Semiconductor Devices

M. L. Embree and J. Sevick

In 1948, Bell Laboratories made a quiet announcement to the press and started a revolution in the electronics industry. It revealed the invention of the transistor, a tiny device that together with semiconductor diodes held the germ of No. 1 ESS with its hundreds of thousands of semiconductor devices.

The advantages of semiconductor devices were immediately apparent. They operated at extremely low power and did not have either the hot cathodes of vacuum tubes or the mechanical parts of relays. But in 1948, the semiconductor devices were rather primitive. Between them and the semiconductor devices of No. 1 ESS lie almost two decades of intensive research and development pointing toward continually improving electrical performance, increasing reliability, and lowered costs.

By 1956 semiconductor devices were reliable enough to be used in the trial of the Morris electronic central office. And in the eight years between Morris and Succasunna, silicon devices using diffusion technology were perfected and giant steps in reliability were achieved.

By the time development started on No. 1 ESS, many types of transistors and diodes were available to the circuit designer. There was such a large number of types in fact, that indiscriminately used they could have created difficult problems in development and manufacturing. In No. 1 ESS, therefore, the trend was toward concentration—the goal was as few types of transistors and diodes as possible. Every pertinent factor, from system philosophy to device physics, was weighed in characterizing the types of semiconductor devices No. 1 ESS required. The primary objective was versatile and reliable performance at an overall minimum cost. Most of the transistors and diodes in the system are miniature switching types used primarily in logic circuits.

A diode coupled AND-NOT gate, generally known as a low-level logic (LLL) circuit, is the basic building block of No. 1 ESS. It is a high performance circuit combining fast switching speeds, large fan-in and fan-out (i.e. the number of signals that can be applied to the input of the circuit and the number it can handle as output, respectively), and excellent margin. With this approach, only three types of transistors and eight types of diodes fill the No. 1 ESS semiconductor requirements. Actually, one of the three transistors, a varistor and a reference diode, are employed in such small numbers that they do not
Transistors

The first transistor, designated 25A, is a logic device capable of switching in less than 50 nanoseconds. The second, the 20D, is a 1-ampere memory driver. Prototypes of these devices were first made in 1959, and their developments since then have similar stories of evolving inside structures and outside packaging. This part of the story can be told in terms of the 25A alone.

The evolution of the logic transistor for No.1 ESS. The first stage (a) is a diffused base silicon mesa structure. The second (b) is an epitaxial structure. The last stage (c) is the planar epitaxial structure. The crystal substrate is designated N⁺ in (b) and (c).

Diodes

Diodes comprise the greatest number of semiconductor devices in a No.1 ESS office. A typical 10,000 line office contains over 200,000 diodes of eight types which are used for logic switching, energy storage, voltage level shifting, memory access isolation, voltage regulation and numerous other important applications.

Diodes are electronic devices which act as good conductors when voltage of one polarity is applied and as good insulators for potentials of the opposite polarity. The critical junction region of the diodes used in No.1 ESS is formed by high temperature diffusion of boron into one side and phosphorous into the other side of a thin slice of ultra pure single crystal silicon. Ohmic (non-rectifying) metallic contacts are applied to the surfaces and the slice is cut into properly sized and shaped wafers.

Over 80 per cent of the No.1 ESS diode components is made up of two types which are used in low level logic circuits, the 447A logic diode and the 449A level shifter diode. The logic diode switches millimperre currents in much less than a millionth of a second to perform the required logic functions. The 449A level shifter diode switches millimperre currents in much less than a millionth of a second to perform the required logic functions. The 449A level shifter diode switches millimperre currents in much less than a millionth of a second to perform the required logic functions. The 449A level shifter diode switches millimperre currents in much less than a millionth of a second to perform the required logic functions. The 449A level shifter diode switches millimperre currents in much less than a millionth of a second to perform the required logic functions. 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"Nickel Lead

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Similar devices used in other major elec-

Gold Plated

Bell Laboratories Rec. June 1965

and its “off” capacitance is less than 25 pico-

current, switching type designated

amperes must be switched in tens of nanoseconds

where currents from tens to hundreds of milli-

Great strides in semiconductor device reliabil-

ity have been made since Morris. All of the tran-

and diodes for No. 1 ESS are made by the

nector processing and modern reliability control tech-

niques. Similar devices used in other major elec-

tronic systems have shown the reliability required

for No. 1 ESS. It is clear that the No. 1 ESS de-

vice reliability objective will be met.

