Dual Voltage Operation of Relays and Crossbar Switches

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(Manuscript received June 27, 1955)

The operating speed of a relay or switch varies with the amount of electrical power supplied to it. For a given device, the speed can be increased by raising the voltage. Since the electrical energy is converted to heat, the speed is usually limited by the heat dissipating characteristics of the device.

A means for operating relays and switches on high voltage and then changing the circuit to hold them operated on low voltage is described. The circuit is switched by means of a solid state junction diode.

Reduction of relay operate times to half their former values, and reduction of switch operating times to one-third their former values can be obtained with commercial circuits. The wire-spring markers of the No. 5 crossbar system are equipped with dual voltage circuits for speeding the operation of the crossbar switches of the switching network.

I. INTRODUCTION

Making a connection from a customer's telephone to any of the other fifty million telephones in the United States requires a large and complex data processing or switching system. The equipment for this switching system is located in thousands of telephone central offices throughout the country. The equipment in a modern telephone central office may be listed within one of two catagories, the equipment which provides the "talking" or transmission connections through the office, and the control equipment which selects and controls these connections for the talking transmission facilities. Telephone switching offices in which the control equipment has been centralized are labeled "common" control switching offices since the centralized control equipment is available and used "in common" by all of the customers of the office.

In these common control switching offices information which is received from the calling customer is stored in "memory-mechanisms". Other memory devices store information about the switching network which is needed for routing the call to the called customer. A few common control circuits interpret the stored information, test for idle connecting paths and operate the switching mechanisms needed to establish a transmission interconnection from the calling customer's telephone to the called customer's telephone. Where the called customer is associated with another telephone central office, a transmission connection to this distant office is selected and information is transmitted through this transmission connection so that the distant office may complete the connection to the called customer.

The number of operations required of the common control equipment is determined by the total number of interconnections for which this common control equipment must provide the control facilities. Therefore, the number of common control units which will be required will increase or decrease as the rate of interconnections is increased or decreased. However, the number of common control units required will depend upon the speed of operation of each of these common control units. The greater the speed of operation, the smaller the number of common control units which are necessary. If this common control equipment can be made to operate fast enough, a single control unit would be sufficient for an entire switching office. Therefore, there is a strong economic incentive to develop fast operating control circuits.

One of the most complex and costly control circuits in a modern switching office, such as the No. 5 crossbar office, is designated a marker. A typical No. 5 crossbar office would require 6 markers or 20 frames (23 inch) of marker equipment.

Although this marker guides hundreds of separate actions it is fast in its operation, requiring less than half of a second to serve each customer's call. If the marker operation could be made faster, fewer markers would be required. It has been estimated that if its operation could be speeded by a factor of 10 then only one marker could handle the traffic for a large office. Therefore, the cost of a switching office is not only dependent upon the manufacturing and maintenance costs of relays and crossbar switches but also upon their operating speed.

To build fast operating markers, the basic building blocks of the switching office must also be fast operating. In a No. 5 crossbar office two basic building blocks are the electromagnetic relay and the electromagnetic crossbar switch which are shown on Figs. 1 and 2. A typical office would contain about forty thousand relays and a thousand crossbar switches. Four million relays and a hundred thousand switches are capable of serving about one million customers using No. 5 crossbar offices.

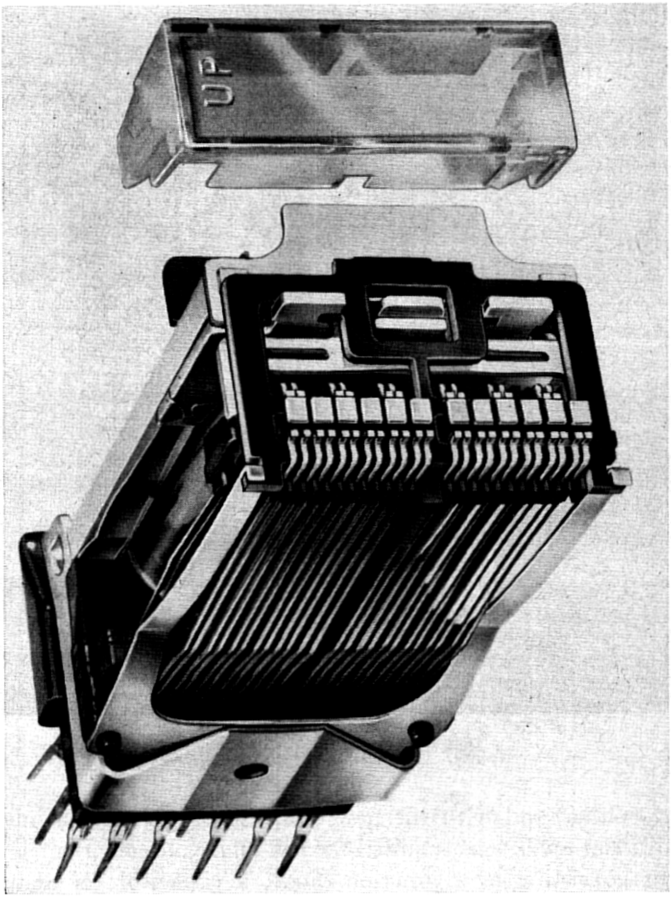

Fig. 1 — Modern telephone type relay known as type AJ or AF.

