No. 1 ESS: System Organization and Objectives

By W. KEISTER, R. W. KETCHLEDGE and H. E. VAUGHAN

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This paper is an introduction to the No. 1 electronic switching system, a new general-purpose switching system developed for use in the Bell System. Organization and objectives of the system are outlined to provide a background for the detailed technical papers which follow.

I. INTRODUCTION

1.1 *General*

The continuing expansion of present-day services, the demand for additional types of service, and the anticipation of new service offerings in the future all indicate a need for a new general-purpose switching system for the Bell System. The No. 1 electronic switching system (ESS) has been developed to meet this need. It is a general-purpose telephone switching machine capable of providing either two-wire or four-wire switching for local, toll, or tandem applications. No. 1 ESS provides today's services as well as several new ones, and is sufficiently flexible to provide for the ever-changing need for future services. It is economically competitive for present applications and will provide new services at relatively low cost.

The purpose of this paper is to outline the objectives of the system and to provide a brief description as background for the several more technical and more detailed papers which follow. Switching systems are, in general, complex and not easy to describe. No. 1 ESS not only entails many new concepts of switching system organization, but the equipment and apparatus used are also different from those of previous switching systems. As a consequence of this, No. 1 ESS is the largest development project ever undertaken by Bell Laboratories for the Bell System. The papers in this issue should give an adequate description of all the major concepts and techniques used in the system. Other papers, particularly those treating programming and testing aspects, will be published in forthcoming issues of this and other journals.

1.2 *History*

Since 1945, Bell Laboratories has conducted an active program of research and exploratory development in electronic switching. The Morris, Illinois, trial[1] of the world's first electronic switching office demonstrated the value of many of the basic concepts used in No. 1 ESS, in particular the use of a stored program and the basic maintenance philosophy. The system at Morris provided customers regular commercial-grade service and some additional new services. The trial established valuable guides for production design in hardware, data formats and programming. In addition, the trial also provided excellent training for many young engineers who later had a major part in the design of the No. 1 ESS. Although all of the hardware units and data processing programs for No. 1 ESS are new, their design relied heavily on the experience gained at Morris. The development of No. 1 ESS has now relegated the Morris system to history.

II. OBJECTIVES

2.1 *Economics*

Essential objectives for a new switching system are that it be at least the equivalent in service features of existing systems and be economically competitive with these systems for some significant segment of the market. These objectives must be attained on the basis of today's market rather than some hypothetical market of the future. The new system must be introduced in an environment of a very large number of older systems, and the general capability of the over-all switching network will be determined largely by the capability of the majority of the offices. The process of achieving improvements in the over-all system must be one of evolution over a period of years. However, the new system must have greater capability than the older systems in order that this improvement can be realized as the percentage of new offices increases. This points up another important essential. A new office must be compatible with the older offices with which it must operate, since modification of older units in service is inconceivable if we would attain the economic advantages of a new office design.

The economic balance over a range of sizes in the No. 1 ESS plan is quite different from that in electromechanical common control offices such as crossbar. The electronic system is based on a single high-speed central processor which is essentially the same in both large and small offices. In a system like No. 5 crossbar, a multiplicity of control units must be used due to their slower speed. This allows the amount of control equipment — as, for instance, the number of registers and markers in the crossbar system — to be increased as the office grows, so that the full burden of a control capable of handling a large office need not be borne by a small initial installation.

The new system must meet the standards of reliability that have been established by electromechanical systems. The operation of a complete office by a single central processor is a definite problem when reliability is considered. In a multi-marker office of No. 5 crossbar, the failure of a single marker merely reduces the traffic capacity of the office. However, the failure of the controller in an office depending on a single central processor would make the office completely inoperative. The solution followed in No. 1 ESS is to duplicate all units essential to proper operation of the office.