At both, the Holmdel Laboratory experimental system, and during testing at the Succasunna

office, the failure rate of semiconductors has been somewhat higher than the objective rate. How-

ever, this is largely the result of system testing and the rate of failures has decreased as the tests

come closer to completion.

To sum up, the semiconductor devices of No. 1 ESS have been designed to achieve electrical

characteristics suitable for broad uses—mechanical ruggedness to permit automatic circuit as-

semble; low cost to help achieve economical tele-

phone service; and utmost reliability, reducing office maintenance and achieving the primary

goal of accurate, reliable telephone service to Bell System customers.
Testing the System

BEFORE No. 1 ESS can handle even the simplest telephone call, or execute the most routine maintenance procedure, it must be able to respond correctly to any logic problem presented to it. This ability must be tested and proved before the efficiency and accuracy of the program itself—which controls call processing—can be examined.

Any telephone system undergoes some testing at the factory and is run through a gamut of testing after it is installed in a central office building. This testing is performed even on the type of system that has been in production for many years. Its purpose is to ensure that each machine that comes off the assembly line will operate within the values set by the design specifications. A new system, however, may stand or fall on the first machine to be manufactured, because the effectiveness of the whole design is evaluated on the basis of that machine’s performance.

Evaluation testing is a two-pronged attack. Its first point is straightforward. Every unit of hardware is tested both for its particular electrical or electronic functions—as a pulse inverter, or a delay network, etc.—and for its performance as part of an integrated system. The second point of the attack is much more complex. An effective testing scheme must put a system through all its paces, so to speak. The range of tests must exercise the system in such a way that it demonstrates its response to all situations within the objectives of its design. A precise and meticulous testing scheme can do more than reveal shortcomings, conflicts, and errors in the design. It can suggest, by its results, changes in the design and sometimes in the design objectives.

In a program-controlled system, evaluation testing is equally concerned with hardware and the program. Although the call-processing programs of No. 1 ESS cannot be fully tested until all the system’s circuits are operating, special test programs are a powerful tool. Hardware is the first concern and special “X-ray” programs were designed to examine all the hardware units of No. 1 ESS one at a time in sequence. These programs have a very high “resolving power,” that is, an ability to pinpoint the source of an indicated trouble.
The sequence of an X-ray Program. A test failure causes a transfer to a common failure point. "Record and advance" orders the program to stop central control and store addresses to the program store and to receive words in return. Lamps on the test panel allow him to monitor the contents of a number of flip-flop registers of central control and the states of important circuit points. When the required minimum of basic sanity is achieved, the tester keys a direct transfer to the beginning of the X-ray program and the CCMT releases central control to proceed on its own. However, the CCMT remains attached to central control. During X-ray testing, it is called upon for three important functions.

First, the CCMT provides "flags" that signal central control to stop, or to transfer to central control at a specified address. The latter is called an "interrupt." The CCMT contains two program-address match circuits, and each one continually compares the program address register with a pre-set number. When a match occurs, the circuits produce a flag. The flag causes central control to stop its clock circuits and guides the mechanism that shows a tester the point in the program where the failure occurred. Any suspected circuits are then examined by an oscilloscope, and the tester orders central control to send addresses to the program store and to receive words in return. Lamps on the test panel allow him to monitor the contents of a number of flip-flop registers of central control and the states of important circuit points. When the required minimum of basic sanity is achieved, the tester keys a direct transfer to the beginning of the X-ray program and the CCMT releases central control to proceed on its own. However, the CCMT remains attached to central control. During X-ray testing, it is called upon for three important functions.

Second, the CCMT continuously monitors central control and stores addresses to the program store. This is a sign that it can execute successive program instructions. Second, it must transfer program control directly from one location to another in the program store, and it must perform a return-address operation on a transfer. This is known as a "J" option, and it is the mechanism that shows a tester the point in the program where a test fails.

Basic sanity is achieved through manual testing with a mobile, plug-in unit called the Central Control Manual Tester (CCMT). In essence, the CCMT simulates all the units of a working system by sending instructions to central control and governing their operation. Actually, the operator of the CCMT controls the clock circuits of central control and steps them along at manual speeds so that the instructions are carried out one at a time.

