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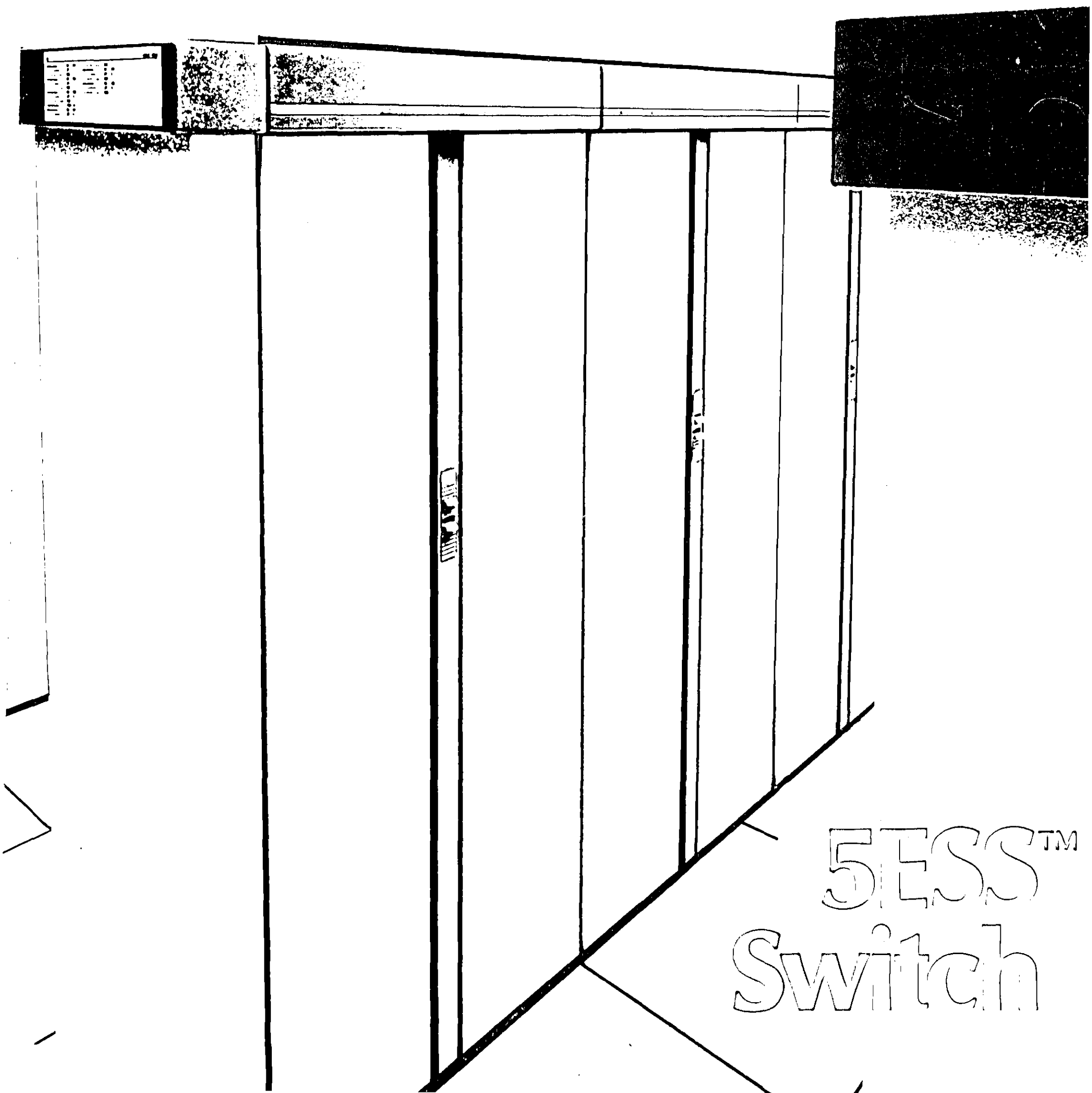

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The 5ESS *Switching System:*

Introduction

By K. E. MARTERSTECK and A. E. SPENCER, JR.*

(Manuscript received November 14, 1984)

This special issue of the *AT&T Technical Journal* is devoted to the *5ESS*™ switch. In this introductory paper the authors provide some historical background; outline the characteristics of this new, advanced system; and summarize its architecture, features, and status.

I. BACKGROUND

In March 1982, the first *5ESS* switch was cut over in Seneca, Illinois. This new, multifunctional, time-division digital switching system is the product of development efforts at AT&T Bell Laboratories that can be traced back to the 1950s. Development of the *5ESS* electronic switch was, and continues to be, driven by the worldwide evolution of both switching technologies and expanding telecommunications needs.

To introduce the more detailed articles that follow, this paper offers a brief history of AT&T Technologies electronic switches, discusses the characteristics of the new *5ESS* switch, and introduces some of its technologically innovative features.[1]

1.1 Local switching systems

The first general-purpose electronic switch, the *1ESS*™ switch[2] (which was cut over in Succasunna, New Jersey, in May 1965), contained a *space-division* switching network and a digital electronic data processor under Stored Program Control (SPC).† It was primarily intended to serve urban areas with large numbers of lines (between

* Authors are employees of AT&T Bell Laboratories.

† Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

10,000 and 65,000) and heavy traffic, including many business customers. The *2ESS* switch, introduced in 1970, was designed to serve fewer lines (2000 to 10,000) and to meet the lighter traffic needs of suburban residential areas. In 1976 the smallest of AT&T Technologies space-division electronic switching systems, the *3ESS* switch, began meeting the needs of rural Community Dial Offices (CDOs) with fewer than 4500 lines.

Also in 1976, new processors became available to modernize the *1ESS* and *2ESS* switches, doubling their call-carrying capacities. The 1A *ESS* switch incorporates the 1A processor, which has a readable and writable memory. The 2B *ESS* switch is equipped with the 3A central control, which combines integrated circuit design with semiconductor memory stores.

The first local electronic switches replaced earlier, wired-logic electromechanical systems such as the No. 1 and No. 5 crossbar and the still earlier step-by-step and panel progressive control systems. Stored program control led to greater flexibility in system design and reduced operations expenses in the telephone network. In early 1985, more than 3700 local electronic switching offices served more than 60 million lines worldwide.

Because of the high cost of processors and their associated memories, by the mid-1970s electronic switches still could not economically replace the smallest electromechanical switching systems. Yet these offices, serving 2000 or fewer lines, accounted for approximately 60 percent of the switching systems in the U.S. network. One response to this situation was remote switching. In 1979, the No. 10A Remote Switching System (RSS) (see Ref. 3) became available to connect these small offices to nearby host electronic switches by means of T- and N-carrier systems.

1.2 Toll switching systems

With the deployment in January 1976 of the first *4ESS* switch[4] in Chicago, fully digital electronic switching was introduced into the long distance network in the U.S.

The *4ESS* switch, a high-capacity, toll and tandem switching system, brought many major technical advances to the switching art. The most important change was the use of a *time-division* digital network in place of the space-division network. Because of the rapid growth in the number of digital transmission systems, the switching network of the *4ESS* switch was specifically designed to pass Pulse Code Modulation (PCM) signals without conversion. Transmission and switching functions were more closely integrated than in any previous switching system. Economic considerations, such as significant reductions in installation, operating, and maintenance costs, played an important part in the introduction of the *4ESS* switch. By the end of 1984, more than 100 systems were serving both North American and international applications. These systems have a total of 3.3 million trunk terminations and carry more than 5 billion calls per month.

1.3 Distributed systems

Following the successful introduction of time-division digital switching into the toll network, planning began for its application, with digital stored program control, in the local environment. Among the alternatives considered were adaptations of the 1A *ESS* switch and the *4ESS* switch for local digital switching. Technology, however, was advancing rapidly in such areas as lower cost, more powerful microprocessors, and high-speed, fiber-optic communications systems. Such advances set the stage for a new generation of electronic switching with heavy emphasis on distributed network and distributed control. Thus, evolving technology and a strong market interest in digital systems led to the development of the *5ESS* switch.

II. SYSTEM CHARACTERISTICS

The *5ESS* switch complements the earlier systems, which so successfully replace the larger electromechanical local and toll offices. For example, it can bring electronic switching to even the smallest local office. In addition, the *5ESS* switch provides digital services and capabilities for an extensive range of applications. To these ends, the new switch was designed with seven major characteristics in mind:[5]

1. The *5ESS* switch is a *single system with multiple applications* (local, toll, operator services) that can cover the entire range of office sizes needed in telephone networks throughout the world. Table I shows a matrix of switching systems applied (as of 1983) across the metropolitan, suburban, and rural markets in the local, toll, and operator-services applications. The distributed control, modularity, and extensibility of the *5ESS* switch allow it to serve all of these markets and applications. One consequence of this approach is the development of unified software to introduce new features throughout the family of *5ESS* switches without regard to application or size. Well-defined internal interfaces allow a flexible, modular approach for both hardware and software so the system can be economically configured to meet the special needs of each market segment. For example, in the area of PCM transmission, two different international standards (North American and European) exist. From the start, the basic architectural and timing parameters of the *5ESS* switch were designed to be compatible with both standards.

2. The *5ESS* switch provides *integrated interfaces* between digital switching and transmission systems for both subscriber carrier systems

Table I—Switching systems used in metropolitan, suburban, and rural markets in local, toll, and operator-services applications

Application	Market: Metropolitan		Suburban		Rural	
Local	Crossbar tandem No. 1 crossbar No. 5 crossbar 1*ESS* 1A *ESS*	*5ESS*	No. 1 step-by-step No. 5 crossbar 2B *ESS*	*5ESS*	CDO No. 1 step-by-step 3*ESS* 10A RSS	*5ESS*
Toll	No. 4 crossbar 1A *ESS* 4*ESS*	*5ESS*	No. 5 crossbar local/toll 1A *ESS*	*5ESS*	No. 1 step-by-step local/toll	*5ESS*
Operator services	No. 5 crossbar Automatic Call DistributorTraffic Service Position System	*5ESS*	No. 5 crossbar Automatic Call Distributor Traffic Service Position System *5ESS*	*5ESS*	Manual Traffic Service Position System/remote trunk arrangement	*5ESS*

and interexchange circuits (24- and 30-channel systems). The *5ESS* switch also has an efficient, easily maintained interface to analog interexchange circuits to simplify introducing the system into existing networks. Overall, the integration of functions will lead to a more rapid movement toward the integrated digital network and to the Integrated Services Digital Network (ISDN).

3. The *5ESS* switch permits the *graceful incorporation of new technology* as it becomes available. This objective is not new, of course. For example, just as the 1*ESS* and 2*ESS* switch processors were upgraded in the mid-1970s with new technology, the ferreed network was also replaced by the smaller and more economical remreed at about the same time. Similarly, since the system's introduction in 1976, virtually all the major units of the 4*ESS* electronic switch have been redesigned to take advantage of technological innovations.[6] These upgrades have pointed to the advantage of well-defined intermodule interfaces. Such interfaces become even more crucial as technology reduces the physical size of equipment and the replacement of units becomes important at the equipment bay level. The distributed nature and well-defined interfaces of the *5ESS* switch also allow easy replacement and evolution of selected components as market trends warrant. For example, the switching module processor has already been upgraded to raise call-handling capability above initial capacity.

4. The *modular design* of the *5ESS* switch allows increases in both network and processor capacity in reasonable, cost-effective increments. Earlier SPC switches had large growth modules. The resulting breakage penalty was as much as 5 to 10 percent of the switch price. To enable the system to be responsive to changes in forecasts and demographics, the design of the *5ESS* switch allows for the addition or removal of equipment in operating exchanges and for conversion from one switching application to another (e.g., from remote switch to stand-alone exchange).

5. The *5ESS* switch is *highly reliable.* Automatic fault detection, fault location, and reconfiguration capabilities ensure that faults can be identified, isolated, and repaired in a timely manner, thereby providing better service at lower maintenance cost.

6. The *5ESS* switch is designed for both *local and centralized maintenance.* The provision of centralized maintenance has been one major factor in the economic attractiveness of stored program control for growth and replacement of electromechanical systems. When both approaches are provided, local maintenance can be used when the first systems are introduced. Then, as the number of systems increases, telephone administrations can introduce compatible centralized maintenance systems to obtain additional economic benefits.

7. The *5ESS* switch allows *new features to be introduced by means*

of software. Techniques used in the *5ESS* switch, such as a sophisticated operating system, a high-level language, and a modular design, make possible the rapid addition of features.[7] In fact, the software environment is essentially the same among modules, enabling software to be ported among the various modules as architecture and feature needs evolve. Since maintenance routines constitute more than 50 percent of the system's software, these routines are also designed to facilitate changes.[8] In addition, considerable effort has been expended on powerful off-line development systems and rigorous design methodologies[9] that have already proven effective during the initial applications of the *5ESS* switch's software. They are expected to be increasingly valuable as the demand for services and features continues to grow, particularly in light of important new concepts, such as the evolving ISDN.

III. *5ESS* SWITCH TECHNOLOGY, ARCHITECTURE, AND FEATURES

3.1 Technology

The technological sophistication of the *5ESS* switch is apparent at every level of its design, from devices to architecture. Examples of state-of-the-art technology in the *5ESS* switch include:

1. Gated-Diode-Crosspoint (GDX) switch—a completely electronic (solid-state) line interface that reduces the space used by 60 percent over comparable interfaces and greatly improves reliability.

