

An Experimental Switching System Using New Electronic Techniques

By A. E. JOEL, JR.

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This is the first of a series of articles describing an experimental electronic telephone switching system employing a number of new techniques. These include use of a stored program, a network employing gas tube cross-points, time-division common control and large-capacity barrier grid tube and photographic storage systems.

I. INTRODUCTION

Following recent activities in switching research^{1,2} and the development of new solid state devices, engineering studies indicate that a telephone switching system using new electronic techniques is practicable. An experimental electronic switching system designed and built for laboratory purposes is described in this paper. Other articles will present the various parts of the system in more detail (e.g., Refs. 3, 4 and 5).

Earlier papers have outlined many of the techniques which are available in electronic switching,^{6,7} and the particular choices which were made for this experimental system have been publicized.⁸ A brief review is given here.

The experimental system may be said to have a space-division electronic switching network for telephone connections, in which the connections themselves are made under the direction of time-division (one-at-a-time) common control. Large-capacity temporary and semipermanent electronic storage units fulfill most of the memory requirements of the system. The time-division control uses a program stored in the semipermanent memory. This program specifies the manner in which an office will function on various types of calls and provides various service features. Since a photographic memory medium is used in the semipermanent memory, the operating features of the office may be changed readily.

II. ORGANIZATION OF THE EXPERIMENTAL SYSTEM

Fig. 1 is a block diagram of the major components of the system. The upper portion of the figure shows the section through which telephone connections are established. This is known as the switching network. It interconnects lines with other lines, lines with trunks, and lines or trunks with tone sources.

The remainder of the system is its time-division control. The scanner is directed by the central control to examine the current flow condition of lines and trunks (current on or off), with the results of this examination determining all actions in the information inputs to the system. The signal distributor seizes trunks and sends information over them to distant offices; it is directed to control the flow of current in the trunk circuit by the central control. The barrier grid store contains the temporary memory used to assemble the line and trunk call status information obtained from the scanner. The flying spot store holds in its permanent memory information about the service characteristics of the lines and trunks and a program to direct all the control operations

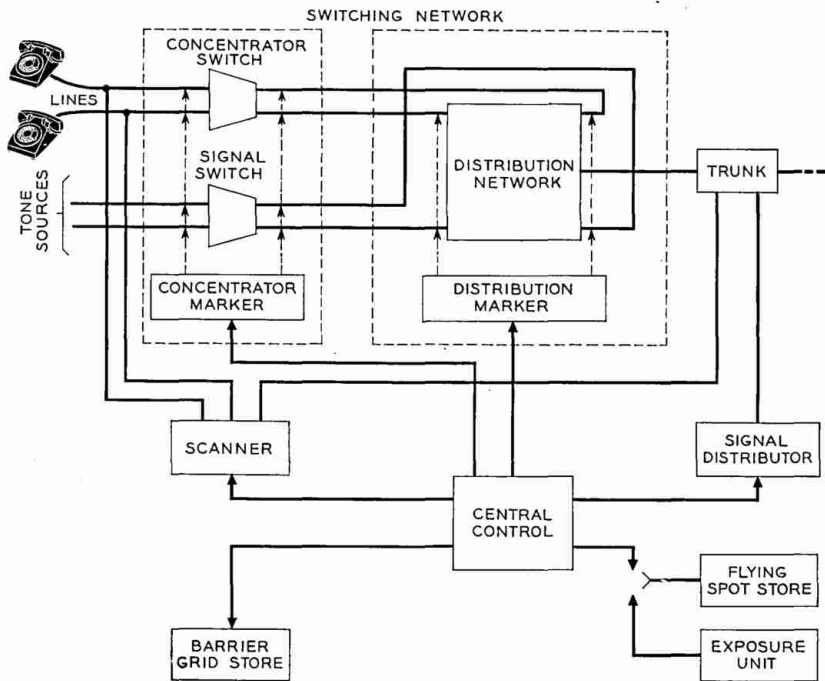


Fig. 1 — Block diagram of experimental system.

which take place in the system. As its name implies, the central control is the focal point for directing each of the other components of the system.

Obviously, the time-division control concept takes advantage of the speed of electronic devices. Its techniques will be described in more detail after the following discussion of the electronic space-division switching network, which illustrates the manner in which all major system components are controlled.

III. SPACE-DIVISION SWITCHING NETWORK

A space-division network is one in which physical devices are taken into use by a particular call for the entire duration of the call. A switchable transmission circuit (in space) is established between the calling and called customers. All present-day electromechanical systems are of this type. Unlike previous space-division networks, however, this experimental system uses only electronic devices.

3.1 *Components*

The transmission path established through the experimental network has no metallic contacting elements like those in crossbar or step-by-step switches. Instead, each crosspoint is a two-element gas tube or gas diode (see Fig. 2) in which the gas breaks down when sufficient voltage is applied across the electrodes.^{9,10} An electrical path is established through this gaseous discharge which transmits the speech current and controls the connection.

As in a crossbar switching network, cascade stages with concentration, distribution and expansion configurations are used. Each switch-

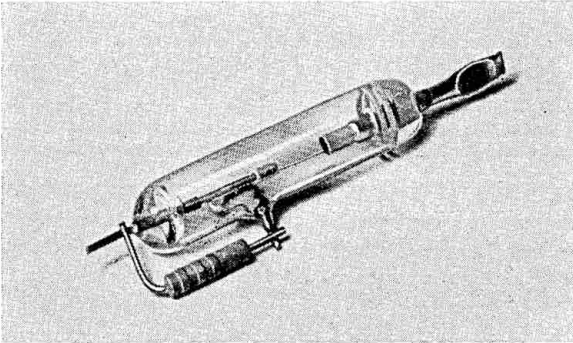


Fig. 2 — Gas tube crosspoint.

ing network stage has its own control, which is called a marker and has subdivisions called a concentrator marker and a distribution marker.

All network connections are made through several gas tubes in series (see Fig. 3). The number of tubes in series varies with the type of connection, eight being employed on an intra-office call and seven on calls between lines and trunks. Only one crosspoint tube is used in the concentrator stage, but six are employed in the distribution switching network.

3.2 Transmission

All talking paths through gas tubes are single-wire with ground return. Transformers are used to convert from line and trunk balanced pairs to the single-wire circuits in the sections of the switching network. Balanced pairs carrying only voice currents (dry circuits) also terminate in transformers between the concentrator and distribution switching sections of the network. In the present experimental system only in-office concentrators are used. However, this type of network and its controls can be readily adapted for use with remote concentrators.

Electronic crosspoints restrict the power level of the signals which may be transmitted through the switching network. Therefore, a new telephone ringing arrangement has been developed for use with electronic switching.¹¹ The customer station set (Fig. 4) is provided with a

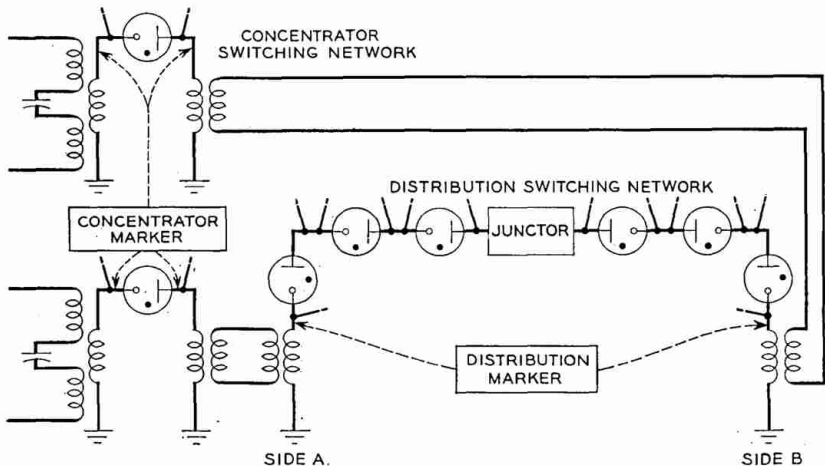


Fig. 3. — Switching network plan.

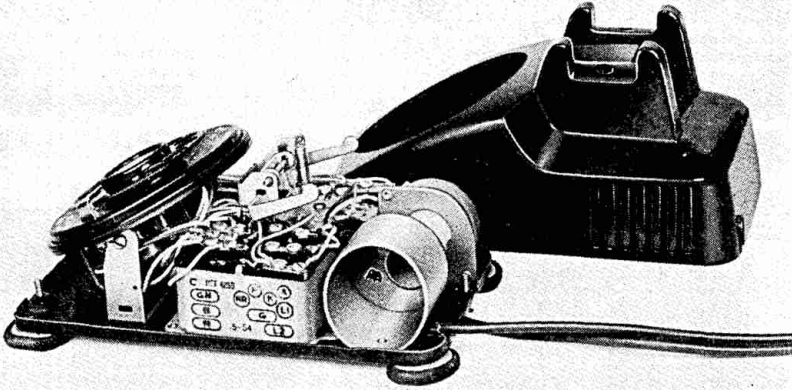


Fig. 4 — Telephone set with tone ringing.

transistorized tuned-circuit amplifier and a receiver element with an acoustic resonating chamber.

