisen, but in addition the engineers of the Bell System have continued their search to find new and better means for meeting telephone switching demands. This work has resulted in the adoption of the crossbar type central office switching equipment. Two offices of this type were placed in successful operation during 1938 and others are in process of manufacture and installation.

It will be appreciated that for large metropolitan areas, the development and economic introduction of a central office switching system which differs materially from the existing systems is a rather large undertaking. The system must fit into the existing plant as a whole without material change. Generally any important changes affecting the subscribers' use of the telephone or the methods used by switchboard operators should be avoided. Existing numbering plans should not be affected, existing classes of service should be continued, and the addition of others made feasible in case they should be required.

All of these and many other factors have been taken into account and all requirements have been met by the crossbar system which offers important improvements in telephone switching, both in operation and maintenance. Its introduction does not make any of the existing equipments obsolete in the sense that these equipments will be less serviceable nor will it cause their replacement. Central offices of the crossbar type can be installed in the same building with existing penel central offices without loss in operating economies in either type of office. Certain equipment, such as the existing and additional outgoing trunks to other central offices, manually operated switchboard positions, operating room and maintenance desks, power plant and alarms, can be used in common by the two types of offices in the same building.

General

Before describing the crossbar system it is desirable first to give a brief outline of the principal functions of a dial central office equipment. Such an office is capable of serving 10,000 subscriber line numbers, and is provided with a sufficient number of connecting switches, trunks and associated circuits so that under usual peak loads of traffic, calls will be completed promptly.

The central office circuits, in response to the lifting of the receiver by the calling subscriber, connect the subscriber line to the switching equipment. This equipment then extends the calling line, "link by link," through several switching stages to the called line as determined by the called office code and line number dialed by the calling subscriber. When the connection has been established to the called line, the subscriber bell is rung and, when the subscriber answers, the talking connection is completed. During the conversational period the connection is held under control of the calling telephone, and when the telephone receivers are replaced, the central office equipment and the telephones are released for use on other calls. The equipment, of course, transmits the busy tone signal to the calling subscriber if the called line is found busy, and automatically routes a call for a discontinued or an unassigned line to an operator who informs the subscriber of the status of such a line.

Operators and associated switchboards are provided in the dial system to handle certain classes of calls and to render assistance to subscribers when required. Calls to these operators are established in response to the dialing of operators' codes in a manner similar to the establishment of calls to other subscribers.

Operators are usually provided to complete calls terminating in a dial office which are originated by subscribers served by manual offices.

Prior to the introduction of the crossbar system, the Bell System employed two general types of dial central offices. These are the well known step-by-step and panel systems.

The step-by-step system has been used generally in the smaller cities which are frequently served by a single central office or by a relatively small number of offices and where the trunking problems are consequently less complicated. The switches of the step-by-step system are controlled directly by the impulses from the subscriber dials and, necessarily in conformity with the dial, the system operates on a decimal basis. The selectors of this system are first moved under control of the dial to any one of ten vertical positions, corresponding to the numeral of the digit dialed, and in the case of trunk hunting switches is then automatically rotated over a row of ten trunk terminals to find an idle trunk during the interdigital time of the dial.

The step-by-step switch thus has access to ten different groups of trunk terminals with ten terminals each. The location of the trunk groups on the switches is governed by the digits dialed and consequently the relocation of a group necessitates directory changes. These limitations in trunk access and flexibility are not material handicaps in the smaller cities throughout the country where the system is giving excellent service.

The panel system meets the complex service requirements of the larger cities with their large volume of traffic and multiplicity of central offices. In these cities the number of trunk groups is large and the number of trunks in the groups varies widely. Further, the number of groups and their sizes are frequently changed by the introduction of new offices and changes in the character or extent of existing central office areas.

In the panel system, senders are provided which record and store the dial pulses as they are dialed and then independently control the operation of the switching units. The large panel type switches provide access to large groups of trunks and to a large number of groups, and at the same time permit considerable variation in the sizes of the groups. The necessary flexibility in the size and location of the trunk groups is obtained by flexibly wired routing equipment provided in decoder circuits which are associated with the senders. These facilities permit trunk group locations on the switches as dictated by traffic regardless of the office codes listed in the directories and dialed by the subscribers. The panel system also readily provides for the routing of calls through intermediate or tandem offices where the traffic between offices can be more economically handled in this manner.

The crossbar system also makes use of the sender and decoder method of operation and provides a still greater flexibility in the trunking arrangements than is obtained by the panel system.

The Crossbar System

The two outstanding features of the crossbar system are the "crossbar switch" which is used for all major switching operations, and the "marker" system of control which is used in the establishment of all connections throughout the crossbar office.

The crossbar system is essentially a relay system employing simple forms of relays and relay type structures for all switching operations. The apparatus consists almost wholly of crossbar switches, multi-contact relays and the usual small relays similar to those generally employed in all telephone systems. The switching circuits are wired to the contacting springs of the switches, and the connections through the switches are made by pressing contacts together by means of simple electromagnetic structures instead of the moving brushes and associated fixed bank terminals of other systems.

The use of relay type apparatus with its small, pressure type contact surfaces economically permits the use of twin or double contacts with thin layers of precious metal for all contact points. Obviously, double precious metal contacts make for reliable operation, especially with the low speech and signaling currents inherent to a telephone system.

The short mechanical movements and the inherently small operating time intervals of the "relay-like" crossbar switch permit the use of common circuits or "markers" to control the operation of the switches. This has permitted the use of large assemblies of switches and associated relays on unit frames which can be wired and completely tested for operation in the factory before the units are shipped.

In the design of the switching frames and associated control circuits, one of the objectives realized has been the standardization of a relatively small number of different types of equipment units, thereby simplifying manufacture and merchandizing. This also simplifies the engineering of the equipment by the Telephone Companies in the preparation of their specifications to meet the particular traffic requirements of the various central offices.

The marker system used for controlling the switching operations has many advantages, the more important of which will be disclosed later in the general description of the operation of the equipment. It might be mentioned here, however, that the marker is an equipment unit consisting almost entirely of relays, which completes its functional operations in the establishment of a call in a fraction of a second. This short operating time permits a few markers to handle the entire traffic in the largest office. The markers are connected momentarily by means of multi-contact relays to the various switching units of the office to control the establishment of the calls through the crossbar switches.

An outstanding advantage of the marker system of control is the "second trial" feature, by means of which two or more attempts can be made to establish a call over alternate switches and trunks when the normally used paths are all busy. The markers are arranged to detect short-circuited, crossed, grounded and open-circuit conditions at all vital points, and before releasing from a connection they make circuit checks to insure that the connection has been properly established. When trouble conditions are detected, they make a second attempt to complete the connection, after sounding an alarm and recording the location and nature of the trouble encountered. The marker system facilitates the introduction of new service features and changes in operation, which may be found desirable from time to time, due to the fact that the principal controlling features of the entire system are vested in a small number of markers.

Apparatus

Crossbar Switch

The crossbar switch from which the system derives its name is the basic switching unit of the system. Figure 1 shows the front view of a 200-point crossbar switch.

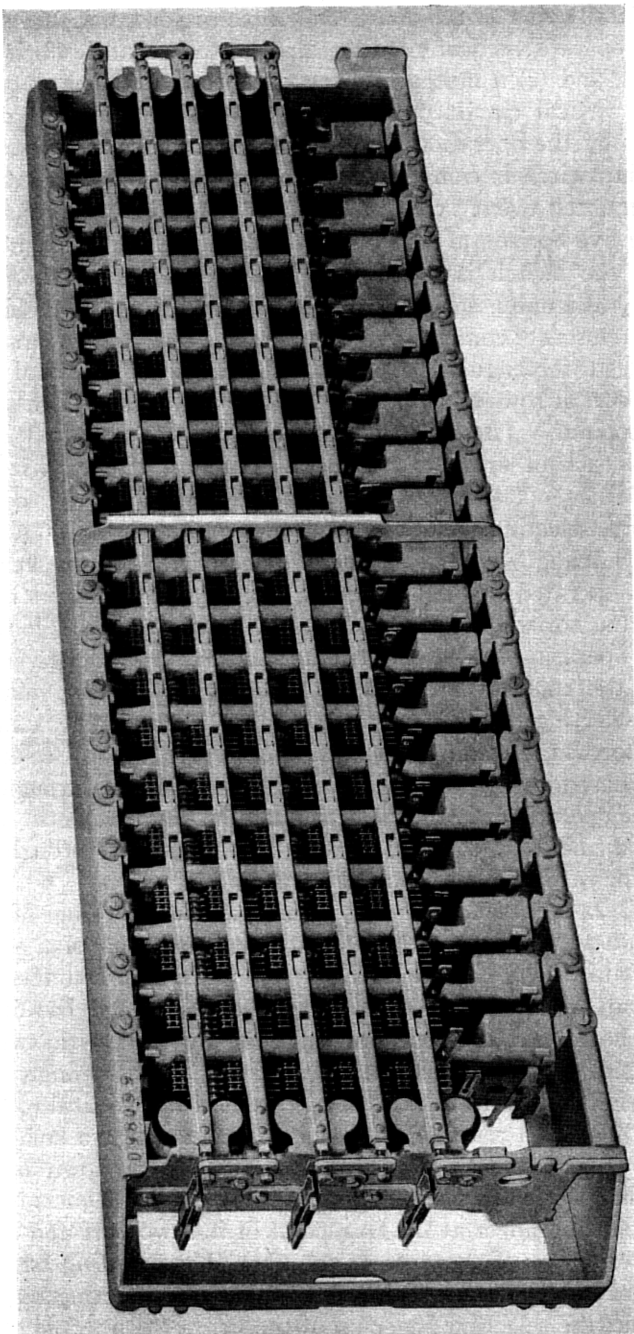

Fig. 1—Crossbar switch—front view.

Fundamentally this switch consists of three major functional parts: (*a*) twenty separate vertical circuit paths, (*b*) ten separate horizontal circuit paths, and (*c*) a mechanical means for connecting any one of the twenty vertical circuit paths to any one of the ten horizontal circuit paths by the operation of electromagnets. From a structural viewpoint the switch is comprised of a rectangular welded frame on which are mounted twenty vertical units and the selecting mechanism consisting of five horizontal bars operated by ten selecting magnets.

Primarily the switch is a multiple relay structure with twenty vertical relay-like units, each unit having an operating or "holding" magnet and ten sets of contacts in a vertical row. The switch arrangement provides a rectangular field of contacts in twenty vertical rows and ten horizontal rows or a total of 200 sets of contacts, one set at each "crosspoint." These crosspoint contacts are operated independently of each other by a coordinate operation of the horizontal and vertical bars. The horizontal bars are controlled by the ten horizontal or "selecting" magnets and the vertical bars by twenty vertical or "holding" magnets. Any set of contacts in any vertical row may be operated by first operating the selecting magnet corresponding to the horizontal row in which the set of contacts is located, and then by operating the holding magnet associated with the vertical row. Since the contacts are held operated by the holding magnet alone, the selecting magnet is operated but momentarily and is released as soon as the holding magnet is operated. After the selecting magnet is released, other connections may be established through the switch by the operation of other selecting and holding magnets. It is thus apparent that ten connections can be established through the switch, one for each of the horizontal paths.

From Fig. 2 the rather simple mechanical interlocking of the horizontal and vertical bars which causes the operation of a set of crosspoint contacts will be understood. The ten sets of contacts in a vertical row are associated with the vertical or "holding" bar of the row. Each horizontal or "selecting" bar is provided with twenty selecting fingers which are made of flexible wire. These fingers are mounted at right angles to the bar, one at each of the vertical rows of contacts. Thus when a selecting bar is rotated through a small arc by its magnet, the selecting fingers will move up or down into a position so that when a holding bar is operated by its magnet, it will engage the selecting finger at the crosspoint of the two bars and cause the corresponding set of contacts to operate. The selecting bar and the fingers not used will then be released when the selecting magnet is released, but the selecting finger used to operate the selected set of crosspoint contacts will remain latched and the contacts held closed by the holding bar until the holding magnet is released at the end of the connection. The selecting fingers are each provided with a damping spring to reduce vibration on the operation and release of the fingers.

