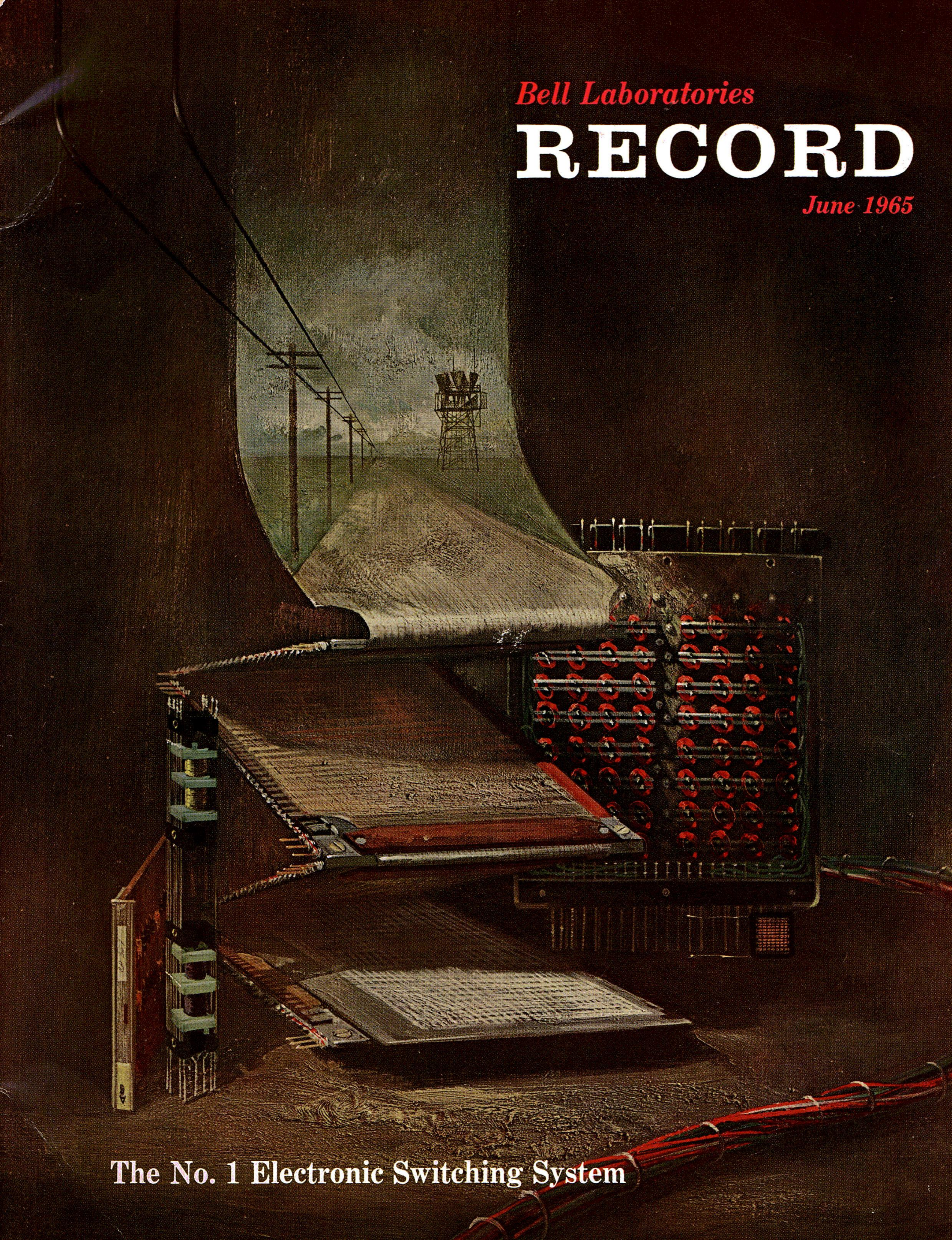
Bell Laboratories

RECORD

June 1965



The No. 1 Electronic Switching System

Bell Laboratories **RECORD**

Volume 43 • Number 6 • June 1965

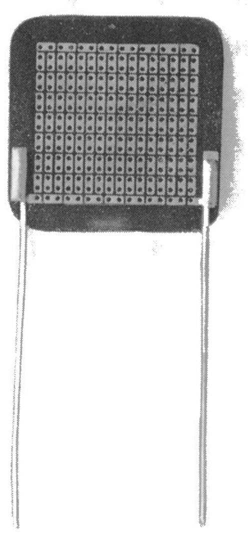
Contents

THE BELL LABORATORIES RECORD is published monthly by Bell Telephone Laboratories, Incorporated, 463 West Street, New York, N. Y. 10014, J. B. FISK, President; K. PRINCE, Secretary; and T. J. MONTIGEL, Treasurer. Subscription: $2.00 per year; Foreign, $2.95 per year. Checks should be made payable to Bell Laboratories Record and addressed to the Circulation Manager. Printed in U. S. A.

Cover *Devices on this month's cover are all components of the sole subject of this issue: The No. 1 Electronic Switching System. From the ferreed switch and the ferrite sheet (large and very small squares at the right) to the logic circuit (extreme left) and the ferrod sensor, all are unique devices in telephone switching. A part of the twistor memory occupies the center of the picture. This device holds the stored program, a set of instructions that shapes the system's responses to the requests of telephone customers. (Cover painting by Paul Lehr.)*

Electronic Switching

A Score of Years of Organized Attack



It was inevitable that modern electronic technology would be applied to the switching machines of the telephone plant as it has to the transmission network. There is nothing casual or haphazard, however, in the form that electronic switching has taken in the Bell System nor in the date of its appearance as an operating office serving telephone customers. This program has been the largest sustained Bell System development effort toward a single goal ever undertaken by Bell Laboratories.

Prior to World War II various individuals had given thought to the possibility of an electronic switching system. Note that this was years before the transistor was invented or named. Immediately after the war, we organized a switching research effort to explore ways in which the evolving technology could be usefully applied to the problem of switching telephone calls. In 1953 an electronic switching organization was formed in the Development Area, hopefully looking toward a practical electronic switching telephone office. The 12 years since 1953 divide into two periods of a half dozen years each. The first culminated in the Morris, Illinois, experimental trial office; the second, in the Succasunna, New Jersey, office, giving commercial service. Thus, we come to the fruition of 20 years of Bell System organized effort directed toward an electronic switching system.

The final phase of the effort—the creation of the detailed design information, fabrication of the first models, tests of the hardware and software—was started in 1959. In the fall of that year, we set the goal of mid-1965 as the date for the first cutover. Bell Laboratories people engrossed in this project, view with some pride and much satisfaction the successful meeting of this schedule date.

The unique characteristics of No. 1 ESS and its solutions of technical problems will unfold as you read the articles in this issue of the RECORD. There is an over-all uniqueness of the system to which your attention is directed for a moment. Compare No. 1 ESS with earlier switching systems.

The manual telephone switchboard was designed on the prior decision that switching would be accomplished by a human operator manipulating plugs, jacks, and keys. Step-by-step switching was based on the prior decision that switching would be accomplished with step-by-step switches controlled directly by the pulses generated as the customer dialed. Likewise, panel and crossbar switches were chosen as the central building blocks for those systems. In the case of electronic switching systems, no such prior decision was made. Compare one aspect of No. 101 ESS (RECORD, *February 1963)* and No. 1 ESS. Both systems use much common type of equipment. But No. 101 ESS uses time division switches, and No. 1 ESS space division.

When work on electronic switching started, we understood the principles of common control and its huge advantages. We believed that electronic circuits would operate with such high speed that a single control would serve even a large office, and we saw the advantage in this, as distinct from a multimarker arrangement where competition arises between them. Further, we clearly recognized the usefulness of large memories with short access times. But the important decision to use memory to store the system logic evolved as the development work progressed.

There are two new and fundamental characteristics of electronic switching: the high speed electronic central control, and the use of memory to store the system logic which in turn determines, in detail, how the office will perform its functions.

And so, electronic switching came into being without a single piece of apparatus being prechosen as the preferred solution to any particular problem.

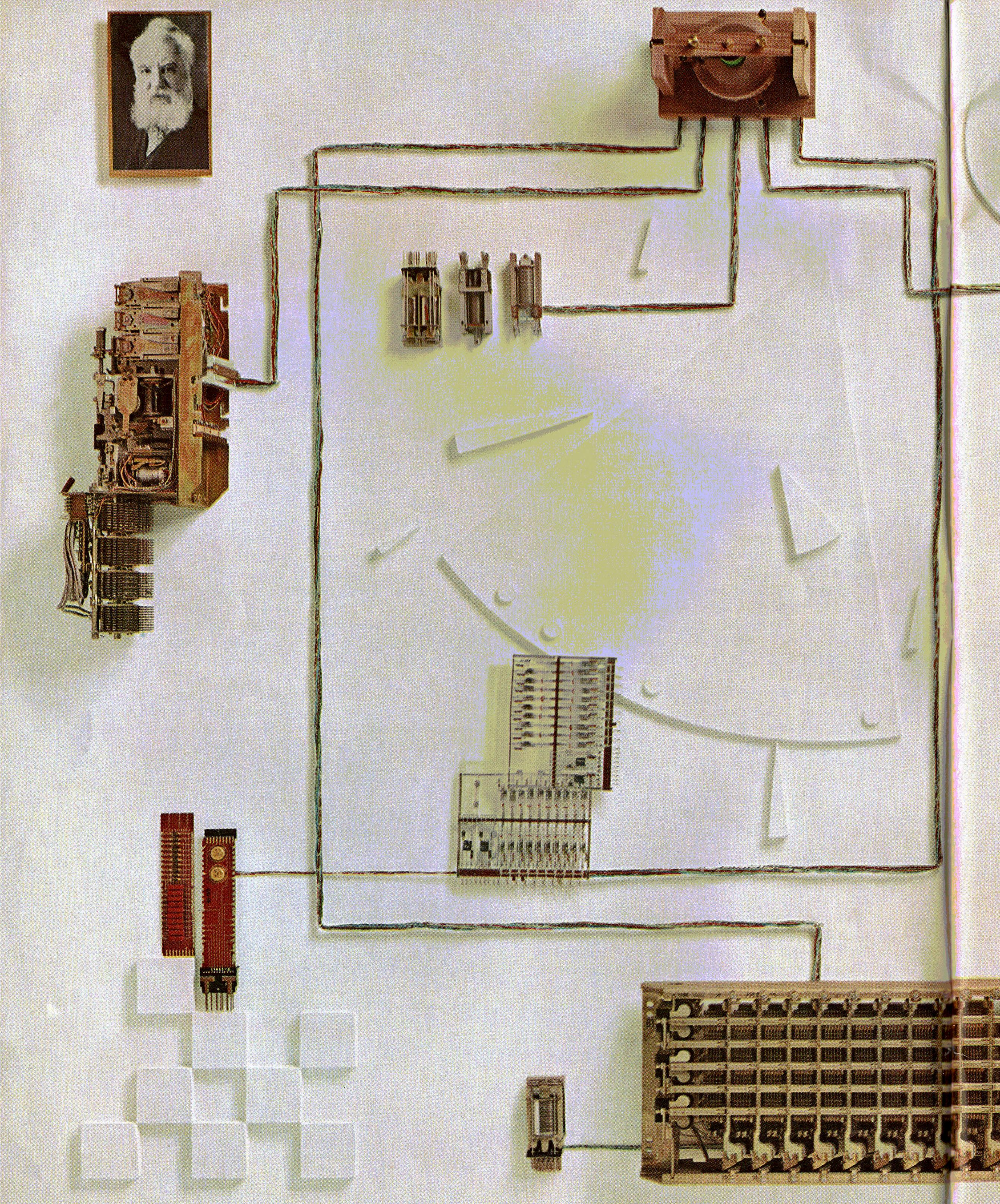
In the final phase of No. 1 ESS development, our partnership with Western Electric has grown steadily broader and deeper as WE has produced, in hardware, Bell Laboratories' designs of apparatus and equipment, and delivered on tough schedules to meet close deadlines. The understanding, the give-and-take, and the real cooperation in this undertaking have been marvelous to behold.

