All the highly sophisticated control actions described in the previous articles point toward one goal—establishing the speech path that bridges two telephone customers. The switching network makes the connections forming this bridge.

The Switching Network

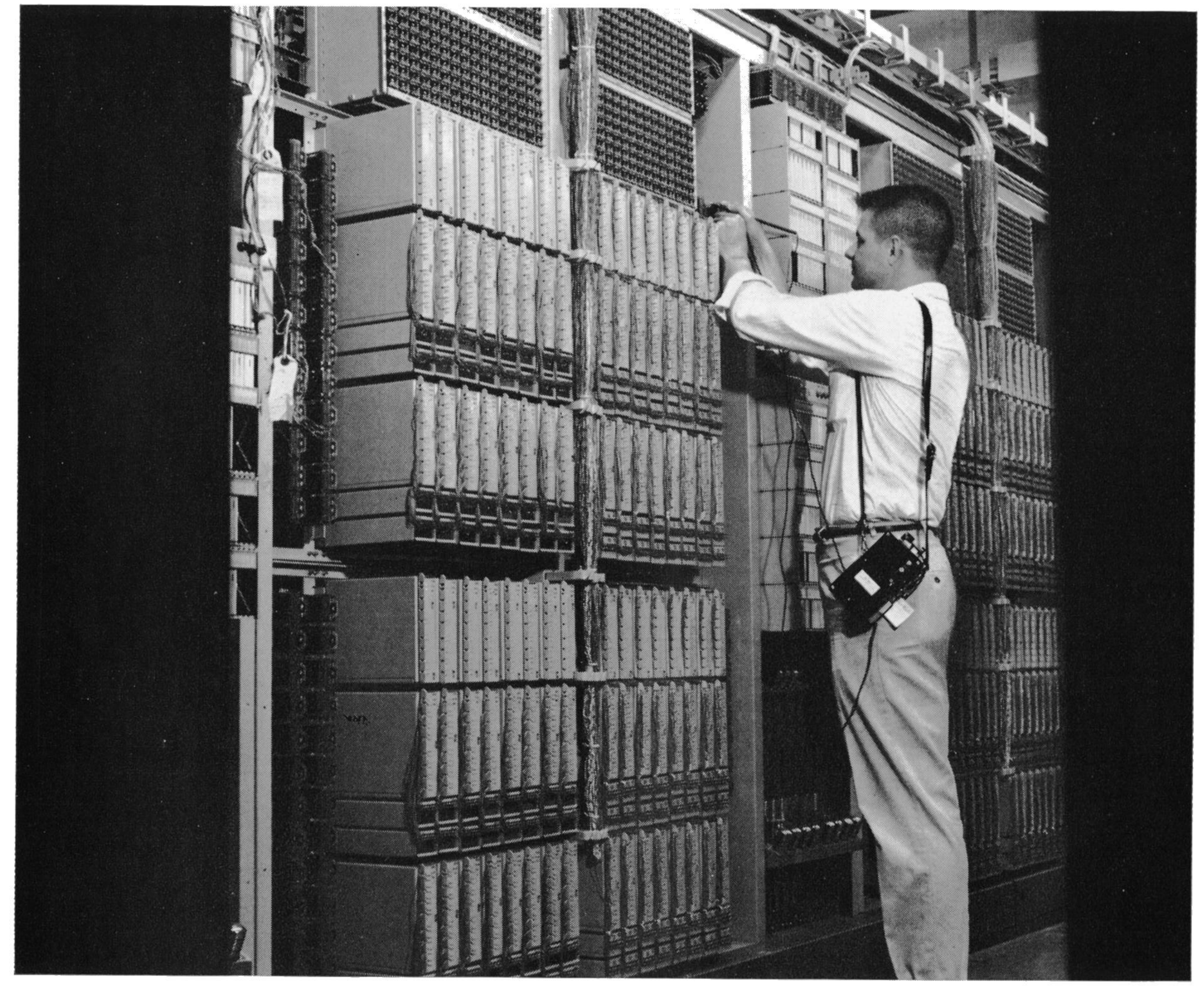
A. Feiner

THE HISTORY of the telephone switching network is marked by the periodic introduction of new apparatus—Strowger switches, panel and rotary selectors, crossbar switches, and in the Morris trial, a network of gas tubes. The switching network of No. 1 ESS, built upon the ferreed switch, falls between electromechanical switching methods and the all electronic methods of the Morris office.

A natural control philosophy for the network accompanied each new switch. In step-by-step exchanges, the switches themselves participate in interpreting the dialed information and choosing the network connection. In the crossbar network, the markers consult the memory contained in the third switched lead, called the "sleeve," to find a set of idle switching links and make a connection. The gas tube network introduced "endmarking;" voltage marks placed on the end terminals caused the tubes in between them to break down, thus establishing a path between telephones. In No. 1 ESS, the logic and memory functions that generate control information for the network are completely divorced from the network itself.

Why not an electronic network for an electronic switching system? The gas tube network of the Morris office was a technical success, but it had serious drawbacks. Most prominently, gas tubes could not carry high amplitude 20 cycle ringing signals, and so were not compatible with most types of existing telephone sets. The balanced metallic contacts of the ferreed switch (RECORD, *February 1964*) permit conventional supervisory and alerting signals, do not stand in the way of new transmission techniques, and meet the requirements of high speed.

Actually, the need for a high speed network does not arise—as it may seem at first glance—from a desire to make faster connections between telephones. The real need is for a network that can work compatibly with the high speed control



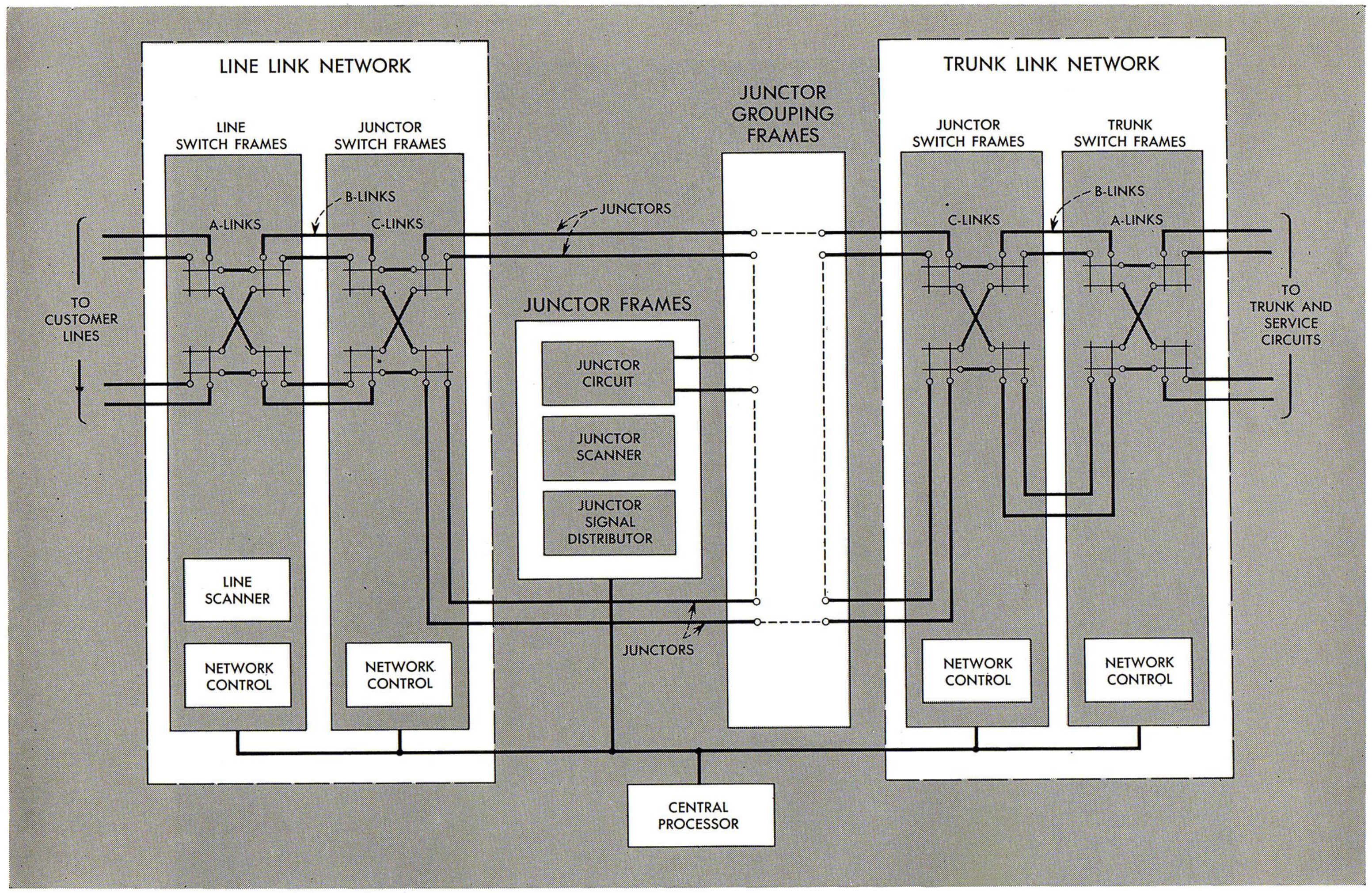
J. Bodirae, a Western Electric craftsman, performs an installation test on line switching frames.

circuits of an electronic office and that can be used not only for final speech connections but also to connect information receivers, senders, ringing circuits, and other equipment when they are needed. Because the No. 1 ESS network performs all these actions its trunk and control circuits are greatly simplified. However, about four network connections are needed for every call.

The No. 1 ESS switching network (see the drawing on page 238) is called "octal," a name derived from its eight stages of ferreed switches, in which each switch is an eight-by-eight array of crosspoints. This plan is a compromise between three important factors—complexity, economy of crosspoints, and maximal size (i.e. the number of lines and trunks a single office can serve.) A network of four-by-four switches, for example, would need more stages to attain the same maximal network size and equivalent blocking performance. It would contain fewer crosspoints, but the saving would be offset by more complex wiring and control requirements.

The octal network is composed of two types of four-stage subnetworks—the line-link and trunk-link networks. Any network, up to a maximum size of 64,000 lines and 16,000 trunks, is assembled from these basic units. Link networks are connected through the junctors to establish traffic paths for the three common types of central office calls—intraoffice, interoffice, and tandem (trunk-to-trunk) calls. One novel feature of No. 1 ESS is that intraoffice calls through intraoffice junctors bypass the trunk-link network. The junctor circuits extend battery circuits and supervisory signaling circuits to these calls. All other traffic is connected to the battery and supervised at the trunk circuits.

Line traffic in a No. 1 ESS office is concentrated in the first two stages of the line-link network. In a typical No. 1 ESS office, 64 lines have access to only 16 second-stage links. This two-stage, four-to-one concentrator configuration



The general organization of the No. 1 ESS switching network. Its building blocks are the line-link and trunk-link networks, each of which contains two types of equipment units. Two stages of the network are packaged in each of those units. In addition to the ferreed crosspoints, the line switching frames house the line circuit equipment containing a ferrod and a bipolar ferreed for each line. This equipment is analogous to line relays and cut-off contacts in electromechanical systems.

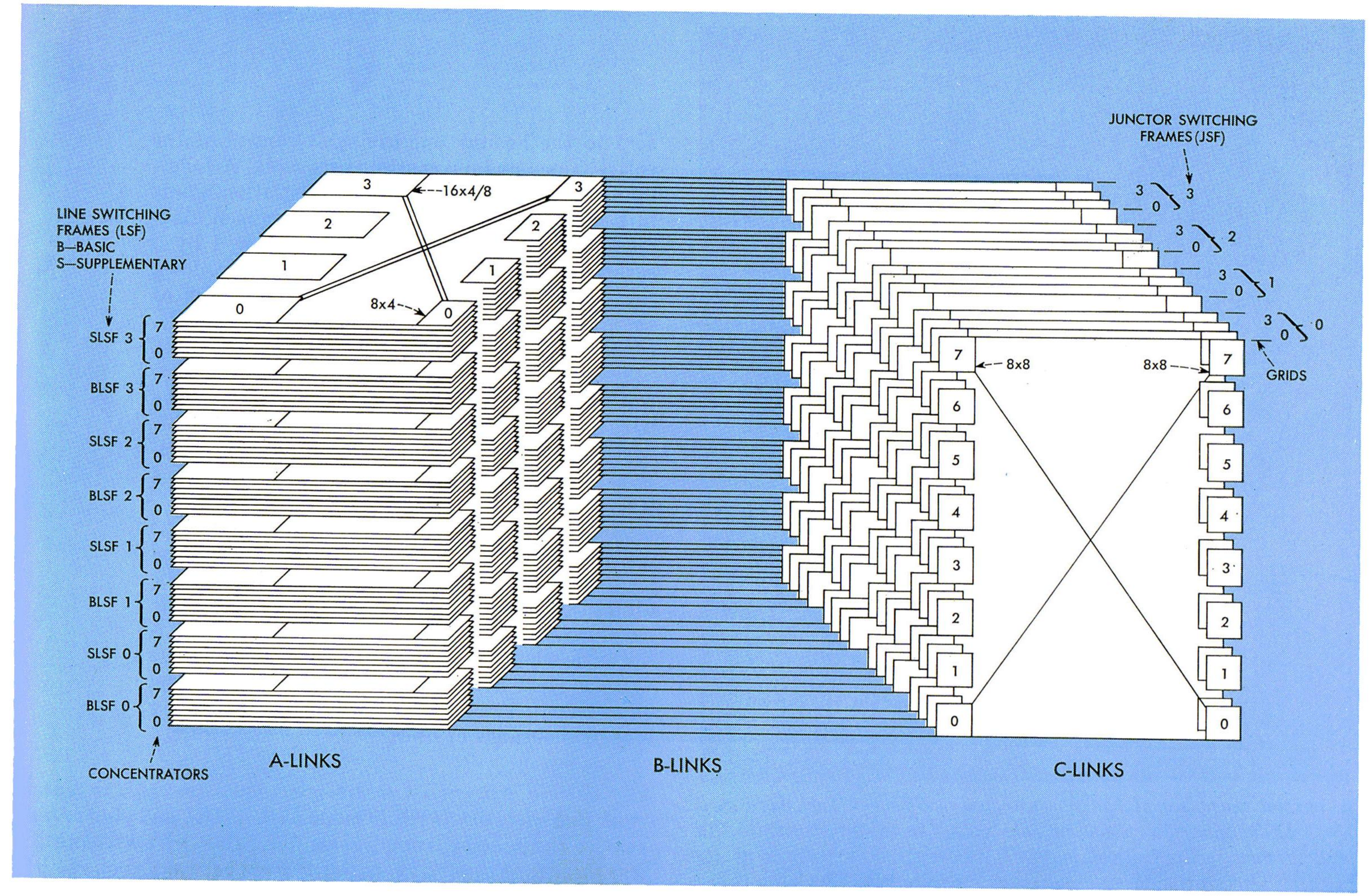
is uniquely efficient in its use of crosspoints. It requires only six crosspoints per line and its traffic performance equals or surpasses that of previous four-to-one concentrators which typically required ten crosspoints.

