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System Organization and Objectives

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This paper describes the system organization and objectives of the No. 2 Electronic Switching System. The place of No. 2 ESS in the Bell System and the design approach used are outlined and traffic capacity estimates are discussed. This paper also serves as an introduction to the detailed set of papers which follow.

I. INTRODUCTION

1.1. *General*

The No. 1 Electronic Switching System described by Keister, Ketchledge, and Vaughan in the September 1964 issue of the B.S.T.J. has been in commercial service since May of 1965, when the first installation was activated in Succasunna, New Jersey. Since that time, many additional installations have been made and electronic switching has been clearly established as a valuable switching medium for use in the Bell System.

The No. 1 ESS was designed for use in metropolitan areas where large numbers of lines with heavy traffic are served. Although a few installations of No. 1 ESS have been made in nonmetropolitan areas, the need within the Bell System for another system that would be economically attractive in the size range from 1000 lines to about 10,000 lines has been evident. This need will be met by the No. 2 ESS.

Broadly, then, the objectives established for the No. 2 ESS were to complement the No. 1 ESS by offering economical electronic switching service for nonmetropolitan offices in the medium size range. These broad objectives have more specific implications on customer services, maintenance and administrative features, traffic capacity, floor space, and, of course, cost.

II. OBJECTIVES

2.1. *Customer Service Feature Objectives*

By and large, the service features offered on all local switching systems are and should be the same. However, there are some small differences that result from differences in the intended field of application. Just as offices for use in nonmetropolitan areas tend to be smaller than those used in metropolitan areas, the service features that are required tend to differ. For instance, four-party and eight-party lines are fast disappearing from large cities but are still required in some suburban and rural areas.

Since No. 2 ESS is intended for application in nonmetropolitan areas, the objective for the initial package of customer service features is to provide features appropriate for such areas. It is a further objective to provide the features in the form of a "basic group" that would be present in all offices plus additional groups of features that would be optional. Specific features to be provided in the initial installations of No. 2 ESS are covered in a companion paper.[1]

2.2 *Maintenance and Administrative Objectives*

A high degree of dependability, maintainability and operational efficiency are required in all local switching systems. Experience indicates that electronic switching systems can meet these requirements at annual costs considerably less than with conventional switching machines.

Because of its intended use in nonmetropolitan areas, the No. 2 ESS was designed to be largely unattended. That is, wherever economically practical, maintenance tests, translation changes, traffic and plant measurements, and so on, were designed to be controlled remotely. Of course, repair or replacement of circuit packs, connections to cables, and so on, all require work in the office.

The companion article by Beuscher and others covers both hardware and software aspects of the No. 2 ESS administration and maintenance plan.[2] Of particular interest in this article is the system trouble example which describes the sequence of actions from a particular trouble detection through system repair.

2.3 *Flexibility*

More and more it is becoming apparent that flexibility is an extremely important objective for any new switching system. Many services being provided today had not been conceived even 20 years ago when the No. 5 crossbar system was designed, let alone at the time the step-by-step and panel switching systems were invented. Twenty to forty years from now, the electronic switching systems of today are likely to be called on to provide customer services and operating features not known today. For this reason, every attempt was made to make No. 2 ESS a flexible system.

The use of a stored program common control is, of course, a major step in providing the desired flexibility. In addition, hardware flexibility is provided by extensive use of modular equipment, connective frames and simplified peripheral communications.

2.4 *Traffic Capacity*

For an office of about 10,000 lines in a nonmetropolitan area, most Bell System requirements can be met with a minimum capacity of 16,000 busy hour calls and 40,000 ccs (hundred-call-seconds). However, it is clear that any capacity greater than these minima that can be achieved at reasonable cost would be valuable in the future for new services or increased calling rates. We discuss busy hour call capacity estimates for No. 2 ESS in Section V.

2.5 *Economic Objectives*

It is easy to say that the cost of a system to meet the preceding objectives should be as low as possible, and this, of course, is true. But what might be a realistic objective to shoot for? Since the No. 5 crossbar system is currently installed in the Bell System in this field of application, it was felt that a reasonable objective for No. 2 ESS, with its many attractive features, was to be competitive with standard No. 5 crossbar systems in terms of installed first cost. Thus the advantages of the No. 2 ESS in terms of simplified installation (relatively sophisticated factory test, shipment of several equipment frames as a factory wired unit and extensive use of plugs and jacks for interunit wiring) would be recognized in this economic comparison but other advantages, such as new service features, reduced maintenance, and administrative costs would not. This enables the using telephone company to benefit from its new equipment immediately upon installation and does not require it to anticipate future savings in order to prove in modern telephone equipment.