To achieve faster operating relays and crossbar switches a new dual voltage circuit has recently been developed. With the dual voltage circuit, a high voltage will be momentarily applied to the magnet of a relay or crossbar switch, producing a very fast operating device. The high voltage, which is obtained from a capacitor which has been precharged to this high voltage, will be applied during the operation of the relay device. A short time after the crossbar switch or relay operates, a germanium junction diode will automatically switch from the high-voltage capacitor circuit to the standard voltage (48 volts) for holding operated the device. Crossbar switch or relay operating circuits with the usual

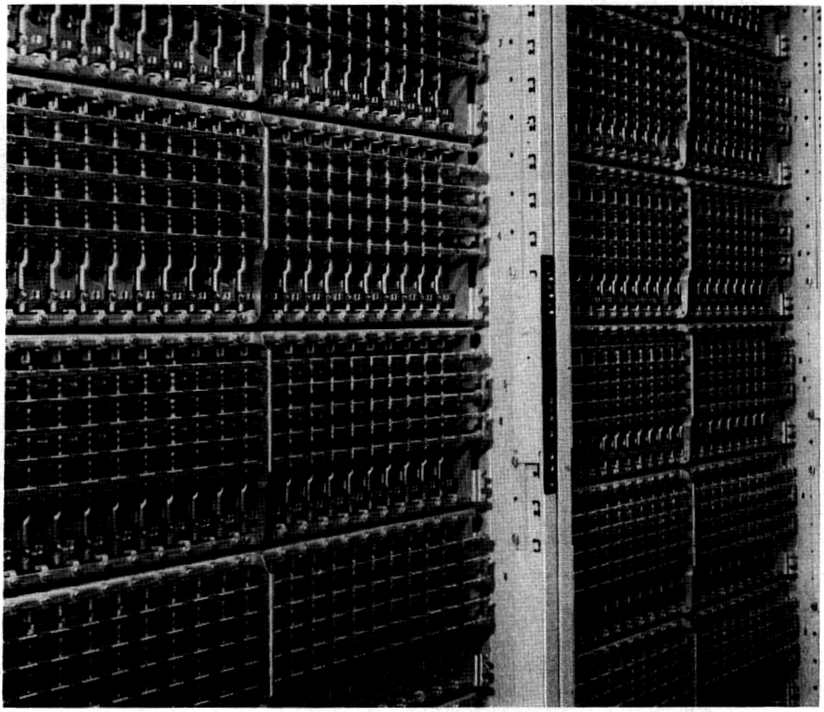

Fig. 2 — Crossbar switches.

constant voltage and with the new dual voltage are shown in Fig. 3. The additional apparatus required for the dual voltage circuit is a compact unit consisting of a junction diode, a capacitor (of about 4-mf capacity) and a resistor as shown in Fig. 4.

Without the new dual voltage circuit, the operating time of a typical crossbar switch hold magnet is 0.055 second or for a typical wire-spring relay, it is 0.0055 second. With this dual voltage circuit the crossbar switch hold magnet will operate in 0.018 second, which is about one-third of its former operate time, and the relay will operate in 0.0029 second, which is about one-half of its former operating time.

The dual voltage circuit is now in use for fast operation of crossbar switch hold magnets of No. 5 crossbar offices. Fewer markers are necessary with the faster operating crossbar switches and faster markers. The dual voltage circuit causes a small increase in the cost of markers but this is insignificant compared to the saving resulting from fewer markers. It is expected that the future application of the dual voltage circuit to relay circuits and to other types of switching offices will produce additional savings. Table I shows the gain in speed which can be obtained with typical telephone relays.

