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No. 4 ESS:

System Objectives and Organization

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This article is an introduction to a series of articles that describe the No. 4 Electronic Switching System. Objectives and the organization of the system are given and the overall operation is explained.

I. INTRODUCTION

1.1 Background

A new toll Electronic Switching System, No. 4 ESS, has been developed to meet the expanding needs of the telecommunications network, including the effects of continuing toll message growth. The first four No. 4 ESS offices were placed in service during 1976, starting with the Chicago 7 office on January 17.

The purpose of this article is to serve as an introduction to the ten more technically detailed articles that follow. This introduction highlights the objectives of the new system in comparison to existing Bell System toll, or trunk, switching systems and outlines the features and characteristics of No. 4 ESS that differ from previous electronic switching systems, particularly the No. 1 ESS.

Expectation of a trunk switching version was implicit in the early planning and development of the first Bell System local electronic switching system, which came to be known as No. 1 ESS. It was clear even then (late 1950s) that if the anticipated improvements in flexibility, reliability, and economy were realized, these advantages would be equally applicable to toll and tandem switching.

The opportunity to test this thesis came early. The first local No. 1 ESS was cut into service in May of 1965.[1] Even before this initial cutover, upon the urgent request of the United States government, development was started of a four-wire combined line and trunk switching system based upon No. 1 ESS and designed for use in a special noncommercial switching network. This version of No. 1 ESS is now the principal switching system used in the government-controlled AUTOVON (Automatic Voice Network) in the contiguous United States. Although it had

Table I — Bell System toll switches, January 1, 1967

Systems	Erlangs	Attempts/ Hour	Total Number
No. 4A crossbar	6,200	116,000	73
No. 1 crossbar tandem	1,700	47,000	237
No. 5 crossbar local/toll	1,100*	20,000*	407
Step-by-step intertoll	330*	5,000*	500

* Nominal

been expected that the special four-wire No. 1 ESS might evolve into a commercial toll ESS, this did not occur. The primary reason for this was that growing requirements for switching capacity appeared to exceed the inherent capability of the specialized AUTOVON switch.

1.2 Planning studies

Serious study specifically aimed at determining Bell System needs for a toll ESS began at Bell Laboratories early in 1966. At that time the principal Bell System toll switches consisted of the systems listed in Table I. Of these several types of systems only one, No. 4A crossbar, provided full toll capability, including a four-wire network, for service as a control switching point in the network hierarchy.

The early studies addressed the problem of determining the maximum traffic, or call-handling, capacity that should be set as an objective for the new system. Traffic capacity has three interrelated dimensions which must be maintained in reasonable balance:

Trunk connections or terminations
Office network load
Call attempts per hour

In principle, optimum traffic capacity can be determined as a function of nationwide network structure, traffic load, and economics; in turn the desired traffic capacity has a profound effect upon switching system architecture and technology. Alternatively, the state of the switching art may set a limit upon capacity lower than otherwise desirable.

For these reasons, system studies and development studies proceeded in parallel, with a continual interchange of information and mutual effort to match the desirable with the possible. Historical trends and projections into the future indicated a continuing growth of toll message traffic at a rate of 8 to 9 percent a year. When this growth was translated into switching requirements and matched against the capacity of the largest available toll system, No. 4A crossbar, it was clear that, by the late 1970s, many metropolitan areas would require a multiplicity of toll switching offices. This results in network inefficiencies and administrative complexities, both of which carry economic penalties. In order to quantify these effects and relate them to an objective system capacity, two major study efforts were undertaken.

One pioneering study investigated in detail what came to be known as the multimachine penalty. The penalty accrues from the lowered efficiency of "splintered" trunk groups, additional interoffice trunking, more traffic routed up the hierarchy, and double-switching. The studies were conducted on model metropolitan areas based on New York and Los Angeles.

