A High-Speed Line Scanner for Use in an Electronic Switching System

By A. FEINER and L. F. GOELLER, JR.

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A high-speed multiposition electronic switch has been developed to act as a time-division information-gathering device for the experimental electronic switching system. This switch, called the scanner, provides central control with random access to all lines and trunks terminating in the central office and permits sampling their states for the reception of supervisory and dial pulse signals.

I. INTRODUCTION

An earlier article[1] on the experimental electronic switching system described the role of a scanner in an electronic telephone office. The scanner, which is the real-time data input circuit for the system, can be thought of as a multiposition electronic switch. Directed by a binary-coded address from the central control, the scanner samples the voltage present at any one of its input terminals and transmits a quantized one or zero signal to central control. All lines and trunks are examined periodically at a rate fast enough to detect dial pulses as well as supervisory changes in state.

In addition to lines and trunks, the scanner connects to a number of test points in other functional units of the electronic switching system to simplify automatic testing for preventative or corrective maintenance. The place of the scanner within the electronic switching system is shown in the block diagram, Fig. 1.

1.1 *Line and Trunk Circuits*

The scanner is a voltage-operated device and as such draws very little current from the circuits it samples. Scanner voltages are developed in line and trunk circuits as shown in Fig. 2. Line circuits, which are associated with the great majority of scanner inputs, operate in a straightforward manner. Very little current flows from the −50-volt central

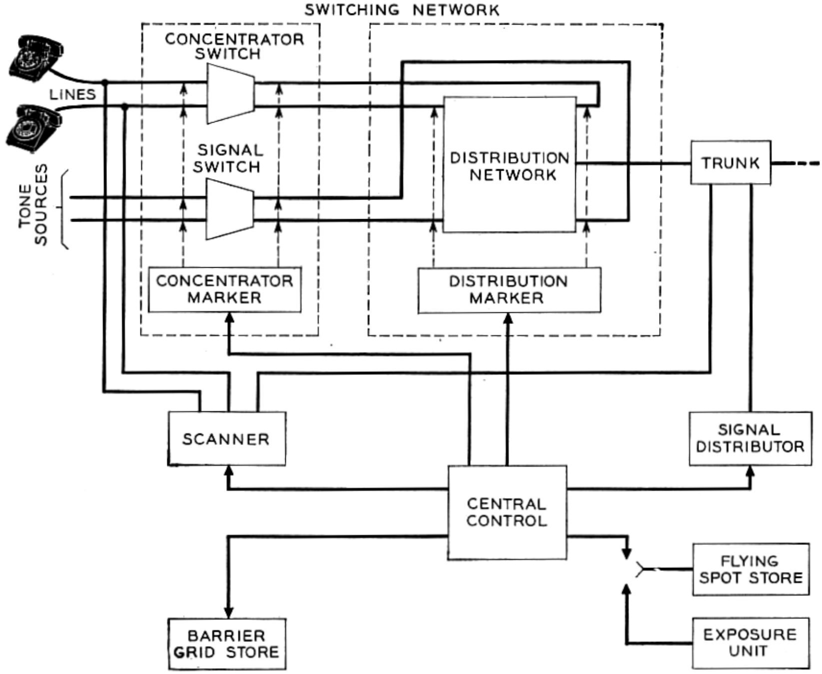

Fig. 1 — Block diagram of the experimental electronic switching system.

office battery when the customer's phone is on hook. Thus, point A is at ground and point B is at -50 volts. When the customer picks up his phone, the loop is closed through the subset and current flows through R_A and R_B, driving A negative with respect to ground and B positive with respect to -50 volts. The low-current subset designed for use in the experimental electronic switching system requires the central office to provide a dc termination of 2300 ohms. Thus, the terminating resistors offer a convenient source of signal voltage to operate the scanner input circuits.

Trunk circuits differ considerably from line circuits and require modified scanner inputs. The trunk circuit shown in part in Fig. 2(b) (as well as the various test points throughout the system which must also be scanned) transmits a signal of $+15$ volts or ground to the scanner when transistor Q_1 is cut off or saturated.

As long as negligible current flows through the ring side of the trunk, the voltage across R_2 is less than the forward drop across D_2. Thus, very little current flows through the base-emitter junction of Q_1, D_1 and R_2;

Q_1 is cut off and the scanner sees +15 volts through R_3. When the operator at the 3 CL switchboard seizes the trunk, however, she connects the ring conductor to −24 volts. Current flows from ground through R_2, the voltage across R_2 exceeds the forward drop across D_2 and the emitter of Q_1 is driven negative with respect to its base. The transistor is saturated and a voltage very close to ground is transmitted to the scanner. When the operator at the switchboard dials, the connection between the ring conductor and the −24 volt battery is interrupted at the dial pulse rate; the collector voltage at Q_1 follows the dial pulses; L_1, C_1 and D_1 protect the circuit from noise and foreign potentials.

In the scanner, voltages from a line or trunk are used to bias a diode.

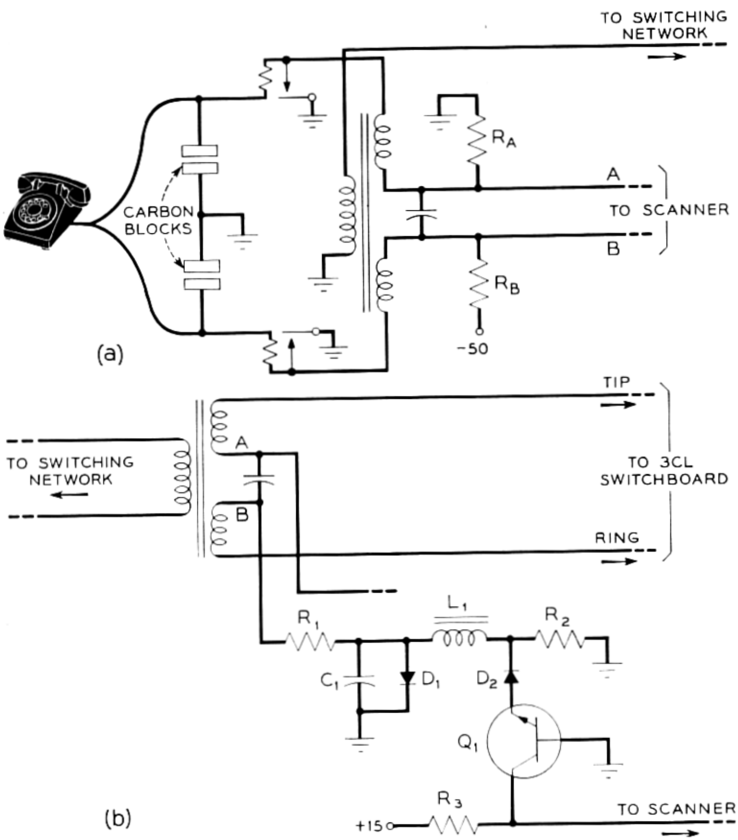

Fig. 2 — (a) Customer line circuit; (b) portion of trunk circuit which develops scanner voltage.