Sixteen line concentrators, their control circuits, and the line scanner are packaged in each line switching frame. The scanner and the line connect through a single bipolar ferreed which disconnects the scanner element (the ferrod) from the line after the system recognizes a request for service. The bipolar ferreed has only one winding and its contacts open or close in response to the polarity of the control current.

The other network stages are packaged in junctor and trunk switching frames. Each contains two stages of eight-by-eight ferreeds providing 256 inputs and 256 outputs. In the junctor frame, one additional ferreed is associated with every junctor output. Independently controlled, this switch is an access point through which operators can verify a connection and it is also used for some specific system tests on established connections. It is generally called the "no test" access.

A fully equipped line link network (see the drawing on page 239) contains four line switching frames and four junctor frames with a capacity of 4096 lines and 1024 junctors. If the calling rate of an office is unusually light, the concentration ratio of the network can be increased by adding line switch frames and multipling the "B" links. For busy metropolitan offices, a line switch frame has been developed with a basic concentration ratio of two-to-one.

A fully equipped trunk link network contains four junctor switching frames and—for a one-to-one trunk concentration ratio—four trunk switching frames. The number of these frames also can be increased in situations where the amount of



The internal relationship of the four stages of switching in a line-link network showing interconnections and component equipment units. A fully equipped line-link network with a four-to-one concentration ratio contains 4096 lines and 1024 junctors connecting to other line and trunk-link networks. A trunk-link network can be shown in much the same kind of diagram by replacing the concentrating switches with eight-by-eight switches in the first two stages of the network.

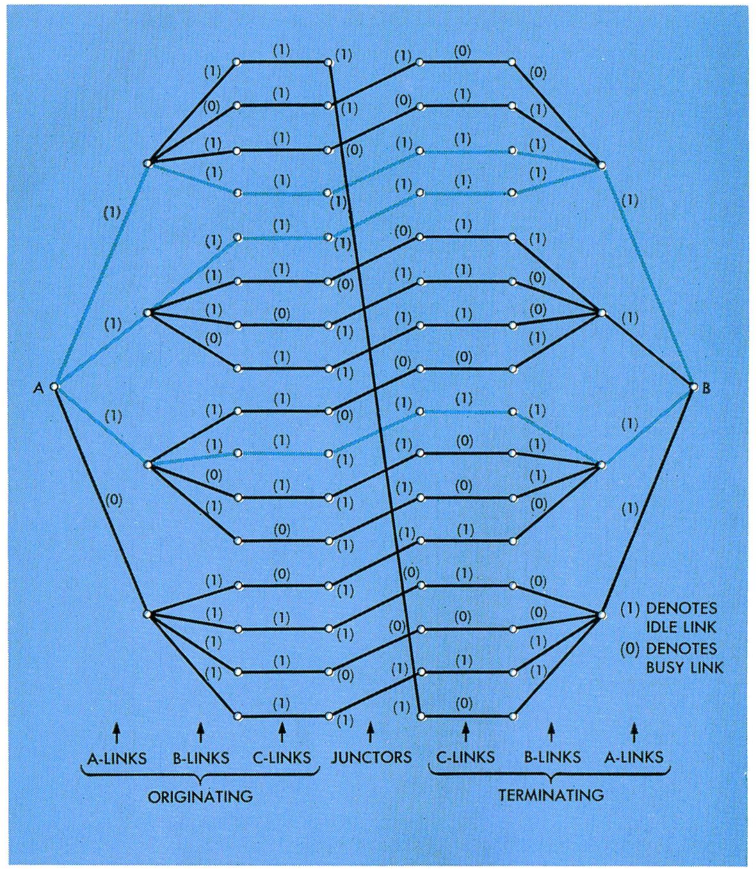
traffic warrants a larger concentration ratio. A jack and plug arrangement at the junctor grouping frame facilitates changes in the inter-network cabling during growth or a change in the traffic pattern.

Control of any switching network with its multiplicity of possible switching paths for any telephone call, requires some form of memory to tell the system which links are busy and which are idle at any given time. Conventional central offices use a sleeve lead as the memory, and the system tests the sleeves before hunting for a path. No. 1 ESS, however, uses the call store memory to control the network in a unique manner.

A special area of the call store, known as the network map (see the drawing on page 240), contains a record of the busy and idle states of all links in the office. One bit of information—a binary zero or a binary one—identifies the state of each link. When the system needs a path for a call, therefore, it need not consult the network, but only the map. While a call is in progress, every link in its path is identified in a "path memory word" written into the call store. These links are marked busy in the network map. As soon as the talking parties hang up, the links are marked idle in the map and the memory path word is erased from the call store.

The central processor actually decides what path to set up through the network for any call. It consults the network map, decides on the idle links to be used in the path, and informs the various network frames of their parts in the connections. (Each frame completes a two-stage fragment of a connection when a call is set up.)

Information defining the crosspoints to be closed in a frame is sent over the peripheral bus unit to the network controller serving that frame. A frame is first signaled, over an enable lead, to



A partial mapping of the possible paths between two lines in a No. 1 ESS office. To choose an idle path, the system consults the link memory which stores a bit for every link to represent its busy or idle status. A "1" indicates an idle link. Thus the three solid blue lines show the only three idle paths in this mapping.

expect an order from the bus; then the actual instruction is sent. Because the bus and the network controllers are both duplicated, the enable signal defines the combination of bus and controller that will receive the instruction. There are four possible combinations; hence four enable leads serve each frame.

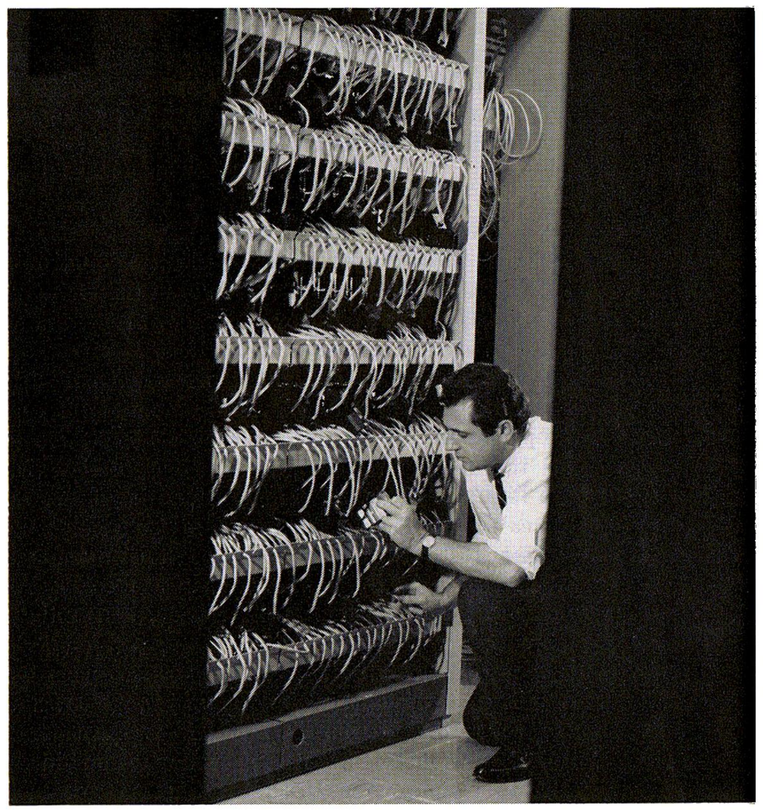
The controller stores the instruction data in a buffer register and uses it to close wirespring relay contacts that define a control-pulse path in the ferreed switches. After relay contact chatter stops, a high current pulse is applied to the crosspoints. The operation of the controller is checked at every stage of its internal sequence. Nineteen milliseconds after it sends an order, central control scans the outputs of two flip-flops associated with the controller. Their states indicate whether or not the order has been executed successfully.

Normally, the controllers operate independently of each other. Each can accept one order every 20 milliseconds and it controls only half of the network switches in the frame. However, if a fault is detected in either controller, an order is sent to the healthy one giving it control of the entire frame and quarantining its mate. A follow up order cuts through sixteen observation points in the quarantined controller to a common diagnostic bus. This second order is followed by a series of test orders designed to narrow down the possible causes of the trouble. Execution of these test orders results in a printout on the teletypewriter containing an accurate clue to the fault.

The 20-millisecond control cycle of the network is dictated by the operating speed of the wire spring relays in the ferreed pulse path. This speed is sufficient for the system—a typical network controller is used only five per cent of the time during a busy hour.

The ferreed network of No. 1 ESS is a unique cross between electronic and electromechanical switching techniques. Not only does it solve the difficulties experienced by earlier all electronic networks, but it introduces a much greater flexibility to telephone switching. Three basic frame designs yield networks that efficiently span the unprecedented range of a few thousands to many tens of thousands of lines.

Any desired pattern of interconnections between the line and trunk link network is easily made with a jack and plug arrangement at the junctor frame shown here. In electromechanical offices these interconnection patterns must be changed by rewiring.



Standardization was the keynote in the mechanical design of No. 1 ESS. The result—fewer frames and equipment options than any conventional system—means greater economy, from manufacture through installation and maintenance.

Mechanical Design

D. H. Wetherell

To a casual observer one telephone central office is much like another, and a 10,000 line No. 5 crossbar office in New York is indistinguishable from one in California. But the frames of seemingly alike switching equipment often are tailored precisely to fit different traffic patterns requiring many different features and services. There are, for example, more than 125 different frames manufactured for No. 5 crossbar offices and hundreds of possible service options. Obviously, the more frames and options, the higher the manufacturing cost, and the more difficult it is to plan for change and growth. The most flexible systems are adaptable to many situations with little change in basic equipment.

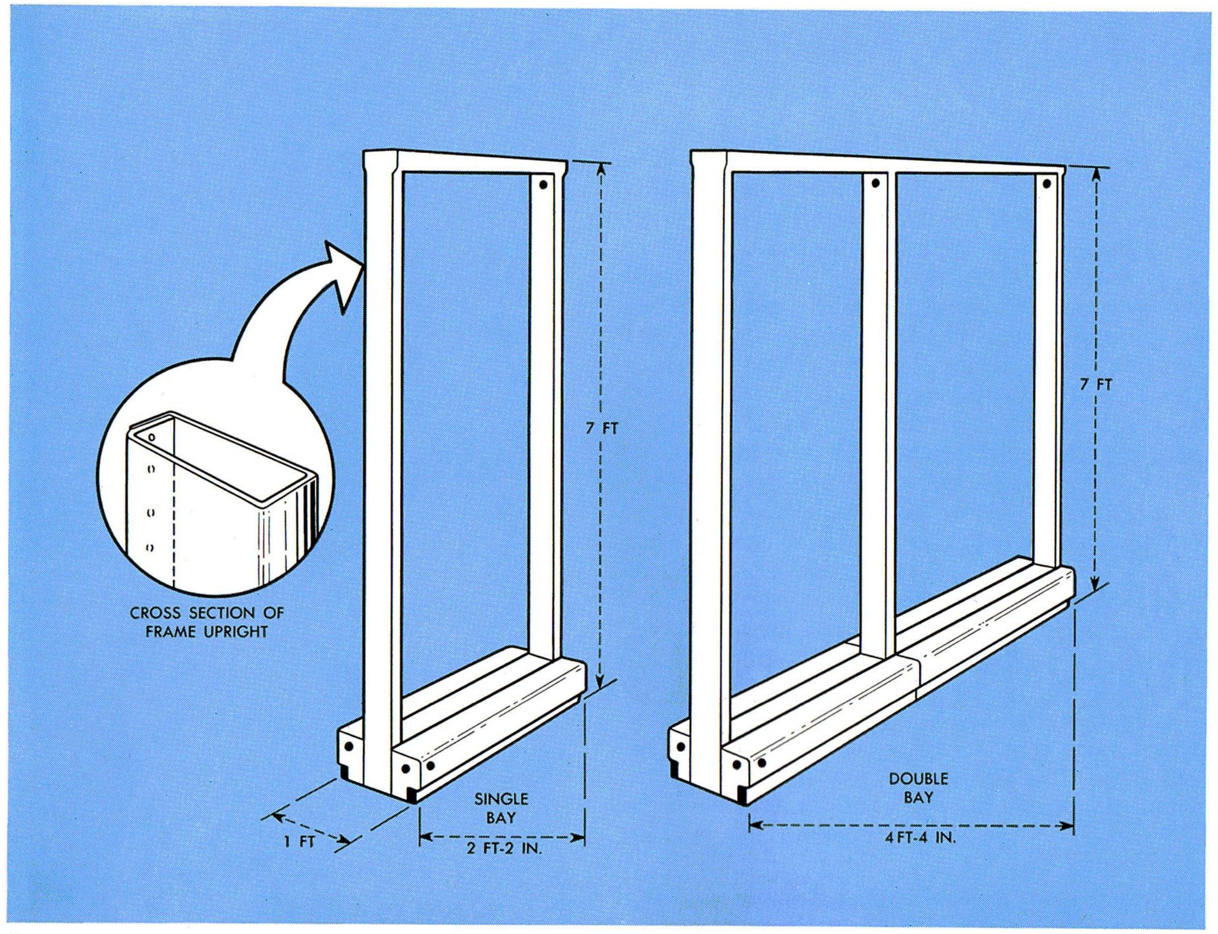
The apparatus and equipment of No. 1 ESS was designed to accent the flexibility and versatility of stored program operation. Previous articles in this issue have described the great variety of features and services No. 1 ESS offers; a much greater variety than any electromechanical system. And it does this with more highly standardized equipment that occupies a smaller volume of space than the equipment of any electromechanical office having a comparable number of lines.