The second study was directed at a projection of the economics of future toll switching installations in each of 241 metropolitan areas in the contiguous United States. Data were gathered for each area on existing installations, the current traffic load, and forecasts of future traffic growth. From these parameters, a computer model was constructed which could accommodate switching offices with any postulated capacity, cost, and traffic characteristics, including multimachine penalties. By means of this model, comparative costs could be determined over any span of years on an area-by-area or a systemwide basis.

The early development studies that paralleled the systems studies followed No. 1 ESS principles closely, extending them to define a multiprocessor structure controlling a multiplicity of suboffice four-wire ferreed switching networks. It was estimated that a set of six No. 1 ESS-type processors would handle 200,000 call attempts per hour providing an electronic toll office of at least twice the capacity of the No. 4A crossbar system. The price was estimated to be well below the No. 4A crossbar price at comparable traffic sizes.

Information derived from the study models, taking into account the development data, led to the conclusion that a good and reasonable capacity objective for a new toll system would be a design that could grow to two to three times the size of No. 4A crossbar. Greater size would be useful in a few areas of the country, but the major benefits would be achieved at the three times 4A level. Overall Bell System savings accruing from a system of the projected size and estimated cost were very large and justified a quick approval of standard development.

II. EVOLUTION OF REQUIREMENTS AND SYSTEM PLAN

During the early planning period it was assumed that service features of a new system would, at least in an initial development, be an extension and improvement of the toll features of No. 4A crossbar, that maintenance and administrative features would be enhanced, and that the new CCIS (Common Channel Interoffice Signaling)[2] system would be incorporated in the design. When approval was given to start actual development (1968), work on the elaboration and refinement of requirements was stepped up to match the needs of the development program.

In any large project, particularly when it is based on a new technology such as electronic switching, it is neither possible nor desirable to formulate final objectives and requirements independent of design and development.

If original objectives are sound and challenging, it is likely that technical breakthroughs will occur during the course of development and that objectives can be broadened and requirements can be extended. This was particularly true in the No. 4 ESS project.

There were three major technical advances that appeared early in the program which profoundly affected the course of development. These were:

(*i*) A new central processor design[3] of such high capacity that system objectives could be met (and eventually exceeded) with a system architecture based on a single processor pair instead of the multiprocessor arrangement originally envisaged. This carried with it a basic design technique and methodology which came to be known as 1A Technology[4] and which eventually permeated the entire system. The processor, designated the 1A Processor, was equally applicable in a larger version of the local No. 1 ESS.

(*ii*) A time-division switching network of such high capacity, small size, and basic economy that it displaced the ferreed network that was initially planned.[5] A major advantage of this network, which made extensive use of 1A Technology, was that it matched the accelerating trend toward use of digital transmission facilities.[14] As a result, it became possible to design No. 4 ESS as an integrated switching-transmission system with hitherto separate functional organizations cooperating in the development. This new interface opened the way to many new opportunities for improved efficiency and economy.

(*iii*) Enhanced trunk maintenance and record-keeping capability based on a minicomputer. An auxiliary facility known as the circuit maintenance system,[6] together with a related new trunk test position, made possible a much more efficient interface between the craft force and the trunk test and maintenance operations. The system incorporates mechanized record keeping to handle the large amount of continually changing office information related to trunk and facility interconnections.

As the system plan of No. 4 ESS evolved to take advantage of the concepts outlined above, it became possible to extend the system objectives and formulate system requirements in a new framework. Most important, the capacity objectives could now be converted to requirements and explicitly stated as three times 4A. Furthermore, it soon be-

Table II — Major service features

	No. 4A Crossbar	No. 4 ESS Objectives
Capacity		
Call attempts/hour*	116,000	350,000
Network load, erlangs†	6,200	28,000
Trunk terminations	22,400§	110,000
Digit capacity	14	14
Translation (electrically alterable)—digits	3 or 6	1 to 10
Code conversion		
Digit deletion	3 or 6	1 to 10
Digit prefixing	1 to 3	1 to 10
Automatic alternate routes	7	13
Class marks—fixed	16	1/trunk group
Common Channel Interoffice Signaling	√	√
International gateway	√	√#
CCITT No. 6 signaling		√#
Centralized Automatic Message Accounting	√	√