2. Digital signal processor[10]—a high-performance, high-density Very-Large-Scale Integration (VLSI) component that on one chip combines generation and detection of multiple tones with signal filtering, thereby reducing cost, space, and power requirements. This chip performs over 1 million operations per second.

3. Fiber optics—low-cost, high-capacity, internal communication links between modules that are resistant to electromagnetic interference.

4. Distributed control—microprocessor-controlled switch modules that provide call-processing intelligence, and allow for system growth in modular increments and full feature capabilities at remote locations. These modules are coupled by a packetized control network that ensures reliable and efficient communication among all the elements of the system.

3.2 Architecture

The *5ESS* switch has a modular, distributed architecture consisting of an administrative module, a communications module, and a number of switching modules (see Fig. 1). The communications module contains a message switch, which handles the packetized system control messages, and a time-multiplexed switch, which interconnects switching modules with one another, as well as with the administrative module. Fiber-optic Network Control and Timing (NCT) links connect modules.

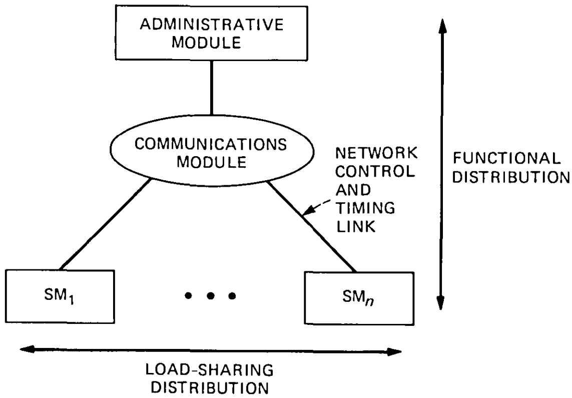

Fig. 1—Distributed architecture of the *5ESS* switch.

In the architecture of the *5ESS* switch, those functions that are best done globally—such as administration, resource allocation, and maintenance access—are provided in the administrative module. Those needs that are best handled close to the external interfaces—such as most of the individual call handling, provision of network capacity, and terminations for lines and trunks—are distributed in the switching modules. Thus, the switching modules provide the major processing power in the system, performing over 95 percent of the per-call work. In addition, they form the basic growth unit and, as such, can be physically located either locally or at geographically remote sites.

The design of the *5ESS* switch will enable it to evolve to support Universal Information Services, a telecommunications industry goal that will enable network providers to offer their customers integrated transport, dynamic allocation of network resources, and adaptive, logically provided services.

3.3 Features

The flexible architecture of the *5ESS* switch allows it to fulfill the needs of a spectrum of markets. For example, it provides basic and advanced subscriber services; toll and operator services; and extensive operations, administration, and maintenance features. Feature sets are being planned to take full advantage of the information-age capabilities of the ISDN. Table II shows the planned capacity levels through 1985 in terms of rated busy-hour calls, number of distributed switching modules, and line capacity.

IV. STATUS

The first multimodule *5ESS* switch was put into service in August 1983 at Sugar Grove, Illinois. The first local/toll *5ESS* switch was cut

Table II—*5ESS* switch capacities through 1985

Year	Rated Calls/Hour*	Maximum Number of Switching Modules	Nominal Line Capacity†
1983	130,000	30	50,000
1984	200,000	48‡	50,000
1985	300,000	192	100,000

* Sustained operation, including customer features, all effective attempts, all messages billed, with no degradation of maintenance and administrative responsiveness.
† Allows for typical mixture of lines and trunks.
‡ Includes remote switching modules.

over at Bradford, Pennsylvania, in October 1983. The remote switching module and integrated *SLC*® 96 carrier were cut over at Spotsylvania, Virginia, in April 1984. The first *5ESS* switch with the international feature set was ready for service in Seoul, Republic of Korea, in February 1985.

The early thrust of the *5ESS* switch has been small- to medium-size local and local/toll applications. In 1985, with the advent of the high-capacity enhancements and new features such as business and residence custom services, the application of the *5ESS* switch will be expanded in both the North American and international markets. The early buildup of shipments of the *5ESS* switch has been substantial. From just 183,000 lines shipped at the end of 1983, *5ESS* switch line shipments grew by an additional 2.5 million in 1984, and more than 6 million lines will be shipped in 1985.

V. SUMMARY

This paper has presented a general introduction to the *5ESS* switch. Its distributed architecture, use of sophisticated digital technologies, and modular hardware and software design put the *5ESS* switch at the leading edge of SPC switching systems. The papers that follow discuss the system in more detail. The first discusses applications planning[11] for the *5ESS* switch. This is followed by papers on the overall architecture,[12] the operational software,[7] the maintenance software,[8] the circuit-level hardware,[13] the physical design of the hardware,[14] and the software development system.[9] The last set of papers addresses the first application and field experience,[15] the operations plan,[16] and factory testing.[17]

VI. ACKNOWLEDGMENTS

The authors wish to acknowledge the efforts of all those people in the development and systems engineering organizations of AT&T Bell Laboratories and AT&T Technologies who have worked so diligently to bring about the *5ESS* switch.

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The 5ESS *Switching System:*

Applications Planning

By W. R. BYRNE and G. P. O'REILLY*

(Manuscript received December 8, 1983)

The *5ESS*™ system is designed for switching applications in rural, suburban, and metropolitan areas. It can function as a local, local/toll, or toll switch, and has features that make it suitable not only for use in the United States but in almost all countries. The modular design of the switch makes it particularly useful for solving wire center and network problems. This article discusses methods for solving such problems and presents some economic study results demonstrating the savings that can be achieved.

I. INTRODUCTION

The *5ESS* system represents a major step in switching system architecture evolution.[1] Using distributed control, modular hardware and software, and integrated electronics, the *5ESS* system makes possible the integration of digital interoffice trunk facilities, digital carrier subscriber loop systems, and digital switching. Its modular design provides remote switching systems for small office applications. An integrated operator service position system is planned to round out the complete set of switching features.

Figure 1 gives a pictorial description of the various applications displayed over a large geographical area. The applications include

1. Local office growth and modernization
2. Access tandem, and operator services
3. Toll office growth and modernization
4. Small office modernization via remote switching
5. New wire center via remote switching

* Authors are employees of AT&T Bell Laboratories.

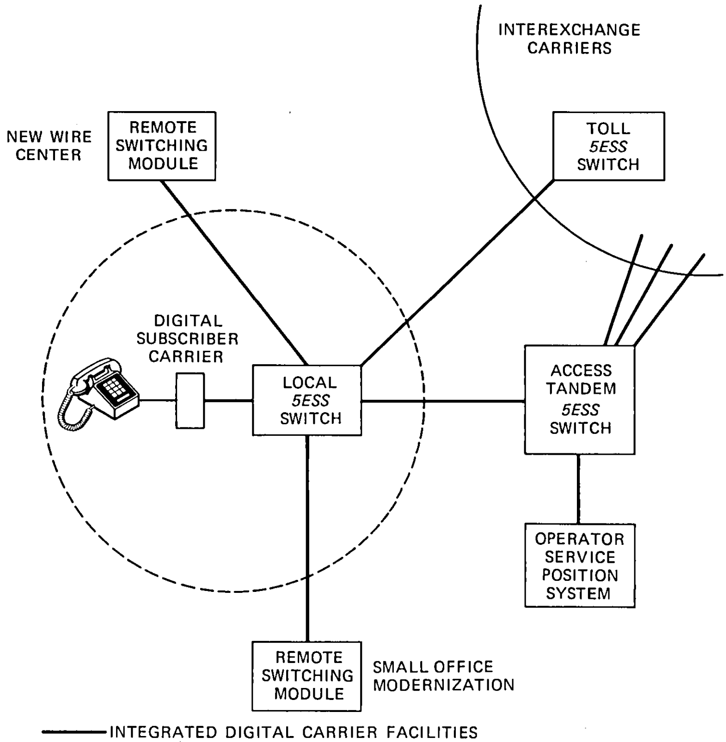


Fig. 1—*5ESS* switch applications.

6. Integrated digital subscriber carrier systems
7. Integrated interoffice facilities via digital carrier.

Digital synergies between loop, switching, and interoffice transmission technologies are changing network planning methods.[2] Traditionally, the network planning process was perceived as a collection of related but essentially noninteracting disciplines, each of which was responsible for the evolution of a particular network function (subscriber network, local switching, interoffice facilities, toll switching, or operator services). As Fig. 2 illustrates, the communication among these disciplines was often limited to an exchange of completed plans. Such an exchange would ensure, for example, that a planned rehoming of an end office from one toll center to another was made known to those who were planning for the affected interoffice facilities. The process of developing the plan, however, was typically limited to a single discipline.

Such an approach was justified in an environment where the network technology was characterized by well-defined boundaries among the various functions. However, the advent of integrated interfaces between switching systems and digital loop and trunk facilities has

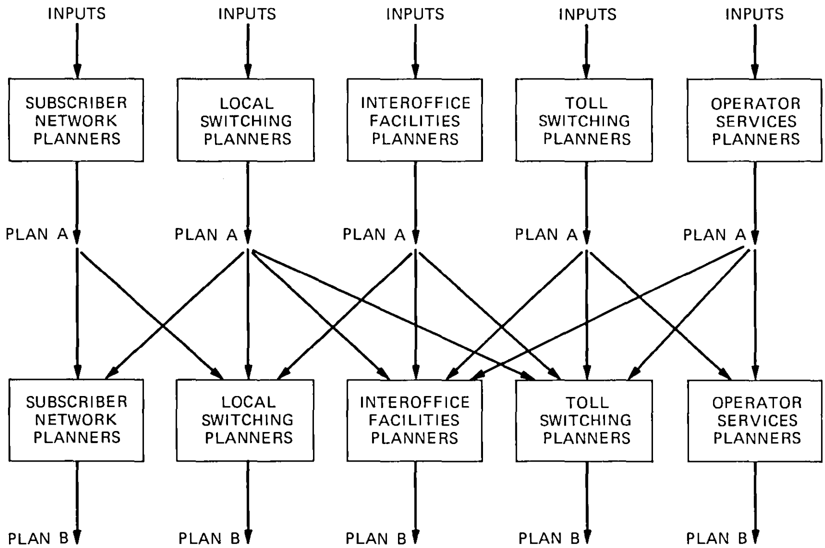


Fig. 2—Traditional approach to planning process.

forced joint-area planning studies. Remote switching, which requires a host office for centralized administration, a change in trunk routing patterns, and oftentimes a change in interoffice facilities, necessitates further joint planning studies. Figure 3 gives a broad overview of the process by which two or more planning disciplines join together for a common study. It is important to point out that most often these

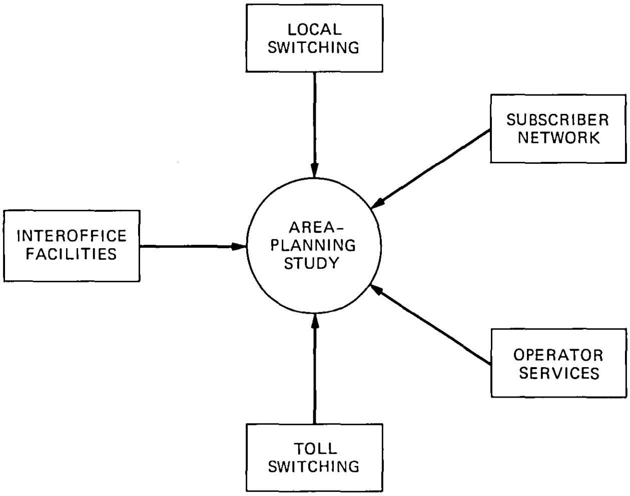


Fig. 3—Area-planning approach to planning process.

studies are made pairwise between disciplines, e.g., local switching and subscriber network, local switching and interoffice facilities, or toll switching and interoffice facilities. This process concentrates on the important interactions between disciplines, avoiding simultaneous study of all disciplines in great detail. The major elements in such a study include

1. Recognizing the problems, formulating alternative solutions, and coordinating assumptions with related disciplines.
2. Assessing which interactions (if any) are likely to be significant
   a. Performing a conventional, noninteractive study in those cases where no significant interactions are identified, or
   b. Performing interactive studies involving two or more disciplines as needed, where interactions do exist.
3. Documenting the conclusions and obtaining project approvals, where all affected organizations give their concurrence to the resulting plan.

Joint-area planning studies between disciplines have placed renewed emphasis on estimating total life-cycle costs of various network alternatives over the planning horizon. Not only should the initial cost of equipment be considered, but ongoing growth costs, operations expenses, administration expenses, maintenance expenses, building additions, distributing frame expenses, rearrangement expenses, and revenue from potential new services all contribute to identifying and evaluating the best network solution.

The remaining sections of this paper describe *5ESS* switch applications in more detail. Section II covers the application of integrated subscriber carrier and interoffice facilities for a single wire center. Sections III and IV cover the applications and interactions involved in network area planning. Section V discusses the application of the *5ESS* system in metropolitan areas.

II. WIRE CENTER AREA PLANNING USING THE *5ESS* SWITCH

As previously described, traditional local switching modernization studies were directed at comparing various switch replacement alternatives for individual wire centers. The modeling boundaries separating the local switch from the subscriber loop and interoffice facilities studies are shown in Fig. 4. Important factors included in these wire center modernization studies were switching equipment costs and capacities, maintenance costs, land and building costs, and feature availability.