These tests look to a two-fold result which, incidentally, illustrates the psychological metaphor, "basic sanity." First, all the hardware necessary for communications between central control and the program store must be operating. The ability to communicate is a fundamental test of sanity. In addition to this, there must be no interference from hardware that is not required to operate. Noise, of course, can make chaos of an attempt to communicate.

Using the CCMT, the tester orders central control to send addresses to the program store and to receive words in return. Lamps on the test panel allow the tester to monitor the contents of a number of flip-flop registers of central control and the states of important circuit points. When the required minimum of basic sanity is achieved, the tester keys a direct transfer to the beginning of the X-ray program and the CCMT releases central control to proceed on its own. However, the CCMT remains attached to central control. During X-ray testing, it is called upon for three important functions.

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Second, the CCMT is a data input to central control. Two 24-bit switch groups transfer input data to a program-address memory. The two groups transmit start-up addresses and other data. They also function as control switches to cut in special parts of the X-ray program or to bypass other inputs. One lamp bank displays the input data of any desired 24-bit word in the system memory. The X-ray program consists of a series of alternating checks and responses. An accurately performed exercise produces a specific result and the check affirms it. If a failure occurs, the machine enters into a transfer with a J option and turns control over to a point in the program known as the common failure leg. (See the drawing showing a transfer with a J option.) The address of the transfer match circuit set in this leg stops central control. The tester, signaled by the J option lamps on the control console, then gives control of the program to the CCMT.

To clear up the trouble, the program is returned to the test on which the failure occurred. (A lamp group on the CCMT displays the address at which the J option was executed.) The operator now controls the clock circuits and guides central control step-by-step through a return path. He may use the interrupt to cause the system to stop in the middle of an exercise and a programmer may enter the program at that point.

After the X-ray program has exercised the program store and central control in all its possible circuit combinations, other system units are brought in. The first of these is the central pulse distributor. Again the X-ray program sends orders, and determines the internal condition of the unit from its response. This testing proceeds, in this case, in complete harmony. Other troubles yield only evanescent indications persisting if central control is stopped on a given program address. The program to stop, or to transfer to central control at a specified address. The latter is called an "interrupt." The CCMT contains two program-address match circuits, and each one continually compares the program address register with a pre-set number. When a match occurs, the circuits produce a flag. The flag causes central control to stop its clock circuits and guides the mechanism that shows a tester the point in the program where the failure occurred. Any suspected circuits are then examined by an oscilloscope, and the tester orders central control to send addresses to the program store and to receive words in return. Lamps on the test panel allow the tester to monitor the contents of a number of flip-flop registers of central control and the states of important circuit points. When the required minimum of basic sanity is achieved, the tester keys a direct transfer to the beginning of the X-ray program and the CCMT releases central control to proceed on its own. However, the CCMT remains attached to central control. During X-ray testing, it is called upon for three important functions.

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The Bell System's first commercial electronic central office is housed in this building at Succasunna. It began serving 4300 New Jersey Bell Telephone Co. customers on Sunday, May 30, 1965.

United States Secretary of Commerce, John T. Connor at the Waldorf Towers, New York City receives an add-on conference call from Governor Hughes at Succasunna. Mayor Louis Nero of Roxbury Township was the third party in the call on No. 1 ESS.


The first official call through the system had been made two days before during the New Jersey Bell Telephone Company's dedication ceremonies. Governor Richard J. Hughes of New Jersey had initiated the system by adding-on John T. Connor, U.S. Secretary of Commerce to a conversation between him and Mayor Louis Nero of Roxbury Township, New Jersey. Mr. Connor was in New York City and the governor and mayor were at telephones in Succasunna.

Add-on is one of three system "memory services" now being tried by 200 customers served by the Succasunna office. Two more services will be added at a later stage of this trial. (Features and Services in this issue describes the five services.)

State, county, and local officials heard A.T.&T. Board Chairman Frederick R. Kappel describe the new installation as one of great significance in the history of communications. He said that No. 1 ESS will "open up an era of communications service that is more personalized, more human, than ever before by reason of its capacity to remember and do various special things that the individual customer wants it to do."

The electronic central office was developed, he said, to serve the future needs of the country for speedier and more abundant communications—in words, in data, in pictures, in symbols. This requires a more efficient and more versatile switching system than electromechanical devices permit.