While the big effort of the operating companies in the use of electronic switching offices to serve our customers better is yet to come, many operating company people have made individual contributions to the development and design effort. Others are preparing themselves to plan and operate No. 1 ESS offices in their territories. The significant contribution of the operating companies to date has been the coordinated planning to install No. 1 ESS offices throughout the country as fast as equipment is made available by the Western Electric Company.

There is no better example of the necessity for and the benefits derived from the association of the research and development people, the manufacturing and installation groups, and operating company people than this Bell System achievement of a common goal of better telephone service in timely fashion.

This post-war score of years has brought rapid progress in switching technology. Not the least is a kind of intellectual and organizational maturity which allows the designer to proceed in orderly fashion from the requirements to be met to the choice of system and apparatus to meet the stated objectives. Service to our customers will benefit greatly from this maturity.

W. A. Mac Nair
Vice President
Transmission and Switching Development



The Evolution of Telephone Switching

W. Keister

THE OPENING OF THE No. 1 Electronic Switching System office at Succasunna, New Jersey in May, 1965 was the culmination of the largest single development project ever undertaken by Bell Laboratories for the Bell System. Because millions of man hours have been spent on this one development, it would appear, at first glance, that nothing less than a revolution in telephone switching has been in the making. In one sense it is a revolution, or at least the first stage of one: Electronic switching systems, in the next few decades, will replace all existing Bell System switching systems. But in a deeper sense, the No. 1 Electronic Switching System (henceforth ESS) is the product of years of accretion of experience along many lines in the evolution of telephone switching systems.

Among the most significant trends have been a functional separation of switching actions and the actions that control them, a clarification of the roles of logic and memory in telephone switching, and the burgeoning of solid state electronics technology into an array of extremely high-speed, versatile devices which opened new areas in switching techniques. As all these trends matured they made the development of No. 1 ESS not merely feasible, but in a sense inevitable.

Technically speaking, the ancestry of No. 1 ESS runs back through crossbar systems to panel systems. Both of these are strictly electromechanical systems, but both are definite stages along the road to common, or centralized, control which reaches its highest present development in No. 1 ESS. The basis of this technique is that actual switching actions can be separated from the actions that control them, and call connections through a switching network can be directed for many lines by one "common" group of control equipment. The control equipment routes a call through the network and is then released to act on other calls.

The concept was first tried in the panel system about 40 years ago. It was developed through early crossbar systems, and came to full maturity in the No. 5 crossbar system. In modern crossbar systems the network has no control function at all; control is the exclusive function of specialized equipment. However, in order to handle traffic demands effectively, the No. 5 crossbar system requires a number of duplicated groups of control equipment to serve one office. Electronic speeds allow No. 1 ESS to operate with only one control for an entire office.

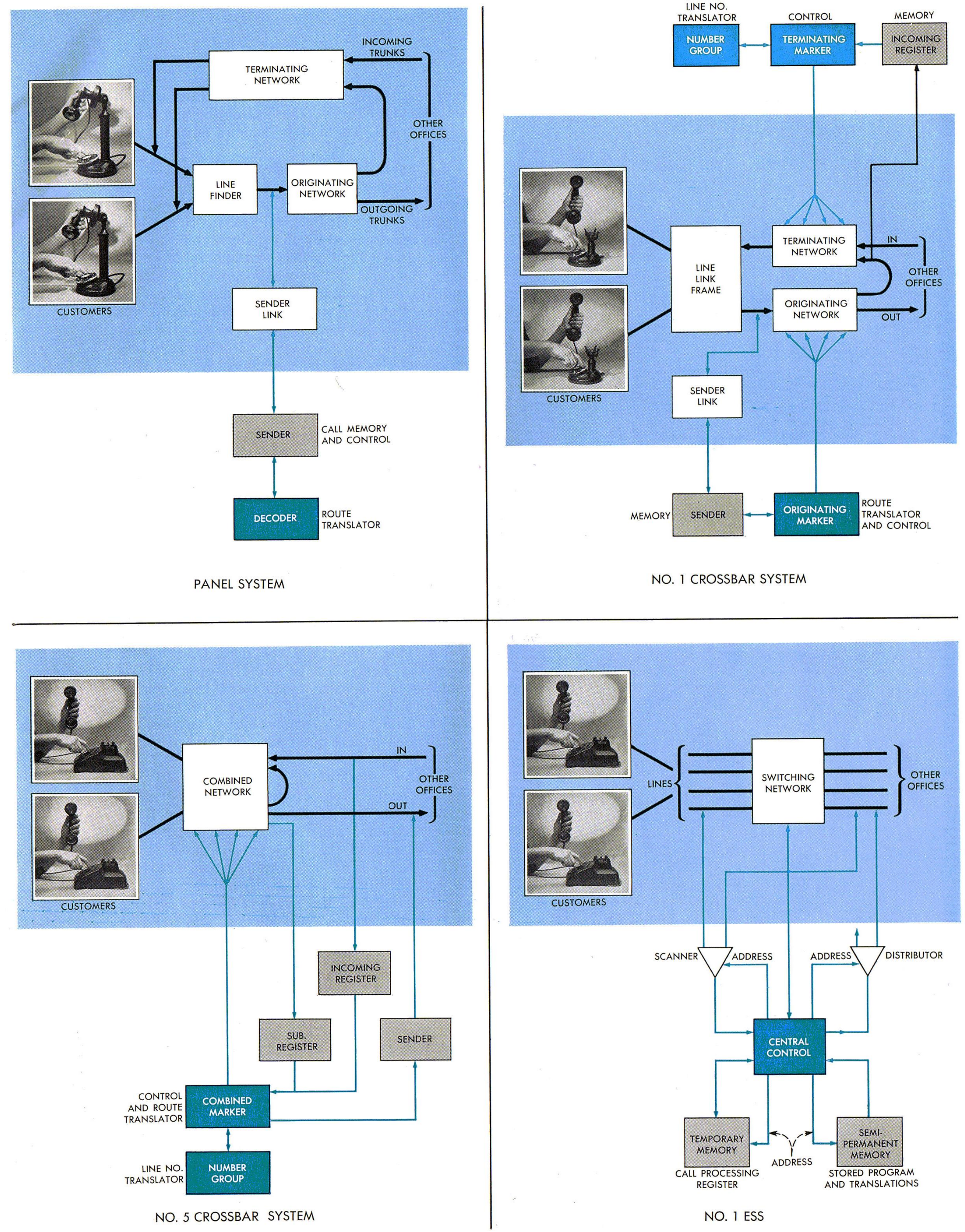
Common control was not born with "automatic" switching systems. The first automatic system, the step-by-step system, is designed for direct control. Contact arms select terminals on the switch in direct response to the dialed digits. Because telephone numbers must correspond to the location of particular terminals, direct control allows little flexibility in the layout of the switching network. The technique is also rather profligate in its use of switching equipment—the amount of equipment tied up in completing one call under direct control is inherently capable of completing hundreds of calls in the same time.

The first elements of common control, units called registers, decoders, and senders, were introduced in the panel system. These units are never permanently associated with single lines or calls but are used in common by large groups of lines. Dialed digits are stored in the register and then converted by the decoder from decimal numbers to a nondecimal number system. The sender uses the converted numbers to control the panel switches. There is no fixed relation between the converted digits and the original dialed digits and the translation can be changed by changing cross-connections in the decoder, thus providing flexibility in rearranging trunk connections.

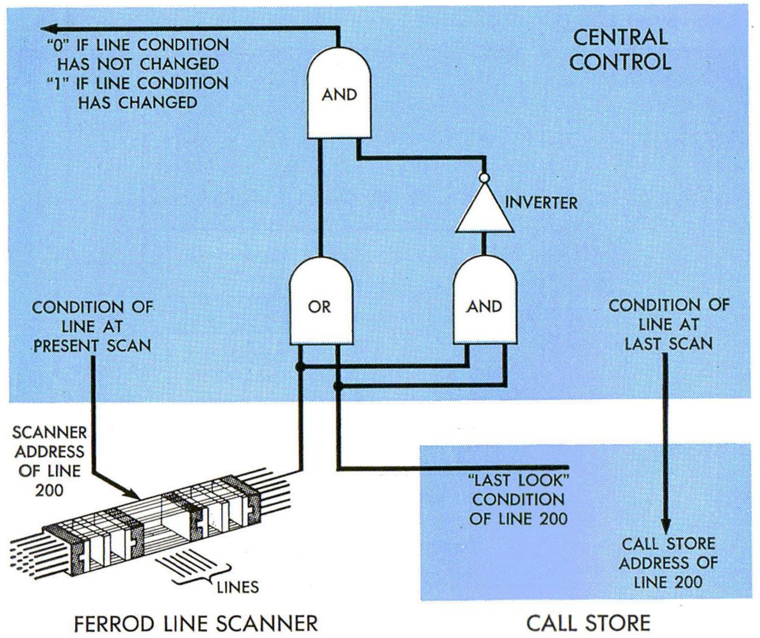
In the late 1930s, common control took a major step forward in the No. 1 crossbar system. The switching network of this system is not constrained by the numbering system in any way, and hence it can be designed purely in terms of traffic requirements. This singular freedom stems from a new device, the "marker". In addition to translating dialed digits, as the panel system decoder does, the marker locates idle trunks and directs the network to them. If traffic congestion impedes the first attempt to find a connecting path through the network, the marker makes a second attempt. Similarly, if all trunks are busy on the direct route to a desired central office, the marker chooses an alternate route via another office. The philosophy behind these valuable features is that the marker can be made to examine the system to see if certain components are busy or idle. On the basis of its findings and the information represented by the dialed digits, it can then determine the most efficient way to make a desired connection.