* Level for engineering the office on a "10 high day," busy hour average.
† Level for engineering at 0.5% first trial matching loss.
§ Typical mix of one-way and two-way trunks.
\# Not to be available initially.

came possible to expand the network load and termination requirements to a higher level and to specify that the network should be designed to operate on an essentially nonblocking basis. The new capacity requirements and a feature list for No. 4 ESS are shown in Table II, in comparison with No. 4A crossbar.

It might be observed here that the capacity levels achieved in the final design were as follows:

Call attempts/hour	500,000 (550,000 peak)
Network load, erlangs	47,200
Trunk terminations	107,520

It will be noted on Table II that, except for the large increase in capacity, the basic toll switching features of No. 4 ESS are essentially an extension of No. 4A crossbar features. Beyond these new capabilities, however, major improvements were planned for the new system in terms of cost, performance, ease of installation, maintenance and administration, network management features.

Cost: A primary objective was to keep the basic cost of the system below that of No. 4A crossbar in the 4A size range. Above single 4A size, large cost savings were inherent in the system because 4E incremental costs would be much lower than a second and third 4A. Reduced multimachine penalties also would generate first-cost savings.

Performance: Overall network objectives for fast call setup and disconnect (made feasible by CCIS) established rigid switching time requirements on No. 4 ESS. These resulted in substantial impact on the design. Objectives were also established for various types of irregularities, based on current system performance, surveys of customer reactions to the irregularity when it does occur, and the difficulty of implementation. In addition the current ESS objective of no more than 2 hours of office down time per 40 years was applied, and objectives were established for maximum incidence of system errors such as call cutoffs or loss of calls in process of being set up. These objectives were then apportioned to the system components involved and applied to the No. 4 ESS design.

Installation: A reduced installation interval was planned in terms of plug-connected frames and expanded factory testing.

Maintenance, Engineering, and Administration: With availability and cost of skilled manpower becoming a matter of increasing concern, recognition of the need to hold down the staff to operate the office led to numerous objectives to enhance the maintenance and administrative features. These include:

People-oriented, error-resistant, and efficient personnel interfaces.

Automatic generation of operations reports by the system itself.

Modular equipment and data concepts to allow trunk rearrangements on a group (12) or digroup (24) basis.

Easy-to-understand and use interactive commands to alter the data base for routing and other translation changes.

Elimination of many of the paper records by storing them in the system.

Use of plug-ins through the system to facilitate installation and maintenance.

Provision of automatic error analysis techniques.

Software-controlled job assignments.

Network Management:[12] In addition to the traditional network management features, No. 4 ESS was planned to provide improved control and surveillance functions. For example, one objective was to detect on a real-time basis hard-to-reach codes and take action to block calls to such codes. In addition to restricting traffic in overload situations, the system should also act to expand routing opportunities. These features are intended to cope with the increasingly complex network and to maintain the overall efficiency in presence of traffic surges that can occur in overloaded portions of the network.

In addition to the objectives in the above major feature areas, which are detailed in subsequent articles, there were a number of other objectives such as designing the system so it would facilitate the addition of future features. Also, in 1971, the objective was set to cut over the first