If the diode is held in the back-biased state, an interrogation pulse coupled through capacitors to the diode will be blocked; if the diode is forward-biased, the pulse will be passed and can be detected. Although the actual "transmission gate" circuitry is somewhat more complicated and will be described in detail later, it is shown in its simplest form in Fig. 3.

1.2 *Scanner Operation*

The functional arrangement of the scanner is shown in Fig. 4. Transmission gates are located at the points of intersection of 32 horizontal wires and 32 vertical wires arranged in a square array. To determine which of the 1024 gates is to be interrogated, central control addresses the horizontal and vertical wires that intersect at the gate in question. A five-bit address selects a path through the input selector from the pulser to the driver associated with the desired horizontal. The output selector sets up the path from the output amplifier and lock-up amplifier associated with the vertical lead to the detector. A 1-microsecond 6-volt interrogation pulse called the enable scanner pulse (ENS) is then sent from central control. The ENS resets the lock-up amplifiers, erasing information stored in them from the previous scan, and then starts its journey through the input circuits, the addressed transmission gate (if properly biased), the output circuits and, from the detector, back to central control. Delay through the pulser and input selector guarantees that the resetting of the lock-up amplifiers will be completed before the pulse gets through the transmission gates.

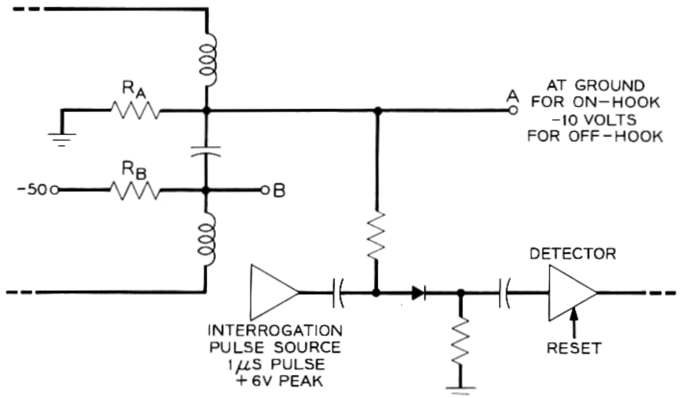

Fig. 3 — Simplified transmission gate.

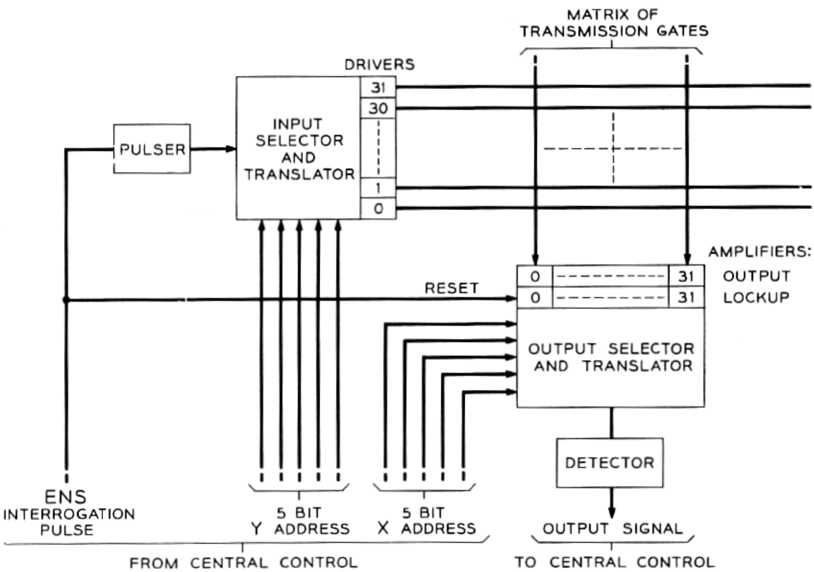

Fig. 4 — Block diagram of the scanner.

It should be noted that any one horizontal lead is associated with 32 transmission gates. All 32 will be interrogated by one ENS pulse, and their lock-up amplifiers will be either set or not set as dictated by the state of the circuit being scanned. The five-bit address to the output selector can then be varied to transmit the state of as many of the 32 lock-up amplifiers as desired to central control without sending another ENS pulse.

1.3 *Scanning Rates*

Central control operates the scanner in two different modes to obtain the information it needs in the most efficient manner. As long as a customer is not using his phone, his line remains in a quiescent state; central control would waste program time if the line were scanned too often. Similarly, when a customer is talking, his line is in another dc state which does not change rapidly. Only when the customer is dialing do rapid changes in the dc state of his line occur. Thus, all dialing lines must be scanned much more rapidly than idle or busy lines. Fig. 5 shows the idealized line voltage at point A of Fig. 2(a) as the customer picks up his phone, dials a number and carries on a conversation. A supervisory scan samples his line (and all other lines, trunks and test points in the system)

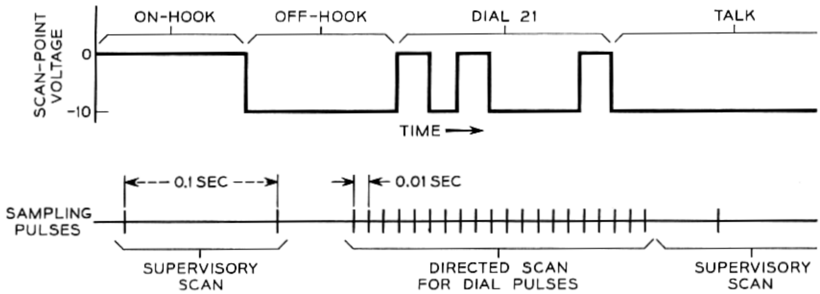

Fig. 5.—Idealized dial pulse voltage at scan point, as sampled by the scanner.

every 0.1 second. When an off-hook is discovered, the central control is programmed to sample the line 10 times faster (every 10 milliseconds) until all dial pulses have been registered. When the connection is set up, central control reverts to the less frequent supervisory scan which will detect hang-up when it occurs and signal the removal of the connection.