The economic objectives of No. 1 ESS are being realized through a basic design which has been optimized in its details and will be economical in production and in operation over a period of years. The economics of the equipment design have been based on quantity manufacture of its component parts. By the use of the stored program, it has been possible to plan a system which requires no wired options during manufacture and therefore leads to efficiency in production. The system units are designed for a minimum of interconnections between frames, so that most of the wiring and much of the detailed testing can be done at the factory rather than on location during the process of installation. Trouble detection and fault location have been highly automated through the use of stored program. Since most of the system logic involving telephone service features has been placed in the stored program, the introduction of new service features and modifications of existing features will be greatly simplified. In many cases, modifications will be made by changing programs rather than by wiring changes.

It is believed that important savings will be realized in the current development effort required to maintain the system design over a period of years during which its service features and operational environment change.

2.2 *Size*

An important item in planning the system was to determine the range of sizes over which the system would be applicable. Two major parts of the system are greatly influenced by size. One is the network, which must be planned to serve the entire range, with systematic growth from the smallest to the largest size encompassed by the design. The other is the central processor, whose call handling capability must be sufficient to care for the largest office while also being economical when used at only a fraction of its total capacity in smaller offices.

The appropriate size range was determined by making a survey of the range of office sizes. Information for this survey was obtained from the operating telephone companies, who provided information on the number of wire centers and the size of each wire center in each company. This information, covering a total of over thirty million lines in the Bell System, was analyzed by a digital computer to provide statistical information on the makeup of the potential market. The general nature of the results is indicated in Tables I and II. From these it is apparent that there are a very large number of very small wire centers, but that there is a large volume of business in large wire centers. Fifty per cent of the total lines are served from wire centers of 19,000 lines or greater. It was decided that it was not necessary to design an office large enough to accommodate the largest wire centers, because the differential cost per line becomes negligibly small in the higher office sizes. For example, the cost of two 50,000-line units will not be significantly more than the cost of a single 100,000-line unit. For this reason, a decision was made and verified by a number of studies that an upper size limit of 65,000 lines would be reasonable. The lower size limit is determined purely by

Table I — Total Bell System Lines in Service vs Central Office Size*

Per Cent of Total No. of Lines	Office Size
75	over 7,500
50	over 19,000
25	over 32,000

* Data as of January 1, 1960 (includes community dial offices).

TABLE II — CENTRAL OFFICE BUILDING TOTALS VS NUMBER OF LINES SERVED*

Per Cent of Total No. CO Buildings	Lines Served
25	less than 230
50	less than 750
75	less than 3000

* Data as of January 1, 1960 (includes community dial offices).

economics, but should extend down to at least the 4,000- to 5,000-line size, since the survey showed that a large number of offices are initially installed in this size range.

From a traffic standpoint, the maximum size of the system is set by the capacity of the central processor for handling calls in real time. The maximum capacity of the No. 1 ESS has been set at 100,000 calls in the busy hour. This figure was determined through studies of the cost and complexity of central processors of various designs, weighed against the traffic needs in the wire centers in the Bell System. The capacity of the central processor is determined by the basic speeds of the electronic circuits, its basic clock cycle time, the complexity of its individual logic operations and the amount of processing done in parallel.

2.3 *Flexibility*

The system has been planned to make maximum use of the flexibility inherent in a stored program. Central control is designed so that its wired logic represents basic logic operations which are related to telephone switching functions only through the sequences of instructions in the program. By means of the stored program, most of the logic decisions in call processing have been converted to basic logic operations. This philosophy is extended to items such as trunk circuits. The physical equipment in a trunk circuit is in most cases limited to that necessary for detecting and generating the signals required on these trunk circuits and performing basic switching operations such as loop closure or loop reversal. All sequencing of these operations, including timing of the duration of signals, is performed by central control under instructions from the program. This has the effect of minimizing the variety of trunk circuits required and reducing their cost, since changes in timing or sequence of operation can be made through changes in the program.

