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Electronics in Telephone Switching Systems

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In recent years a number of fundamentals has been discovered through research which place new tools at the disposal of the circuit and system designers. Examples of this "new art" are concepts such as information theory, dealing with the quantization and transmission of information, and solid state principles from which have developed the transitor and other devices. This paper surveys certain new art principles, techniques and devices as they apply to the design of new telephone switching systems.

Over the past forty years a great background and fund of knowledge has developed in the field of telephone switching. Constant improvement in available devices has resulted in increasing the scope of their application. The field has almost reached a point of perfection as an art and is now rapidly entering a more scientific era.

The tools of the present day telephone system design engineer are well known and some are illustrated in Figure 1. These are the relay and the various forms of electromechanical switching apparatus. But over the years, while the art employing these tools was developing, the field of electronics has also been developing. Its applications were most needed when dealing with its characteristics of sensitivity rather

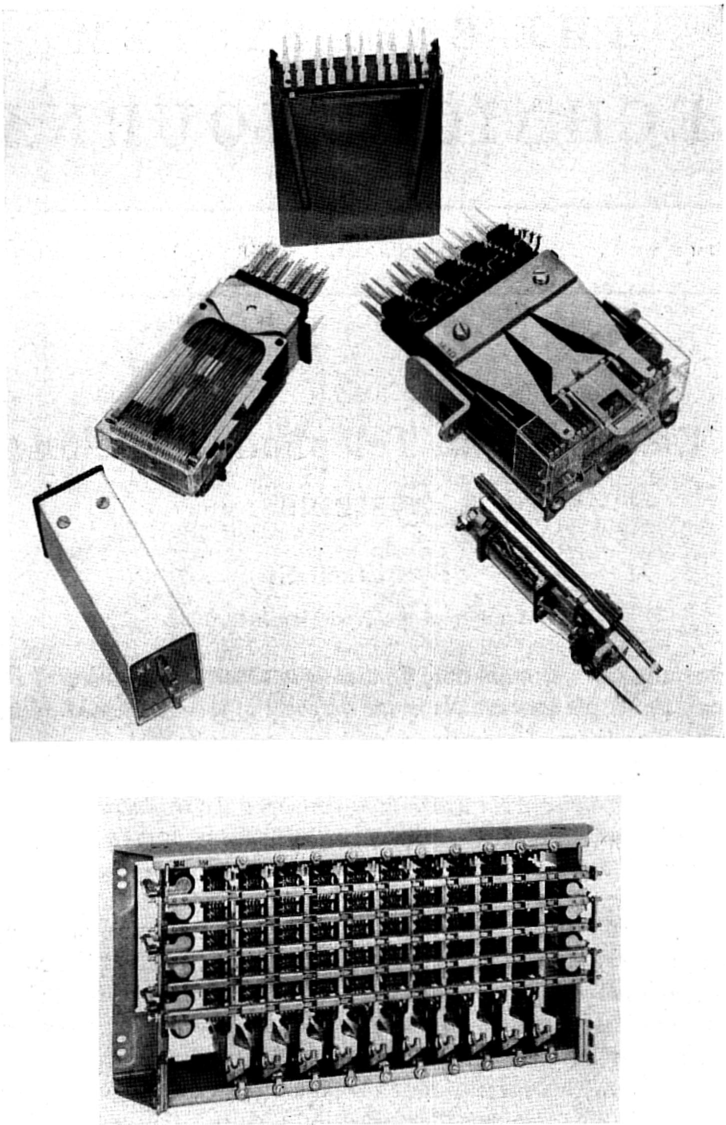

Fig. 1 — Typical telephone relays and switches.

than speed. Even in the telephone switching field, this property of electronics has made its inroads to provide us with better signaling and more accurate timing.

It was not, however, until World War II that the speed advantages of electronics were exploited. This exploitation came primarily in the quantizing of information, both in transmission and information processing equipment. In the latter field new digital computers made their appearance. These machines brought forth the development of new forms of electronic devices, most important of which are those classified as "bulk memory" devices.[1] Later in this paper the characteristics of many of these devices will be discussed in more detail.

In the post-war period the exploitation of another phase of electronics developed from research in semiconductor devices. The transistor is perhaps the best known invention to emerge from these investigations. The impact of the application of semiconductor devices is yet to be felt in the electronics industry and it will most likely find greatest application in the information processing field and in communications generally.

Before one may understand and appreciate the impact electronics will have on the design of new telephone switching systems it is necessary to consider the question: "What is a Telephone Switching System?" By evolution it is now generally recognized that the central office portion of a telephone switching system consists of two principal parts and certain physical and operational characteristics of these parts. These parts, as illustrated in Figure 2, are the interconnecting network, or conversation channel, and its control.

In some switching systems, particularly those of the progressive

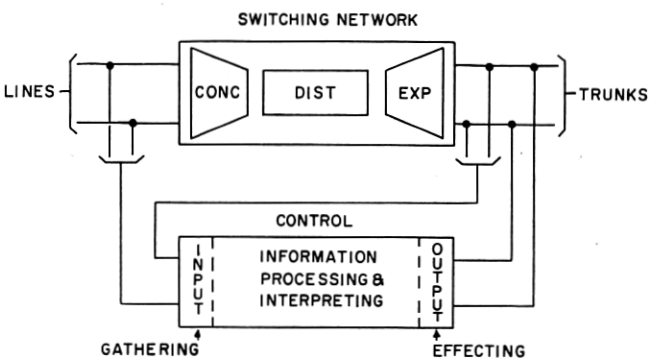

Fig. 2 — Principal parts of common control telephone switching system.

direct control type, such as the step-by-step system, these parts are inexorably integrated. But in the modern systems they have largely been separated. For purposes of the following discussion this type of system, viz., common control, will be assumed. The bulk nature of the electronic memory devices makes them more readily adaptable to systems of the common control type, where the control functions consisting of the receipt, interpretation, and processing of input signals and the effecting of output signals may be concentrated.

INTERCONNECTING NETWORK

In electromechanical switching systems the interconnecting network is composed of crossbar switches or other electromechanical devices. Each connection through the network is physically separated in space from the others and hence the type of network can be called generically a "Space Division" type of network. Such networks are subdivided functionally. First there is the concentration stage where active lines are separated from those not being called or served at a particular time. Next there is distribution stage where interconnection of active lines and trunks is accomplished. Finally there may be an expansion stage where active call paths are connected to selected destinations.

In electronic switching systems three classes of switching networks have been described.[2] These are:

a. "Space Division" similar to the space division for electromechanical apparatus except that electronic devices such as gas tubes are employed in place of mechanical contacts as the crosspoint element.[7]

b. "Time Division" where calls are sampled in time, each one being given a "time slot" on a single channel.[3,4]

c. "Frequency Division" such as employed in carrier systems where each call is modulated to a different frequency level on a single transmission medium.[5,6]

Thus in electronic switching the interconnecting networks derive their basic characteristics from the known methods of telephone transmission. Since transmission techniques are used it is generally not feasible to pass direct current signals through such networks. Also certain ac signals such as 20-cycle current now used for ringing are of such a high power level that they would overload the electronic switching devices employed. For this reason it appears that to accomplish switching with an electronic interconnecting network a change is required in the customer's apparatus to make it capable of responding to a lower level ac for the call signal. Telephone sets with transistor amplifiers and an acoustical horn are being developed. (See Fig. 3.) Interrupted tones in the voice frequency range can be used effectively to call the user to the telephone.[8]

As in most electromechanical switching networks, the concepts of connecting successive stages of switching devices (stages to perform the functions of concentration, distribution and expansion) to form the network also apply. Since there is more than one method of interconnection, the successive stages of a network may employ different switching techniques — electronic, electromechanical, or both. In electromechanical switching, different devices may also be used in different stages.