"Not until the transistor was invented at Bell Telephone Laboratories in 1948 did electronic switching begin to emerge as a practical prospect," Mr. Kappel said. "Its inventors were investigating certain basic electronic characteristics of matter in the solid state. But whatever purpose beyond the search for knowledge they may have had in mind, there are today some 50,000 transistors in Succasunna's new central office—testimony, I think, to the value of so-called 'pure' research to progress."

"Just as the Telstar satellite showed the way to new achievement in intercontinental services," Mr. Kappel said, "to this electronic central office is the forerunner of a new era of convenience for our neighborhoods and our nation. The strength of America's communications system lies in what we call the 'switched network'—in the tremendous number of its inputs and outputs, its great speed and versatility, and its ability to connect any user anytime with any other. ESS is going to do this job for us better, faster and—in time—cheaper than ever before.

Succasunna is the first step in the nationwide conversion to electronic switching. Soon to follow are cutovers in Maryland, New York, and California. Mr. Kappel said that a dozen or more electronic offices are now in various stages of installation and that a new office will be installed every working day in the early 1970s. All switching in the Bell System, he said, will be done electronically by the year 2000.
THE AUTHORS

William Keister (The Evolution of Telephone Switching) is Director of the Electronic Switching Systems Engineering Center and is responsible for planning the engineering of electronic switching systems. Mr. Keister joined Bell Laboratories in 1930. His early work was on switching and signaling systems. He has organized and taught courses on switching circuit design to Laboratories personnel and is co-author of The Design of Switching Circuits. During World War II, Mr. Keister instructed Army and Navy personnel in operating and maintaining radar fire control equipment. He was appointed to his present position in 1958.

Mr. Keister received the BSEE degree from M.I.T. in 1929 and the MSEE degree from the Polytechnic Institute of Brooklyn in 1930. He is a member of Eta Kappa Nu, Tau Beta Pi, and the IEEE. He holds 51 patents with 6 pending.

John J. Yostpille (Features and Services) is Head of the Local Electronic Switching Planning Department. He is responsible for planning and setting engineering requirements for local central office applications of No. 1 ESS. He first joined Bell Laboratories in 1942 and in 1948 was in the first class of the Communications Development Training Program. He was first concerned with the design of toll switching equipment and after that with electronic switching. Before he was appointed to his present position he was a group engaged in systems planning.

Between 1942 and 1948 Mr. Yostpille was on leave of absence from the Laboratories during service in the Navy and studies at M.I.T.

Mr. Yostpille received the BSEE degree in Electrical Engineering from M.I.T. in 1948 and the MSEE degree from the Polytechnic Institute of Brooklyn in 1955.

Sigmund Silber (Co-author The Stored Program) is a member of the Electronic Switching Program Department, and has been engaged with the development of the executive control program for No. 1 ESS. Mr. Silber joined Bell Laboratories in 1941. While attending the Communications Development Training Program, he was engaged in various rotational assignments. Since then he has been concerned with the memory and program aspects of No. 1 ESS and certain data processing systems. He established program requirements for more than one data processor using the same memory. Most recently, he has been working with the system program test team for the Succasunna office of No. 1 ESS.

Mr. Silber received the B.A. degree in mathematics from Lehigh University in 1961. He is now studying toward the Ph. D. degree at New York University. Mr. Silber is a member of Tau Beta Pi and the IEEE.

Anton H. Dobhlaier (The Control Unit) is a member of the Electronic Switching System Design Department. For the last 10 years he has been concerned with electronic switching development, particularly the logic design of control units for electronic switching.

Mr. Dobhlaier joined Bell Laboratories in 1949. Until he transferred to his present assignment, he worked with an apparatus development group designing nonlinear networks involving copper oxide and thermistors. He holds one patent on a self-banding thermistor.

Mr. Dobhlaier was born in Munich, Germany. He entered this country in 1911 and received the B.A. degree from Columbia College in 1937 and the M.S. degree from the Columbia University School of Engineering in 1939 where he was a Pulitzer Scholar.

He is a member of Phi Beta Kappa, Tau Beta Pi, and Sigma Xi.

E. H. Siegel, Jr. (The Stored Program) supervises a System Program Group concerned with the design of call processing programs for No. 1 ESS. Mr. Siegel joined Bell Laboratories in 1957 and for three years worked on the design of the barrier grid store circuits and system integration for the Morris trial ECO. Following that he was concerned with call store circuit design for No. 1 ESS and was appointed to his present position in 1963.