2.1 Integrated subscriber carrier system planning

When modernization studies involve the *5ESS* switch as a replacement alternative, additional factors must be considered. Consider Fig.

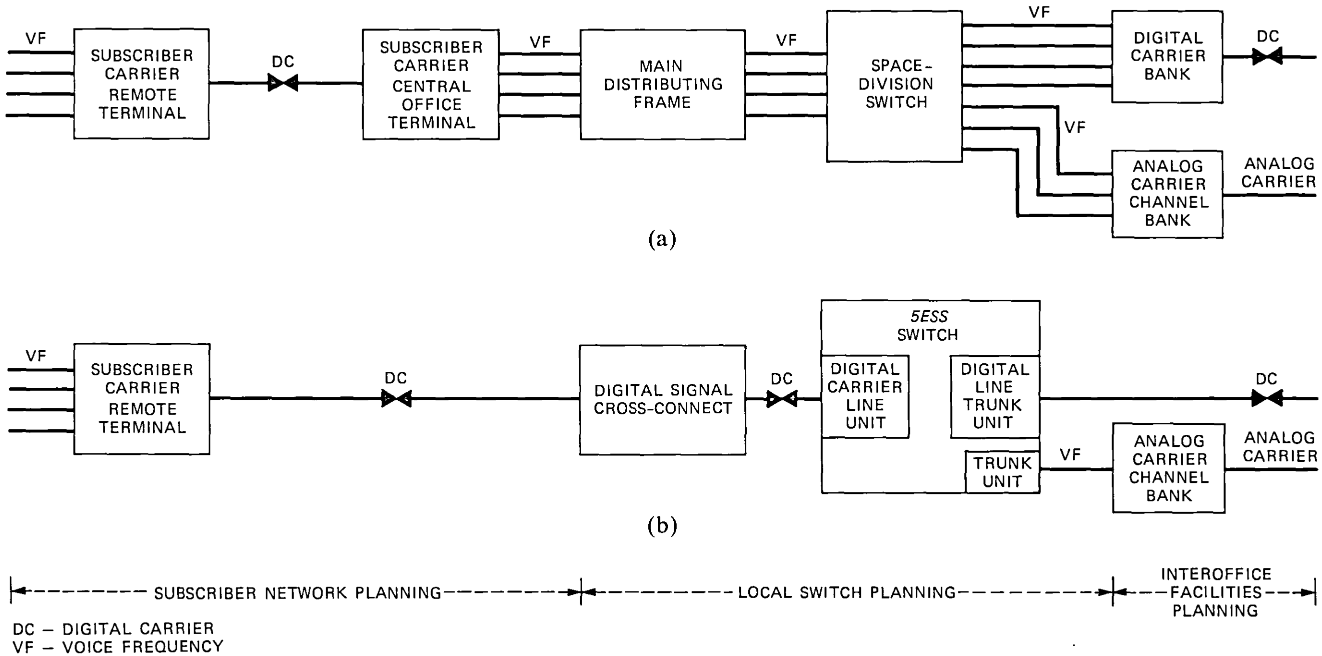


Fig. 4—*5ESS* switch integrated digital interfaces.

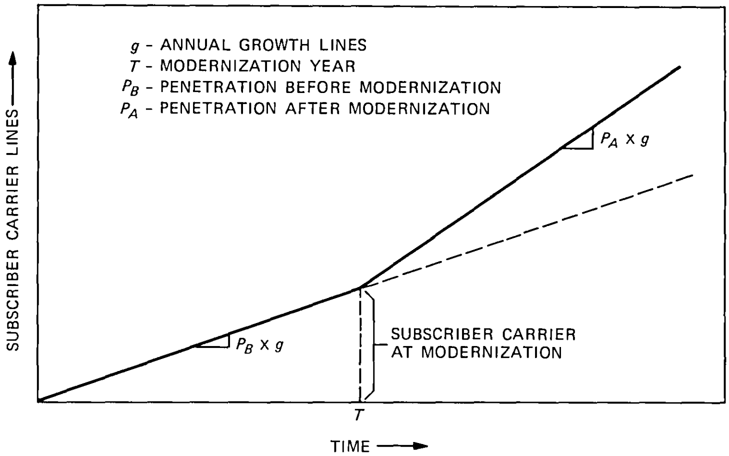


Fig. 5—Increased subscriber carrier penetration after modernization.

4, which shows a comparison of nonintegrated and integrated switching and transmission interfaces. Figure 4a shows that the main components of a subscriber carrier system in a conventional (nonintegrated) interface with an analog switch include the Remote Terminal (RT),* Digital Line (DL), and Central Office Terminal (COT). In contrast, Fig. 4b shows that the need for COTs is eliminated when interfacing a digital subscriber carrier system (such as the *SLC*® 96 carrier) with the *5ESS* system. The digital links from the RT terminate directly on a digital interface called the digital carrier line unit of the *5ESS* system. This arrangement obviates the need for individual subscriber line terminations on the Main Distributing Frame (MDF) and line terminating equipment on the switch.

Since the per-line termination cost of a subscriber carrier system is reduced when integrated with the *5ESS* switch, application of such systems can be economically justified in more areas. The increased penetration of the subscriber carrier systems illustrated in Fig. 5, at the time of modernization, results in additional savings by avoiding cable expansions and related structure costs. (See Refs. 3 through 6 for a detailed description of subscriber planning methods.)

In summary, the incremental capital-savings-per-growth line realized through termination of subscriber carrier systems directly on the *5ESS* switch versus termination on a central office without this capability is made up of the following five components:

1. Analog line termination savings
2. Reduced MDF termination costs
3. Elimination of the COT

* Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

4. Reuse credit for the COTs displaced at the time of modernization

5. Less distribution cable and structure (minus additional subscriber carrier electronics costs).

In addition, opportunities for reducing maintenance costs arise as a result of eliminating the COTs and reducing MDF frame activity for those working lines served by an integrated digital subscriber carrier system.

2.2 Integrated digital facility planning

Similar opportunities for cost reductions exist when terminating digital carrier interoffice trunks directly on the *5ESS* system. Referring again to Fig. 4, in the case of central offices with no integrated interface to digital facilities, digital carrier trunks terminate on digital channel banks and analog carrier trunks terminate on analog carrier banks. In the case of a *5ESS* switch, analog trunks terminate via analog channel banks and the *5ESS* trunk unit. For digital carrier trunks, the need to provide digital channel banks is eliminated and these trunks terminate directly on the Digital Line Trunk Unit (DLTU).

Potential savings from digital carrier integration on the *5ESS* system are a function of the facility strategy assumed at the time of modernization. The options include the following:

1. Continue the planned analog and digital trunk penetrations regardless of replacement switch type. This is typical of traditional planning studies.

2. Place all growth on digital facilities after the year of modernization but leave the existing analog plant in place.

3. Place all growth on digital facilities and replace existing analog carrier facilities with digital carrier in the year of modernization. This is the most aggressive digital strategy.

The major savings associated with integrated digital carrier on the *5ESS* system can now be summarized as follows:

1. Switch termination savings, i.e., the lower cost of terminating trunks on a DLTU versus terminating trunks on an analog interface.

2. Elimination of the need to buy digital channel banks for growth and the associated maintenance savings.

3. Reuse of the existing digital channel banks at the time of modernization.

4. Elimination of the need to purchase new analog carrier banks and the associated maintenance savings for facility strategies 2 and 3 outlined above. In addition, maintenance of existing analog carrier banks is eliminated under strategy 3.

Other considerations include reduced trunk testing costs associated with integrated digital carrier and additional rearrangement costs incurred at the time of modernization for segregation of digital special-service circuits that are not integrated with the switch.

2.3 An example wire center planning study

As an example, consider a crossbar local/tandem switching system with the following characteristics:

1. Size: 20,000 lines, 4000 trunks
2. Growth per year: 1000 lines, 300 trunks
3. Twenty-five percent of the growth lines are being placed on subscriber carrier systems each year to handle cable exhausts and subscriber line growth beyond 18,000 feet from the wire center. Ten percent of the lines are presently on the subscriber carrier.
4. Fifty percent of the trunks are presently served by digital carrier and 50 percent by analog carrier.

Consider replacing this entity with the *5ESS* local/tandem system in 1985. We want to compare this with the Present Method of Operation (PMO), which involves growing and maintaining the existing equipment to meet the new demands. The cost of the PMO in terms of first cost, life-cycle costs, and revenue requirements is a useful reference for comparing alternative plans.

The lower-cost integrated interfaces with digital subscriber carrier systems drop the subscriber carrier prove-in distance, after replacement, from 18,000 feet to approximately 12,000 feet from the wire center. Sixty percent of the new line growth demand can then be placed on subscriber carrier. Similarly, because of the integrated interface to digital carrier trunks, 100 percent of the new trunk growth is placed on digital facilities (strategy 2, discussed in Section 2.2).

Figure 6 shows an economic comparison of the two alternatives. The modernization plan using the *5ESS* switch is approximately 30 percent less costly in terms of life-cycle costs. Note that the integrated interfaces account for almost 80 percent of the net savings when comparing these two plans. Additional revenues result from Custom Calling Services and enhanced Centrex service offerings. In the past, large-scale studies performed by AT&T with the Operating Telephone Companies (OTCs) showed the switching/transmission synergies to be significant. In particular, South Central Bell developed a company-wide modernization plan for 240 step-by-step and crossbar entities in their regions.[7] The overall results showed that 16 percent of the total network savings were attributable to these synergies. The effect of the digital synergies is largely a function of the subscriber carrier and interoffice facility digital strategies.

2.4 New wire center planning using the remote switching module

The Remote Switching Module (RSM) is a *5ESS* switch module that is geographically separated from a host *5ESS* switch. The RSM

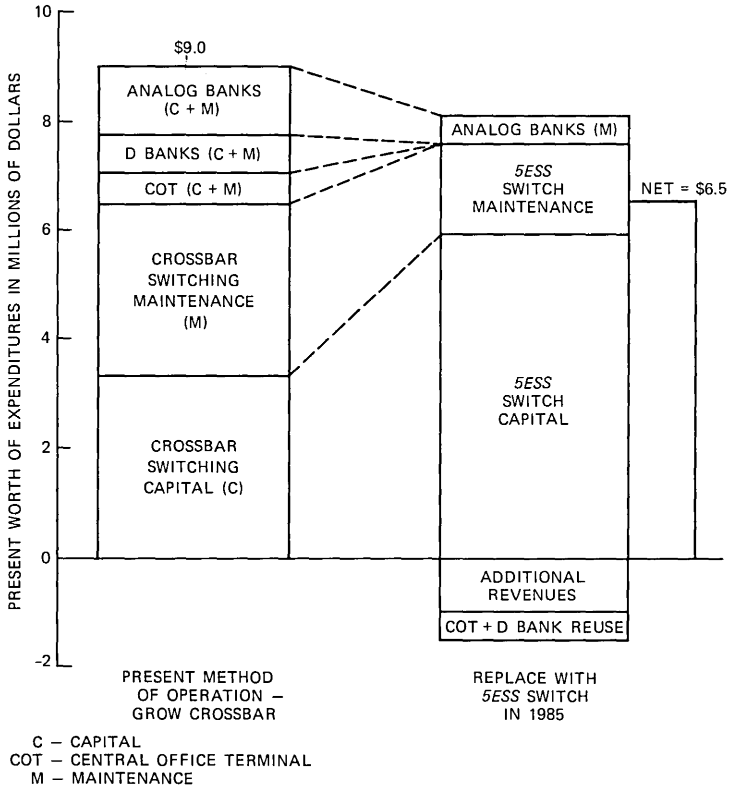


Fig. 6—Twenty-year life-cycle analysis.

module is linked to the host *5ESS* switch via digital carrier facilities. Reference 1 discusses the architecture of the RSM. The RSM is an ideal candidate for new wire centers and replacement of small step-by-step or crossbar switches.

When used to switch lines alone, the RSM can currently serve up to 4000 lines. Later in 1985, this capacity will be increased to 12,000 lines. It is possible to switch all traffic not contained completely within the RSM through the host *5ESS* switch. This approach is economical for small wire centers with small amounts of traffic to neighboring centers. The cost of the longer transmission path through the host is balanced by the higher traffic efficiency of larger trunk groups, and the elimination of trunk administration and maintenance costs at the RSM site.

However, an RSM can interface with analog and digital lines and trunks in the same way as a *5ESS* switch. Terminating analog or digital trunks on an RSM is often important for small offices offering Extended Area Service (EAS), where large volumes of interoffice traffic justify direct trunk groups to many adjacent class 5 offices.

Integrated digital subscriber carrier is also an important feature of an RSM. Subscriber carrier systems are more widely used in the remote locations for which RSMs will often be considered.

The RSM brings to the small office market all of the features offered by the *5ESS* switch, including new business and residence features. The RSM offers the wire center planner the following benefits:

1. The RSM can share the office code (NNX code) of the host office.
2. The RSM is administered and maintained centrally through the host switch. This reduces the staff requirements at the remote wire center.
3. The RSM architecture can grow from a single-switch module (serving up to 4000 lines) to a larger remote system with multiple-switch modules (serving 12,000 or more lines).
4. The RSM can grow into a *5ESS* switch by adding an administrative module and a communications module.
5. A *5ESS* switch can be converted to an RSM if a second *5ESS* switch is located within hosting range (approximately 100 miles, depending on transmission media).