A new system must compete with existing ones (see *Features and Services* in this issue) both in new features and services for customers, and economically. One important consideration, for instance, is building space. Many panel and step-by-step systems are nearing the end of their economic lives and a compact switching system such as No. 1 ESS occupies only a fraction of the floor space the older ones use. Thus older systems can give way to No. 1 ESS with only small alterations in existing telephone company buildings.

The varieties of equipment for No. 1 ESS offices and for No. 5 crossbar offices is a dramatically revealing contrast. Compared to the more than 125 types of frames for No. 5 crossbar, there are only 30 types of frames for No. 1 ESS—a 4-to-1 reduction. Wired system options are an even sharper contrast. No. 5 crossbar has more than 1200 wired options, No. 1 ESS only about 20—a reduction of about 60 to 1.

Mechanical design of No. 1 ESS ranged widely from equipment used in large quantities, such as circuit packs and ferreeds, to one-per-office equipment, such as the master control center and the card writer. We will discuss only a few representative examples in this article—the design of the frameworks which support the equipment and apparatus, and a few of the major items of apparatus.

Equipment frames are a logical beginning. The goal was frames of modular size that would be functional building blocks free of options.



Basic single bay frame module and double bay multiple. Sheet metal uprights centered on the base provide an 8.5-inch deep apparatus mounting space at the front and a 3.5-inch deep wiring space at the rear.

To start with, designers could call on the long experience with electromechanical offices containing varied types of central office frames, as well as the experience of the Morris office and frames designed exclusively for an electronic system. Several basic questions were raised. First, should frames be double-sided as they were in Morris, or the more conventional kind with equipment and wiring directly accessible from the aisles? Second, should equipment and wiring be exposed, or covered? Third, how high should frames be, how wide, and how deep for No. 1 ESS equipment?

The answers to these questions were straightforward. First, the electron tubes and germanium diodes and transistors of the Morris office necessitated air conditioning. Double-sided, enclosed frames eased this problem. Also, at that time designers thought that double-sided frames saved floor space. The semiconductors of No. 1 ESS can tolerate higher temperatures and so do not require air conditioning. Besides, studies showed that double-sided frames saved little, if any, floor space. To complete the case for single-sided frames, they are less expensive to build and install and easier to test and maintain.

The standard height of No. 1 ESS frames was set at seven feet. This height is compatible with the smaller No. 1 ESS functional units and it results in shorter leads. Short frames are maneuverable; they fit in standard elevators and through doors, easing both installation and maintenance. Also they are supported entirely from the floor and need no overhead structures. Craftsmen seldom need stools or ladders for testing or maintenance—an added safety feature.

Finally, the argument for short frames was, in part, an argument against conventional eleven foot frames. The high density of electronic equipment leads to floor loading that is as great for short frames as for tall ones stocked with electromechanical equipment. For example, the heaviest No. 1 ESS frames hold the twistor memories. A single frame of this kind weighs about 1800 pounds and covers a four and one-third by one foot area. A tall frame with such volume would exceed the floor loading limits of many existing buildings.

The advantages of short frames are partially offset by floor space considerations. Despite this, a typical No. 1 ESS switchroom requires less than one-half the space of comparable electromechanical switchrooms.

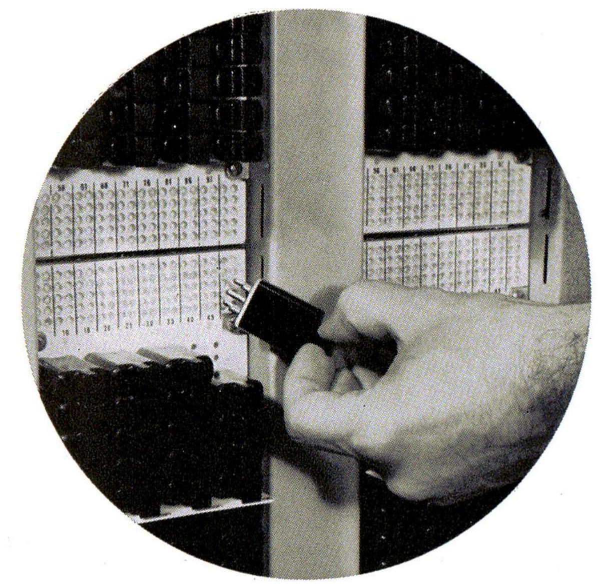
A cable rack rests on top of the frames in each lineup. Additional cross-aisle cable racks are placed just above and at right angles to these at each end of the lineup and at intermediate points when they are needed. This arrangement of racks serves a dual purpose. It simplifies cable routing and it rigidly interconnects frames and lineups, adding stability.

The basic frame module is 2-feet 2-inches wide and 12 inches deep. Frames have a variety of widths, including 2-feet 2-inches, 3-feet 3-inches, and 4-feet 4-inches. However, when frames are combined in a lineup, the combination is always a multiple of the basic module. (See the drawing on page 242.) The 2-feet 2-inch width is most common. Three circuit pack housings can be mounted adjacent to one another in the 23 and one-half inch space between uprights on this frame. It is also adequate for the larger apparatus units, such as the twistor memory, the teletypewriter, magnetic tape recorder, and card writer.

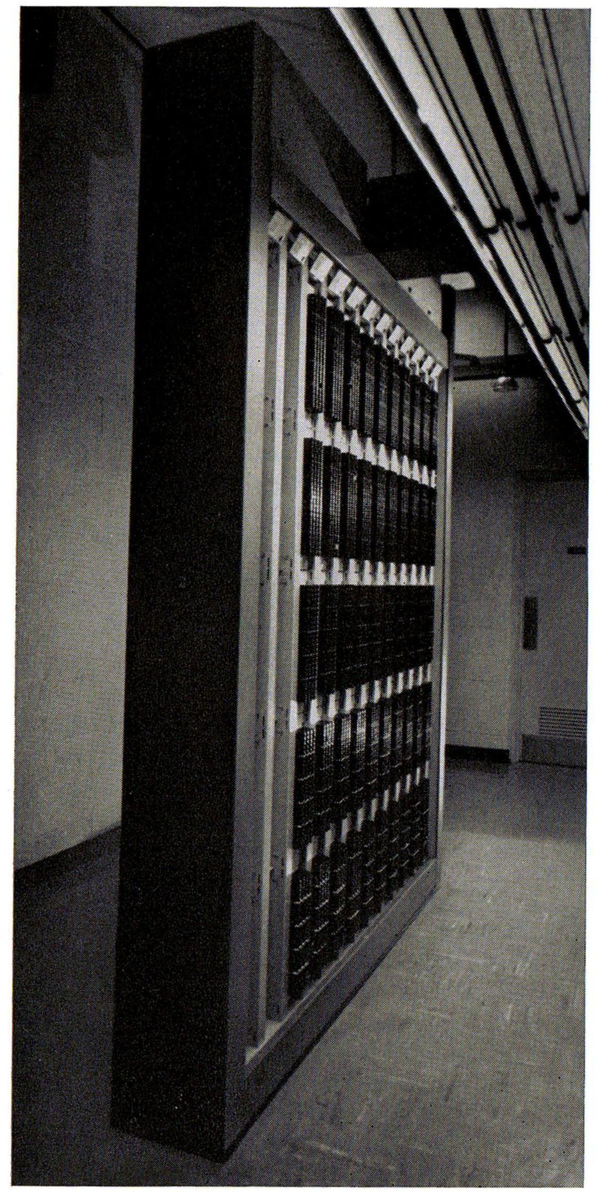
The depth of the frames was determined primarily by the size of No. 1 ESS apparatus. It also permits six rows of frames to be mounted between standard building columns with 30-inch wide maintenance aisles and 20-inch wide wiring aisles.

A main distributing frame (MDF) compatible in height and floor space areas accompanies the switching and equipment frames. Conventional MDFs are double-sided—protectors on one side, cross-connecting terminal strips on the other. No. 1 ESS has two frames—a protector frame and a cross-connection frame which is called the MDF. These frames are a further contrast between older offices and No. 1 ESS. To terminate, say 6000 conductor pairs, a conventional crossbar office requires an MDF 14-feet long. No. 1 ESS terminates the same number of pairs on an MDF only 6-feet 6-inches long.

MDF terminals are arranged in columns, 1200 pairs of terminals to a column. Connections are



Central office equipment can be disconnected from the protector frame merely by pulling the protector forward to a detent position. This action disconnects only the central office equipment and not the outside cable pair which remains protected.



The protector frame guards system circuits against lightning and other high voltages. Protector units also serve tip and ring conductors of a cable pair. White blocks between the groups of protectors in each vertical column are test points.

made to these solderless, quick-connect type of terminals by forcing the insulated wire into a tight-fitting tapered slot. (See the drawing and photograph below.) The terminal cuts through the wire insulation and its spring-action grips the wire firmly.

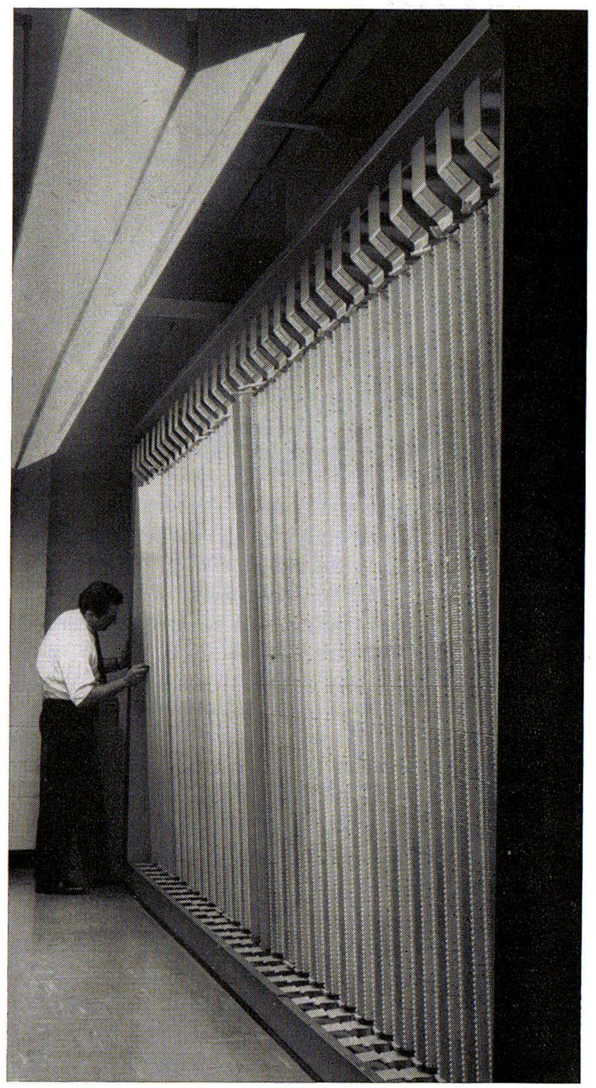
A new kind of plug-in protector unit on the protector frame houses the carbon blocks for tip and ring circuits. The frame has 12 verticals each containing five panels that, in turn, each mount 100 protector units—a total of 6000 units per frame. At the back of the frame they connect to outside plant cables and tie cables to the MDF.

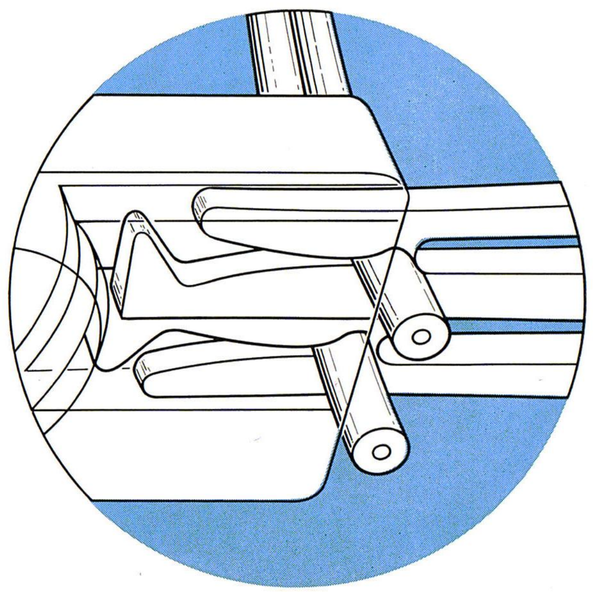
The equipment frame design could not be "frozen" until the designs of all equipment units and apparatus were well established. Some of the pertinent factors in this design were the packaging of semiconductor circuits, the ferrite sheet and twistor memories, the ferreed switches, the ferrod sensors for scanners, and the design of such components as AMA recorders and the teletypewriter to fit the new traffic and maintenance record concepts of No. 1 ESS. The remainder of this article will discuss some of these components and their mechanical design.