Fig. 6 shows the basic time cycle of central control, which repeats every 0.1 second. In each 5-millisecond interval central control obtains from the scanner a sample of the state of half the dialing lines in the office. Then $\frac{1}{20}$th of all lines, trunks and test points are scanned. During the remainder of the 5 milliseconds, central control performs other functions such as outpulsing, setting up connections through the network or test programs. The time devoted to sampling each line has to be very brief to permit central control to operate serially in this manner; the scanning interval approaches 2.5 microseconds.

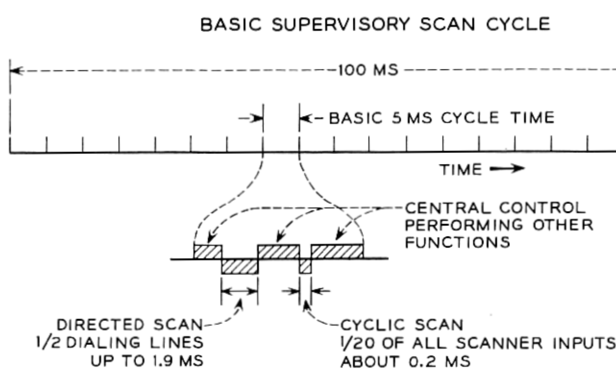

Fig. 6 — Time relations in scanner operation.

1.4 *Use of Scanner Information in Central Control*

Each line in the office is associated with, in addition to a particular scanner input, two binary cells in the temporary memory (barrier grid store[2]). These so-called line spots define the three basic states of a line as follows: (a) idle: 00; (b) talking: 10; (c) a register is assigned (line is dialing): 01.

When any given line is being scanned, central control is, at the same time, also examining its line spots. When the line is in the idle or talking state, it is scanned at the relatively infrequent supervisory rate, as described above. Should the output of the scanner show that a line is off-hook when its line spots are in the 00 state, the customer has taken his phone off hook since the last time the line was scanned. Similarly, if the line is on-hook but has 10 for its line spot state, central control knows that the customer has just hung up. In either case, central control will take the action demanded by the nature of the change and then bring the line spots up to date.

When off-hook is first detected, central control assigns the line an additional spot group in a section of the barrier grid store referred to as an originating register. In addition, the line spots are changed to 01. On the next supervisory scan, 01 in the line spots indicates to the central control that it is to ignore the scanner output regardless of what it is. The dialing line will be examined every 10 milliseconds through a specially directed scan where the line's address is obtained from the originating register. The over-all program involving the directed scan and the originating register counts, translates and stores dial pulses, and keeps the originating register up to date. It also times interdigital periods and, finally, signals the completion of dialing so that the connection can be established to the called party by means of another program.

II. PROBLEMS INVOLVED IN SCANNING

External conditions impose limitations on scanner design in two ways. First, the scanner must conform to over-all system requirements. Second, outside plant and customer subset circuits provide dial pulses and supervisory voltage levels that vary considerably from one loop to another. The scanner must be capable of recognizing and properly quantizing this wide variety of signals.

2.1 *Systems Considerations*

Of the systems factors involved, the most important is time. If the sampling action of the scanner is to provide central control with all the signal information transmitted by the customer's dial, the sampling rate must be at least twice the highest signaling frequency. The subsets to be used will have 20-pps dials which, when dial speed and break-time variations are considered, will have a minimum make-time of 15 milliseconds. This established the 10-millisecond scan rate for dialing lines. The supervisory scan, although somewhat slower, must be fast enough to detect off-hook in time to permit central control to set up an originating register spot group in the barrier grid store before dial pulses are received. One scan every 100 milliseconds is satisfactory for this purpose. The maximum rate at which the scanner can be operated is determined by delays through blocks of equipment operated in tandem, RC discharge times and other circuit limitations.

In the supervisory scan, lines and trunks are sampled in a fixed order determined by adding 1 to the address of the last line or trunk inspected. In the dial pulse scan, however, consecutive addresses do not necessarily have any relation to each other. Thus, the scanner must provide random access to all inputs.

The scanner address and ENS leads must be compatible with the outputs from central control, and the scanner output signal must be capable of operating central control circuitry.

2.2 *Customer Circuit Considerations*

With regard to customer loop variations, Fig. 7 shows a worst tolerable condition from the dc standpoint. The subset itself has a maximum resistance of 1800 ohms in series with the dial and switch-hook contacts.

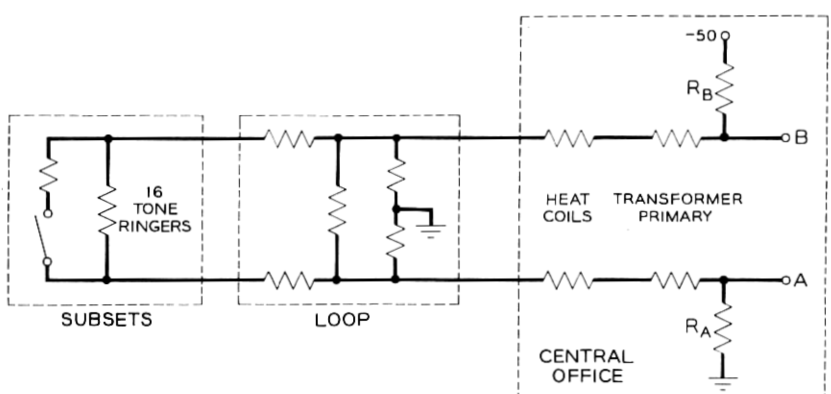

Fig. 7 — Dc circuit for a long customer loop.