The application of the RSM to a small but rapidly growing community is illustrated in Fig. 7.

III. NETWORK PLANNING USING THE *5ESS* SYSTEM

As discussed in Section II, the *5ESS* switch, coupled with digital subscriber carrier systems and digital interoffice facilities, provides new solutions to wire center evolution problems. The advantages of the *5ESS* switch are equally effective for those planning the evolution of a network[8] of local switches, tandem and toll switches, new wire centers, operator services, and the operations systems and centers that administer and maintain the network.

The principal benefits that the *5ESS* system offers to network planners are the following:

1. Remote switching. The RSM is a low-cost alternative to small office modernization that offers all the revenue potential of a *5ESS* switch. Because RSMs are monitored and administered through a host switch, the operation expenses of RSMs are much lower than stand-alone switches.
2. A remote switch that can grow into a *5ESS* switch. This keeps the getting-started cost low for small offices with a high growth potential. It provides the planner with a switch that can grow into a stand-alone switch when growth actually occurs, and provides safeguards for areas where growth rates turn out lower than expected.
3. An integrated Operator Service Position System (OSPS). The

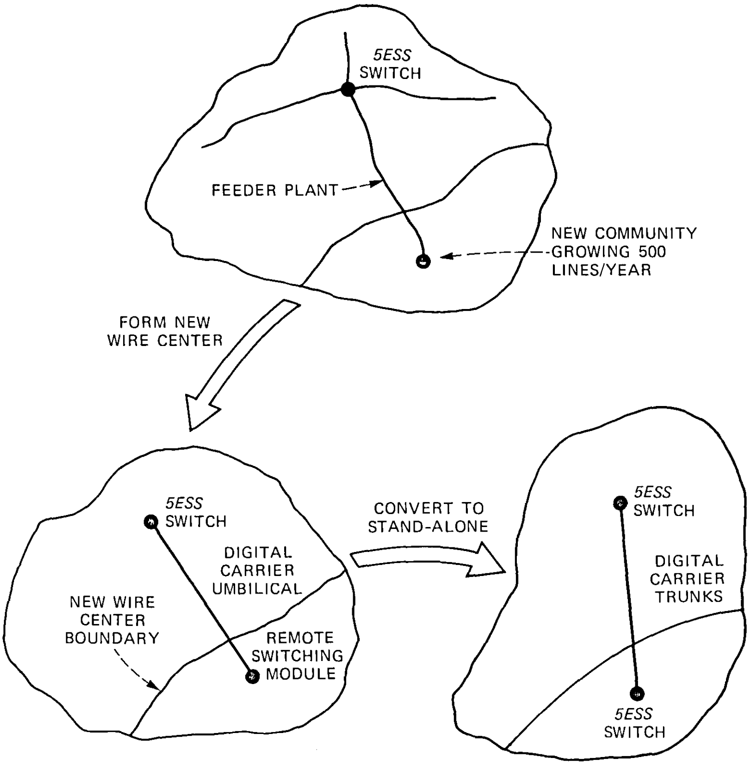


Fig. 7—Application of a remote switching module to a new wire center.

presence of OSPS will allow modernization and expansion of operator services when tandem and toll offices are considered for modernization. Since OSPS will be fully integrated into the toll and tandem *5ESS* switch, Operations, Administration, and Maintenance (OA&M) costs are reduced compared to a stand-alone operator system.

4. An integrated digital subscriber carrier (*SLC* 96 carrier) interface. This lowers the cost of deploying pair gain systems and provides an inexpensive solution to cable exhaust problems. In addition, several integrated subscriber carrier systems can be used to modernize very small Community Dial Offices (CDOs).

5. An integrated interface to digital carrier facilities. This lowers the cost of upgrading Voice-Frequency (VF) and analog carrier systems to a digital carrier.

6. Tandem and toll capabilities that allow the switch to serve as a combined local/tandem, pure tandem, or pure toll switch.

7. Remote toll and tandem switching capability. The RSM can be used as a small toll or tandem switch to serve inter-LATA (Local

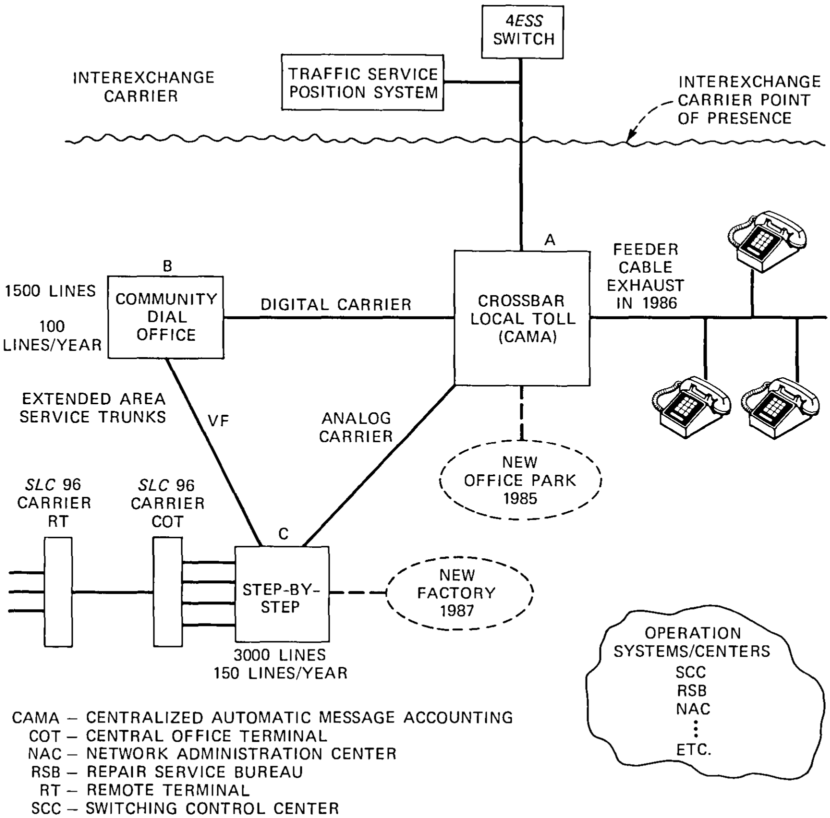


Fig. 8—A sample network planning problem.

Access and Transport Areas) or intra-LATA traffic in those areas where a stand-alone toll switch cannot be economically justified.

8. Integrated Services Digital Network (ISDN) capabilities. Integrated digital interfaces to digital loop and digital trunk facilities are leading to an integrated digital network. End-to-end digital services are being added to the network, providing new voice and data service revenues to the telephone companies.

The complexity of a network planning study varies with the size of the network being considered and functions included in the plan (e.g., operator services or tandem switches.). Such a study can be as small as a network of two or three interconnected switches or as large as the entire telecommunication network for a large city. To illustrate the application of the *5ESS* system to network planning, consider the network shown in Fig. 8. Assume that a group of OTC network planners have the responsibility of planning the evolution of this intra-LATA network and have the following objectives:

1. Modernize the entire network to provide new revenue-producing services to existing residence and business customers.

2. Introduce operator services into the exchange network.

3. Provide up-to-date business services to the new office park and factory.

4. Minimize the cost of the projected feeder cable exhaust in 1986.

5. Reduce OA&M costs.

6. Keep the economic impact on the rate payer (revenue requirements) as low as possible.

The network planner is faced with many possible approaches to the network problems in terms of network products and the timing of the network evolution steps. Typically, the network planners must examine many solutions to find the one that comes closest to satisfying all of the objectives. As discussed previously, one plan included in most network studies is the PMO. Although few of the planning objectives can be met with the PMO, the cost of the PMO is included for reference. One solution the planner might consider is shown in Fig. 9. The network is modernized over six years as follows:

1985

1. Replace the crossbar at office A with a new digital switch.
2. Lay a new feeder cable to office A.
3. Add a new operator service system.
4. Upgrade the facility between A and C to digital.
5. Add digital carrier banks at office C.
6. Establish a new wire center and switch at the office park.
7. Expand the operation center to support the new wire center and operator system.

1987

1. Replace the step-by-step at office C with a digital switch.
2. Remove digital carrier facilities from office C and reuse at office B.
3. Convert the VF facility between B and C to digital.
4. Expand the feeder cable to the new factory.

1990

1. Replace the 2000-line CDO at office B.
2. Remove digital channel banks.

Note that two feeder routes had to be expanded, the CDO at office B was too small to justify replacement until 1990, and the operation support centers and systems had to be expanded to support the new operator system and the wire center at the office park.

One possible approach using the *5ESS* system is shown in Fig. 10. The network is modernized over three years as described below:

1985

1. Replace crossbar at office A with a *5ESS* switch.

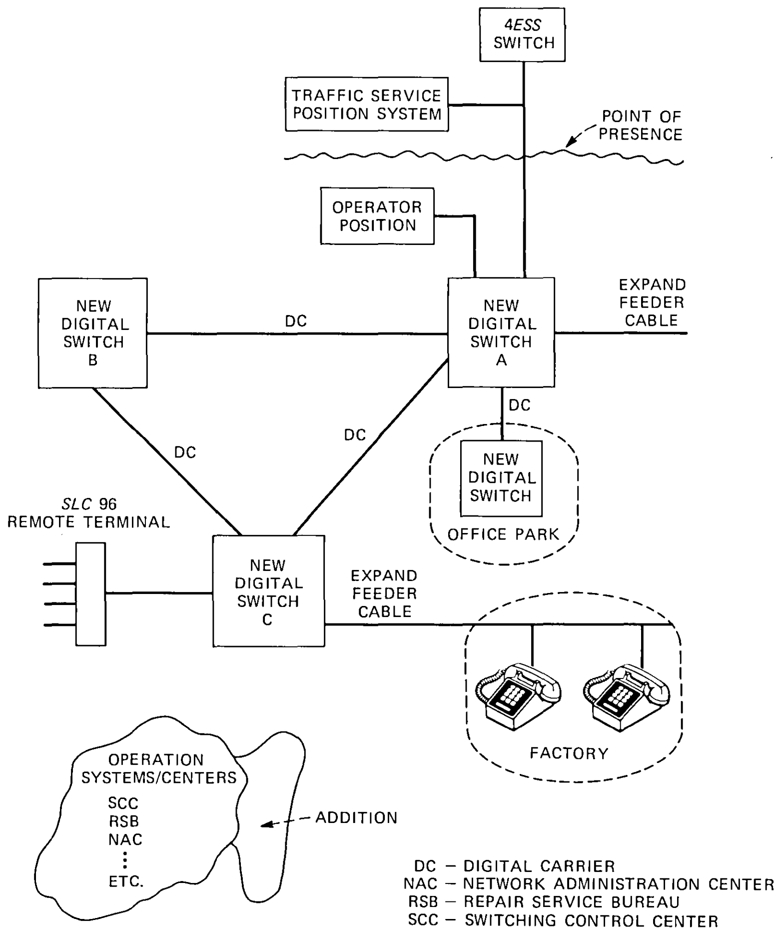


Fig. 9—Network plan 1.

2. Upgrade the facility between office A and C to digital.
3. Replace step-by-step at office C with an RSM (begin collecting new service revenues).
4. Replace CDO at B with an RSM (begin collecting new service revenues).
5. Upgrade the facility between B and C to digital.
6. Add RSM in the office park.
7. Reduce operation center staff due to consolidation of operations support of offices B and C at office A.

1986

1. Deploy integrated *SLC* 96 carrier from office A to avoid feeder exhaust.

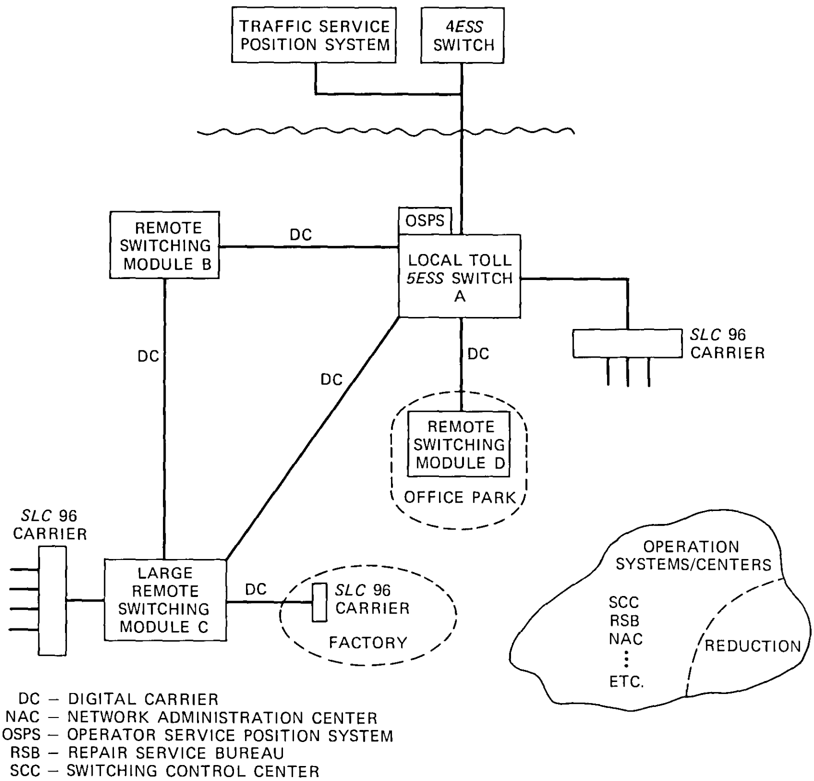


Fig. 10—Network plan 2—applying the *5ESS* switch.