In electromechanical space division networks certain types of crosspoints are more adapted to common control operation than others. Systems with electromechanical selector switches most generally are set progressively. In systems with relays or relay-like crosspoints all crosspoints involved in a connection may be actuated simultaneously. In either case the switching device, or the circuit in which it is used, has a form of memory. This memory, shown as a square labeled M in Fig. 4, may be the ability of a selector to remain mechanically held in a particular path connecting position or in a locking or holding circuit associated with a crosspoint relay or crossbar switch magnet.

To minimize the time consumed by the common control elements, simultaneous operation of relay or relay-like crosspoints is most desirable. However, this type of network requires a grid of link testing and control leads such as shown in Fig. 5 for a typical stage of a crossbar switching network. In a network of this type the calling rate capacity is limited by the slow actuating speed of the electromechanical relay or switch. Efficient network configurations can be devised for

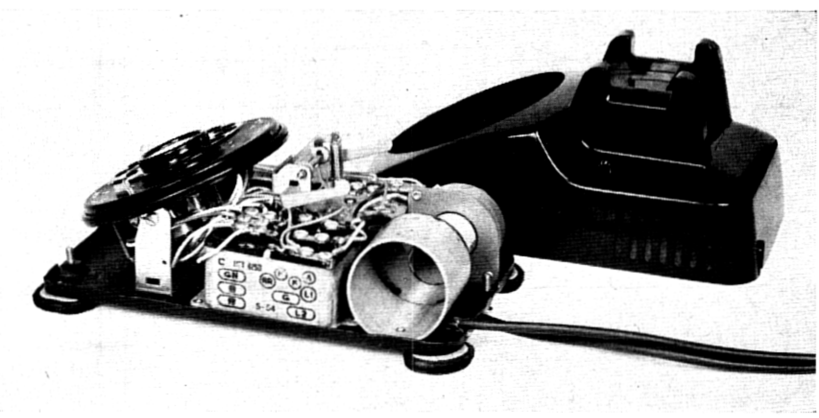

Fig. 3 — Tone ringer telephone set.

large capacity. To set up connections at a high rate in such a network requires a plurality of controls each capable of operating on all or part of the network. In any case, the controls function in parallel on the network because of the speed considerations.

With electronics applied to space division switching networks, two improvements over the operation of relay type space division networks may be achieved. First, the speed of operation of the crosspoint elements may be made high enough so that only one control is needed to operate on networks of the size now requiring a plurality of controls. Second, the properties of proposed electronic crosspoint elements are such that the principle of "end-marking" may be employed.

In contrast to the grid of testing and actuating wires required in electromechanical versions of space division networks, the electronic space division switching network requires only the selectors at each end of a desired network connection to apply the marking potentials. (This is what is meant by "end-marking"; see Fig. 6). The electronic cross-

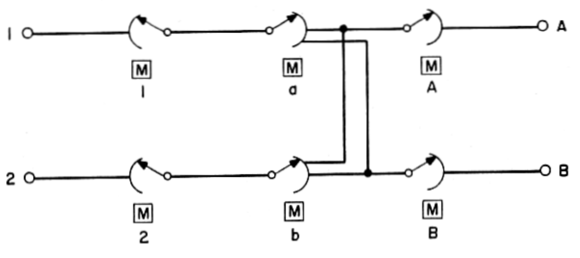

Fig. 4 — Space division switching.

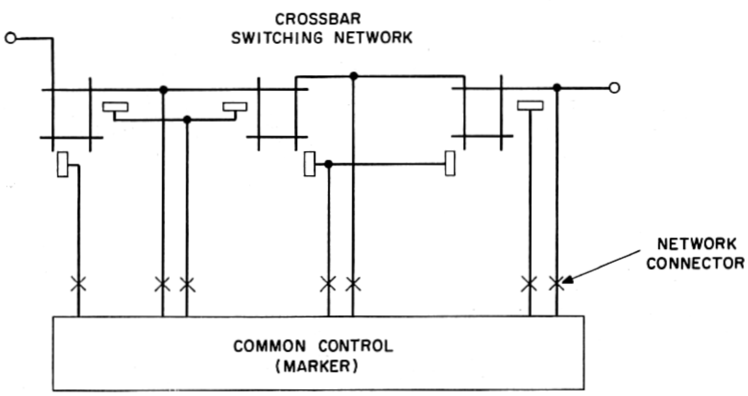

Fig. 5 — Typical common control of a crossbar switching network.

point element will be actuated if the link to which it connects is idle. Eventually all available paths between input and output will be marked. Means must be provided for sustaining only one of the possible idle paths. Here the memory property of the crosspoint device takes over to hold the path until it is released by release marks or removal of the sustaining voltages. So it may be seen that in space division networks the memory requirements must be satisfied the same as in electromechanical networks.

Multiplexing and carrier transmission systems[9] employ time and frequency division but the physical terminals at both ends of a channel for which the facilities are derived have a one-to-one correspondence which can only be changed manually. In a switching system means must be provided to change automatically the input-output relations as required for each call. Here the need arises for a changeable memory for associating a given time or frequency slot to a particular call at any given time. At some other time these points in time or frequency must be capable of being assigned automatically to different inputs and outputs. For the period that they are assigned, some form of memory must record this assignment and this memory is consulted continuously or periodically for the duration of the call.

With time division switching this new concept in the use of memory in a switching network appears most clearly, see Fig. 7(a). To associate an input with an output during a time slot the memory must be consulted which associates the particular input with the particular output. To effect the connection during a time slot the input and output must be selected A memory is consulted to operate simultaneously high speed

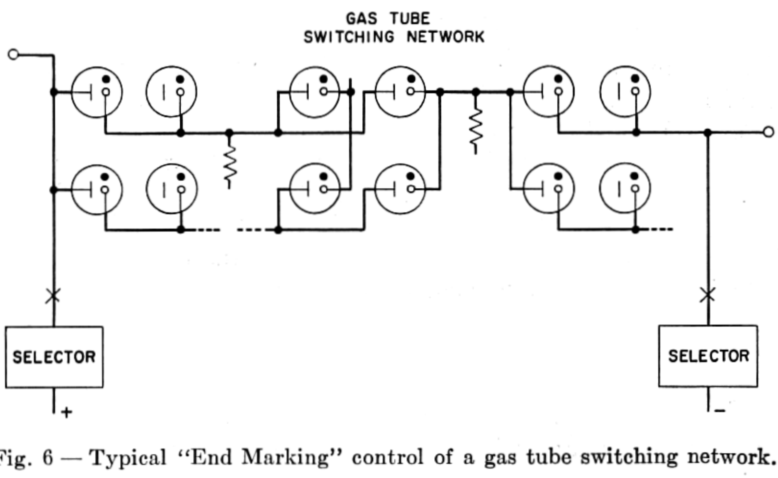

Fig. 6 — Typical "End Marking" control of a gas tube switching network.

selectors for both the input and output. Each selector receives information from a memory which actuates crosspoints to associate the input or output with the common transmission medium. The information from the memory which controls the selection process is known as an "address". The crosspoint is non-locking since it must open when the selector receives its next address. The individual memory of crosspoints for space division networks has thus been changed by time division to changeable memory, usually in the form of a coded address associated with each time slot. Furthermore since the successive addresses actuate the same selectors and hence may be held in a common high speed device, electronic bulk memory is ideally suited for this task. The memory must be changeable to allow for different associations of input to output at different times.