Originating and terminating networks are separate in the No. 1 crossbar system. Each has its own marker to translate between telephone numbers (i.e. dialed digits) and control numbers. The terminating marker is assisted by a number group translator which can select a particular line from a group on an equipment frame in the central office. The line number on the equipment frame need not correspond to the telephone number, a factor that overcomes many constraints in the layout of the network and permits the network engineering to take account of the variation in the traffic load between individual customers.

A further improvement in these principles is embodied in the No. 5 crossbar system, first put in



These diagrams show how the concept of common control and the concept of the roles played by logic and memory have evolved through the major switching systems from panel to No. 1 ESS. A major trend is the removal of any control function from the network. Notice how in the panel system sender links are part of the network, as they are in the No. 1 crossbar system. Also, these two systems have both terminating and originating networks. In No. 5 crossbar, and in No. 1 ESS, the networks have become strictly passive elements in terms of control. Notice how memory and logic in No. 1 ESS, are entirely discrete functions.



PRESENT LOOK	LAST LOOK	OUTPUT	MEANING
0	0	0	STATE UNCHANGED—OFF HOOK
0	1	1	STATE CHANGED—CALL START
1	1	0	STATE UNCHANGED—TALKING
1	0	1	STATE CHANGED—CALL END

A highly simplified way to apply logic circuits in line scanning is shown here. The central control directs the line scanner and the call store memory to report on the present and last states of line 200. The logic function to be performed is: if both states are 0, or if both states are 1, then the output signal should be a 0. (The table shows the output for various combinations of bits.) If the two states do not agree, however, then the output signal is a 1 to indicate that central control must take action on the line. If either the present or the last state, or both states, are 1, then the output of the OR gate is a 1. If both states are 1, the output of the lower AND gate is a 1 which the inverter changes to a 0. This is applied to the second input of the upper AND gate. Thus, the output of the combined circuit is 0 if both the present and last states are 1 or if both are 0.

service in 1947. A single network controlled by a single marker serves both originating and terminating traffic. The marker handles outgoing and incoming calls.

A number of parallel evolutionary trends in telephone system design emerged during these 40 years. We have been describing the major one, the evolution of common control systems themselves. It was accompanied by an equally significant evolution in switching devices and apparatus. Originally, the panel system used motor-driven shafts, clutches, cams, and innumerable other mechanical devices. But these were difficult to maintain, and as relays became more reliable they took the place of much of the mechanics. Crossbar systems, meanwhile, skirted the mechanical hazards with the relay-like crossbar switch and with control circuits that were almost exclusively relays.

During this time circuit designers began to look at their product in a wholly new light. They saw that they were not designing electrical circuits so much as logic circuits and that the intricate connective patterns between relay contacts needed to establish a talking path between telephones could be viewed as the stage-by-stage progression of the simple logical relations AND and OR. For example, consider a lamp plugged into a wall socket controlled by a wall switch. The lamp will not light unless both the lamp switch AND the wall switch are turned on. On the other hand, take the action of the dome light of an automobile which lights if one of the front doors OR the other is opened. Relays can be wired to open or close contacts in the same fashion and these simple logical relations can be repeated as often as necessary to form a highly complex system that decides complicated logical questions. (See the drawing on this page.)

All this was taking place within an all-encompassing change of the business and social environments that telephone systems served. Businesses expanded and decentralized; populations clustered around the large urban centers. This created demands not only for more telephone service, but for different kinds of services, and telephone system designers began to think of systems that would perform these services and could be adapted to new services as the need arose. Circuits which began to grow more sophisticated and more complex to meet the exigencies of the new types of services reached a point where the operating speed of relays became inadequate. Even crossbar systems, the last word in electromechanical systems, were reaching a practical limit in what they could be made to do. A new direction was needed.

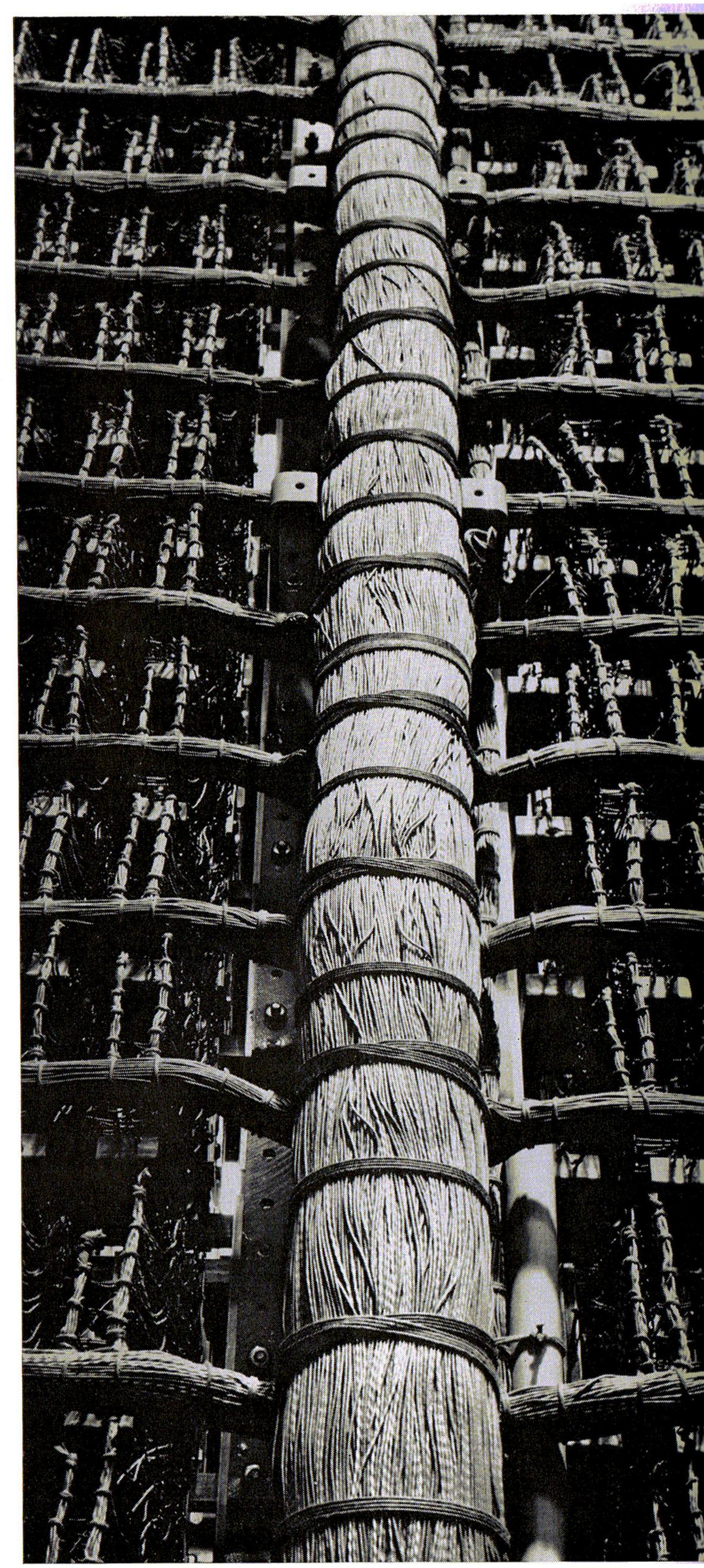
Electronic switching techniques first came into their own in digital computers that operated suc-

cessfully in many weapons systems during the second World War. Studies made at Bell Laboratories soon after the war indicated that these high-speed electronic techniques could be pointing that new direction. But electronic technology, at that time, rested squarely on vacuum tubes which fell far short of the cost and reliability requirements of a practical telephone system. The last corner was turned with the invention of the transistor; an electronic system could now be built that would be competitive with electromechanical systems.

One dilemma remained: A system design usually is current for 10 to 15 years, its service life may be very much longer. New technical advances are made during a system's "design life," and social changes create new demands for features and services that the system is not equipped to handle. Often, the best way to effect these features and services is to design a new system to replace the old one, but the long service life imposes a more costly solution. Existing offices must be modernized and adapted to changing service requirements even while new installations of a more modern system are taking place. It often requires a greater effort to redesign an old system than to design a new one. And it often costs more to modify the old system for new features than to provide these features with a new system. Now, how do you design a system so flexible that it can be adapted to features that are not even foreseen at the time? Electronics had the answer—stored program operation.

The idea of a stored program system sprang from a close consideration of the roles of logic and memory, the twin operators that play such an important part in every telephone system. Memory is information, what to do. Logic is the decision-maker, how to do it. Memory knows what telephones to connect; logic decides what path to take between them. In the panel system, the sender provides memory and shares logic functions with the decoder. In crossbar systems, the two are more clearly defined; the senders and registers provide memory, the markers make the logical decisions.

In No. 1 ESS, the logic procedures for making telephone connections are written in the form of a stored program which is placed in a changeable memory. And therein lies the system's great flexibility. Logic was "written" in copper wire in the



Wired logic. This intricate pattern of wires in a No. 5 crossbar system connects the many relays that perform the complex memory and logic functions required of the marker in directing telephone calls through the maze of a switching system.

electromechanical systems, and each circuit was wired to perform one specific operation. To change the operation it was often necessary to rework and rewire circuits extensively. A No. 1 ESS program is contained on plug-in cards inserted in the memory. To change a logical operation, it is only necessary to change a memory card.