Semiconductors are mounted on printed circuit packs which are plugged into molded wire spring connectors mounted in die-cast aluminum housings. One circuit pack can hold about 70 typical components. The actual number may vary from as few as six relatively large components to as many as 84 small components such as resistors, capacitors, and transistors.

Printed wire paths on the circuit pack phenol fiber board are gold plated at one end forming 28 connector terminals. The size of the packs and the number of terminals reflect both the experience of the Morris office and compromises among such factors as the total number of contacts needed for the system, lead lengths, cost, and the number of circuit pack types required.

The ferreed switch is the crosspoint element of the No. 1 ESS network. It consists of two small sealed-reed switches operated and released by controlling the magnetization of two adjacent remendur plates. (The story of the development of remendur, together with a description of its magnetic properties, is told in *Some Magnetic Materials* in this issue.) Shop wiring runs on the rear of the frame to terminals on the back of the switch. Installation wiring runs to another set of terminals on the front of the switch. Thus the installer can work in the wider equipment aisles and not interfere with shop wiring.





"Quick-connect" block on distributing frame speeds up making cross connections. Craftsman merely holds insulated wire in the slot opening of the terminal clip and forces it into place with a hand tool.

In many large central offices, the length of the main distributing frame (MDF) determines the length of the building. The MDF of No. 1 ESS, shown here, is three-quarters the height and requires only one-third to one-half the floor space of large distributing frames in conventional offices.

The system may use four types of these two-wire switches. The first, the most common, is an 8-by-8 array of crosspoints. The second comprises two 8-by-4 arrays. The third, called a 16-by-4 out of 8 array gives 16 lines access to eight links, but each line access to only four of the eight. The fourth type comprises four 4-by-4 arrays. There are also two types of bipolar ferreeds, one a 1-by-8 and the other, eight individual cross points.

The ferrod sensor (see page 209 of *From Morris to Succasunna* in this issue) is the building block of all No. 1 ESS scanners. To conserve mounting space, a ferrod sensor contains two ferrods in tandem. Their "egg crate" apparatus mountings accommodate 128 dual units. The mounting is not only a physical support, but serves as an array of magnetic shields preventing interference between adjacent sensors.

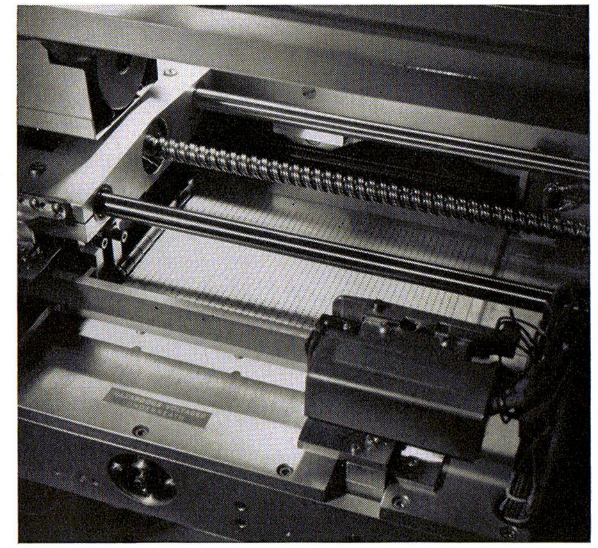
The operation of the program store twistor memory is described in *Memory Devices* in this issue. The 64 twistor planes of the memory module are mounted vertically in an aluminum and steel framework. Each plane is made of stable glass-bonded mica with solenoid tapes and twistor tapes cemented to each side. Resilient springs hold the memory cards in close contact with the twistor tapes.

To change information on a twistor card is a matter of magnetizing or demagnetizing its vicalloy magnets. This is done with a memory card writer. A complete complement of 128 cards is removed from a program store memory module with a card loader and transferred to the card writer. To permit safe handling of the card loader, both the program store and the card writer frames require a maintenance aisle at least four feet wide.

Since cards are stacked in the module back-to-back, and removed in this same position, two passes through the card writer are necessary when changing memory information. The first pass writes those 64 cards with magnets facing in one direction; the second pass writes the other 64 cards.

As the writing head passes over the length of a card it magnetizes initializing magnets, senses their location, and writes each bit of each word in passing. Because the initializing magnets are used for position sensing there are few critical mechanical tolerances in longitudinal card and head positions. After the writing pass, the card is automatically reinserted in the card loader.

The box-shaped card loader supports the cards in the same relative position they occupy in the memory module. When cards are removed from the module, they are engaged by pins on individual finger-like actuators whose pointed tips are inserted between pairs of cards in the wide spaces opposite the twistor planes. The actuators rotate in unison causing small transverse pins to enter openings in the cards as needed to extract the cards from the modules.



Card writer with a twistor memory card in position. Tops of other cards held in the card loader, can be seen just above the spiral shaft. The roller at the left holds the card writing head at a precise distance above the surfaces of the magnets.

The insertion force on each card is limited to between four and six pounds. Individual pre-tensioned springs control this force and an interlock stops the drive motor if the force exceeds the upper limit. This assures that all cards seat properly and protects the memory from damage if a card jams or sticks. Since all cards are inserted simultaneously, the loader's total seating force is 500 to 800 pounds.

These designs, along with the designs of much other equipment and apparatus were based on two decisions which had to be made simultaneously. First, circuit configurations were considered in terms of all the system functions and reduced to the fewest possible number. Second, many ways of packaging each device were studied and compatible designs were selected. On the basis of these decisions, the variables needed for a particular functional frame could be selected from a catalog containing a minimum of different apparatus and framework types. The goal throughout the development of No. 1 ESS was to achieve a modular design that would be most economical to engineer, manufacture, install, operate, maintain, and administer. The apparatus and equipment are a giant step forward in combining versatility and flexibility with standardization.

No. 1 ESS power plants are much simpler and more economical than those used in the Morris office. Succasunna, however, introduces an entirely new idea in its use of precision dial tones and call progress tones.

Power System and Ringing and Tone Plants

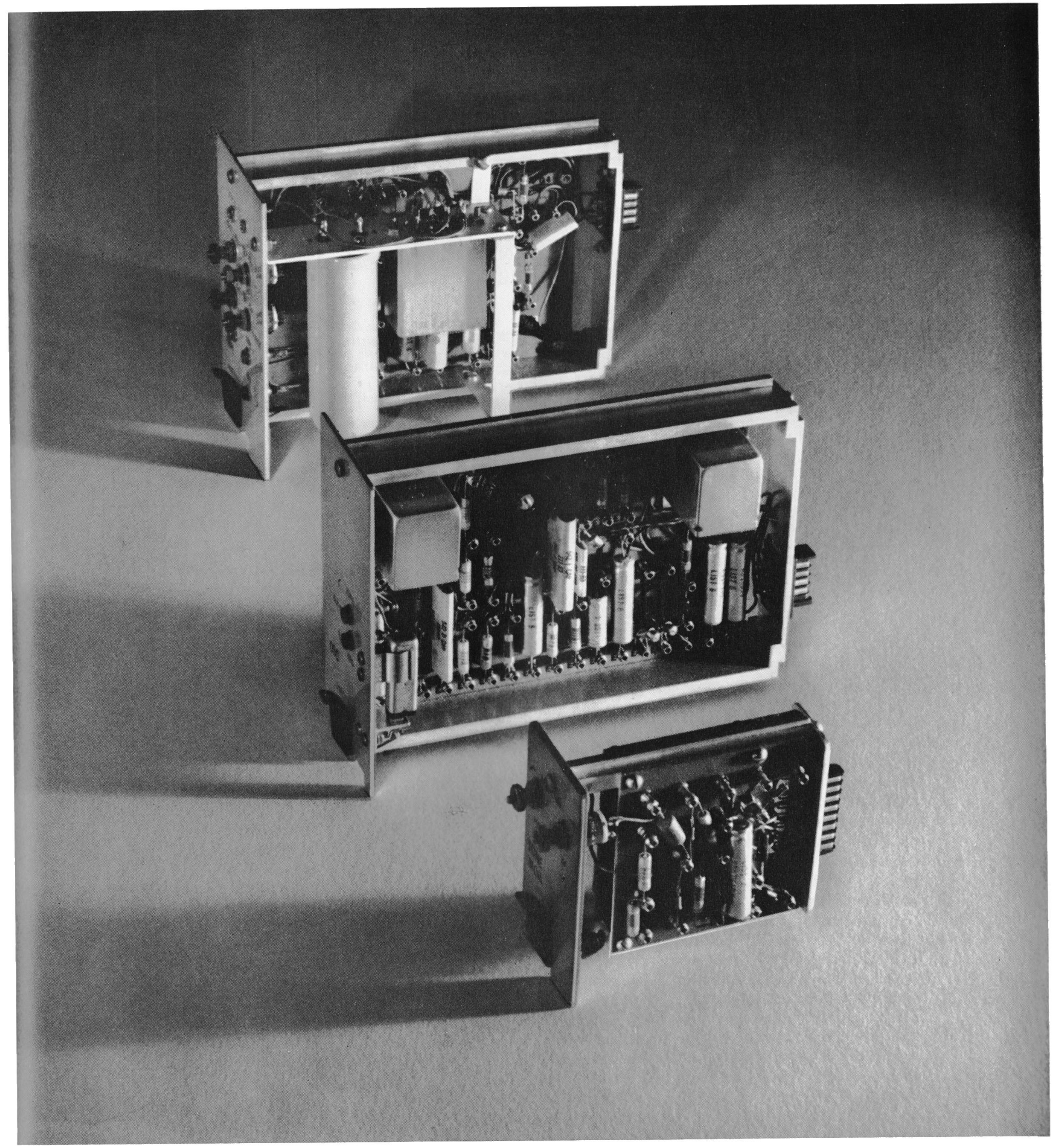
J. W. Osmun and J. R. Montana

In the four years between the trial of the electronic central office in Morris, Illinois and the opening of the first No. 1 ESS office at Succasunna, New Jersey the design of solid state devices took a giant step from a very promising art to a well rounded technology. The transition had a marked effect on the power supply plant and on the ringing and tone plant of No. 1 ESS. In the former it led to a greater simplicity and economy, in the latter to a new philosophy of precision dial tone and call progress tones.

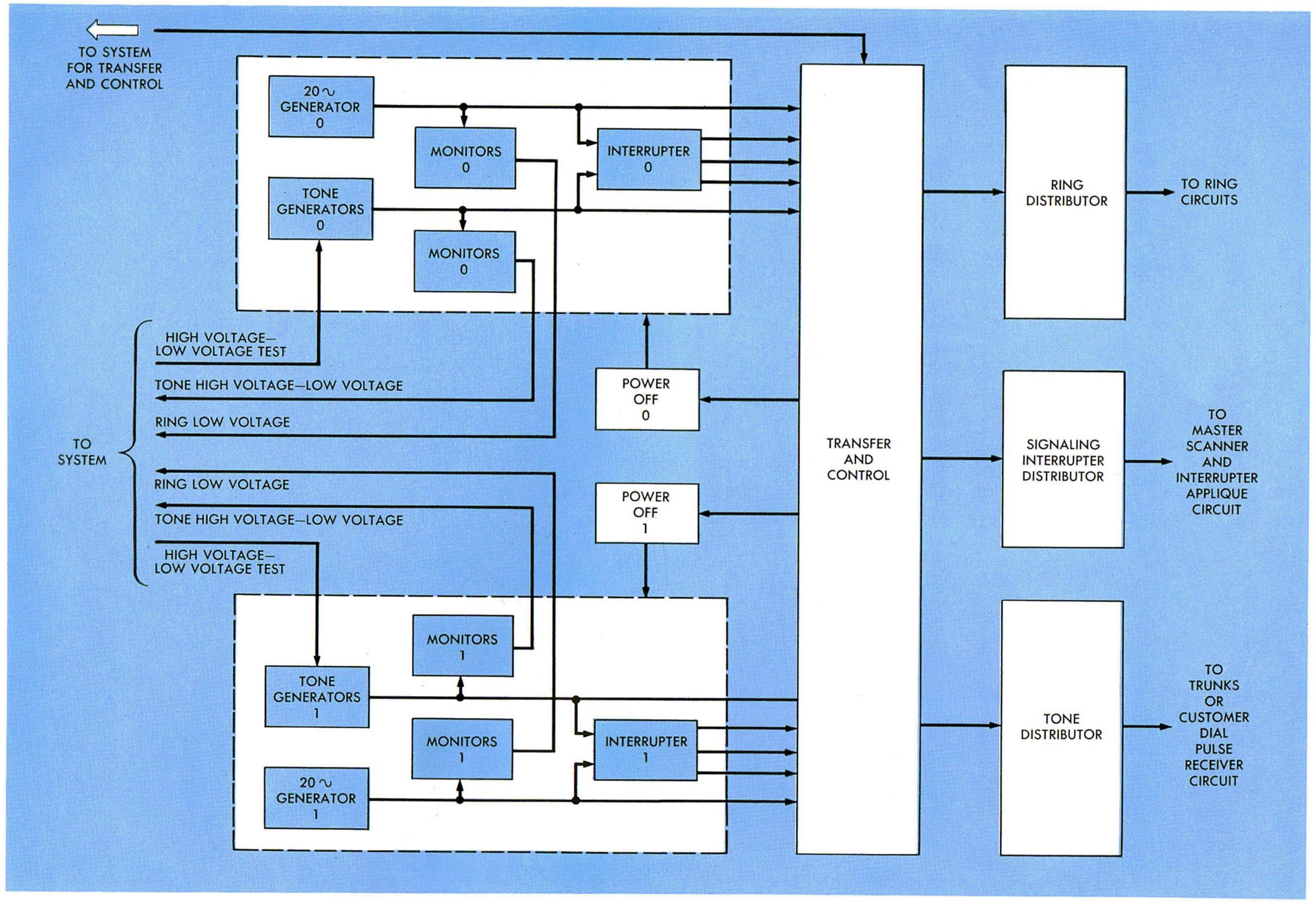
Refinements in the power supply plant were the result of changes in the electronic system rather than a matter of new concepts in the design of power systems. The Morris office used a great variety of devices—transistors, semiconductor diodes, gas tubes, electron beam tubes, relays. They required a total of about 80 separate and precise voltage levels. Furthermore, the gas tube switching network of that office could not switch 20-cycle ac ringing current, and so it was not compatible with existing customer telephone sets.