In frequency division the control characteristics of the interconnecting network require a modulation frequency to be assigned each simultaneous conversation to be applied within the bandwidth of the common medium. As shown in Fig. 7(b) the application of the modulation frequencies requires a separate selector for each input and output. These

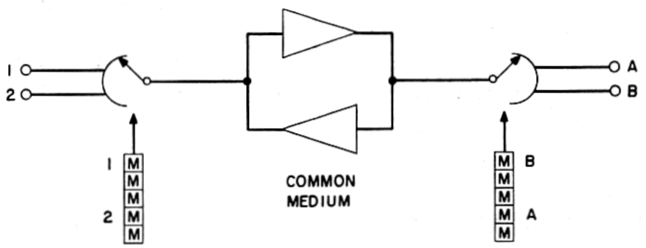

Fig. 7(a) — Time division switching.

selectors are nothing more than space division switching networks and therefore require memory in the switching devices whether they are electromechanical or electronic.

In addition to memory for associations within the switching network, selecting means are also needed to activate a terminal to be chosen in space division (e.g., Fig. 6), to place address information in the proper time slot in time division switching or to set the frequency applying switching network in frequency division.

CONTROL

The control of the switching system provides the facilities for receiving, interpreting and acting on the information placed into it. In par-

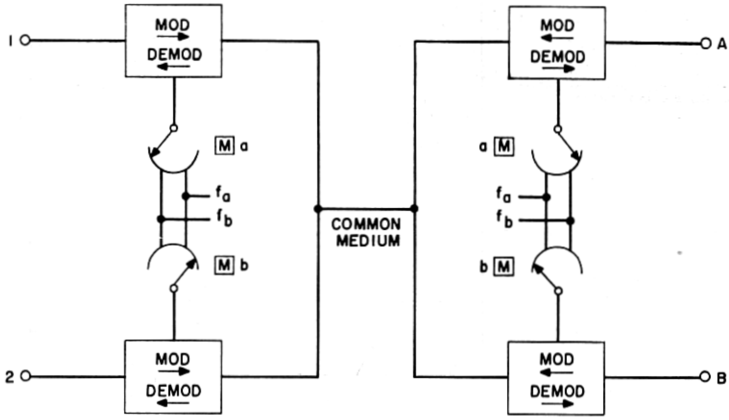

Fig. 7(b) — Frequency division switching.

ticular this is the address of the output desired. A service request detector (SR-D) is provided for each line or trunk.

In electromechanical systems these logic and information gathering functions are performed by relays or electromechanical switches. In order to keep up with the flow of information from a large number of customers, a number of register circuits must be provided to perform the same function simultaneously on different calls. Here information is being gathered on a "space division" basis and therefore a control switching network may be visualized as depicted in Fig. 8. The registers designated R-M constitute the memory used to store the input information as it is being received in a sequential manner from lines and trunks. As in the case of the conversation switching network, a space division control switching network has been used in electromechanical systems because the speed of these devices is not adequate to accommodate the rate at which information flows into the system. It is interesting to note in passing that in the step-by-step system the control and conversation switching networks are coincident. In the No. 5 crossbar system[10] the same network is used for both control and conversation on call originations but when so used the functions are not coincident, that is, the network is used for either control or conversation. In other common control systems, separate control networks known as "register or sender links" are employed.

When using relays to receive the information pulsed into the office by customers or operators a plurality of register circuits are needed. The number of the registers required is determined by the time required to actuate the calling device and for it to pulse in the information. The registering function has two parts, one to detect or receive the information and the second to store it until a sufficient amount has been received for processing. The processing function is usually allotted to other circuits such as the markers in Crossbar systems.

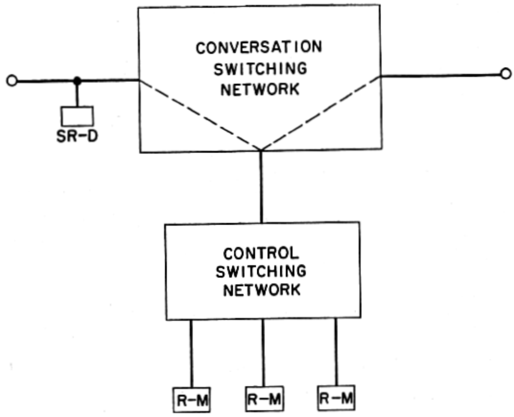

Fig. 8 — Control access.

Since the input of information to a switching system is usually limited to two conductors, a serial form of signaling is used. It would seem only natural that if a detector were fast enough it could function to receive the serial information in several simultaneously active inputs. Relays are not fast enough to do this, but high speed time sharing electronic devices have been designed to perform this information gathering function. Since it is a time sharing arrangement it is analogous to the time division switching. A time division control access as shown in Fig. 8 and 9 requires memory to control the time division switching function. Time sharing when applied to the gathering of information in telephone switching systems has been called "scanning". The individual register memories are still in parallel form because of the relatively long time required for sufficient information to be received before processing may start. Higher speed means for placing information into switching systems such as preset keysets is one way of reducing, if not eliminating, this need for parallel register storage in the switching system prior to processing. However, with this type of device one merely transfers the location of the storage from the central office to the customer's telephone set. The fundamental limitation is the rate at which a human being is able to transfer information from his brain into some physical representation.

Lower cost memory is a practical means for improving this portion

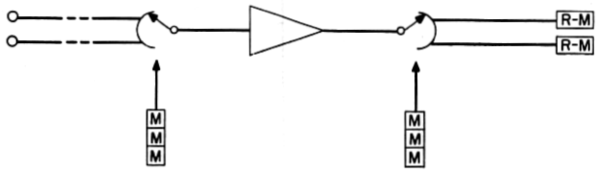

Fig. 9 — Time division control access with separate functional memory.

of the switching system. Many small low cost relay registers have been designed and placed into service.[10] Electronics, however, offers memory at one tenth, or less, of the cost per bit if used in large quantities with a common memory access control. New low cost bulk electronic memories are now available to be used in this manner. As shown in Fig. 10 the memory for the control of the time division control access network and the register memory may be combined in the bulk memory.

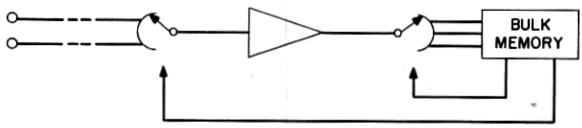

Fig. 10 — Time division control access with bulk memory.