Formal logic is a discursive process, often making swift transitions between broad categories of argument. Programmed logic analyzes a call situation into discrete steps starting when a calling customer lifts his receiver and proceeding through a chain of control actions to establish a talking connection. To the customer, the connection seems to be made instantaneously; actually, the system deals with each step in turn. With considerable simplification, it works about like this:

Every few milliseconds, the system checks, or scans, each customer's line and records its state—on-hook, off-hook, dialing, busy, in a talking connection, etc. The state detected at each scan is compared with the state recorded at the previous one. No action is taken if there is no change. When the system encounters a change of state—from on-hook to off-hook, for example—it consults the program to find what action is indicated. In this case, the off-hook state indicates that the customer wishes to place a call and the program directs that dial tone be sent to his line. While the customer dials, the program directs that his line is to be scanned at regular intervals, and each digit is recorded in turn but no further action is taken until he completes dialing.

After the system registers all the dialed digits, it again consults the program for the next step. For a regular station-to-station call, this step is to make connections through the switching network to the called telephone. That telephone may be busy or idle and the program is prepared for either eventuality. If the phone is busy it directs that busy tone be sent to the calling party. If idle, the called phone is rung and ringback tone is sent to the calling party.

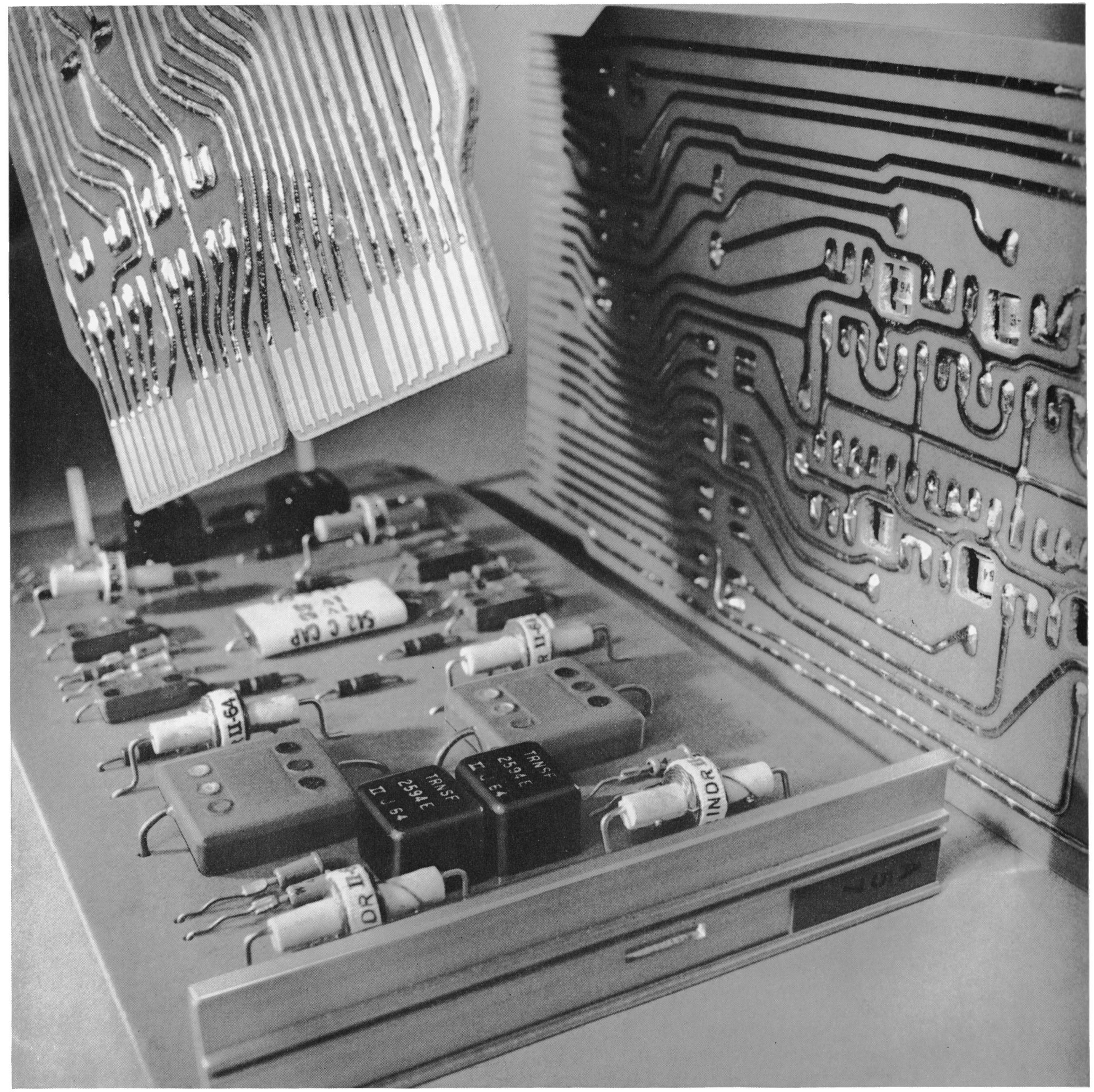
When the call is answered, this state is registered and again the line is scanned at regular intervals but no action is taken until the parties hang up, at which time the program directs that connections be taken down. The whole process is characterized by a continuous interplay between the programmed logic and the temporary memory (a kind of electronic slate) that is associated with each customer's line. This memory records the instantaneous state of the line, and it registers dialed digits and other transitory information needed during the progress of a call. When a call is completed, the slate is wiped clean of information pertaining to it.

Programmed logic, in this description, wears the same discursive mantle that was attributed to formal logic. Actual program instructions, however, are not written in this way but are cast in machine language and its alphabet of binary symbols. The operations performed on the binary instructions by wired logic in the central control are the same as are used in most information processing machines. They consist of, for example, *shifting* information from one register to another where it may be *compared* with the contents of a third, while the difference is *stored* in another register, and *read out* in still another. A number of special instructions are highly relevant to call processing that would be valueless in conventional computing. For example, the busy and idle states of trunks can be represented as a binary "1" and a binary "0", respectively. If the state of a group of trunks is stored in a register, then an instruction to "find the rightmost zero" locates an idle trunk for a call in progress.

Translation and interpretation of the program instructions is handled by the wired logic of central control. This component of No. 1 ESS is the most far-reaching development of the concept of common control in present switching systems. It is concerned only with the basic information processing operations, not with the telephone switching logic which is all contained in the stored program. Logic and memory are thus completely separated from the switching network and the trunk equipment which are essentially passive parts of the system.

Only one central control processes telephone calls at any given time, while in a crossbar system it is common to furnish up to ten markers. For greater reliability, every No. 1 ESS office has a duplicate central control which is kept up to the moment on the progress of all calls in the system, but this is *only* for reliability. Electronic speeds, three or four orders of magnitude above the speed of electromechanical components, allow one central control to handle all calls in the system. It works on only one call at a time, but at such speed that it appears to handle all calls simultaneously.

Stored program control had its first trial with the Electronic Central Office in Morris, Illinois in 1960, where it was proved completely feasible. In fact, the stored program concept was the only thing that emerged from the trial unscathed. The components, the system organization, the organization of the program itself, all have been changed and improved for the Succasunna office of No. 1 ESS. In a sense, then, an evolutionary trend in electronic switching has been foreshadowed. In the next article, we will examine some significant details of that trend.



Some of the circuit packs that perform the logical functions for the No. 1 ESS central control, shown here slightly larger than actual size. Central control is composed of thousands of these relatively simple logic circuits intricately connected to perform the necessary steps in processing the information central control acquires from other parts of the No. 1 ESS system.

A milestone in telephony, the Morris trial proved beyond doubt the validity of the stored program concept. But on the level of hardware nothing is left from Morris; Succasunna is a new office grown out of four years of intensive development.

From Morris to Succasunna

R. W. Ketchledge

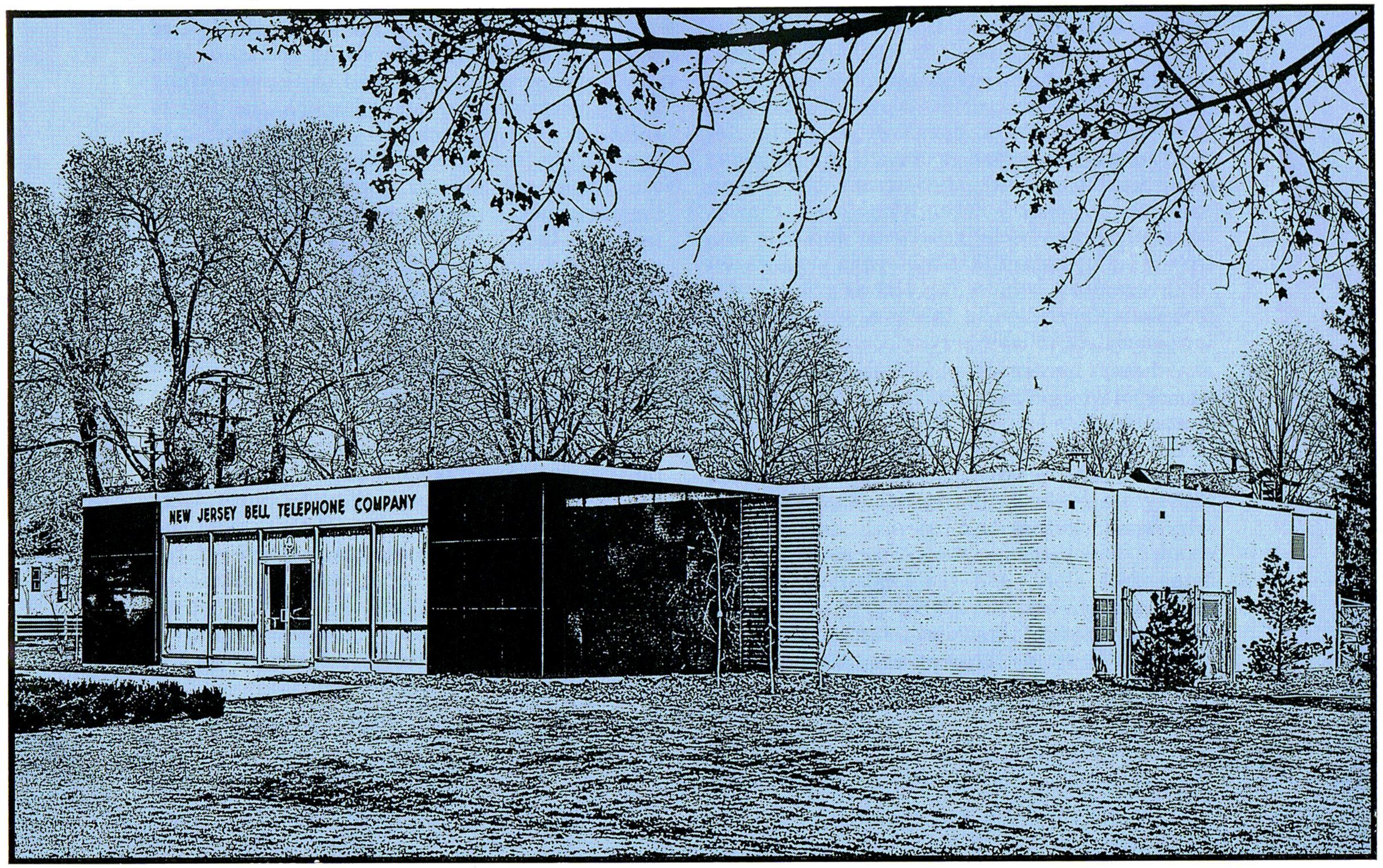
THE ELECTRONIC CENTRAL OFFICE in Morris, Illinois was a pivotal point in the history of telephone switching. Turning back to electromechanical systems, we can see the Morris office as the highest point in the evolution of the concept of common control. Turning ahead to a switching future that is clearly committed to electronic techniques, we can view it as an archetype whose basic outlines may be shadowed in a number of future systems, but whose actual components already have been transformed into the much different components of No. 1 ESS. Although no components have survived the Morris office in their original form, No. 1 ESS embodies the basic idea of the trial system and the changes in components were made because they served the idea more effectively. That idea—stored program control—will become as familiar in the Bell System as the telephone itself.

