A Telephone Switching Network and Its Electronic Controls

By S. T. BREWER and G. HECHT

(Manuscript received November 17, 1954)

A high-speed telephone switching network with electronic controls is described. The high speed allows one-at-a-time operation, reducing both the number and complexity of control circuits. Germanium diodes, transistors, cold-cathode tubes and fast relays perform the control functions; glass-sealed relay contacts provide paths for speech. A laboratory model of the network has performed reliably for over three years.

INTRODUCTION

In considering the value of speed in a telephone switching network, first let us take the subscriber's viewpoint. It is obvious that any increase in speed of establishing connections gives the subscriber better service. The actual improvement in service, however, turns out to be very modest. For example, if the subscriber saves a half second on each connection through the switching network, he saves one second over-all on the originating and terminating connections of a local call. With the present method of dailing, dialing time tends to obscure any saving in time due to a faster switching network.

Actually, the chief goal in seeking higher switching and control speeds is the reduction in the cost and complexity of the controls. This may be illustrated by citing an example from the present switching art. Consider a large No. 5 crossbar switching network. To handle the desired traffic, six markers may be required. Each marker is capable of controlling the switching network, but due to its low operating speed (and the slow speed of the network's crossbar switches), a single marker cannot establish all of the originating and terminating connections required during a busy hour. In addition to the duplication of markers, elaborate connectors are required so that various markers can be associated with different portions of the switching network. The markers and marker connectors furthermore require lockout protection so that two markers cannot attempt to control the same portion of the switching network at the same time.

Now consider a switching network and controls much faster than those presently used. Such a system could handle a 10,000-line central office on a "one-at-a-time basis" without requiring duplication of the controls. Thus, the connector problem is almost eliminated and there is no necessity for lockout among competing controls. The switching network and controls which we describe in this paper constitute a model of this type of high-speed system. In addition to reducing the system to one set of control circuits we have devised circuits which perform terminal selection and channel control functions in a greatly simplified fashion.

GENERAL OBJECTIVES

In any project such as this, certain general objectives are established at the outset. These objectives guide the designer in his choice of tools or devices and act as a framework within which the designer works. In our particular case, these general objectives were:

(a) Speed of network and controls should permit operation with one set of control circuits.

(b) The design should be based on a large central office carrying heavy traffic, specifically, an office with 10,000 subscribers and 2,000 trunks, and handling a total of 50,000 originating and terminating calls per busy hour.

(c) The control circuits should be active during 70 per cent or less of a busy hour. (This limit was set to avoid excessive delay in gaining access to the control circuits.)

(d) A minimum of maintenance should be required.

(e) Circuits should function reliably throughout a 40-year life.

(f) The switching network should operate with the present type of subscriber instrument and existing methods of ringing, dialing, and supervision.

(g) The switching network and controls should be incorporated in a functionally complete but skeletanized high speed telephone system to provide a practical working test of the system and all of its components.

DEVICES USED IN DESIGN

General objectives (a), (b), and (c) dictated that we use high-speed devices as the backbone of our design. From these objectives and the assumption that the controls are used twice on a particular connection (once to establish and once to release the connection), we calculate that

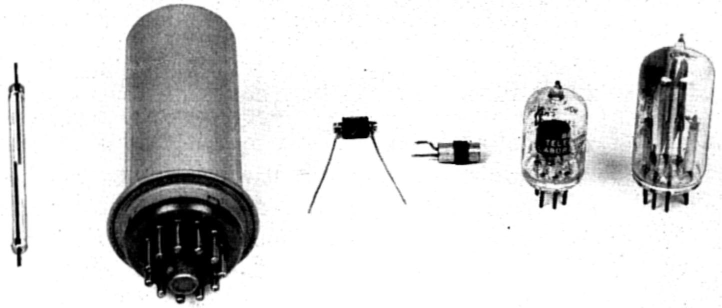


FIG. 1 — Typical high-speed devices used in design. From left to right: glass-sealed reed switch; mercury contact (3-transfer) relay, point contact germanium diode, point contact germanium transistor, cold-cathode diode, grid-controlled cold-cathode tetrode.

the maximum overall time for the connect and release operations is 50 milliseconds. Thus, crossbar switches and relays of conventional design are too slow to meet our minimum objectives. However, objective (f) indicated the use of a metallic path through the switching network. These objectives and objectives (d) and (e) regarding reliability and low maintenance led to the selection of the dry reed switch for use in the switching network. In control circuits subject to heavy use and requiring a metallic path, mercury contact relays were selected. Where circuits required electron tubes, cold cathode diodes, triodes, and tetrodes were used. These are simple and rugged and have the big advantage that they do not consume power or deteriorate during stand-by periods.

Germanium diodes were selected for the circuits performing code translation because they are simple and fast. Transistors were chosen for the channel selecting circuit. This choice was made to gain design and operating experience with a relatively new tool. The basic high speed devices used in our design are shown in Fig. 1.

GENERAL DESIGN CONSIDERATIONS

A high-speed switching circuit can be designed by one-to-one substitution of new devices in existing designs. In general, if the new devices are very much faster or different than the old, this method fails to take full advantage of the capabilities of the new tools. Hence, we have used the method of designing "from scratch." It is beyond the scope of this article to detail all of the advantages obtained by the second and more complete approach to design. However, a result which may be considered typical is the evolution of a new method of channel control which distinguishes the system.

THE SERIES MARKING METHOD OF CHANNEL CONTROL

The general philosophy behind the series marking method of channel control may be understood by comparing it with a present method. As an example of a present method, let us take that used in a four-stage No. 5 crossbar switching network. For a channel between a particular line and trunk to be useful its A, B, and C links must be idle. Leads associated with these links are carried through individual contacts on connector relays to each of the markers in the central office. In one marker, a channel testing relay performs a busy test on the A, B, and C links comprising each channel. Those channels which are found to be completely idle compete in a relay lockout circuit which selects one of the channels for use. This is what we call a parallel method of switching network control. It can be seen that every marker in the office requires individual access to each A, B, and C link of the switching network.

In the series marking method of control which we use, marking voltages are applied to the line and trunk. Enabling voltages are applied to the A and C links through high resistance. If a particular A or C link is associated with a busy path, the holding circuit, being low in impedance, will determine the link voltage and block the enabling signal. In this simple manner, busy paths are automatically isolated and excluded from the path marking operation. The voltage marks then extend fan-wise over idle paths from the selected line and trunk toward the center of the switching network. In the center of the switching network, these marks are passed through a connector relay to the mactors.* There, a simple coincidence circuit matches the voltage received from the line with that received from the trunk side of the switching network. If a match is obtained, it indicates that the complete line to trunk path is idle. In this simple manner, which requires no individual access to the A and C links, each mactor determines whether its associated line-to-trunk channel is idle.

FUNCTIONAL RELATIONSHIP OF SWITCHING NETWORK AND CONTROLS

With this preamble of our objective and philosophy, let us now consider the switching network and controls which we evolved to meet our requirements. To demonstrate the feasibility of the electronic controls

---

* The mactor is a new type of control circuit which takes its name through abbreviation of the functionally descriptive term, MAtcher-seleCTor-connectOR.

and the speed and reliability of the circuits, the switching network and controls were skeletonized and built as an integral part of an automatic telephone system known as the DIAD system.* The other parts of the system have been described earlier; furthermore, one can follow the operation of the switching network and its controls as separate entities. For these reasons we will consider the system operation only from the time the switching network receives an order to establish or release a connection until the time the controls answer, "Have taken the desired action," or "Could not perform the desired action."

A general idea of the physical relation of the various circuits and the type of construction used may be obtained from Fig. 2, which is a front view of the two switching bays. In addition to power supplies, the left bay contains test and monitor panels and the three line frames. The right bay contains three power supplies, the two trunk frames, the mactors, the switching control or sequence circuit and the switching number groups. A rear view of these two bays is shown in Fig. 3. This view gives a general picture of the wiring and cabling. Fig. 4 shows a close-up of line frame 11. On the left of the panel are three 3 × 3 primary switches, toward the right of the panel are four mactor connector relays. Fig. 5 is a rear close-up of line frame 11. This gives a better conception of the division of the crosspoint array into switches than the previous view. It also illustrates the very simple method of wiring the horizontal and vertical multiples within the switches. Having examined the apparatus itself through photographs, let us now see how these various pieces of equipment function together.

The functional arrangement of the switching network and associated controls is illustrated in block schematic form on Fig. 6. Although only 4 lines, 4 trunks, and 2 line frames are shown, the functional relations are unchanged in going to larger networks. The general operation of the various blocks may be summarized as follows:

(1) The DIAD, through the SWITCHING NUMBER GROUP CONNECTOR, tells the NUMBER GROUPS and the SWITCHING SEQUENCE CIRCUIT what terminal(s) (line and trunk or trunk alone) of the SWITCHING NETWORK to manipulate, and whether to establish a connection or release a connection.

(2) The SWITCHING SEQUENCE CIRCUIT applies enabling voltages to the NUMBER GROUP and MACTOR circuits where appropriate, in response to connect or relase signals from the DIAD.

---

* The word "DIAD" derives from "Drum Information Assembler and Dispatcher." The magnetic drum memory and other aspects of the system were described by W. A. Malthaner and H. E. Vaughan, An Automatic Telephone System Employing Magnetic Drum Memory, Proc. I.R.E. Oct., 1953.

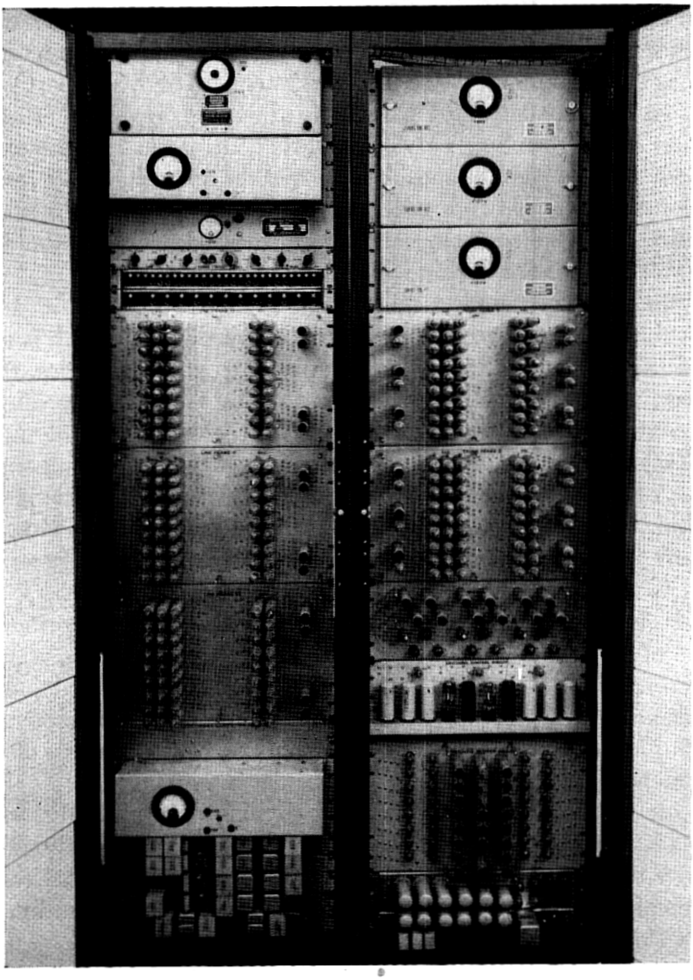


Fig. 2 — Switching network and controls — front view.

(3) The LINE NUMBER GROUP CIRCUIT accepts the line information furnished by the DIAD and converts it into codes, voltages, and impedances which can be applied to control the desired line of the switching network on connect.

(4) The TRUNK NUMBER GROUP CIRCUIT accepts the trunk information furnished by the DIAD and converts it into codes, voltages, and impedances which can be applied to the proper trunk of the SWITCHING NETWORK on connect or release.