Memory appears in the control portion of a switching system in many ways. Some are obvious and others are more subtle. Fig. 11 shows a typical electromechanical switching system, much like No. 5 crossbar and attempts to indicate various memory functions. First there is active memory designated A such as the call information storage A_2 whether in a register, sender or marker during processing. There is also certain pertinent call information storage associated with trunk circuits such as a "no charge class" on outgoing calls or the ringing code used on incoming calls. Another type of active memory A_1 has been mentioned in connection with switching networks to remember the input-output associations. In most electromechanical systems active memory has been emplemented with relays or switches.

Another form of memory is also employed in all telephone switching systems and much effort has been devoted to devising improved means for effecting this memory. This memory is of the type that is not changed with each call but is of a more permanent nature. Examples of this type of memory, which may be called passive memory, designated P, (Fig. 11), are the translations required in common control sytems to obtain certain flexibility between the assignment of lines to the switching network and their directory listing. These translations between equipment numbers (network location) and directory numbers are required to direct incoming calls to the proper terminals (such as the number group frame in No. 5 crossbar, Fig. 12) and to provide on originating calls information for charging purposes (such as the AMA "Dimond" ring translator,[12] Fig. 13). Each of these translators for a 10,000 line office represent about 10^6 bits of information. Another use for passive memory is to translate central office codes into routing information. In local central offices this is also done by cross-connections as shown in Fig. 14.

Another form of passive memory is the punched card or tape. These have been used widely in telephone accounting systems. A step toward electronic memory is the card translator which provides routing information in the crossbar toll switching system[13] (see Fig. 15). Here the cards represent passive memory and are selected and read by a combination of electromechanical action and light beam sensing with phototransistor detectors. One such device equipped with 1,000 cards represents the storage of approximately 10^5 bits of information.

In all of the above types of passive memory limitations in the speed are involved in the choice of devices used within the memory or the access to it. This is one of the reaons these translators are subdivided so that the various portions may be used in parallel in order to satisfy the total information processing needs of the office.

A discussion of passive memory would not be complete without one further illustration, Fig. 16. This is a wiring side view of a typical relay circuit in the information processing portion of a switching system. It

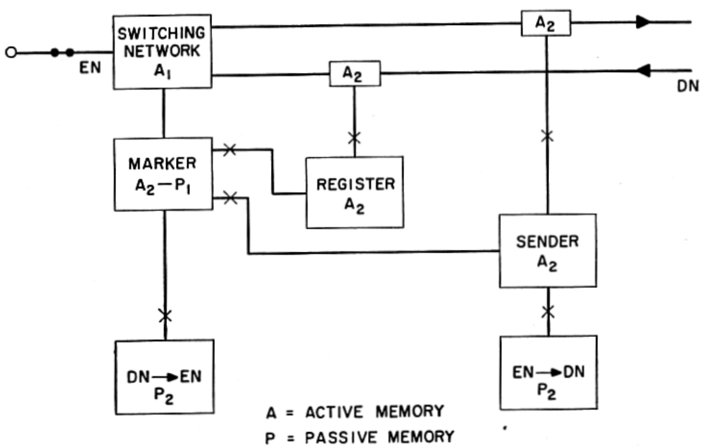

Fig. 11 — Memory in typical electromechanical switching system.

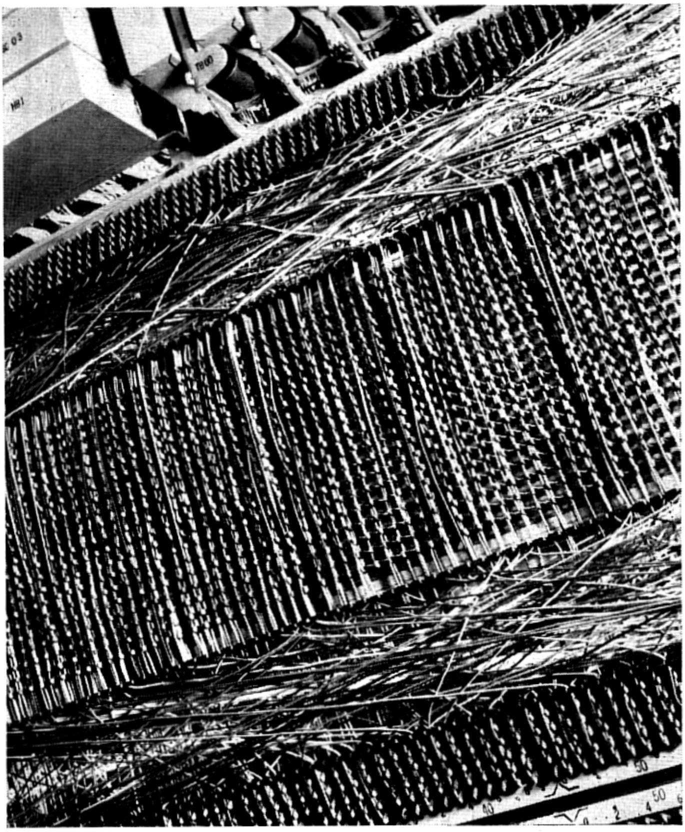

Fig. 12 — No. 5 number group.

could be any other unit, for example, a trunk circuit. The principal point is that each wire on such a unit is remembering some passive relationship between the active portions of the circuit, such as relays. This is the memory of the contact and coil interrelationships as conceived by the designer and based on the requirements of what the circuit is required to accomplish. It is the program of what the central office must do at each step of every type of call. Modern digital computers have been built with the ability to store programs in bulk memories for the solutions of the various types of problems put to them. It is conceivable that the program of a telephone contral office may also be stored in bulk memories to eliminate the need for much of the fixed wiring such as appears in relay call processing circuits.