In Succasunna, on the other hand, gas tubes and electron tubes have been eliminated and the requirement for precise multilevel power has gone with them. In addition, the ferreed network was designed to transmit dc as well as voice frequency signals. These changes allow No. 1 ESS to operate within voltage limits that are even wider than those required in electro-mechanical systems. It is designed to use two voltage levels, +24 volts and −48 volts, and it can tolerate swings of approximately 10 per cent above or below either level. The power is supplied by two common battery power plants that are protected against commercial power failure by a standby engine alternator.

In its use of precision tones, No. 1 ESS is unique among telephone central offices. An office requires four fundamental tones — TOUCH-TONE® dial tone, audible ringing tone, high tone, and low tone. High tone is a single frequency,



Tone amplifier, tone oscillator, and tone monitor (top to bottom) of No. 1 ESS tone plants.



Block diagram of a typical No. 1 ESS ringing and tone plant.

the others are mixtures of two separate frequencies. The four component frequencies from which the mixtures are selected (see the table on page 249) are generated as pure sinusoidal signals in transistor oscillators and are added together and amplified by transistor feedback amplifiers. (The drawing on page 249 shows the waveforms generated by the amplifiers.) Each oscillator contains tuned reed selectors, much like those used in the BELLBOY signaling system, (RECORD, *September, 1964*), that select the basic frequencies within 0.5 percent. The actual output of the oscillators, a square wave, is converted by bandpass filters to a sine wave with a harmonic level 60 db down from the basic frequencies.

Audible ringing tone also is generated as a combination of two precision tones. In conventional central offices, audible tone is superimposed on inaudible 20-cycle ringing power and it is interrupted and distributed from the ringing plant. In these offices the two tones often are generated simultaneously. In No. 1 ESS, 20-cycle ringing is generated in one set of generators, and audible ringing is generated and interrupted in a separate set. Audible ringing tone is distributed within the office and applied to loop and trunk circuits through balanced 900-ohm office wiring in the same manner as all other tones.

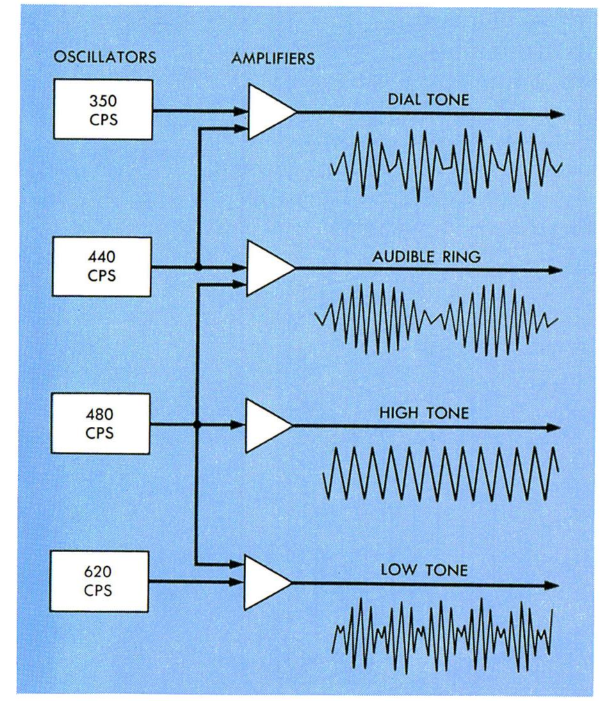
Continuous outputs from the generators and all outputs from the interrupters are fed to a transfer and control circuit which then directs the various tones to appropriate distribution circuits. Both continuous and interrupted ringing signals for ac-dc, and superimposed ringing are fed to these panels. All signaling interruptions —30, 60, and 120 interruptions per minute—are sent to the network via an applique circuit. All tones are routed from output transformers through splitting resistors to furnish a balanced output.

No. 1 ESS is the only system in operation with signaling plants designed on the philosophy of precision tones. The plants used in No. 1 ESS are not compatible with other systems. However, their expected performance makes it safe to consider ESS as a pioneer in a technique that will be adapted to other large switching systems. There are four primary advantages. First, in present switching systems, signaling techniques require rather wideband receivers at the distant termination of loops and trunks. No. 1 ESS signaling is received within a much narrower range than is possible in conventional systems. Second, low loss which is a vital factor in interoffice trunking gives rise to stringent return loss requirements. The No. 1 ESS signaling system easily meets them. Third, the precise nature of No. 1 ESS tones result in even less noise and crosstalk than occurs in conventional systems. Finally, the controlled harmonic content of the signals permits machine recognition of tones, a capability that may lead to new features. Apropos of this, the precision tones will not interact with other apparatus that is actuated by tones, such as TOUCH-TONE receivers. Each device functions only on an exact tone.

The drawing on page 248 shows the layout of a typical No. 1 ESS ringing and tone plant with its duplicate ringing generators, tone generators, and interruptors. Thus each office has essentially two plants, one always in operation the other in reserve. One plant is called the 0 side, the other is called the 1 side. The generators on both sides of the plant are supplied with power. However, to reduce gear and contact wear in the interrupters, only the working one is supplied with power. Although the program selects the generator that actually transmits signaling tones to the office, a manual switch can supersede this control if routine maintenance or an emergency requires a change from the working to the reserve side of the plant.

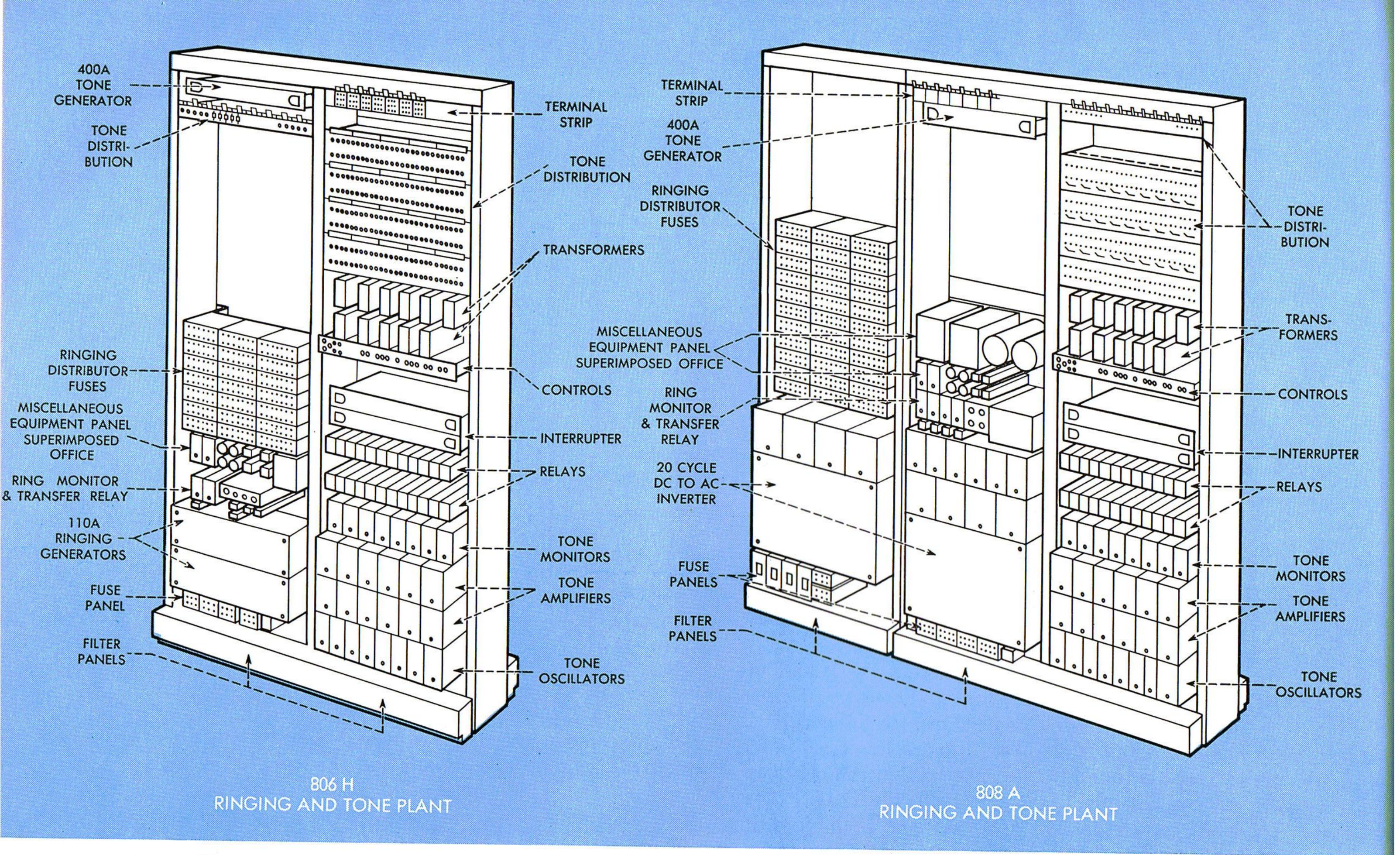
Readers of previous articles in this issue will recognize that the provision of duplicate plants stems from the No. 1 ESS requirements for reliability. They will also expect programed maintenance of the plants. Since precision tones require a precise voltage supply, the output of the working generators are monitored, and error signals are fed to the master scanner if the output level varies beyond acceptable limits. Thus the system is informed if a generator malfunctions and can order a switch to the reserve side of the plant. To check the operation of the monitors themselves, maintenance programs switch the tone generators from normal to high voltage or to low, and then check the monitors to see if they detect the change. Various outputs of the ringing generators also are monitored. Unlike the tone generators, however, ringing generators do not fail marginally. Therefore, to check the ringing generator monitors, the system merely shuts off power to the generators.

TONES	FREQUENCIES (cps)
TOUCH-TONE	350 + 440
Audible Ringing	440 + 480
High Tone	480
Low Tone	480 + 620
Line Busy Tone	Low Tone at 60 ipm
Paths ("fast") Busy Tone	Low Tone at 120 ipm



The four basic frequency components of No. 1 ESS ringing and tone signals and the waveforms generated by the transistor amplifiers when the basic frequencies are mixed to form the tones.

Two sizes of ringing and tone plants have been designed to accommodate small or large offices. A third, intermediate, size is underway for the future. At present, the 806H Plant, which has a ringing capacity of ½ ampere, is used for smaller offices like Succasunna. For large offices, there is the 808A Plant which has 6-ampere transistor generators. These large generators were recently designed to operate from −48 volt battery supply so that they will not be affected by any possible ac power failure. The intermediate sized plant will be rated at about 1.5 amperes. The tone generators are designed to supply the largest office and are the



Equipment arrangements of the small and large ringing and tone plants. The tone bay is the right panel in each framework, the ringing bay is the left panel. The empty areas in each plant are reserved for the additional ringing fuses and tone splitting resistance panels, added as an office grows.

same in all offices.

In the present plants, interrupters are motor-driven cam and spring machines. Special timing pulses transmitted from the plant to central control inform the system about the state of the machine ringing brushes so the system can select the proper brush and deliver "immediate ringing" to a called telephone. Code ringing is generated in the connecting ringing circuits.

Except for the small rotary interruptor, the ringing and tone plants are entirely solid state. In fact, to handle the larger currents that must be interrupted in large offices, solid state devices are used as interrupter followers in the ringing part of 808A Plant. Fully solid state interrupters are planned for use in future No. 1 ESS offices. A feature of these interrupters is all-transistor timing circuits that are synchronized with the 20 cps signal. All the interrupting switches also will be solid state devices.

As the drawings on this page show, much of the equipment in the ringing and tone plants is panel mounted on standard No. 1 ESS frameworks. The extensive use of solid state devices lends itself to the plug-in module type of construction for most of the circuits, and this results in a very efficient use of space on the frames and convenience in maintenance. Unlike electro-mechanical systems which require ringing distribution fuse panels and tone distribution panels in many parts of the office, No. 1 ESS ringing and tone distribution is confined to the ringing plant itself. The equipment is arranged on the framework in a way that allows additional circuits to be added quite simply.

The power, ringing, and tone plants were designed to meet the complex requirements of an electronic switching system. In general, they meet them economically. Solid state circuits have the high reliability and easy maintenance that generally accompanies this design technology. In step with other major subsystems of No. 1 ESS, the ringing and tone plant presents a new philosophy of telephone system design with the traditional reliability that is always demanded of a telephone switching system.

Concentration of control into one central processor and the complexity and speed of No. 1 ESS circuits make new demands on maintainability and dependability. The system must detect and recover from troubles almost instantaneously and must do much of its own trouble analysis.