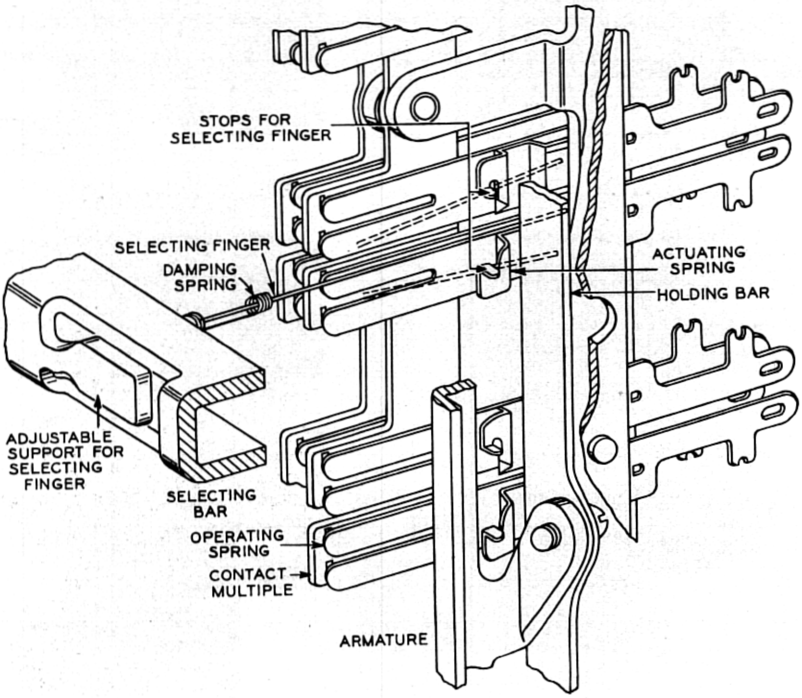

Fig. 2—Crossbar switch selecting mechanism.

It will be noted that the selection operation is performed by five horizontal bars although there are ten horizontal rows of contacts. This is accomplished by operating the bars in either of two directions. As shown in Fig. 1, two magnets are associated with each bar, one whose armature is on top of the bar, the operation of which causes the selecting fingers to move in a downward direction, and the other whose armature is below the bar causing the fingers to move upward. The selecting bars are restored to the normal or mid-position by the centering springs located on the end of the switch adjacent to the magnets.

Figure 3 shows the vertical unit of the crossbar switch with its ten sets of normally open "make" type contact springs, the holding magnet at the bottom, and the long vertical armature to which is attached

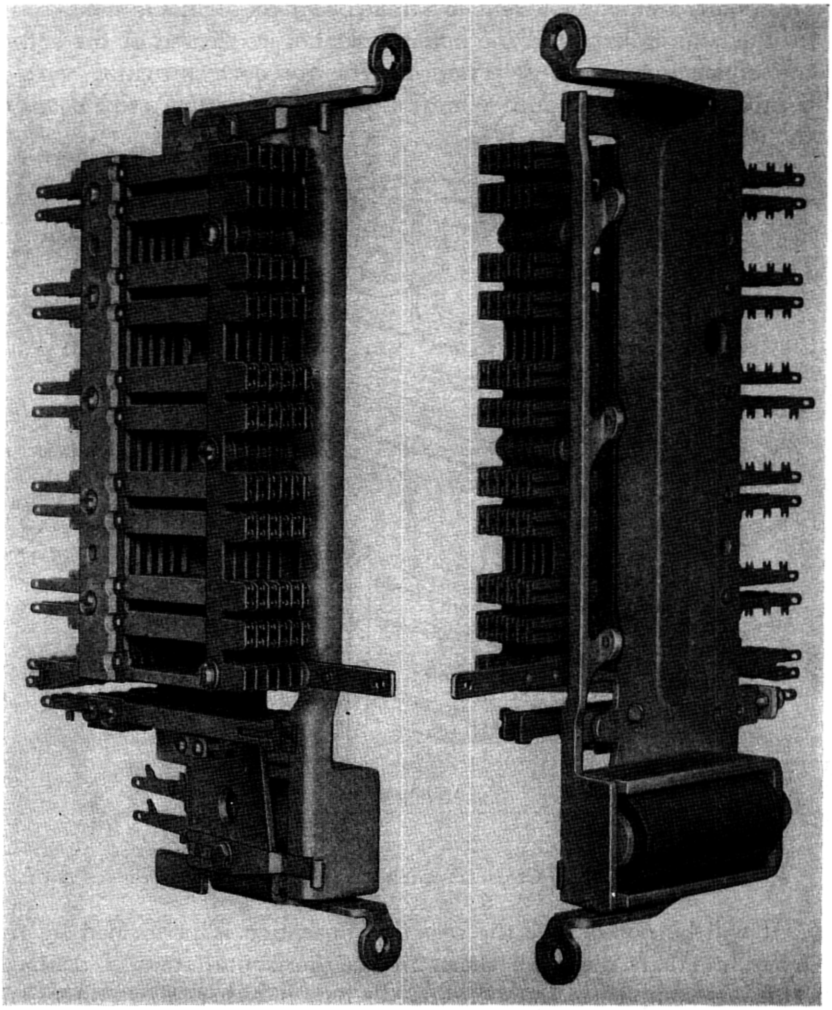

Fig. 3—Crossbar switch vertical unit.

the vertical holding bar. The vertical unit shown has six pairs of contacts at each of its ten crosspoints. Other vertical units are provided with ten sets of 3, 4 and 5 pairs of contacts per set. One spring of each pair as shown is a fixed spring consisting of a projection of an insulated vertical metal strip, made in the shape of a comb. This strip extends from the top to the bottom set of contacts of a vertical row. Wiring lugs are provided at the lower end of these vertical strips facing the rear to which are wired the lines or trunks of the vertical circuit paths. At the lower end of these strips and facing the front is another projection used by the maintenance force for testing purposes. The mate or movable spring of each pair is individually insulated from all other springs. These springs extend to the rear of the switch for wiring purposes and may be strapped horizontally to the corresponding springs of adjoining vertical units to extend the horizontal circuit path through the switch.

The contacting ends of the thin movable contacting springs are bifurcated to provide two flexible contacts in parallel. The contacting surfaces on these springs as well as the mating fixed springs are provided with a thin layer of palladium. The use of the double precious metal contacts is an important feature of the crossbar system in providing more reliable contacting surfaces. Experience has shown that the chance of simultaneous failures of both contacts of a pair is extremely small. The actual contacting surfaces of each pair of springs consist of small bars of contact metal located at right angles to each other. These bars are composed of a ribbon of nickel capped with a thin layer of palladium. This crossbar arrangement of contacts provides a rather large area over which the two springs can make contact with each other, and thereby permits considerable tolerance in the manufacture and adjustment of the contact spring assemblies.

The switch may be equipped with "off normal" contact spring assemblies. When these are furnished they are associated with each selecting or holding magnet and are operated like relay contacts when the associated magnet operates, regardless of which crosspoint contact is closed. They are used to perform circuit functions as required in the various uses of the switch.

In the design of the switch special attention was given to the problem of wiring and cabling. Figure 4 shows the wiring terminals on the rear of the switch. These terminals are arranged for individual wiring and also have staggered, notched projections so that the terminals can be readily strapped together horizontally with bare wire as shown. This is an important feature of the switch since it permits a multiple of terminals to be easily soldered together and reduces the wire congestion on the switch.

The 200-point crossbar switch is 9¼ inches in height and 30½ inches in length. In addition a 100-point switch 20½ inches in length is provided. This switch is similar to the 200-point switch but is equipped with 10 vertical units.

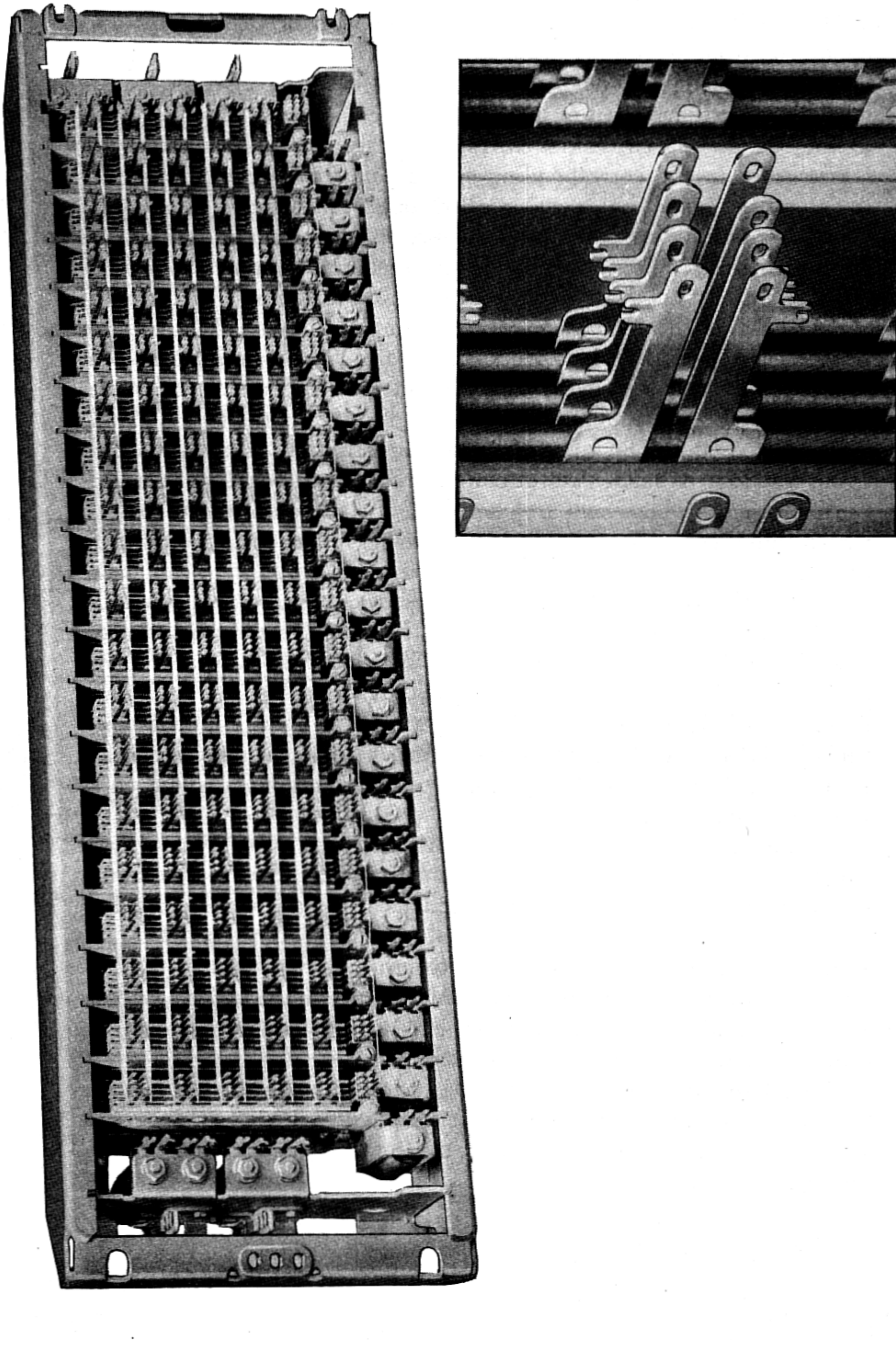

Fig. 4—Crossbar switch—rear view.

Multi-Contact Relay

The multi-contact relay used in the crossbar system is shown in Fig. 5. It resembles in design the vertical unit of a crossbar switch.

