Transistors and Their Circuits in the 4A Toll Crossbar Switching System

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NATION-WIDE dialing is one of the more recent advances in the telephone art and has been the subject of papers presented before the AIEE.[1] The heart of nation-wide dialing is the new no. *4A* toll crossbar switching system. It is this system which, at the various control switching points, receives the digits dialed by the toll operators or by the subscribers. It then automatically determines the routing of the call to any destination in the United States, as well as in Canada, and proceeds to establish the connection to succeeding control switching points or to the local office. In this system it is necessary to translate the digits received into information as to the location of trunks on the switches, the kind of outpulsing required, the number of digits to send forward, and other such instructions.

The translator needed for the no. *4A* system must have a large capacity, for it has to be capable of furnishing the information to route a call to any one of thousands of central offices in the United States and Canada. As frequent changes are made in the routing of calls due to the growth of the system and modifications of central offices, corresponding changes must be made in the routing information at the control-switching points. It is therefore necessary to be able to quickly and economically change the routing information pertaining to any given set of input digits. In short, the translator must perform functions similar in nature to those accomplished by quick reference card files.

In order to meet these requirements it was necessary to develop a new type of translator[2] radically different from any previously used. Its operation is based on selecting a particular card from a stack of cards in accordance with the input digits. It obtains the routing information from the output code registered on the card. To determine this output code the translator depends upon that revolutionary new device, the transistor. The purpose of this paper is to describe the transistor and its circuits, as used in the card translator.

Fig. 1 shows a card with the output information registered on it in the form of enlarged holes. In the translator this card stands in a vertical position, resting on the tabs along its lower edge. When all cards are in their normal position, they line up and the holes in the cards form unobstructed, horizontal tunnels, called channels, through the entire stack. The tabs on the lower edge of the card correspond to the input digits for which this card supplies the routing information. A particular card is selected by automatically lowering the support from under its tabs thus allowing it to drop a distance slightly greater than the height of an unenlarged hole. All channels through the stack of cards will then be blocked by the dropped card except those for which the holes in the card have been enlarged. This results in a pattern of clear channels which represents the output information. Determination of whether a channel is clear or blocked is made by passing light beams through the holes. Fig. 2 illustrates the change from all cards normal to one card dropped.

The Channel Circuit

Fig. 3 is a block diagram of the circuit used to determine whether a particular channel is interrupted by a dropped card or not. Each block, with the exception of the light source, represents a piece of equipment provided individually for each channel. The light source is common to all channels. If the hole in the dropped card for a particular channel has been enlarged, the light will pass completely through the stack of cards and fall on the phototransistor. The phototransistor converts the presence of light into an electrical signal which, after being increased by the transistor ampli-

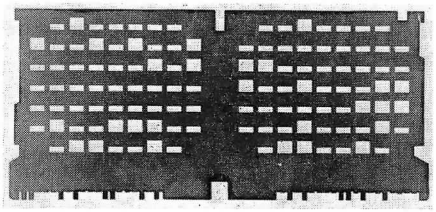

Fig. 1. Translator card showing tabs used for selection, and the enlarged holes representing routing information

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Paper 53-218, recommended by the AIEE Communication Switching Systems Committee and approved by the AIEE Committee on Technical Operations for presentation at the AIEE Summer General Meeting, Atlantic City, N. J., June 15–19, 1953. Manuscript submitted March 17, 1953; made available for printing April 23, 1953.

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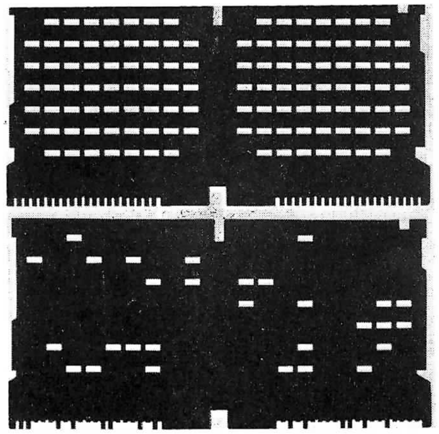
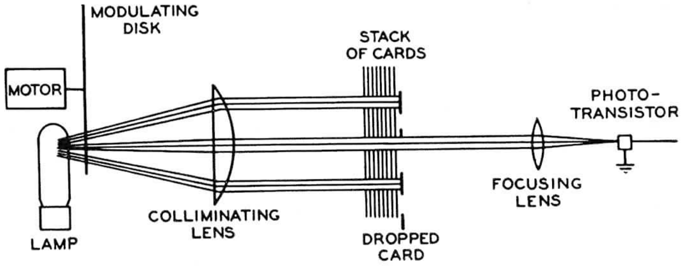