A New Approach To System Maintenance

R. L. Campbell & W. Thomis

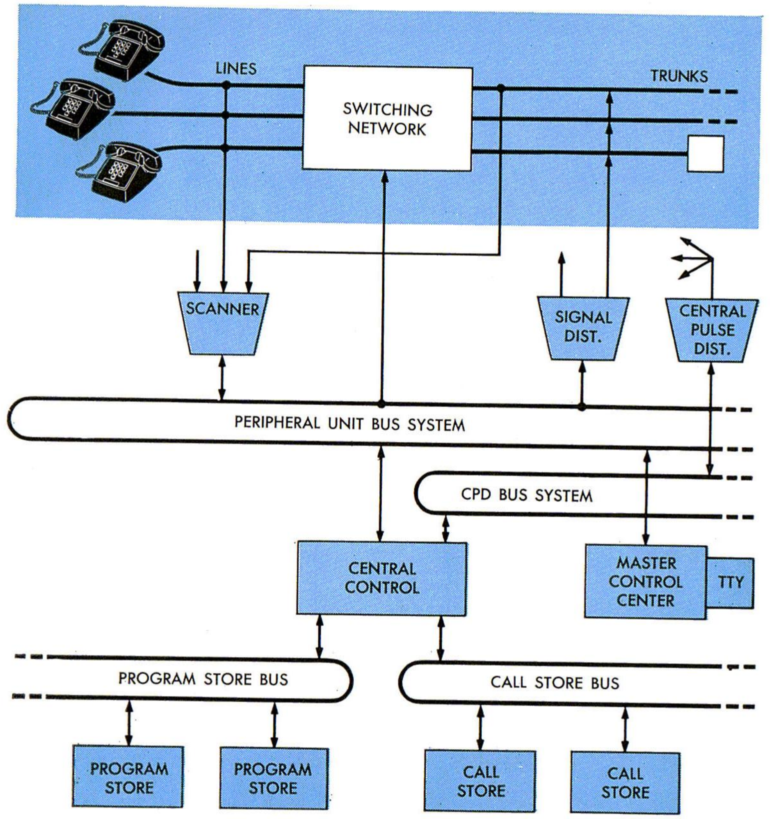
A BASIC PREMISE in the philosophy of maintenance for No. 1 ESS is that the machine itself can and should locate faulty components almost automatically. This singular idea emphasizes the power of stored program control—the program is the major instrument of maintenance. But, though it is a new departure in telephone switching systems, programmed maintenance is only one of many factors making the maintenance scheme of No. 1 ESS unique in telephone systems. Another significant consideration is the intense concentration of system control into one central control unit.

In a No. 5 crossbar office, control is concentrated in the marker, but a large office may have many markers. If one, or a number, stop operating, calls are directed to the remaining ones and, from a customer's point of view at least, the office still gives largely satisfactory service. But in a No. 1 ESS office, control is concentrated in one of only two central controls. If one fails, it must be repaired immediately, for if the duplicate unit also fails, no calls can be processed. Thus the road to dependability in No. 1 ESS runs through relatively new terrain.

Like any telephone system, No. 1 ESS must be dependable, servicing telephone calls continuously and accurately even in the face of trouble. And it must be maintainable. This means that the system must be designed so that faulty components can be located and replaced rapidly and economically.

Reliable components are essential to dependability. No. 1 ESS semiconductors are all silicon devices, unqualifiedly more reliable than the germanium devices of the Morris trial. Epitaxial processing techniques, invented at Bell Laboratories, also add to their life. Furthermore, the magnetic materials fundamental to many devices are processed with careful control to produce high stability. These measures, described in other articles in this issue (See *Semiconductors* and *Some Magnetic Materials*) produce only a tolerable *rate* of failures, however. The vast number of components in No. 1 ESS (hundreds of thousands of semiconductors, for instance) average about one failure every few days. The system maintenance plan must cope with these component failures so the system continues to give accurate, uninterrupted telephone service despite the trouble.

A basic element of the maintenance plan for No. 1 ESS, is the duplication of all major subsystems. If one fails, its twin takes over. In essence,



To process any call in No. 1 ESS, a chain of units must be operating properly. The links in the chain are units drawn from various subsystem communities. Each subsystem community is a duplicate of the others—the central control community consists of two units, the program store community of two to six units, etc. A failure in any one link in the chain temporarily interrupts system operation. Interruptions, when they occur, are very short; the system can switch between duplicate units within subsystem communities in a period about equal to only one machine cycle.

this creates the possibility of many systems, or rather of one system with a multiplicity of possible arrangements. If a subsystem fails, the system reorganizes itself around the duplicate and continues to process calls.

Special maintenance programs and circuits direct this reorganization or "recovery." Subsystems are grouped according to type (e.g. central control, call store) and each group is called a subsystem community. (See the drawing on this page.) Generally speaking, a special recovery program governs each community. If a failure disrupts the community, the program surveys it, determines which subsystems are operable, and interconnects them to provide a functionally complete community.

Recovery programs must fulfill some rigorous requirements. First, because even a single trouble may interfere extensively with normal, often basic, machine operations, the recovery programs must be highly flexible in their use of equipment. (The programs are complemented by special backup switching circuitry so that the recovery process never relies exclusively upon any particular item of equipment.) Second, these programs must decide unerringly which subsystems are operable even when there are multiple troubles or inconsistent or contradictory indications of trouble. And they must do this in a matter of milliseconds or risk undermining the accuracy of call processing. During recovery, all call programs are suspended. However, some, such as dial pulse scanning programs, which are scheduled every few milliseconds, cannot be deferred or calls will go astray. (See *The Stored Program* in this issue.) Therefore, recovery programs must accomplish their mission between two clicks of a telephone dial, so to speak.

Accuracy depends largely on the system's ability to detect the *presence* of any trouble before it can interrupt service to telephone customers. Several trouble detection techniques are employed in the system.

- Duplicate equipment operates in parallel. Both central controls, for instance, receive all data on all calls in the system, although only one directs the actual connections. Key points in each are matched to see if the two are operating identically.
- Special checking circuits are built into subsystems to detect operating anomalies.
- Information between subsystems is redundantly encoded and special circuitry checks the consistency of received information. This allows detection of errors in transmission as well as troubles in the sending unit.
- Subsystem equipment that is infrequently used in the normal business of the system is routinely exercised at regular intervals to check its condition.
- Call programs are designed to recognize incorrect or invalid system responses to call processing operations and report them.

The first three of these techniques use maintenance circuits to detect troubles; the others use the programs' trouble-detecting capabilities. If the circuits detect trouble, they create a high-level interrupt and pass control to the recovery programs which then isolate the trouble. If programs encounter trouble indications, they call in recovery programs immediately.

All these features have one end in view—dependability; and No. 1 ESS is expected to set a new standard of dependability for large electronic systems. This, however, is only half the battle. The rest, maintainability, is fought by "trouble qualification" and "diagnostic" programs.

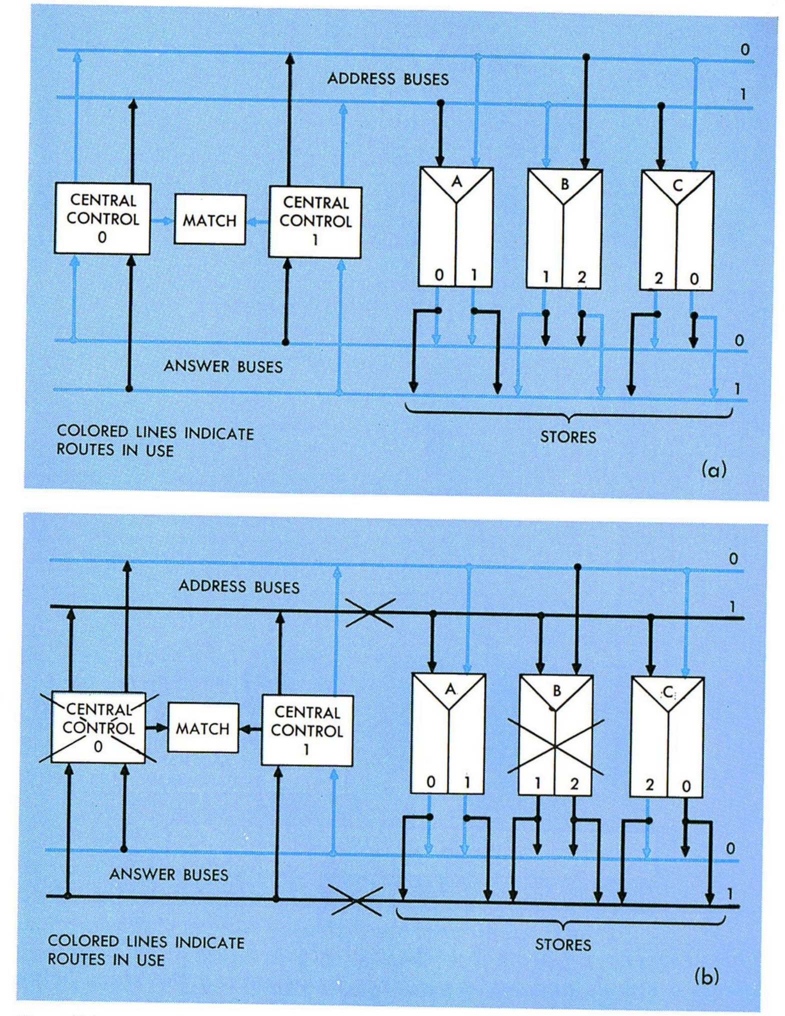
Conceptually, trouble qualification programs begin where recovery programs end. (Actually, the two often overlap.) These programs survey a stricken community, identify and isolate faulty subsystems, and restore to service subsystems that the recovery programs may have temporarily quarantined. If the recovery program has determined that the trouble will not interfere with normal call processing, trouble qualification may be done in the system's "spare" (excess) time. Or, as an alternative, trouble qualification may be done during recovery. (This is the point at which the two often overlap.) Most No. 1 ESS subsystems may be treated either way depending on the nature of the trouble and the prevailing conditions when it is detected.

Some component failures create erratic or nonreproducible trouble symptoms which the trouble qualification programs tend to classify as transient errors. In this case, the programs may certify faulty equipment as trouble-free and return it to service. Too many misinterpretations of this sort could lead to disaster. Therefore, the trouble qualification programs are designed to recognize excessive "transient errors" and to identify and isolate the subsystem they emanate from.

Diagnostic programs are quite specific, each designed to analyze troubles in a particular subsystem. They test the subsystem exhaustively, process the results, and identify the fault by a trouble number. The system teletypewriter prints out the number and maintenance personnel merely look it up in a "fault dictionary" which directs them to the physical location of the faulty plug-in circuit package. Since almost all No. 1 ESS circuits are mounted on plug-in packages, repair generally consists of replacing one or two packages.

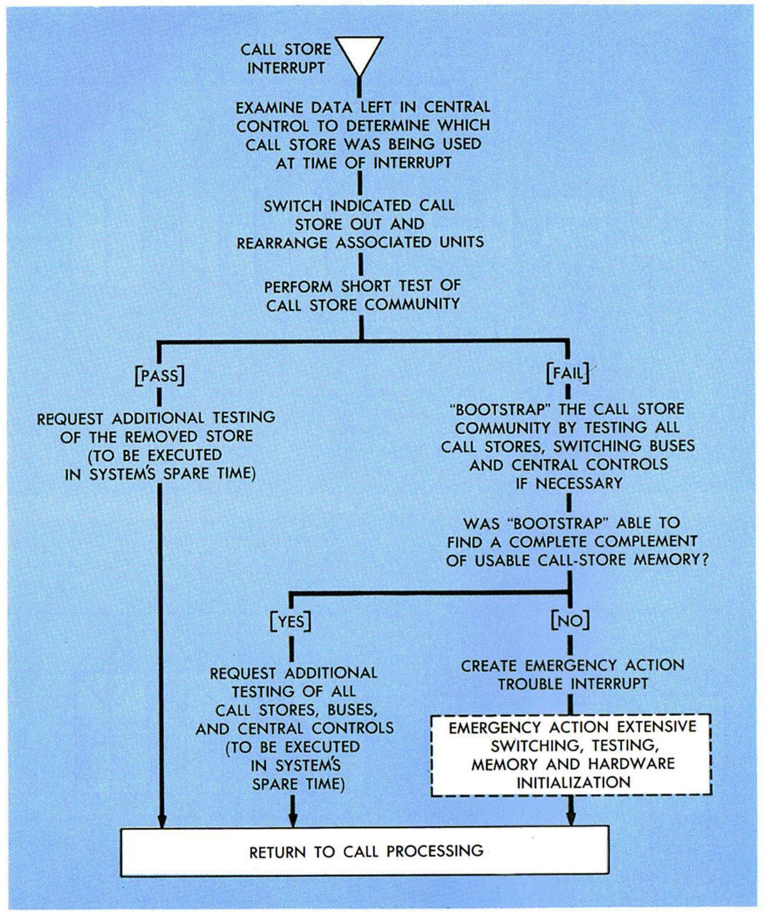
In brief, then, a cycle of maintenance begins with the detection of a trouble, and proceeds through qualification and diagnosis to correction or repair. This is the general procedure in all the subsystem communities of No. 1 ESS. However, certain communities lend themselves particularly well to a discussion of a specific phase of the cycle. The program store community is a good example of the use of trouble detection facilities. The call store community furnishes a clear picture of recovery and trouble qualification techniques. And the central control, with its thousands of circuit packages, strikingly emphasizes the advantage of automatic diagnostics. Accordingly, we will discuss each phase of the maintenance cycle in terms of those particular subsystem communities.

Trouble detection circuits serving the program store must detect the existence of a trouble before it affects call processing. This is tantamount to detecting many store troubles almost at their inception. For example, some troubles can change data read out of the program store into an irrational instruction. If central control were to act upon the garbled information, it could conceivably interrupt service on all calls in the office. To prevent such a catastrophe, almost all the trouble detection techniques we have outlined are applied to the program store community.



Possible routes between the three program stores and the central controls of a system via the buses. Blue lines are the actual connections, black lines are possible routes not being used. At the top is a normal configuration with address and readout routing. Each central control uses different routes to a store. An operating configuration can always be established as long as one copy of all the information in the stores is available along with one bus and one central control. For example, if central control 0, store B and bus 1, stopped operating (crossed-out units on bottom drawing) an operating system would be possible in a new system configuration involving central control 1, stores A and C, and bus 0.