1987

1. Deploy integrated *SLC* 96 carrier at the new factor to avoid feeder cable expansion.
2. Expand *5ESS* switch at office A to include operator function.

All offices are replaced in 1985 to achieve maximum new revenue potential and to avoid unnecessary purchases of nonintegrated digital channel banks. If capital constraints in 1985 prevent modernization of all offices in one year, offices B and C could be scheduled in later years. Since the RSMs in B, C, and D, as well as the operator system at A, are operated and administered through the *5ESS* switch at A, the load on operation center staff and the operations support systems will be reduced. Feeder exhausts in 1986 and 1987 are avoided by using integrated subscriber carrier systems. The *5ESS* system allows all business features to be extended over the subscriber carrier lines to the new factory location. Note that the RSM at offices B and C can either continue to direct trunk the EAS traffic or route traffic through the host *5ESS* switch.

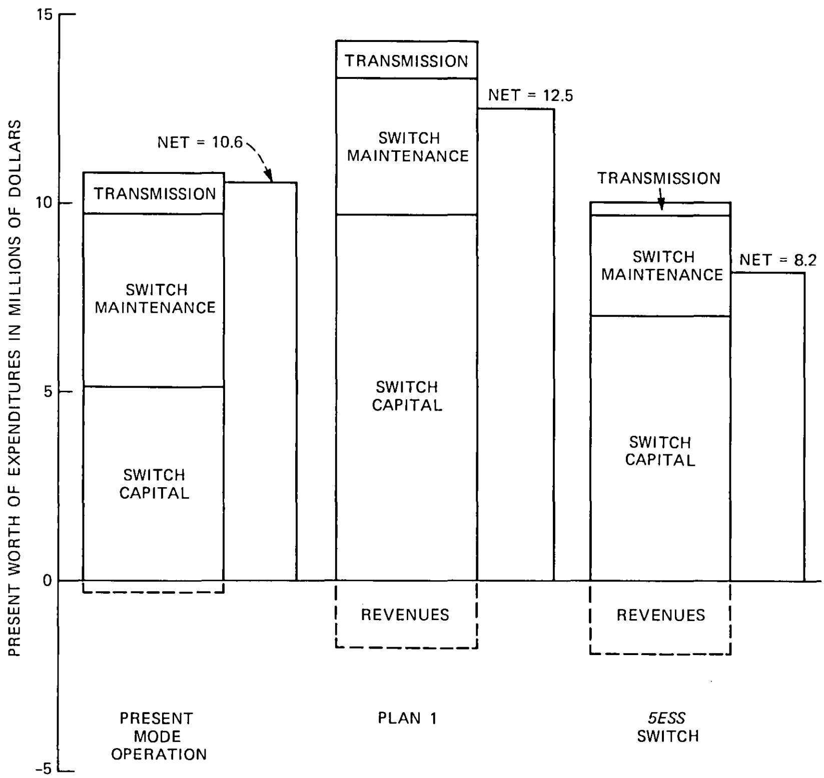


Fig. 11—Life-cycle economic analysis (1984–2000).

To evaluate the alternative network evolution planning strategies, it is necessary to use life-cycle economic techniques together with annual capital constraints. A first-cost analysis could point to solutions that in the long term are far from optimum. As an example, Fig. 11 shows an economic comparison of the three alternatives considered. The *5ESS* system alternative is the least costly alternative over the study period. While the switching capital is greater than the PMO, the plan realizes more new service revenues from the earlier modernization of the offices, and significantly lower maintenance and administration expenses. The *5ESS* system plan also avoids the capital cost associated with feeder route expansions. Note that the first plan with all stand-alone digital switches is not economically preferable to the PMO.

IV. OTHER NETWORK APPLICATIONS

In addition to solving local network problems as illustrated in Section III, the *5ESS* switch can be used in pure toll networks and to implement an access tandem network.

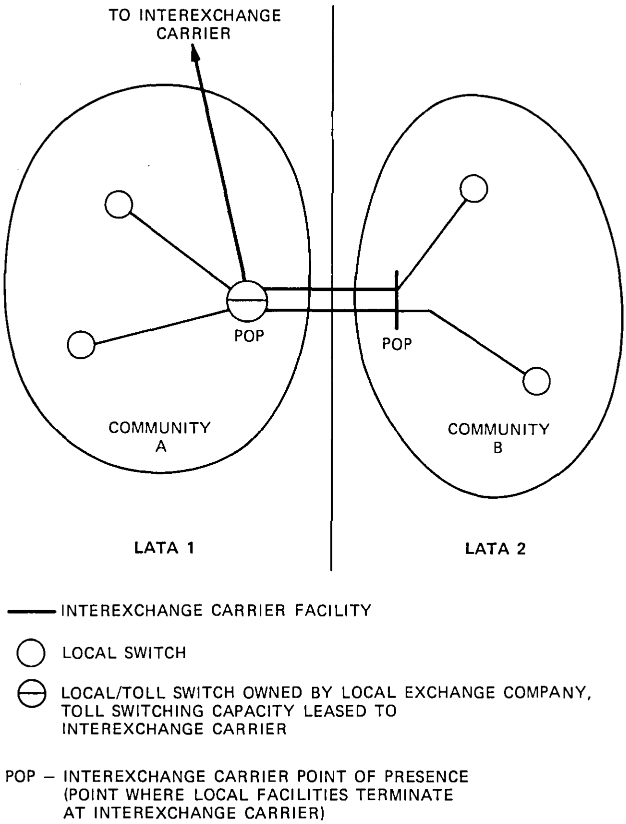


Fig. 12—A sample inter-LATA network.

4.1 Toll networks

Toll switches are used by Interexchange Carriers (ICs) to transport traffic between LATAs. The *5ESS* switch with its complement of toll features and its distributed architecture can provide new solutions to toll switching network problems. As an example, consider the network shown in Fig. 12. As a result of the Bell System divestiture, communities A and B fell on different sides of a LATA boundary. An IC is therefore required to provide service between them, according to divestiture rulings, and is leasing toll switching capacity and facilities from local exchange companies. Communities A and B are forecasted for continued growth and the local/toll switch is planned for replacement by the local exchange company. The IC wishes to establish a separate toll switch to handle larger forecasted toll traffic volumes. However, current traffic levels do not justify a large switch. An RSM serving as a small toll switch is a good candidate and is shown in Fig. 13. This need for small toll switches is common along LATA boundaries and along

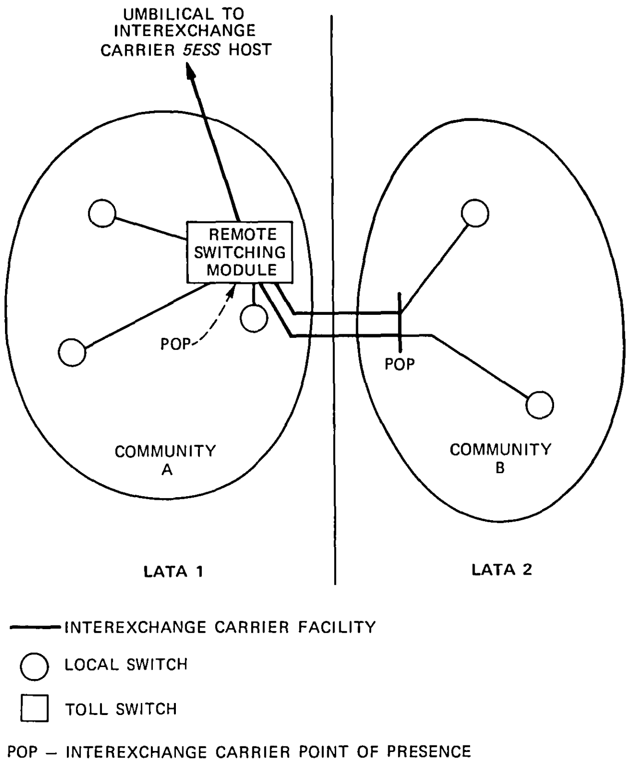
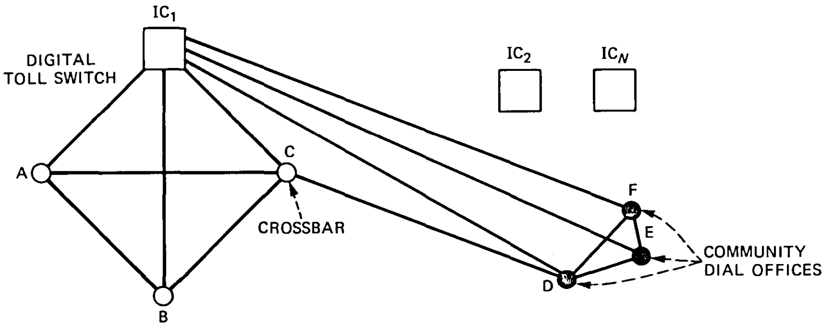


Fig. 13—Applying the *5ESS* switch to an inter-LATA network.

international boundaries where nearby towns have strong communities of interest but lie in different toll areas.

4.2 Tandem networks

A primary need of telephone companies in the postdivestiture environment is for access tandem switches. These switches serve as an interface between the local switches and ICs. Access tandems concentrate the interexchange calls from local offices and route these calls to the proper IC. Consider the network shown in Fig. 14. Today the network consists of six local switches, each having toll trunks to a digital toll switch owned by IC_1. IC_2 through IC_N also wish to provide service. The telephone company can put in trunks from each local switch to each IC or it can establish an access tandem network. Unless the traffic between each local switch and IC is initially large, direct trunk groups are difficult to justify economically. Indeed, if the traffic to the ICs—other than IC_1—is small but growing, significant savings can be realized by sending this traffic to a tandem where all

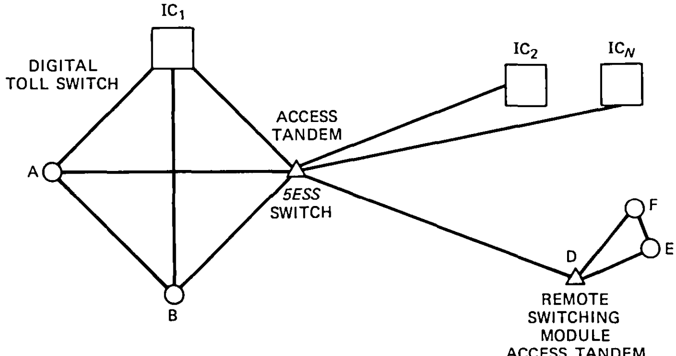


IC – INTEREXCHANGE CARRIER

Fig. 14—A sample access tandem network.

the traffic for ICs is consolidated and then trunked. In our example, we will replace office C with a *5ESS* switch and establish it as an access tandem. In addition, we will replace the small CDO at office E with an RSM and it too can serve as an access tandem. The result is shown in Fig. 15.

Note that some of the larger local offices shown will continue to trunk traffic to IC_1 over direct groups, since the amount of traffic can justify direct trunking. All local switches, however, use the *5ESS* switch (directly or via the RSM) to access IC_1 through IC_N. In fact, some of the smaller offices now use the access tandem to route traffic to the digital toll switch of IC_1. This solution saves significant facility costs, helps modernize the local switches, and provides for an efficient tandem switching structure that can flexibly accommodate uncertain, yet growing, IC traffic demands.



IC – INTEREXCHANGE CARRIER

Fig. 15—Applying the *5ESS* switch to access tandem network.

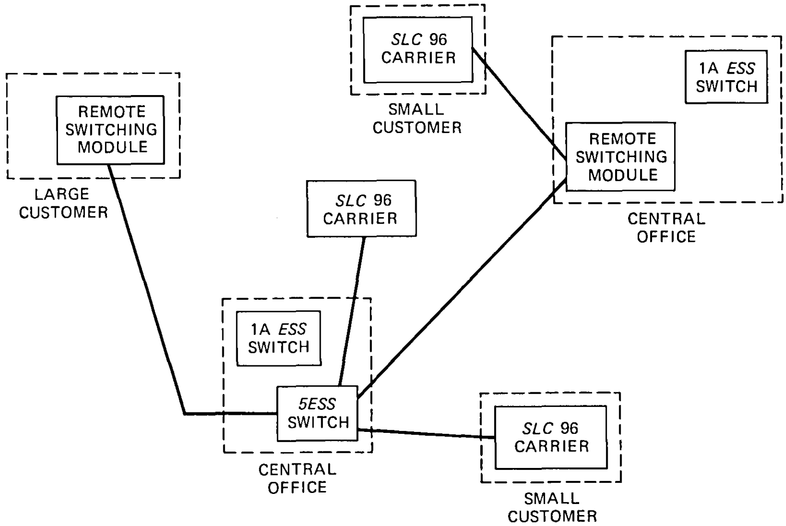


Fig. 16—Digital access networks.