The switching network has been designed for flexibility in a variety of situations. The basic pattern consists of line frames and trunk frames connected together by groups of junctors of three types. Junctors are provided between line frames and trunk frames for connections between lines and trunks. Junctors from line frames back to line frames are used for line-to-line connections, and likewise junctors between trunk frames are used for tandem traffic and other trunk-to-trunk connections. The number of line frames and trunk frames can be varied independently and the junctor group sizes adjusted according to the mix of inter- and intra-office and tandem traffic. The network has been designed so that frames of four-wire ferreed switches can be used without modification of the central processor complex or its basic network control programs. In this way, the single basic system design can be adapted to a variety of local, toll, and tandem applications which in the past have required quite different system designs.

III. SYSTEM ORGANIZATION

3.1 *Outline of System Plan*

The basic concept of the No. 1 ESS is that of a high-speed electronic central processor operating with a stored program to control the actions of the central office on a time-sharing basis. The general system organization is illustrated in the block diagram (Fig. 1). The switching network provides the means for making interconnections between the lines and trunks to be served by the system and also provides access to the various service circuits required in handling telephone calls. These include tone sources, signaling detectors, ringing sources and the like. All information processing is handled by a central processor consisting of central control and the temporary and semipermanent memories. The temporary memory is used for storage of the transient information required in processing calls, such as the digits dialed by the subscriber or the busy and idle states of lines and trunks. The semipermanent memory contains the stored program and translation information. The contents of this memory need not change during the processing of a call. When the semipermanent information must be changed for any reason, these changes can be made on a manual basis without interfering with the operation of the office. The semipermanent memory also has the advantageous characteristic that its stored information is not erased by circuit malfunctions.

The central control consists of wired logic for performing information processing operations. It is organized on a word basis, with a word length of 24 bits, and operates on a basic cycle time of 5.5 microseconds. It is important to realize that the logic wired in central control is designed for information processing. The telephone switching logic is contained

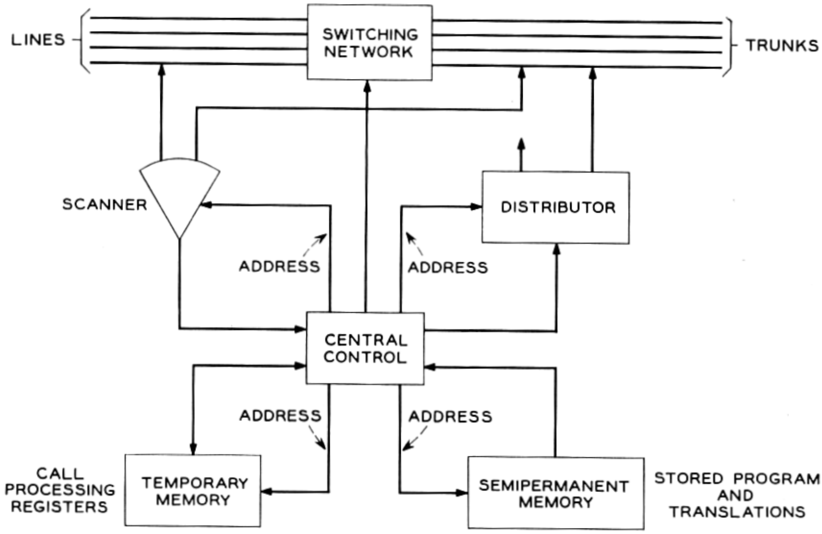

Fig. 1 — Central information processor with stored program (No. 1 ESS).

in the stored program. Thus, the hardware of the control complex is largely independent of the type of telephone service to be provided and the service treatments to be offered to the subscribers. This leads to great flexibility, since the same equipment can be used with different programs to provide a variety of services.

Input information for the central processor is provided by scanners connected to various points in the system where information must be obtained. These include the lines and trunks and signal receivers. The scanners are directed periodically to the lines to detect service requests, to the trunks to detect incoming calls, and to the signal receivers for detecting dialed digits and other control information. The process of recognizing this information involves periodic scanning and recording the results of these scans in temporary memory.