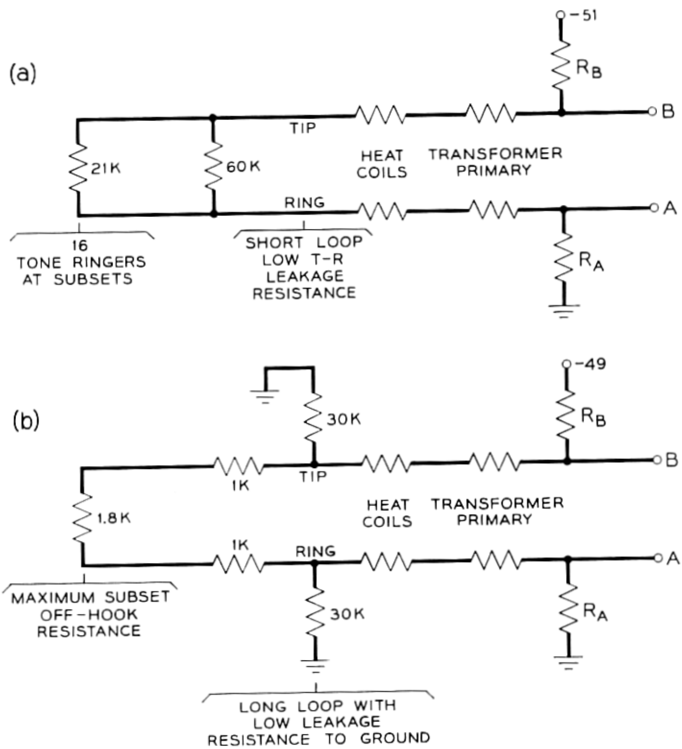

Fig. 8 — (a) Worst on-hook dc condition: interrogation pulse tends to be blocked when it should pass through gate; (b) worst off-hook dc condition: interrogation pulse tends to get through when it should be blocked.

Tone-ringers, which replace bells in the experimental systems' subsets, have about 340,000 ohms resistance.* An eight-party line with two subsets per customer makes the total shunt tone ringer resistance as small as 21,000 ohms. Because the maximum subset current must be limited to 13.5 milliamperes, outside plant leakage currents must be kept very small by comparison; the minimum leakage resistances permitted are 60,000 ohms from one conductor to the other and 30,000 ohms from either conductor to ground. These are the worst conditions which can be permitted if extreme values of component variation within the scanner occur and maximum longitudinal induction (15 volts, peak to peak) is present.

* While they are being operated, tone ringers have a much lower impedance. Thus the scanner must be programmed to scan ringing lines between bursts of ringing current to detect answer correctly.

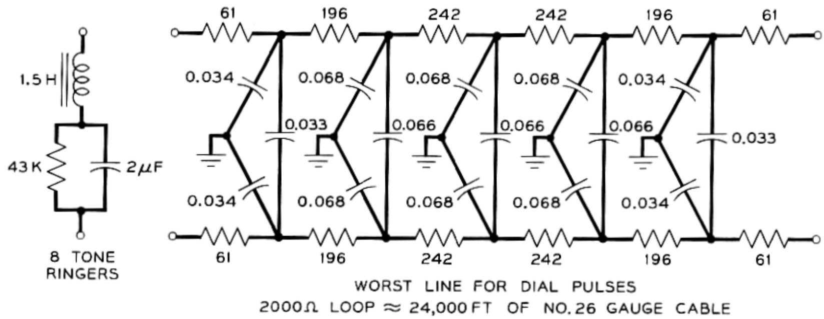

Fig. 9 — Circuits to simulate loop and tone ringers.

Supervisory voltages at the scan points are a function of the resistances discussed above. Two limiting cases exist: the condition in which the scanner comes just short of mistaking an on-hook condition for off-hook, and *vice versa*. Fig. 8 summarizes these dc loop conditions.

In addition to the circuit resistance, shunt capacity of the loop and reactance of the tone ringers affect dial pulses. Fig. 9 shows an artificial line designed to simulate the worst tolerable path for dial pulse transmission. The total conductor resistance is 2000 ohms and the distributed capacitance corresponds to approximately 24,000 feet of exchange area cable. Fig. 9 also shows an equivalent circuit for eight tone ringers. All these reactive components tend to round off the sharp corners of dial pulses and provide the scanner with dial pulse trains that, in the worst cases, look very much like sine waves.

Noise picked up by the loop can distort dial pulses badly. One of the worst noise problems is produced by 60-cycle voltage induced in open-wire telephone lines by power lines that run near them. Fairly large voltages from this source are often encountered, but fortunately they are, in most cases, of the same magnitude and phase in both the tip and ring conductors. Fig. 10(a) shows a train of dial pulses from a distant customer, in terms of the voltage across R_A of Fig. 2(a). Fig. 10(b) shows the dial pulses submerged by 60-cycle pick-up. If a differential oscilloscope is placed across points A and B in Fig. 2, however, the 60-cycle voltage will be balanced out. In addition, because of the direction of the battery current through the resistors, the dial pulse voltages add; this almost doubles the dial pulse signal. The scanner has been designed to use the voltage between points A and B to balance out 60-cycle interference and improve margins by taking advantage of the increased pulse height available.

III. SCANNER CIRCUITRY

If longitudinal induction were not a factor, the simple transmission gate of Fig. 3 could be adapted very simply to the practical problem of line scanning. Although not all loops are disturbed by longitudinal induction, it is desirable to make all line circuits identical and capable of eliminating the undesirable effects of longitudinals to permit straightforward administrative procedures.

3.1 *Trunk Gate*

Test points within the central office and scan points associated with most trunk circuits are not subject to induction. Fig. 11 shows the transmission gate developed for such circuits. It is relatively simple to divide the matrix into two groups of gates, one containing only balanced gates and the other, for trunks and special circuits, containing either the balanced gate or the one shown in Fig. 11.

The only differences between the circuit of Fig. 3 and that of Fig. 11

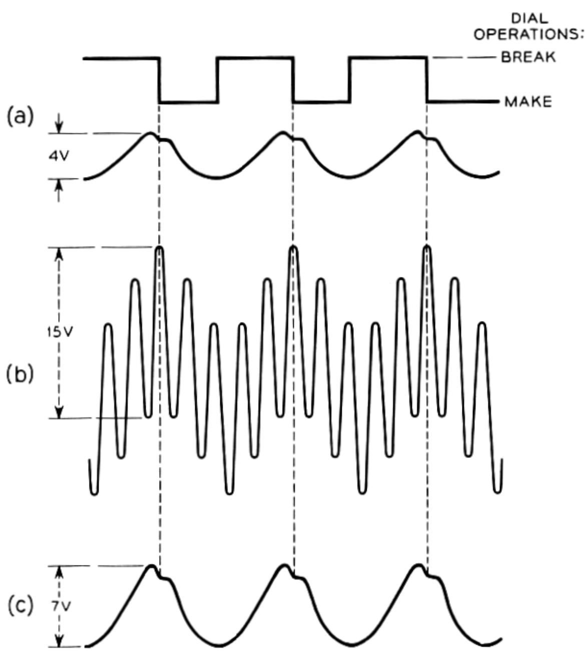

Fig. 10 — Scan point signals: (a) voltage at point A of Fig. 2, dial pulses from long loop; (b) same as above, with 60-cycle longitudinals present; (c) voltage at point A minus voltage at point B of Fig. 2, with 60-cycle longitudinals present.

are noise-filtering capacitors and a very small bias current which keeps the diode slightly forward-biased when point A is held near +15 volts. This bias aids in keeping charge from ENS pulses from being trapped on the cathode side of the diode and altering the diode bias.