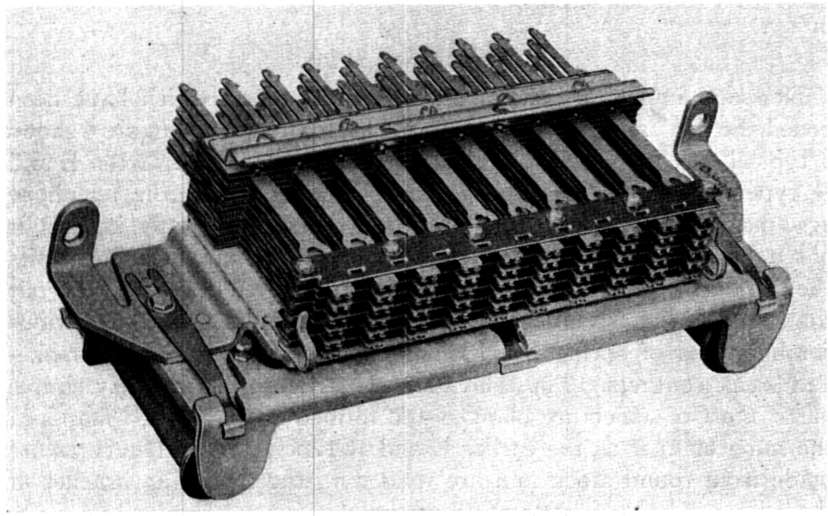

Fig. 5—Multi-contact relay.

The relay is provided in four sizes in respect to the number of contacts, namely, in 30, 40, 50 and 60 sets of individually insulated contacts, all of which are of the normally open type which are closed when the magnets of the relay are operated. Each relay is provided with two separate magnets, armatures and associated groups of springs, and both magnets are energized in parallel in order to close all of the contacts. By operating the two magnets independently the structures can be used as two separate relays, each equipped with 15, 20, 25 or 30 sets of contacts. The relay occupies a mounting space approximately 2″ x 11″ and is provided with a cover.

All contact springs are equipped with twin contacting surfaces similar to the contacts used on the crossbar switch except that they are composed of solid bars of precious metal due to the heavy duty requirements. To facilitate wiring, these relays are manufactured with two types of wiring terminals. In one type the movable springs are of graduated lengths and are provided with notched lugs for bare wire strapping to permit the multipling of springs horizontally to corresponding springs on other relays mounted adjacent. In the second type the strapping lugs are omitted and all springs are of the same length and are provided with soldering eyelets for individual or non-multiple wiring.

The multi-contact relay finds its chief use in the common connector circuits where a large number of leads must be connected simultaneously to a common circuit.

U and Y Type Relays

New and improved general purpose small relays which have been coded the "U" and "Y" type are used in this system. Figure 6 shows a typical "U" type relay. Although somewhat similar to the E and R type relays which have been in a common use in the telephone systems for many years, it differs from them principally in that it has a heavier and more efficient magnetic structure which permits the use of a greater number of contact springs. These relays permit the use of spring assemblies up to a maximum of 24 springs in various combinations of springs, including transfer contacts, simple make-and-break contacts. The relays are constructed of relatively simple parts, most of which are blanked and formed in the desired shapes in the same manner as the earlier E and R type relays. The cores are made from round stock and are welded to the mounting bracket of the relay. The structures of all of these relays are similar and differ principally in their spring assemblies and windings.

In order to insure more reliable contact closures, the relays are equipped with twin contacts. Various types of contact metal and sizes of contacts are provided, depending upon the characteristics of the circuit controlled by the contacts.

Improved methods of clamping the springs in their assemblies, together with the design of the springs, provide stability and minimize manufacturing and maintenance adjusting effort.

Contacts practically free from chatter on both the operation and release of the relay have been obtained by the use of relatively heavy stationary springs, short thin movable springs, and a pivoted arrangement of the armature suspension. By reference to Fig. 6 it will be seen that the rear ends of the armature are pivoted by two pins which project through holes in the hinge bracket mounted on the rear spring assembly. In the earlier flat type relays of the E and R type, the armature was suspended at the rear by means of a reed type armature hinge.

The Y type relays make use of the same manufacturing tools and processes as the U type. Copper or aluminum sleeves are provided over the cores beneath the windings to secure the slow-release characteristics required on these relays. The relay armature is embossed so that when the relay is operated satisfactory contact is made between the metal surfaces of the magnetic circuit which insures uniform time characteristics.

In both the U and Y type relays the cylindrical cores permit the use of form wound coils which are wound on special machines and slipped

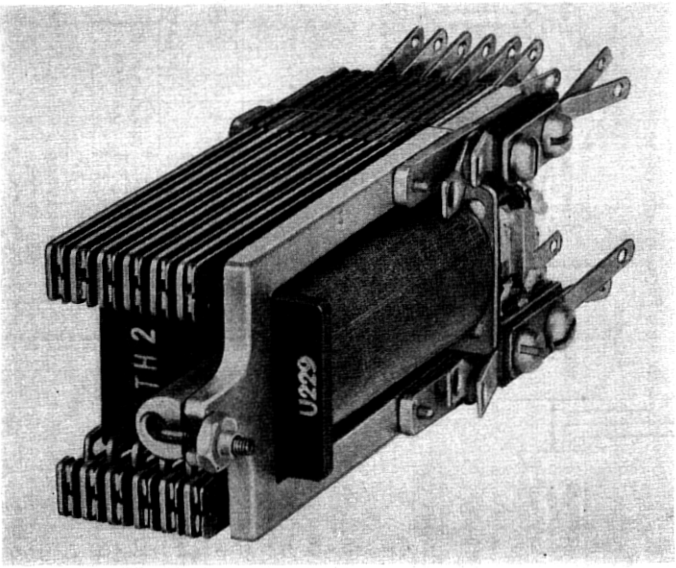

Fig. 6—"U" type relay.

over the cores when completed. In the manufacture of these coils a removable mandrel is used. It is covered with a layer of sheet cellulose acetate and accommodates several coils. These coils are then automatically wound on the mandrel from different spools of insulated wire. Separations are left between adjacent coils so that when the winding operation has been completed the individual coils can be separated. A very thin sheet of cellulose acetate is automatically interleaved between successive layers of wire to hold the wire in place and to provide insulation between layers. This general method of winding coils also is used for the magnets of the crossbar switches and multicontact relays.

Functions of the Equipment Units

The general operation of the system as a whole may be more easily understood by first describing the principal equipment units in the system and their functions before proceeding with a description of the

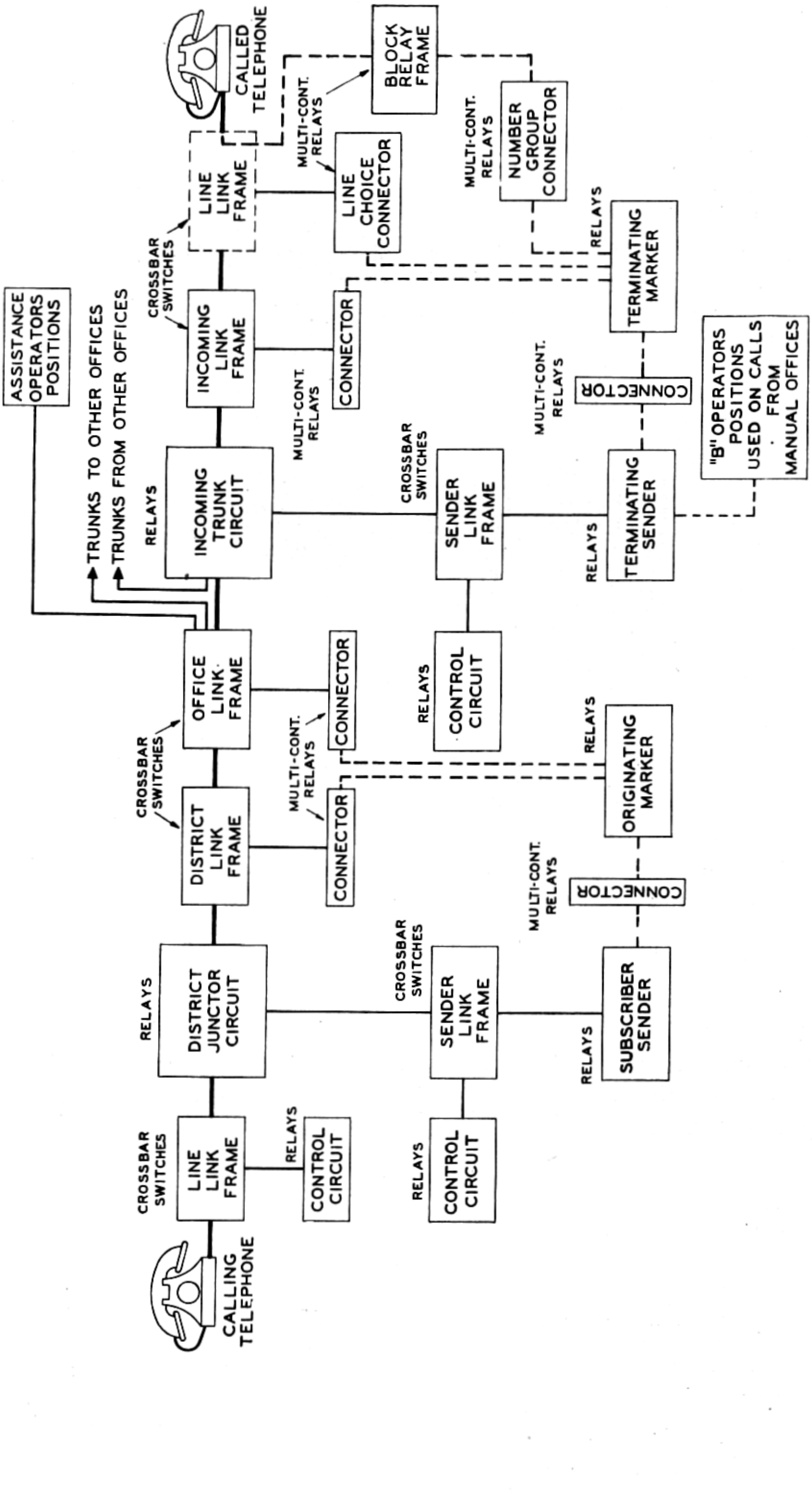

Fig. 7—Functional arrangement of equipment units.

operation of the circuits. A simplified block diagram of the principal equipment units of the system is shown in Fig. 7. It will be noted that in general there are three types of equipment units:

1. The transmission battery supply and supervisory circuits consisting of the "district junctors" and the "incoming trunks."
2. The crossbar switch frames.
3. The common "control" circuits, the "senders" and the "markers."

The "district junctor" and the "incoming trunk" circuits are composed principally of small relays. The district junctors furnish the talking battery for the calling subscribers and supervise the originating end of connections. The incoming trunks control the ringing of the called subscriber bells, furnish talking battery for the called subscribers, and supervise the terminating end of connections.

The switch frames, which consist almost entirely of crossbar switches, provide the means for switching between the subscriber lines, the district junctors and the incoming trunks. Switch frames also are used for switching the district junctors and the incoming trunks to the senders.

The "senders" consist principally of small relays and their functions are similar to those of the operators at a manual switchboard. The "subscriber senders" register the called numbers from the subscriber dials and transmit the necessary information to the "markers," to the "terminating senders" and to the manual operator positions in manual offices for completing connections to the called lines. The subscriber senders also control the operation of the selectors in distant panel offices. The "terminating senders" in the terminating end of the crossbar office receive the numerical digits of the called numbers from the subscriber senders of any dial office and transmit the required information to the "terminating markers" for setting up the connections to the called lines.

The "markers" are the most important control circuits in the system. They are composed of both small and multi-contact relays. There are two types, one for originating traffic and one for terminating traffic. The operating time of the markers is short, considerably less than one second, and consequently only three or four markers of each type are required in the average office.

The "originating markers" determine the proper trunk routes to the called office. They have access to all outgoing trunk circuits and all the crossbar switch frames that are used for establishing the connections to the called office trunks. They test the trunk group to find an idle trunk to the called office, and also test and find an idle channel through the switch frames, and finally operate the proper selecting and holding magnets of the crossbar switches to establish the connections from the subscriber line to the trunk circuit.