Once transistorized amplification is placed in the telephone set, it is an obvious step to use it to improve speech side-tone transmission. In the experimental system the use of a lower line current (approximately 10 milliamperes) permits a reduction in the size of the concentrator line transformers and the amplification in the telephone set helps overcome the insertion losses of the transformers.

3.3 Ringing

When the telephone receiver is on the switchhook the ringer is bridged across the line. A tone signal in the voice band that is sent through the switching network over the line to call a customer can be detected by the tuned circuit, amplified and radiated as sound energy. The tuned circuit responds to different frequencies for different parties, as in harmonic ringing. When the tone is transmitted the amplifier draws a small amount of line current, and this might look to the scanner like a receiver-off-hook or answer condition. For this reason, the scanner is directed to a line being rung only while its amplifier is drawing a minimum of current, during either the ringing cycle or the silent interval.

The ringing tones are applied through a concentrator-like network called the signal switching network, which is controlled by the concentrator marker. Two connections are set up through the signal switching

network whenever a line is being rung. One of these is for sending tone ringing to the called line, the other is for sending audible ringing tone to the calling line (see Fig. 17). Should difficulty be encountered in setting up the talking connection when the call is answered, an alternative connection will be established through the signal switching network, using paths previously engaged for the ringing functions.

IV. FUNCTIONAL CONCENTRATION

The control of the switching network serves to illustrate functional concentration, one of the principal features of the electronic switching system. To the rest of the system, the markers for the concentrator and signal and the distribution switching networks appear to be two black boxes. On command, they can set up or take down connections between trunks or between lines and trunks.

The commands are electrical control signals received in parallel in two parts, one part known as the "address" or "location" at which something is to be done, the other as the "instruction" or "order". The addresses are specific line or trunk numbers in coded form, usually binary digits (bits). The orders are to set up or release a connection at the designated address. The way in which this control is effected is briefly described in what follows.

In the marker, the address code is translated (from binary to one-out-of- n) and the electronic selector, in the form of a semiconductor diode matrix, applies a suitable voltage or "mark" potential to address the line terminal on the grounded side of the transformer. Potentials elsewhere in the network are controlled so that the set up or release order may be executed to the marked point. As a result, a connection is established from one marked address point to another marked address point, or a connection to a marked address point is released. This is the so-called "end-marking" principle which has been previously employed in the electronic control of relay crosspoints.¹² In this application, however, electronic crosspoints are used as the transmission medium as well as for the memory and control functions.

The switching network controls are designed so that, on release orders, the connection about to be released will be traced. At the end of a connection not being marked for release, the trunk will be identified; that is, its address in binary form will appear in the marker as the connection is released. This trace or identification operation occurs as part of each release order; it is used to process disconnect information for the trunk. Fig. 5 shows the switching network of the experimental system

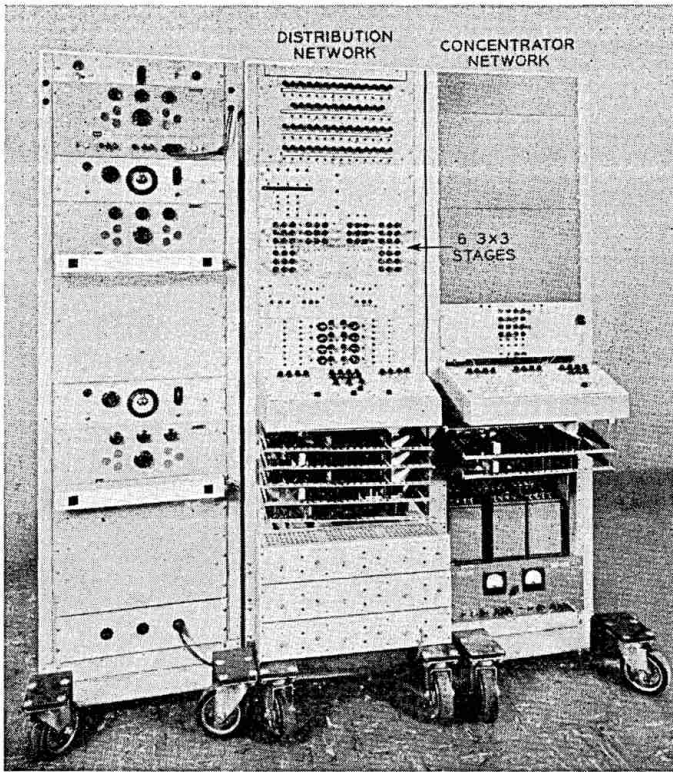


Fig. 5 — Experimental switching network.

setup, which uses 3×3 switches in the distribution switching network and 2×2 switches in the concentrator and signal switching networks. The marker circuits are located in the rear.

Most system components have a limited amount of output information. In the case of the switching network the output is a signal that a connection was either “set up” or “not set up” (due to blocking or trouble). As will be shown later, other major components of the system employ this same functional concentration method of control with address and order inputs and simple outputs.

Table I lists the “address”, “instructions” and “outputs” of each of the major blocks of the system. With the functional concentration concept, each major unit may be viewed from a system standpoint as a black box to which may be assigned a simple but complete statement of what it can do. Here there is considerable contrast between electronic and modern electromechanical common control systems. In the latter

TABLE I — COMMANDS

Block of System	Address	Instructions	Outputs
Concentrator	Line	{Connect Side A {Connect Side B {Trace Release	{Successful {Blocked {Busy
	Trunk		
Distribution Network	Trunk, Side A) Trunk, Side B}	{Connect Release	{Successful Blocked Busy
Scanner	Line	Interrogate	{0 1
Signal Distributor	Trunk (or Line)	Set Reset	—
Barrier Grid Store	Spot Coordinate (x and y)	Regenerate (Read) Reverse (Read) Write 1 Write 0	{0 1
Flying Spot Store	Spot Coordinate (x and y)	Advance Transfer Expose Off Plate	Command

case, it is sometimes difficult to assign a broad system function to each of the inter-unit control paths.

V. TIME-DIVISION CONTROL

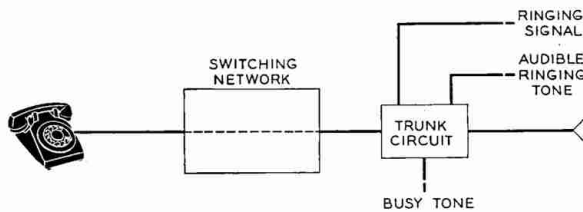
5.1 *Speed Advantage*

A switching network employing gas tubes and controlled in the above manner is more than 10 times faster than conventional networks employing electromechanical devices. This speed advantage is utilized in several ways. First, "one-at-a-time" operation is made possible; that is, sufficient capacity is available so that, even for large offices, only one marker is required to handle all the traffic. Second, system functions which usually are performed in trunk and register circuits may be performed by temporarily establishing certain network connections. For example, incoming trunk circuits in many electromechanical systems ring the called party and return audible tone to the calling party [see Fig. 6(a)]. In this electronic system, each of these functions is accomplished by setting up separate network connections from the appropriate line to a signal source [see Fig. 6(b)].

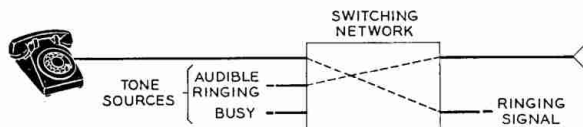
But electronic crosspoints are slow compared with speeds which may be obtained with the other electronic elements in the experimental system, such as transistors and semiconductor diodes. The use of devices of this type enables the control portions of the system to process all the information concerning each call on a "one-at-a-time" or time-division basis. This is possible because these devices are from 1,000 to 10,000 times faster than electromechanical elements.

The experimental electronic system is of the common control type, with the control serving all calls during their establishment and release but not during conversation. Time-division common control means that the control as a whole is acting on only part of one call at any particular instant of time. Transistor and diode logic circuits, known collectively as the central control, process call information among the various functionally concentrated system components on a one-at-a-time basis.

For purposes of control, each second of time is subdivided into hundreds of thousands of information-processing cycles. During each of these cycles, one or more system components may be commanded to perform one of its functions for a single call. The information processed by the central control comes from the system inputs, the lines and trunks. To gather this information, another functionally concentrated system element, the scanner, is employed to convert information oc-



(a) ELECTROMECHANICAL SYSTEM



(b) ELECTRONIC SYSTEM

Fig. 6 — (a) Example of trunk circuit functions in electromechanical system; (b) example of use of switching network for signaling and supervisory functions.