II. FUNDAMENTALS OF SWITCHING RELAY OPERATION

It is a well known fact that the operating time of a crossbar switch or relay will decrease, as the voltage applied to the magnet winding is increased or as the resistance of the magnet winding is decreased. For en-

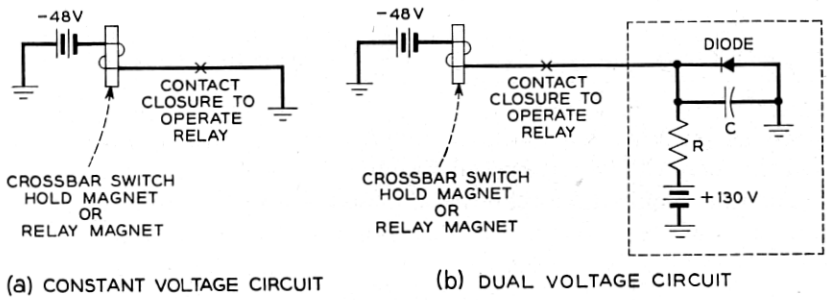

FIG. 3 — (a) Constant voltage circuit. (b) Dual voltage circuit.

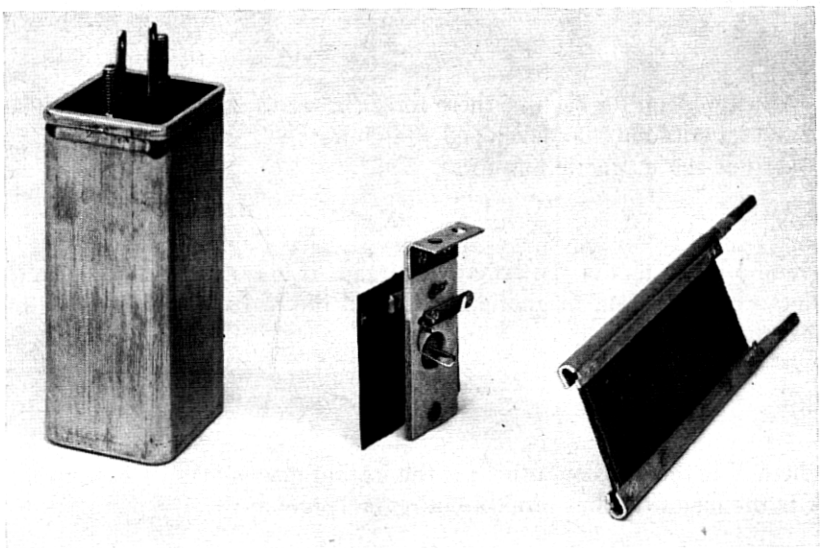

FIG. 4 — The apparatus of a dual voltage circuit.

TABLE I — COMPARISON OF OPERATING SPEED OF TYPICAL RELAY DEVICES

Type	Relay Device		Operate Time Milliseconds		Per Cent Operate Time Saving
	Magnet Resistance in Ohms	Magnet Turns	With Constant Voltage Circuit	With Dual Voltage Circuit	
Crossbar switch hold magnet	1250	14,000	55.0	18.0	67
Wire spring relay	16	1,580	3.3	1.7	49
Wire spring relay	270	2,110	5.5	2.9	47
Wire spring relay	700	5,050	11.0	4.2	62
Wire spring relay	2500	19,400	15.0	6.0	60
Flat spring relay	400	5,300	10.6	4.6	57

gineering purposes a quantitative relationship of relay operating time and the relay characteristics is desirable.

The time required for operating the relay armature will depend upon the forces which are applied to the armature, the greater the resultant force the smaller the operating time. Under dynamic conditions there are three forces which are acting upon the armature, the operating force due to the magnetic flux F_ϕ, the restraining spring forces, F_{RS}, and the armature mass inertia force, F_M. The resultant of these forces must be zero, therefore:

$$F_\phi - F_{RS} - F_M = 0$$

An expression for each of these forces in terms of the circuit or relay characteristics may be developed as follows:

(a) For the magnetic flux force, F_ϕ:

$$F_\phi = K_1\phi^2$$

where ϕ is the flux of the armature airgap. If it is assumed that the reluctance of the iron magnetic circuit and the leakage flux is negligible then:

$$\phi = \frac{K_2 N i}{X}$$

where N is the magnet turns; i is the instantaneous magnet current and X is the instantaneous armature airgap. Therefore:

$$F_\phi = K_3\left(\frac{Ni}{X}\right)^2$$

(b) For the restraining spring force, F_{RS} :

For a typical relay it may be assumed that the restraining spring force increases directly as armature airgap decreases or:

$$F_{RS} = \frac{K_4}{X} + K_5$$

(c) For the armature mass inertia force, F_M :

$$F_M = M \frac{d^2X}{dt^2}$$

where M is the armature mass.