The signal distributor is the inverse of the scanner. It is connected to the various points in the system where actions must be controlled by the central processor. Central control can address the distributor to a particular terminal where a flip-flop or other memory device can be set to start an action. At a later time, central control can address the distributor to terminate this action. In the present design, the system handles this distributor action through two types of units. One is the central pulse distributor, which is all-electronic and is used for high-speed actions. The other, the signal distributor, makes use of a relay tree to perform lower-speed actions such as the control of trunk relays.

Thus the facilities provided in the system can be divided into several categories, such as the switching network with its associated terminal circuits which perform the physical functions required in making connections and detecting and producing signals; the central processor, with its wired logic to perform basic information-processing functions; the scanner and distributor, providing input and output communication for the central processor; and the stored program, which contains instructions for performing all the switching tasks in ordered lists of instruction words.

Particular distinction needs to be made between the program and translation information contained in the semipermanent memory. The program is the lists of instructions for performing all of the service features. It is part of the basic design of the machine and is not influenced by the characteristics of the particular installation. Ordinarily, it will not be changed except for some significant change in features or the sequence in which actions are to be performed, which would correspond to redesign and wiring changes in electromechanical offices. The translation section, on the other hand, contains the specific layout of facilities in the particular office: the association of subscriber directory numbers with the equipment location of their lines, the classes of service to be provided — such as individual and two-party, coin, extended area dialing and so on — and also the specification of trunk routes and their location and alternate routes to be used when available. This information must be changed periodically with the inward and outward movement of subscribers, changes in their class of service, and readjustment of trunk routes. Means are provided for making these changes on a periodic routine basis.

3.2 *Hardware*

The equipment and apparatus of No. 1 ESS has been designed for large-volume manufacture at minimum cost. Note that even a volume of only one million lines a year means over 15 million ferreed crosspoints, $1\frac{1}{2}$ million electronic circuit packages, 5 million transistors, 15 million diodes, etc. Obviously, such production rates must be highly mechanized.

Equipment and apparatus must be of special design to be adaptable to low-cost mechanized manufacture. Further, the high manufacturing volume justifies greater development effort and the creation of special devices and components. Thus No. 1 ESS uses many apparatus items that were developed for this particular application and whose design was tailored for mass manufacture. The ferreed switch is a good example. It is designed to be made as an array, not as an assembly of individual crosspoints. The control coils are not wound individually and then connected in series. Rather they are wound in simultaneous rows and columns from continuous lengths of wire.

Choice of technology is based on function and cost. In No. 1 ESS, relays are used in substantial quantities. The relay has cost advantages over an electronic approach where speed and function permit. For example, control of ferreed switches involves routing a high-current pulse through a selected path in the matrix of windings. This can be done by means of diodes and PNPN triodes, and indeed such a control structure was developed initially. However, by appropriate design of the control circuits one can, in effect, substitute a relay contact for a high-current diode. The cost advantage of the relay approach is substantial.

Standardization and minimization of codes are other important steps to low-cost volume manufacture. In No. 1 ESS strong efforts were made to standardize the hardware and to achieve the necessary variability by program or translation methods. An example of equipment standardization is the network equipment. Only six codes of frames permit assembly of a switching network suitable for any local office. Two additional codes take care of four-wire networks for toll offices. An example of device standardization is the use of only two codes of transistors, the low-power 29A and the relatively higher-power 20D. The 29A is used in the many logic circuits, in audio amplifiers and oscillators, and in broadband feedback amplifiers and regulators. Another effect of standardization has been the virtual elimination of wired options. Most electromechanical switching equipment makes liberal use of wired options to meet the variations of size and features of different installations. Thus the equipment is specially wired and tested at the factory. In No. 1 ESS the corresponding variations are stored in memory. The factory makes a particular frame the same way every time to a fixed set of test requirements.