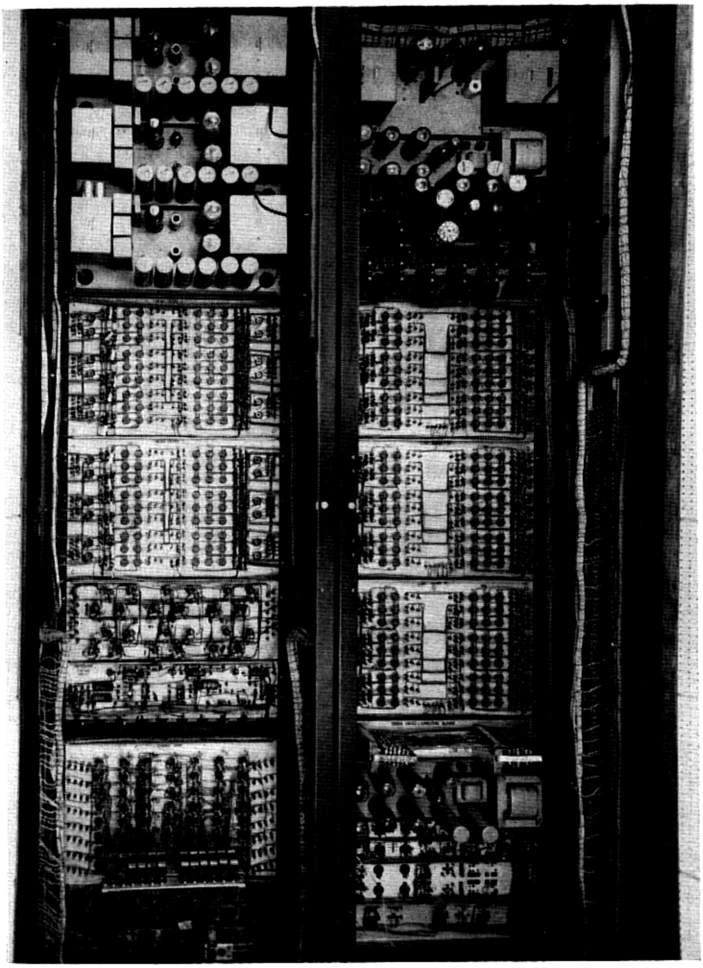


Fig. 3 — Switching network and controls — rear view.

(5) The SWITCHING NETWORK passes on voltage marks from the marked line and trunk to trace idle paths on connect, provides a metallic talking path between line and trunk during the conversation, and releases the connection upon receipt of a release signal from the trunk number group.*

---

* It is interesting to note that after the connection is established, it is sufficient to furnish only trunk information to perform a release. This is true because the series holding path from trunk to line constitutes a memory of what line and what crosspoints are associated with a particular trunk.

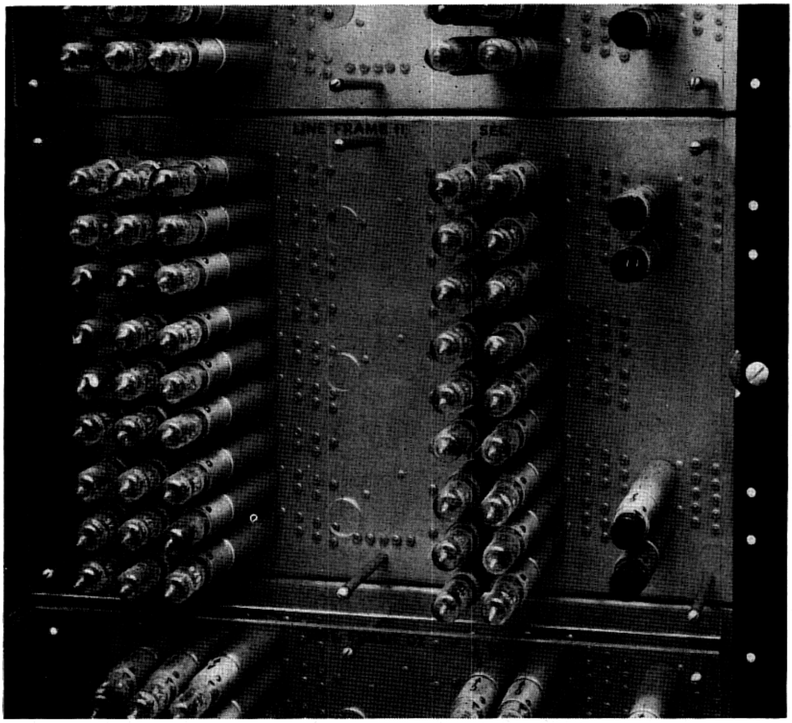


Fig. 4 — Front view of line frame 11.

(6) A pair of MACTOR CONNECTORS, on connect, receive line frame and trunk frame marks and operate to associate the MACTORS with the paths leading between the indicated LINE FRAME and the TRUNK FRAME.

(7) Each mactor, on connect, (through the operated connector) "matches" the two idle-path marking signals received from LINE FRAME and TRUNK FRAME to determine whether the mactor's associated line to trunk path is idle; if the path is found to be idle, the mactor competes in lockout with other mactors which found idle paths, and the mactor which is selected by the lockout operates its associated talking path.

With this description of the principal functions of the switching network and associated control circuits as background, we shall proceed to examine the various components in greater detail.

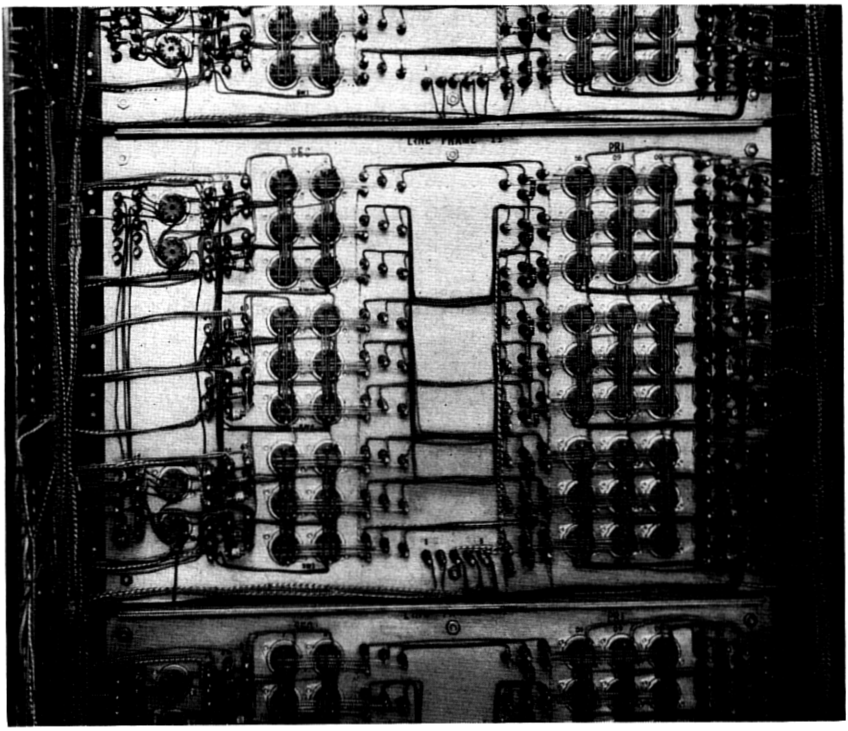


Fig. 5 — Rear view of line frame 11.

THE SWITCHING NETWORK

The Switch Crosspoint

The basic building block of the switching network is the crosspoint. One crosspoint appears at each intersection of horizontal and vertical multiples. The packaging design of the crosspoint is such as to achieve maximum flexibility in the laboratory operation and testing of the network. The crosspoint has two parts, (1) a switch assembly using reed contacts, and (2) a small cold-cathode diode.

The crosspoint is shown on Fig. 7. It consists of four reed contacts or switches in an actuating coil with appropiate mounting and connecting parts. Each reed contact consists of two 52 alloy* rods sealed in opposite ends of a piece of glass tubing containing helium gas. The contacting ends of the 52 alloy* rods are rhodium plated. The soft

---

* This is an iron-nickel alloy containing approximately 52 per cent nickel.

steel cylinder housing the switch assembly (1) serves as a mechanical housing and a support for the plug and socket; (2) acts as a magnetic shield between adjacent crosspoints; and (3) acts as a partial return path for the magnetic circuit of the reed contacts. The plug on one end of the switch assembly serves to connect the crosspoint assembly to the external circuit, while the socket on the other end receives the cold-cathode diode. (Where the switch assembly is used as a simple relay, a short-circuiting plug replaces the cold-cathode diode.)

The operating margins of the switching network are to a large extent a function of the variation in diode breakdown and sustain voltages with

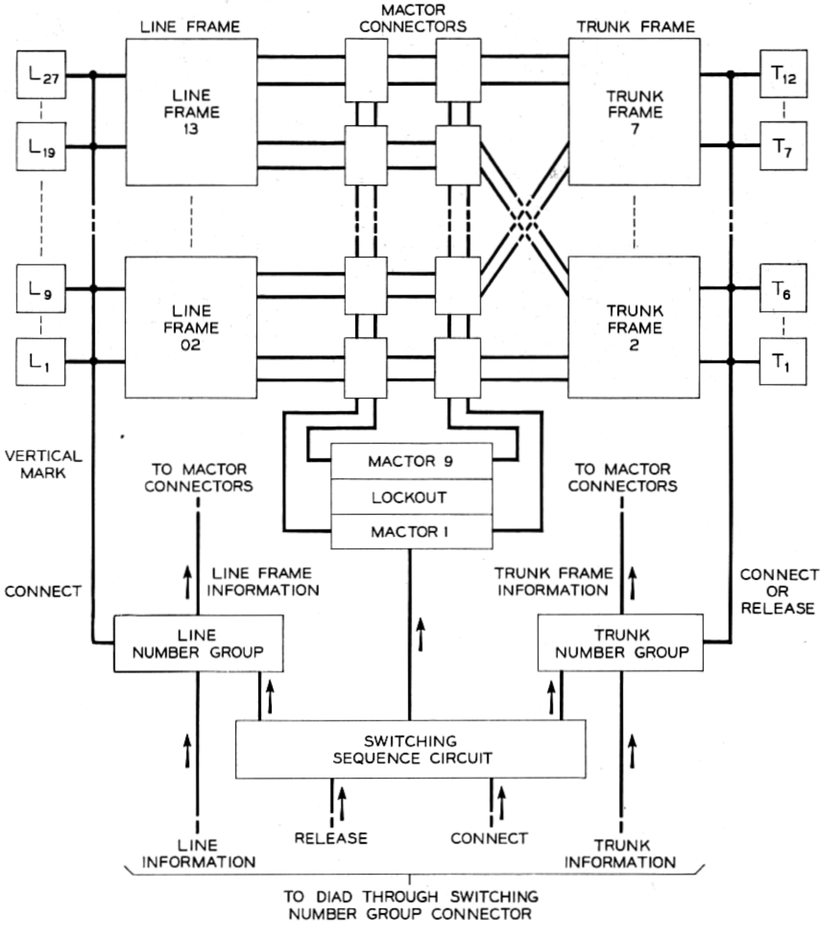


Fig. 6 — Relation of switching circuits.

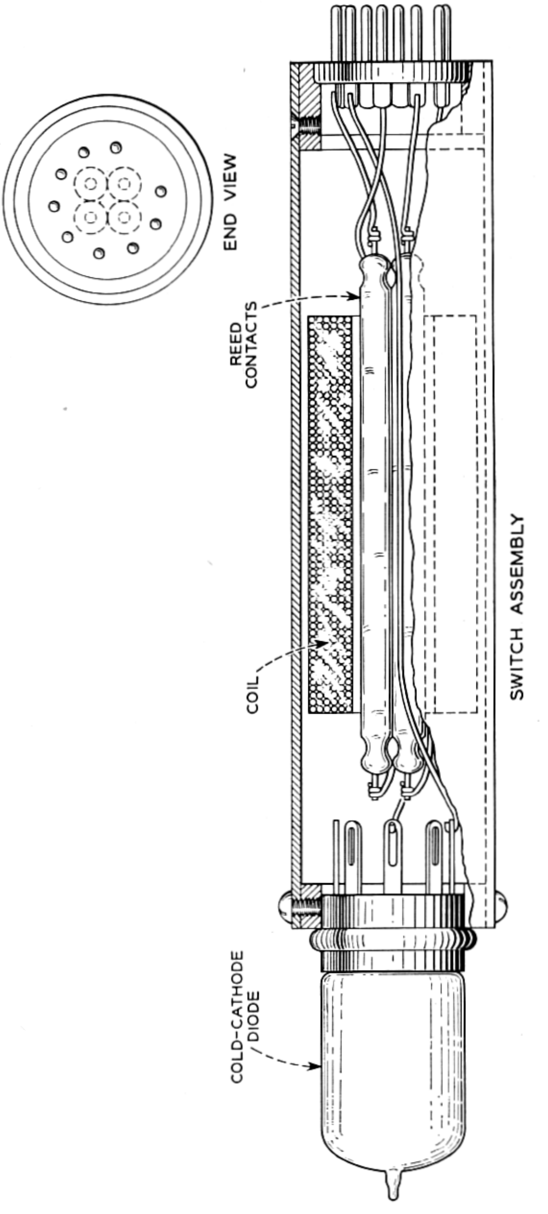


Fig. 7 — Crosspoint assembly.

age, temperature and also the variation from unit to unit. To assure satisfactory operation, electrical and life requirements were specified on the basis of the switching network needs and the A-1676 diode was designed to meet these requirements. In designing the switching network, arrangements which would lead to overly severe requirements on the diode were avoided. The A-1676 diode is a simple, rugged structure which meets or exceeds the requirements in every regard.