Therefore the equation:

$$F_\phi - F_{RS} - F_M = 0$$

May be written as:

$$K_3 \left(\frac{Ni}{X}\right)^2 - \frac{K_4}{X} - K_5 - M \frac{d^2X}{dt^2} = 0 \qquad (1)$$

This is known as the mechanical differential force equation of a relay. This equation by itself cannot provide a relationship between the instantaneous armature airgap X and time t since the electrical current i is an unknown factor. Therefore, to define the electrical current i it is necessary to develop an electrical differential equation as follows:

$$iR + N \frac{d\phi}{dt} - E = 0$$

where R is the circuit resistance and E the continuously applied voltage.

Since $\phi = \dfrac{K_2Ni}{X}$

$$iR + K_2N^2 \frac{d\left(\frac{i}{x}\right)}{dt} - E = 0 \qquad (2)$$

The dynamics of electromagnetic relays are governed by these two differential forces (1) and (2) one electrical and one mechanical. These basic equations are identical with those of other electromechanical transducers, such as loudspeakers.

An approximate solution of the two differential equations which is suitable for some engineering purposes for electromagnetic devices has been provided by R. L. Peek, Jr.* It defines the operating time as follows:

$$t \text{ (time)} = K_6 \left(\frac{E^2}{R}\right)^{-1/3} + K_7 \left(\frac{E^2}{R}\right)^{-1} \qquad (3)$$

The constants K_6 and K_7 are determined by the mechanical, magnetic and electrical structure of the relay device. Relay devices with different mechanical, magnetic or electrical structure will be defined by equations with different constants of K_6 and K_7. Two relays with identical mechanical and magnetic structure, but with different magnet coils, may be defined by the same constants K_6 and K_7 if the coil constant, which is N^2/R, is the same for both relays.

A typical crossbar switch hold magnet which consists of 14,000 turns with 1,250 ohms resistance operates in 0.055 second with 48 volts applied and operates in 0.014 second with 178 volts applied from a constant source. The actual experimental operating times, as a function of E^2/R, are shown in Fig. 5. These experimental data closely approximate the equation:

$$t = 0.03 \left(\frac{E^2}{R}\right)^{-1/3} + 0.05 \left(\frac{E^2}{R}\right)^{-1}$$

where t is expressed in seconds. For any type crossbar switch hold magnet for which the coil constant, N^2/R, is $14{,}000^2/1{,}250$, the operating time

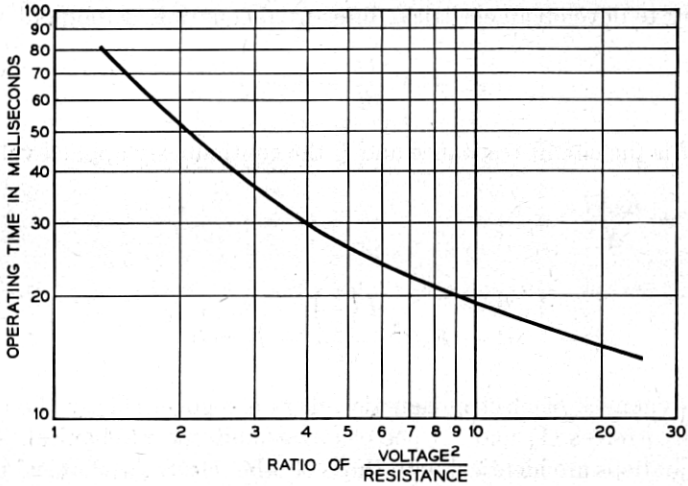

FIG. 5 — Crossbar switch hold magnet operating time.

* R. L. Peek, Jr., Estimate and Control of the Operate Time of Relays, B.S.T.J., **33**, Jan., 1954.

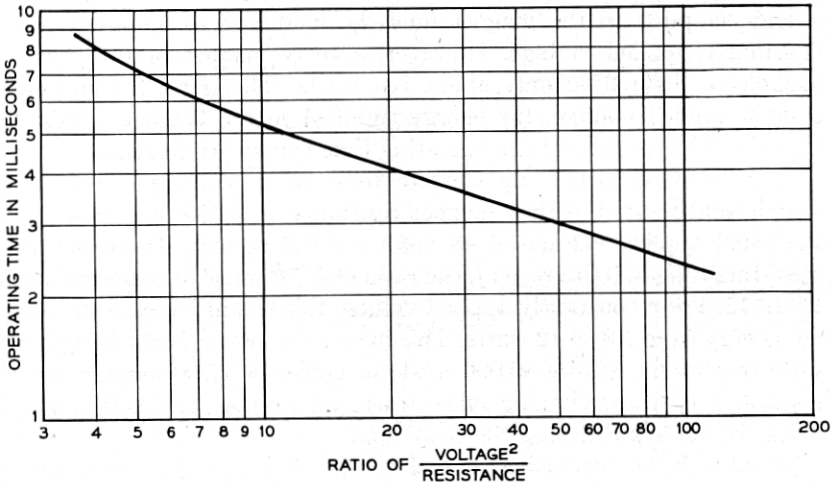

FIG. 6 — Relay operating time.

for any applied voltage and for any coil resistance may be evaluated from Fig. 5.