The choice of seven-foot-high equipment arrangements (instead of 11.5-foot) eliminates the need for special buildings and allows maintenance from the floor, without ladders. This also contributes to the objective of simplified installation and growth. As a part of the general objective of dependability, and to permit reuse of existing buildings, air conditioning is not required. While most offices will doubtless be air conditioned, it will not be required for machine operability.

No. 1 ESS uses unregulated storage battery power fed by silicon-controlled rectifiers. The equipment has therefore been designed to operate over a ± 10 per cent voltage range. This design eliminates the need for end cells, counter cells and their associated switches.

Transmission has received particular attention. All outgoing trunks include loop compensation networks to improve return loss characteristics. Tones are generated by precision transistor oscillators and are fed to lines and trunks out of precisely balanced terminations. These and other similar measures, including careful control of noise, were taken in recognition of the role of the switching center in the maintenance and improvement of transmission objectives.

3.3 *Programs*

Approximately 90 programs totaling about 100,000 words are used to control the operations required for telephone service and to control the maintenance of the system. These programs, each an ordered set of instructions to provide a particular function, are stored in the program store. The call programs provide the solution to any problem a customer can present to the system, either directly or through some other switching system. An assembly of call programs must tailor-make a connection according to the demands of the customer.

Several approaches toward providing programs for a large number of different offices could be used. A generic program, which is the same for each office, with detailed differences listed in a parameter table, is the approach used in No. 1 ESS. The generic program includes all features for a large number of offices, covering sizes from 2,000 to 65,000 lines and means for handling growth and changing traffic conditions. This approach simplifies record keeping, because only the parameter tables which specify present size and operating conditions are unique to each office. Additional data which characterize a particular office are found in translation tables also in the program store. Typically, 18 different sets of translations are required in each office. These include directory number to equipment number translations for both lines and trunks, class of service, and special treatment for lines and trunks.

In the future, economics may dictate the need for several generic programs—for instance, one for small offices, one for large offices, one for four-wire offices, and perhaps some combinations of these.

The development and preparation of programs for the system require the use of several utility programs written for a commercial computer, an IBM 7094 in this case. These programs are used to convert the language of the programmer to the language of the machine, to assemble and compile the individual pieces of call and maintenance programs, and to load information onto a tape which finally controls the writing of the magnets on the twistor cards. Additional programs are used to assemble, compile, and load parameters and translations. Utility programs will be used by the Western Electric Co. as tools for manufacturing the programs put into commercial installations.

IV. DEPENDABILITY

4.1 *Objectives*

The dependability requirement on a telephone office is limited only by what the state of the technology can provide. Certainly a new system must at least be comparable to existing offices. This means outages of no more than a few minutes in 40 years. Heretofore no large electronic machines have been able to approach this kind of dependability. In fact, the dependability objective represented one of the major challenges of the No. 1 ESS development. Since No. 1 ESS is a large digital information processor, it is a cousin to the general-purpose digital computer. However, the dependability requirement requires that No. 1 ESS be a very different kind of system with a much higher level of redundancy.

4.2 *The Large Immortal Machine*

The large size of No. 1 ESS and the unique dependability requirement lead to the term "large immortal machine." It also implies that No. 1 ESS is a new kind of information processor, a kind that has never been developed before.

Another way of contrasting No. 1 ESS with a computer is to compare the relative hazards of a machine data processing error and a total machine failure. In a general-purpose computation center a machine stoppage is a nuisance: the problem must be rerun. But a data processing error could be called a "disaster" because the results come out wrong. In a telephone office it is the other way around. A data processing error may cause a particular call to be mishandled. This is a nuisance, particularly to the customer whose call must be redialed. A total machine failure in a telephone office, however, means no telephone service during the outage, and the magnitude of such a disaster need not be argued. The key point is, of course, that the dependability requirement on No. 1 ESS is both remarkably severe and quite different from that of general-purpose computers.