The "terminating markers" perform similar functions in the terminating end of the office to set up the connection from the incoming trunk circuit to the called subscriber line. They have access to all of the subscriber lines terminating in the office, and to all crossbar switch frames used for connecting to subscriber lines. They test the called line to determine whether it is idle, and also test for and find an idle channel through the switch frames and finally operate the proper magnets of the crossbar switches and establish the connection to the called subscriber line.

In addition there are common "control" circuits associated with the "line link" and the "sender link" frames for controlling the operation of the switches on these frames. There are also the common "connector" circuits, consisting mainly of multi-contact relays, which are used for connecting the markers to the senders, to the switch frames and to the test terminals of the called subscriber lines.

It should be noted that the line link frames, although shown separately, are used for both originating and terminating traffic.

After the talking connection has been established between two subscribers, all of the common control units, such as the senders, markers, connectors, line link control circuit, and the sender link frames and their associated control circuits, will have been released, and the talking connection will be maintained in this condition by the holding magnets of the crossbar switches used on the line link, district, office and incoming link switch frames. These switch magnets are held operated under control of the supervisory relays in the district junctor and the incoming trunk circuits and are released when the subscribers replace the receivers.

Trunking Arrangements

The fundamental method of using the crossbar switch for setting up connections is illustrated in Fig. 8. This figure shows a 200-point crossbar switch with twenty vertical units each wired to a subscriber line and ten trunks strapped horizontally across the switch. With such an arrangement, any one of the twenty lines may be connected to any one of the ten trunks. The number of lines which can be connected to the same ten trunks may be increased to forty by adding a second 200-point crossbar switch with twenty different lines connected to its verticals and by wiring the horizontal contact multiple of this second switch to the horizontal multiple of the switch shown

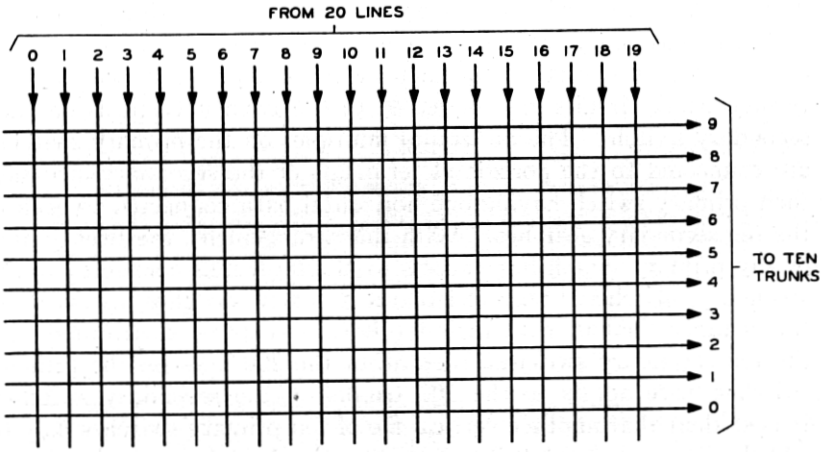

Fig. 8—Simple trunking arrangement with a single 200-point crossbar switch.

in Fig. 8. By adding other switches in this manner, any number of lines may be given access to the ten horizontal trunks.

To obtain greater trunking access, two groups of switches known as "primary" and "secondary" are used. Figure 9 illustrates this primary and secondary switch arrangement as used in the "line link" switch frames and in various forms throughout the crossbar office.

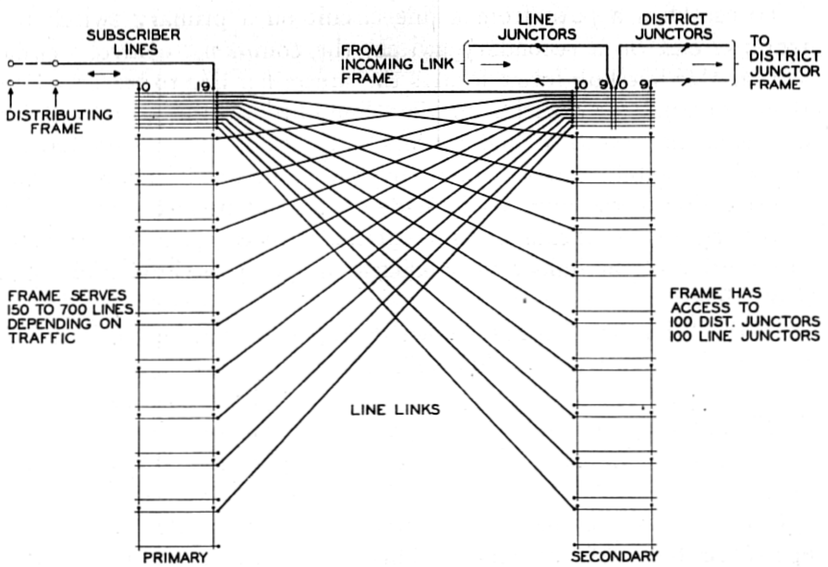

Fig. 9—Primary-secondary trunking arrangement.

The switches are arranged in two vertical files of ten primary switches and ten secondary switches. There are twenty subscriber lines connected to the verticals of each of the ten primary switches and twenty trunk circuits are connected to the twenty verticals on each secondary switch. The horizontal multiples on the primary switches are connected to the horizontal terminals of the secondary switches, each primary switch having one horizontal path connected to each of the ten secondary switches. With this arrangement, the twenty lines of any primary switch have access to all 200 trunks connected to the secondary switches. Since all of the primary switches are wired in this manner, that is, with their ten horizontal paths distributed over the ten secondary switches, then all of the 200 lines on the primary switches have access to the 200 trunks on the secondary switches. It is evident that another vertical file of ten primary switches may be added with twenty subscriber lines connected to the verticals of each switch, and with the horizontal paths strapped and connected to the horizontal paths of the primary switches shown. This would give 400 lines access to the 200 trunks on the secondary switches. In actual practice on a line link frame, several files of primary switches may be connected together in this manner depending upon the traffic volume of the subscriber lines. The circuit paths connecting the horizontal rows of terminals of the primary switches to the horizontal rows of terminals of the secondary switches are called "line links."

To establish a path from a line circuit on a primary switch to a trunk circuit on a secondary switch, the common "control" circuit serving this line link frame locates the subscriber line to be served and then simultaneously selects an idle "line link" on the primary switch on which the subscriber line appears and a group of trunks wired to a secondary switch in which there are one or more idle trunks. Thus the selection of the line link is made contingent upon the availability of trunks, and by means of this together with the primary-secondary distribution of the links a very efficient usage of the links and trunks is obtained.

In the "line link" frame shown in Fig. 9, it will be seen that the trunks on the verticals of the secondary switches are split into groups of 100 trunks each, one group being connected to the "district junctors" and used for originating traffic and the other group of 100 trunks being connected to "line junctors" and used for terminating traffic.

It will be noticed that there is but one crossbar switch appearance of a subscriber line in the office. This is on a vertical unit of a primary crossbar switch where both the originating and terminating calls are

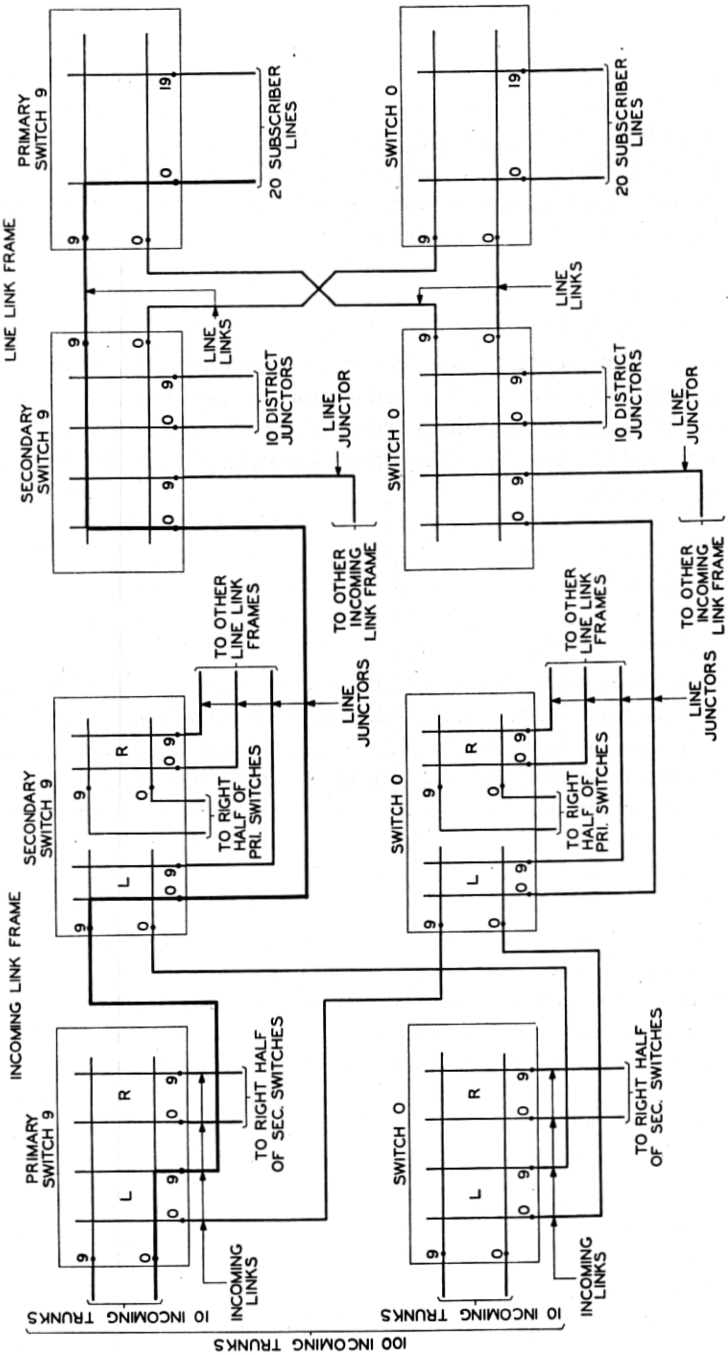

Fig. 10—Double primary-secondary trunking arrangement.

completed by means of the same line link circuits. Thus all originating traffic from any of the twenty lines on any primary switch flows through the associated ten line links to the 100 district junctors and all terminating traffic to these twenty lines flows through the same ten line links from the 100 line junctors.

This single "primary and secondary" trunking arrangement also is used at other points in the system, such as in the originating and terminating sender link switch frames, where the circuits reached are non-directional, that is, where any one of the selectable circuits wired to the frame can be used for setting up a connection.

For the switch frames where the circuits reached are directional, that is, where a particular called line or a particular group of trunks must be used in order to complete a connection, the problem of trunking becomes more complex and it is necessary to provide a trunking arrangement using two "primary and secondary" switch frames arranged in tandem.

Figure 10 shows a typical arrangement of this kind which is necessary to secure the required trunking flexibility and efficiency. This figure shows an "incoming link" frame to which incoming trunks are connected and a "line link" frame to which subscriber lines are connected as described above. These two frames are used in tandem for establishing the terminating connections between the incoming trunks and the called subscriber lines. As is indicated, 100 incoming trunks are connected to the 100 horizontal paths of the ten incoming link frame primary switches, there being ten incoming trunks connected to each of the primary switches. A total of 150 to 700 subscriber lines may appear on the verticals of the primary switches of the line link frame; however, only 200 lines or twenty on the verticals of each of the ten primary switches are shown in the figure.