A typical relay of the wire-spring type which consists of 2,110 turns with 270 ohms resistance operates in 0.0055 second with 48 volts applied and operates in 0.0023 second with 178 volts applied from a constant source. The actual experimental operating times, as a function of E^2/R, are shown in Fig. 6. These experimental data very closely approximate the equation:

$$t = 0.01 \left(\frac{E^2}{R}\right)^{-1/3} + 0.005 \left(\frac{E^2}{R}\right)^{-1}$$

where t is expressed in seconds.

For any wire-spring type relay (with intermediate travel) for which the coil constant, N^2/R, is 15, the operating time for any applied voltage and any coil resistance may be evaluated from Fig. 6.

III. THE DUAL VOLTAGE CIRCUIT

The operate time is 0.0055 second for the wire-spring type relay with a coil resistance of 270 ohms when the usual voltage of 48 volts is applied. If it is desired to reduce this operate time to 0.0029 second, as an example, the ratio of E^2/R must be increased from 8.5 to 55. For a constantly applied voltage the ratio of E^2/R has the dimensions of power in watts. Therefore, to decrease the operating time to 0.0029 second, the energy supplied to the magnet must be increased to 55 watts for a constantly applied voltage. However, a relay magnet of this type is capable of dissipating only about ten watts. Therefore, for any constantly applied voltage, the energy supplied to the magnet cannot be materially increased and the operating time cannot be decreased.

As mentioned earlier, the operate time for a type typical crossbar switch hold magnet with a magnet resistance of 1,250 ohms and with the usual applied voltage of 48 volts is 0.055 second. To reduce this operating time to 0.018 second, the ratio of E^2/R must be increased from 1.8 to 12. For a constantly applied voltage this would increase the magnet energy from 1.8 to 12 watts. This increase in power is not acceptable since this would require 80,000 watts of power or 1,700 amperes at 48 volts in a typical switching office where an average of 6,800 magnets would be energized during the busy hour.

To decrease the operating time of a relay or switch it is necessary to abandon the restrictive concept of circuits with only one voltage. Instead, the basic requirements of a fast operating device dictate that two different or dual voltages be used for energizing it. Several years ago J. C. Rile suggested that a circuit of this type could be used to improve the operating times of switches in crossbar systems.

With dual voltage operation a voltage of large magnitude is momentarily applied to the magnet. The magnitude of this momentarily applied voltage will quickly decay and will be supplanted by a lesser voltage which will be constantly applied to the magnet to hold the relay or switch operated until it is to be released. In this way, the operating speed will be determined by the magnitude of the larger voltage which is momentarily applied to the magnet. Because this larger voltage is applied for a very short period of time the magnet heating which it produces will be negligible. Therefore, the magnitude of this larger voltage is not limited by magnet heating. The heating power dissipated in the magnet will be primarily the result of the lesser voltage when constantly applied to the magnet. This lesser voltage can be small and need be sufficient only for holding the relay or switch operated. For dual voltage operation, it would be possible to develop a circuit using relay contacts to switch from the larger voltage to a lower voltage after the crossbar switch or relay had operated. However, this circuit would introduce two problems; first, the switching of a high voltage and current with relay contacts, and second, the fire hazard from overheating the magnet of the crossbar switch or relay if the switching contacts failed to promptly remove the larger voltage. To overcome these problems a dual voltage circuit as shown in Fig. 3(b) was developed which operates the crossbar switch or relay by a momentarily applied voltage obtained from a capacitor which has been precharged to the larger voltage. Since the capacitor has limited energy, there is no possibility of overheating the relay. No relay contacts are required to switch from the initially applied voltage to the lesser continuously applied voltage since the germanium junction diode performs this switching function.