Fig. 2. End view of the stack of cards. The upper section shows all cards normal, the lower shows one card selected and dropped

Fig. 4 (right). Optical section of channel circuit



fier, is used to trigger a cold-cathode gas tube. The gas tube, in turn, operates the channel relay. This relay is located in the associated equipment which uses the information supplied by the translator to actually process the call.

In making a detailed examination of the channel circuit it is convenient to break it down into two parts, the optical section and the electrical. The optical section includes everything up to the point where the light falls upon the germanium of the phototransistor. This part of the channel is shown functionally as Fig. 4. The light source is a standard projection-type lamp normally rated at 500 watts. To obtain long life it is operated in the translator at half voltage at which level its input is approximately 170 watts. This type of lamp was chosen because of its high concentration of light in a small plane.

The light from the lamp passes through a motor-driven perforated disk which modulates it with an approximate square wave at a 400-cycle rate. Modulated light is used because it is easier to build a-c than d-c amplifiers, and also, in this manner, the ratio between the light and dark currents of the phototransistor is the important factor rather than the absolute value of either. The modulated light is collimated by a lens to minimize the loss as the beam passes through the holes in the card. Unless interrupted by a dropped card, this light beam will pass through all of the cards and fall on the lens which focuses the light on the sensitive area of the phototransistor. The minimum light intensity at the lens of the phototransistor is 34 foot-candles. This supplies about 12 millilumens to the phototransistor, a figure relatively small when compared to the light intensity required by conventional photoelectric cells. The electrical part of the channel circuits starts with the phototransistor and is shown in Fig. 5. The light acts as the emitter of the phototransistor. The collector is of the conventional type for point-contact transistors.

As is normal in grounded-base transistor circuits, the collector of the phototransistor is biased in the high impedance direction. A variation in the light intensity causes a variation in the collector impedance of the phototransistor. The type used has an impedance of about 10,000 ohms when dark, which is reduced to approximately 3,000 ohms when illuminated. The output of an illuminated phototransistor, when coupled to the amplifier, ranges from 1.3 to 12 volts, positive peak (400 cycles), depending upon the age and condition of the transistor.

Since the discrimination by the channel circuit between a clear or blocked light path depends upon the presence or absence of an a-c output from the phototransistor, noise of sufficient magnitude, if present when the channel is dark, would cause a false indication. To guard against such false operations the Western Electric Company, during the manufacturing process, checks each phototransistor for dark noise. If during a 5-minute interval the dark voltage exceeds 20 millivolts, that phototransistor is rejected.

The phototransistor is coupled to the amplifying transistor by transformer *T1*. This permits convenient matching of impedances and separation of the d-c bias voltage. A voltage-limiting varistor *V* is connected across the input of the transformer to limit surges which might otherwise damage the amplifying transistor. The circuit of the transistor amplifier is a conventional common-base arrangement.

The voltage gain of the amplifier, including the input transformer to the gas tube, ranges from 40 to 100. However when operating in the translator, the phototransistors normally will drive the amplifier to saturation, which limits the output to 160 volts positive peak or less. For the purpose of guaranteeing operation a minimum output voltage of 38.5 has been set as a rejection point for a phototransistor-amplifier combination.

The output of the transistor amplifier is normally sufficient to break down the control gap of the *376B* cold-cathode gas tube. Sufficient current flows in this control gap to insure reliable transfer to the main gap when the output control relay *O* in the associated equipment operates. But to provide greater operating margin, the bias of −24 volts is removed from the control anode just before channel operation is required. The relay *R*, which substitutes ground for the bias voltage is operated by a circuit which checks that the card being dropped is completely down. This down-check circuit utilizes two holes in the card which are never enlarged and employs two photo transistors to detect the presence or absence of light through these holes.