It would have been a trivial application of electronic technology if the Morris office had been developed merely as an attempt to "modernize" telephone switching by substituting electronic techniques for electromechanical ones. The motive behind it was far broader, being nothing less than the desire to develop the most flexible telephone system that could be conceived. The design of such a system would, clearly, have to take full advantage of the most reliable and versatile devices and techniques available. This conception inevitably led away from thinking of electronic circuits as a way to perform familiar functions faster, and into considering how their unique characteristics could be channeled into performing new kinds of functions for a new kind of system.

For example, from the point of view of a telephone customer a switching system that operates in tenths of seconds gives perfectly satisfactory service. Therefore, it would be pointless to control the switching network in millionths or even thousandths of a second if the object were only to make connections at astonishing speed. But suppose a cycle of time for the system were sliced into infinitesimally small pieces, or slots. In one slot the system could hande all network connections that had to be made, in the next slot it might diagnose its own internal condition, in the succeeding one it could direct an intricate new service. In the twelve seconds it takes the average person to dial a seven digit number, the system would perform millions upon millions of separate tasks involving a host of logical operations. Time, and the manner in which it is used,

Morris, Illinois

Succasunna, New Jersey

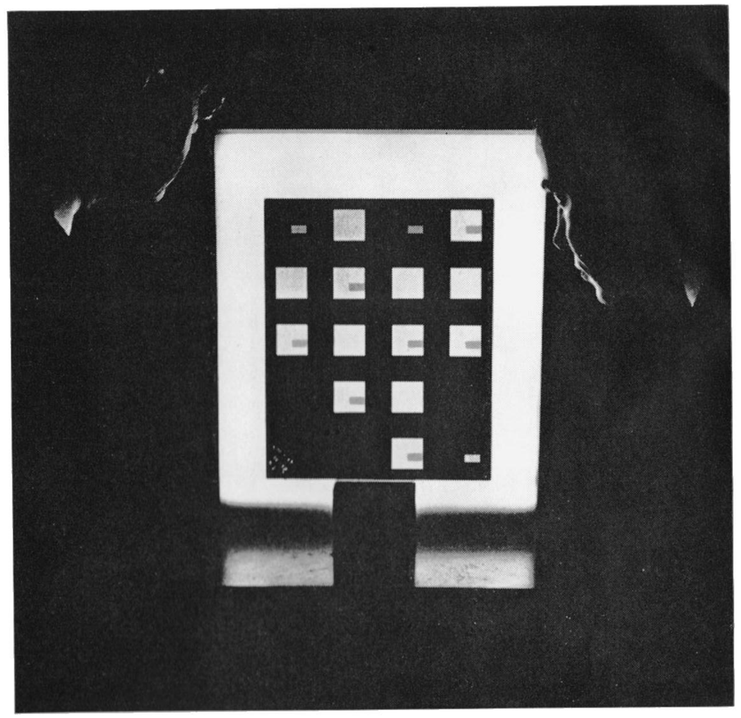


is thus one of the most intricate problems in the design of an electronic switching system.

It would not be difficult to design each component in the office to operate at the highest speed that can be achieved electronically, but it might be prohibitively expensive and somewhat pointless. A more exacting task is to define the range of speed needed in each of the various components, and then to design the office so that they all work synchronously. The memory devices, for example, must operate in microseconds because of the great number of instructions that must be read from the program and converted to control information that is sent to the switching network. The network itself, however, does not have to match the operating speed of the memories. If it operates in milliseconds, or even in fractions of seconds, there is only a remote possibility that it will be overpowered by traffic demands. The judicious use of buffers to hold information until the network is ready to act upon it helps to synchronize the very high speed memories and the slower network.

One of the most important lessons learned during the Morris trial was that the components of an electronic switching system should be designed to perform a particular function; speed of operation is only a characteristic of that function, it is not an end in itself. To illustrate this more explicitly, we will discuss, in turn, three examples of the changes made between Morris and Succasunna in which different decisions were made in terms of speed. In the first example, the memory devices, speed remained essentially the same but other considerations influenced the decision to develop a new type of device for Succasunna. The second example is the switching network; the network at Succasunna is inherently slower than the network at Morris. Finally, the method of switching between duplicate controls is an operation that was made much faster for Succasunna because the Morris trial showed that faster operation in this case was necessary for completely reliable service.

A heavy burden is placed on the system's memory devices. Their reliability cannot be overstressed, they must have large storage capacity in the smallest feasible volume; and information stored in them must be efficiently arranged and readily accessible. In the Morris office, the memories were electron beam devices; the semipermanent (or program store) memory was the flying spot store, and the temporary (or call store) memory was the barrier grid store. In the Succasunna office these have been replaced by solid-state devices; the program memory is the

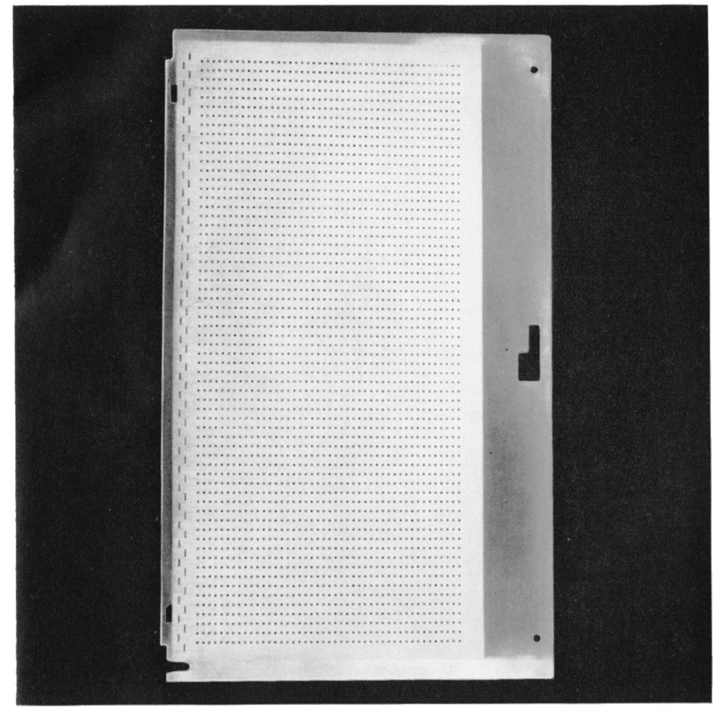


The photographic plate used in the semipermanent memory in the Morris office is examined by R. W. Ketchledge (right) and C. A. Lovell. Each of the squares on the plate can hold 33,000 bits of information recorded as dots or absence of dots in particular locations. Four plates made up the semipermanent memory containing over 2 million bits of information.

permanent magnet twistor, the temporary memory is the ferrite sheet.

The decision to develop the solid-state devices was not made lightly. The flying spot store and the barrier grid tube operated quite successfully in the Morris office, and although the ferrite sheet has clear advantages over the barrier grid tube in size and in accessibility of information, the flying spot store is quite competitive with the permanent magnet twistor in these characteristics. In all, the really clear area of choice was in the greater reliability of the solid-state devices.

When the design of the Morris central office began, solid-state technology could not yet offer the range of reliable devices needed in a telephone office. Therefore, sections of the Morris system, such as the switching network and the memory devices, were constructed with electron tubes even though the limitations of this technology were well known. Electron tubes were judged to be adequate for a trial that would last little more than one year, but in terms of the long life predicated for commercial telephone systems designers were already thinking ahead to the development of highly reliable solid-state devices. Thus, when after the Morris trial, the



This twistor card is inserted between folded stacks of twistor memory planes, the semipermanent memory of the Succasunna ESS. Each of the 2,816 vicalloy spots contains one bit of information, a zero if the spot is magnetized, a one if it is not. There are 128 cards in a twistor module and 16 modules in a twistor store. An ESS central office contains two to six stores.

development of a solid-state memory was shown to be feasible, the decision was, in a sense, already made.

In other areas of comparison, however, the distinction between the flying spot store and the twistor was not at all clearly drawn. In the matter of capacity and physical size, for example, each has advantages and disadvantages. The capacity of the store used at Morris was under five million bits, but Morris was a small office serving only 435 lines. The smallest size planned for a No. 1 ESS office is about 3,000 lines and it has the capacity to grow to 65,000 lines. Vast amounts of memory are needed to control an office at its ultimate size.