In a typical circuit with a constant voltage, the closure of the controlling contact or contacts applied ground potential to the magnet of the relay device and thus 48 volts are applied. Because of the inductance of the magnet the current build-up is slow. This slow current build-up results in a slow operating relay device (as compared with the dual voltage circuit). With the dual voltage circuit for high speed operation, the relay device will be operated by a momentarily applied voltage of 178 volts (130 + 48) instead of the usual 48 volts. After operating, the relay device will be held operated with 48 volts. The voltage of 178 volts which is momentarily applied to the relay device is obtained from a capacitor which is precharged. As shown in the dual voltage circuit in Fig. 3(b),

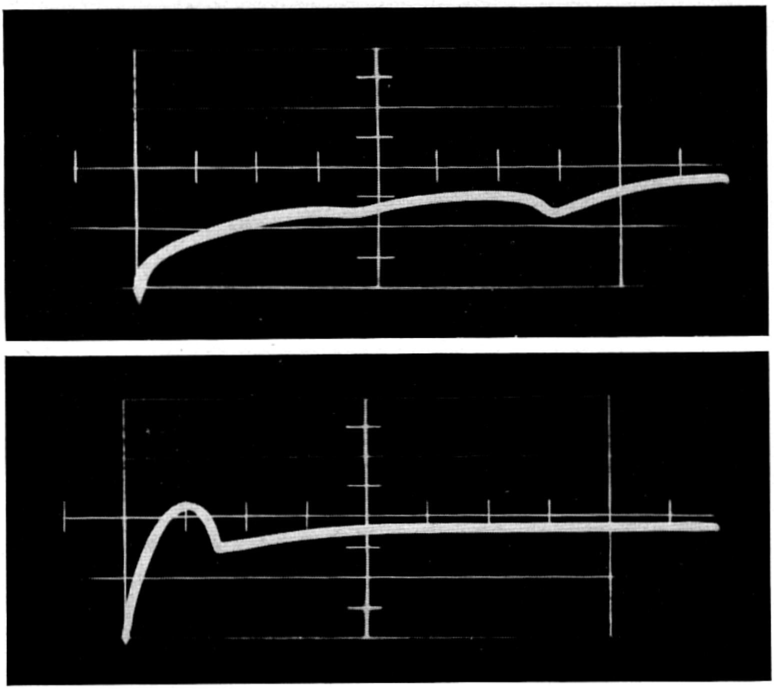

FIG. 7 — Current in crossbar switch hold magnet. Time division is 0.01 sec.

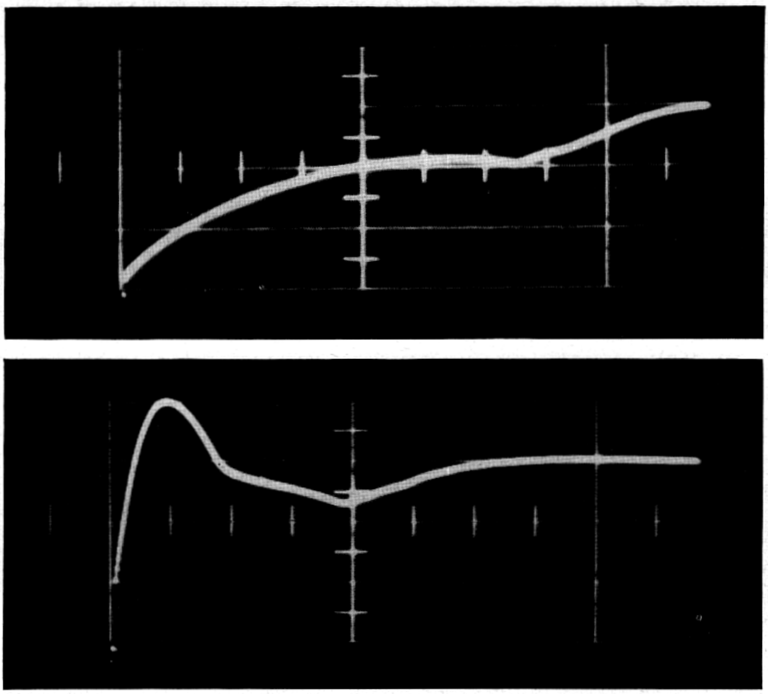

FIG. 8 — Current in typical relay magnet. Time division is 0.001 sec.

the +130 volt potential precharges the capacitor to +130 volts before the relay is to be operated. The closure of the controlling contact or contacts applies this +130 volts to the magnet winding already connected to −48V and thus a 178 volt potential is momentarily applied. Because of the larger voltage which is applied to the magnet winding the current will build-up rapidly resulting in very fast operation. This rapid build-up of current for the dual voltage circuit is contrasted with the usual slower build-up of current as shown in Fig. 7 for the crossbar switch magnet and in Fig. 8 for the wire-spring type relay magnet. The voltage which is applied to the magnet winding will have an initial magnitude of +130 volts but will decay rapidly to ground potential, as shown in Fig. 9 for the crossbar switch magnet and in Fig. 10 for the relay magnet. While the capacitor is discharging its energy into the relay, the voltage across the capacitor will drop from +130 volts toward a −48 volt potential. As long as the capacitor voltage is of a positive polarity the diode will act as an open switch contact and no current will flow through the diode. However, when the capacitor voltage has decreased to about −0.5 volt the diode will act as a closed switch contact and current will flow through the diode. The current which flows through the diode will hold the relay or crossbar switch magnet operated.