Single Path Circuit

A single path through the switching network is shown on Fig. 8. In each of the four crosspoints, the general operation is the same. The cold-cathode diode in series with the coil in the control lead is used (1) to pass tracing voltages through idle paths while remaining an open circuit for busy paths and (2) to break up parasitic paths in parallel with operated crosspoints, and thus to avoid marginal release requirements on the crosspoint relays. The reed contact in the sleeve lead, S, is used to establish a series path through the switching network for the purpose of holding the crosspoint relays of the selected path operated during the conversation. The reed contacts in the tip, T, and ring, R, paths are used to establish a series metallic path for signaling and talking between subscriber and trunk. Within the switching network the route of the tip and ring leads parallels that of the sleeve lead, and hence, tip and ring leads will not be shown or described in detail in the sections to follow. The fourth reed contact is used for display purposes only and has not been shown on Fig. 8.

In the following description of Fig. 8, a complete switching network is assumed, although for simplicity, branching paths have been indicated by "multiple whiskers". Starting from the idle condition, a path through the switching network is established as follows:

(1) Line frame and trunk frame identifying signals (marks of +130 V and −85 V, respectively) are applied to operate the proper connector relays to associate the mactors with the paths which go between the desired LINE FRAME and the desired TRUNK FRAME.

(2) A switch enabling mark (−85V) is applied to the idle A links leading out of all line primary switches having the same switch number as the desired line.

(3) A vertical identifying mark (+130V) is applied to all lines having the same vertical number as the desired line.

(4) All diodes appearing between verticals marked in (3) and A links enabled in (2) break down and, in doing so, produce voltage shifts on the associated A links leading into the line secondary switches.

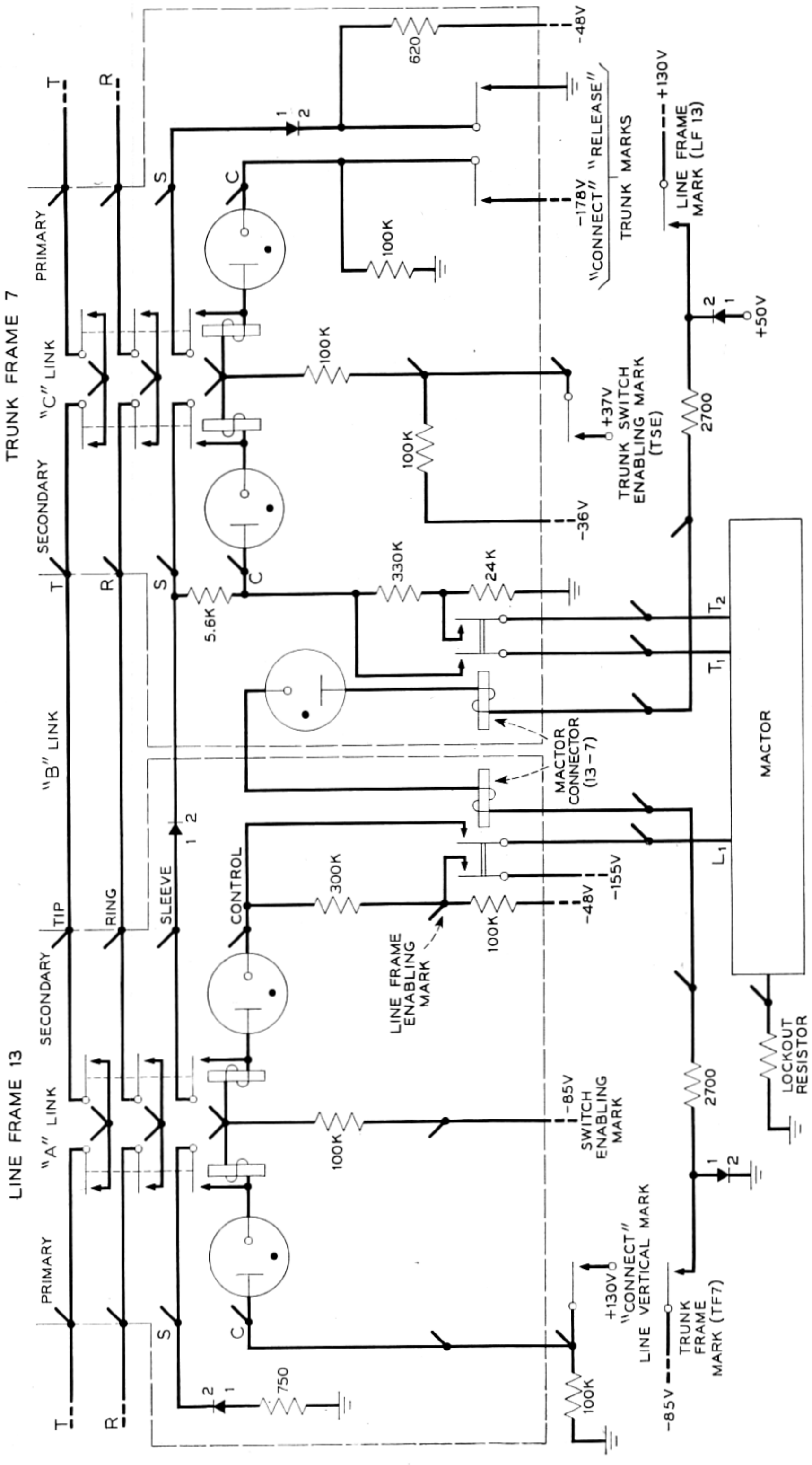


Fig. 8 — Single path through switching network.

(5) The left contact on the line side MACTOR CONNECTOR RELAY during step (1) has applied an enabling bias of − 155V to the control leads which lead out of the desired line frame to the mactors.

(6) The voltage shifts on the marked A links, in conjunction with the enabling biases of step (5), cause breakdown of idle line secondary diodes connecting between marked A links and the enabled B link control leads.

(7) Breakdown of the secondary diodes produces voltage shifts or marks which are fed on the control leads into the L_1 terminals of the mactors, each mark representing an idle path between the desired line and the mactor in question.

(8) On the trunk side, an enabling mark (+37V) is applied to all idle C links.

(9) A trunk mark (−178V) is applied to the individual trunk to which connection is desired.

(10) As a result of (8) and (9), the trunk primary diodes representing connections between idle C links and the desired trunk are broken down, producing voltage shifts on these links.

(11) Each mactor, through an idle-test circuit, samples the voltage on its T_1 lead, and, if this voltage indicates an idle B link, the mactor connects an enabling bias of +107V to its T_1 and T_2 leads.

(12) The voltage shifts on the marked C links, combined with the enabling biases applied by the mactors' idle-test circuits, cause breakdown of all of the trunk secondary diodes representing idle paths usable for the trunk half of the desired connection.

(13) The breakdown of the trunk secondary diodes puts voltage shifts or marks on the T_1 leads going to the mactors, each mark representing an idle path between the desired trunk and the mactor in question.

(14) Mactors which receive marks from both line and trunk sides indicate through a matching or coincidence circuit that their associated paths through the switching network between the desired line and the desired trunk are idle and available for use.

(15) The mactors which indicate a match energize their respective transistors, which compete in a common lockout circuit.

(16) The transistor which wins the lockout competition (i.e., achieves the fully conducting state) thereby selects the corresponding switching path for use.

(17) In response to the lockout operation, the selected mactor raises the current in both line and trunk halves of the selected path and operates the crosspoint relays associated with this path.

(18) During the conversation the selected path is held operated or "locked up" over the series sleeve lead path between ground on the line

end of the connection and the −48v battery on the trunk end of the connection.

(19) The mactors are retired and the paths which were marked but not used are restored to normal by the removal of the line and trunk marks and the removal by the switching sequence circuit of various enabling voltages.

(20) At the completion of the conversation the connection is released by the temporary application of ground to the sleeve lead at the trunk, thereby bringing both ends of the holding circuit to the same potential and causing release of the crosspoint relays involved in the connection.

Regarding the holding circuit, it will be noticed that there is a 750-ohm resistor in series with the sleeve lead at the line end of the connection. This resistor simulates the winding of a cut-off relay. Hence, if a cut-off relay were required, it would be a simple matter to substitute the operate winding of a relay for the 750-ohm resistor.

A more detailed description of the control of the switching network is provided in Appendix I.

CHANNEL SELECTORS OR MACTORS

Functional Description of Mactors

As the description of the switching network has indicated, the mactors perform the functions of (1) matching of line and trunk idle-path tracing marks, and (2) selecting and connecting for use one of the idle paths revealed by the matching operation. To these general functions, in the present system, we have added the function of performing an idle-test on the B links of the switching network. The idle-test precedes the other portion of the mactor operation; hence, a mactor is enabled to continue its functions only if its associated B link is idle. Each mactor contains, as its principal elements, 4 cold-cathode gas tubes and a reed relay associated with each, and a transistor. One gas tube and relay combination performs the idle-test; another combination receives the path tracing voltage from the line side of the switching network; the third such combination receives the path tracing voltage from the trunk side of the network; the transistor (in conjunction with those in other mactors) functions to select one of the idle paths for use, while locking out all others; and finally, the fourth gas tube and relay combination receives a triggering signal from the transistor and functions to establish a connection over the selected path. For a detailed description of how these functions are performed, we refer the reader to Appendix II.

Mactor Design Features

In general, the design of the mactor in the present system was based on maximizing the operating margins of switching network, rather than minimizing the amount of apparatus in the mactor. However, it should be noted that there are only as many mactors as there are alternate paths or channels in the switching network (3 in our scaled-down model, perhaps 10 in a full-sized office) and this means that the amount of apparatus in the mactors is a very small proportion of the total office equipment. The use of a separate idle-test, and the detection of line and trunk path tracing marks on different gas tubes lead to increased margins. The idle-test circuit used in the mactor is of particular interest because it uses a new grid-controlled cold-cathode tube, type M-1652. This tube, V1 of Fig. 15, has control characteristics similar to those of a hot-cathode gas tube, while possessing all of the long life advantages of a cold-cathode tube in applications involving a low duty ratio. The main cathode, MC of V1 also functions as a keep-alive anode, while KC is a keep-alive cathode. Discharge is initiated in this keep-alive gap by the application of −178 volts to terminal CE 1 a few milliseconds before the tube is required to respond to the control signal. At the same time the keep-alive gap is energized, the main anode, MA, is enabled by the application of +130 volts to terminal AE 1. The tube is now ready to respond to a signal on its control grid. A negative potential of 20 volts or more on the control grid prevents transfer of discharge to the main gap while ground potential assures that transfer to the main gap will take place. In addition to the advantages of this tube from the standpoint of life, the fact that it will trigger on relatively small voltage shifts in high impedance circuits is utilized in the present circuit design.

The advantage from a margin standpoint of receiving line and trunk path-tracing marks on separate tubes may be understood if we consider what happens when these marks are received across the start gap of a single tube. It is evident in such a case that the variations of line and trunk path tracing marks must be summed in determining the least favorable circuit operating conditions. However, when the two marks are received on individual tubes, the marks are quantized before combining or matching takes place, so that variations in the two marks are never added together.

Perhaps the most interesting design feature of the mactor is the negative resistance lockout circuit using the switching transistor, type A-1698. In the usual operating routine, the lockout in this circuit is decided on a time basis; i.e., due to statistical time variations one transistor is operated and fully conducting before other transistors are energized. In the occasional "dead heat", a plurality of transistors can reach the high current condition together. In this case, it is significant to note that the transistor in each mactor has a high (29,800-ohm) base load resistance which gives it a negative emitter-to-ground impedance throughout the operating region. The emitter-to-ground impedances of the various mactors' transistors are connected in parallel, and this parallel combination is connected in series with a common lockout resistor (29,800-ohms). It can be shown that this circuit is unstable if more than one transistor is conducting in the operating region. Thus, even though two or more transistors should reach the operating region, one of them quickly assumes most of the circuit current and drives the other(s) into the quiescent region of positive emitter-to-ground impedance and virtually zero emitter current. The maximum time required for one transistor to reach the high current state and drive the other(s) to the quiescent state is the "severance time". For the lockout circuit employed in the mactor, there is a severance time of approximately 0.5 microsecond. It is essential, of course, to avoid producing an output before the lockout has been resolved. This requires that the circuit responding to the transistor have a minimum response time considerably exceeding the severance time. In the mactor circuit this is assured by the fact that the minimum triggering time of the cold-cathode tube, V3, is approximately ten microseconds. In addition, it will be noticed that there is a delay in response caused by feeding the transistor output. which occurs across the base load impedance, through an RC filter before placing it on the start cathode, SC, of V3. This RC filter was designed to have a delay great enough to take care, not only of the severance time, but also of possible temporary ambiguities caused by contact chatter in the L4 relays. These provisions result in a lockout circuit which is "a priori failure-proof".