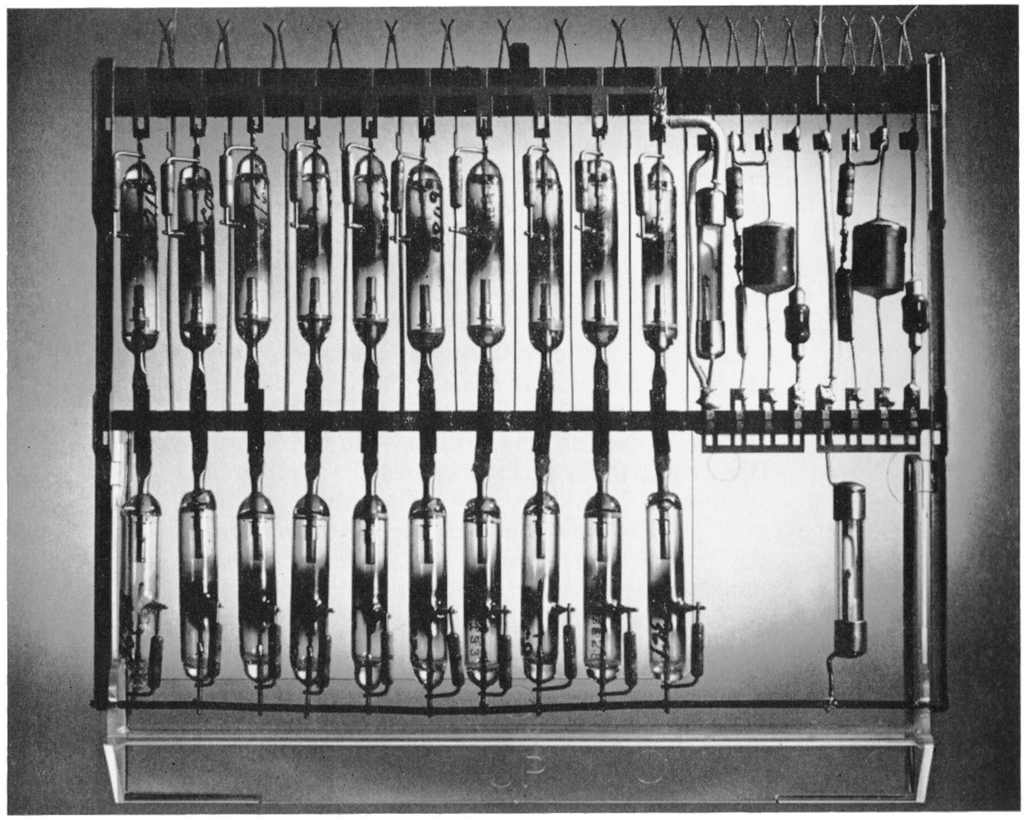
Two proposals were made. One was for a flying spot store with a capacity of 25 million bits, the other for a permanent magnet twistor of 6 million bits. The permanent magnet twistor was chosen because it eliminated the problems inherent in the high voltages and hot cathodes of the electron tube device, it required less development (at the time it was proposed) than the flying spot store, and it offered the superior reliability of a fully solid-state memory.

In the competition between the temporary memory devices—the barrier grid store and the ferrite sheet—the choice was clearer. The ferrite sheet memory can store a longer word than the barrier grid store, it is a more economical device, and again, it is a fully solid-state device.

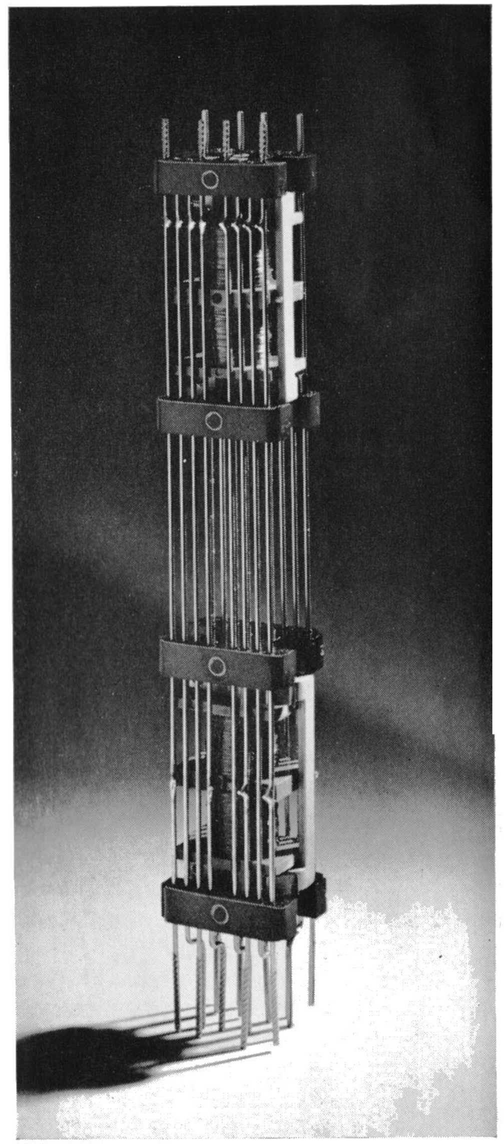
The switching network of the Morris office represented the first study of fully electronic switching under conditions closely resembling commercial operation. From this point of view, the Morris network was a technical success, but it had certain drawbacks. One of the most serious was the inability of gas tubes to carry either high amplitude 20-cycle ringing signals or direct current from the telephone lines. In keeping with the inclination toward solid-state devices, a PNPN diode that had many of the characteristics of gas tubes was considered for commercial application. However, a study of the operation of a remote line concentrator which employed the PNPN diode showed that it had the same difficulty with ringing signals and direct current. DC switching through the concentrator was proposed and this led to the consideration of switching devices with metallic contacts. These can handle wideband signals including dc signals, they have only negligible transmission losses, and they can handle higher power than either gas tubes or diodes. All these properties are even more valuable in switching network crosspoints than they are in a line concentrator. Thus, the invention of the ferreed crosspoint, the basic element in the No. 1 ESS switching network, grew out of these remote line concentrator studies.

The ferreed consists essentially of two magnetic reeds sealed in a glass envelope mounted between plates of a two-state magnetic alloy. The alloy can be very rapidly switched from one state to the other with a relatively short pulse of current, and it has the property of high remanence—it will remain magnetically saturated until another pulse switches it back to the first state. The switching can be done in milliseconds, as it actually is, or even in microseconds, so it is much faster than an ordinary electromechanical switch. It is, however, slower than switching performed by gas tubes or diodes, one reason being that the inertia of the reeds must be overcome each time the device is switched. However, as we have noted, the switching network is one place in the system where some speed could be traded for other important characteristics, so the ferreed crosspoint switch was developed for No. 1 ESS.

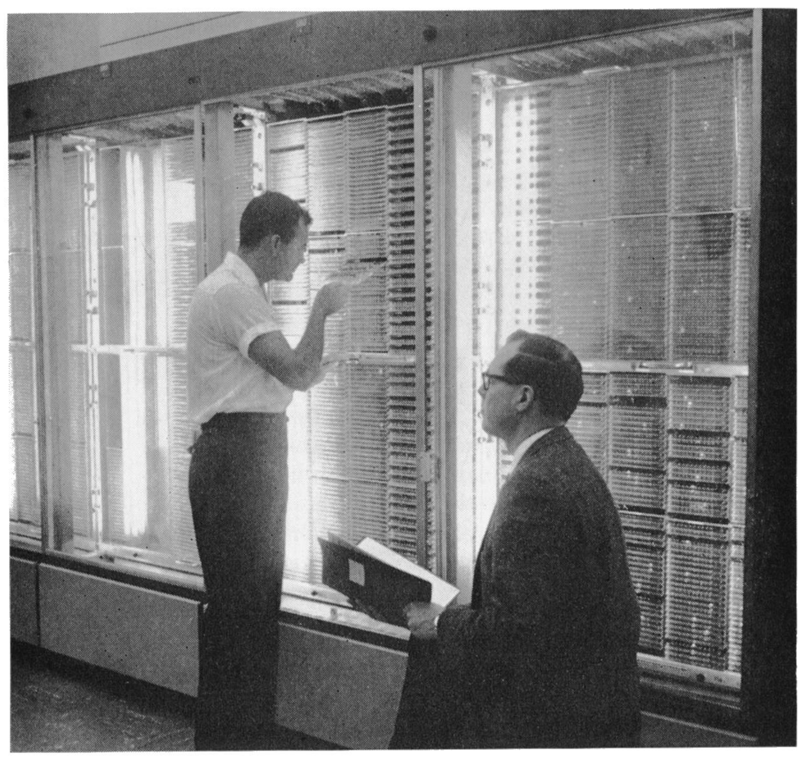
Control techniques of a ferreed switch are quite different from those of diodes and gas tubes and the new techniques necessitated changes in the



The gas tubes used in the switching network at Morris. The system contained more than 23,000 of these tubes which operated successfully throughout the year's trial.



The ferrod, a magnetic current sensing device, is the basic element of ESS line scanners. Each telephone line is connected to a ferrod sensor. Ferrods are arranged in 64 rows, 16 to a row. Every one tenth of a second, central control instructs the scanner to check all the ferrods in a single row simultaneously. The device is introduced at Succasunna.



Overall view of part of the switching network at Morris. The dots of light at right are tubes that were being used in talking connections when this picture was taken.