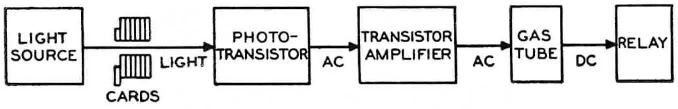


Fig. 3. Block diagram of channel circuit

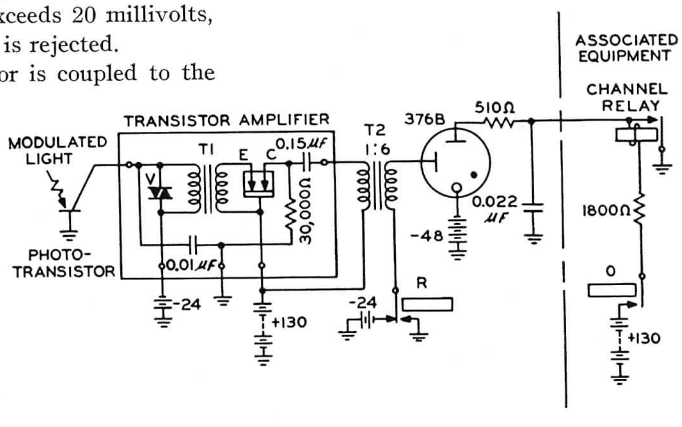


Fig. 5. Electrical section of channel circuit

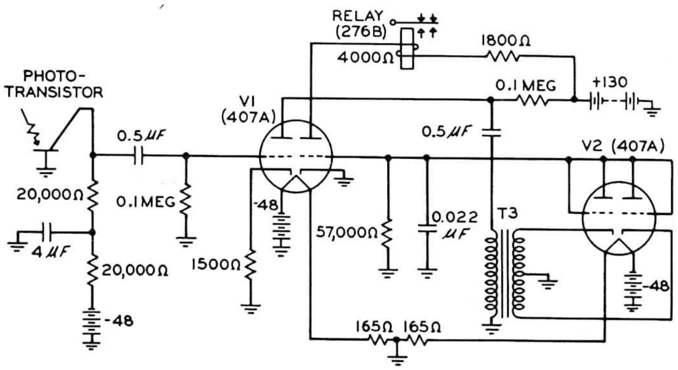


Fig. 6. Card-down check circuit

Fig. 6 shows the card-down check circuit. It differs from the routing-information channel circuits in that the operation of a relay is required when the light is blocked. Therefore the transistor amplifier-gas tube circuit is not applicable. For the down-check channels, the output of the phototransistors is amplified by the first section of a conventional double-triode thermionic-emission tube *V1*. The a-c signal at the plate of *V1* is rectified by a conventional full-wave rectifier consisting of transformer *T3* and tube *V2*. The rectifier voltage is negative with respect to ground and when it is impressed on the grid of the second section of tube *V1*, that section is driven past cutoff. Therefore, as long as light falls on the phototransistor, no current flows through the relay. When the dropped card blocks the light, the negative voltage on the grid disappears and the tube conducts, thus operating the associated relay. While the prime purpose of this down-check is to signal the associated equipment that the card is in position for recording its output code, advantage is also taken of this circuit's ability to distinguish between a light and dark phototransistor at any time to provide alarms in the event of a lamp or modulating disk failure.

After the card has been checked down and the associated equipment is ready to accept the output of the card, that equipment connects a positive 130-volt battery through its channel relays to the main anodes of the gas tubes. All gas tubes associated with illuminated channels will have their control gaps broken down and will transfer to the main gaps. This operates the corresponding channel relays in the associated equipment. The relays, in operating, lock to ground and thereby extinguish the main gap discharges, thus increasing the life of the gas tubes. Those channels which have been blanked out will not have the control gaps of the gas tubes broken down. Therefore when the 130 volts is applied, the relays associated with the darkened channel will not operate. The operation or nonoperation of the relays in the associated equipment completes the function of the channel circuits.

The capacitor and resistor network at the main anode of the tube is to prevent transients due to the operation of other channels from falsely breaking down the main gap of a dark channel.

Channel Packages

The phototransistor is mounted in a tube along with a lens which focuses the colliminated light on the transistor. Fig. 7 is a cutaway view of the *3A* phototransistor showing the relationship of the lens to the transistor. To mount in the translator, the tube is slipped into an accurately positioned hole and clamped in place, using the slotted ear. This mechanical fastening is also the ground connection. The output lead from the collector is attached with the use of a slip-on connector.