FUNCTIONAL DESCRIPTION OF SWITCHING SEQUENCE CIRCUIT

The switching sequence circuit, see Fig. 16, is the common control circuit which functions whenever a connection through the switching network is established or released.

In the first case, when the switching sequence circuit receives an (ES) establish signal from the switching information dispatcher, (1) it prepares the line number group circuit and trunk number group circuit to handle the coded signals on the line and trunk information leads (signals which correspond to the line and trunk to be connected together) (2) it applies operating voltage to the mactors, (3) it applies the connect trunk marking voltage to all the trunk frames of the switching network, and (4) it applies enabling bias to the C links of the switching network.

After one of the idle paths between the line and trunk in question has been selected and the path established, the switching sequence circuit restores the number group circuits, mactors and mactor connectors to normal and removes the connect voltage mark and C link enabling bias from the switching network. The switching sequence circuit then transmits an OK signal to indicate to DIAD that the required connection has been made. Finally, the switching sequence circuit restores itself to normal.

In the second case, that in which the switching sequence circuit receives a (DS) disconnect signal from the switching information dispatcher, the sequence circuit enables the trunk number group (to handle the signals on the trunk information leads) and applies a release ground to the trunk number group elements. (As was noted earlier, a connection is released from the trunk side only of the switching network.) Sufficient time is allowed for the crosspoint relays in the path to release (about 10 milliseconds). Subsequently, the release ground is removed, and the trunk number group circuit is restored to normal. Finally, a pulse is sent out on the OK lead which signifies to DIAD that the path in question has been released and at the same time the switching sequence circuit restores itself to normal.

Connect and release cycles for the switching sequence circuit are described in detail in Appendix III.

SWITCHING NUMBER GROUP CIRCUIT

The switching number group circuit comprises the following parts: line vertical number group, line switch number group, trunk number group, and mactor connectors. All of these circuits have been skeletonized to conform with the skeletonized switching network. One of them, the line vertical number group, is shown in detail in Fig. 17, while other portions of the number group appear in block diagram.

The switching number group circuit performs two functions: (a) it decodes the signals on the line and trunk information leads from "2 out of 5" to "1 out of 10" and (b) it provides the means for selecting and connecting to the proper points in the reed-diode switching network and for applying the several connect and release voltage marks. The number group circuits were designed on the basis that the signals on the line and trunk information leads are in the form of the equipment designations of the line and trunk which are being served; that is, frame, switch and vertical. Each digit is indicated by the presence of +150V on two out of a group of five information leads, the other three leads being at +100V.

(In the quiescent state, all the information leads would be at +100V, which means that no information is being supplied to the switching network.) The switching number group circuit is enabled and released by the switching sequence circuit. In setting up a connection, the switching sequence circuit applies +200V to the main anodes of the line number group digit tubes via the LNG lead and +200V to the main anodes of the trunk number group digit tubes via the TNG lead. On the release of a connection, only the trunk number group is enabled.

The decoding and selection operations of the number group circuit are described in Appendix IV.

COMPONENT AND CIRCUIT TESTS

Of the five types of cold-cathode gas tubes used in the design, three are essentially commercial products. These are the WE 376-B, the BTL A-1703, and the BTL A-1704. The latter two tubes are versions of the WE 425-A and WE 426-A without the plastic mounting flange and external resistors.

The other two tubes types, the BTL A-1676 and the BTL M-1652 are not commercial products. The A-1676 diode which appears in each crosspoint was tested as part of the tube design and development effort. Life tests on this gas diode gave a life expectancy of 3,000 active hours. Since the tube is used only momentarily each time a connection is established, this corresponds to an in-circuit life of 240,000 years. Such figures, of course, merely mean that a high degree of reliability may be expected in using this tube. The other non-commercial tube, the M-1652, is of interest because it is a grid-controlled cold-cathode tube which can be triggered reliably from low voltage, low power signals. The control characteristics of eleven of these tubes were measured in detail. Each tube was found to be suitable for use in the mactor circuit, where it is used as the idle-test tube. A typical control characteristic of one of these tubes is shown on Fig. 9.

Each reed-diode crosspoint was tested individually in four respects: (1) dc coil resistance, (2) insulation resistance, (3) operate and release current, and (4) operate and release time. The last two tests were made with positive and negative polarities of operate current and with contacts strapped in series and in parallel. The reversed polarity test established that any residual effect due to hysteresis in the magnetic material was very small. The operate and release tests with contacts in series and in parallel gave a measure of the total spread from the most sensitive contact to the least sensitive contact. Control limits were calculated for

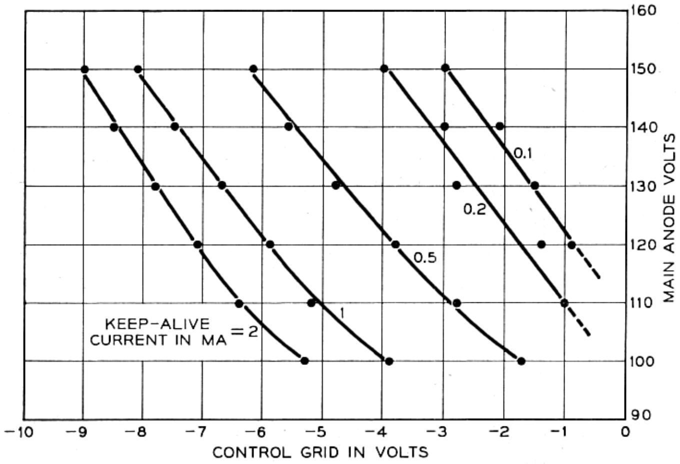


Fig. 9 — Trigger characteristic of grid-controlled cold-cathode tube.

the data on dc resistance, operate and release currents, and operate and release times in order to reveal any crosspoints which were out of control in any of these parameters.

The switching number group, switching sequence circuit, mactors, line frames, and trunk frames were tested individually before being interconnected. The tests consisted generally of making breadboard circuits which would apply the proper operating and information signals to the circuit under test. The test input information was then put through a variety of conditions calculated to exercise every element in the circuit.

Following the testing of individual circuits, they were assembled on the two switching bays, interconnected, and tests of the combined apparatus were made. Principally, these combined tests consisted of: (1) measurement of the timing of all of the important steps in establishing and releasing a connection, and (2) checking the satisfactory operation and release of paths involving all possible combinations of line, trunk, and interconnecting path.

Timing Measurements

The timing measurements were made by putting the switching network and control circuits through connect-release cycles repetitively at about 15 cycles per second, and observing operation on an oscilloscope. For the measurements which led to the sequence chart of the normal connect cycle, Fig. 10, the sweep of the oscilloscope was triggered from the ES pulse which starts the connect cycle.

Taking the start of the connect cycle as zero on the time scale, and the times in milliseconds, the following relations are apparent: (1) at $t = 4$, the major control circuits; (line number group, trunk number group, and mactors) receive their enabling voltage from the switching sequence circuit; (2) at $t = 6$, the line and trunk number groups operate; (3) at $t = 8$, the mactor connector relays operate; (4) at $t = 10$, the mactors complete their idle-tests, receive voltage marks from line and trunk sides of the path, and one or more of them returns to the switching sequence circuit a "match" signal (MS); (5) at $t = 12$, the mactor lockout circuit operates to perform the path selection, and the current is increased in the selected path; (6) at $t = 13$, the crosspoints in the selected path operate; (7) at $t = 15$, the main anode voltage is removed from V1 of the switching sequence circuit; (8) at $t = 19$, the enabling voltages are removed from the number groups and mactors; (9) at $t = 23$, the main anode voltage is re-applied to V1 of the switching sequence circuit; (10) at $t = 23$, the switching sequence circuit sends an OK signal

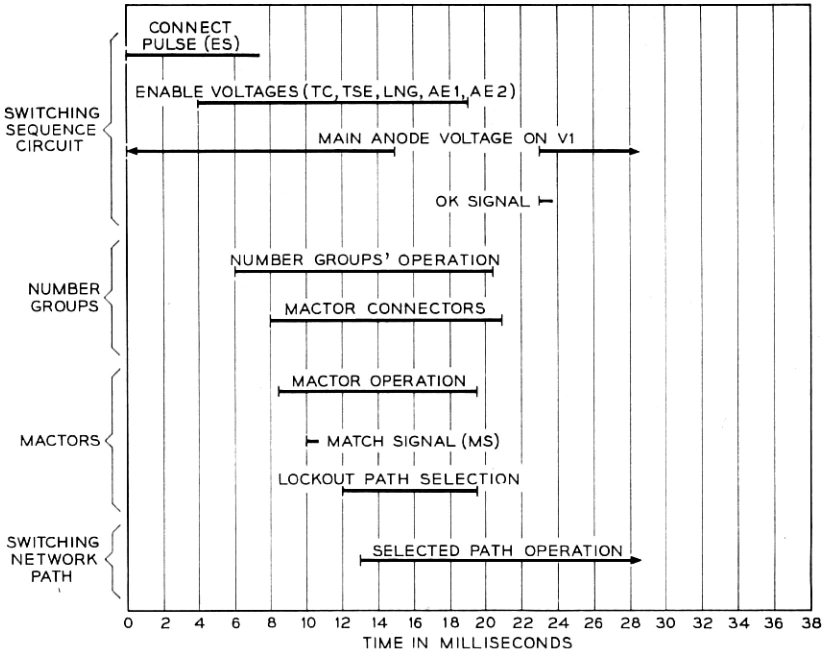


Fig. 10 — Connect cycle when call is completed.

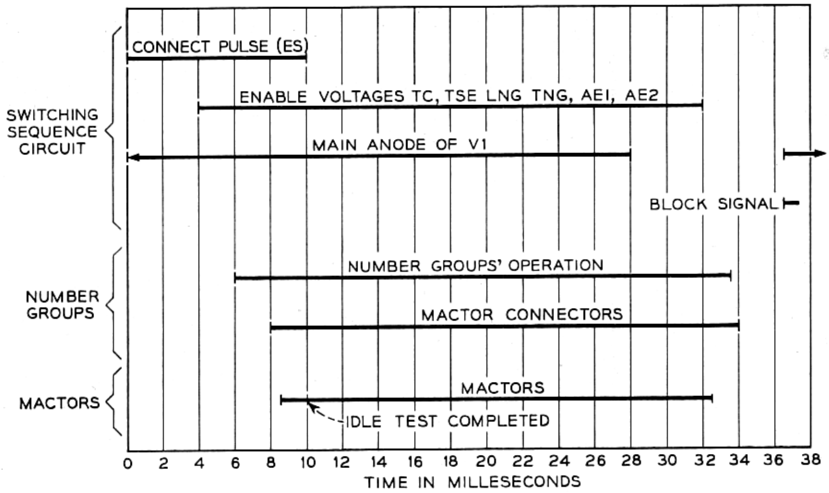


Fig. 11 — Connect cycle when call is blocked.

through the switching number group connector to the switching information dispatcher, indicating that the switching network and controls are ready for a new connect or disconnect operation. The above cycle description assumed that an idle path was found.

The time relations which were measured with all usable channels busy are shown on Fig. 11. In this case, no idle path is found and the cycle differs from the above beyond (3), as follows: (4) at $t = 10$, the mactors complete their operation without finding an idle path, and therefore without sending a match signal to Switching Sequence Circuit; (5) at $t = 28$, the time-out circuit removes main anode voltage from V1 of the switching sequence circuit; (7) at $t = 34$, number groups, mactors, and mactor connectors release; (8) at $t = 36.5$, main anode voltage is reapplied to V1 and the switching sequence circuit sends a BLOCK signal through the switching number group connector to the switching information dispatcher, indicating that the desired connection could not be obtained, but that the switching network and controls are ready for the next operation.

The disconnect cycle has only one possible sequence, since there is no question of blocking forcing the system into an alternate cycle. The disconnect cycle is simpler, too, since the connection is released from the trunk end alone. Thus, the line number group and mactors are not required to function on a release operation. Time readings on the release cycle, which are displayed in the form of a sequence chart on Fig. 12, were taken with the start of the oscilloscope sweep synchronized with the DS pulse which is used to initiate the release cycle. Taking the start of the DS pulse as zero on the time scale, and the time in milliseconds, the following relations are apparent: (1) at $t = 3.5$, the trunk number group receives enabling voltage from the switching sequence circuit; (2) at $t = 6$, the trunk number group operates, (3) at $t = 9$, the trunk release (TR) voltage is applied to the trunk, and main anode voltage is removed from V2 of the switching sequence circuit; (4) at $t = 12$, the crosspoints comprising the connection release; (5) at $t = 18$, the trunk release signal is removed from the trunk, enabling voltage is removed from the trunk number group, main anode voltage is re-applied to V2, and an OK signal is sent through the switching number group connector to the switching information dispatcher; (6) at $t = 19$, the trunk number group releases and all circuits are back to normal.