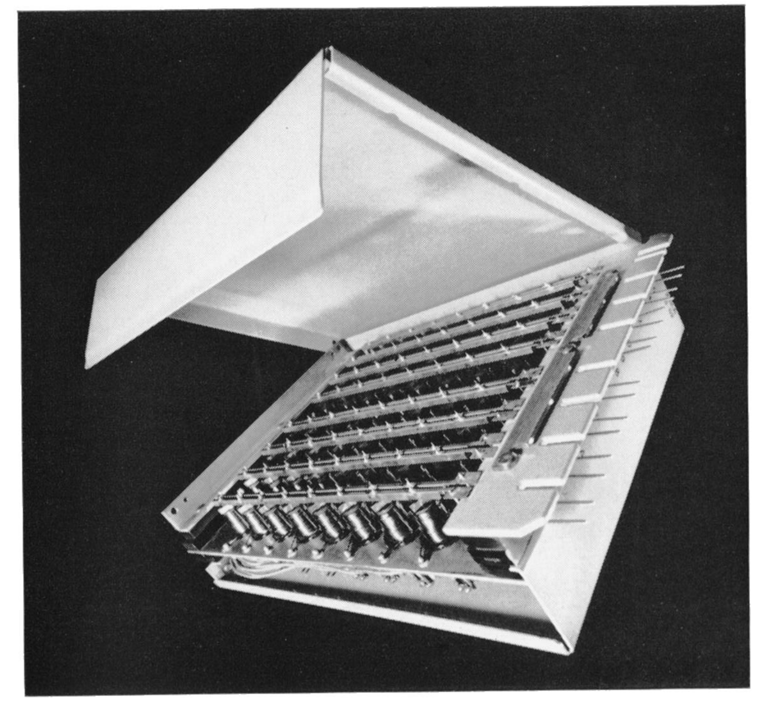
overall system and development of new control devices. The control circuits for the first ferreed were composed of semiconductors, but as the switch was developed it became apparent that the operating speed of semiconductors, in this case, is gratuitous. Therefore, the diodes were replaced with relays which reduced the cost of the control network.

A new control device grew out of the problem of line scanning. The ferreed gives the switching network the ability to extend the metallic wire path from a customer's telephone to any part of the central office. To start this action, the system must sense the presence or absence of current in the customer's line which indicates if the telephone is off-hook or on-hook. A fast scanning device is needed to examine all the lines in the office at frequent intervals so that a customer does not wait for service. Furthermore, for transmission reasons the line must remain balanced and undisturbed by the scanning action.

The ferrod—actually a saturable core transformer—grew out of these requirements. It consists of a rectangular ferrite stick surrounded by two solenoid windings connected in a balanced arrangement on each side of a customer's line. Two single turn loops pass through two small holes in the center of the stick. If the customer's telephone receiver is on-hook there is no current flow in the line, and a pulse applied to one winding produces a corresponding pulse in the other. However, if the receiver is taken off the hook, current flows in the line and saturates the ferrite stick. Thus, when the pulse is applied, the saturation blocks the output pulse and the telephone is known to be off-hook.

As the first article in this issue has pointed out, No. 1 ESS has gone about as far as it is possible to go with common control: Only one group of control circuits in the system is used to give telephone service at any time. However, to guard against loss of service in the event of a failure, each office has twin control systems. Both keep up to the minute on the progress of all calls through the office because each actually processes every call, although only one actually controls the switching network. If the active control should develop trouble, the standby is immediately switched in to take its place. The switching must be done fast enough to keep from losing any calls.

Relays performed the switching in the Morris office. They required tens of milliseconds to operate and at this speed they occasionally caused a dial pulse to be lost if a customer was dialing during the changeover. To raise the switching speed to the range required to avoid the loss of



The basic 8-by-8 crosspoint array of ferreed switches that make up the switching network at Succasunna. To connect two customer's lines for a telephone call eight of the individual ferreeds in the array close in a specified pattern and they remain closed without any holding power.

any calls in progress, the No. 1 ESS bus system was devised.

This system is simply a set of high-speed data channels (actually, for reliability, each office has a duplicate set) that permanently interconnect all equipment units in an office. Electronic gates control the flow of data, selecting the particular channel over which any equipment unit can send or receive. The gate settings can be changed in microseconds in order to establish a new pattern of information flow between the units. The buses are easily extended to new equipment that may be added as the office grows.

There is no question that electronic switching has come of age. Indeed, the myriad changes between Morris and Succasunna almost justify that this article be subtitled The Evolution of Electronic Switching. In Morris, electronic techniques were used as widely as possible to explore all their potential. The experience showed where the techniques were superior to electromechanical techniques, where they were inadequate, and where they just were not necessary. In the following articles we will turn from the ancestry and history of electronic systems to a direct consideration of No. 1 ESS itself.

Although No. 1 ESS brings many new features and services to telephone customers, it must also compete with existing systems. Stored program control puts No. 1 ESS ahead of today's systems in many ways by expanding established services and giving them a new versatility.

Features and Services

J. J. Yostpille

FROM THE PRINCIPLES of telephony discovered in a Boston laboratory 90 years ago, to the investigations leading to the development of No. 1 ESS, the progress of the communications industry has been linked tightly to research. We have seen how various streams of research came together in No. 1 ESS to produce, at their confluence, a switching system that embodies a major conceptual advance in telephony—stored program operation. What are the practical results?

To the Bell System customer, No. 1 ESS may mean a whole new range of optional services depending on the results of customer trials. With these services he can reach a 7- or 10-digit number by dialing only 2 or 3 digits, he can arrange a telephone conference simply by dialing two or three other conferees, he can have calls routed from his own telephone to any other nearby telephone by dialing a short code. To the Telephone Operating Company, these and other services we will discuss in this article are commercial assets, but they are only the public face of No. 1 ESS. Behind that there are the hard practical requirements that a new telephone system must be economically competitive with existing ones, and it should be easy to maintain and to administer. No. 1 ESS has several things in its favor along these lines and each reflects the versatility of stored program operation for a telephone system.

One thing in the system's economic favor is that new services can be added by changing program cards, a far more economical process than the extensive rewiring and equipment modifications that accompany most changes in electromechanical offices. Another asset is that No. 1 ESS can serve more customers than any other system, a capability it derives primarily from the high-speed central control which is directed by the program.

Maintenance and administration are more easily performed than on any other system. Guided by maintenance programs, the system continually checks its own internal condition and, over a teletypewriter, reports any discovered faults and their locations. Most maintenance jobs are thereby reduced to a matter of replacing faulty circuit packages. Administrative personnel can communicate with the machine over the teletypewriter and instruct it to change, cancel, or add to information in its memory that is pertinent to growth or additions to an office.

In all these features, the program can be viewed as the moderator in a dialogue between the customer and the system, and between maintenance or administrative people and the system. Each special service, for example, is delineated in a sequence of actions in the program. A customer starts the sequence by dialing a 2- or 3-digit code which is referred to the program by central control. The code is recognized as the signal for a special routine and central control, directed by the program, sets it in motion. Some routines are started by a momentary "flash" of the switchhook instead of a code. Five optional services are being tried on an experimental basis by 200 selected customers in the Succasunna office of No. 1 ESS. They are called Abbreviated Dialing, Dial Conference, Add-on, Automatic Transfer, and Preset Automatic Transfer.

Abbreviated Dialing replaces a 7- or 10-digit number usually with a 2 or 3-digit code. A customer with an ordinary dial telephone can have a list of eight abbreviated 3-digit codes to represent eight numbers he calls frequently, or he can have a list of 30 numbers that require 4-digit codes. TOUCH-TONE® telephones will have an extra (eleventh) button to replace the first 2 digits of each code which are the fixed prefix "11".

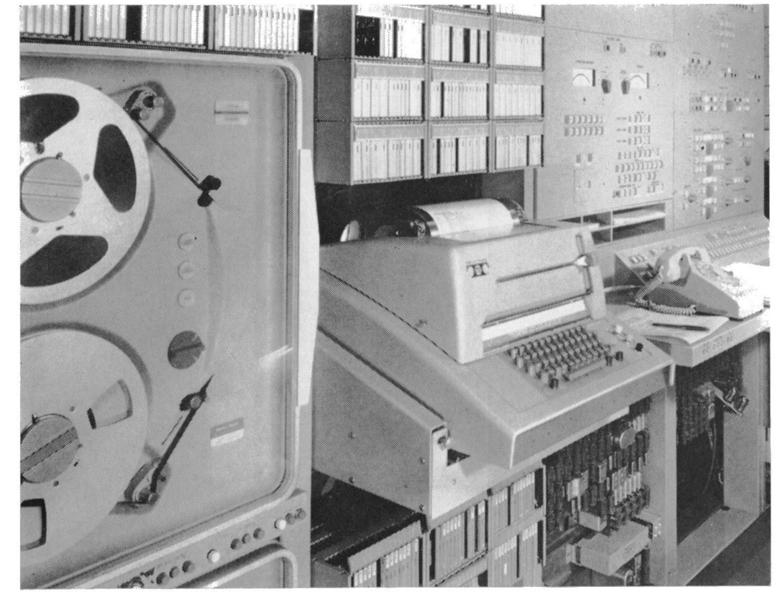
Dial Conference lets the customer control his own conference hookup without the services of an operator. He dials a code that results in the connection of his line to a 4-port conference trunk, then dials two or three telephone numbers which are connected to the trunk in turn.

Add-on, a modified form of conferencing, lets a customer turn a 2-way conversation into a 3-way conference. A momentary "flash" of the switchhook brings dial tone and the customer dials the code digit "2" and the number he wishes to "add-on". His first call is automatically held and all three lines are connected in a conference trunk.

Automatic Transfer and Preset Automatic Transfer, variations on one theme, permit a customer who is visiting friends for the evening, or making a business call, to reroute incoming calls from his telephone to his host's or his colleague's telephone if it is in the same local area. For Automatic Transfer, the customer dials a code and the number he wishes calls transferred to. For Preset Automatic Transfer, he has a list of eight numbers, each represented by an abbreviated code. To transfer calls to any number on the list, he merely dials the appropriate code.

These are only a few samples of the many services No. 1 ESS can provide. Their execution is based on a continuous exchange of information between the switching network and central control, and between central control and the temporary and semipermanent memories. For example, abbreviated codes are not contractions of the actual telephone numbers, but consist of the 2-digit prefix "11", and any third digit. When the customer dials the code, it is stored in the temporary memory. (See the drawing on page 213.) Central control is then directed by the program to examine and interpret the code. The program, recognizes the prefix followed by the third digit as an Abbreviated Dialing code. Alternatively, it recognizes the multifrequency TOUCH-TONE signal of the eleventh button as equivalent to the prefix. A list stored in the memory translates between the code and the wanted telephone number. Central control takes the full number from the semipermanent (program store) memory, transfers it to the temporary (call store) memory as if the customer had dialed it, and directs the system to "dial" or outpulse the complete number.

In the case of transfer service, a record of the customer's transfer request is stored in the temporary memory together with the number he wishes calls transferred to. The system refers to the temporary memory when a call comes in to the customer's number, and instead of completing a call there it reroutes it to the transfer number.