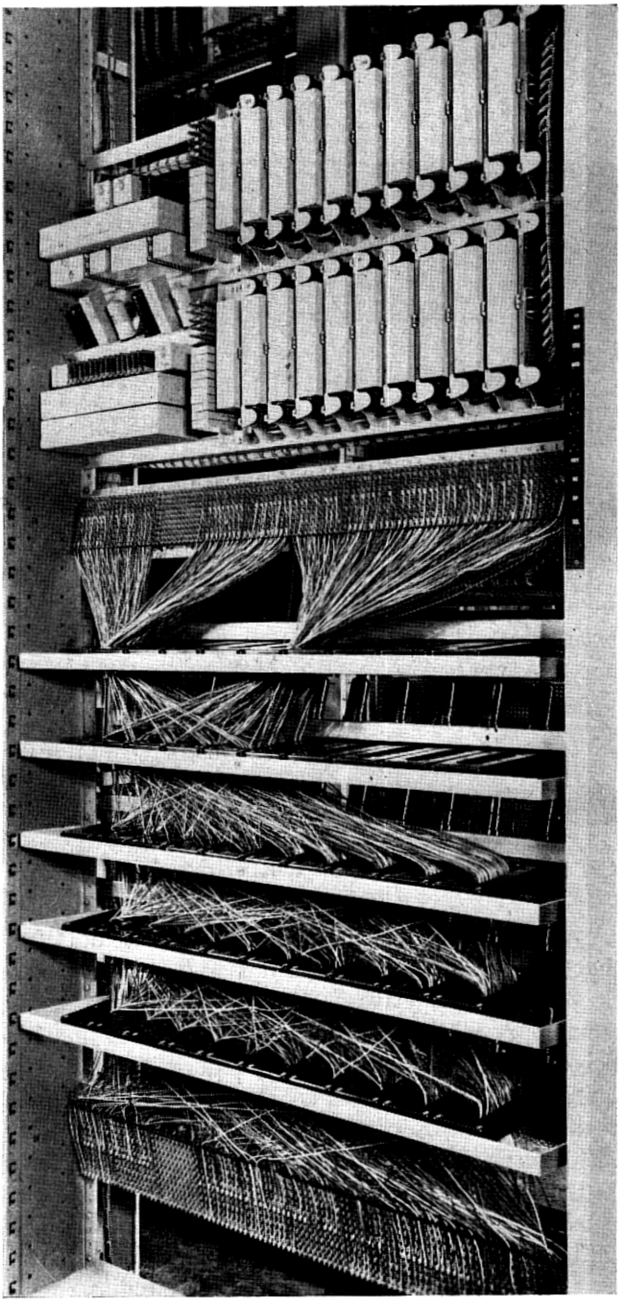

Fig. 13 — AMA translator.

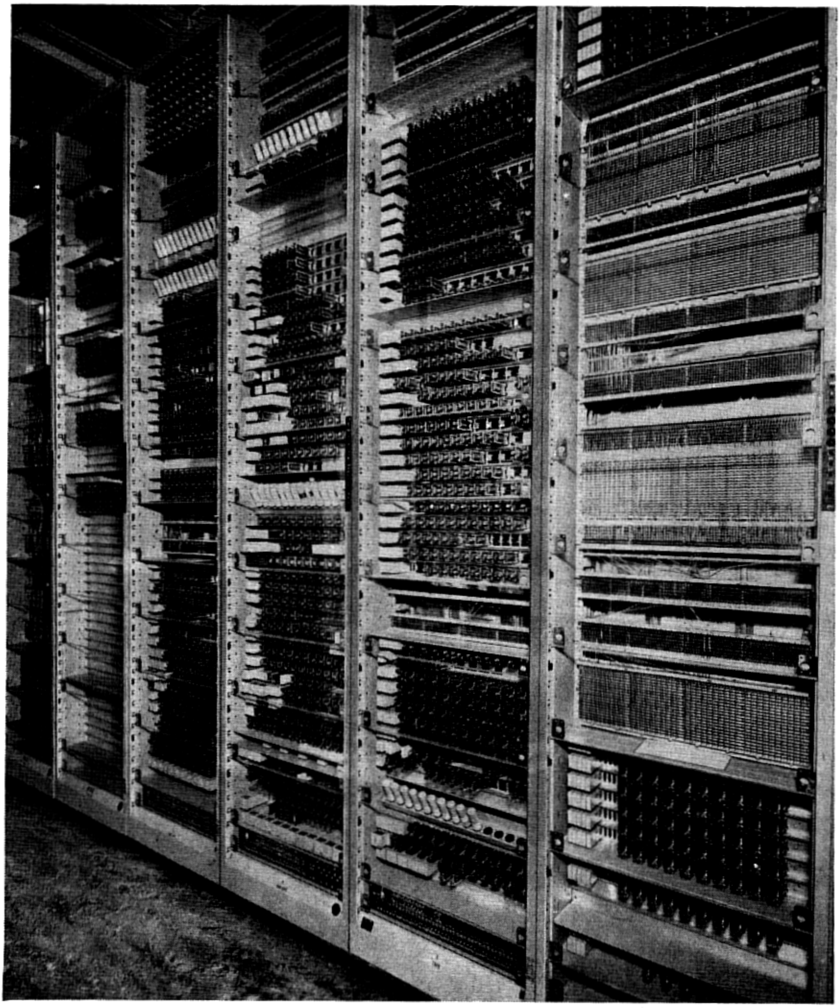

Fig. 14 — No. 5 route relay frame.

The form of memory available in electronics is considerably different from that which has been previously available. Electronic memory has been characterized as "common medium" or "bulk" memory. A single device is used capable of storing more than a single bit of information which is the limit of most relays or other devices capable of operating in a bistable manner. A number of different types of electronic bulk memories have been devised for digital processing. They differ appre-

Fig. 15 — No. 4A card translator.

ciably in physical form, each taking advantage of the phenomenon of some different area of the physical sciences — electrostatic, electromagnetic, optic. Magnetic tapes[14] and drums[15] (Fig. 17), cores[18] (Fig. 18), electrostatic storage in tubes[16, 17] (Fig. 19) and ferroelectrics[19, 20] (Fig. 20) and photographic storage[21] (Fig. 21) are available.

Several properites of these memory devices are of interest. Being electronic, the speed with which stored information may be read is of primary interest. This is known as "access speed". Another property of these common medium memory systems or devices is the ability to change what has been written. If the changes can be made rapidly enough they may be used in electronic systems in much the same manner as relays are used in electromechanical systems to process information. If the change must be made relatively infrequently, such as changing photographic plates, they may be used as substitutes for the type of memory in these systems which are provided by cross connections and wiring. The required fixed or semipermanent electronic memory may be characterized primarily by a high reading speed, large capacity, and the ability to hold stored information even during pro-

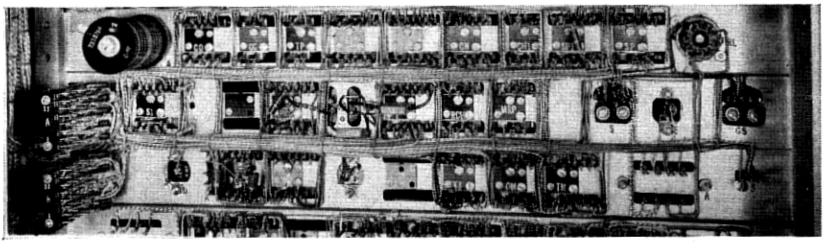

Fig. 16 — Wiring side of relay unit.

longed intervals of loss of power. The amount of memory is measured in terms of binary digits or "bits". The number of bits equivalent to single cross connection can be rather large. Therefore, electronic memory replacing fixed memory such as in the card translator in modern electromechanical systems should be high in bit capacity, from 10^5 to 10^7 bits for 10,000 lines.

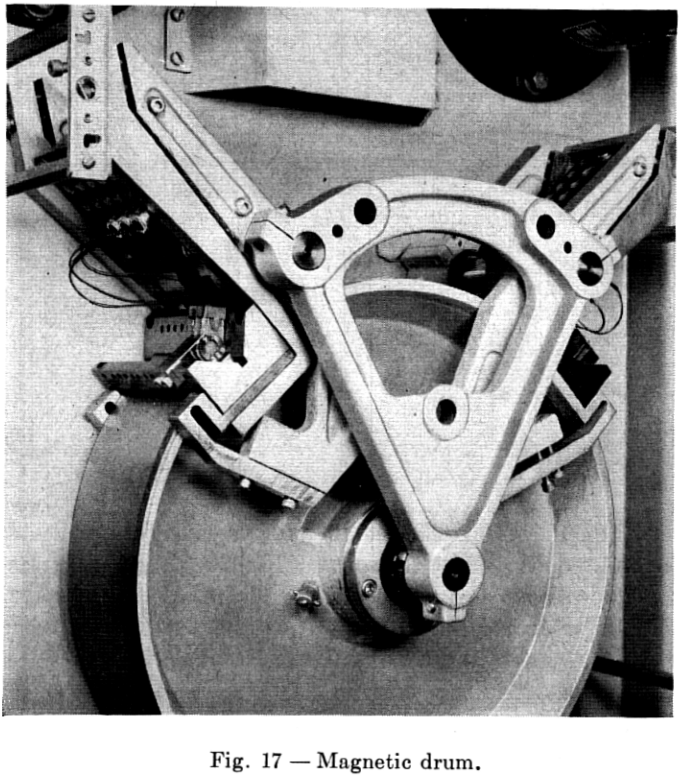

Fig. 17 — Magnetic drum.