In order to connect a particular incoming trunk to a particular called line, an idle channel is selected through these two switch frames, consisting of an "incoming link" on the incoming link frame, a "line junctor" between the two frames and a "line link" on the line link frame, and all are connected in series as shown in the figure. It will be noted that the incoming trunks on each of the primary switches have access to twenty incoming links appearing on the twenty verticals of the switch. These twenty incoming links are distributed over the ten secondary switches of the frame, two links being connected to each switch, one to each half switch. It will be observed that in order to provide for the distribution of the twenty incoming links over the ten secondary switches, the horizontal paths of the secondary switches are separated between the tenth and eleventh verticals, thus taking advantage of the flexibility of the crossbar switch by providing twenty horizontal paths instead of ten on each switch. The incoming links, on each half of these secondary switches, have access to "line junctors" appearing on the verticals of these switches. These line junctors are in turn distributed over the secondary switches of all the line link frames in the office. There will be at least one line junctor as shown, from each secondary switch on an incoming link frame to a secondary switch on every line link frame in the office, or a minimum of ten line junctor paths between any incoming link frame and any line link frame. The number of the line junctors between these frames will vary depending upon the number of frames required in an office. The line junctors on the verticals of each of the line link frame secondary switches in turn have access to ten line links on the horizontal paths. These ten line links are, as described above, distributed over the primary switches of the line link frame, one to each primary switch. These line links then have access to the called subscriber lines which appear on the verticals of the primary switches. With this arrangement of switches and the three groups of interconnecting link paths, any incoming trunk can be connected to any called line on the line link frame shown, or by means of other groups of line junctors, to a called line on any other line link frame in the office.

Terminating markers are employed for selecting the paths through these switches to connect an incoming trunk to a called subscriber line. The marker, as will be explained later, records information which permits it to connect to the test wire and holding magnet of a called line and to the test wires and switch magnets of the groups of incoming links, line junctors and line links through which the incoming trunk may be connected to the called line. The marker simultaneously tests these three groups of paths and "marks" an incoming link, a line junctor and a line link which are idle and are accessible to one another, and then operates the switch magnets to connect these three paths and the incoming trunk and the called line together. The paths are selected in an ordered arrangement, so that the lowest numbered incoming links, line junctors and line links are preferred and are used as long as they are available. This increases the efficiency of the paths as compared with a random selection, since it reduces the chance that one or two of them although idle cannot be used because the third one is busy.

A double primary and secondary trunk arrangement similar to the one shown in Fig. 10 is employed for connecting district junctors to outgoing trunks in the originating end of the office.

Brief Description of Circuit Operation

The operation of the system will be described by tracing the progress of a call through the system. The establishment of a call from one crossbar subscriber to another crossbar subscriber may be divided into four stages: two in the originating end of a connection and two in the terminating end.

1. The calling subscriber is connected to a sender for the purpose of registering the called number which is dialed.

2. The subscriber sender is connected to an originating marker and the marker selects the switch frames for establishing the connection to an outgoing trunk.

3. The outgoing trunk circuit is connected to a sender in the terminating end to register the called number.

4. The terminating sender is connected to a terminating marker and the marker selects the switch frames for establishing the connection to the called subscriber line.

The first stage in the progress of a call is illustrated in Fig. 11. It will be seen that the line of a calling subscriber terminates on a vertical unit of a primary crossbar switch located on a line link switch frame. When the subscriber receiver is lifted from the telephone preparatory to dialing, a line relay is operated, as in other systems, and the circuits proceed with the establishment of the connection to an idle subscriber sender which will register the called number when it is dialed.

The circuit functions on this stage of the call are as follows:

1. The subscriber line is located by the "line link control" circuit which is common to the line link frame, by a coordinate method of testing. That is, the control circuit determines the primary crossbar switch in which the line is located and the particular vertical unit in the switch on which the line is terminated. This operation is similar to the line finder operation in other dial systems, except that the operation is accomplished by relay operations instead of by a mechanically traveling brush.

2. The line link control circuit then simultaneously selects an idle line link between the primary switch in which the line appears, and a secondary switch on which a group of district junctors appears which has at least one idle district junctor in the group and which has access to idle senders and an idle sender link.

3. This will bring into operation the common "sender link control" circuit of the sender link switch frame to which the selected group of district junctors is connected. This control circuit will select an idle district junctor in this group which appears on a primary switch on

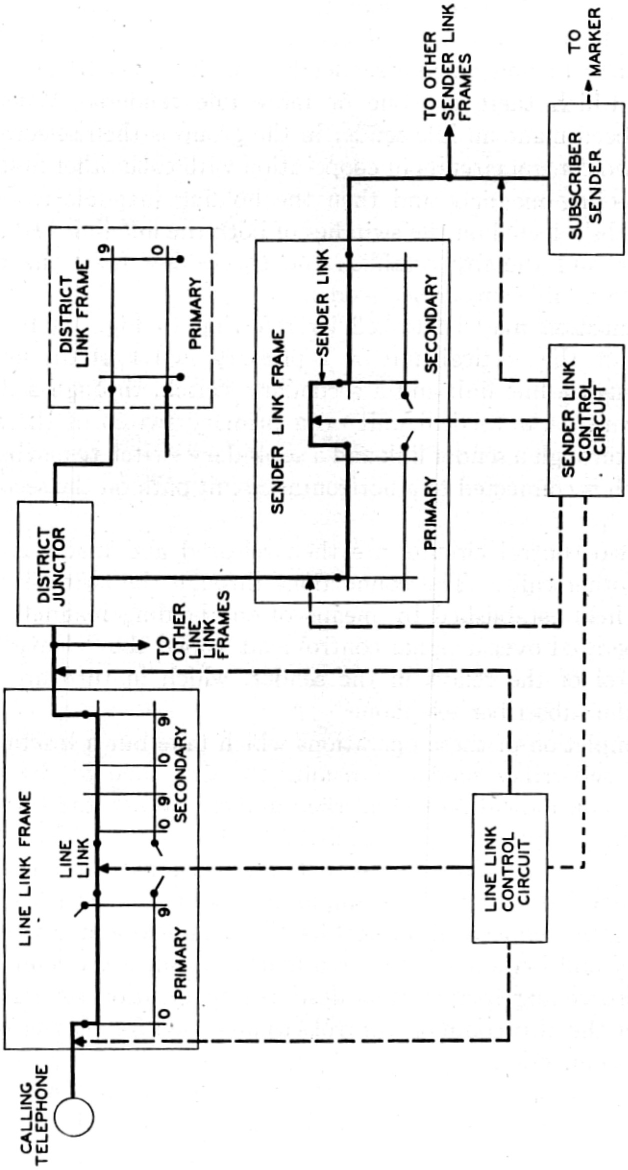

Fig. 11—Calling line connected to district junctor and subscriber sender.

the sender link frame. There are ten sender links serving the selected district junctor. These ten sender links and the ten sender groups to which they have access on the secondary switches are then tested simultaneously to find an idle sender link with access to a group of senders in which there are one or more idle senders. When this choice has been made an idle sender in the group is then selected.

4. The two control circuits in cooperation with each other first operate the selecting magnets and then the holding magnets associated with the paths selected on the switches of both the line link and sender link frames, and thereby establish the connection from the calling subscriber to an idle subscriber sender.

This connection may be traced by referring to Fig. 11, from the calling line on the vertical unit on a primary switch of the line link frame, through a line link and a secondary switch, through a district junctor circuit, to a vertical unit on a primary switch of the sender link frame, through a sender link and a secondary switch to a subscriber sender which is connected to a horizontal circuit path on the secondary switch.

5. The two control circuits are then released and made available for use on other calls. The connections through the switches to the sender are held established by means of the holding magnets which are held operated over a signal control lead, called the "sleeve" lead, under control of the relays in the sender, which in turn are under control of the subscriber telephone.

Upon completion of these operations which take but a fraction of a second the subscriber sender transmits the dial tone to the calling subscriber as an indication to dial the number. When the subscriber dials, electrical impulses are transmitted to the sender, which receives and registers them. When the sender has registered the office code, which in New York City for example is contained in the first three digits dialed, the sender will connect itself to an idle originating marker by means of multi-contact relays of a marker connector circuit.

Before proceeding further it is desirable to mention several other functions of the two common control circuits used for setting up this part of the connection.

1. The control circuits signal to the sender the class of the calling line, that is, for example, whether the line is a coin line or a non-coin line.

2. The sender link control circuit signals to the sender the number of the district link switch frame on which the selected district junctor appears, since this identification will be used later in the establishment of the connection.

3. The sender link control circuit tests the circuit paths chosen from the line circuit to the sender before disconnecting from the connection, in order to insure the proper establishment of the connection. In case of a failure the control circuits will make repeated trials to establish the connection over different paths and give an alarm to the maintenance force.

4. Emergency control circuits are provided for use in case the regular control circuits are removed from service for maintenance reasons.

The next stage in the progress of the call is illustrated in Fig. 12. In this stage of the call the principal control unit is the originating marker. Its major function is to control the switches in the establishment of the connection to an idle outgoing trunk circuit to the called office, which may terminate in a distant office or in the same office as the calling subscriber.

When the subscriber sender connects to the originating marker through the connector circuit, the sender transfers the called office code indication and the district link frame identification to the marker circuit. The called office code indication causes the operation of a "route" relay in the marker corresponding to the particular office called.

There are a number of "route" relays in each marker and one is assigned to each called office routing. The route relay is connected as required by the office code to which it is assigned, so that it will direct the marker to the trunks of the called office and to the office link switch frame on which these trunks appear and indicate the number of trunks in the group. The route relay also is connected to determine the type of the called office, such as Crossbar, Panel, or Manual, and to set up the corresponding circuit conditions in the subscriber sender to enable the sender to handle the connection properly after the marker has been released. The connections of the route relay contacts to the control relays in the marker are made flexible so as to permit the assignment of any route relay to any office code and to permit changes to be made from time to time in the route information, changes in trunk group sizes and location, changes in the type of terminating office, etc. The route relays and associated flexible connection facilities represent a considerable portion of the marker equipment, especially in large metropolitan offices where several hundred central offices are involved.

When the route relay is operated, the marker proceeds with the establishment of the connection as follows:

1. It connects to the office link frame on which the trunks to the

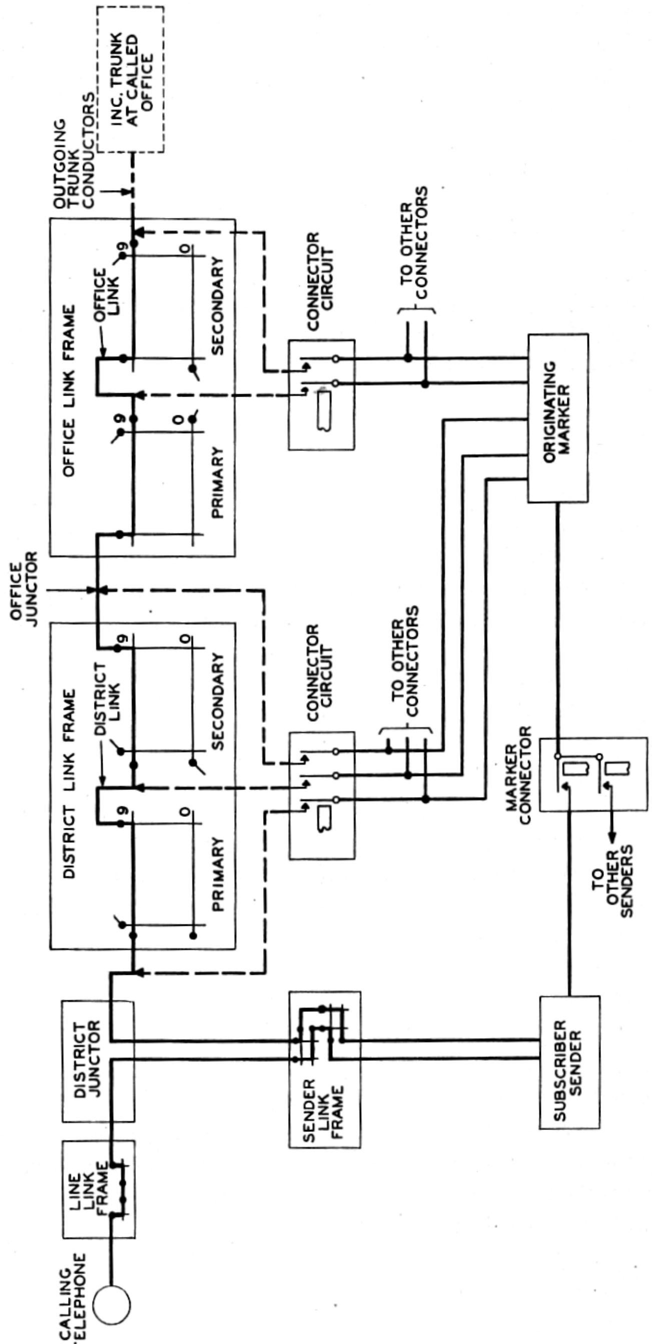

Fig. 12—District junctor and subscriber sender connected to the outgoing trunk.

called office appear. This connection is made through the office link frame connector circuit, one of which is provided for each office link frame. Through this connector the marker is extended to the test leads of any desired trunk group on the office link frame and to the crossbar switches of the frame. When so connected the marker has exclusive control of the trunks and switches of the frame and other markers which desire connection to the same frame are deprived of access until the connected marker releases.