First, there is considerable duplication of equipment. Specifically, all the information in the program store is duplicated and the duplicate stores are individually connected to the central control by duplicate communication buses, creating two separate but parallel equipment loops. (See the



The recovery program for the call store community generally effects a simple and rapid recovery by removing the store being used at the time of an interrupt from service. A small percentage of troubles require considerable testing of equipment. But, re-initialization of the memory and hardware (i.e. returning them to an initial processing state) is required only in very rare cases.

drawings on page 253.) Second, there are special trouble detection circuits. Each store internally checks itself in a number of ways every time it fetches information for central control. If the results of the checks are all affirmative, the store generates an "All Seems Well" (ASW) pulse along with the read out information. Special central control maintenance circuits initiate a reread if the pulse is missing, and order a trouble interrupt if the second reading also lacks the ASW pulse.

A third specific trouble detection mechanism is redundant coding of the information transmitted between the stores and the central control. Each word in the program store contains seven check bits in a Hamming code designed so that central control can detect and correct any single error in a data word or detect any single or double error in the program word and its memory address. If there is an error in the address or if there is a double error in the word, central control rereads the memory. A single error in the program word is acceptable in the second reading. Anything else causes a trouble interrupt.

These specific trouble detection mechanisms are backed-up by the central control matching feature. Certain troubles may escape detection by the store check circuits or the central control Hamming check circuit. In this event, there will be differences in the data read from two program stores (assuming only one is faulty) producing a central control mismatch which, in turn, generates a trouble interrupt.

Some program store troubles do not hinder the normal operation of the store. For example, a store may always send an ASW pulse no matter what the internal checks show. Troubles of this nature are detected by routine tests which are scheduled frequently enough so that there is only a negligible chance that two or more faults will occur in a store between tests.

Many of the trouble detection circuits in the call store community are similar to those associated with the program store. Troubles in the call store immediately create a system interrupt and the call store recovery program takes control. (See the drawing at left.)

Because the call store memory itself cannot be used, the program starts by analyzing certain clues left in central control, including the address at which trouble was detected and summary information on the nature of the trouble. On the basis of these clues, the recovery program determines which call store caused the interrupt, removes it from service, and switches-in the neighboring stores as temporary memory for both central controls. It then cursorily tests the reorganized memory and, if it passes, ends the interrupt. Recovery completed, the system returns to call processing.

The large majority of call store trouble interrupts are caused by straightforward faults which can be rapidly and accurately handled by this approach. Some troubles, however, are less tractable. For example, a fault in the bus rather than in the call store causes failure of the final, cursory, test. The recovery program then initiates exhaustive testing to find enough operable units for the necessary complement of call-store memory. This could involve switching of call stores, buses, and central controls. If even this extensive switching and testing fails to establish a workable organization of units, the program starts an Emergency Action trouble interrupt. Recovery at this stage may involve switching and testing all types of system equipment. However, such emergencies are rare events with the highly reliable components of No. 1 ESS.

After the "new" or reconfigured system begins service, a trouble qualification program is called in to identify all the faulty subsystems in the affected call store community. This program is sandwiched in between call processing programs whenever it will not interfere with the urgent business of processing telephone calls. In general, it has two possible courses.

- *If the system reorganized itself along a normal, rapid recovery path* the qualification program conducts a test which determines whether the root of the trouble is an actual fault or a transient error. An actual fault is handled by diagnostic programs. A transient error leads to the examination of error records, and possibly additional qualification procedures.
- *If the system reorganized itself along an unusual recovery path* the qualification program tests all call stores, both buses, and all the central control equipment associated with them. The results of these tests identify the faulty units. Diagnostic programs, executed later, actually pinpoint the fault.

Thus the recovery programs are designed to rapidly recover the system's call processing ability while the qualification programs may work at greater leisure to identify faulty units.

Diagnostic programs perform exhaustive tests on a subsystem, attempting to isolate any single fault to within one or two circuit packages. Central control, which abounds in these packages, relies strongly on automatic diagnostic techniques. Because the recovery programs can identify a faulty central control and force it into standby status, the active central control can be used to test the standby. The complete duplication of the two, their synchronized operation, and the match circuits that directly compare twin points all enter into this testing.

Diagnostic testing consists of asking the machine a series of questions with known responses. A wrong answer indicates a group of possible troubles and the intersection of all groups uncovered by the diagnosis is the actual trouble spot. The questions, of course, are asked in binary language. The answers are simple binary zeroes or ones. For example, a question might be: Can this flip-flop be set? The answer is yes or no—zero or one. The output of a diagnosis is a long string of bits, and ideally each possible fault produces a unique pattern of bits.

Diagnostic tests proceed sequentially through different areas of central control hardware. Each test is run simultaneously on both machines and twin critical points in each are compared via the match circuits. A match means success; a mismatch, failure. The sequence of tests begins with the power and clock circuits and may run through 28 areas of central control. In general, if a test uncovers a failure in a specific area, the diagnosis is terminated.

The final phase in the maintenance cycle—repair—begins with the interpretation of the diagnostic program output. The machine itself takes the first step. A diagnostic output is generally a huge binary number, quite difficult to work with. (The central control diagnostic result, for example, contains 5000 bits.) Therefore, the system processes this result and presents the craftsman with a small decimal number. This can be done because the binary result actually contains a relatively small amount of information compared to what could be contained in a 5000 bit code.

A trouble locating manual is the craftsman's primary tool for translating diagnostic printouts into specific trouble identifications. Data for this manual was produced on the No. 1 ESS system at the Holmdel Laboratory by deliberately inserting every possible type of catastrophic trouble into the machine, one trouble at a time, and recording the diagnostic results. The results were reduced to decimal numbers, sorted, and printed in a dictionary-like format together with their associated faulty identification.

The craftsman translates a diagnostic result into a specific trouble identity by matching the trouble number with a number in the manual. The entry gives him instructions on repairing the trouble. Usually, repair consists of replacing a circuit package.

After he has completed the repair, the craftsman checks to see that it actually has cleared the trouble by requesting, via the teletypewriter, a rerun of the diagnosis. If it passes, the repair is affirmed. If it fails, other techniques must be employed. However, the procedure should suffice for the vast majority of faults.

The maintenance plan described in this article has a two-fold aim. First, it should achieve for No. 1 ESS a service life of decades with a total downtime (i.e. periods during which the whole system is inoperative) of less than an hour. Second, it should allow the system to handle thousands of calls between errors. These are rigorous demands. If they are achieved, No. 1 ESS will be among the most reliable digital machines ever built.

The development of No. 1 ESS cut across many areas of science and engineering. Metallurgists at Bell Laboratories developed a completely new alloy for the ferreed switch and processed old alloys used in the twistor memory to dimensional tolerances that were unheard of a few years ago.

Some Magnetic Materials

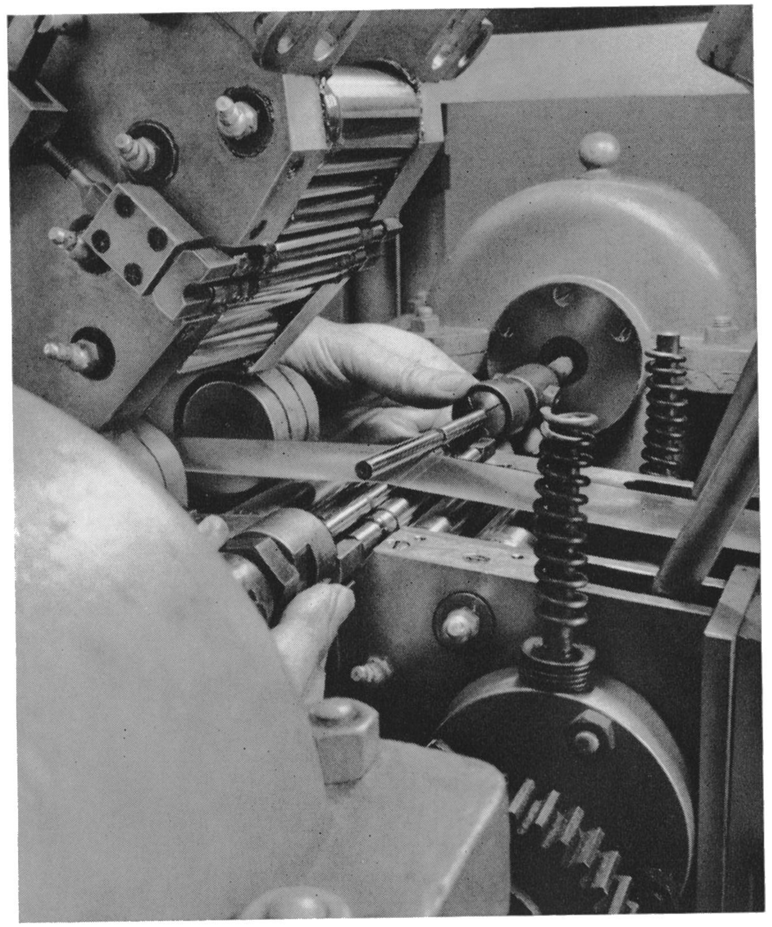
D. H. Wenny

THE FAMILIAR PASTIME of coining names to characterize an era has produced, for our own times, such sobriquets as The Atomic Age, The Space Age, and The Electronics Age. It could with equal justification be called The Age of Materials. Neither the atom bomb, nor missiles and spacecraft, nor the transistor would have been possible without new materials or a far more complete and precise knowledge of the properties of known ones than had existed previously. New materials and new uses for old ones are the subject of a lively, continuous search, and are among the truly characteristic products of our age.

A strong theoretical base is one significant mark of this trend. Far from the Edisonian method of trying thousands of materials for a job until one is found that works, the contemporary course is first to study the physical phenomena of existing materials. Frequently, this establishes a better understanding of the relationship between the structure and the properties of materials. That understanding may lead, over many paths, to the development of new materials with new properties.

Often, studies may reveal unsuspected properties that make a metal well suited to use in new technologies. Or they may show that it can be worked in a way that alters its properties to adapt them to a desired end. Again, a number of metals with known properties may be combined into an alloy with new properties that uniquely serve a special application. On the one hand, then, research into materials is stimulated by a basic scientific interest. On the other, there is a very practical concern stemming from a pressing need to meet requirements of new technologies.

A unique system, No. 1 ESS demands unique characteristics of the metals that govern many of its functions. Impure magnetic materials in the memory devices, for example, could have a disastrous effect on the system's reliability. Unstable magnetic material in the crosspoints of the ferreed switch could degrade the quality of the voice paths. To a large extent, the accuracy with which No. 1 ESS processes telephone calls is a direct reflection of the quality and performance of the materials in its millions of individual parts. This article will discuss three of those materials. Taken together, they illustrate the re-



The laboratory rolling mill used to produce experimental strips of vicalloy foil for the bar magnets of the twistor memory cards.

search into the properties of metals and the new techniques in metallurgy that Bell Laboratories called upon during the design of the system.

The first material, Molybdenum Permalloy, is an old alloy known for its high permeability and low coercive force. These properties have led to its extensive use in communication system apparatus. But these are normally "soft" magnetic properties. To adapt permalloy for use as the twistor tape of the program store memory (see *Memory Devices* in this issue), they had to be converted, so to speak, to permanent magnet properties. The conversion was affected by new processing techniques first worked out in the laboratory and subsequently translated to large scale production methods.

The second material, Vicalloy, is a contrasting variation on the same theme. It is also an old alloy, but its magnetic properties made it an eminent candidate for the tiny bar magnets of the twistor memory card. However, for that purpose it had to be rolled into extremely thin sheet and put through a continuous strand heat treatment to develop the desired permanent magnetic characteristics. This combination of processing steps, which had never been tried on long lengths of thin vicalloy sheet, is the primary factor in controlling the magnetic properties. The problem, then, was to develop a reliable rolling and heat treating procedure that could be scaled up to produce thousands of feet of thin permanent magnet sheet with precise control of the basic structure of the alloy and, in turn, its magnetic characteristics.

The third material is Remendur, the latest addition to the family of cobalt-iron-vanadium alloys developed at Bell Laboratories that have had so many uses in communications apparatus. Remendur was developed at Bell Laboratories specifically to fill the need for a temperature stable isotropic magnetic material for the ferreed switch. It has been highly successful in the switch and will be produced in large quantities for this application alone. However, its unique properties may be well suited to many other jobs.

Molybdenum Permalloy

Molybdenum Permalloy has had many uses in the past thirty years. Its fabrication is a rather lengthy process that includes melting, casting, rolling, drawing, and forming the bulk alloy into the shape required for specific applications. No matter what the final form, however, one step is always taken to remove the mechanical strains resulting from the many preparatory stages: The material is annealed at 1050 degrees Centigrade for an hour or more after it is fabricated. In its fully annealed, strain-free state, Molybdenum Permalloy has a low coercive force of 0.03 oersteds or less and a high initial permeability of at least 20,000.

Permalloy's magnetic characteristics for the 0.3 mil by 4 mil twistor tape (a mil is a thousandth of an inch) are shaped to the needs of a coincident current memory device. This means that the values of the magnetic parameters of the Molybdenum Permalloy are rather sharply changed from those in the familiar form of the alloy. For instance, to permit precise discrimination of the coincident currents, the minimum squareness ratio required for the hysteresis loop is 0.7. Also, to ensure that the tape will deliver a suitable output pulse when it is switched, it must have a fairly high residual induction. The residual induction of twistor tape is greater than 5000 gauss. Finally, to stabilize the residual flux and establish a minimum drive for switching from one remanent state to the other, the coercive force of the twistor is 3.5 oersteds—approximately 100 times its normal value in annealed Molybdenum Permalloy.