If the capacitance in the dual voltage circuit is very large, the voltage applied to the magnet winding would be 178 volts and would decay very slowly to 48 volts. With this very large capacitance, the operating time of the crossbar switch or relay would very closely approach the operating time which is obtained when a continuous voltage of 178 volts is applied. However, for smaller and more practical values of capacitance the operating time would be somewhat greater than for the continuously applied voltage of 178 volts. Fig. 11 shows a graph which correlates for

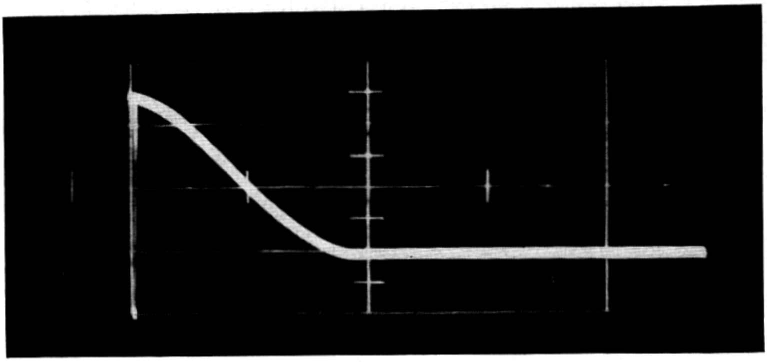

FIG. 9 — Voltage across crossbar switch magnet with dual voltage circuit. Time division is 0.01 sec.

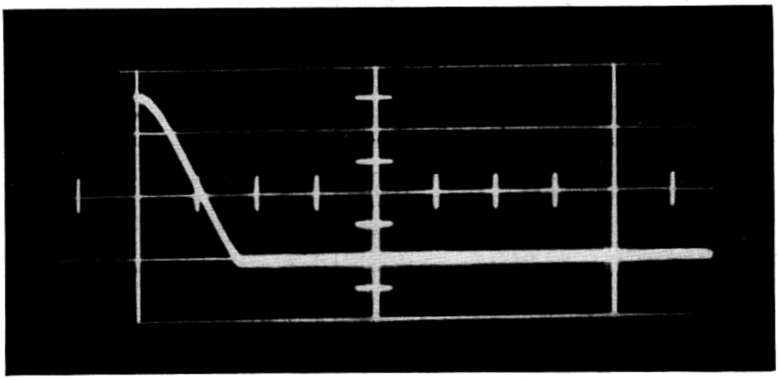

FIG. 10 — Voltage across relay magnet with dual voltage circuit. Time division 0.001 sec.

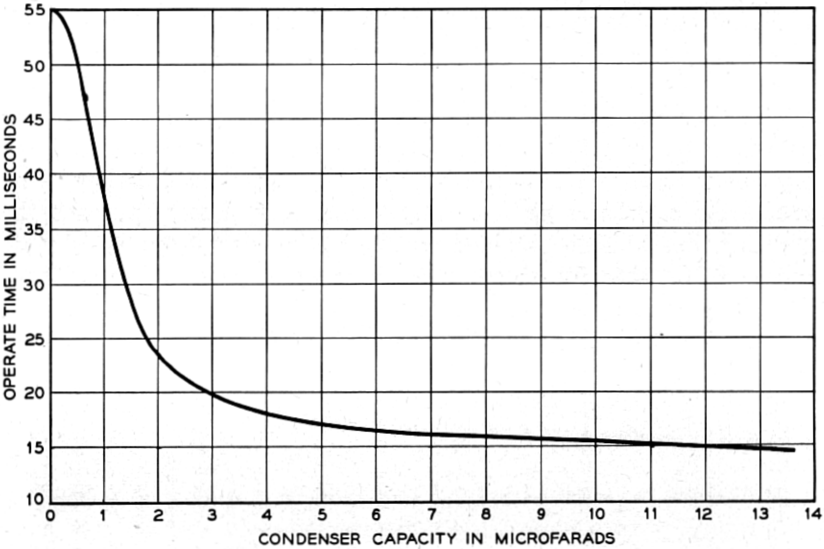

Fig. 11 — Operate time of crossbar switch as a function of condenser capacity.