2.6 *Other Objectives*

Obviously many other objectives were also established for No. 2 ESS. For example, it should provide service as reliable as, or better than, existing systems; it should occupy minimum floor space, and it should have as short an installation interval and as small an installation effort as possible.

III. SYSTEM DESCRIPTION

3.1 *General Design Plan*

The design of No. 2 ESS was derived from experience with both the No. 1 ESS and No. 101 ESS. The system uses a ferreed network and other peripheral units similar to that of No. 1 ESS. The No. 2 ESS control is a new design based on the smaller type of control which is being used in the No. 101 Electronic Switching System.

The rationale behind these design decisions is clear. The No. 1 ESS serves large offices and creates a high production of network and peripheral apparatus. The designer of the small system gains the benefit of this large production by using the same apparatus. In the control area the small office designer has greater flexibility since he creates his own high production based on the large number of entities in the small office field. He, in addition, has the advantage of moderate traffic capacity requirements. It is, therefore, reasonable to have a specialized design for the small office control which attempts to minimize costs at some sacrifice of traffic capacity.

3.2 *Control Unit*

Figure 1 is a block diagram of the No. 2 Electronic Switching System. Although reminiscent of most electronic switching system block diagrams, there are several points which can be made in conjunction with this figure. The control consists of duplicated central controls, each working with a common maintenance center. Each central control has been designed as a single switchable entity. That is, the frames which contain the program and translation store, the call store, the program control and the input-output are treated as one entity rather than individually switchable units. This reduces both the quantity of equipment required and the quantity of program required for the administration of redundancy.

The processor frame used in No. 2 ESS contains the program control (instruction processing logic), a semiautonomous input-output section, capacity for 16,384 16-bit words of call store (temporary memory) and capacity for 512 bipolar central pulse distributor points. The call store may be equipped in steps of 4096 words while the central pulse distributor may be equipped, as required, with packages of eight central pulse distributor points. High speed transistor resistor logic is used for all logic applications in this frame. This logic uses thermocompression bonded beam leaded silicon devices with thin film resistors on an alumina substrate. Growth frames are available which allow expansion of the call store to 32,768 words and the central pulse distributor to 16,384 points.

The basic program and translation store frame for No. 2 ESS contains four permanent magnet twistor modules with a total capacity of 65,536 22-bit words. In addition to the basic frame, growth frames are available which allow this store to be expanded in steps of 16,384 words to a maximum size of 262,144 words.

The semiautonomous input-output unit which is included in each processor frame shares the call store with the program control on what is generally a lower priority. The input-output unit works together with the program to: (*i*) scan for line originations, (*ii*) collect