3.2 *Balanced Line Gate*

The balanced line gate is shown in Fig. 12. Longitudinal voltages are coupled in phase to both ends of the diode leaving the net dc bias voltage unaffected. Capacitor C_1 blocks the central office battery but is a low impedance to both longitudinal voltages and dial pulses. Capacitors C_4 and C_5 are very high impedances to low-frequency signals, but transmit the 1-microsecond ENS pulse readily. They can be made to have large voltage ratings in small physical sizes and, coupled with hit filters R_1C_2 and R_3C_3, effectively protect other scanner circuits from lightning and other noise voltages which may be picked up by the loop.

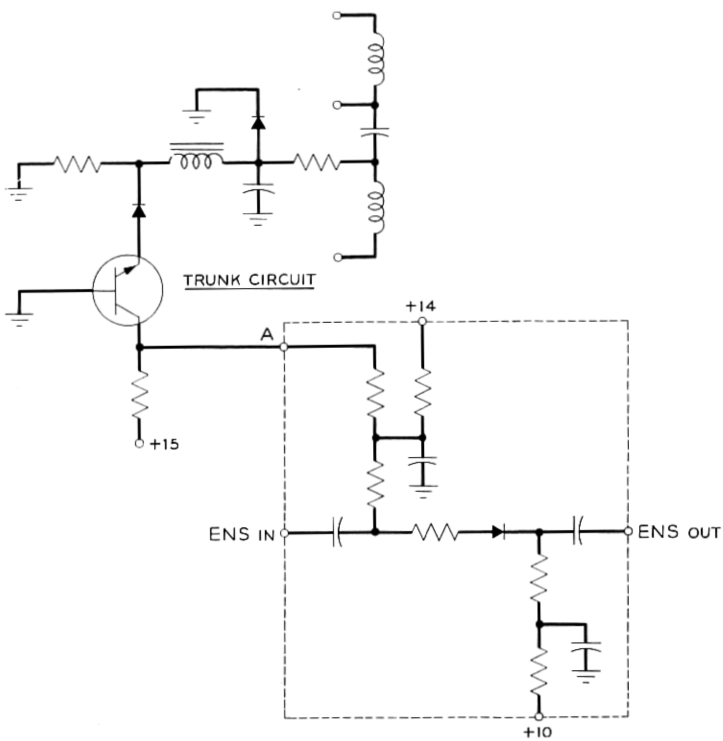

Fig. 11 — Transmission gate for trunk circuits and test points.

Because 32 gates associated with a horizontal matrix lead are pulsed in parallel, R_7 is inserted to equalize variations in diode forward resistance; R_4 is the dc return path for the diode, and offers a convenient place to forward bias the diode to reduce the effects of trapped charge; R_2 is required to maintain ac circuit balance.

The balanced line gate has been exhaustively tested for effects of component variations, loop variations, longitudinal induction and lightning hits.

3.3 *Input Selector*

Although the matrix of line and trunk gates is the heart of the scanner, the access circuitry which enables central control to sample one particular scan point out of the 1024 available requires careful consideration. The ENS pulse must be steered to one of 32 horizontal matrix leads, and a path from one of 32 vertical matrix leads must be established to the detector which transmits the quantized output signal back to central control.

The input selector is a transistor "tree" as shown in Fig. 13. In the first stage, only one of the eight transistors has its base grounded; the input translator holds the other seven base leads at a positive voltage. A positive pulse applied to the eight emitters in parallel thus finds only

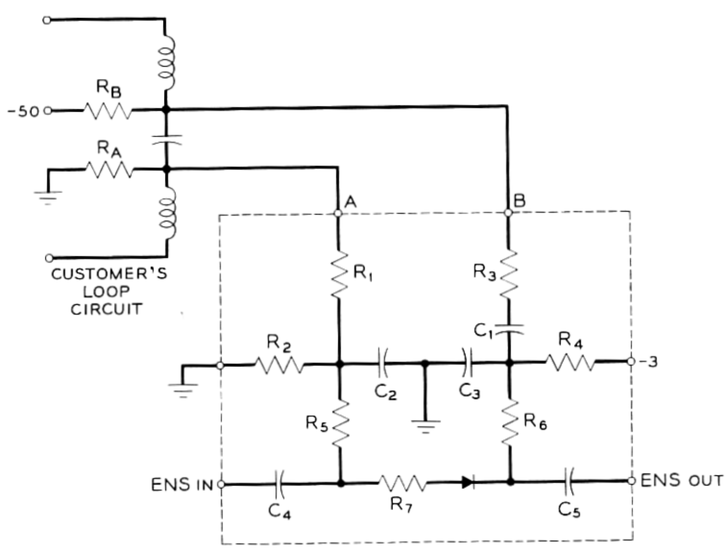

Fig. 12 — Balanced transmission gate for customer loops.

one emitter-base junction forward-biased. In the second stage of the transistor tree, the positive pulse finds only one of four paths open to it as a result of translator base voltages, and the one-out-of-32 selection is performed.

The input translator, part of which is shown in Fig. 14, is made up of diodes and resistors. It is driven, through several sets of gates and amplifiers, by address flip-flops in central control.

Once the path to a matrix horizontal lead has been established through the input selector, the ENS pulse, reshaped and amplified by suitable circuitry, can be applied.