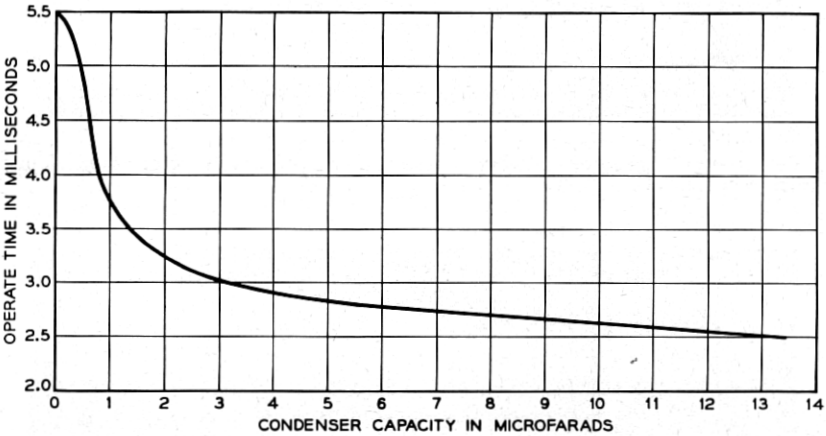

Fig. 12 — Operate time of typical relay as a function of condenser capacity.

various values of capacitance the corresponding operate time of the crossbar switch hold magnet while on Fig. 12 is shown a similar graph for the wire-spring type relay. In a typical dual voltage circuit design with a capacitor of 4.0 microfarads, the operate time of the crossbar switch magnet is 0.018 second while the operate time of the relay is 0.0029 second.

IV. APPLICATION TO NO. 5 CROSSBAR MARKERS

A typical No. 5 crossbar office may contain 1,000 crossbar switches with 20,000 hold magnets. To speed up the operation of these magnets through the use of the dual voltage circuit, it is *not* necessary to provide a capacitor-diode network for each magnet. The network is part of the marker. The magnets have the −48 volt central office battery connected to one terminal of their windings. The other winding terminals are wired to the contacts of connector relays so that these circuits can be extended into the markers. When a marker establishes a connection, it operates the proper connectors, through which it reaches the magnets it wishes to operate. Without the dual voltage feature, the marker would place ground on the leads corresponding to magnets to be operated. For dual voltage operation the marker connects the capacitor-diode network, instead of ground, to the magnet lead. Having the dual voltage network in the marker permits the network to be successively used for the operation of many magnets. The time required to recharge the capacitor for its next use is not a serious problem here. There is adequate time to recharge the capacitor while the marker is performing other functions. The charging time is determined by the size of the resistor and capacitor.

The switching network of a No. 5 office (Fig. 13) is a three-stage arrangement. A connection requires a line link, a junctor and a trunk link. The combination of these three elements is called a channel. Before operating any magnets, a marker tests the elements of the available

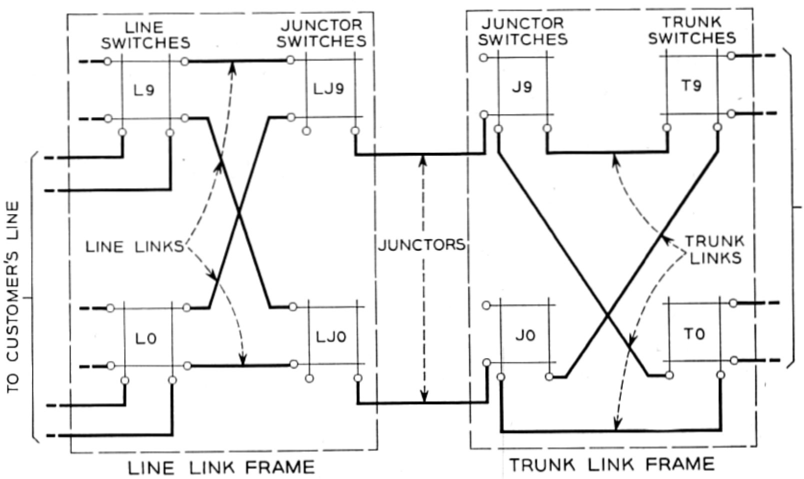

FIG. 13 — No. 5 crossbar switching network.

channels and selects the channel to be used. Having made channel selection and operated the proper select magnets, the marker then operates all the appropriate hold magnets simultaneously. Three capacitor-diode circuits are required in each marker to accomplish this simultaneous operation. The switch crosspoints are closed by the operation of the hold magnets. Closure of the crosspoints connects all the hold magnets of the channel together in multiple so they can be held by ground supplied from the register or trunk circuit after the marker disconnects.

ACKNOWLEDGMENTS

The authors wish to thank J. A. Ceonzo for doing the laboratory work on which the commercial development was based, and N. P. Santoro for obtaining the laboratory data used in this text.