OPERATIONAL TESTS

In addition to the tests described earlier, it was decided to check both conductors of every path which could be set up, using the switching network's controls to connect and disconnect. Since there are 27 lines, 12 trunks, and three possible paths between each line and trunk, and two conductors for each path, a total of 1944 connections were tested. In testing all possible combinations as described here, any single portion of the circuit is involved in a number of tests, giving a certain degree of

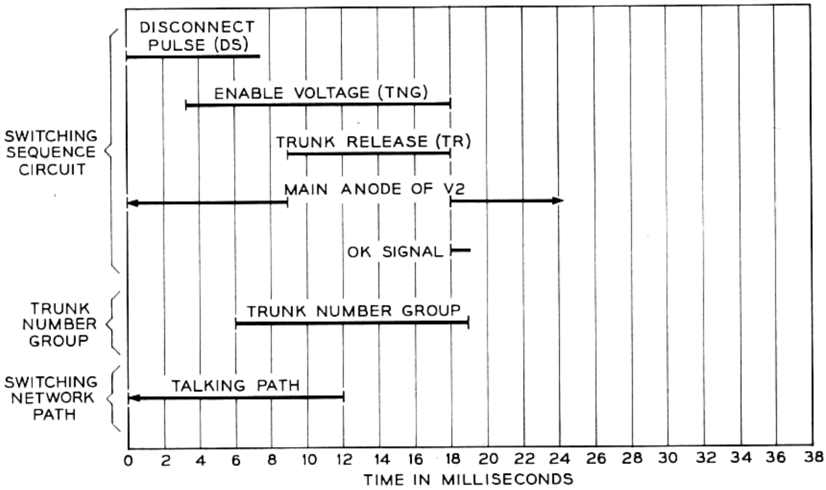


Fig. 12 — Release cycle.

redundancy. Nevertheless, a full testing schedule was considered desirable in the present instance for two reasons: (1) the operate and hold characteristics of crosspoints in a marginal case can be a function of how they are combined (i.e., crosspoints x and y could operate satisfactorily in different paths, but fail to operate in a path which involved both of them); and (2) a full test increased the likelihood of discovering any incipient troubles. In testing a larger switching system by this method, the total number of operations required and the degree of redundancy associated with a full test would be excessive. In such a case the ideal test would operate on a fully automatic basis and would follow an abbreviated schedule which would test each element of the switching system the desired number of operations only.

PERFORMANCE OF NETWORK AND CONTROLS

For forty-two months the switching network and controls were operated to gain information on reliability. The results of this operation are summarized briefly on Fig. 13. The left column lists the major circuits which required adjustment or replacement of elements. The second and third columns, give, respectively, element replacements made as a result of preventive maintenance and those made as a result of equipment failures. Most of the germanium diodes which were replaced were used as relay contact protection. Diodes used as logical combining elements have functioned reliably with no failures. Three means of improving the situation regarding diodes used as contact protection are: (1) install all diodes on plug-in mounts so preventive maintenance can catch incipient troubles, (2) use a diode with a higher inverse voltage rating, or (3) use resistance-capacitance contact protection. The germanium diode failure rate diminished with time, indicating that we were weeding out the weaker diodes. Early in the tests the diodes were transferred to plug-in mounts; therefore, most later diode replacements were made as a result of routine maintenance tests without incurring circuit failures.

Twenty-eight vacuum tubes were replaced during the tests. Ten were replaced as a result of circuit failure while eighteen were replaced as a result of routine tests. All of these vacuum tubes were used in the regulated power supplies. To catch weak tubes before they produced failures, the following monthly power supply regulation check was applied. With 80 per cent of the maximum rated load applied, the power supply output voltage should not sag more than 3 per cent. If a power supply passed this test, no further check was made. If it failed, tubes were

CIRCUIT SERVICED	ELEMENTS REPLACED ON ROUTINE BASIS	ELEMENTS REPLACED BECAUSE OF CIRCUIT FAILURE	TYPE OF ELEMENTS RESPONSIBLE FOR SERVICING	REMARKS
POWER SUPPLIES	18	10	VACUUM TUBES	TYPE REQUIRING MOST REPLACEMENTS: SERIES REGULATOR TUBES, 6Y6
NUMBER GROUPS	9	24	POINT CONTACT GERMANIUM DIODES	18 DIODES FAILED SIMULTANEOUSLY DUE TO ABNORMAL POWER VOLTAGE. DIODES TYPE 400E
SWITCHING SEQUENCE CIRCUIT	—	2	POINT CONTACT GERMANIUM DIODES	2 DIODES TYPE 400E HAD LOW BACK RESISTANCE; REPLACED WITH GERMANIUM AREA JUNCTION DIODES
TRUNK FRAMES	—	5	POINT CONTACT GERMANIUM DIODES	DIODES IN TRUNK HOLDING CIRCUIT (TYPE 400E) OPEN CIRCUITED
GENERAL	—	—	COLD CATHODE GAS TUBES	BREAKDOWN TIMES ERRATIC; LIGHTS INSTALLED TO PROVIDE INITIAL PHOTO-IONIZATION

Fig. 13 — Maintenance summary.

checked individually and replacements made as needed. Vacuum tube failures were the chief source of trouble requiring further design effort. The higher degree of power reliability which would be necessary in a commercial system could be achieved by (1) duplicate power supplies with automatic switching to the spares, and (2) by designing individual supplies to a higher order of reliability.

Early in the tests, we discovered that gas tube breakdown times were longer and more erratic than desired. We know that all cold-cathode tubes for their operation depend on a small residual ionization. In the tubes we used, this ionization was provided by a small smear of radium bromide in each tube. The ionization from this source alone proved insufficient to assure stable sensitivities and breakdown times. Therefore, we installed three line-type incandescent light sources of 60 watts each behind the dividing strips of the bays. The resulting photo-ionization produced very consistent tube performance.

Despite the troubles mentioned above, the overall reliability of the switching network and controls has been very satisfactory. Examination of our maintenance log reveals only 23 circuit failures in 42 months, most of the failures occurring early in the test. In particular, the reliability of the cold cathode gas tubes, mercury relays and reed relays has been outstanding. Where germanium diodes function in logic circuits, we have encountered no failures. The transistor lockout circuit which performs the channel selection has operated throughout the period of test without any transistor replacements.

CONCLUSION

The construction and testing of a 27-line, 12-trunk model of a telephone switching network and its associated electronic control circuits and their operation in the laboratory for over three years have demonstrated the technical feasibility and the reliability of the basic design. On the basis of 50,000 calls per busy hour and 57 per cent active time of the control circuits, this network and its controls are fast enough to permit one-at-a-time operation in a busy 10,000 line telephone exchange. In the design of this skeletonized model, one of the objectives achieved was the use of relatively simple components having practical tolerances. Although the network and its controls were designed specifically for the DIAD telephone system, these circuits are sufficiently flexible that they could be adapted to other information handling systems such as digital computers.

ACKNOWLEDGEMENTS

A number of people have helped to make this high-speed network and its controls a success. We wish specifically to acknowledge the contributions of E. Bruce to the basic reed-diode network and to the series-marking method of control. B. G. Bjornson designed the transistor lockout circuit used in the mactor. D. S. Peck and W. G. Stieritz designed and tested the A-1676 gas diode. The mechanical design of the crosspoint element and other parts is the work of J. F. Müller. L. Maggi and L. J. Robinson assembled and wired the equipment and assisted in the testing.

Appendix I

THE SWITCHING NETWORK AND ITS CONTROL

The switching network and mactors are shown on Fig. 14. The network is laid out in standard 4-stage fashion except that the entire circuit is skeletonized. Thus, a network which might contain 10,000 lines and 2,000 trunks in a large office is scaled down to contain 27 lines and 12 trunks. In Fig. 14 only one line frame and one trunk frame have been shown. The other line frames and trunk frames would be similar to those shown. The numbering of lines, switches and frames is such as to

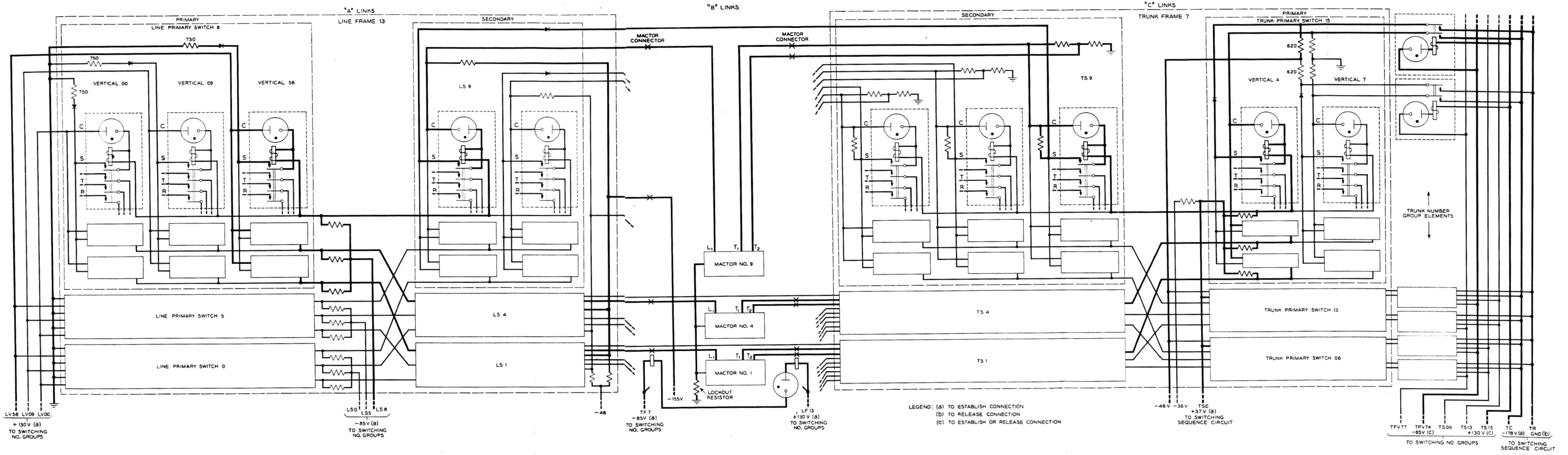
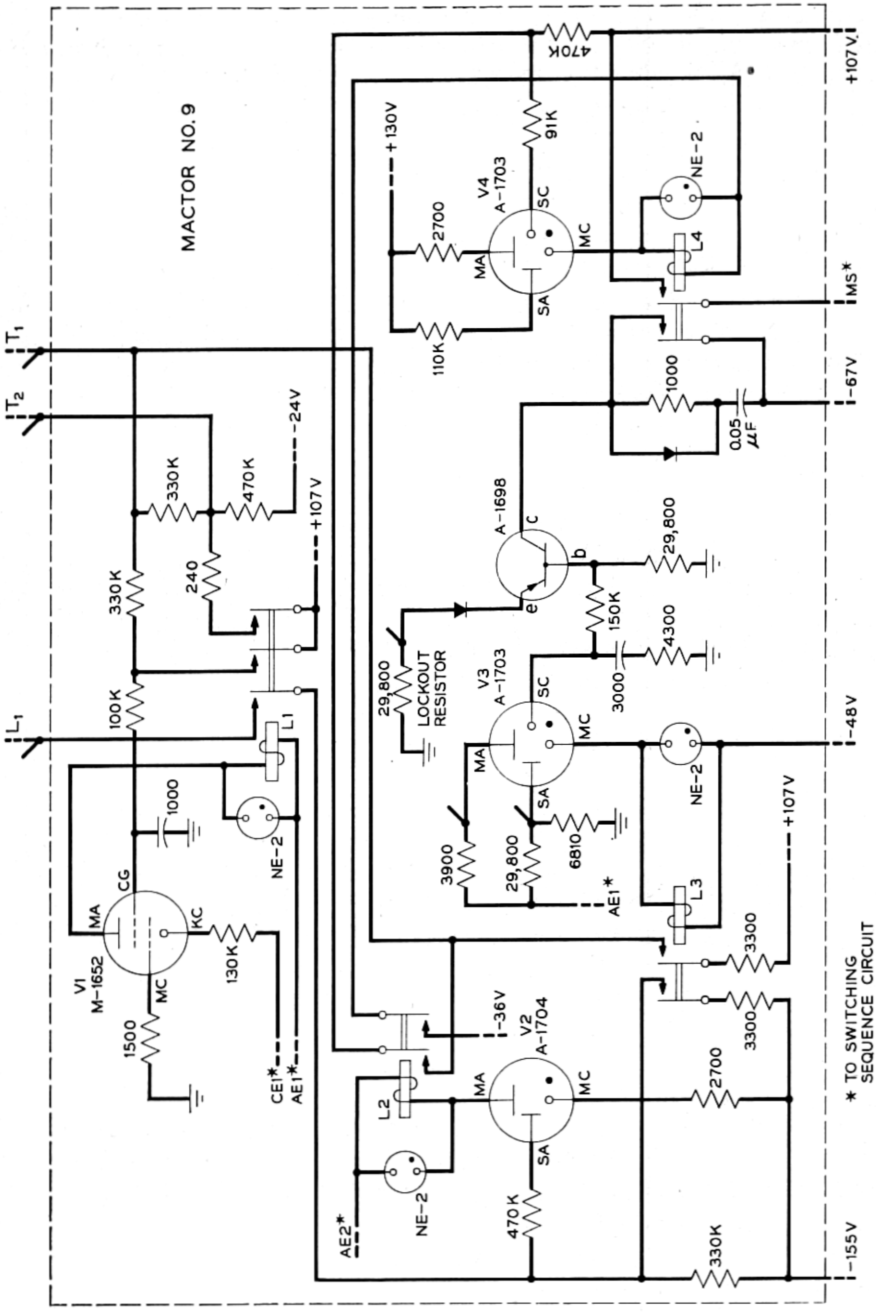


Fig. 14—Switching network and mactors

indicate the full-sized office on which the skeletonized model is based. In the body of this article we described the operation in terms of a single path through the switching network. Now we will see how this description applies when we consider the complete switching network.