V. MODERNIZING METROPOLITAN AREAS

Many metropolitan areas are dominated by the presence of the 1*ESS*™ and 1A *ESS* systems, which have replaced most of the large electromechanical offices in these areas. These are advanced stored program control switches with a rich set of business features. One might be led to conclude that the application of the *5ESS* switch to these areas will consist of completing the replacement of the remaining electromechanical switches. However, the following are two additional types of application for which the *5ESS* system is ideally suited:

1. Deployment of digital access networks
2. 1*ESS* system replacement.

5.1 Digital access networks

A digital access network is an overlay network consisting of the *5ESS* system, digital loops, and digital remote switches. Figure 16 illustrates the concept. The objective is to locate new technology where it is needed, to provide ubiquitous access to digital networks for any customer in the area, and to provide a cost-effective and minimum-capital solution without requiring the replacement of Stored Program Control (SPC) technology.

This technique may become more popular in the future with the development of optical remote modules, where fiber lightguide interconnects the hosts and remotes and where fiber is extended into the loop plant with such systems as Fiber *SLC* 96 carrier. The trend in some metropolitan areas is towards fiber backbone routes and fiber

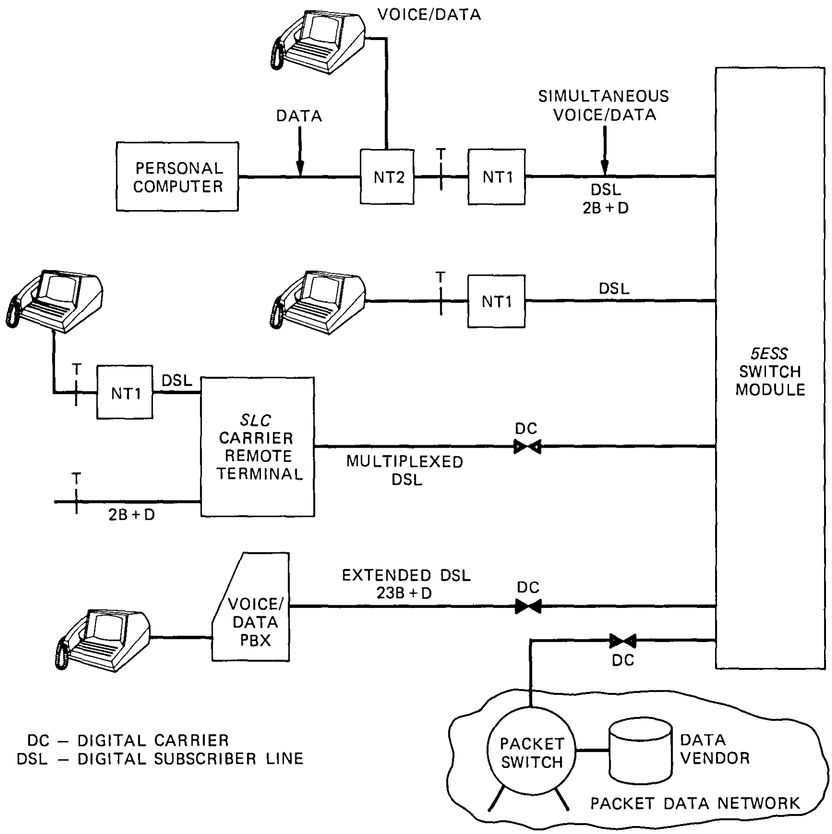


Fig. 17—ISDN access arrangements.

rings. This trend coupled with optical remote switches will accelerate the deployment of digital access networks.

The initial applications of the *5ESS* switch will be replacements of those electromechanical systems that are colocated with other SPC switches. Rather than replacing them by consolidation with the SPC switch, the *5ESS* switch technology can be placed in the existing SPC wire center. From here the digital access network will begin.

5.2 *1*ESS *system replacement*

Many 1*ESS* systems are relatively small, but are experiencing growth. They demand new features and capabilities available only on the 1A *ESS* system or new time-division digital systems like the *5ESS* switch. In these instances, with high subscriber carrier penetration, and the ability to reuse the line and trunk link networks of the 1*ESS* system, the replacement of the 1*ESS* system can be economically justified.

5.3 Evolving the network towards ISDN

The *5ESS* system, with its integrated digital interfaces to subscriber carrier systems and to digital carrier trunks, is helping to lead the way to an ISDN where there are no analog to digital conversions. When end-to-end digital services are added to this network, the ISDN can be realized. ISDN interface standards are being defined by the International Telegraph and Telephone Consultative Committee (CCITT) and by the Exchange Carrier Standards Association. Figure 17 shows the potential access arrangements for Digital Subscriber Lines (DSLs), extended DSLs to digital private automated branch exchanges, and multiplexed DSLs over integrated subscriber carrier systems. Current *5ESS* switch plans call for development of ISDN capabilities that incorporate both circuit switching for voice traffic and packet switching for data traffic. These capabilities will lead the way to simultaneous voice and data applications across the network, accelerating the trend towards end-to-end digital networks and services.

VI. CONCLUSION

This paper demonstrates that the *5ESS* switching system provides planners with the major building blocks needed to evolve today's network into a digital network offering end-to-end digital services. The modularity of the *5ESS* system design, coupled with the ability to distribute control to remote switching modules, offers new low-cost solutions to long-standing network problems (e.g., small office modernization). It provides new ways to affect the evolution of the entire telecommunications network (e.g., local switching network, access tandem networks, interexchange carrier network, operator services). Low-cost interfaces between the *5ESS* switch and digital loop systems and digital transmission facilities allow network planners to convert the network from analog to digital gracefully.

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The 5ESS *Switching System:*

Architectural Overview

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(Manuscript received December 12, 1983)

This paper presents an overview of the *5ESS*™ system architecture. The administrative, communications, and switching modules are described, together with an overall view of the software architecture. Operations and maintenance aspects and a short discussion of evolutionary trends are covered.

I. *5ESS* SYSTEM ARCHITECTURE

The *5ESS* system architecture was conceived to satisfy the goals set forth in the introductory paper.[1] This architecture incorporates a combination of distributed and centralized control to produce a robust system that will meet present and future switching needs.

The hardware architecture, shown in Fig. 1, has three major components:

- An Administrative Module (AM),‡ which provides systemwide administration, maintenance, and resource allocation.
- A Communications Module (CM), which provides a hub for distributing and switching voice or digital data, control information, and synchronization signals.
- One or more Switching Modules (SMs), which provide local switching and control functions, and the interface to subscriber lines and interexchange circuits.

* AT&T Bell Laboratories. † AT&T Network Systems.

‡ Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

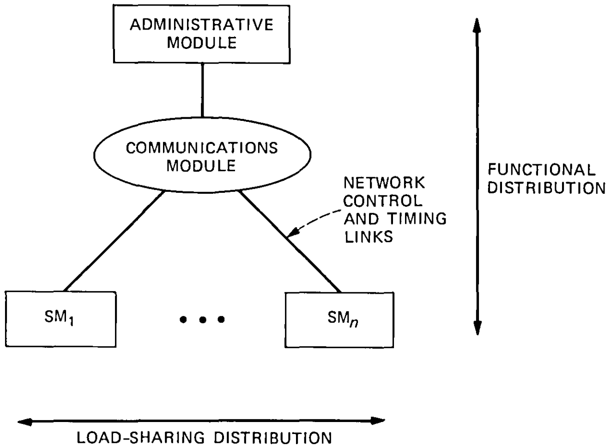

Fig. 1—*5ESS* system distributed architecture.

The following sections describe the functions of these subsystems and their interrelationships. In addition, they discuss the Remote Switching Module (RSM) and the subscriber carrier system.

1.1 Administrative module

The AM provides the system-level interfaces required to operate, administer, and maintain the *5ESS* switch. It performs functions that can most economically be done globally, such as common resource allocation and maintenance control (see Fig. 2). For reliability the Administrative Processor (AP), currently an AT&T 3B20D computer (see Ref. 2), is fully duplicated, and the two processors work in an active/standby configuration. In normal operation the active processor has control and, at the same time, keeps the data in the standby up to date. Thus, when a fault occurs in the active processor, the standby is switched into service with no loss of data.

The AM performs many call-processing support functions, including systemwide craft maintenance access, diagnostic and exercise control and scheduling, software recovery and initialization, and certain fault-recovery and error-detection functions best done on a centralized basis. Within the AM there is error-checking circuitry for detecting and isolating faults. The AM also performs administrative functions and provides software access to external data links and to disk storage.

Today the call-processing functions of the AM consist of routing and resource allocation. Routing involves the determination of the SM on which the terminating line or trunk appears and the selection of an available trunk in a trunk group. The AM also allocates and releases global resources, such as Time-Multiplexed-Switch (TMS) time slots.

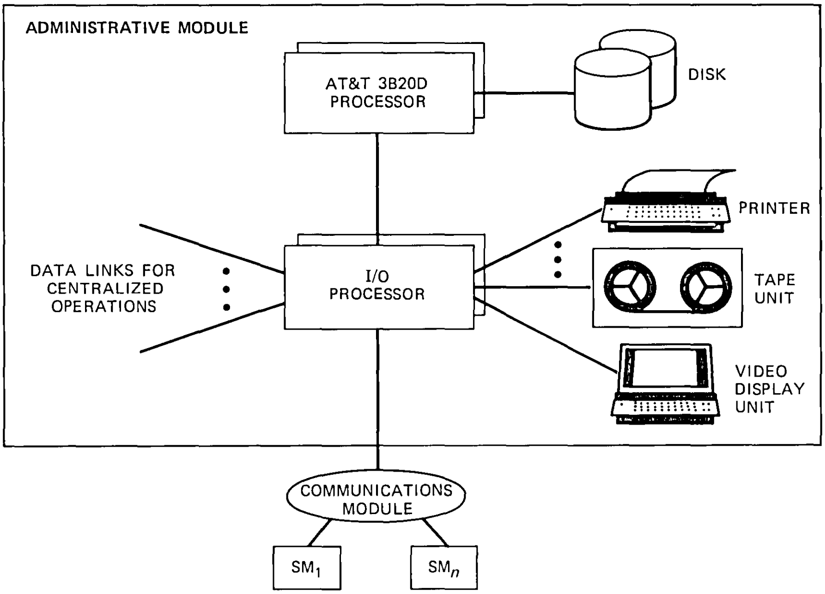

Fig. 2—Administrative module.

A disk memory provides flexible mass storage for programs and data. When needed, these programs and data are transferred to the main memory in the AP or to the memories in the SMs. In the unlikely event of a duplex system failure, the disk also provides rapid program and fixed-data recovery, as well as retention of billing data.

The I/O Processor (IOP) is a subunit of the AM. It is equipped with a scanner/signal distributor, which accommodates functions such as major building and office alarms. Interfaces with operations support systems, video display units, hard copy printers, magnetic tape drives, and a Master Control Center (MCC) are also provided through the IOP.

The MCC provides the human-machine interface for the *5ESS* switch. This includes displaying the system status and providing manual control over system operations. Telephone companies have the option of using (1) a language similar to that used in the 1A *ESS*™ system or (2) the new International Telegraph and Telephone Consultative Committee (CCITT) standard craft interface language (MML). The craft interface also supports an extensive color graphics display of system unit status as well as a menu-based command and control language.

1.2 Communications module

The basic function of the CM is to provide consistent communication between the SMs, and between the AM and the SMs. The Message

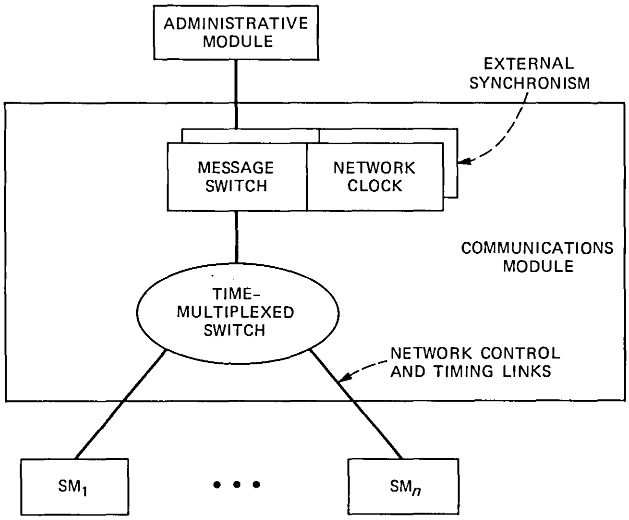

Fig. 3—Communications module.

Switch (MSGS) transfers call-processing and administrative messages between the SMs and the AM, and between any two SMs (see Fig. 3). The MSGS performs a packet-switching function within the *5ESS* switch utilizing CCITT X.25 level-2 protocol to transfer control messages through the CM and its terminating Network Control and Timing (NCT) links. This protocol includes error detection, positive message acknowledgment, and message retransmission in the event of a transmission error. An MSGS can support a combined total of 48 SMs and RSMs. A current development will allow the MSGS to grow and support nearly 200 SMs.

The message interface and clock unit also provides the clock that synchronizes the time-division network. This clock can be synchronized through an external source or run on an internal reference basis with periodic updating. The *5ESS* switching network uses a time-space-time architecture. As illustrated in Fig. 4, a Time-Slot Interchange Unit (TSIU) in each SM performs the time-division switching; the TMS in the CM performs the time-shared space-division switching. At each interface unit the outputs from lines and trunks are converted into 16-bit time slots. These bits are used for signaling, control, and parity, and for binary-coded voice or data. The time slots are switched through the Time-Slot Interchanger (TSI) and time multiplexed into NCT links of the TMS.