TABLE II — LINE CONDITIONS

		Scanner Output Line Condition	
		0	1
Barrier grid store output (line spot L1)	0	Idle or Dialing	Request Service or Dialing
	1	Disconnect	Talking

curing simultaneously on all lines and trunks into a series of time-related events.

Two major system components, the scanner and signal distributor, play a most important role in the time-division control, since they permit the interchange of information signals to and from space-separated inputs and outputs (lines and trunks). The experimental system is further limited to one-at-a-time operation because the barrier grid store can only read, write or regenerate one memory bit at a time and the flying spot store can only read out one word at a time. The basic rate for all of these one-at-a-time information processing operations is in the range of 100 kilocycles per second.

5.2 Scanner

The scanner is a collection of transistor and diode logic circuits arranged to examine an addressed line or trunk and determine whether current is flowing in it. A telephone line normally has no current flowing, but, when the receiver is raised from the switchhook, current flows.

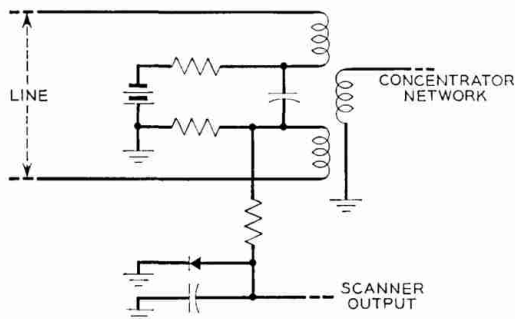


Fig. 7 — Line circuit.

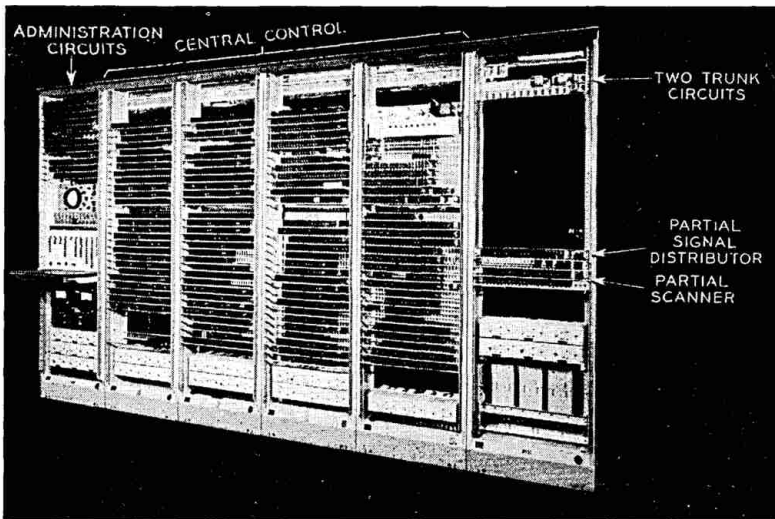


Fig. 8 — Experimental central control (including scanner and signal distributor).

This flow is interrupted during each dial pulse. If the scanner is addressed (directed) to the line during a receiver-on-hook condition or in the middle of a dial pulse, no scanner output results, but if it is addressed to the line when the receiver is off-hook and not in the middle of a dial pulse, an output signal is given by the scanner (see Table II). There are a few simple passive elements per line or trunk in the scanner. These, together with concentrator switching network line crosspoints and selector, are the only per-line units in the system (see Fig. 7). The experimental system includes a skeletonized version of the scanner since only a few lines and trunks are served. It is shown as part of the central control equipment in Fig. 8.

The scanner serves several different purposes. First, it is directed to each line every 0.1 second to determine if the line is requesting service to start a new call, if the line is in use or if the customer has hung up. Once a request for service is detected, the scanner is directed to the line every 0.01 second so as to be sure to recognize the shortest detectable open period that may occur on a line with a 20-pulse-per-second dial. Fig. 9 illustrates the two scanning rates as they occur on a calling line. The scanner is also directed to called lines approximately every 0.1 second during ringing to detect whether the call has been answered. If it has, the ringing of the called line is stopped by release of the connection from the ringing trunk.

5.3 Signal Distributor

The scanner gathers information when directed; the signal distributor is the component which performs the inverse function: "effecting." For the experimental system it is skeletonized as shown in Fig. 8. The signal distributor consists of a large number of output flip-flops (two-state electronic circuits) which are either set (operate) or reset (release) as determined by addresses and commands sent to it from the central control. The flip-flops respond rapidly, so that these commands may be given to the signal distributor at speeds in keeping with the logic of the central control. The flip-flops can then operate relays or other devices which must be used on individual lines or trunks for signal-control purposes.

An example of this is the sending of supervisory and dial pulse signals over trunks. The signal distributor is addressed to a device in the trunk circuit which will close the loop. Sufficient time must then elapse before the first dial pulse may be sent to allow relays at the distant end of the trunk to respond. During this time (hundreds of milliseconds), the high-speed electronic system controls are busy performing other functions, and the signal distributor may be ordered to set or reset other flip-flops for other slower-speed control needs, such as originating calls on other trunks. Dial pulses are sent (see Fig. 10) by repeatedly addressing set and reset orders at the required rate (10 or 20 pps) to the flip-flop associated with the trunk. During each of these periods the signal distributor may be sending pulses, as directed, over several trunks.

The signal distributor is also used for effecting other slow-speed output functions, such as returning called party supervision to originating offices over incoming trunks. The only slower-speed system functions not performed by the signal distributor are those which take place in the network markers.

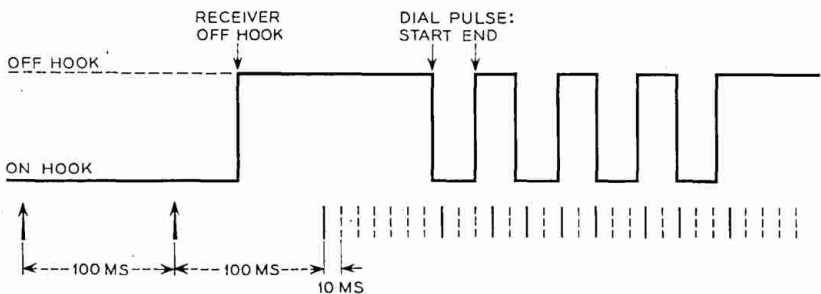


Fig. 9 — Two-rate scanning of calling lines.

VI. LARGE-CAPACITY MEMORIES AND THEIR USE

6.1 *Barrier Grid Store*

There are two types of memory used at present in electromechanical systems: changeable memories, which store call status information such as called numbers as they are dialed, and translation memories, which store information that is needed for determining the routing of a call. Changeable memories usually are locking relays or selector switches with a number of positions (multistate locking relays); translation memories usually are nothing more than cross connections or relay contacts wired so that operating combinations will produce a desired action.

The memory functions of the experimental electronic office are functionally concentrated in new high-speed electronic memory media. The "call status" or "temporary" memory is in the form of a barrier grid or electrostatic storage tube.¹³ Each tube is integrated into a complete set of electronic circuits to control the selective addressing, reading and order-writing of any one of the thousands of spots in a few microseconds. The complete assemblage is known as a barrier grid store. The store used in the experimental system is shown in Fig. 11 and described in detail elsewhere in this issue.³ The barrier grid store is used to record all of the call status information for each line, trunk, register or sender, as relays do in electromechanical systems. The memory spot array of this temporary memory medium is subdivided for these functions.

Each line and trunk has two spots associated with it. The state (0 or 1) of one of these spots (L1) is related to the condition of the line the last time it was scanned. The other spot (L2) indicates whether the line or trunk is being served by the control portion of the system; usually, this means that a coded representation of the line number is stored in

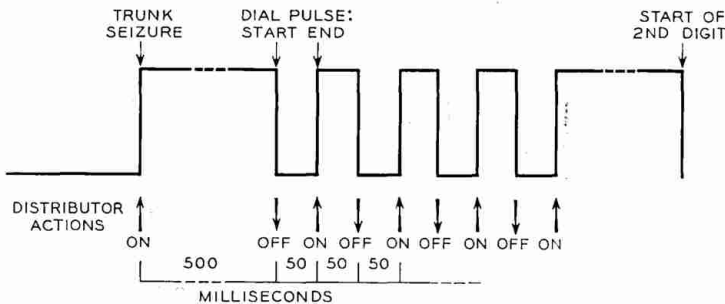


Fig. 10 — Outputting by signal distributor.