As a specific example, let us assume a connection is desired between the line appearing at VERTICAL 56 on SWITCH NO. 8 of LINE FRAME 13 and the trunk appearing at VERTICAL 4 on SWITCH 15 of TRUNK FRAME 7. This line and trunk appear near the top of Fig. 14. Leads involved in establishing and releasing a connection between this line and trunk have been shown by heavy lines on Fig. 14.

At the bottom center of Fig. 14 there are leads which carry line frame and trunk frame information on the basis of which the proper mactor connector relays may be operated. In the example we are considering, the LF13 and TF7 leads would be energized, thus operating the two mactor connector relays which are shown on Fig. 14. Their operation associates the mactors with the B links extending between LINE FRAME 13 and TRUNK FRAME 7. Now let us examine the line frames and see how the proper line terminal is marked. This is done by first applying enabling voltage to the idle A links of the desired switch and all other switches having the same switch number, and then applying marking voltage to the proper vertical number on all line primary switches. Since both of these voltages are required to produce breakdown in the line primary diodes, only diodes associated with the desired line or with similar numbered lines on other line frames are broken down. Referring again to Fig. 14, at the bottom center of the line frame are line switch leads designated LS 0, LS 5, LS 8. In this case, the LS 8 lead is energized, resulting in the application of an enabling bias to the idle A links leading out of line primary switches numbered 8 on all line frames. At the bottom left of Fig. 14 are terminals designated LV 56, LV 09, and LV 00. In our present example, LV 56 has a marking voltage which is applied to VERTICAL 56 on every line primary switch. However, since only the line switches numbered 8 have enabling marks on their links, the vertical mark is effective in breaking down only the crosspoint diodes associated with VERTICAL 56 on LINE PRIMARY SWITCHES 8 of each line frame. At this point, it should be noted that if any of the A links had been busy, the voltage on the links would be determined primarily by the holding circuit of the busy path (which has a low impedance) rather than the link enabling voltage, which passes through a 100K link resistor. This link voltage for busy paths is arranged to act as a bias which prevents the breakdown of primary diodes. This same method of marking links busy applies to the C links.


MACTOR NO. 9
T$_1$
T$_2$
L$_1$
330K
470K
-24V
+107V
330K
240
100K
1000
NE-2
L1
V1
M-1652
CG
MA
KC
MC
130K
1500
CE1*
AE1*
470K
+107V
91K
V4
A-1703
SC
MC
MA
SA
2700
110K
+130V
NE-2
L4
MS*
-67V
1000
0.05 µF
A-1698
c
b
e
29,800
150K
4300
3000
V3
A-1703
29,800
LOCKOUT RESISTOR
-48V
NE-2
+107V
3900
29,800
6810
AE1*
L3
3300
3300
-36V
V2
A-1704
L2
NE-2
AE2*
470K
2700
330K
-155V
* TO SWITCHING SEQUENCE CIRCUIT

The foregoing paragraphs have described the process of marking the idle line links. In the ensuing description, let us assume that all of these links were found idle, and therefore were marked. The marks or voltage shifts are passed on to the appropriate inlets of the various line secondary switches of the line frames, here represented by LS 1, LS 4, and LS 9 on LINE FRAME 13.

It will be noted that the line side relay of the mactor connector pair, when it operated, applied an enabling mark of −155V to the control leads of the B links leading out of LINE FRAME 13 toward TRUNK LEAD 7. Inter-frame links which go to other trunk frames or which come from other line frames receive no enabling marks and hence cannot be marked in the next step of the path tracing operation.

As a result of the marks appearing at the inlets of the line secondary switches, plus the enabling marks applied by the mactor connector relay, the secondary diodes which could be used in establishing the desired line-to-trunk path are broken down. (Note that secondary diodes on frames other than LINE FRAME 13 are not broken down because of the absence of the −155V B link enabling signal.) The breakdown of secondary diodes on LINE FRAME 13 places path tracing marks on the corresponding control leads which pass through the contacts of the left mactor connector relay. These marks then proceed to the L_1 terminals of the various mactors. In this case, the marks from LS 1, LS 4 and LS 9 go, respectively, to MACTORS 1, 4 and 9. This completes the path tracing and marking operation for the line half of the connection.

The marking of the trunk half of the connection (again see Fig. 14) is similar to the marking of the line half of the connection in general principle but varies somewhat as to specific detail. First, all of the idle C links are enabled by the application of +37V to the terminals marked TSE on the TRUNK FRAMES. (Those C links which are busy remain at a voltage which is determined by the division of the −48V holding battery in the busy paths.) Then a −85V trunk frame and vertical identifying signal is applied to the terminal TFV 74 while a trunk switch identifying signal of +130V is applied to terminal TS 15. As a result of these two signals, a trunk number group element shown at the top right of Fig. 14 is selected and operated. The other elements have either no signals applied, or a signal on one side only, and hence do not operate. The SWITCHING SEQUENCE CIRCUIT then applies a "trunk connect" voltage of −178V to terminal TC. This voltage is passed up the number group multiple, through the connect contact of the operated number group relay, and placed on the control lead of VERTICAL 4 of TRUNK PRIMARY SWITCH 15 on TRUNK FRAME 7. The trunk connect voltage, in connection with the enabling voltage on idle C links, results in the breakdown of all primary switch diodes connecting between the marked trunk and the enabled links. The breakdown of these diodes places a voltage shift, or mark, on the idle links connecting TRUNK PRIMARY SWITCH 15 to the various trunk secondary switches of TRUNK FRAME 7. For purposes of further description, we will assume that all of the C links extending from TRUNK PRIMARY SWITCH 15 to trunk secondary switches of TRUNK FRAME 7 were idle and hence received path tracing marks.

We will leave the path tracing marks for the time being and consider what is happening on the trunk side of the mactors and mactor connectors. It will be recalled that a pair of mactor connector relays has operated. The contacts on the trunk side mactor connector relay extend control leads from the trunk secondary switches of TRUNK FRAME 7 to the mactors. The control leads which are thus extended are those associated with the B links going from TRUNK FRAME 7 to LINE FRAME 13, the frames on which the desired trunk and line appear. The control leads are carried to the T_1 and T_2 terminals of the various mactors. In this particular case, the control leads from TRUNK SECONDARY SWITCHES 1, 4 and 9 are associated with MACTORS 1, 4 and 9 respectively. By means of an idle-test circuit which is a part of each mactor, the mactors examine the voltages on their T_1 terminals. Voltages of approximately -24 volts at these points represent busy B links and prevent the idle-test circuits from functioning, while ground voltages represent idle paths and trigger the idle-test circuits. Assuming that each of the B links under test was found to be idle, each mactor idle-test circuit applies an enabling mark of +107V to its T_1 and T_2 terminals. These enabling marks travel back over the mactor connector multiple and through the contacts on the mactor connector relay to reach the control terminals of the appropriate links leading from TRUNK SECONDARY SWITCHES 1, 4 and 9. These enabling marks, in connection with the path tracing marks which earlier were placed on the C links, cause breakdown of the trunk secondary diodes of the crosspoints which receive both of these signals. The breakdown of these trunk secondary diodes extends the idle-path tracing marks to the T_1 terminals of the mactors. In the case we are considering, the marks from TS 1, TS 4, and TS 9 are received on the T_1 terminals of MACTORS 1, 4 and 9, respectively.

The mactors at this point have idle-path tracing marks on their L_1 terminals and also on their T_1 terminals. Each mactor performs a match of these two marking voltages and thereby indicates the idle or busy status of the corresponding path between the desired line and trunk. Assuming that the match indicates the path to be idle, each mactor energizes its portion of the common transistor lockout circuit. The lockout circuit is designed so that only one transistor can remain in the conducting state. In this case, we will assume that it is the transistor in MACTOR 9 which conducts and selects the path, and that MACTORS 4 and 1 are locked out. MACTOR 9 then shorts out resistance in series with its L_1 and T_1 terminals, thereby operating the 4 reed-diode crosspoints in its associated line to trunk path. The operated path is the one running across the top of Fig. 14 whose central link extends between LINE SECONDARY SWITCH 9 and TRUNK SECONDARY SWITCH 9. The operation of the various crosspoint relays comprising this path establishes a metallic holding path between ground on the line end of the connection and −48V on the trunk end of the connection. The various enabling and marking voltages which were applied to the switching network by the switching sequence and number group circuits are now removed. Removal of these voltages causes the various gas tubes shown on Fig. 14 to de-ionize and restore to normal, while the newly operated path remains locked up to the −48V battery.

When it is desired to release the connection after the conversation is completed, the trunk number group is operated. Referring to Fig. 14, the trunk to be released is selected by the application of −85V to terminal TFV 74 and +130V to terminal TS 15. These two voltages operate a trunk number group element shown at the top right of Fig. 14. Then the switching sequence circuit grounds the TR lead and this ground is passed up the number group multiple, through a contact on the operated number group element, and onto the sleeve lead of the trunk. Ground appearing on the sleeve lead reduces the holding voltage to zero, and the crosspoint relays comprising the path release, freeing the crosspoints and links involved for subsequent use. Ground is now removed from the TR terminal, and the −85V and +130V signals are removed from terminals TFV 74 and TS 15, respectively. The previously operated trunk number group element releases, and at this point the entire switching network and controls are back in the original state.

APPENDIX II

Mactor Operating Cycle

The mactor operating cycle may be followed by referring to Fig. 15. The sequence is as follows:

(1) Anode and cathode enabling voltages of +130V, ground, and −178V are applied by the switching sequence circuit to terminals AE 1, AE 2, and CE 1, respectively.

(2) Through the operation of the appropriate mactor connector the L_1 terminal, and the T_1 and T_2 terminals are associated with control leads from the line frame and trunk frame, respectively, of one of the B links which could be used for the desired connection.

(3) If a particular B link is busy, a potential of about −24V appears on T_1, and hence on the control grid (CG) of V1, preventing transfer of the discharge to the main cathode-anode gap (MC-MA); however, assuming the B link to be idle, ground potential appears on CG via T_1, causing the transfer of discharge in V1 to the MC-MA gap and causing the operation of relay L1.

(4) Operation of relay L1 applies +107V to terminals T_1 and T_2 to enable the control leads associated with the trunk side of the B link and also extends the connection from terminal L_1 down to the start anode, SA, of V2.

(5) Assuming the line half of the path through the switching network to be idle, a path tracing mark of 0 volts (nominal) appears at the normally negative start anode, SA, of V2, initiating a discharge from this electrode to the main cathode, MC.

(6) Discharge in V2 shifts to the main gap (MC-MA), thus operating relay L2.

(7) Operation of relay L2 applies −36V to the main cathode of V4 and also extends the control terminal, T_1, to the start cathode, SC, of V4.

(8) Assuming the trunk half of the path through the SWITCHING NETWORK to be idle, a path tracing mark of −48V (nominal) appears at terminal, T_1, whence it is connected to the start cathode, SC, of V4.