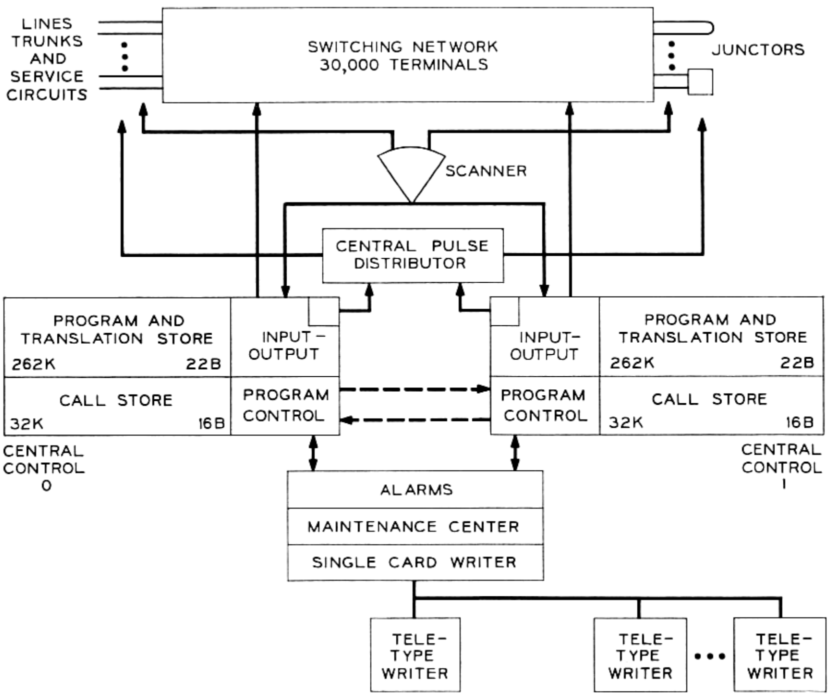

Fig. 1 — No. 2 ESS Block Diagram.

dialed digits and tone signals, (*iii*) outpulse, and (*iv*) transmit data. Use of the input-output unit for digit receiving and sending functions has allowed the normal program interrupt cycle to be set at 25 milliseconds rather than the usually required 5 to 10 milliseconds. In addition, the precise timing and short scan intervals available through the input-output unit has allowed simplification in circuits such as incoming trunks from step-by-step offices. The input-output unit is fully discussed in the Control Unit paper.[3]

3.3 *The Network*

While generally using the same apparatus as No. 1 ESS, the No. 2 ESS network has been designed to minimize "getting started" costs. This was easier to achieve in No. 2 ESS since the ultimate size of the system will be considerably smaller than the ultimate size of No. 1 ESS. The system uses a two-wire folded four-stage ferreed network with lines, trunks, and service circuits all appearing on the same side. It is therefore not necessary to have a separate line and trunk link network in small offices. Only two types of frames are used to make up the No. 2 ESS network:

(*i*) The network control junctor switch frame contains eight 64 × 64 octile grids which form the third and fourth stages of the network. Each grid is made up of sixteen 8 × 8 ferreed switches arranged for 64 inputs and 64 outputs. This frame contains a pair of controllers which operate the junctor network and the network and scanners of the line-trunk switch frames.

(*ii*) The line-trunk switch frame can accommodate 512 inputs which concentrate to 256 outputs. This frame is made up of sixteen 32 × 16 ferreed concentrators. These concentrators are made up of eight 4 × 4 switches in the first stage and four 8 × 4 switches in the second stage. This frame also contains a 512 point ferrod line scanner. One, two, three or four line-trunk switch frames can be connected through B-links to the 512 inputs of the network control junctor switch frame to form a complete line-trunk link network.

At 4:1 concentration ratio, each line-trunk link network can provide up to 2048 terminals for lines, trunks and service circuits. At 2:1 concentration ratio, 1024 terminals would be provided per line-trunk link network. Through use of circuit and wire junctors additional networks can be added with an ultimate capacity of fifteen networks which can carry over 100,000 ccs of traffic.

3.4 *Trunks, Junctors and Service Circuits*

The trunks, junctors, and service circuit designs of No. 2 ESS are generally the same basic types as those in No. 1 ESS. The primary difference has been in the use of a special integrated circuit package which has been designed specifically to control relays. This package, called the peripheral decoder, offers several advantages over previous trunk control schemes. Each peripheral decoder pack can operate and hold up to 12 relays and would typically be used to control four universal trunks or circuit junctors. Information is sent from a central pulse distributor point serially to the peripheral decoder where the information is stored on flip-flops and decoded to operate the desired relay. From the program point of view, the relays are thus controlled at electronic speeds. Use of the peripheral decoder also allows the trunk control to be equipped with a single pack at a time as trunks are added to the office. In addition, the peripheral decoder is a good application for integrated circuits since it will be a high production circuit package. The peripheral decoder is described in detail in the companion articles on the Peripheral System, and Apparatus and Equipment.[4,5]

3.5 *Installation and Growth*

A significant effort has been made in No. 2 ESS to simplify growth and change of equipment and to reduce installation intervals. Most of the connections between the central control frames and the connections to the maintenance center are through plug-in connectors. In addition, both the call store and program store growth units are equipped with plugs and jacks. It is planned that the entire control complex will be plugged together at the factory and tested as a system through X-ray programs. The same X-ray programs will be used when installing the control complex at the central office site.