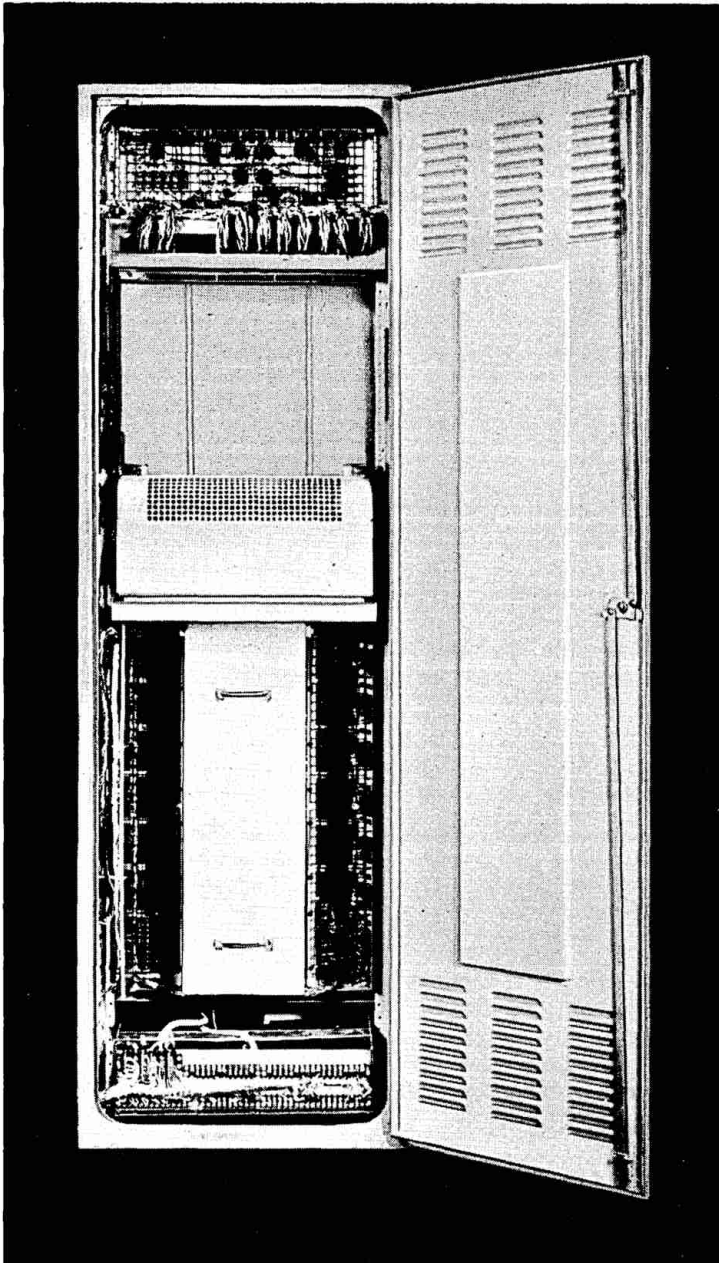


Fig. 11 — Experimental barrier grid store.

some group of spots in the barrier grid store. In addition, there is a spot (T3) assigned for each trunk of a group to aid in the hunt for an idle trunk. These spots are grouped so that the T3 spots of all trunks in the same group are adjacent.

Generally, all spots other than line or trunk spots are grouped by function and called "registers." Registers are assigned so that they comprise columns of spots; that is, the spots for any one register have the same x address coordinate. In the experimental system there are six types of registers:

1. Originating registers — to record dial-pulsed calls and control the completion of intra-office calls.

2. Outpulsing registers — to store information that controls the sending of called numbers over a trunk to a distant office on a dial-pulse basis.

3. Ringing registers — to store information that controls the ringing of the called line and the sending of audible ringing to the calling line.

4. Disconnect registers — to store information that controls the release of established connections.

5. Main program register — to store information relative to the identity of any particular 0.005-second division of time (the basic time subdivision of the system).

6. Network register — to store information concerning the type of call being handled by the network so that the appropriate program sequence can be referred to at the conclusion of a network action.

To enable adequate control by the central control and stored program, the amount and type of information stored in their spots varies among the register types. Table III lists this information for each of the register types. Note that spots are used much like relays in electromechanical switching systems to store coded line or trunk equipment numbers, dialed digits, number of digits dialed (digit location counter) and other numerical items. Other spots are used for call status indications such as "dialing completed" or "network requested". Fig. 12 shows a typical assignment of line, trunk and register spots in the square memory array of the barrier grid tube.

Registers of categories 1 through 4 above are considered as call-carrying registers. The number of each of these types provided is dependent upon the amount of traffic to be handled by the system. All registers of a given type are usually set up so that their corresponding spots have the same y address. In this way, the barrier grid store is used so that the x address indicates the type of register and the y address the particular spot in the register.

TABLE III — REGISTER SPOTS

Originating Registers	Outpulsing Registers	Ringing Registers	Disconnect Registers	Main Program Register	Network Register
Activity	Activity	Activity	Activity	Ringing scan Timer function	Activity
Number assigned to calling line equipment	Number assigned to outgoing trunk	Number assigned to called line	Number assigned to line equipment		Program address
Last look		Ringing trunk used		Interval counter	Register number
Call state		Ringing code			
Abandoned interdigital timer	Interpulse interdigital timer	Don't answer timer	Disconnect timer	Timer	Type of register
Pulse counter	Pulse counter and fourth digit		Trunk guard timer		
Digit location counter	Digit _i location counter				
First digit	Fifth digit				
Second digit	Sixth digit				
Third digit	Seventh digit				
Fourth digit	Signal distributor address				
Fifth digit					
Sixth digit					
Seventh digit					
Dial tone					
Permanent signal and partial dial					
Outgoing call					
Terminal line busy					
Network request					
Concentrator trunk used					

Each of the call-carrying registers has at least one spot which is used to indicate its busy or idle condition. This spot is known as the "activity" spot and is used when a search is made for an idle register. This concept for register-busy tests is similar to that used for physical trunk (or line) facilities (T3 spots), but it applies only to an entire group of spots in a column.

Spots in the registers may be reused for different call functions at different periods during the progress of a call, thus reducing total memory requirements. For example, groups of four spots are used to record the numerals of the called directory number as dialed. When dialing is completed and it has been determined that the call is intraoffice, the equipment number of the called line, translated from the directory number in the flying spot store, is stored by the spots which formerly held the called directory number.

Some functions in electromechanical systems depend upon the dif-

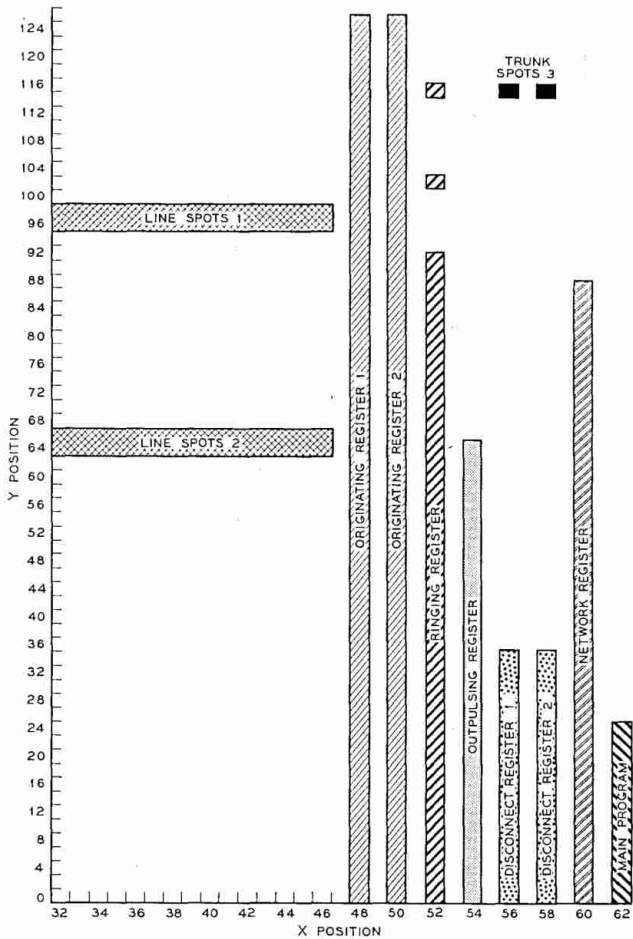


Fig. 12 — Barrier grid store spot layout.