(9) The appearance of −48V on the start cathode, SC, in conjunction with the +130V on the start anode, SA, causes the start gap of V4 to break down.

(10) With the start gap broken down, the discharge in V4 transfers to the main cathode-to-anode gap (MC-MA), operating relay L4,

(11) Operation of relay L4 sends the switching sequence circuit a "match" signal of +107V via the terminal labeled MS, to indicate that the mactor has found its complete line-to-trunk path idle; operation of L4 also places the mactor's transistor in lockout competition with those in other Mactors by energizing the collector of the transistor with −67V.

(12) Assuming that this transistor wins the lockout competition, it will go to the high current condition, and, in doing so, will produce in the common lockout resistor a voltage drop which will prevent transistors in other mactors from reaching the high current condition.

(13) The high current condition produces a negative voltage at the base, b, of the transistor, which negative voltage is passed to the start cathode, SC, of V3, initiating discharge in its start gap (SC-SA).

(14) Discharge in V3 transfers to the main gap (MC-MA), operating relay L3.

(15) Operation of L3 increases the current and causes the crosspoint relays to operate in the line and trunk halves of the selected path through the switching network.

(16) Previously applied enabling voltages appearing at terminals AE 1, AE 2, and CE 1 are removed from the mactor by the switching sequence circuit, interrupting discharges in tubes V1, V2, and V3 and releasing relays L1, L2 and L3.

(17) Release of L2 interrupts discharge in V4 by removing voltage from its main cathode, MC, while simultaneously causing relay L4 to release.

(18) During the release of the various relays, the NE-2 cold-cathode diodes absorb some of the inductively stored energy, thus limiting the magnitude of voltage transients.

(19) After a deionization time of a few milliseconds, the entire mactor is again in its normal state and ready to function on a new call.

(20) Because the connection which was just established remains held up over the sleeve lead's series metallic path, it requires no further servicing from the mactor.

APPENDIX III

DETAILED DESCRIPTION OF SWITCHING SEQUENCE CIRCUIT

Connect Cycle

Refer to Fig. 16, which shows the SWITCHING SEQUENCE CIRCUIT. On "connect" the voltage on the ES lead rises abruptly from approximately +100V to +150V. This causes the control anode of tube V1 to rise momentarily from ground to +50V. Thereupon, V1 fires, conduction transfers to its main gap, and the two mercury contact relays L1 and L2 operate. However, before L1 and L2 operate, the switching number group connector operates and applies the appropriate signals to the information leads of the number group. The operation of L1: (a) enables all the trunk primary switches by applying +37V to the idle C links over the TSE lead, and (b) enables the line and trunk number group decoding tubes of the switching number group circuit by applying +200V to their main anodes over the LNG and TNG leads. Relay L2 applies −178V, +130V and ground to the mactors, +130V to the time-out tube (V3) and +130V to the match tube (V4) and −178V connect mark (TC) to the trunk frames.

If there is at least one idle path available, the mactor or mactors so indicate by applying +107V to the MS lead of the switching sequence circuit. This voltage fires the match tube, V4, which operates relay L4.

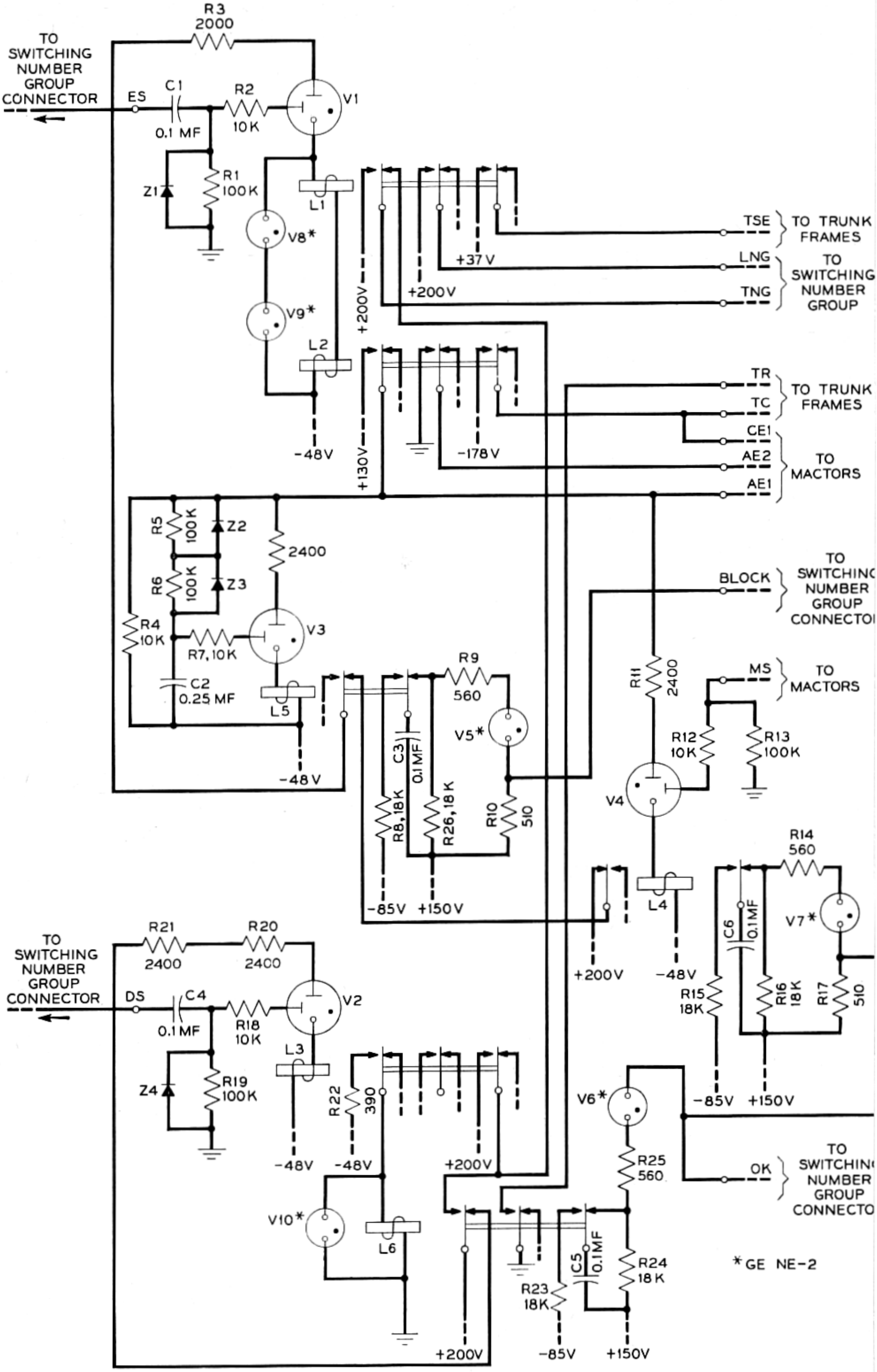


Fig. 16 — Switching sequence circuit.

When relay L4 operates, it removes the +200V from the main anode of V1 and at the same time starts the charging of condenser C6 through resistance R15. Tube V1 stops conducting and relays L1 and L2 release. In releasing, these relays remove the +37V and −178V connect marks from the trunk frames, remove +200V from the switching number group circuit, remove −178V, ground and +130V from the mactors and remove +130V from tubes V3 and V4. During the approximately 7 milliseconds required to operate relay L4 and release relays L1 and L2, the crosspoint relays of the talking path are being operated.

After the switching number group and mactors are disabled and all the "connect" voltages are removed from the switching network, the connection is held up between −48V and ground via the sleeve lead. After relay L2 releases, relay L4 releases, thereby restoring +200V to the main anode of V1. At the same time condenser C6, which had become charged between +150V and −85V (to a total EMF of 235 volts), is discharged through gas diode V7. This discharge current develops a negative voltage pulse across resistance R17 about 60 volts in peak amplitude and approximately 0.3 millisecond in duration. Thus, the voltage on the OK lead drops momentarily from +150V to +90V, and this voltage shift is transmitted via the switching number group connector to the DIAD circuits, indicating that the connection called for has been made and that the switching sequence circuit is back to normal and ready to handle another connect or release.

It is recognized that the match (MS) signal does not furnish a positive check that the path has been closed through from line to trunk. However, since this can be verified later as a part of supervision, it was felt the extra time and increased circuit complexity required to make a positive determination that tip and ring are connected through the switching network was not justified.

In connection with the circuit for generating the match signal, it should be noted that one of the purposes of resistance R16 is to prevent tube V7 from firing when the contacts of mercury relay L4 are "bunched" on operate. (The voltage, being divided between resistances R15 and R16, is not high enough across R16 to break down V7, which has a nominal breakdown of 180V.) Also, R16 completes the discharge of C6 after its potential has dropped below the sustain voltage of V7.

If no complete idle path is available between the line and trunk in question, none of the mactors will be fully operated; that is, none of the L4 relays in the mactors will be operated. Thus, no match signal will be sent out by the mactors and condenser C2 in the switching sequence circuit will continue to charge toward +130V through the series-parallel combination of R5, R6, Z2, and Z3 until the potential across C2 reaches the breakdown voltage of the control gap of V3. This occurs about 25 milliseconds after the appearance of the ES signal. V3 fires, conducts in its main gap and relay L5 operates to perform in the same way as did relay L4 to restore the number group circuit, mactors, and switching network to normal and release relays L1 and L2. Relay L5 also initiates the charging of condenser C3 through resistance R8. Relay L2 in releasing removes voltage from V3, allowing it to de-ionize and relay L5 to release. When L5 releases, condenser C3 discharges through gas diode V5 and a 60V (negative) pulse similar to the OK signal appears on the BLOCK lead to indicate that the connection called for was not made. At the same time, voltage is restored to the main anode of tube V1 and the switching sequence circuit is thus ready to accept another connect or release signal. While relay L5 is releasing, condenser C2 is discharged through resistance R4 and the series-parallel combination of R5, R6, Z2 and Z3.

When the ES signal is removed, that is, the voltage on the ES lead drops abruptly from +150V to +100V, condenser C1 is discharged rapidly due to the low forward conducting resistance of the germanium varistor Z1 in parallel with resistance R1.

The two small gas diodes V8 and V9 which are connected in series across relays L1 and L2 have a nominal breakdown of 90V and are employed to limit the inductive voltage developed by the windings of these relays on release, without substantially increasing the relay operate or release time.

Release Cycle

The indication that a connection through the switching network is to be released is an abrupt rise in voltage on the DS lead from its normal potential of +100V to +150V. This abrupt rise fires gas tube V2 which operates relay L3. Relay L3 (a) applies +200V to the trunk number group and (b) operates relay L6. Before the contacts of relay L6 close, however, the trunk number group functions and the number group element corresponding to the trunk in question is operated. Then relay L6 applies release ground (via a contact on the trunk number group element) to the trunk sleeve terminal. This reduces the holding voltage on the control path of the connection through the switching network to zero, causing the crosspoint relays to release.

The operation of relay L6 also starts the charging of condenser C5 through resistance R23, and interrupts operating current to tube V2 and relay L3. When L3 releases it de-energizes L6 and removes a connection of +200V from the trunk number group. (However, the trunk number group is still receiving +200V through L6.) Relay L6 in releasing: (a) removes release ground from the trunk control terminal, (b) removes +200V from the trunk number group, (c) restores main anode voltage to tube V2 (which meanwhile has become de-ionized) and (d) allows condenser C5 to discharge through gas diode V6 and produce a 60V negative pulse on the OK lead in the same way that the "connect" OK pulse is generated. About a millisecond following the OK pulse, the trunk number group releases. However, the switching sequence circuit is ready to handle another connect or release just as soon as the OK pulse appears, since the trunk number group is restored to normal before any of the relays L1, L2 or L3 could be re-operated on a subsequent ES or DS signal.

The sequence of operation in applying and removing the release ground is designed so that the relatively heavy release current (100 MA) is established and interrupted with mercury contacts instead of reed contacts of the trunk number group element. The release ground is held on the trunk for sufficient time to insure the release of the switching path crosspoint relays.

As in the case of a connect, no positive check of the release of the path is made and for much the same reasons.

The gas diode V10 (nominal breakdown 90V) limits the inductive voltage surge from the winding of relay L6 without substantially increasing either its operate or release time.