The amplifying transistor, transformer *T1*, varistor *V*, the resistor, and two capacitors of the amplifier are packaged as a convenient plug-in unit. Fig. 8 shows these transistor amplifiers. As shown the transistor is mounted under a removable cap on the package so that it may be conveniently replaced if necessary.

The gas tube, transformer *T2*, and the associated resistor and capacitor are also assembled as a packaged unit.

Transistor Performance Tests and Data

Like all classes of devices, transistors have certain characteristics which determine their suitability for any given application. In the card translator, the size advantage as compared to electron tubes was, of course, valuable. However, their ability to work at very low power levels and their relatively long life were the most important factors in their selection. Exactly how sensitive they were and what was their life had to be determined. Also transistors are not free from noise and, in addition, they are known to be affected by temperature. The effects of both these parameters on the ultimate performance of the card translator also had to be evaluated.

The reliability of the transistor circuit was the first and most important question to be answered. To test for this, three card translators were installed in the laboratory and equipped with a total of 272 channel circuits. These translators were connected in the normal service manner to standard associated *4A* crossbar system equipment. Then call after call was sent through the system. In all, 28,000,000 translations were made, each translation requiring the operation of many channels. Only one failure to operate occurred during these translations which might be ascribed to a failure of a channel circuit. The reliability of the circuit was thereby well established.

During the time the tests for reliable operation were continuing, the effect of the internal noise of the two types of transistors was being investigated. Noise produced by the phototransistor would be the more critical of the two as it would be amplified. If the noise was great enough, false operation of a channel relay would result. No false operations due to transistor noise were observed. To obtain data on whether there was margin against the

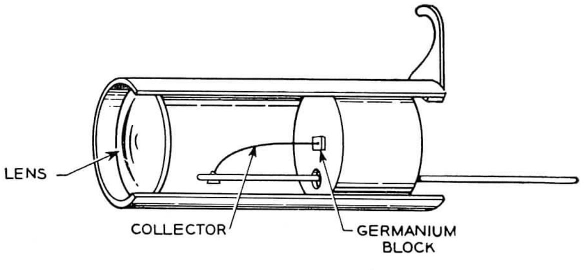


Fig. 7 (left). Cutaway view of phototransistor

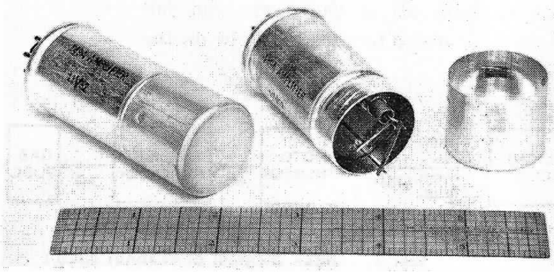


Fig. 8 (right). Transistor amplifiers

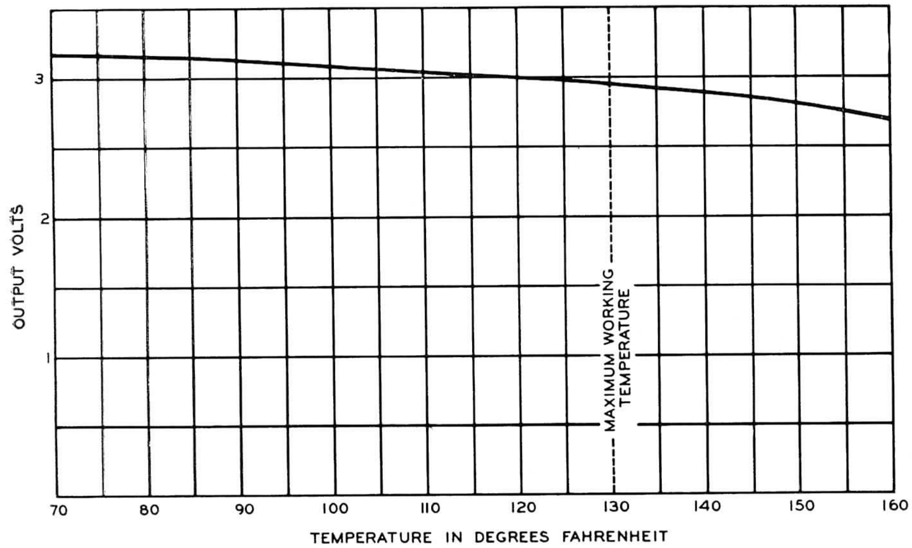


Fig. 9. Average temperature-output voltage characteristic of a phototransistor

effect of noise, several phototransistors which normally would be rejected by the Western Electric Company because of their noise voltage were installed in the translator. There was no adverse effect.