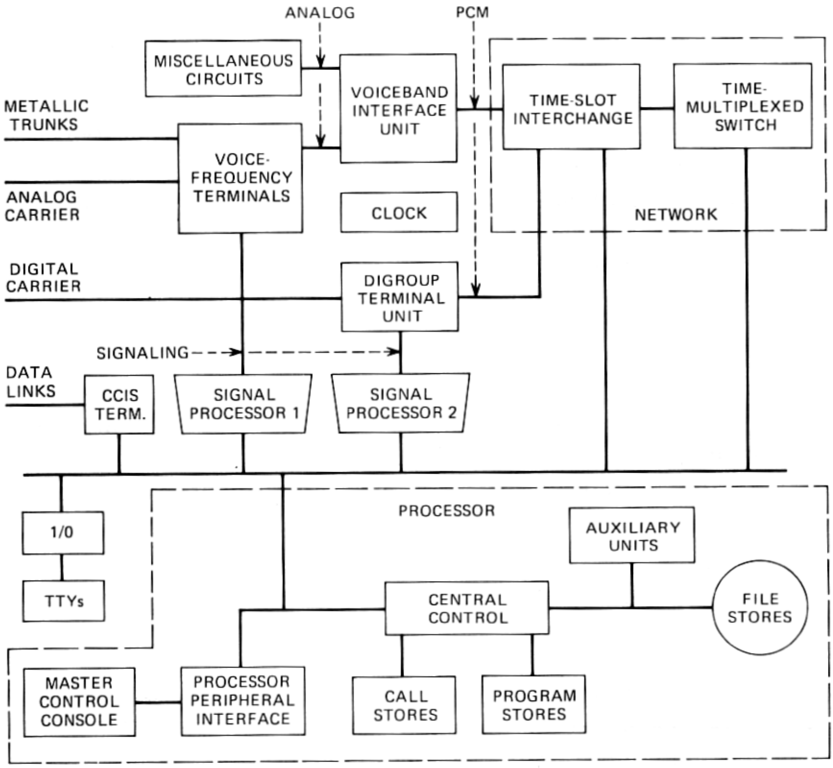

Fig. 1—No. 4 ESS office.

system over in the beginning of 1976. These objectives as well as the great majority of the other objectives that were set for the system, have been met.

III. SYSTEM ORGANIZATION

3.1 Outline of system plan

The general system organization is illustrated in the block diagram (Fig. 1). No. 4 ESS, like No. 1 ESS, uses a high-speed electronic central *processor* (1A Processor) operating with stored-program control to control the actions of the central office on a time-shared basis. However, although No. 4 ESS shares this basic concept with No. 1 ESS, there are a number of rather fundamental differences in the two system plans. The most significant of these is the use of the solid-state PCM time-division *network*. The decision to develop No. 4 ESS around a time-division switch was made early in 1970 after extensive studies and comparisons with other alternatives. Some of the major characteristics of this network are:

A time-space-space-space-space-time switching configuration organized in two types of frame: the *time-slot interchange* and the *time-multiplexed switch*.

High capacity, which, as mentioned above, not only meets but exceeds the system objectives.

Low blocking (virtually nonblocking), which eliminates need for trunk rearrangements for load balancing.

A T-carrier-compatible DS-120 input format—an 8.192 megabits per second PCM bit stream that accommodates 120 voice-frequency channels.

Small floorspace requirement due to use of the solid-state techniques.

Use of plug-in units and connectorization to ease installation and maintenance.

Solid-state technology (1A Technology) throughout.

In addition, a *clock,* accurate to 5 parts in 10^{10} over a 1-week period, times the office and the digital lines that home on No. 4 ESS.

The DS-120-format digital inputs to the switching network are provided by two types of transmission equipment: *voiceband interface units* and *digroup terminal units.*

In the voiceband interface unit[7] the analog signals are sampled 8000 times per second and converted to standard (μ255 companded) 8-bit PCM frames. One hundred twenty channels are grouped together in a 128-time-slot format. The *voice-frequency terminal* units extract supervisory and dial pulse information and, conversely, convert the information they receive from *signal processor 1* to dial-pulse and supervisory information. Each voiceband interface frame includes seven active units and a spare (840 trunks).