3.4 *Pulser and Drivers*

Reshaping is performed by the pulser, shown at the left in Fig. 15. The first stage is a blocking oscillator and the second is a transistor

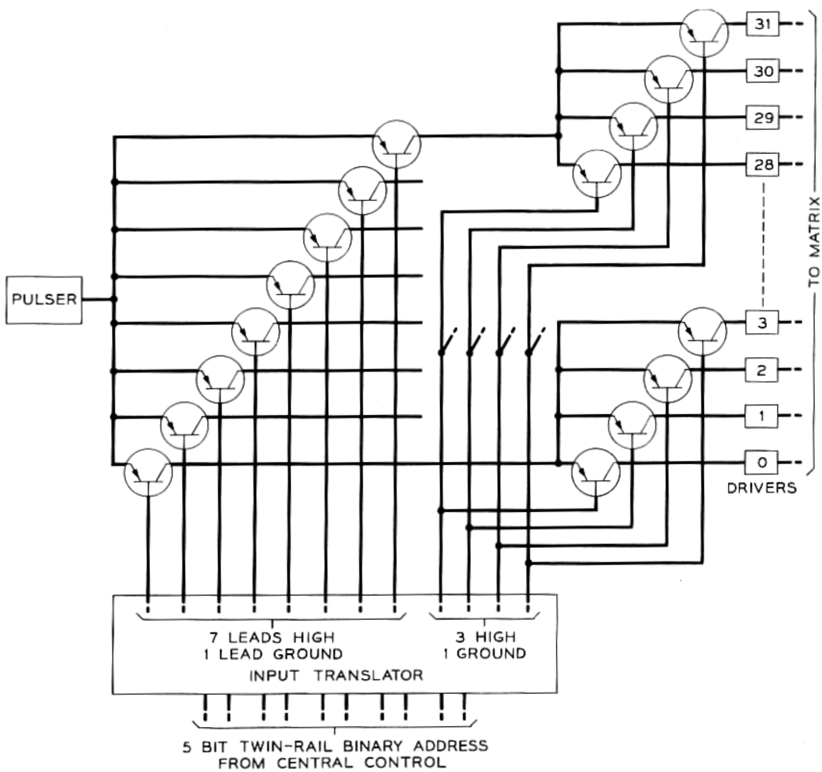

Fig. 13 — Input selector.

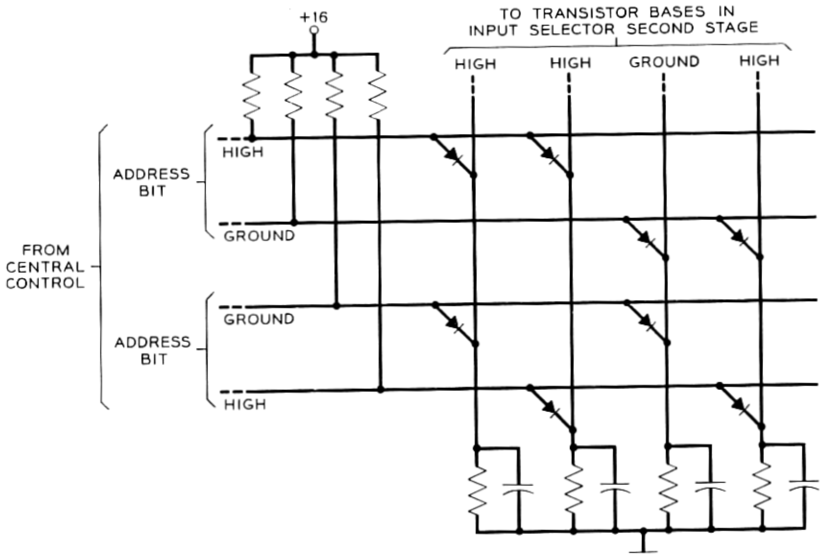

Fig. 14 — Portion of input selector translator.

switch. When Q_1 is triggered by an ENS pulse from central control, regeneration through the pulse transformer T_1 drives Q_1 into saturation; Q_2 , normally biased to cutoff by the forward voltage drop across D_2 , is driven to saturation by the current pulse in the third winding of the blocking oscillator pulse transformer. The collector voltage of Q_2 has a rise time on the order of 0.2 microsecond; this fast-rising positive pulse is applied to the input selector and steered to the desired driver, shown at the right of Fig. 15.

The driver is another transistor switch. The high-current pulse from Q_2 is stepped up through pulse transformer T_2 , saturates Q_3 and applies a 6-volt pulse through zero impedance to the matrix horizontal. The 6-volt supply must be accurately regulated; if it drifts higher, the ENS pulse may pass through off-hook line gates that are back-biased by the minimum permissible amount. If it drifts lower, the ENS pulse may not be able to pass through line gates where leakage currents have raised the on-hook bias to the maximum level.

Both the pulser and driver have capacitors on all voltage supply leads to filter noise and eliminate ringing. Protective resistors are inserted wherever required in transformer leads to protect the transformers against possible transistor short circuits.

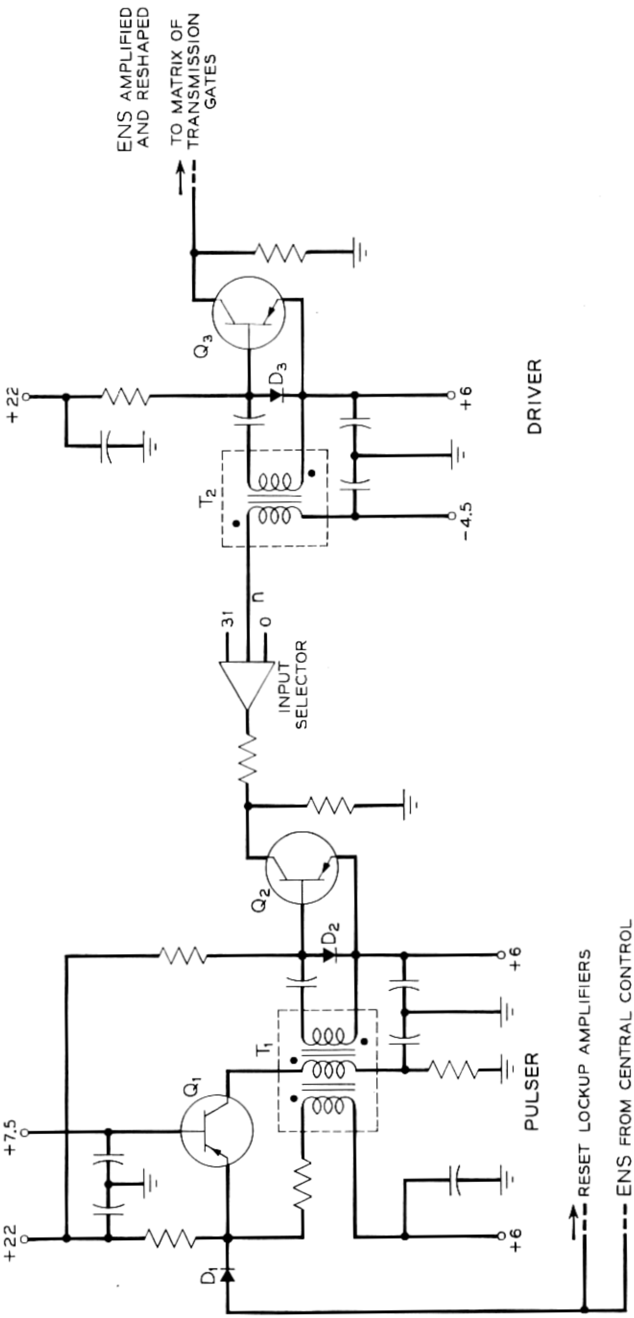

Fig. 15 — Pulser and driver.