Some of the maintenance center functions also include capabilities which aid in both factory test and installation of the machine. These functions provide (*i*) manual access to internal processor states, registers, and memory locations; (*ii*) control capability over execution of program segments, and (*iii*) emergency override features which put the machine under manual control.

To aid in peripheral system installation, bus communication between the control and the peripheral frames and all B-link connections within the network are on plug-in connectors. In addition, trunks and service circuits are equipped on easy-to-install mounting plates while peripheral decoders, as already mentioned, are on plug-in packages.

IV. PROGRAMMING

4.1 *Program Size*

Basic program and translation requirements for small (single line-trunk link network) No. 2 ESS offices are estimated at less than 65,000 22-bit words. Thus these offices may be served by a single four module program store per central control. As the offices grow in size and feature requirements, additional program modules may be added as already described.

The instruction format used in No. 2 ESS is the same as that used in No. 101 ESS and consists of two types. Type 1 uses a 22-bit word which contains a 5-bit operation code and a 16-bit address plus a check bit. Type 2 contains two complete 10-bit instructions, each of which contains a 5-bit address and a 5-bit operation code. The short 5-bit address is made effective by extensive use of relative and implicit addressing of both program and call store information. Experience on No. 101 ESS and No. 2 ESS has shown that this format is highly efficient in the use of program store space thereby aiding in meeting the low cost objectives for the system.

4.2 *Call Programs*

We leave the details of the systems programming to later papers.[1,2,6] However, with the emphasis on low system cost, a few points are worth reviewing. We have already mentioned the highly efficient micro-type orders used for program instructions. The major feature of these kinds of instructions is that very few bits are wasted in unused options and unneeded address bits, as is often the case with larger, fixed length program instruction words.

Also simplifying both program and administration is the use of general purpose registers within the temporary memory for all types of calls. These registers consist of a progress mark which defines the state of the call plus other information pertinent to the call. Call registers containing progress marks generally use the same format and the same register size, thereby allowing common programs to be used for many different call states.

The progress marks themselves define the first address of the program required to process the particular call. The preponderance of call processing can then be described as a series of transfers to the individual progress mark programs. In addition to straightforward call processing techniques, great emphasis has been given to the use of common subroutines. Many progress mark programs consist entirely of calls to nested subroutines. In order to help in this effort some special orders and push-down list features have been included in the basic instruction repertoire to aid in the writing and to facilitate the use of subroutines. The Control Unit System article further describes the No. 2 ESS order repertoire.[3]

4.3 *Maintenance and Administrative Programs*

Maintenance and administrative programs constitute over half of the programming job, hence considerable effort has been extended to seek simplifications in this area. In the control system the maintenance structure is based on a single interrupt level, a single match circuit, a few internal check circuits and good program access between the on- and off-line units. These factors, in conjunction with low component counts and the single switchable entity concept, all tend to reduce and simplify the programs. In the periphery, the small number of frame types and options has reduced the adminstrative and growth program needs as well as creating some maintenance simplification.

V. TRAFFIC CAPACITY

In designing a small office, many trades are made which favor low cost over real-time traffic capacity. Care must be taken, however, to leave sufficient capacity to allow a reasonable range for newly started offices and growth. Current estimates indicate that the No. 2 ESS may be engineered for up to 19,000 busy hour calls with a traffic mix of one-third intraoffice, one-third outgoing, and one-third incoming calls. This estimate has been derived from several sources. Among these are: (*i*) cycle counts in the programs, (*ii*) simulation of the programs, (*iii*) laboratory measurements as the programs are being debugged, and (*iv*) comparisons with existing systems.

The busy hour call calculation has been made by determining the number of calls that may be carried with the processor occupied at 95 percent (peak capacity) and reducing this result by an allowance for false starts (number of false starts assumed equal to 30 percent of originating calls). The total is further reduced to allow a 30 percent peak with the final result being 19,000 busy hour calls for engineered load. In general, all calculations have been very conservative.

5.2 *Dual Office*

While it is generally expected that the capacity of 19,000 busy hour calls will be quite adequate for the No. 2 ESS field of application, techniques are being explored for expansion beyond this capacity. These techniques are aimed at the situation where very large unanticipated growth is necessary at a No. 2 ESS installation. Figure 2 is a block diagram for a dual No. 2 ESS office. This diagram shows a pair of No. 2 ESS offices with the networks joined by junctors. In addition, data links would be provided for communications between the controls of each suboffice. With this plan, all connections within a suboffice or between suboffices would use only eight stages of network. In addition to this, trunk groups would be distributed between the suboffices in the same way as they would be for a single office. In order to facilitate the use of common trunk groups and a common network, the data links would be used to exchange network status information, trunk status information, and supervision where necessary.