2. The marker next tests the outgoing trunks to the called office and selects an idle one. If, as determined from the route relay, the trunks are divided over more than one frame, the marker will connect to the second group of trunks on the second office link frame in case the first group of trunks is found to be busy.

3. The marker also connects by means of a connector circuit to the district link frame associated with the district junctor to which the calling line is connected. The identification of this frame was obtained from the sender and the sender link control circuit as previously mentioned. Through the connector circuit of the district link frame the marker is extended to the control leads of the district junctor circuit and the crossbar switches of the district link frame. As in the case of the office link frame, only one marker is connected to a frame at a time.

4. The marker after selecting an idle trunk circuit which appears in a horizontal circuit path on one of the secondary switches of the office link frame, then proceeds with the selection of an idle channel through the switches of the two switch frames. A number of these connecting channels is provided between the district junctor and the outgoing trunk. Each channel consists of a "district link" on the district link frame, of an "office link" on the office link frame, and an "office junctor" connecting the district link frame to the office link frame. The marker tests a group of these channels simultaneously and selects an idle one. It then operates the switch magnets which will connect these three paths of a channel, and the district junctor and the outgoing trunk together, thereby establishing a connection from the district junctor to the outgoing trunk.

5. When the marker has completed this operation it checks the connection to insure that it has been properly established and that it is capable of being held under control of the district junctor, before releasing itself from the connection.

6. The marker performs these functions in approximately .5 second, then releases and becomes available for use on other calls.

It will be observed that the three links involved in establishing the connections between the district junctors and the outgoing trunks are used in series and are chosen simultaneously. Generally in other systems the establishment of a connection involving three such paths, is made in three successive stages with a possibility that after a selection has been made at one stage it will be found that the paths accessible to it are all busy and, therefore, the connection cannot be completed.

Before describing the next stage in the establishment of a call, it is desirable to point out other features and functions of the originating marker.

1. The marker permits wide variations in the sizes of trunk groups, permitting trunk groups as small as two and as large groups as may be required. This makes for an efficient use of the office link frame terminals and thereby tends to reduce the office link frame equipment.

2. The marker makes a second trial to establish connections over alternate trunk routes in case calls cannot be completed over the normally used groups because of busy conditions.

3. The marker makes a continuity test of the circuits over which the switches are controlled and tests them for short-circuits, crosses, opens and grounds which would interfere with the proper establishment of a call and where troubles are detected, it signals this condition to a common "trouble indicator" where an indication of the trouble and its location is recorded and a maintenance alarm given. The call is then completed over another group of circuits.

The first stage in the progress of the call through the terminating end of a crossbar office is illustrated in Fig. 13. It consists of connecting the incoming end of the selected trunk to a terminating sender for the purpose of receiving the number of the called line from the subscriber sender.

When the incoming trunk is selected by the originating end of the office equipment, the "sender link control" circuit associated with the terminating sender link frame on which the incoming trunk appears, is called into action. The control circuit then proceeds with the following functions:

1. To locate the incoming trunk circuit, which appears on one of the ten horizontal paths of a primary switch.

2. It selects an idle sender link between this primary switch and a secondary switch on which there is an idle terminating sender.

3. The control circuit selects one of the idle terminating senders reached through the secondary switch and then operates the selecting and holding magnets associated with the selected circuits, which will establish the connection from the incoming trunk to the terminating sender.

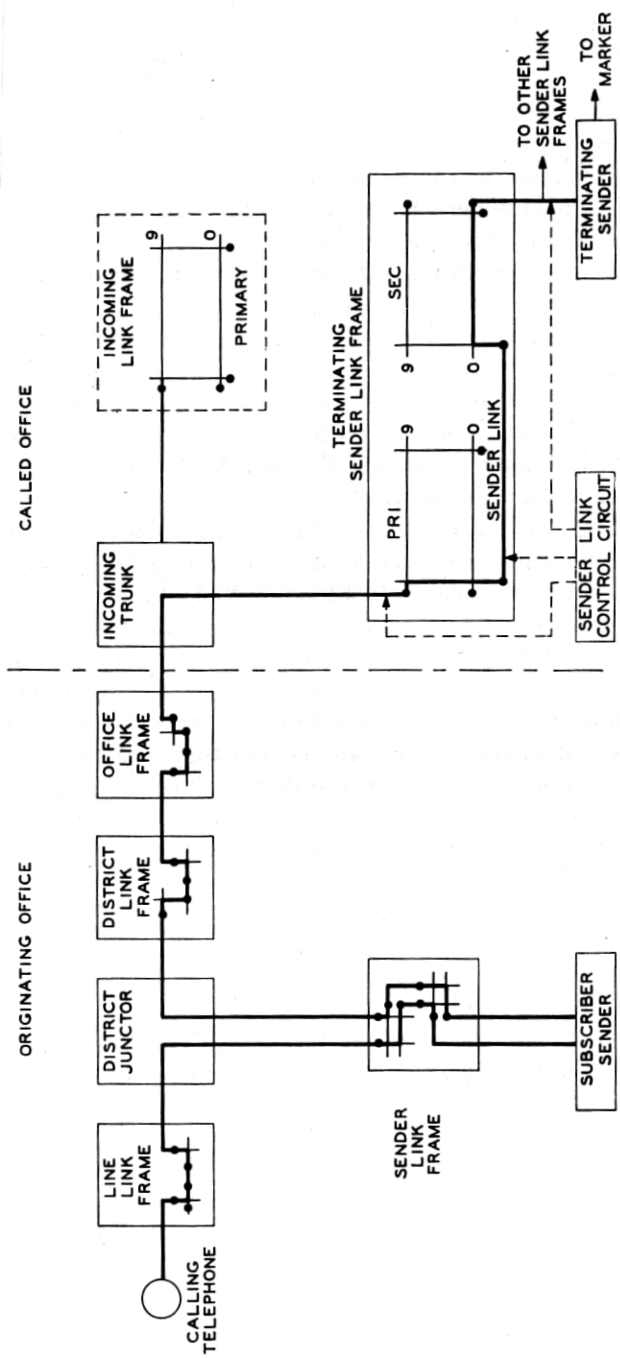

Fig. 13—Connection established to terminating sender.

4. The control circuit will signal to the terminating sender the number of the incoming link frame in which the incoming trunk appears. This frame identification will be used later in establishing the connection to the called line.

5. The control circuit will then disconnect after checking to insure that the connection to the sender has been properly established and that it will be held under control of the trunk and sender circuits after the control circuit leaves the connection.

As soon as this operation has been completed, which takes but a fraction of a second, the terminating sender will be in direct connection with the subscriber sender in the originating end of the connection. This path may be traced, by referring to Fig. 13, from the subscriber sender through the sender link frame, through the district junctor, through the district link and office link frames, over the outgoing trunk to the incoming trunk, and through the terminating sender link frame to the terminating sender.

At this stage of the connection the calling subscriber is still connected with the subscriber sender, and dialing may be still in progress. As the subscriber proceeds with the dialing of the digits of the called number, the subscriber sender will transfer them to the terminating sender. This is done by means of impulses transmitted over the circuit paths between the two senders. When the subscriber sender has completed the transfer of the called number to the terminating sender, the subscriber sender will be released and the calling line will then be connected through the district junctor to the incoming trunk.

When the terminating sender has secured the record of the called line number, the sender then connects to an idle terminating marker by means of multi-contact relays of a connector circuit.

The next stage in the progress of the call is shown in Fig. 14. The terminating marker is the principal control unit at this point in the connection. Its principal function is to provide means for establishing the connection from the incoming trunk to the called subscriber line.

When the terminating sender has connected to the terminating marker, the sender will transfer both the called line number and the incoming link frame identification to the marker. The terminating marker then proceeds to establish the connection to the called line as follows:

1. It connects itself to the particular "number group connector" circuit including the "block relay" frame in which the called line appears in its numerical sequence. All subscriber lines are provided with a set of three test terminals which appear on the block relay

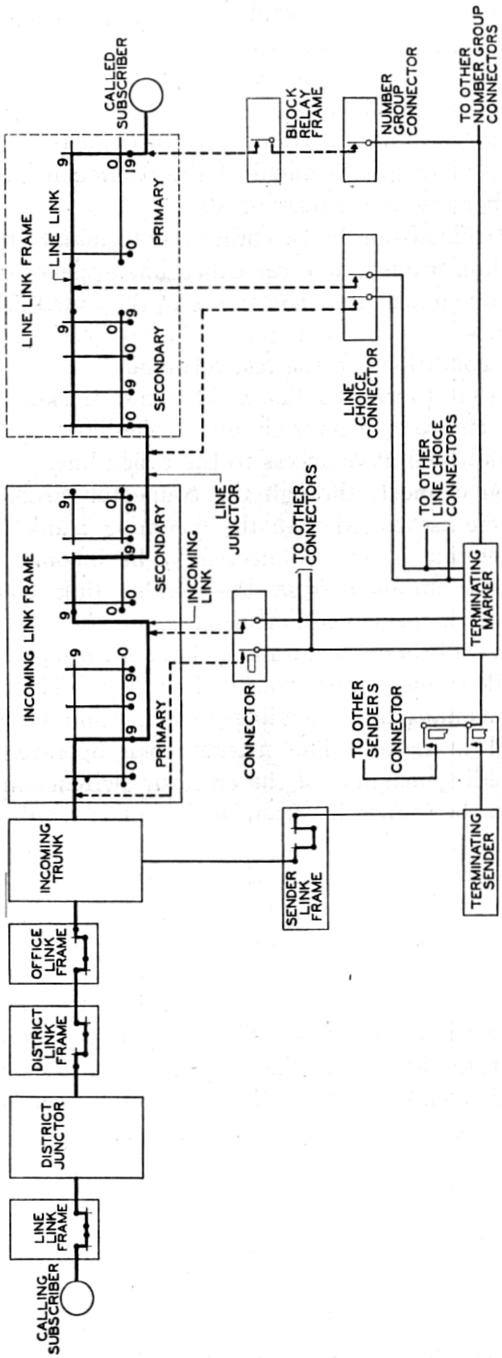

Fig. 14—Connection established to called line.

frame. These terminals correspond to the director number of the subscriber line. A number group connector generally has access to the test terminals of several hundred line numbers depending on the terminating traffic to the lines.

2. The marker will obtain a connection through the number group connector to the busy test terminal of the particular called line and determine whether the line is busy or idle.

3. It will determine from the two other test terminals, the identification of the line link frame where the called line appears, and the horizontal group of line links which has access to the called line. In addition, it determines the type of ringing to be applied to the called line from the circuit conditions on the test terminal.

4. Assuming that the called line is idle, the marker will connect, through the line choice connector circuit, to the line link frame and to the ten line links which have access to the called line.

5. It will then connect, through the connector circuit, to the incoming link frame associated with the incoming trunk to which the calling subscriber line is now connected. The incoming link frame identification was obtained from the sender link control circuit through the sender as previously mentioned.