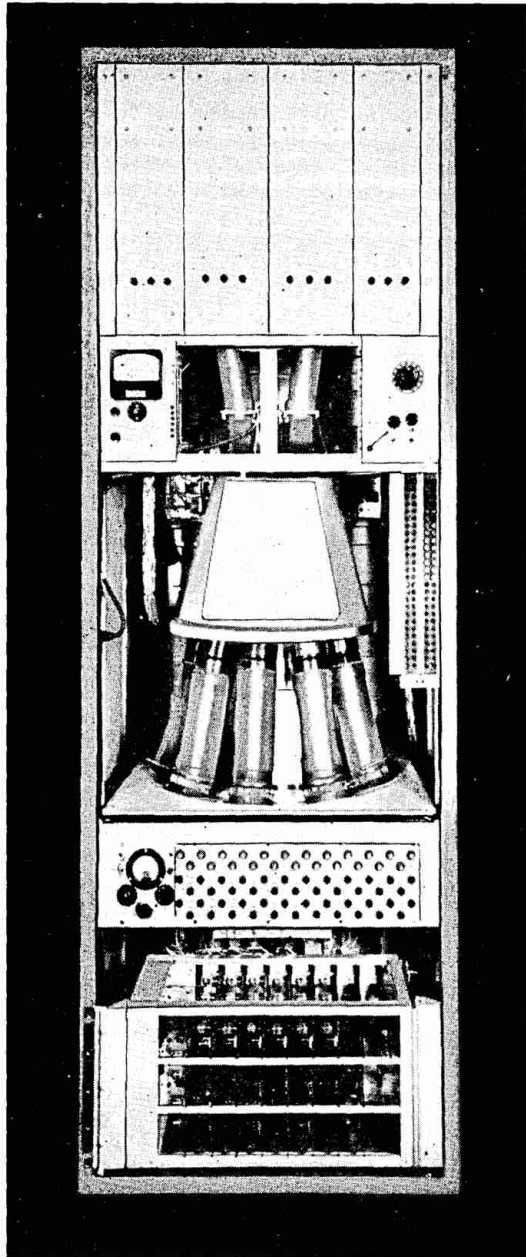


Fig. 13 — Experimental flying spot store.

ference in operate or release time of two or more relays. Such arrangements are used to distinguish a dial-pulse line opening from a call abandonment or a line closure between dial pulses from an interdigital interval. Slow operate or release relays are also used to determine time intervals such as those needed to distinguish a short accidental operation of the switchhook or a hit on the line from a disconnect. In the experimental electronic system, a time-counting technique employs barrier grid store spots which are part of the various registers. A counter consists of a group of spots. If a count is to be scored, the binary record in the spot group is changed by recording the next higher binary number. Scoring is under the control of the main program and may occur each 0.005 second or a multiple thereof.

6.2 *Flying Spot Store*

The second new type of memory provides the "semipermanent", "translation" or "wired-in" functions, using photographic plates as the memory medium, with digital information being recorded as transparent or opaque spots. These plates, together with an optical system, a cathode ray tube with digital-servo deflection control and photocells, are combined with electronic addressing and amplifier circuits in what is known as a "flying spot store". As described elsewhere in this issue,⁴ stores of this type are capable of recording on photographic plates, selectively addressing and reading any word group of bits of stored information in a few microseconds. Fig. 13 shows the flying spot store used in the experimental system.

6.3 *Plate Exposure Process*

The information to be placed on the photographic plates is first key-punched into business machine cards, each card containing an address and the order to be stored at that address. These cards are then processed by punched card business machines which produce a magnetic tape with information arranged by successive flying spot store addresses, a channel at a time. This tape is then read by a portable exposure control unit, Fig. 14, which is temporarily connected to the flying spot store. Unexposed photographic plates are inserted into their channels one at a time while the exposure unit reads the tape, addresses the store and turns the cathode ray beam on or off as determined by the information read simultaneously from the tape. Each plate is exposed in a few seconds

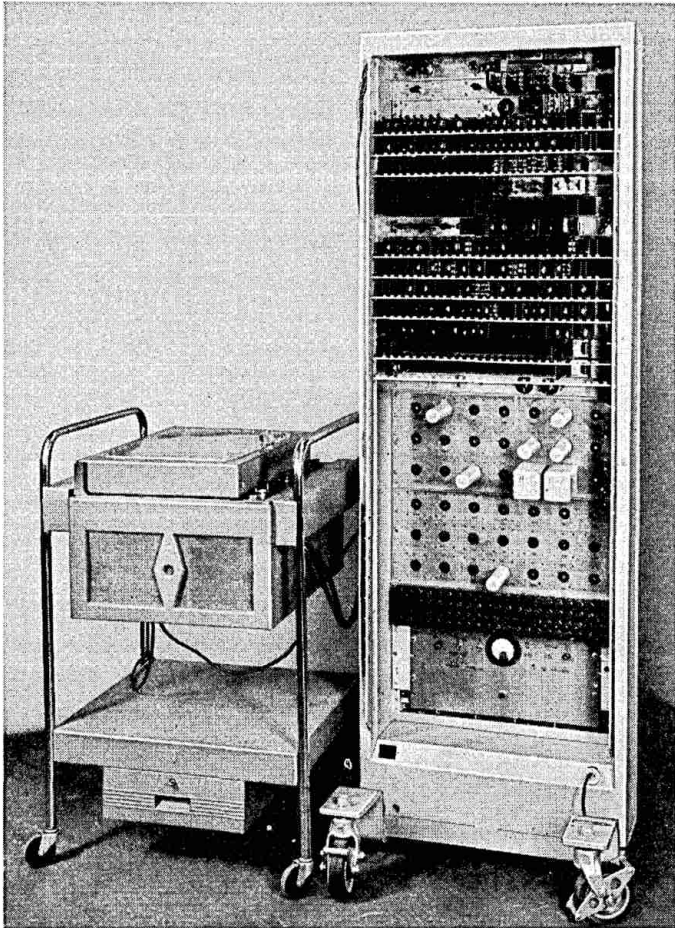


Fig. 14 — Experimental exposure unit.

and then removed to be developed. After being exposed and developed, all plates are inserted back into the proper channels. The magnetic tape may be rerun with the exposure unit in a "verifying" mode of operation, in which the channel outputs are compared, one at a time, with the magnetic tape which was used to control exposure. In this way, any exposure or developing errors may be detected before the plates are used in the system. Once verified, the store may be disconnected from the exposure unit and connected to the system central control.

VII. SYSTEM TECHNIQUES

7.1 *Stored Program Technique*

One of the techniques which is basic to the design of flexible and general-purpose digital computers is also of great value to the present experimental electronic switching system. This is known as "the stored program," in which binary-coded information is stored and read out of the flying spot store as needed to control most of the system's actions.

In a sense, the stored program is a further effort to concentrate functionally. In electromechanical systems the determinations of sequences and consequences of decisions are based on the predetermined circuit wiring in many circuits, markers, registers, senders, trunks, lines, etc. In the electronic system the flying spot store contains sequences of coded commands for the various parts of the system. This memory is ideal for this function since it is permanent and can be changed only by changing photographic plates. Changes in the program are engendered only when a change in service or administration is necessary.

Each order readout of the flying spot store is first interpreted by the logic circuits of the central control in one cycle. Thus, the proper gating and forming of the command to another system component may be executed when the next order is read into the central control from the flying spot store. Sometimes the commands are combination orders for two system components, as discussed above for the supervisory line scan. Other commands for a system component may require more information than can be contained in a single output word from the flying spot store. An example is a command to a marker, in which the parts of the network command are assembled in transistor flip-flops in the central control during several word readouts from the flying spot store until the complete command is ready.

The stored program is designed to be self-perpetuating, so that the system will not stop for lack of knowing what to do. To achieve this, the addressing of the flying spot store is advanced automatically one step at a time in the x coordinate on each readout cycle. This automatic advance is internal to the store, but a duplicate record of the address at which the flying spot store is directed is maintained in the central control.

There are two ways of changing the y (or x) coordinate of the address to jump the reading to a different portion of the photographic plate. The most important of these is the "decision" transfer, in which the flying spot store address is changed according to the interpretation of the out-

puts from one or more system components. The other type of transfer is of the "nondecision" type, which is used when jumping to addresses where translations appear, rather than the program. This type of order is also used when the end of one program section is reached, to permit advance to the next section which may be at a completely different address.

Use of the stored program technique permits the command sequences to be tested independently of the switching system. Simulation of the system is accomplished with modern high-speed electronic digital computers. Some 19 kinds of calls were successfully simulated using the stored program on a computer before the experimental system itself became operative.

7.2 *Main Program*

As implied above, the program is made up of many sections. Each section contains orders or instructions for handling a particular system routine or type of call. Flow or sequence charts are used extensively to make possible precise specification of required system actions. As may be observed from Fig. 15, which is a layout of the words stored in the flying spot store for the experimental system, some sections are related directly to the types of subdivisions of the barrier grid storage medium. Other sections are related to the frequency with which actions are performed in the system, such as the 100-millisecond line scan or the 10-millisecond dial pulse scan, and to the instructions for dealing with network actions and making translations from directory to equipment number. Overseeing all these routines is a main program which determines the sequence and time limitations, if any, for the individual routines and instructions. The end of each routine or sequence causes a transfer to the next point of the main program. To start the system into operation, the flying spot store is addressed to the beginning of the main program and thereafter the action should be self-perpetuating if the program is logically correct.