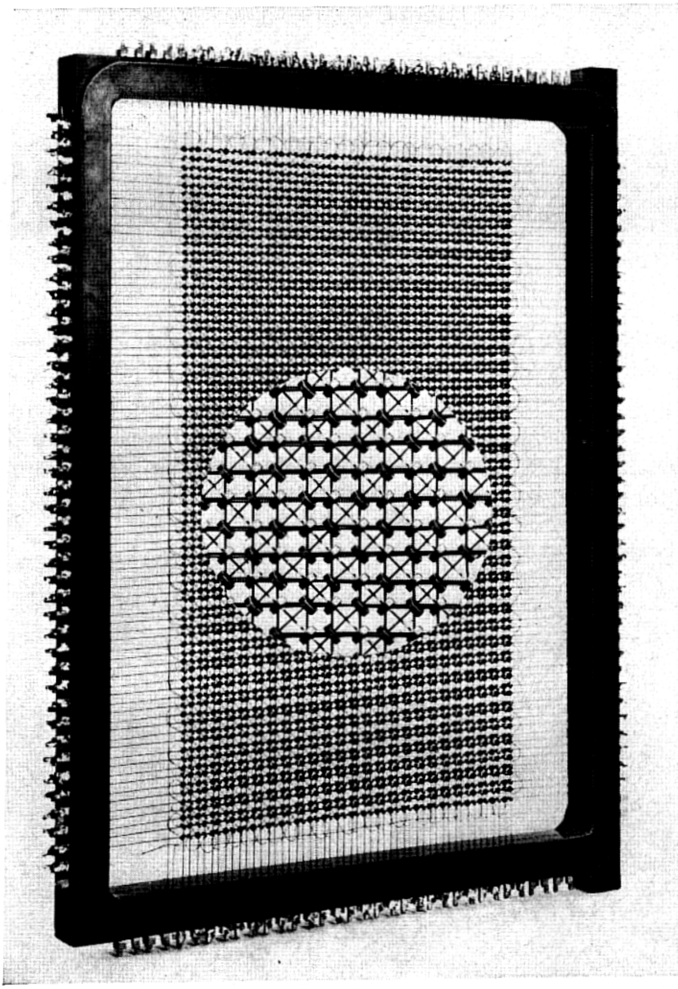

Fig. 18 — Magnetic core array (Courtesy of IBM).

One way in which electronic memory for various system applications may be evaluated is given by the chart of Fig. 22. This chart attempts to show, for the various forms of storage, the relation between the capacity in bits and cycle time, which includes access, reading and, if necessary, the regeneration time of the stored information. For sake of simplicity, ferroelectric and magnetic core memories have been combined as coordinate access arrays. Single bit electronic memory will be described in more detail later.

In the control portion of a switching system it is not only necessary to gather and store information but it must be interpreted and appropriate action taken. This function is called "processing". Processing circuits control the information gathering and storage functions and perform logical functions to produce the necessary flow of information. In the logic circuits of electronic systems, to keep pace with the time sharing nature of the information gathering function, the devices used must be several orders of magnitude faster than their counterparts, the relays, of the electromechanical system. The scanning and bulk memory

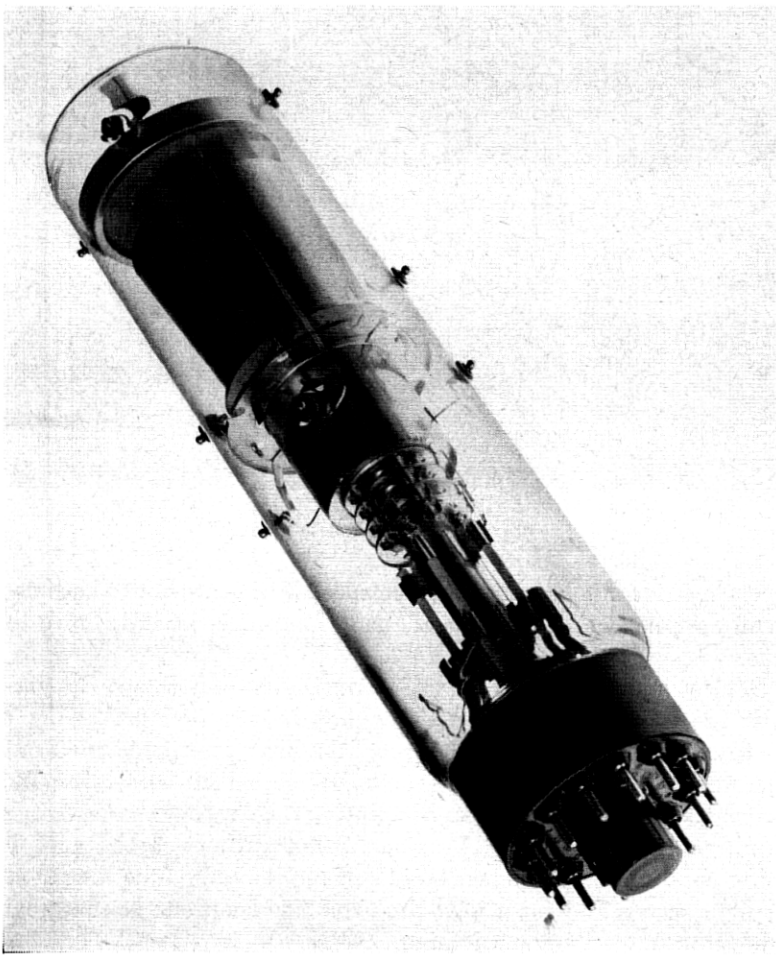

Fig. 19 — Electrostatic storage tube.