Mr. Siegel received the BS in EE degree in 1946 and the MS in EE degree in 1957 from Lehigh University where he held the Gutshall Scholarship in electrical engineering. He is a member of Tau Beta Pi and the IEEE.

Raymond W. Ketchledge (From Morris to Succasunna) is Director of the Electronic Switching Laboratory. He joined Bell Laboratories in 1942 and for four years was associated with military development of infrared detection and underwater sound systems. During the next six years he participated in the development of a submarine cable system and a broadband coaxial carrier system. In 1953, he was appointed Electronic Tube Development Engineer and was responsible for the development of gas tubes and storage tubes. In 1954, he was appointed Switching System Development Engineer responsible for the development of electronic memories and switching networks for electronic switching systems. Mr. Ketchledge was made Assistant Director of Switching Systems Development in 1956 and was appointed to his present position in 1959.

Mr. Ketchledge received his BS and MS degrees from M.I.T. in 1942. He is a member of Sigma Xi and a Fellow of IEEE. He holds 51 patents with 6 pending.

Bell Laboratories Record

June 1965

W. Keister

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memory devices and following that he spent two years on the development of solid state electro-optical devices.

Mr. Osmun received the B.S.E.E. degree in Ceramics from Rutgers University in 1949, the M.S.E. degree in 1951, and the Ph.D. in 1954. He is a member of the American Ceramic Society and Sigma Xi.

A. Feiner (The Switching Networks in Head of the Electronic Switching Networks Department and is responsible for the development of switching networks, trunks, and switches, and for transmission aspects of No. 1 ESS. Since joining Bell Laboratories in 1953, Mr. Feiner has been associated with various phases of electronic switching techniques. Born in Vienna, Austria, Mr. Feiner did his undergraduate work at the Vienna Institute of Technology. He received the M.S. degree in Electrical Engineering from Columbia University in 1952. He is a member of Tau Beta Pi.

A. Feiner

D. H. Wetherell

D. H. Wetherell (Mechanical Design) Head of the Electronic Switching Equipment Department is responsible for the design and development of equipment for No. 1 ESS. Mr. Wetherell joined the Western Electric Company in 1923 and Bell Telephone Laboratories in 1925. He worked on the development of equipment for all types of switching systems until World War II when he was appointed supervisor of a group designing airborne radar systems. After the war he supervised a group working on the development of equipment for full telephone switching systems and later headed a group developing circuits and equipment for nationwide dialing.

Mr. Wetherell received the B.S.E.E. degree from Lafayette College in 1923. He is a member of Tau Beta Pi.

J. W. Osmun

J. W. Osmun (Co-author Power Supply and Ringing and Tone Plants) a member of the Power Systems Laboratory, specializes in electronic ringing and tone power plants. He joined Bell Laboratories in 1954 and graduated from the Communications Development Training Program in 1956. His early work at the Laboratories was in ringing power plants and transistorized dc-dc power converters. From 1953 to 1947 Mr. Osmun served as a parachute jumper with the U.S. Army, spending one year in the South Pacific theater of operations.

Mr. Osmun received the B.S.E.E. degree from the University of Nevada in 1953. He is a member of Phi Kappa Phi, Sigma Tau, and the IEEE.

J. R. Montana

J. R. Montana (Co-author Power Supply and Ringing and Tone Plants) a member of the Power Systems Laboratory, has been working on precise tone power supplies for No. 1 ESS, step-by-step, and No. 5 crossbar systems. Mr. Montana joined Bell Laboratories in 1944. He was first involved with the mechanical design and the preparation of manufacturing drawings of electromechanical equipment for various systems such as AMA. Later he was concerned with germanium and silicon, and then with rectifiers and inverters for development leading to the Morris trial. In 1961 he became a member of the Power Development Group and worked extensively on designing equipment for hardened sites and central offices.

Mr. Montana is a graduate of Brooklyn Technical High School and attended the Polytechnic Institute of Brooklyn.

R. L. Campbell (Co-author A New Approach to System Maintenance) is a member of the Electronic Switching System Center. He joined Bell Laboratories in 1960 and has worked since that time in the Electronic Switching Maintenance Planning Department at both the Whippany and Holmdel, New Jersey Laboratories.