6. The marker will then select an idle channel through the incoming link and line link frames as previously described. This channel will consist of an "incoming link," a "line junctor," and a "line link" all to be connected in series. The marker then operates the proper selecting and holding magnets of the crossbar switches in each frame which establishes the connection from the incoming trunk to the called subscriber line.

7. The marker will then cause the incoming trunk to start the proper ringing over the called subscriber line and to transmit the ringing tone signal over the trunk to the calling subscriber.

8. At this point the terminating marker and the terminating sender will have completed their functions and, together with the terminating sender link frame, will be released. The complete connection will then be established from the calling line to the called line and the conversational circuit completed when the called subscriber answers.

If the terminating marker finds the called line busy it will cause the incoming trunk circuit to transmit a busy tone to the called subscriber.

The terminating marker has the following other important functions:

1. If the call is for a PBX (Private Branch Exchange) the condition on one of the test terminals of the called line in the number group connector will inform the marker that the line is one of a group of lines. The marker will test all of the lines in the group, testing up to as many as twenty simultaneously, and will select an idle one.

The lines of a PBX may be assigned to non-consecutive numbers within the usual 10,000 series, and with the exception of the numbers dialed, they may be assigned to line numbers in a special group of 2500 outside of the 10,000 series. These features reduce the necessity for number changes due to the growth of private branch exchanges, and conserve subscriber line numbers in the office. The lines of a PBX group can be distributed over several line link frames and over two number group connectors to equalize the terminating traffic load n the case of busy private branch exchanges.

2. The marker recognizes numbers dialed which are unassigned, disconnected or changed numbers, and automatically routes such calls to an operator who will inform the calling subscribers as to the status of the numbers called.

3. In case the called number is on a party line, the marker determines from one of the test terminals which station of the line is to be rung, and signals the incoming trunk to provide the proper ringing.

4. The marker tests the continuity of the circuit paths to be used to the called line before establishing the connection, to insure that the connection is properly set up and that it will be held under control of the subscriber telephone after the marker disconnects. The marker also tests for short-circuits, crosses and grounds, and in case of a failure due to any inoperative condition it will connect itself to the common trouble indicator and leave a record of the trouble and its location and give an alarm to the maintenance force.

Figure 15 shows the complete talking connection through the various trunks and switch frames as finally established after all of the common control circuits have been released.

On a call to a subscriber served by a panel dial office, the connection is routed through the district link and the office link frames in the same manner as on a call terminating in a crossbar office, but in this case the idle trunk chosen on the office link frame terminates in an incoming panel switch in the distant panel dial office. The subscriber sender of the crossbar office causes the incoming and final selectors in the terminating panel office to select the called subscriber line without the aid of any terminating senders in either office. When the subscriber sender has completed these functions it will be released and the connection will be established from the calling line over the inter-office trunk circuit and through the terminating panel incoming and final selectors to the called line. On this type of call the subscriber sender operates in the same manner as though the called line were in a crossbar office, and the selectors in the panel office operate in the same manner as though the call had originated in another panel office.

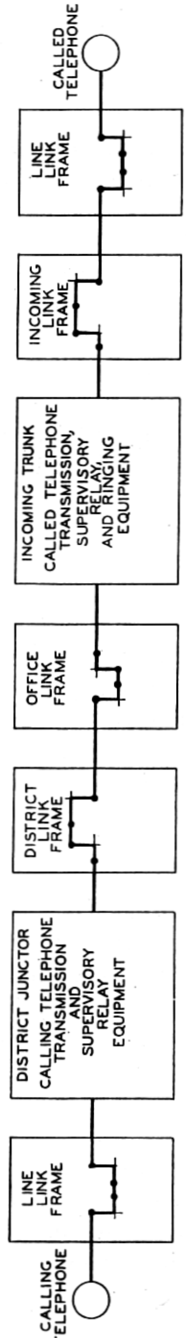

Fig. 15—Completed talking connection.

No changes are required in the panel selectors to function with the crossbar office.

On a call for a subscriber in a manual office, the call would be routed through the switches of the district link and the office link frames as previously described and connected to a trunk circuit on the office link frame which terminates in the "B" switchboard in the manual office. The subscriber sender of the crossbar office then transfers the called number by impulses transmitted over the interoffice trunk circuit to the operator's position equipment in the manual office. The called number appears in the form of visible numbers on the operator's keyshelf. The operator completes the connection by "plugging" the associated trunk circuit, which terminates on a cord and plug, into the called subscriber line jack.

A call originating in a panel dial office for a subscriber line in a crossbar office reaches the crossbar office through an incoming trunk circuit as in the case where the call originated in a crossbar office. The call from the panel office is then handled by the crossbar office terminating sender and marker in exactly the same manner as described for calls originating in the same crossbar office.

A call originating in a manual office for a line connected to the crossbar office reaches the crossbar office over an incoming trunk circuit from an "A" operator's position in the manual office. These incoming trunks in the crossbar office are similar to the incoming trunks previously described. In this case, however, the incoming trunk is connected to a terminating "B" sender and by means of this sender to a "B" board operator in the crossbar office. The "B" operator will obtain the called number verbally from the distant "A" operator and then, by means of the keyset on her position, register the called number in the terminating sender. The terminating sender will then select a terminating marker and the connection will be established in exactly the same manner as described for a call originating in a crossbar office.

Maintenance Facilities

Automatic routine testing circuits are provided for testing all the principal circuit units, such as the district junctors, incoming trunks and senders. These test circuits automatically put each circuit, one after the other, through all of its functions on all classes of calls to insure that it performs satisfactorily. It tests the important relays of the circuits to insure that they have the proper adjustment to handle the worst circuit conditions. In case any circuit fails to meet the test conditions, the test is stopped and an alarm given to the maintenance force.

Trouble indicator circuits are provided for use in connection with the test and maintenance of the marker circuits. These circuits are arranged so that when trouble is encountered by a marker, the marker will seize the trouble indicator and operate combinations of relays and light small lamps which indicate the nature and the location of the failure and give an alarm to the maintenance force.

Equipment

Figure 16 shows a typical switch frame used in the crossbar system. This particular frame is a "line link" frame which serves a group of subscribers for both originating and terminating traffic. The frameworks on which the equipment is mounted are constructed of rolled

Fig. 16—Line link frame.

bulb angle iron sections with a sheet metal base. The bulb angle construction provides a framework which is light in weight and has the required strength, and permits an equipment mounting arrangement which conserves space and facilitates the wiring of the apparatus. The frames are welded and incorporate such features as sanitary base construction, guards to protect the apparatus and wiring against damage from the rolling ladders located between the rows of frames, and a cable duct or runway for the A.-C. power service cables with plug receptacle outlets for use with electric soldering irons, portable lights, etc.

These frame equipments are built in standardized units, which provide the required flexibility to satisfy the variations in telephone traffic and classes of service encountered in the different telephone areas. Where it has been necessary to divide an equipment assembly into several units, due to the limitations of handling, shipping and to care for different classes of service, the equipments have been designed so that the installation effort required for interconnecting such units has been reduced to a minimum.

The bays of equipment located at the right, in Fig. 16, equipped with crossbar switches, are the primary line link bays. The vertical units of these crossbar switches are wired to the subscriber lines. These primary bays are made available in units of 100 and 200-line capacities. As discussed previously the number of primary bays provided in a line link frame may be varied to fit the traffic load of the subscriber lines. The left-hand bay of this frame contains the vertical file of crossbar switches, known as the secondary switches and the vertical units of these switches are wired to district junctors and line junctors. The line link control circuit apparatus, which is common to the frame, is located at the bottom of this bay.

Figure 17 shows a group of three frame units, namely, the subscriber sender link, the district junctor and the district link frames, which are closely associated in the trunking network and have been designed as a fixed equipment group. However, for shipping reasons the group is divided into three separate equipment units. The district junctor circuits, consisting primarily of relays, are mounted in groups on the middle frame. These groups are provided in standardized units of various types, such as those required to serve coin and non-coin subscribers lines. A similar arrangement of frames is used for the combination of terminating sender link, the incoming trunk, and the incoming link frames.

Figure 18 shows a row of subscriber sender frames and a frame of "A" operator senders located at the extreme right. These frames

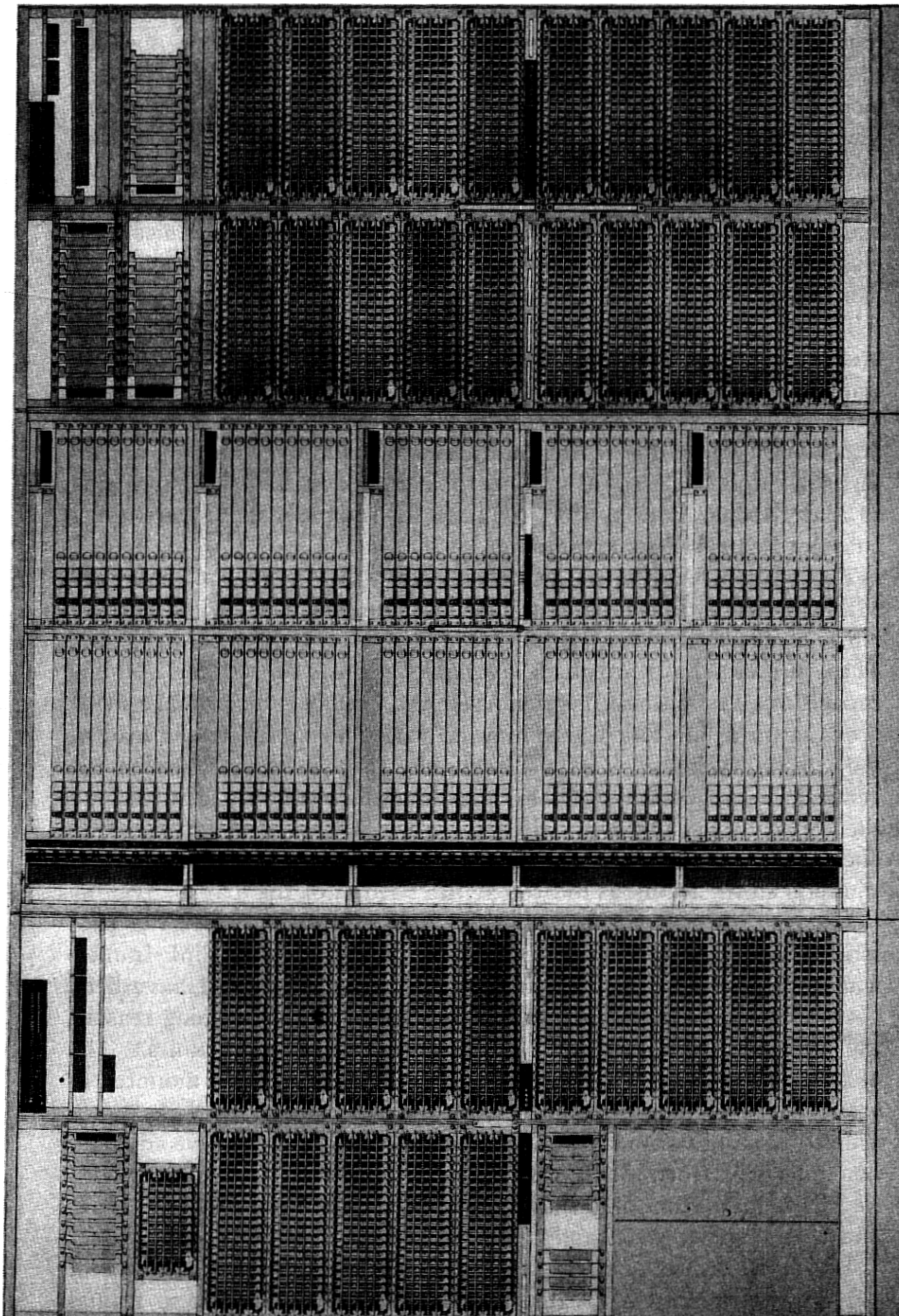

Fig. 17—Three-frame assembly of district junctor, district link and sender link frames.