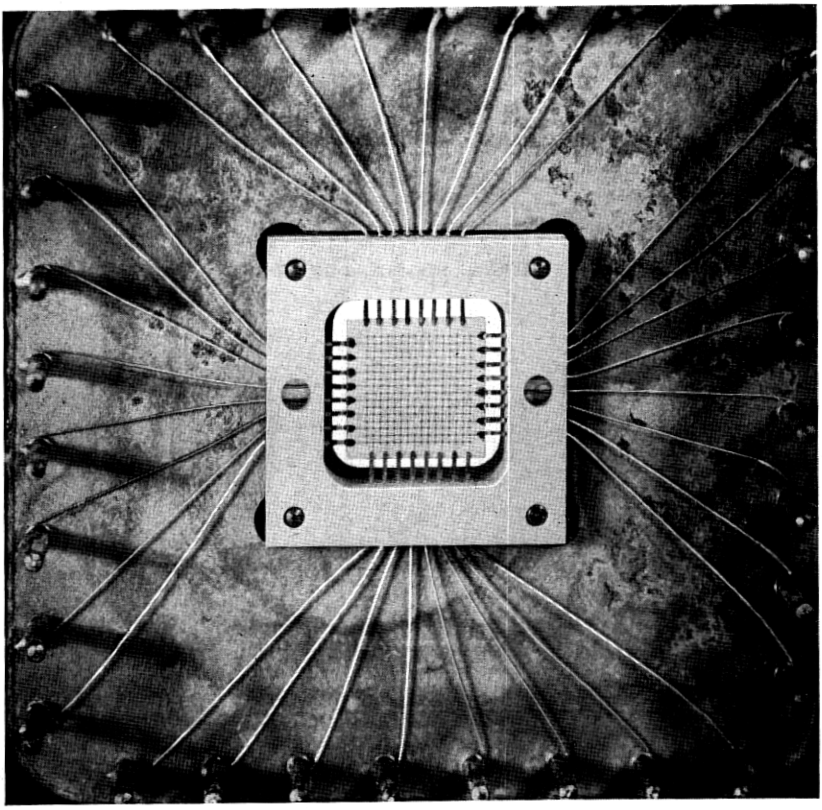

Fig. 20 — Ferroelectric array.

access speeds must be comparable in speed if they are not to become the speed bottleneck. All portions of the system must be in balance time-wise.

Devices and techniques for use in the design of high speed logic circuits are available.[22] With such devices information processing previously carried out by complex relay circuitry may be carried out in microseconds instead of milliseconds. Devices such as semiconductor diodes and transistors seem to be pointing the way to the future in performing these functions.[29] Previously, hot cathode tubes with high power consumption were needed to achieve the same functions at similar high speeds and for a long time this has been one of the greatest deterrents to electronic switching.

Semiconductor diode gate circuits are now quite familiar[23] and take the place of the conventional make and break contacts in the electromechanical switching art (see Fig. 23 for the "AND" function). Magnetic core circuitry is also being exploited to perform high speed switching functions[24] (Fig. 24).

There are a number of differences between the circuit configuration used for relay contacts and diode or magnetic core gates for switching logic. When interconnecting such gates to realize complex logic functions other gates are required when circuit elements are placed in series or parallel, whereas in the wiring of relay contacts in series or in parallel no additional circuit elements are required (Fig. 25). Pulse signals passing through diode gate circuits are usually attenuated since the electronic device is not a perfect switcher (infinite impedance open circuit to zero impedance closed circuit). Some minute currents flow when open and some resistance is encountered when closed. Therefore, some amplification is needed at various places in logic circuits and this can be provided by transistor amplifiers. The use of transistors as the gating element eliminates this shortcoming by providing amplification in each gate (see Fig. 24). Transistors have also been successfully used in a new form of logic to provide relay contact like logic thus eliminating the need for gate elements to represent the series of paralleling functions[25] (see Fig. 26).

The processing of information usually requires a sequence of logic actions. To provide such sequences, momentary elements similar to locking relays but with microsecond action times are required. When this condition obtains a bistable or "flip-flop" circuit using transistors may be employed. Several forms of transistor circuits have been devised using either the Eccles-Jordan principle,[26] negative resistance properties,[27] such as achieved with a gas tube, or a regenerative approach.[28] Some suggestions have been made on the use of semiconductor diodes in special energy storing circuits to amplify pulses instead of the more conventional transistor amplifiers.[30]

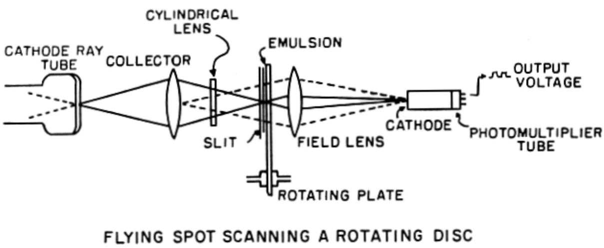

Fig. 21 — Photographic storage (from Proc. I.R.E., Oct. 1953).

EQUIPMENT CONCEPTS

In what has been said, consideration was given only to the concepts and circuitry of electronic telephone switching systems, but the things which the manufacturer and user come in contact with are the physical or equipment realizations of these concepts. One thing that is outstanding about the physical aspects of an electronic system is the large number of small components which are required. Fortunately, most of these components such as resistors, diodes, transistors, condensers, etc., are all of the same physical or similar mechanical design. From the manufacturer's point of view the problem then is to find the most economical way in which these many devices may be manufactured, assembled and tested, because of the large numbers required in a system. The basic solution appears to be: automatic production. This has led to the concept of small packages of components. These packages are the building blocks of a system and contain basic circuits which may be used repetitively. The trend in making such packages appears to be the use of printed wiring with automatic means of placing the components on the printed wiring boards.[31]

Despite the fact that there are large numbers of these small com-

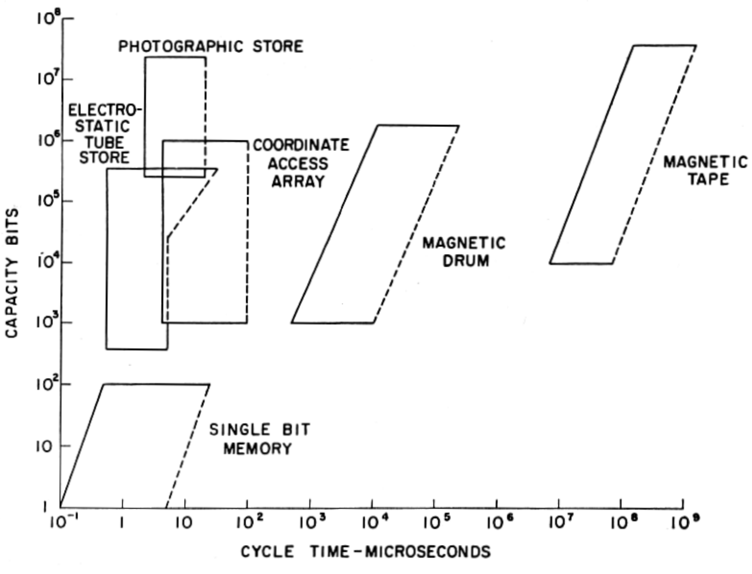

Fig. 22 — Memory system capabilities.

ponents required in electronic telephone switching they are small and when equipment using a multiplicity of printed wiring boards is assembled it takes on the aspect of a three-dimensional arrangement of components, with components mounted in depth as well as on the surface. This is in contrast to electromechanical systems where all components are generally mounted on a vertical surface. By using only one or two common control circuits of a given type (due to high speed) and

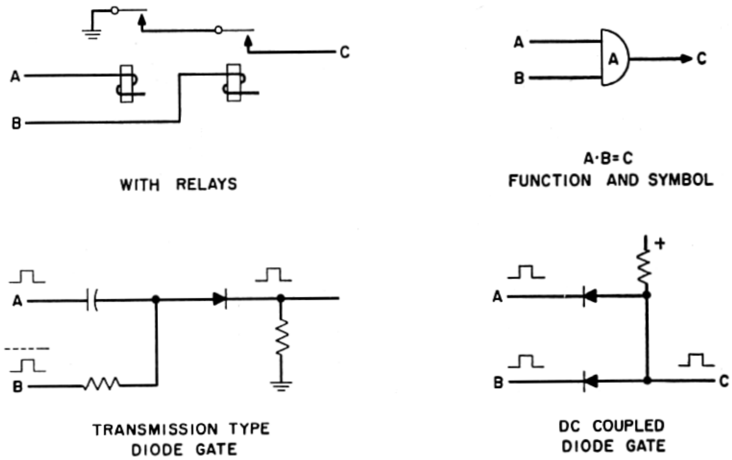

Fig. 23 — The "And" function.