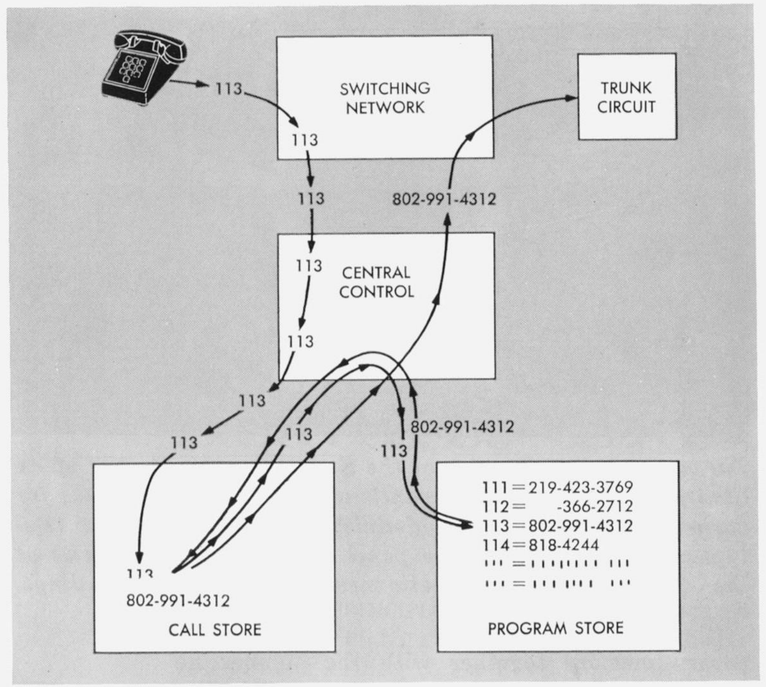


The master control center at the Succasunna No. 1 ESS office. Controls and lamps on the panels at the far right are used for various maintenance and administrative functions. The teletypewriter supplements the panel controls. The tape reels at the left are used for automatic message accounting recordings.

If a customer with Add-on flashes his switchhook for a period less than 1.5 seconds while he is in a talking connection the system interprets it as a request for this service. Central control, under direction of the program, then connects the customer who flashed to a dial pulse receiver and holds the second party. The customer then dials the party he wishes to add and the system establishes a 3-way connection in the network.

These special services can be arranged in electromechanical offices by adding special equipment which, in some cases, may be electronic. Possibly an even better measure of the versatility of stored program operation lies in the flexibility it provides for some of the most commonplace features of a telephone switching system. Take the example of a hunting group. This is a familiar service found in most business and PBX systems in which an incoming call that encounters a busy line is routed to another line, then to another if the second is busy, and so on until a connection is made or all lines in the group are found busy.

In electromechanical systems, this is a wired equipment function and, therefore, it has certain limitations. A hunting group is usually restricted to certain blocks of lines and the hunting sequence is arranged consecutively. In other words, if the first telephone number in the group, or block, is number 1111, the second is number 1112, the third



Any telephone call through No. 1 ESS involves a constant exchange of information between central control and the two memory blocks. Abbreviated dialing is illustrated here. The abbreviated number "113" dialed by the customer is stored in the call store memory. Central control then refers the number to the program memory which checks it against a list of eight possible numbers. The full number represented by "113" (it may be 7 or 10 digits) is transferred to the call store memory where it replaces the abbreviated number. Finally, the complete number is sent through the switching network to outgoing trunks to the distant office just as if the customer had dialed it in its entirety.

number 1113, etc. A call to number 1111 can hunt through the whole group if necessary, but a call to number 1113 can only hunt to higher numbers, it can not hunt back to the lower ones.

In No. 1 ESS, the lines in a group and the order of hunting are stored in the memory, the lines are not associated through wiring. A call can be made to hunt through a group of arbitrary lines in any desired sequence. Alternatively, if the call is not completed in the first group it can be shifted to another and made to hunt through that. Customers can operate control keys in their offices which will cause the system to hunt in these patterns, or not hunt at all when that is desired.

Another example of how No. 1 ESS imparts new versatility to an established feature is classes of service. This tested and indispensable feature permits different treatment on PBX lines. Some can be limited to local calls, others to toll calls within a limited area—even to a specified exchange within an area—and still others may be unrestricted. The feature is also used to route and charge calls on various kinds of customer service. Again, wired equipment puts certain bounds on this feature for electromechanical offices. In No. 5 crossbar offices, for instance, there can be only about 100 classes of service. No. 1 ESS increases it tenfold; a total of 1024 classes of service can be stored in the memory. The large number of classes will be particularly useful in offices that elect large numbers of features and services. Each special service can be given a class of service and then allowed on some lines and denied to others.

Features and services can be added to No. 1 ESS offices almost without limit. They seldom curtail the system's normal call-processing ability which is affected mainly by traffic conditions. In any given traffic situation, however, No. 1 ESS can serve more customers than any other switching system. The upper limits on No. 1 ESS are 65,000 lines and 100,000 telephone numbers—party lines account for the discrepancy. In an area with average calling rates—a suburban community like Succasunna, for instance—an office can serve the maximum number of lines. But in an area with a high calling rate, like Washington, D.C., No. 1 ESS may reach its maximum call-carrying capacity with only about 30,000 lines. In this case, the calling rate determines the size of the office.

A rare event that does act to degrade service is an extreme overload on the system. The cause is usually external to the switching system—floods or hurricanes may damage the outside plant, for example, severely reducing the number of trunks available to an office and causing overloads. At such times, electromechanical offices may be forced to invoke line-load control, completely cutting off service for all but essential lines such as fire departments, police, and hospitals. Nonessential lines can only receive calls. Manually operated switches govern the action. When they are thrown, all nonessential lines associated with them are denied originating service and the action is revoked only when the switches are reset.

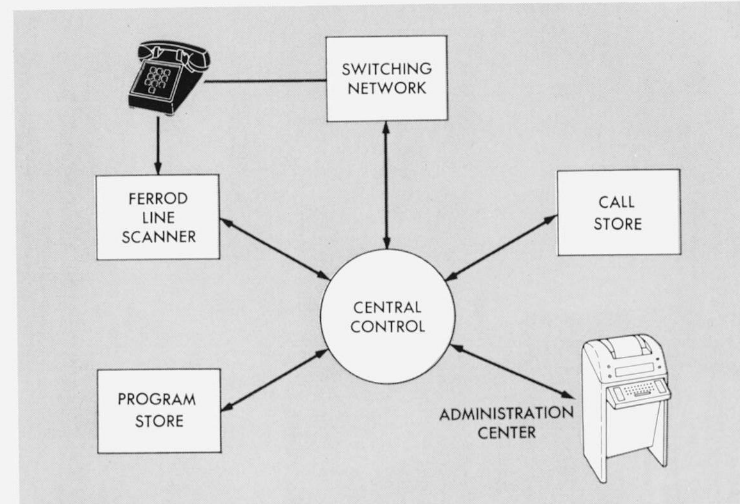
Stored program control, on the other hand, can deal with degrees of overload, continually reorganizing and readjusting the system so that service continues at the most efficient level despite severe changes in internal or external circumstances. The program recognizes a certain hierarchy in the jobs the system must do and acts always to maintain it by periodically measuring the efficiency of service against a certain standard. The standard includes such things as permissible delay in returning dial tone, the number of calls blocked in the switching network, and other

indications of normal or subnormal service. If service falls below an acceptable standard, routine maintenance and similar low priority jobs are dropped. Then, if further adjustment is necessary, processing of new calls is deferred until calls in progress are completely processed. Thus, line-load control is initiated by degrees. Essential lines (indicated by class of service) receive priority, but the system denies service to nonessential lines only at moments of extreme overload. Thus, when line load control must be put into force, No. 1 ESS still serves all essential calls and as many others as it can. Service is not flatly denied to any line, and when the overload subsides, the system automatically returns to normal.

All these features and services are delineated in the program. Still, these things and their ramifications require only about half the program content. The other half is concerned with maintenance, for it is a simple but undeniable fact that the most important task of a telephone switching system is to keep running. A computer may break down in the middle of a problem and the problem may be rerun because all the vital data remains in the computer. But a switching system breakdown is disastrous because requests for service are irrevocably lost. Furthermore, it is a fair rule that the more complex a machine is, the more difficult it is to maintain, and No. 1 ESS is an extremely complex electronic machine. Yet we have said that No. 1 ESS is easier to maintain than any existing telephone system. A major reason for this is that the system participates in its own maintenance.

To accomplish this, No. 1 ESS continually scrutinizes its own performance. If a fault develops, the affected unit is switched out of service and a duplicate takes over. At the same time, a diagnostic program is called in to locate the circuit package causing the malfunction. The location of the package is typed out on the teletypewriter so that the majority of system troubles can be corrected quickly and easily.

This "dialogue" between man and machine is the key to all maintenance problems. It is often necessary, for example, to trace a call in order to find a reported trouble on a connection, but the ferreed switch in the No. 1 ESS network makes it impossible to visually follow a connection between lines and trunks. However, the temporary memory records the locations of all lines and trunks associated with a call in progress, and a special call tracing program will render all these locations to a maintenance man. He merely types in an instruction to trace the call to a specified line. The system will identify the calling line or trunk. This feature is now limited to calls within an office. As No. 1 ESS grows in the Bell System, it will be possible to trace interoffice calls automatically.



A simplified diagram of the No. 1 ESS system showing the bilateral exchange between the central control and the other elements. The teletypewriter is the instrument of communication between the system and the administrative and maintenance personnel.

Communication over the teletypewriter between administrative personnel and the system eases many administrative tasks. Many of these tasks are recurrent ones in all telephone offices. For example, translation data — which includes such things as the location of a trunk group that may be used for an outgoing call, the number of digits to be outpulsed, the equipment location of the called line, the type of ringing sent to a party line, etc.—is frequently changed. In electromechanical switching systems, this data is "recorded" in wired cross-connections and it is changed only by rewiring. In No. 1 ESS, translation records are stored in the memory, and they are changed by typing the new information into the system. This information can be stored and held in the temporary memory until the semipermanent memory twistor cards are changed.

At first thought, stored program control could be considered as a step that makes the operation of a switching system completely automatic. However, as we have seen, it actually provides a means of closer communication between the system and the people who maintain and administer it. In the final analysis, unique as No. 1 ESS is in the history of telephony, its design looks to essentially the same goal as the design of any telephone system. That goal, the ability to process telephone calls rapidly, efficiently, and economically, has been attained through stored program operation.