The dual office concept represents a form of multiprocessing highly suited to telephone applications. In general, each suboffice does business as usual except where a connection is to be completed between the suboffices. The number of inter suboffice connections can be minimized by not permitting service circuit connections between suboffices. For example, when a line originates, the dialing connection will always be made within the suboffice on which the line homes. When a line is called, the ringing connection will always be made within the called suboffice. By proceeding in this way the real time consumed in completing inter suboffice connections is limited primarily to the final talking path.

Except for network status information, the data communication between the offices is simple and does not add a major amount of new work to the normal single office program. Early traffic estimates on dual processing indicate that inter suboffice calls will incur an approximate 20 percent real time penalty while the penalty on intra suboffice calls appears negligible. The emphasis in the dual office is clearly to retain network and trunk efficiency since this is where, in a large telephone office, most of the expense occurs. On the control

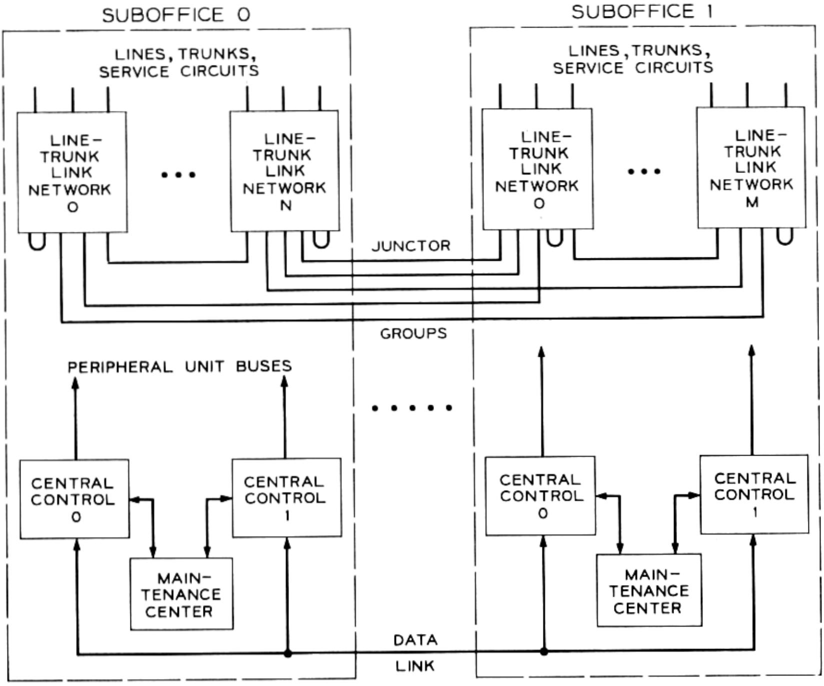

Fig. 2 — No. 2 ESS Dual Office.

side the emphasis is on relatively simple growth and retention of a large part of the single office programs. The dual office version of No. 2 ESS is not aimed at the new office field; the primary objective is to allow a greater growth range for the system while not penalizing the "get started cost" of a single office.

VI. STATUS

The first No. 2 ESS office is scheduled to go into service during the last quarter of 1970 at Oswego, Illinois. Hardware and software are being debugged on two test models at Bell Telephone Laboratories, Indian Hill, Naperville, Illinois. The 2100-line Oswego office is expected to be followed in service by three other offices in 1971, ranging from approximately 1000 to 5000 lines, and thus representative of the typical No. 2 ESS new starts. Western Electric Company price estimates indicate that No. 2 ESS is meeting its economic objectives and wide penetration in the Bell System central office field is expected.

VII. ACKNOWLEDGMENTS

The design of No. 2 ESS contains the contributions of many people at the American Telephone and Telegraph Company, Western Electric Company, and Bell Telephone Laboratories. In addition, the experiences of the many Bell System operating companies using electronic switching systems has provided invaluable information for the design process.

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