In the digroup terminal units[7] five T1 carrier lines are combined to 120-channel, 128-time-slot PCM format, which is the same as the output of the voiceband interface units. The digroup terminal also extracts from the T-lines the necessary control information, passes it to *signal processor 2* and conversely converts the information it receives from signal processor 2 into the T-lines. Each digroup terminal frame contains eight active units and a suitable spare (960 channels). The signal processors perform a number of simple time-consuming functions and thus deload the main processor. These functions include routine scanning, collecting of dial-pulse digits, timing, etc. Signal processor 1, which interconnects with the voiceband interface frame, has individual scan and signal distribute points for the analog trunks. In signal processor 2, these individual points are not required, since the access is directly to the 120-channel bit stream. Both signal processors have additional scan and distributor points for administrative and maintenance functions. Signal processor 1 handles up to 4096 analog trunks and signal processor 2 up to 3840 digital trunks.

The 1A Processor,[1] in conjunction with peripheral processors, with a 700-nanosecond central control cycle and a powerful order structure, allows the call capacity of No. 4 ESS to be achieved without multiprocessing. Another advantage of the 1A Processor, which plays a role very similar to the No. 1 Processor in No. 1 ESS, is electrically writable *stores*.

The *CCIS terminal*,[2] which, except for its bus access circuitry, is common to the terminal used in No. 4A crossbar, handles the routine and repetitive tasks associated with the CCIS (Common Channel Interoffice Signaling) data link.

A minicomputer-controlled Circuit Maintenance System (CMS) has its initial application in No. 4 ESS. CMS provides storage for records such as circuit layout record cards and assists in administration of work flow (e.g., by forming trouble tickets and test position work lists).

In addition to the above major new frames, the system includes some smaller developments, e.g., a sit-down *Master Control Console* (MCC), a 51A test position that replaces the 17-type test position, etc., as well as existing hardware, such as channel banks and test lines. All frames are 7 feet 2 inches high. Power distribution to the switching frames and the new transmission frames is at 140 volts; to the other frames it is still at 48 volts.[13]

IV. SOFTWARE

In No. 4 ESS most of the control, call handling, administrative, and maintenance functions are provided by the stored program.[8–10] The initial program (so called 4E0 generic) was the largest program yet developed for Bell System electronic switching systems. It consisted of about 400,000 instructions, 400,000 diagnostic test words, plus other miscellaneous control data, bringing the total to about 1.4 million 26-bit words. With the features added by the 4E1 generic, the program grew by 45,000 instructions and 70,000 diagnostic test words. The primary objectives of the design were:

Real-time efficiency
Simple personnel interface
Defensive design
Ease of modification

The design of the software system represented a major challenge not only because of its sheer size but (*i*) because it was developed in parallel with the hardware components of the system and (*ii*) because entirely new and difficult problems had to be solved in the design of the recovery software for the network, signal processor, and the transmission interface frames (voiceband interface and digroup terminal). Despite these difficulties, a good-quality program was developed and completed on schedule. Some of the major characteristics of the program system are:

High real-time efficiency (as indicated above, the design not only met but substantially exceeded the capacity objective)

Elimination of timed interrupts to schedule high-priority work

A structure that allows many of the display and control pages to be designed independently of the generic

Maintenance control that allows up to three diagnostics to be executed in parallel

Automatic memory administration by the system

Software-generated test calls

V. STATUS

The first four No. 4 ESS offices were installed in 1976 and are now providing excellent service.[11] Seven more offices are scheduled for service, including the Rego Park office in New York. This office will be the first to go into service with the 4E2 generic, which will provide local tandem features, the maintenance software for a new digital echo-suppressor frame, and many enhancements to the administrative and maintenance features. Work is also already underway on the "gateway" features to provide international service. This generic, called 4E3, will first see service in the Broadway 24 office in New York in the second quarter of 1978. Beyond these committed developments, other work is underway to achieve an even lower-cost system and to provide additional features.

VI. SUMMARY

This paper has presented a general outline of the objectives and organization of No. 4 ESS and thus serves as an introduction to the papers that follow.

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