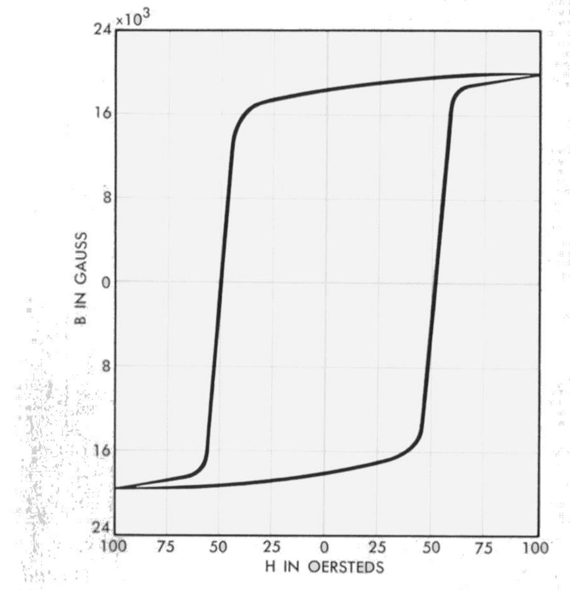
A uniform hysteresis loop and a constant value of coercive force are required over the full length of the twistor tape after it is processed from the rough alloy. This, in fact, is the major metallurgical problem and the greatest deterrent to its successful solution is the variable mechanical strain on the wire during processing operations. For one thing, to reduce the eddy current losses associated with the reversal of magnetization, the alloy is prepared as a flat wire. Flattening reduces some strains and makes it easier to wrap the twistor tape on the copper conductor. In its final form the material is an incredibly thin tape with a cross sectional area less than two millionths of a square inch. A one pound bar of the alloy, a foot long and five eighths of an inch in diameter, is transformed into a ribbon 38 miles long. Obviously, this requires considerable processing.

After the alloy is melted and cast, fabrication begins. The first step is to reduce the alloy to a rod one quarter of an inch in diameter. In laboratory processing, this is done by hot swaging. In larger scale production, by hot rolling. The swaged or rolled rod is coiled and then descaled, annealed, and coated to prepare it for wire drawing. This is done in stages. Tungsten carbide dies are used for the first stages of reduction on the relatively large diameter wire. In the next stage, this wire is processed to a much finer gage. This is done with the diamond dies of multiple die wire-drawing machines. More than 85 dies are required to complete the drawing. Each one brings the wire to a finer, and ever finer, gage.

From time to time the drawing is interrupted and the wire is annealed in a furnace with a protective atmosphere to soften it for further reduction. Since this processing governs the metallic structure of the final product, and because of the inescapable requirement for magnetic and physical uniformity in the wire, every step is rigorously controlled. This process has been highly successful because it draws on fundamental studies in metallurgy conducted at Bell Laboratories in recent years that have established a close correlation between the structure and the magnetic characteristics of the Permalloy ribbon.

Vicalloy

Vicalloy, the next material, was developed at Bell Laboratories over 25 years ago. It was fabricated as a narrow tape and used as the recording medium for weather and time announcements in Bell System Mirrophones. The name Vicalloy is actually an acronym for a 10 per cent *v*anadium, 38 per cent *i*ron, and 52 per cent *c*obalt *alloy*. It is a malleable alloy that can be rolled to thin gages, and then heat treated to induce a range of permanent magnet properties. In practice, however, the heat treatment is quite critical and tends to make the alloy hard and brittle.

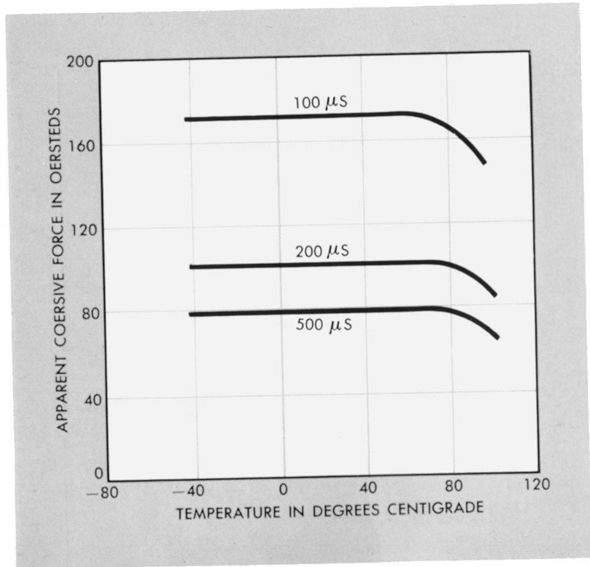


A typical dc hysteresis loop of Remendur composition developed for the series ferreed. The squareness ratio is 0.9. Illustrating the isotropic qualities of the alloy, this loop was measured at 90 degrees to the rolling direction of the processed strip.

As a narrow recording tape for Mirrophones, Vicalloy was processed to wire, flattened, and heat treated. Its magnetic properties seemed to be tailor made for the bar magnets of the twistor memory card. But to be compatible with the procedures in fabricating the cards, the Vicalloy had to be rolled and heat treated in long lengths of thin (1 mil) sheet, six inches wide. The danger was that the material would become so hard and brittle during the continuous strand type of heat treatment, that it would not be able to take all the subsequent handling required in fabricating twistor cards.

Heat treatment was also used on the Vicalloy for Mirrophones, but in that application the tape had a small, narrow cross-section of 2 mils by 50 mils, in 500 foot lengths. Rolling and heat treating proved to be a completely adequate, trouble-free way to produce magnetically uniform small sections with a perfect surface. For the twistor memory card, the strip must be 120 times wider and only half as thick.

Little in the tiny magnet on the memory card suggests its beginnings in a massive and rugged ingot. The magnets are a mere 1 mil by 35 mils by



A graph of coercive force versus temperature in the Remendur developed for the parallel ferreed. Measurements are at three different pulse lengths.

35 mils, and they must be located precisely on the aluminum card. The first stage in processing is to convert the ingot into a long thin sheet 6 inches wide. This involves a long and intricate hot and cold rolling procedure followed by a continuous strand heat treatment. The heat treated strip is cut to proper lengths for cementing to the aluminum card and a photoresist process is applied to etch away all the Vicalloy except the array of magnets.

Uniform etching is essential and it imposes stringent physical requirements on the strip. It must be absolutely uniform in thickness, perfectly flat, untarnished, and free of any kind of surface blemishes. Magnetically, there is the by-now familiar requirement, it must be magnetically uniform over its entire length and cross section. The process would have been difficult to work out for any material in terms of these requirements, but it was particularly difficult for an alloy so hard mechanically that it required special processing. The procedure we have described was first worked out on a small scale at Bell Laboratories, but it was continued successfully when it was translated to large scale production.

Remendur

Remendur, the subject of the remainder of this article, is another vanadium, iron, cobalt alloy. In recent years, the magnetic properties of these alloys have been found to be exceptionally well suited to many functions of communication systems equipment. Remendur was developed to replace the ferrite which proved to be too temperature sensitive for the original ferreed switch. To meet the development schedule of No. 1 ESS, the new alloy was developed in less than 15 months. It started with the pouring of the first experimental 3-pound melt, and ended with the solution of the problems involved in translating laboratory methods to commercial melting and processing procedures for tons of material.

The name, Remendur, reflects the alloy's most significant magnetic characteristic—a remanence greater than 17,000 gauss. Its other properties can be varied for specific functions and include coercive forces ranging from 1 to 60 oersteds, residual inductions up to 20,000 gauss, and hysteresis loops with various ratios of squareness. Thus it bridges the gap between the high coercive force, low permeability characteristics of Vicalloy, and the low coercive force, high permeability properties of such alloys as 2 V-Permendur and Supermendur (RECORD, *April, 1960*).

Varying the values of the magnetic characteristics in Remendur, is a matter of varying the composition of its component metals. Nominally, the composition is 3.5 per cent vanadium, 48 per cent iron, an equal amount of cobalt, and 0.5 per cent manganese. Vanadium is the key to the coercive force—the more vanadium, the greater the potential coercive force. For any composition of the alloy—it has several—the content of vanadium is calculated as approximately one-tenth the desired coercive force, and iron and cobalt are balanced equally. In most compositions the content of vanadium ranges from 2 per cent to 5 per cent, and the iron and cobalt each make up 50 per cent of the remainder.

Controlled processing also can be employed to vary the magnetic characteristics of Remendur. Adjustments in the coecive force can be made by varying certain steps in the processing and heat treatment. The highly significant characteristic, the square hysteresis loop, is a function of the processing procedure and can be obtained on material in the form of rod, sheet, or round and flat wire. Compositions that contain up to 3.6 per cent vanadium become magnetically isotropic after they are cold rolled to a strip and heated for about two hours at 600 degrees Centigrade. This has important implications which will be discussed shortly.

Remendur begins as electrolytic cobalt, Armco or electrolytic iron, pure vanadium, and 90 per cent or 50 percent ferrovanadium. At Bell Laboratories, the alloy has been made by melting and casting these raw materials in air, in a vacuum, or in controlled atmosphere coreless induction furnaces. Consumable electrode arc melting furnaces also have been used successfully to make large quantities of Remendur. Cast ingots have been hot-worked to one-eighth of an inch in thickness through steps of rolling, forging, extrusion, and swaging. Normally, the alloy is cold worked to thin gages after a drastic quench in ice brine from 925 degrees Centigrade.

The isotropic characteristics of Remendur persist through the processing and permit a freedom in design that is rare in workable permanent magnet alloys. With most alloys, the optimum magnetic quality is obtained only if it is measured in the direction of the rolling operation. Remendur parts can be punched or cut from the strip in any direction and still retain good magnetic quality. This solves what would otherwise be an exceptionally difficult problem in producing a "C"-shaped sleeve magnet which is formed by bending the strip. Cold reduced strip is more amenable to bending across the rolling direction than parallel to it. Moreover, high coercive forces and the rectangularity of the hysteresis loop would suffer if the strip were annealed to facilitate bending.

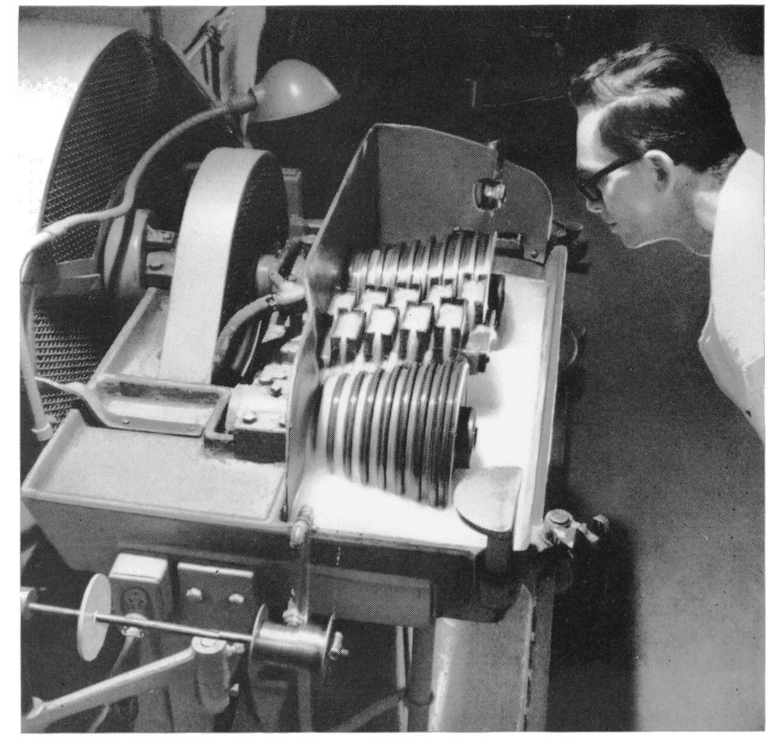
Though Remendur is mechanically quite hard, it has a persistent malleability and ductility. It has been rolled to sheets or foil as thin as 0.2 mil, and drawn to wires as fine as 1 mil in diameter. Wires have been flattened to ribbons 0.5 mil to 8 mils thick and 5 mils to 65 mils wide. In its first practical application, Remendur supplanted the ferrite posts in the parallel ferreed (the first design). It was worked into wires, ribbons, and rods. The different methods of processing imposed different strains on the alloy, but all its magnetic properties remained intact throughout the processing.

The series ferreed (RECORD, *February 1964*) which superseded the parallel ferreed, used the "C"-shaped sleeve magnets made from the isotropic strips discussed above. Experimental strips with these qualities were made at Bell Laboratories from a 3.5 pound melt and processed on small, slow-speed laboratory equipment into strips 1 mil to 12 mils thick. The laboratory procedures were then translated to commercial production on a thousand-pound melt. Despite the obvious contrast between small-scale laboratory operations and a production plant, the process worked perfectly to produce sleeve magnets to rigorous design specifications. The drawings on page 259 and 260 give some indication of the magnetic properties that were obtained.

A bipolar ferreed is used as a cutoff device between the switching network and the line scanners in No. 1 ESS. It contains a Remendur rod, actually a bar magnet, with a coercive force of 48 ± 5 oersteds, a minimum remanent flux of 16,500 gauss, and an energy product of 500 thousand gauss oersteds. Again, small melts at Bell Laboratories served to check the vanadium content and the degree of cold work and the production was then translated to commercial melts that reproduced the specified properties.

During the early stages of manufacture of the series ferreed, the Western Electric Company produced some flat plate magnets to substitute for the "C"-shaped sleeves. Plates can be cut from a strip parallel to the rolling direction and hence do not require isotropic properties. Furthermore, plates do not require the expensive forming procedure of the sleeves. Both plates and sleeves are being used in the Succasunna office in order to compare and evaluate their respective performance.

Some years ago, the Director of the Metallurgical Laboratory at Bell Laboratories told a professional group that metallurgy was moving far to the right of the decimal point. He meant that there would be an increasing need for higher purity materials and for more precise process controls, stretching to measurements in the millionths. No. 1 ESS, as we have seen, is a major part of the technology that has created this need and continues to give it impetus.



R. A. Hinrichsen reduces Molybdenum Permalloy wire on a continuous multiple-die wire drawing machine, one step in processing the twistor tape.