R. L. Campbell

Daniel H. Wenny, Jr. (Some Magnetic Materials) has been supervisor of the Metallurgical Development Group of the Metallurgical Research Laboratories for the last 20 years. In the last few years he has been responsible for work on various metal components for the transistor memory arrays and the ferrite crosspoints of No. 1 ESS. Mr. Wenny joined Bell Laboratories in 1939. His first assignment was studying methods of preparing permalloy dust for cores used in loading coils. In his present position he has worked on a wide variety of base and precious metal alloys for magnetic applications, contacts, springs, reed selectors, delay lines, and transmission lines.

Mr. Wenny received the degree of Metallurgical Engineer from Lehigh University in 1939.

M. L. Embree

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**J. Sevick** (Co-author *Semiconductor Devices*) is supervisor of the Applications Engineering Group of the Semiconductor Device and Electron Tube Laboratory. He is concerned mainly with silicon transistors and integrated circuits. Mr. Sevick joined Bell Laboratories in 1956 and was first assigned to the development of high-frequency germanium and silicon transistors. Later he joined a systems group doing exploratory development work in high speed PCM. After that he was transferred to the Lauredale Branch Laboratory and supervised a group in applications engineering. He presently works at the Allentown Branch Laboratory.

During World War II, Mr. Sevick was a pilot and radar officer in the U.S. Air Force.

Mr. Sevick received the B.S. degree in Education from Wayne State University in 1940 and the Ph. D. degree in Physics from Harvard University in 1952. He is a member of a committee establishing an educational television station in the Lehigh Valley.

**R. S. Cooper** (*Testing the System*) is a member of the Electronic Switching Evaluation Department. He has specialized in systems evaluation, working on the Holmdel experimental No. 1 ESS since 1960.

Mr. Cooper joined Bell Laboratories in 1954 and was enrolled in the Communications Development Training Program which he completed in 1957. During that time he worked on the design and development of military systems and PCM carrier systems. After these assignments, Mr. Cooper was concerned with the Morris trial ECO. He was involved in liaison with the Illinois Bell Telephone Company in preparation for the trial as well as with system evaluation.

Mr. Cooper received the A.B. degree in Physics from Williams College in 1952 and the MSEE degree from Dartmouth in 1954.

At the ceremony marking the cut-over of No. 1 ESS at Succasunna, New Jersey, A.T.&T. Board Chairman Frederick R. Kappel said:

"It would probably take a couple of hundred rooms of this size to accommodate all the people who in one way or another have contributed to this accomplishment — the scientists, and engineers, and craftsmen who developed, designed, and installed its hardware, the mathematicians and programmers who created its software."

The authors in this issue represent only a few of the groups at Bell Laboratories who contributed to the development of the new system. They should be considered only as spokesmen for the men and women, too numerous to name, whose active and enthusiastic cooperation made No. 1 ESS a success.
B. G. Hemmendinger examines one of the digital circuit packages used in the central control unit of the new Electronic Switching System developed at Bell Laboratories. In these circuits, logic functions such as AND, OR, and AND-OR are built up with various combinations of a basic AND-NOT gate. About 27,000 transistors and 90,000 diodes are used in two duplicated central control units for one electronic central office.

**Stored-program control—flexibility for telephone switching systems**

Modern systems that switch your telephone calls use complex control equipment to operate the switches that make telephone connections. Such "common control" equipment is time-shared by many telephone lines. In electromechanical systems, common control apparatus consists of hardware—an array of hundreds of relays wired together to do the switching jobs of a particular telephone exchange.

By contrast, common control in the new Electronic Switching System (ESS) developed at Bell Laboratories is exercised by a multitude of general-purpose digital circuits whose actions are directed by "software"—programmed sequences of instructions stored in memory. The operation of ESS, including the specific telephone services provided, can thus be changed merely by changing the magnetization pattern of memory cards like that shown at left, with little or no hardware rearrangement or rewiring.

More specifically, ESS common control consists of an electronic data processor with a large memory. The memory contains instructions for processing all of the different kinds of calls handled by a central office. Guided by this stored program, the data processor receives and interprets dialed digits, sends signals to appropriate switches, and at the same time detects and diagnoses circuit malfunctions.

With this flexible common control, combining hardware and software, ESS can efficiently provide the various telephone services available today as well as any new services needed for the future.

Memory card, 6 1/2 by 10 1/2 inches, used for storing the ESS control program. Useful information (64 forty-four-bit words) is carried by the card in the form of magnetized spots ("zero") and unmagnetized spots ("one"). The random-access memory stores the control program and other data on 2048 such cards (131,072 words). The control instructions themselves require a minimum of 109,000 words.