3.5 *Output and Lockup Amplifiers; Reset Circuits*

The driver can supply 175 milliamperes to a horizontal lead of the scanner matrix. This current divides among the 32 line gates associated with the horizontal and, due to shunting elements within the matrix and the gate circuitry, output current on a vertical lead may be as small as 1 milliampere, with a duration of 0.5 microsecond.

This output current must be amplified before it can be used effectively. In addition, some threshold value must be established to block noise. These requirements are met by the output amplifier shown in Fig. 16, one of which is associated with each matrix vertical.

Thirty-two transmission gate outputs connect to each matrix vertical; only one of these gates is pulsed at a time. To minimize the shunting effects of the 31 unpulsed gates, the first stage of the output amplifier is a grounded-base transistor with the typical low impedance of that configuration. Acting as a linear amplifier, the first stage transmits current

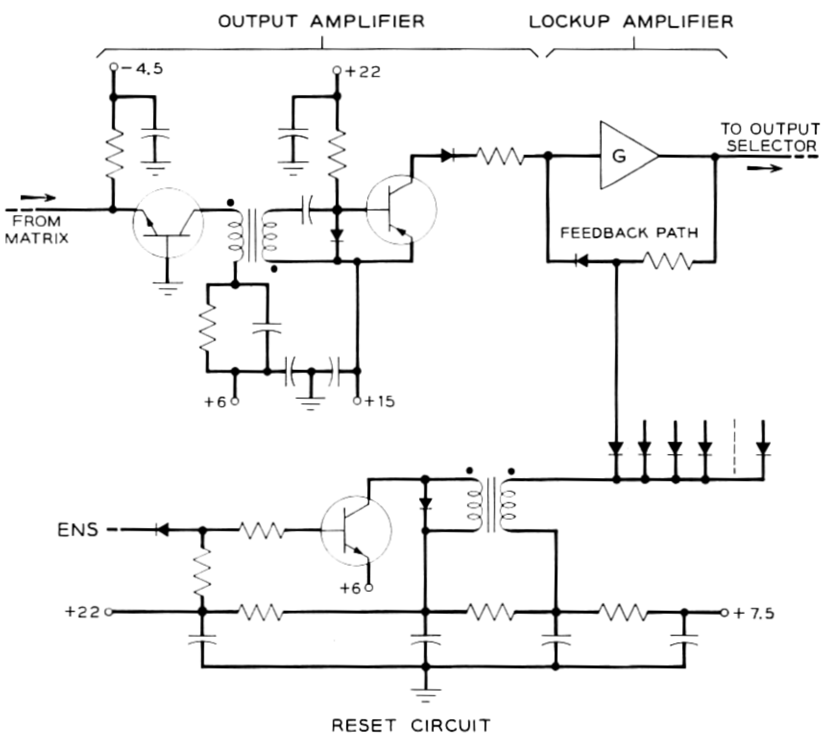

Fig. 16 — Output amplifier, lockup amplifier and reset circuit.

to the second through a pulse transformer. The second stage is the now familiar scanner transistor switch, biased off by the forward drop across the diode. Noise discrimination takes place here; if the input current pulse is less than 1 milliampere, the output pulse from the transformer is unable to turn on the second transistor. For a large enough input, however, the second stage operates and can easily switch the lockup amplifier which follows.

The lockup amplifier, also shown in Fig. 16, is a standard gate amplifier[3] with external feedback added. In the reset position, its input is clamped at +6 volts. A pulse from the output amplifier drives the lockup amplifier input to +7.5 volts, where it is clamped by a diode and maintained by the feedback loop after removal of the pulse.

Each time central control sends an ENS pulse to the scanner, all lockup amplifiers are reset. The ENS pulse triggers a transistor which applies a square negative pulse through a pulse transformer and isolation diodes to the feedback loops of the lockup amplifiers. The transformer is chosen to give a pulse long enough to guarantee resetting the lockup amplifiers, but short enough to be removed by the time the signal is available from the output amplifier.

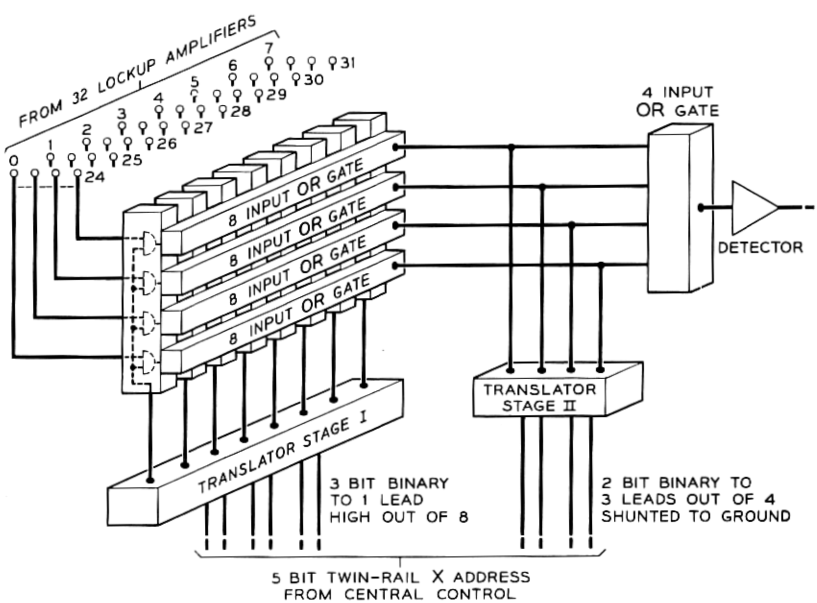

Fig. 17 — Output selector.