The main program is a timetable and priority list of the major functions which the system must perform. Successive cycles of the main program are usually not the same. In the experimental system the main program cycles are normally 5 milliseconds in length. Barrier grid store spots are assigned (see Fig. 12) and used to keep track of the cycle number so that the predetermined main program for that cycle may be carried out. Odd-numbered 5-millisecond cycles may scan lines for odd-numbered originating call registers and even-numbered cycles scan lines

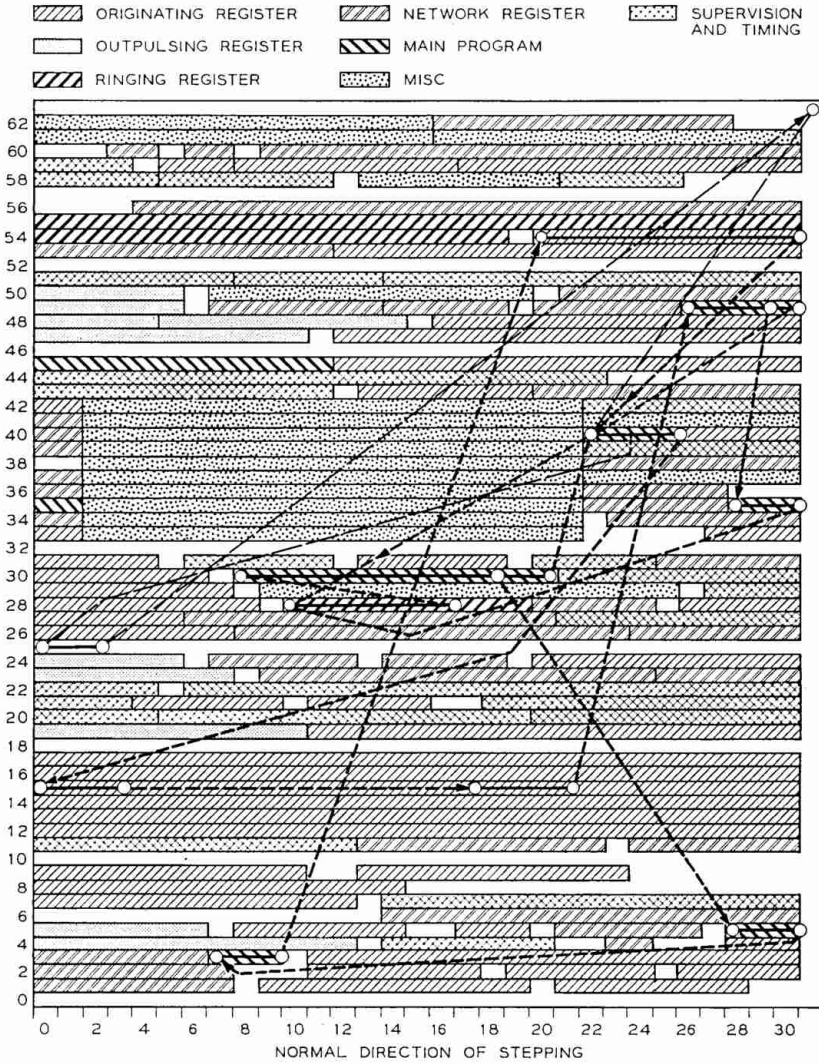


Fig. 15 — Flying spot store spot layout, with typical random access program sequence.

for even-numbered registers. Once during 20 cycles the main program shifts to various functions that must be performed each 0.1 second.

Most cycles provide intervals for commanding or acknowledging completion of network actions. A conventional busy test of the network is made during one central control cycle, as part of a main program se-

quence to determine whether the network may be addressed during this cycle of the main program. This characteristic is known as "network break-in". Similar break-ins alter the main program for synchronizing the scanning of lines for answer during modulation cycles of the ringing tone. Fig. 16 shows a typical main program cycle. It should be noted that the main program is another manifestation of the time-division form of system control.

Since each main program cycle may take a different length of time to carry out its intended functions, depending upon the amount of traffic and break-ins, there is an independent 5-millisecond timing circuit in the central control which the main program refers to after each routine or functional sequence has been completed. In this way, a cycle longer than 5 milliseconds is ended as soon as possible.

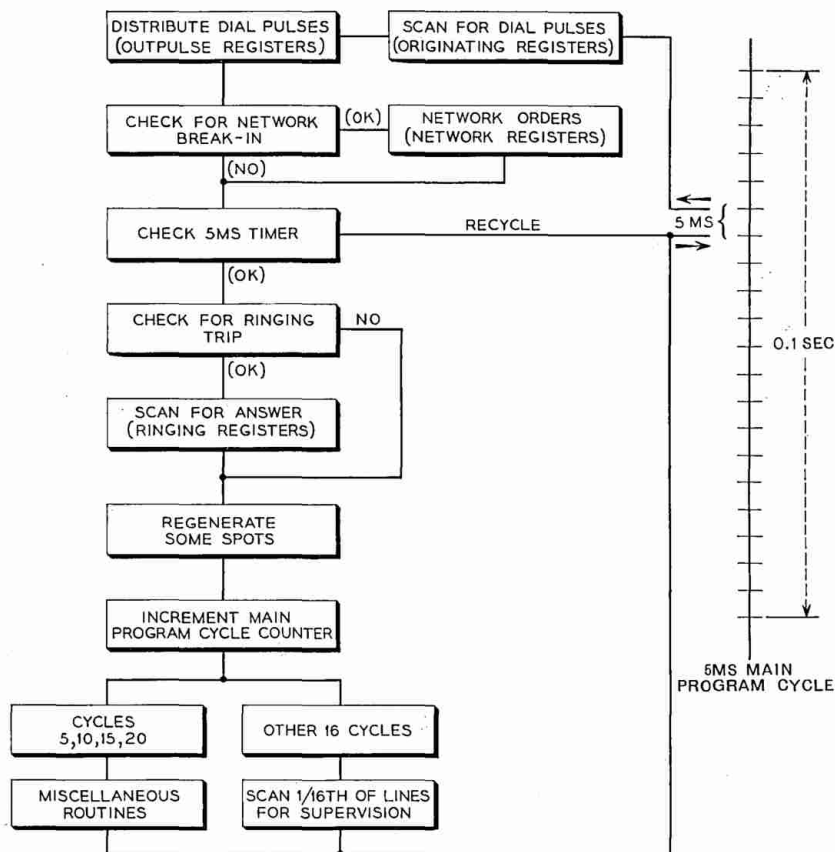


Fig. 16 — Main program.

7.3 *Central Control*

Fig. 1 shows the interrelation of the major components of the system described in the previous sections. Note that the commands for all the system components pass through central control. The central control, shown in Fig. 8, contains circuits which use 1500 germanium alloy junction transistors and 15,000 germanium point contact diodes. These circuits, which are combined to perform the required logic functions, are described in detail elsewhere in this issue.⁵

The central control makes all decisions which control the flow of commands to the various parts of the system.

None of the system's components can work alone or make decisions which will change the routing of a call or other system action. In many cases, the central control must command and receive output information from more than one component before a decision is made. For example, reading the scanner output alone is not enough to make a decision that a new request for service or a disconnect has originated. To do this, the call status store (the barrier grid store) must be consulted. In the store there is a memory spot associated with each line, which is examined at the same time the scanner is directed to the line circuit. This spot is kept up to date by commands from the central control indicating what the scanner saw the last time it was directed there. By comparing, in the central control, the output of the scanner and the barrier grid store at the address corresponding to each line, it is then possible to decide whether there is a request for service or disconnect. (See Table II).

Another example of this cooperation is in setting up a network connection to an idle trunk. The network addresses for the trunks to a particular destination are reached by addressing the flying spot store on the basis of the office or service code dialed. The word read out of the flying spot store gives translation information such as the class of the trunk, as well as the network address. Before the address is passed to the network marker with a command to set up the connection, a spot in the barrier grid store associated with the trunk is addressed to determine whether the trunk is idle.

In the first of these two examples of cooperation, the actions in the various system components occurred simultaneously. In the second, the cooperation occurred as a sequence of actions based on information received from one component and passed via the central control to another. This means that a certain amount of short-term memory, using transistor flip-flops, is needed in the central control. The information is stored temporarily for one or more cycles until this small step in the call has

been completed or while it is being worked on by a slower part of the system, such as a network or trunk.

VIII. CALL DESCRIPTION

Having described the various parts of the experimental electronic system and the new techniques employed, we may now trace the progress of a call through the system. The high-speed time-division type of control makes it necessary to describe more steps for a complete call than are necessary in an electromechanical system. It has been estimated that, at the level of detail with which a call will be described in this section, three times as many steps are required than for a comparable description of a call progressing through the most modern electromechanical system.