Temperature is one of the important parameters which affects the performance of transistors. Since the translator has powerful electromagnets working in close proximity to the phototransistors, there is a distinct heat rise, which had to be carefully considered. The *3A* phototransistor has an upper limit for reliable operation of 130 degrees Fahrenheit. This is not necessarily typical of other phototransistors and is lower than the temperature limit applying to the amplifying transistors. Fig. 9 graphs the change in output voltage of the *3A* phototransistor with respect to temperature. The output voltage of the transistor amplifier has approximately the same percentage change over the same temperature range. Tests for reliable operation were made on 96 of the channel circuits under temperature conditions corresponding to the maximum expected in service, and were found completely satisfactory.

While the reliable operation of the channel circuits under all conditions which might be encountered in service was of prime importance, the life of the transistors will have great effect on the cost of the apparatus and maintenance. Therefore 96 channels were subjected to a series of measurements designed to determine the effect of aging on the transistor elements. For this purpose a test set was used which was arranged to place the worst circuit condition on the transistor equipment that will occur in service. It was equipped to make output voltage measurements of the phototransistors and the transistor amplifiers.

The results of the series of output voltage measurements were subjected to the usual statistical analyzation method. This showed that the performance with age of the transistor elements fits the normal distribution curve. Fig. 10 is an average curve of the output voltage of a group of 96 phototransistors as they change with time. The months in operation represent the total integrated elapsed time during which the phototransistors were exposed to light with all voltages applied. The first group of points on the curve and the group ranging from the 6-month point on were obtained from two separate groups of phototransistors. The two solid lines are curves based on actual measurements. The dashed portion of the curve is based on the assumption that both groups age in the same manner.

The output voltage measurements of the amplifiers were the outputs of particular phototransistor-amplifier combinations. The average change of a group of 96 pairs in the output voltage with time is shown in Fig. 11. Again the first and last groups of points represent two different lots of transistor equipment.

Maintenance in Service

Although every effort has been made to insure the reliability of operation of the card translator and its associated equipment, it is not considered enough in the Bell System to depend solely on the reliability of equipment. It is important to determine, in advance of service failure, whether any element is becoming weak and to take corrective action before actual failure occurs. This is particularly true when devices which approach their end of life gradually are used. The transistor is such a device.

In the card translator this philosophy of preventing service troubles is carried out by periodically making a marginal test of the channel circuits. To accomplish this test the intensity of the light falling on the phototransistors is reduced and the associated equipment is used to check for channel operation. No card is dropped for this test; therefore no channel is blocked off and every channel relay should operate. A record is made by means of the associated equipment showing the channels which operated.