4.3 *Duplication*

Since some failures of individual components are bound to occur over decades of system service, duplication is essential. Every system unit required to maintain service must be provided in duplicate. Not only must there be duplication, but troubles must be found and corrected quickly to minimize exposure to system failure due to multiple troubles. This implies that all units must be continually monitored so that trouble in the standby can be found just as quickly as in the unit giving service. This further implies automatic detection of troubles and automatic switching of service when units fail. These processes are covered in detail in other papers.

4.4 *Repair*

When a trouble occurs, the telephone actions are interrupted as briefly as possible to reestablish an operational machine. Then, on a less urgent basis, the defective unit is diagnosed by the system itself and the results printed on the maintenance teletypewriter.

Where offices are unattended during at least part of the day, alarms and a remote teletypewriter are provided at some other location where 24-hour attendance is available. For minor troubles, not affecting service, the repair can be deferred. A defective trunk circuit can be taken out of service with a teletypewriter message. Major troubles may, on the other hand, need prompt attention to insure service continuity.

4.5 *Maintenance Programs*

More than half of the stored instructions are used for maintenance programs. Some of these programs, in conjunction with logic wired into the hardware, detect and report faults and troubles; others control routine tests and diagnose troubles and control emergency actions to insure a satisfactorily operating system, either by eliminating faulty subsystems or by reorganizing usable subsystems into a new operating combination. The classes of maintenance programs are arranged in a hierarchy of interrupt levels, so that when an error is detected the control system can be forced to stop what it is doing, keep a record of where it is, and after proper maintenance action is taken, restore itself to proceed with normal operation. In the hierarchy, a higher class can interrupt any lower class of maintenance or operating program.

V. TESTING

The separate development of major sections of hardware as individual subsystems, and of programs as other subsystems, and their subsequent successful combination into an operable system present major problems. First, the operation of all hardware subsystems working together to form a single system must be verified. Each of the hardware subsystems is factory tested by a combination of manual and automatic tests. The over-all system operation is checked by a special set of programs known as X-ray programs, which check step-by-step the sequences of operation. Such programs will also be used by Western Electric installation people for checking new installations.

This procedure was also used on the Holmdel, New Jersey, No. 1 ESS as the first over-all check of the system design, and it was here that many interface problems were solved. The solution of these required changes in hardware, program, or both. After the hardware was checked and operating satisfactorily, testing of the call and maintenance programs was begun on the actual system. However, some simulation was usually done on the IBM 7094 computer before the program was submitted to the No. 1 ESS laboratory system. When all programs operate satisfactorily, the system will be tested under simulated traffic conditions and finally under actual traffic conditions.

VI. STATUS

At the time of writing of this article, all of the hardware has been tested by means of the test programs and proved to operate satisfactorily. Many of the call and maintenance programs are now operating on both the laboratory and Succasunna, New Jersey, systems. Other programs are still in preparation. Maintenance programs are usually the last prepared because they must be designed after the operating peculiarities of the hardware have been identified. Publication of untested plans, in general, is dangerous. However, some of the authors of the following articles, on programs as yet only partially tested, have decided to present their plans so that a relatively complete story of No. 1 ESS can be presented under a single cover. When the plans have been fully tested, additional details will be reported.

VII. SUMMARY

This paper has attempted to present a general outline of the organization and objectives of No. 1 ESS. It also serves as an introduction to the papers that follow.

VIII. ACKNOWLEDGMENTS

Because No. 1 ESS is such a large undertaking the efforts of many hundreds of people are involved. Even listing the numerous organiza-

tions within Bell Telephone Laboratories would be difficult and this would exclude the many people in the Western Electric Company, the American Telephone and Telegraph Company, and the operating companies who have contributed in important ways.

REFERENCE

1. Keister, W., Ketchledge, R. W., and Lovell, C. A., Proc. IEE, **107,** Part B, Suppl. No. 20, 1960.