The description will assume an intra-office call to an idle line. No special situations such as call abandonments, all registers or trunks busy, permanent signal or partial dial, network blockage or busy, translation changes, reverting calls or overloads on the control will be covered. However, the experimental system is designed to care for all of these situations.

1. Detect Call Origination — With the system components functioning, the main program causes each line to be scanned every 0.1 second. Approximately one-twentieth of the lines are scanned on each 0.005-second main program cycle. Simultaneously, one of the line memory spots (L1) corresponding to each line being scanned is examined for a change in line state. When the calling party lifts the receiver from the hook, the change is detected on the next 0.1-second scan or, on the average, within 0.05 second.

2. Hunt For and Seize Idle Originating Register — After the call origination has been detected, the availability spots of originating registers are examined until an idle register is found. It is then made busy, and all information previously recorded, which might confuse this call, is erased. The calling line equipment number is written in the appropriate spots of the originating register. A register spot is marked to indicate that it desires to use the network to set up a connection to a dial tone trunk. The L2 spot of the line is marked to indicate a call is now being served by a register.

3. Dial Tone Connection — Assuming the concentrator marker is available, it is addressed with the originating line equipment number. The program order address, which will be required later for the next network action, is placed in the network register. The concentrator marker sets up a connection from the calling line through the concen-

trator to a trunk to the distribution switching network, preferably the A or left side. In this process the identity (address) of the trunk is recorded in the marker. The main program, in the meantime, continues to complete the 0.1-second scan of lines and other functions. Once in each 0.005-second main program cycle the network markers are examined to see if the network is ready for new action (network break-in).

To continue the network actions, the next flying spot store address is read from the network register in the barrier grid store. This program includes routines for the flying spot store to obtain dial trunk spot addresses in the barrier grid store. These spots are examined until an idle trunk is found and marked busy. Its address is then used in the flying spot store to find the address of this trunk on the distribution switching network. Together with the trunk number from the concentrator marker, the address is then placed in the distribution marker with an order to establish the dial tone trunk switching network connection. Once the connection has been successfully established, the calling line receives dial tone and the distribution marker awaits a main program break-in. When this occurs, the network register is made idle and the originating register is marked to indicate that the dial tone connection to the customer is complete and dialing may now start.

4. 10-Millisecond Dial Pulse Scan — At the beginning of each 0.005-second main program cycle, half of the originating registers are examined. If any are busy with a call in the dialing state, the originating line equipment number is read out into the central control, which then directs the scanner to the line to determine if there has been a change from the last time (0.010 second ago) the line was examined. This process continues every 0.010 second as long as dialing is expected.

5. Detect First Dial Pulse — To avoid changing the L1 line spot with each dial pulse, a "last look" LL spot is provided in the originating register, and this is read out along with the line number when the scanner is directed. This spot is compared with the scanner output and, if a change from closed to open is noticed, the beginning (open) of the first dial pulse is detected. As a result, the dial-pulse counter spots are changed to read binary 1 and the abandoned call-timer spot is erased to start a time-count cycle if this line open is longer than a dial pulse. Each succeeding change from closed to open of 0.010-second scans increases by one the binary number in the pulse counter spot.

6. Release Dial Tone Connection — The originating register spot indicating there is a dial tone connection is examined after the first pulse is detected. A test is then made to determine if the network is available. Assuming the distribution network marker is idle, the calling line equip-

ment number is read out of the originating register and transferred to the marker with an order to release the dial tone connection. The line number is coded so that it includes the number of the concentrator switch and the trunk. Only this part of the line number is read out to mark the end of the trunk in the distribution switching network which is to be released. When the connection is released, the identity of the dial tone trunk appears in the distribution marker and is passed to the central control on the next network break-in of the main program. With the dial tone trunk number known, the trunk busy spot T3 is changed to show that the trunk is now idle. It should be noted that the concentrator connection is maintained, so that later connections to the calling line will not block in the concentrator.

7. 100-Millisecond Examination of Originating Registers — Each 0.1 second the main program causes the abandoned call or interdigital time-count spots of the busy originating register to be changed. On each line change detected on the 0.010-second dial-pulse scans, these time counter spots are restored to zero. If a count of two is reached with the last look spot showing a line-open condition, an abandoned call is detected and the network is requested to release the concentrator connection. A count of two with the line showing a closed condition indicates the end of a digit. The binary count in pulse counter spots is read and stored in the central control and the counter cleared in anticipation of the next digit.

8. Move Dialed Digit to Digit Register Spots — A group of spots known as the "digit location counter" spots is read to indicate to the central control the γ address at which the dial-pulse count is to be stored. The binary number in the digit location counter is increased by one. The dialed digit is then written into the appropriate digit spots of the originating register. The main program then continues to make the 0.1 second examination of the time counter of next originating register.

9. Recognizing Local Central Office Code — When the digit location counter reads 3 and the third digit is transferred to the appropriate set of digit spots, the first three dialed digits are read out and referred as an address to a translation area of the flying spot store. The resulting output will indicate, among other things, that the call is intra-office, so an indication is made in the originating register that the call is not an outgoing or service code call.

10. After Registering Seven Digits — When the seventh digit has been counted and registered during a 0.1-second examination, the spots which indicate the state of the register are marked to show that dialing is completed. Thereafter the 0.010-second dial pulse scan is not made for this register.

11. Translation of Called Number — Since this is an intra-office call the four called numerical digits (16 bits) are read out into the central control. Some of these digits are referred to a special translation area of the flying spot store to compress the coding so that the line translation address will fit the address limitations of the store. The called line translation is then made from the compressed directory number to an equipment number and class of service of the called line, including ringing information.

12. Party Lines — Reverting Calls — If the ringing information indicates a party line has been called, the calling line equipment number is read out of the originating register and matched in the central control against the called line equipment number to determine if the call is for another party on the same line.

13. Place Called Equipment Number in Originating Register — The called equipment number in coded form is written in the same spots where the called directory number was accumulated. The interpretation to be placed on this information in the future is determined by the code recorded in the call status spots of the register.

14. Line Busy Test — The called line number is used by the central control to examine the line spots to determine whether or not it is idle. If it is idle, the L2 line spot is changed to indicate that the line is being served by the control portion of the system.

15. Establish Ringing Connection (Fig. 17 should aid in understanding these connections; refer to the circled numbers) — With called line and

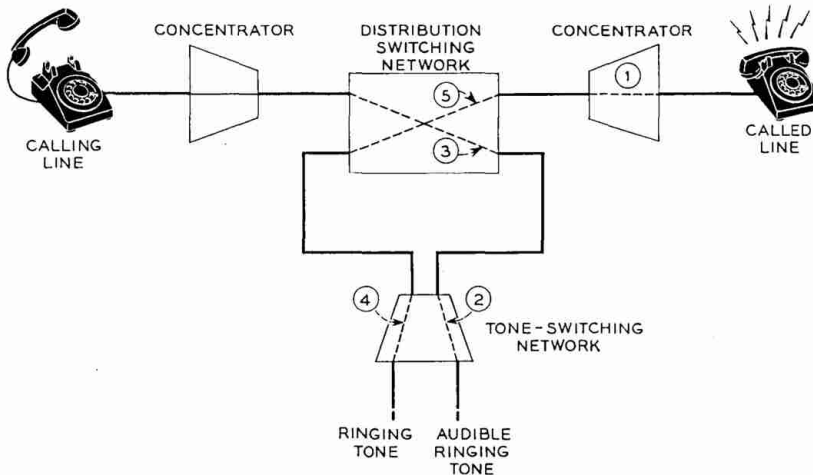


Fig. 17 — Ringing connections.

the network markers idle, the ringing function is started. ① The called equipment number is placed in the concentrator marker with a command to set up a connection between the called line and an idle trunk to the right or B side of the distribution switching network. This completes the actions taken during this 0.1-second register examination by the main program for this call. The number of the trunk to which a connection is established from the called line is read out of the concentrator marker and placed in the central control on the next network break-in operation. An idle ringing trunk is then hunted by examination of spots in the barrier grid store, and an address is obtained from the flying spot store in the same manner as for the dial tone trunk (item 3). The ringing trunk number and the address of the trunk from the concentrator connected to the called line are held in the central control. The former is used as an address for the next operation of the concentrator marker ②, when the audible ringing tone is applied to one of the tone switch output trunks to the right or B side of the distribution switching network. In the process, the particular trunk which is used from the tone switch is identified.

On the next network break-in, the distribution marker is given the address of the output trunk of the ringing switch through which the audible ringing tone is connected. The address of the trunk connected to the calling line, as interpreted by the central control on reading out the calling line equipment number from the originating register, is also read into the distribution marker, and the required distribution network connection ③ is set up. The calling party now hears ringing tone. The originating register number is held in the network register so that it knows what call it is handling.