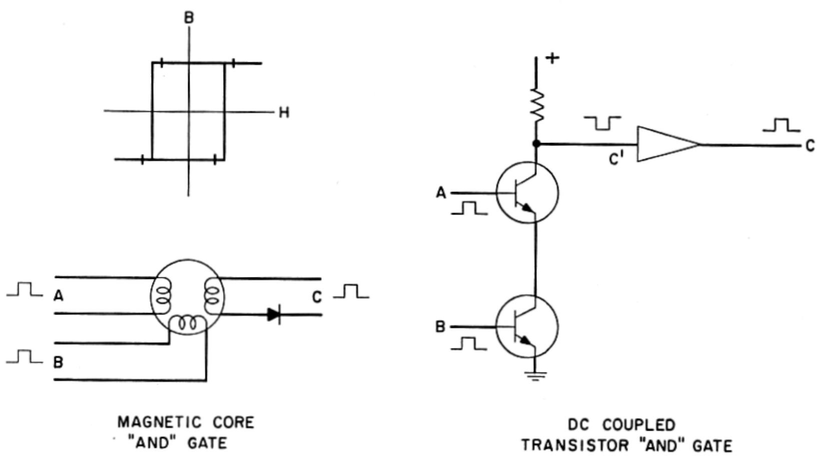

Fig. 24 — Other "And" circuits.

common medium bulk memory, fewer system elements are required which in the overall result in material space saving.

Another phase of the equipment aspects of electronic switching is that the devices require closer environmental control. Air conditioning appears necessary in early systems because of temperature limitations and other characteristics of some of the devices presently available. Also, vacuum tubes and other high power devices may develop objectionable hot spots in the equipment which make it advisable to exhaust hot air.

MAINTENANCE CONCEPTS

There is insufficient experience at this time to say what the maintenance problems of electronic telephone systems will be. Much has been written about the problems encountered in maintaining electronic

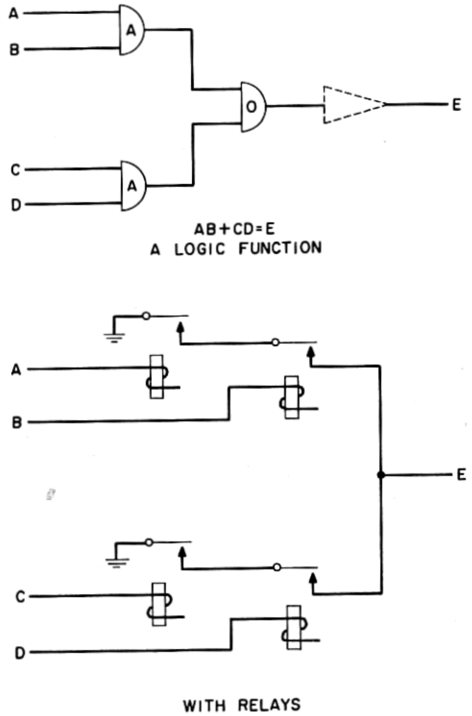

Fig. 25 — A logic function with relays.

computers; however, in designing a telephone system an entirely different philosophy must be pursued since it should not be necessary to have engineering caliber maintenance forces. At no time should the system be incapable of accepting and completing calls. This does not mean that portions of the system may not be worked on for routine or trouble maintenance.

A promising approach appears to be the use of marginal condition routine tests for detecting in advance components which are about to fail.[34] Automatic trouble locating arrangements may be devised for giving information as to the specific location of a package in trouble when it occurs.[35] This automatic trouble locator combined with the equipment concept of plug-in units means that service may be maintained without long interruptions. By designing devices which are reliable, employing them in a manner to give maximum service life and

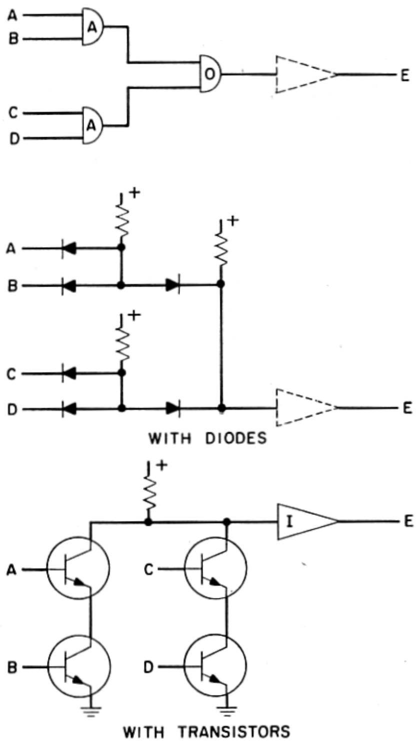

Fig. 26 — A logic function with diodes or transistors.

by judiciously introducing redundancy into the equipment, the chance of simultaneous failures of any two identical parts should be extremely improbable.[32] With automatic trouble locating, the maintenance forces will not be required to have a thorough understanding of the device characteristics and the circuitry used. Centralized repair of defective units as in modern telephone transmission systems[33] and perhaps even expendability of defective units are a distinct possibility.

As a result of some of these maintenance considerations it is quite likely that equipment in the future, besides being smaller and more compact, will appear more generally in enclosed low cabinets rather than exposed frames. The administrative control may be from consoles rather than vertical panels. More attention will be paid to appearance. The appurtenances, such as ladders required for high frames in electromechanical systems, may be eliminated.

Another change in concept which may come with electronics in telephone switching is the form of the power supply. Present day telephone systems use a centralized single voltage dc distribution system with reserve battery. The wide variety of devices and associated voltages, and the need for close regulation in some portions of electronic systems make a reliable ac distribution system with individual power rectifiers at the point of use appear quite attractive. To insure reliability of service the ac distribution must be continuous and not dependent directly upon the commercial sources.

There is no question that reliability is imperative if electronic switching systems are to survive among electromechanical systems which have achieved a high degree of reliability over a long period of years. The device reliability of the first electronic system may not be comparable since some of the components of the electronic switching systems will not in their initial applications be as reliable as the least reliable component in our present day systems. Reliability will be earned and this will probably require considerable effort. Even if initially some devices employed in electronic systems do not measure up to the present high standard which has been set, continuity of high quality service is a must. It is, therefore, necessary to design a system which will mask the shortcomings of any individual electronic component.[32] As their reliability is proven an optimum balance will be sought between system redundancy and component quality. Telephone engineers familiar only with the high degree of reliability of present day apparatus will have to accommodate themselves to the characteristics of new electronic devices.

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