APPENDIX IV

DETAILED DESCRIPTION OF SWITCHING NUMBER GROUP CIRCUIT

Decoding

The decoding is accomplished by means of varistor-resistor networks and sensitive cold-cathode gas triodes. For an example, let us look at the Fig. 17, where the line vertical units digit of our skeletonized version is represented by the LV2, LV4 and LV7 leads (5 would be required for a full digit LV0, LV1, LV2, LV4, and LV7). Let us assume that the LV2 and LV4 leads are at +150V, while the LV7 lead is at +100V. Furthermore, let us note the following circuit conditions: (a) the backward resistance of the varistors Z3, Z4, etc. is greater than 100,000 ohms, (b) the forward resistance of the varistors is less than 1,000 ohms, (c) the resistance of the resistors R3, R4, etc., is 0.5 megohm ± 5 per cent, (d) the breakdown voltage of the control gap of the gas triodes LV9, LV6, and LV0 varies from 62 to 89 volts, (e) the impedance of each source supplying voltage to the information leads is approximately 5,000 ohms, and (f) the bias voltage on the gas triodes is +50V ± 3 per cent. Under the foregoing conditions, the control anode of tube LV6 will rise to a potential sufficient to fire the control gap of LV6, while the control anodes of LV0 and LV9 will remain below the potential required to fire their control gaps. While we have supplied only three input leads and three output digits in our skeletonized number group, the circuit operating margins are very satisfactory with a fully equipped digit, i.e., one with five input leads and ten outputs.

It will be noted in Fig. 17 that not all of the information was coded; as for example, the line vertical tens 0 and 5 (LVT0 and LVT5). Since only two numbers out of the possible ten of a digit were actually provided, it was more convenient to fire the number group tens digit tubes (such as LVT0 and LVT5) directly from the +150V on one of the two information leads and omit the decoding network. This arrangement does not detract from the test value of the overall circuit, since the decoding network is being tested adequately in places where three numbers out of a possible ten are used.

Selection

As we have stated before, one of the functions of the number group circuits is to provide a means for selecting and marking the various points in the switching network. These selection circuits: line vertical, line switch, trunk, and mactor connector, are, in effect, digit combining circuits. The line vertical number group, for example, combines tens and units digit information to select one out of a possible 70 line primary verticals which might be provided in a full-sized office. Referring again to Fig. 17, let us assume that the signals on the information leads correspond to LV09. This means that leads LVT0, LV2, and LV7 will carry +150V, and leads LVT5 and LV4 will carry +100V. These voltages fire the start gaps of tubes LVT0 and LV9. When +200V is applied to the LNG lead by the switching sequence circuit, these tubes will transfer, conduct in their main gaps, and operate the reed-contact relays in their respective cathode circuits. Observe that the anode transfer current for digit tube LV9 is conducted through resistors R3 and R4 and varistors Z3 and Z4 effectively in parallel, with the varistors conducting in the backward direction. The circuit has been designed so that each start gap, when fired, receives sufficient current to insure anode transfer, even if the reverse resistance of the varistors is infinite. Relay LV9 applies +130V to the positive side of the LV09 vertical number group element which consists of a diode and reed relay in series. This diode and relay are identical with those used as crosspoint elements in the switching network. Relay LVT0 applies −85V to the negative side of both the V00 and V09 vertical number group elements. The breakdown potential of the diodes is 180V ± 20V; hence, the only tube which receives sufficient voltage to fire is LV09. When LV09's associated reed relay operates, it applies the +130V connect mark on all the line primary switches in the switching network.

The line switch number group operates in the same manner as the line vertical number group. It selects a line primary switch and applies a −85V mark to the control leads of all the outlets of that switch. Instead of marking only one switch on one frame, however, it marks the same numbered switch on all of the line frames. For instance, if the information leads say that the switch in question is LP8 of LINE FRAME 13, the mark is applied to the idle A links of LP8 switches on all of the line frames.

The trunk number group is a four digit selection circuit in which the two digits, trunk-switch tens and trunk-switch units, are combined to select one out of a group of 20 tubes (one out of three in our skeleton version), each of which corresponds to a particular trunk switch. Also the two digits, trunk frame and trunk vertical, are combined to select one out of a group of 100 tubes (one out of 4 in the skeletonized circuit), each of which corresponds to a particular vertical on a particular trunk frame. Then these two primary selection groups of 20 and 100 are combined to select one out of 2,000 trunk number group elements (one of 12 in the laboratory model). Each trunk number group element corresponds to a particular vertical on a particular switch on a particular trunk frame. On a connect, this trunk number group element puts a −178V mark on the control lead of the particular trunk appearance. On a release, a ground release mark is applied to the control lead of the trunk appearance, as described in the operation of the switching network.

In the setting up of a connection, a mactor connector is used to connect the mactors to the line and trunk control leads of the unique group of channels or alternate paths between the line frame and the trunk frame on which the line and trunk in question appear. There is a mactor connector for the group of paths from each line frame to each trunk frame. For instance, in a large system having 20 line frames and 10 trunk frames, there would be 200 such mactor connectors, while in the laboratory version, there are 3 × 2 or 6. The relays and the diode comprising one connector are in series. One relay and the diode are mounted on the trunk frame, while the other relay is mounted on the line frame.

As indicated in Fig. 17, the proper mactor connector is selected by combining line frame and trunk frame information in a manner similar to that employed in the other selecting circuits in the number group. Suppose we desire to connect a line on LINE FRAME 13 to a trunk on TRUNK FRAME

2. We see that relay LF13 applies +130V to a mactor connector appearance on TRUNK FRAME 2 and to a connector appearance on TRUNK FRAME 7, while relay TF2 applies −85V to a mactor connector on each of the three line frames. The connectors and their diodes function as a combining

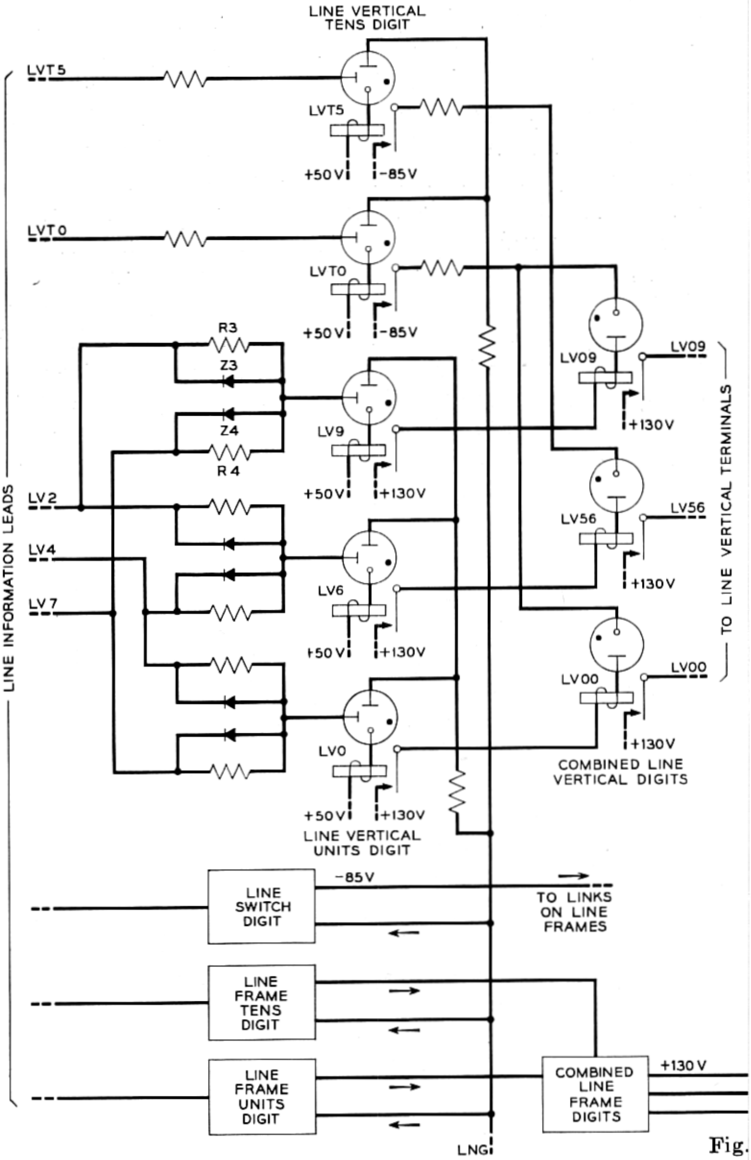
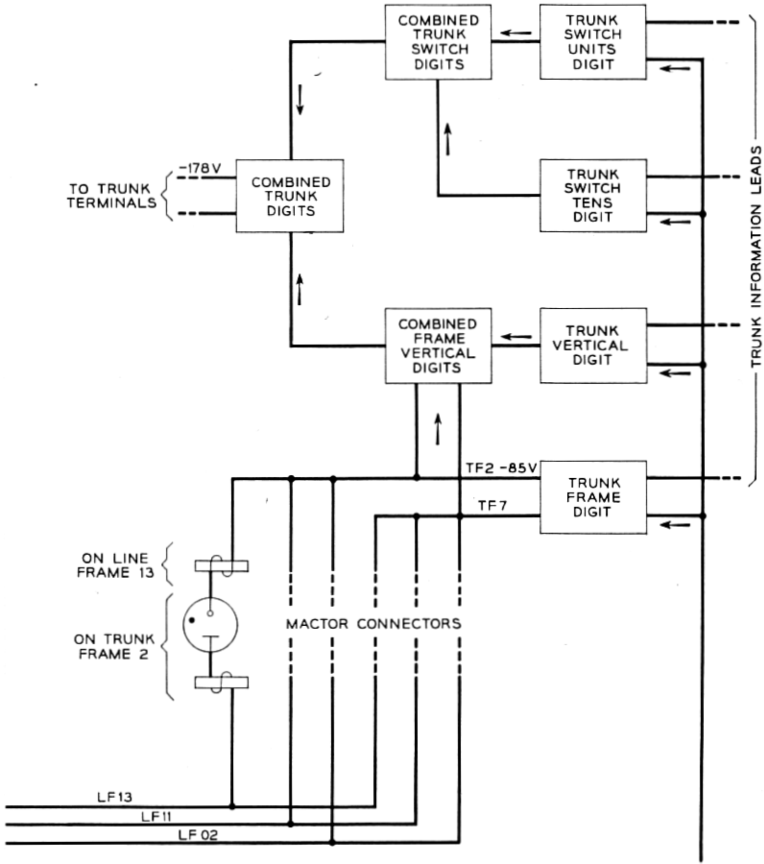


Fig.

matrix; only one connector receives both voltages which are required to fire its gas diode and operate its relays.

When the +200V is removed from the LNG and TNG terminals by the switching sequence circuit, the main gaps of the conducting tubes in the number group circuit are extinguished and the relays which had been operated are released. The only portions of the circuit remaining "on" are the control gaps of those digital tubes which had been originally ionized directly from the signals on the information leads. When the information signals are removed (the potential on all the information leads is returned to +100V), the control gaps of the digital tubes are extinguished and the switching number group circuit is restored to normal.

It will be noted that all of the selections, whether they are 2, 3 or 4



hing number group circuit.

digit, are made with nothing more complicated than gas diodes and triodes and reed-contact relays. In general, a selection of one out of any number can be made in this same fashion with the same simple elements, by breaking up the number into groups of digits and combining them in one or more stages as illustrated in the foregoing paragraphs. The gas diodes, triodes, and reed relays which perform the selection can have wide tolerances on their characteristics which means that inexpensive elements can be employed.

APPENDIX V

POWER SUPPLIES

The power voltages used in the switching network, number group and switching sequence circuits are: −178, −155, −85, −67, −48, −36, −24, −12, +37, +50, +107, +130, +150, and +200. Of these, the −67 volts is obtained by a tap on the −85-volt supply, the −36, −24, and −12 by taps on the −48-volt supply, and the +37 by a tap on the +50-volt supply. These taps consist simply of resistance divider circuits with an adequate capacitive by-pass to ground. The +150-volt supply is associated only with the generation of an OK or BLOCK pulse for transmission from the switching sequence circuit to the switching information section of the DIAD. Since the switching information section of the DIAD uses +150 volts also, no separate source is provided on the switching bays. This leaves eight separate power supplies to consider. One of these, the −48-volt supply, is a heavy-duty, regulated rectifier in our laboratory model; however, all of the circuit design has been based on the use of standard −48-volt office battery with limits of 44 to 50 volts. The other seven supplies are small-capacity regulated rectifiers. These supplies are assumed to have a variation in output voltage due to all causes of ±3 per cent. Because of the one-at-a-time nature of the control, the peak load on the power supplies does not increase as the size of the office increases, so that the present supplies have sufficient capacity to handle the largest presently used switching networks. The one exception to this statement occurs in the case of the −48-volt supply which is used for holding the path operated and to supply talking battery. The loads due to these two functions have peaks which are directly proportional to the number of simultaneous conversations. It should be mentioned, however, that the holding power for the reed-diode switching network is only one-half watt per path for the four stages.