The TMS is a single-stage switching network that provides the digital paths for switched connections between the modules and for control messages among modules. The TMS interconnects the modules through the NCT links.

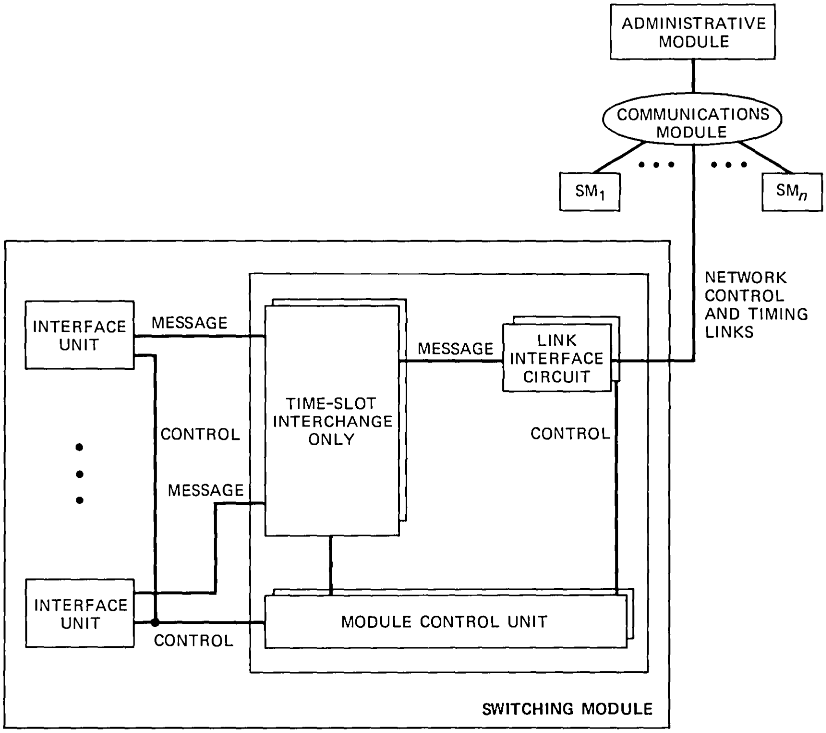

Fig. 4—Switching module.

The NCT links use fiber lightguides. This new technology offers high-data-rate capacity and simple interconnection to switching modules. Compared with conventional cables, the fiber lightguide requires substantially fewer cables to interconnect the various units in the system, simplifying growth procedures. System reconfiguration equipment for maintenance is also reduced. Further, the fiber lightguides are not susceptible to electromagnetic interference and do not create electrical noise.

Each NCT link carries 256 channels (time slots) of multiplexed data in a 32.768-Mb/s serial bit stream. One of the time slots carries control messages, and the remaining 255 time slots carry digitized voice or data. Additional voice/data time slots can be temporarily assigned to the control function in order to transfer large amounts of data. Two NCT links are associated with each module, thus allowing 512 time slots to be routed to and from the TMS. Setting up a path between a line or trunk on two SMs involves finding an idle time slot on one of the NCT links to each SM. A path is then set up through the TMS between these two NCT links on the selected time slot. The TSIU in each SM will establish a path between the chosen NCT time slot and the peripheral time slot associated with the line or trunk.

1.3 Switching module

SMs provide call-processing intelligence, the first stage of switching network, and line and trunk terminals. As a result, the SM is the primary growth unit of the *5ESS* switch (see Fig. 4).

SMs may differ in the types and quantities of interface equipment they contain, depending upon the characteristics of the lines or trunks terminating thereon. Certain equipment is, however, common to all SMs. The common equipment includes a pair of dual-link interfaces, duplicated module processor units, duplicated TSIUs, and a digital services unit. The dual-link interface provides a two-way interface between each SM and the TMS in the CM. The duplicated Module Processors (MPs) control call processing, call distribution, and maintenance functions.

The TSIU contains a signal processor, which handles address and signaling information, and a control interface, which distributes control signals to and from the interface. The TSIU switches time slots between the interface units in an SM and connects time slots from the interface unit to time slots on NCT links. The TSI switches 512 time slots—256 from each of the active NCT links—and 512 peripheral time slots from the interface units. The TSI can connect any of its 512 peripheral time slots to any other peripheral time slot, or to any time slot of either NCT link to the TMS. A local digital services unit provides tone decoding and tone generation capabilities.

A variety of interface units are available in the *5ESS* system. Line units (LUs) provide interfaces to analog lines. Trunk Units (TUs) provide interfaces to analog trunks. Digital Line Trunk Units (DLTUs) provide interfaces to digital trunks and remote SMs, while Digital Carrier Line Units (DCLUs) provide the interface to remote subscriber loop carrier systems. Each SM can accommodate any mixture of these units, with up to 510 channels. Two time slots are used for control.

The LU terminates all of the facilities that are typically categorized as lines, including coin lines and private automatic branch exchange lines. Each terminal can be used for any type of line.

The connection of a line to the *5ESS* system requires the BORSCHT functions: battery feed, overvoltage protection, ringing, supervision, (digital) coding and decoding, hybrid, and testing. Ringing and test functions are provided by high-level service circuits. Channel circuits, which are shared through a concentrator, provide the other BORSCHT functions.

A concentrator, using a solid-state crosspoint network, connects the line terminations and the channel circuits. The crosspoint network consists of newly developed Gated Diode Crosspoints (GDXs) that can withstand the high voltage required for ringing and line testing. As a result, all connections are made electronically, without the use of relays. The concentrator can be provided at 8:1, 6:1, and 4:1 concentration ratios. The concentration ratio can be changed by simply adding or removing plug-in units. These ratios can be mixed within an office if needed. An LU can serve a maximum of 512 lines with an 8:1 concentration ratio.

The TU terminates interoffice trunks, and trunks to operators and to announcement circuits. A TU has 64 data channels and terminates up to 64 voice frequency trunks (that is, trunk traffic is not concentrated). The circuits in a TU are divided into two general categories: trunk circuits and common circuits. Each trunk has an associated trunk circuit, which includes digital coding and decoding, dc signaling, and test access functions. Common circuits are associated with groups of 32 trunks. The functions performed by these circuits include testing, alarming, and multiplexing.

The DLTU provides direct interfacing with digital facilities using 1544-kb/s (24-channel) or 2048-kb/s (30+2-channel) pulse code modulation transmission. A DLTU may terminate up to ten 1544-kb/s digital lines or sixteen 2048-kb/s digital lines.

A DLTU contains a number of Digital Facility Interfaces (DFIs). The DFI is the interface between the digital transmission facility and the *5ESS* switch. Like an analog line or TU, each DFI interfaces to each TSIU by means of peripheral interface control and data buses. The DFI aligns frames; detects alarms, framing errors, and slips; and notifies the module processor when a trouble condition or error threshold is reached.

1.4 Remote switching module

The *5ESS* system can serve remote customers with the same features and services provided to local customers. This capability is provided by the RSM, which can be located as far as 150 kilometers from the host exchange, while still meeting transmission objectives (see Fig. 5). The RSM consists of standard SM hardware augmented by circuits to terminate the digital facilities that connect it to the host exchange. The NCT links at the RSM are converted to T1 data format and transmitted across T1 facilities that terminate on an SM at the host location. The RSM can provide service to a maximum of 4096 lines with a concentration ration of 8:1.

The number of equipped digital lines between the RSM and its host is primarily determined by traffic characteristics. A minimum of two digital lines is presently recommended to provide reliable transport to the host. A maximum of either twenty 1544-kb/s lines with 24 channels

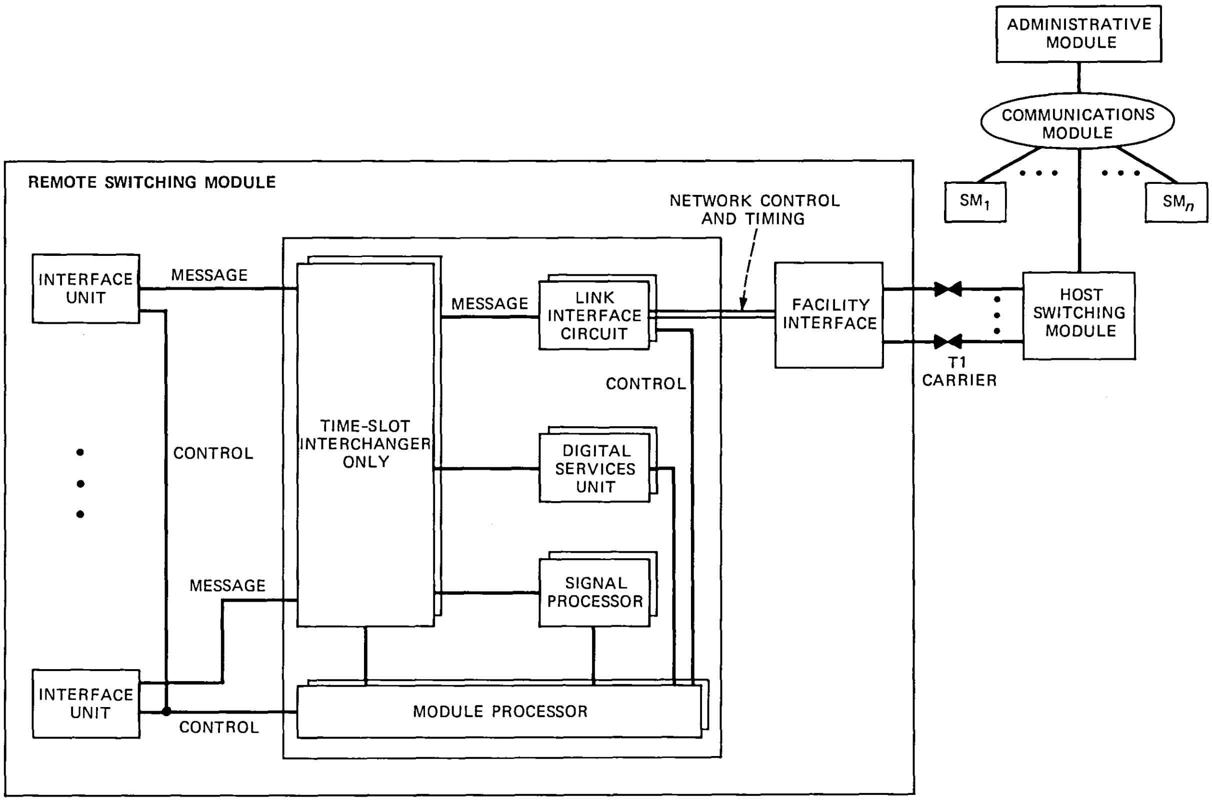

Fig. 5—Remote switching module.

or sixteen 2048-kb/s lines with 30 channels can be utilized to serve traffic between the host exchange and the remote site.

During the normal mode of operation, the RSM is connected by control and data links to its host system. Direct trunks to other offices are also supported. In the rare event of a total transmission failure, the RSM can process calls to lines directly connected to it and over the direct trunks. This processing is called *stand-alone* operation.

During the transition to or from stand-alone operation, intra-RSM calls will be maintained to minimize call cutoffs. Normal dialing patterns will be accepted. When it is not possible to process a request (because the call is destined for lines reached through the host or because features require host resources not available at the RSM), the subscriber will be connected to reorder tone or to a recorded announcement.

In stand-alone operation, the RSM provides access to emergency services, such as police, that normally would be accessed through the host. This provision is implemented independently of the normal links between the RSM and its host.

1.5 Subscriber loop carrier system

The *SLC*® 96 carrier system is a digital loop carrier pair gain system[3] designed as a supplement or replacement for cable. The *SLC* system serves up to 96 subscribers over T1 transmission facilities.

The *5ESS* switch provides a digital interface to the *SLC* 96 system either from an RSM or directly from a local SM. A mechanism for performing spare digital line switching is available in either arrangement. The direct interface between *SLC* 96 system remote terminals and the *5ESS* switch is provided by the DCLU.

II. *5ESS* SOFTWARE ARCHITECTURE

2.1 Software design strategies

For a large software system such as the *5ESS* switch, with its stringent requirements for performance, reliability, maintainability, extensibility, and life-span, it is of paramount importance to define a modular software architecture that exhibits unity of design. The structural integrity of such a software architecture can be preserved by establishing a set of strategies and then using them as guiding principles throughout the design of the software architecture, as well as during the entire life of the system. The most important strategies used in the definition of the *5ESS* software architecture are as follows:

1. Hierarchy of virtual machines—The concept of structuring the software as a set of layers (levels) of abstraction, each defining a virtual (abstract) machine, has been employed in the design of *5ESS*

software architecture. The resulting software structure takes the form of a hierarchy of nested virtual machines.

2. Software modularity—The software implementing each virtual machine is in turn partitioned into modules. A software module is a functionally coherent unit with well-defined interfaces, whose implementation is hidden from all other modules. The changes to its implementation algorithm are transparent to all modules using it.

3. Module portability—The software modules are coded in a high-level language, permitting the object code to run on a variety of target processors. Combining this with the other aspects of the software structure allows modules to be moved among the many system processors (e.g., AP to MP) in order to optimize performance.