The next network break-in is used to establish the ringing tone path to the distribution switching network through the signal network ④. The identity of the trunk from the ringing tone to the distribution switching network is passed to the central control on the next break-in. At this time the final link ⑤ for the ringing connection is established. Tone ringing current of the correct frequency now rings the called telephone.

16. Hunt For and Seize Idle Ringing Register — On the next network break-in of the main program the distribution marker reports the completion of the last link of the ringing connection. The barrier grid store is addressed, by the stored program referred to by the network register, to search for an idle ringing register. The selected register is then made busy. The called line equipment number and the address of the trunk connected to the ringing tone on the trunk switching network are written in the register.

17. Release of Originating Register — The calling line spots are now changed from the control condition and set to indicate talking. The orig-

inating register availability spots are changed to indicate that the register is now idle and available for use on a new call.

18. Scanning Called Line for Answer — Each 0.005 second during the silent period of the ringing cycle, or when the ringing modulation goes through zero, the called line number is read out of the ringing registers. The line number is used to address the scanner to detect the call answer. The register also has spots which time the ringing period so that a limit may be placed on unanswered time.

The answer is detected as a change from line open to closed during the appropriate 0.005-second main program cycle. At this time, the line spots of the called line are taken out of the control condition and put into the talking condition.

19. Release of Ringing Connections — Commands are issued simultaneously to the concentrator and distribution markers with information read from the ringing register to release the ringing switch and trunk switching connection to the called line.

On the next network break-in after these release functions have been successful, the trunk addresses identified in this process are held in the central control for use in establishing the talking connection. Release commands are now sent again to the network markers to take down the audible ringing connection to the calling party. This is also based on the knowledge of the ringing switch trunk address now stored in the ringing register.

20. Establish Talking Connection — On the next network break-in upon the successful release of the second half of the ringing connection, a command is given to the distribution marker to establish a talking connection.

On the next network break-in, when the successful establishment of the talking connection is reported, the availability spot of the ringing register is changed to make it available for another call.

The conversation between the two parties now takes place.

21. Detect Disconnect — The main program continues to cause each line to be scanned every 0.1 second. When, referring to the line spots, a change from line closed to line open is detected on either the calling or called line, a disconnect program is started.

22. Hunt For and Seize Idle Disconnect Register — A search is made immediately for an available disconnect register. The line number is recorded in the appropriate spots and the time-counting spots are set to zero.

23. Disconnect Timing — Each 0.1 second the main program incre-

ments the timer until at least 0.3 second has elapsed. At this time, a spot in the register is marked to indicate a request for the network when next it is idle on a break-in portion of the main program cycle. On each count scoring the timer, the line number is read out of the barrier grid store to address the scanner. This insures that the disconnect is bona fide, since a line hit might also have caused the line to appear open momentarily when the line open was originally detected. During this timing interval the other party's disconnect may also be detected. A different idle register is seized and timing started.

24. Release Talking Connection — If the network is idle, the line equipment number is read from the disconnect register and placed in the concentrator marker as the address part of a trace command. As on all network operations, the number of the disconnect register is written in the network register, together with the type of network action taking place.

On the next network break-in of the main program, the concentrator marker reports back to the central control with the number of the trunk being used by this line in the trunk switching network. The network markers may now proceed to accept release commands based on this trunk number.

The distribution marker identifies the address of the trunk connected to the other party's concentrator. On the next network break-in after successful execution of the previous commands, this address is given to the concentrator marker with a command to release the last link of the intra-office connection.

On the next network break-in, when the successful execution of this last command is reported, the disconnect register is again made available and the line spots of the line whose number is read out of the disconnect register are changed from the control to normal supervisory state.

Later, when the other party's disconnect is detected and timed, the concentrator marker, in response to the trace command, finds the concentrator connection already released and so reports this condition on the next network break-in. At that time, the disconnect register and line spots are restored to their normal states.

IX. CONCLUSION

A number of new electronic switching techniques have been described and their applications in the first experimental laboratory system illustrated. This system is shown in Fig. 18 as it was assembled for proving the feasibility of these new approaches. In addition to the features described, the left bay of the central control (Fig. 8) contains key and

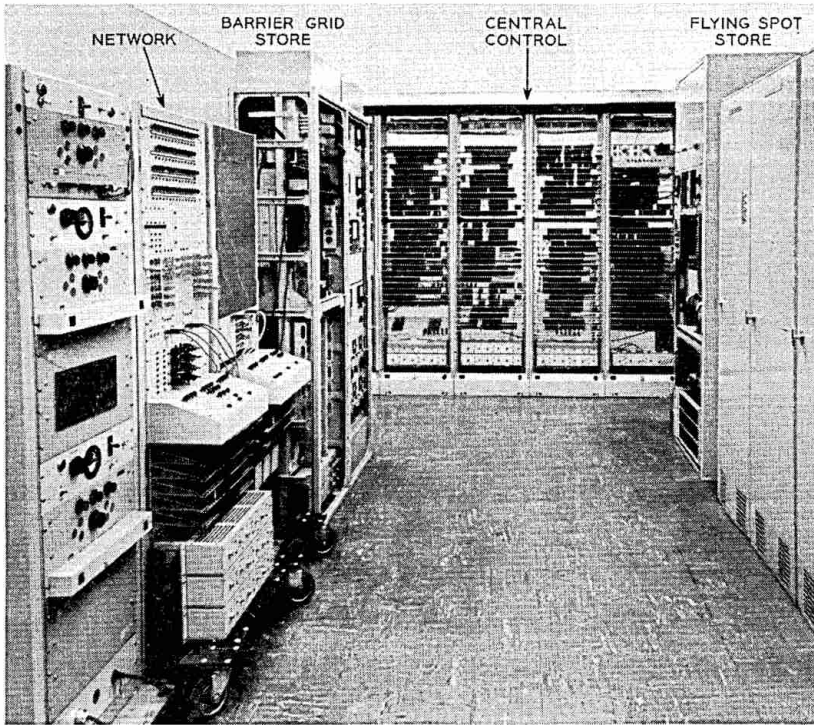


Fig. 18 — General view of experimental system.

indicating equipment to aid in the testing of the system. This includes means for regenerating the barrier grid store when the system program is not functioning during the location of trouble and means for inserting orders into the central control manually.

Descriptions of the circuit, apparatus, equipment and program details appear elsewhere in this issue and will be published in future issues of this publication.

Much has been done to develop the techniques of this experimental system to the point where they should be satisfactory for use with traffic from telephone customers. Other system considerations are being developed before the commercial and trial applications of these techniques take place. Maintenance facilities; system expansion beyond the memory capacities of the present stores; administrative procedures, including traffic recording, remote concentrators, power facilities and other services such as operator class calls are among the new system items which are being developed. At the same time, intensive study of component

and system reliability is proceeding to insure the successful operation of this system.

X. ACKNOWLEDGMENT

The philosophy of this system is an outgrowth of engineering studies made by C. E. Brooks.

REFERENCES

1. Vaughn, H. E. and Malthaner, W. A., An Experimental Electronically Controlled Automatic Switching System, B.S.T.J., **31**, May 1952, pp. 443-468.
2. Vaughn, H. E. and Malthaner, W. A., DIAD — An Experimental Telephone Office, Bell Labs. Record, **32**, October 1954, pp. 361-365.
3. Greenwood, T. S. and Staehler, R. E., this issue, pp. 1195-1220.
4. Hoover, C. W., Ketchledge, R. W. and Staehler, R. E., this issue, pp. 1161-1194.
5. Yokelson, B. J., Cagle, W. B. and Underwood, M. D., this issue, pp. 1125-1160.
6. Joel, A. E., Electronics in Telephone Switching, B.S.T.J., **35**, September 1956, pp. 991-1018.
7. Goudet, G., General Consideration on Electronic Switching, Elec. Comm., **34**, June 1957, pp. 80-91.
8. Ketchledge, R. W., An Introduction to the Bell System's First Electronic Switching Office, Proc. Eastern Joint Computer Conf., December 1957.
9. Townsend, M. A. and Depp, W. A., Cold Cathode Tubes for Transmission of Audio Frequency Signals, B.S.T.J., **33**, November 1954, pp. 1371-1391.
10. Townsend, M. A., Cold Cathode Gas Tubes for Telephone Switching Systems, B.S.T.J., **36**, May 1957, pp. 755-768.
11. Meacham, L. A., Power, J. R. and West, F., Tone Ringing and Push Button Calling, B.S.T.J., **37**, March 1958, pp. 339-360.
12. Hecht, G. and Brewer, S. T., A Telephone Switching Network and Its Electronic Controls, B.S.T.J., **34**, March 1955, pp. 361-402.
13. Hines, M. E., Chroney, M. and McCarthy, J. A., Digital Memory in Barrier Grid Storage Tubes, B.S.T.J., **34**, November 1955, pp. 1241-1264.