3.6 *Output Selector and Detector*

The output selector shown in Fig. 17 is a small diode tree scanner designed to connect lockup amplifier outputs through to the detector under the direction of central control. Three bits of the five-bit address choose one block of four output amplifiers. The other two bits select which of the four is to be observed by shunting the other three leads to ground.

The detector, shown in Fig. 18, provides a twin-rail output to central control. When the addressed lockup amplifier is set, Q_1 conducts and Q_2 is cut off; base-emitter voltages are developed across diodes D_1 and D_2, respectively, the anode of D_1 being slightly above ground and the cathode of D_2 slightly below ground. When the lockup amplifier is not set, it clamps the output selector output to ground. The voltage divider at the base of Q_1 holds Q_1 cut off, and Q_2, its base clamped just below ground and its emitter connected to -4.5 volts through a small resistor, conducts; Q_3 and Q_4 are emitter-follower amplifiers which drive the cables back to central control. The detector has a very fast rise time and is capable of developing enough power to charge up the distributed capacity of the output cables with a minimum of delay.

3.7 *Construction Details*

Scanner circuits are built on printed wire boards and several circuit packages are shown in Fig. 19. The balanced line-gate card, containing

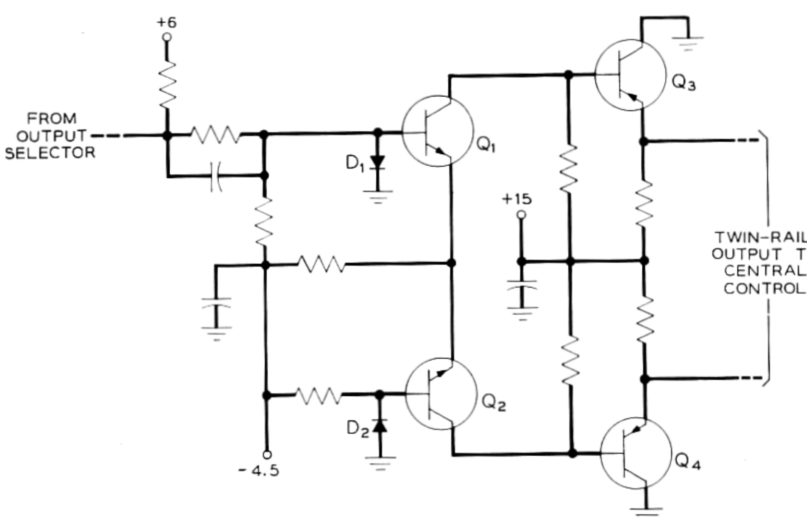

Fig. 18 — Detector.

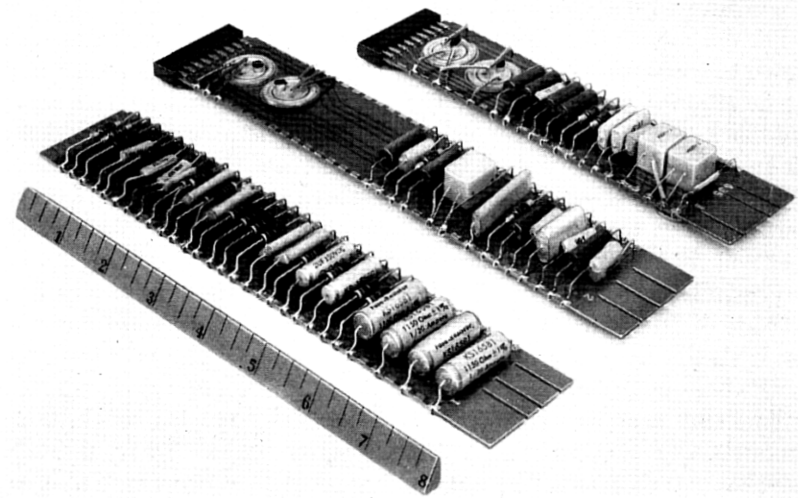

Fig. 19 — Line gate, output amplifier and driver packages (left to right).

two gate circuits and two pairs of line resistors, is shown in the foreground.

Printed wire boards are plugged into jacks arranged on horizontal mounting plates. All connections between circuits are made by wiring from one jack to another. Shunt capacity to ground in such wiring can be fairly large and special pains were taken to design low-impedance circuits where long interconnecting leads were anticipated.

The high current pulses required by the matrix and the sensitivity of the output amplifiers make special procedures necessary to insure a quiet ground. Heavy copper ground straps at each jack position are mounted in every other space between mounting plates, giving all circuits ready access to a very low impedance ground.

With these precautions, it is felt that scanner reliability has been greatly increased and that coupling between individual circuits will cause negligible trouble.

The line and trunk gates (which make up most of the volume of the scanner) contain only diodes, resistors and capacitors. Because these components are quite reliable and because the failure of any one component in a gate circuit will not affect more than one input to the scanner, duplication for reliability purposes is not necessary.

On the other hand, each piece of circuitry used to obtain access to the matrix gates is common to many lines and must be duplicated. Two complete blocks of access circuitry are provided and, in the event of trouble, all the circuits (pulser, input selector, drivers, output amplifiers, etc.) associated with a given matrix are automatically switched out at once and replaced by similar standby circuits. Wire-spring relays under the control of the administration center effect this transfer.

A 1000-line scanner, complete with duplicated access circuitry, can be built conveniently in one electronic switching system equipment cabinet (2 x 2 x 7 feet), with enough space left over to hold the electronic power supply specially developed to provide talking current for customer lines.

IV. CONCLUSIONS

The scanner described in this paper operates serially to sample the voltage levels at 1024 input terminals. These levels are quantized to 1 or 0 and transmitted to central control at a fast enough rate to insure proper operation of the telephone system. Most scanner inputs are connected to customer loops. If loop variations are maintained within the specified limits, the scanner will function properly. Other inputs are used to scan trunk circuits and diagnostic test points within the system.

As part of the rather complete laboratory model of the experimental electronic switching system, a skeletonized scanner is working satisfactorily.

V. ACKNOWLEDGMENTS

Credit is due to B. G. Hemmendinger and F. F. Taylor who contributed much to the scanner circuits and organization. Mechanical design of the scanner, signal distributor and central control is based on ideas of H. A. Miloche and H. J. Wirth, Jr. G. D. Frye was responsible for the equipment aspects of the scanner.

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