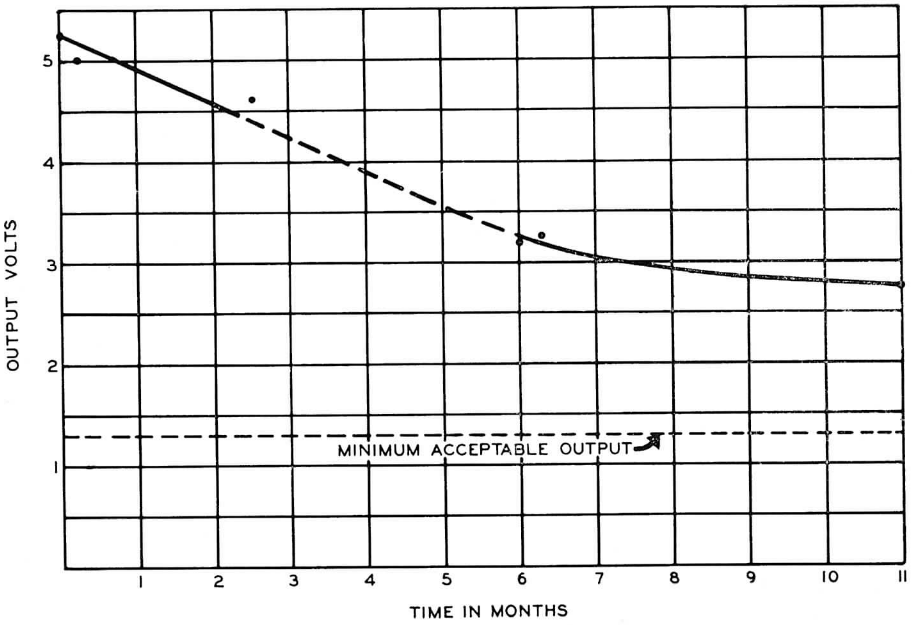


Fig. 10. Average output voltage of 96 phototransistors

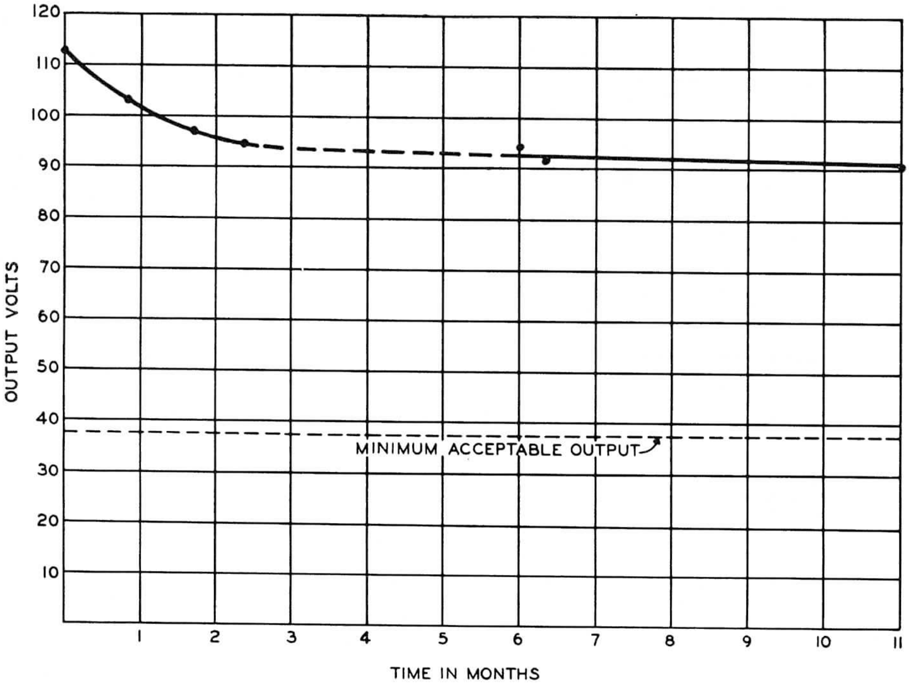


Fig. 11. Average output voltage of 96 phototransistor-amplifier combinations

An examination by the testman of this record will disclose any failure under this test condition.

Although this marginal test will disclose any channel approaching end of life gradually, there always remains the possibility of a sudden failure of some component during service operation. Such a failure will automatically cause a card record to be made of the conditions existing at the time of failure. If this record is caused by maloperation of a channel circuit, it will disclose which one failed thus permitting prompt corrective action to be taken. In the event this trouble occurred on a service call, the system is so arranged that the call will be completed using alternate equipment.

To determine which element has failed when an unsatisfactory channel is detected, the output voltages of the phototransistor and the amplifier are checked against the minimum values permitted and the weak unit can thus be isolated.

Conclusion

The test results show that the transistors and their circuits as used in the card translator are reliable. In addition, their service life appears to be satisfactory. The combination of these two characteristics is a vital factor, especially in view of the key function that translators perform in the *4A* toll switching system. The confidence with which this circuit is regarded is indicated by the fact that over one hundred translators will have been shipped to jobs by June 1, 1953. These installations represent the first commercial application of transistors in the Bell System.

References

1. Crossbar Toll Switching Systems, **L. G. Abraham, A. J. Busch, F. F. Shipley.** *AIEE Transactions* (*Electrical Engineering*), vol. 63, June 1944, pp. 302–09.

2. Automatic Toll Switching Systems, **F. F. Shipley.** *AIEE Transactions*, vol. 71, pt. I, Sept. 1952, pp. 261–69.

No Discussion