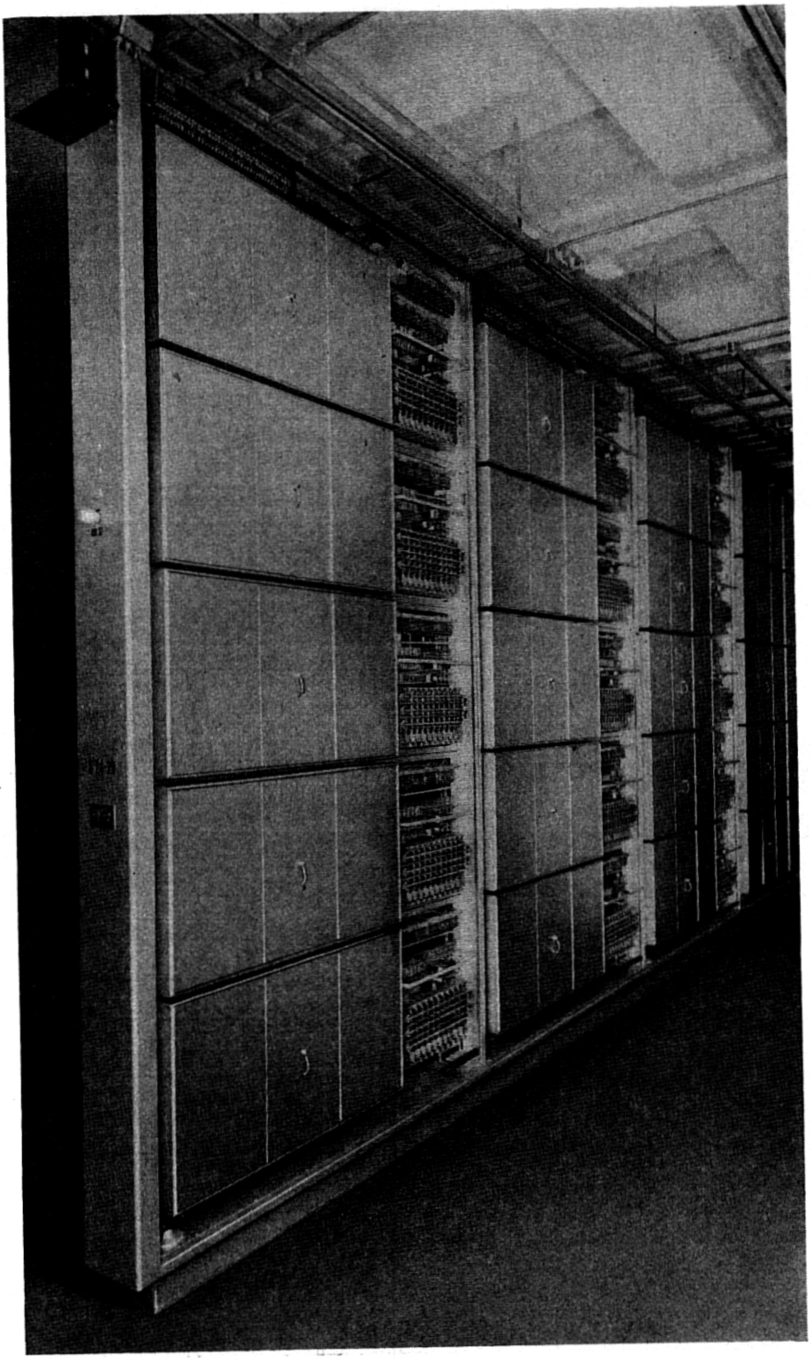

Fig. 18—Sender frames.

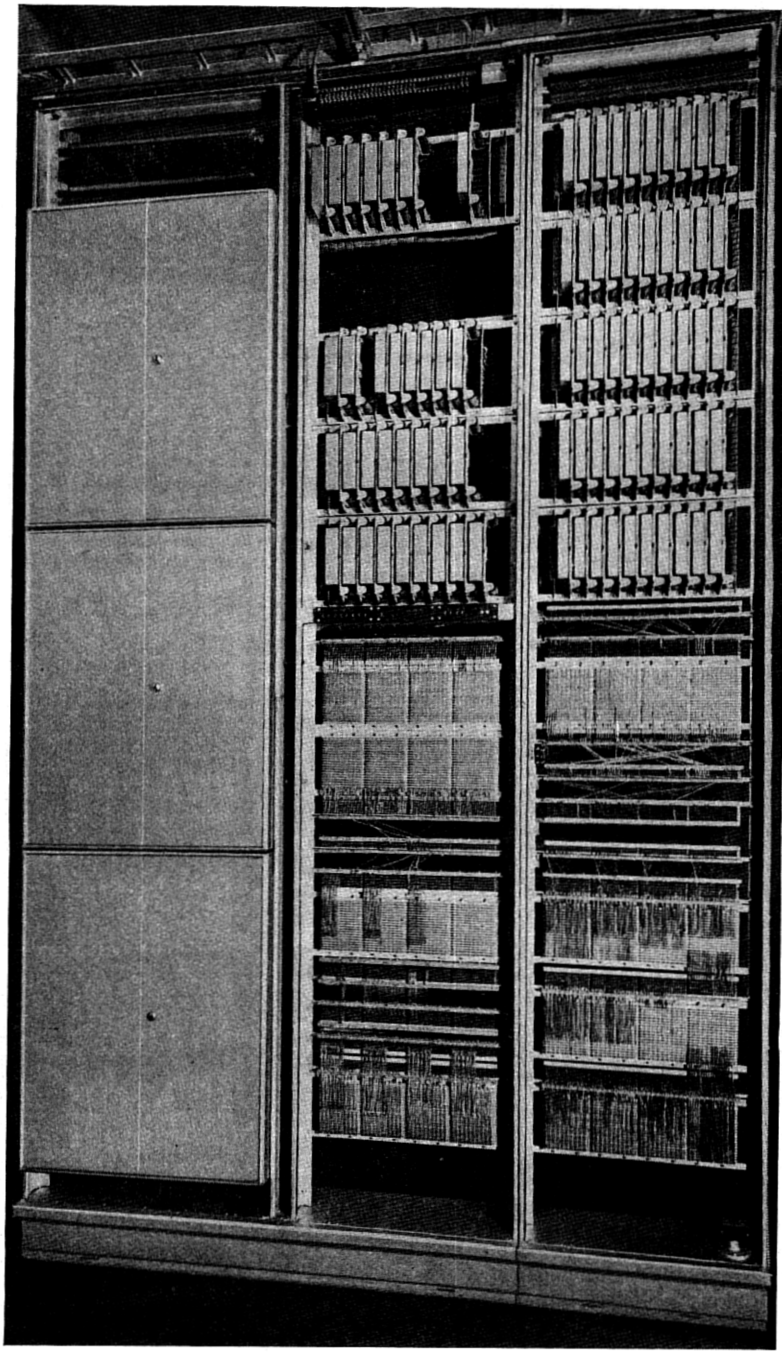

Fig. 19—Originating marker frame.

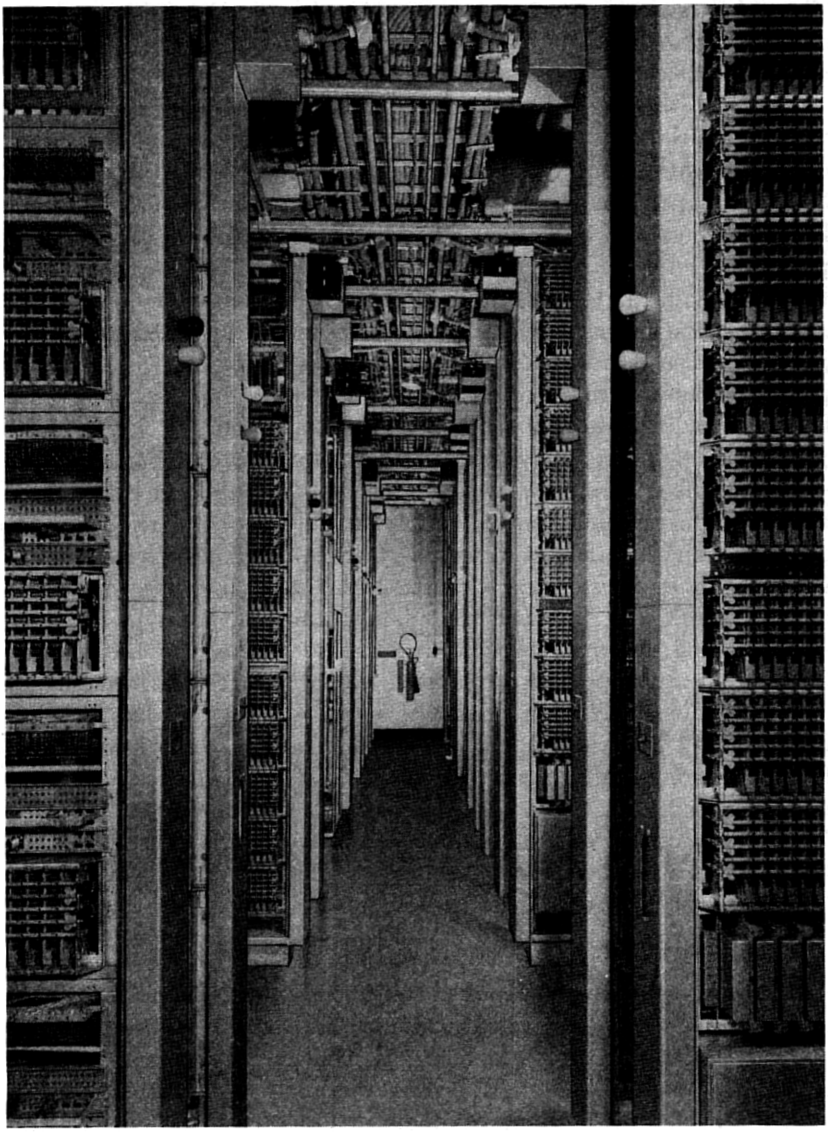

Fig. 20—Battery supply feeders, power wiring, fusing, etc.

accommodate five senders which may be of one type, or a combination of both types. The crossbar switch shown on the right of each subscriber sender unit, is a part of the sender circuit and is employed for the purpose of registering the called numbers dialed by the subscribers.

The "A" operator senders are associated with the "A" operator switchboard equipment and are used for the completion of certain classes of calls such as toll and assistance calls.

A view of the originating marker frame is shown in Fig. 19. There will be a variation in the equipment on this frame for different cities due to the variation in the number of route relays required, the number depending upon the number of central office codes that may be dialed by subscribers and operators. This variable feature is cared for by providing the route relay equipment in bays of 100 codes as shown in the right-hand bay. The terminal fields shown below the route relays on the frame provide the flexible connecting facilities which permit the use of any route relay for any office code and which readily permit changes in routings, variations in trunk group sizes and other features which are subject to change from time to time.

The power plant equipment provided for the crossbar offices is similar to the equipment now being furnished for all large dial central offices. The principal power supply arrangements provide 48-volt direct current for the operation of practically all the signaling and the telephone transmission circuits. Also several other sources of direct current are provided for miscellaneous purposes as in other standard dial systems. A new distribution scheme for the battery feeders on the frames is employed which reduces the amount of copper required. A common set of 48-volt battery feeders supplies the signaling and talking current for all frames. Individual frame filters are connected across the battery supply leads at the frames where a noise-free battery supply is required for talking circuits. Figure 20 shows a view of the overhead battery cables, conduits for the A.-C. power leads, and the fuse cabinets for the fusing of the battery supply to a row of frames.

Application

As mentioned in the first part of this paper, two crossbar dial central offices were cut into service in 1938 and these have now been in commercial operation for several months. One of these offices serves a residential area in Brooklyn, while the other serves a congested business area in the midtown Manhattan district of New York City. The operation of these offices under actual service conditions has been highly satisfactory and our expectations in regard to performance have been fully realized.

This type of system will be used for new offices in large cities instead of the panel system as rapidly as manufacturing and plant conditions permit and the apparatus which was designed for this system will be used in other fields of the telephone system.