4. Distribution of control and data—The distribution of both control and data represents a major software design strategy for implementing the distributed architecture of the *5ESS* switch. Functions and their related data are distributed among the modules providing terminal services (e.g., SMs) and modules providing global services (e.g., the AM).

5. Loosely coupled network—Another important strategy is the design of the *5ESS* switch as a network of loosely coupled modules connected via data links. The processor in each module has its own view of the network and functions consistently with that view. Although loosely coupled, the interfaces among modules are well defined.

2.2 An overview of the software architecture

The *5ESS* software architecture is defined as a hierarchy of nested virtual (also called abstract or logical) machines that spans all processors. The hierarchy is made of a number of virtual machines structured as sequential layers, each using the services of the lower machines and providing additional services for the higher machines. This hierarchy is general, in the sense that a given machine can use the services of any lower machine, not just those of the machine immediately below it. When this view is extended to the entire system, the hardware can be represented as yet another layer at the bottom of the hierarchy, called the physical machine. This layer consists of the processors with their peripherals and is traditionally referred to as the "bare machine" (see Fig. 6).

Most of this software is written in the high-level language C. There are several types of processors controlling each physical module. These include customized microprocessors, an MC68000 chip,[4] and an AT&T Technologies Digital Signal Processor in the SM, an 8086 in the CM, and the 3B20D in the AM. Associated with each control processor is an operating system running on the bare machine and a number of virtual machines that run on the operating system and provide more specialized services.

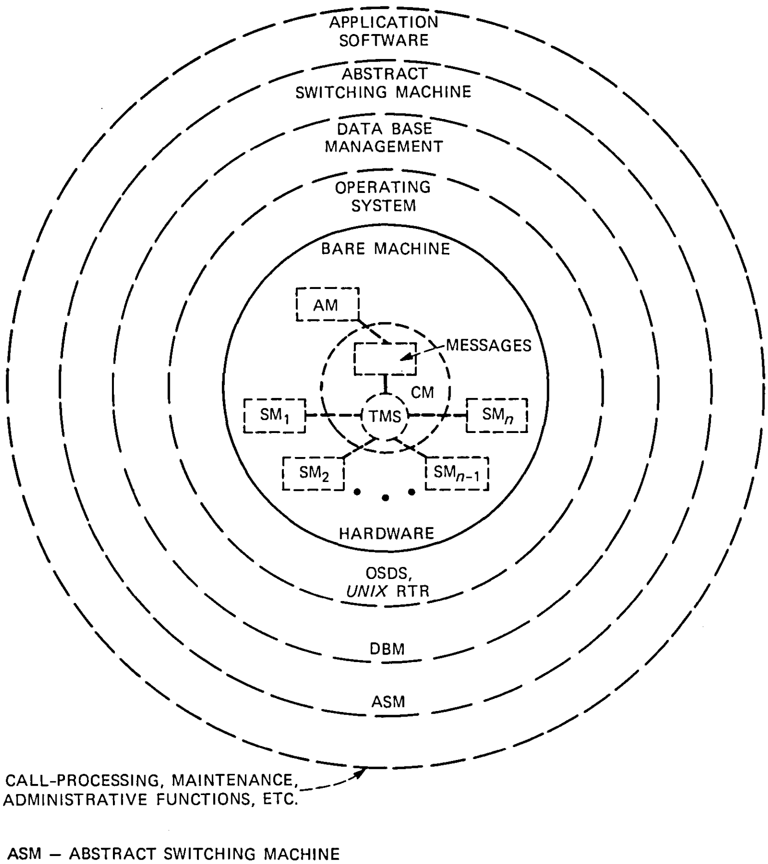

Fig. 6—Software architecture.

The operating system in each processor creates the environment for the concurrent execution of a number of processes by scheduling and synchronizing these processes, providing services in the form of primitives, and managing system resources. The operating system running in the SMs is called Operating System for Distributed Switching (OSDS) and is specially designed for switching applications in a distributed architecture. In the AM there is a general real-time operating system developed for the 3B20D computer, called the *UNIX*™ Real-Time Reliable (RTR) operating system, as well as OSDS, running on RTR in the form of several processes and providing for other "inner" processes an environment similar to that found in OSDS-SM. The OSDS executing in the AM is identified as OSDS-AM. A special interprocess message mechanism is provided in all OSDS environments, allowing processes in different processors to communicate directly. Therefore, the OSDS operating system spans all processors, creating a distributed environment in which processes executing in different processors can cooperate toward the implementation of particular tasks.

The virtual machine just above the operating system in the hierarchy is the Data Base Manager (DBM). The *5ESS* switch does not have a single uniform database but a collection of separate databases with their corresponding DBMs. Some of these databases are distributed among several or all processors.

The next higher virtual machine is the abstract switching machine. It provides a number of logical entities such as terminal, port, connector, and path and a set of operations for manipulating these entities. The software running above this layer can thus provide the switching functions without having to know the detailed implementation of the switching hardware.

Further beyond these virtual machines, the remaining software can be regarded as the application software. It provides major system functions such as call processing, maintenance, and administration by employing the services of the lower virtual machines. The application software is structured as processes running on different processors.

The call-processing application software for the *5ESS* switch also incorporates a highly modular and structured design that is functionally partitioned into several subsystems, such as a feature control subsystem and a peripheral control subsystem. Feature control is responsible for sequencing call-processing actions at a hardware-independent level by sending commands to the peripheral control that manages and controls the switching periphery. This partitioning is applied to the software in both the AP and the MPs. When feature software is separated, new features as well as hardware enhancements can be introduced in a relatively straightforward manner.

Additional software is provided for administrative features in the areas of traffic measurements, plant and service measurements, and charge recording. Trunk and line maintenance, maintenance personnel interface, initialization, fault detection, and overload control are provided by various maintenance software subsystems. All software is supported by the operating system, which manages the computing resources for the *5ESS* switch.

III. OPERATIONS AND MAINTENANCE

All of the operations and maintenance functions can be optionally provided either locally or remotely on a single-office basis, or remotely on a centralized basis serving many offices. The major functions are discussed below.

3.1 Switch maintenance

The MCC is the primary communication medium between maintenance personnel and the *5ESS* system. It displays system status and alarm information, and it provides system control functions, message input and output, and telephone communication with work areas both inside and outside the exchange. Together with the exchange alarms, the MCC offers a complete set of switch and terminal maintenance features. The MCC provides trunk and line maintenance features. Separate Trunk Line Work Stations (TLWSs) are also available for this purpose.

3.2 Line and trunk maintenance

All trunk and line maintenance features can be invoked from either the MCC or an optional TLWS. The optional TLWS is physically identical to the MCC but is restricted to trunk and line maintenance functions. The TLWS performs the following functions: testing subscriber lines, operational testing of trunks, transmission testing of trunks, removing trunks and lines from service, and restoring trunks and lines to service.

3.3 Database administration

The *5ESS* switch stores translation data in a relational database. The *5ESS* Data Base Management System provides database access for maintenance and operations personnel and protects against the introduction of many types of database errors. Data-change and data-retrieval requests made from the MCC or an optional recent-change-and-verify work station add, change, delete, or verify individual records in the database. Automated office-record production is also provided.

3.4 Billing

The *5ESS* switch provides two billing methods: detailed billing and Periodic Pulse Metering (PPM). One billing method may be chosen for all calls, or both methods may be used in the same *5ESS* system for different types of calls (e.g., PPM for local calls and detailed billing for long-distance calls). Billing data may be recorded locally or sent via data links to a centralized recording system.

Detailed billing records are in the form of a standard single entry for each call. PPM pulses are recorded in software registers (a software register can be provided for each subscriber) and, in addition, can be transmitted to the subscriber over the subscriber line.

3.5 Measurements

Traffic measurements give data for the performance supervision of the exchange, for traffic engineering of the network and service circuits, and for long-range exchange planning. To realize this objective, the *5ESS* switch continuously measures exchange traffic and provides appropriate reports. These reports can be produced either on a stand-alone basis or through an operations system.

Other measurements provided by the *5ESS* switch fall into the following categories:

1. Call attempts—These measurements represent the demand for service at the exchange and include traffic distribution (i.e., originating calls, incoming calls, etc.) and the traffic mix (i.e., coin, PBX, and feature calls).

2. Processed calls—These measurements represent the service supplied and include outpulsed and answered calls.

3. Switching system—The measurements in this category are related to the switching system components and include performance measures of the AM, CM, SMs, peripheral units, and service circuits.

4. External periphery—These measurements are related to the performance of other exchanges and trunk groups.

5. Ineffective call attempts—The main objective of these measurements is to determine the cause of ineffective call attempts so that appropriate corrective actions can be taken.

3.6 Centralized operations and maintenance

Centralized maintenance arrangements may be provided either by means of remote work stations or Operations Support Systems (OSSs) that increase the effectiveness of operations and maintenance personnel. Color terminals with pictorial equipment and status displays provide enhanced maintainability. Additionally, menus and standard forms with a cursor-control capability enhance telephone company operations.

Although the *5ESS* switch provides the human interfaces necessary for performing all operations and maintenance tasks, it is also compatible with several OSSs to increase the efficiency of the operations and maintenance personnel.

1. Switching Control Center System (SCCS)—SCCS provides facilities needed for efficient centralized maintenance of stored program control electronic switching systems manufactured by AT&T Technologies and others. It includes a minicomputer that performs real-time and batch analysis of the *5ESS* switch output messages and alerts maintenance personnel if the data show any abnormalities.

2. Remote Memory Administration System (RMAS)—RMAS is a multimicroprocessor system that increases the efficiency of centralized database administration for most types of electronic switching systems. It significantly reduces the time required to enter recent changes and to retrieve data, automates the production of office records, and provides reports that assist in managing both database and the personnel performing this work.

3. Engineering and Administrative Data Acquisition System (EADAS)—EADAS is a minicomputer-based real-time traffic data collection and reporting system. It has the capacity to gather data from up to 48

exchanges. The traffic reports generated for any particular exchange can be routed, via a data link, to a terminal in the exchange, to a central location, or to the printer at the EADAS site. The reports are similar to those provided by the stand-alone *5ESS* switch. A programming capability is also available to develop other types of reports, if desired. EADAS also writes the collected traffic data on magnetic tape for further processing. This provision can be used, for example, to generate weekly, monthly, or busy-season reports for engineering and administrative purposes.

4. Centralized Automatic Reporting on Trunks (CAROT)—CAROT is a minicomputer-based system that controls transmission and operational trunk tests for all exchanges in a particular area that are equipped with comparable remote office test lines and responders. Routine tests are automatically scheduled, performed, and analyzed; the results are automatically forwarded to the appropriate maintenance personnel.

Efforts are now being directed at providing interfaces to the OSSs and data collection systems used by foreign and independent administrations. An early application interfaces with a PDU-10 for United Telephone.

IV. ARCHITECTURAL EVOLUTION PLANS

The modular and distributed nature of the *5ESS* system, in both hardware and software design, allows it to continuously evolve as new technology and new market opportunities arise. Several major areas of architectural evolution are planned:

1. Business and residence custom services—The *5ESS* system will provide a set of features with a number of options to be selected by the customer. This modular feature customization gives the telephone administration greater tariffing options and assignment capabilities to meet the individual differences in customer needs. This mechanism, built entirely in software, can be applied to all customer lines, both individual lines and Centrex lines. It also creates new services by allowing many features to work together that never could before. For example, one service would allow for bridging from a call-waiting arrangement, where the called party talks to two calling parties alternately, to a three-way call in which all the parties can communicate simultaneously.

2. Integrated services digital network services and capabilities—The international community, through CCITT, is developing standards for the integrated services digital network. The *5ESS* system will provide end-to-end digital services via simultaneous circuit-switched voice or data, and packet-switched data, with out-of-band digital signaling. These capabilities will be provided over basic Digital Subscriber Lines

(DSLs), multiplexed DSLs over carrier systems, and primary rate DSLs over T-carrier.

3. High-capacity architecture—The *5ESS* system presently is capable of handling approximately 200,000 peak calls per busy hour, assuming a varied mix of call types and a normal level of maintenance and administrative activities. This will support a typical 50,000-line office, with a maximum of 48 SMs, both local and remote. In the near future the capacity will be expanded to over 300,000 peak calls. Overall, a 100,000-line system will be accommodated. Beyond this large capacity, the *5ESS* system could potentially grow to 500,000 or 1 million peak calls per hour with the continued modular addition of processing power.

4. Larger remote units—The initial RSM for the *5ESS* system is capable of handling 4000 lines. This architecture can be extended to larger line sizes for application in larger office replacements, or with trunking capability as a toll access and routing node. The ability to continuously evolve from a small remote to a large remote to a stand-alone office offers the telephone administration the flexibility to meet uncertain and fluctuating market demands with a minimum capital investment.

5. Remote units over lightguide facilities—The *5ESS* system currently uses integrated digital T-carrier facilities between the host exchange and remote units. However, the fundamental design of the *5ESS* system uses fiber-optic lightguide facilities as the interconnection mechanism between the CM and the SMs. This mechanism will be extended so that remote modules using direct fiber-optic connections will be a reality. This will be especially important in metropolitan areas, where large demands are making lightguide facilities the economic choice.

6. Integrated special services—A sizable portion of switching equipment and transmission facilities in metropolitan areas are dedicated to special services. Special services distinguish themselves from ordinary telephone service because they typically have more complex transmission and/or signaling requirements, they generate higher traffic loads, and they have more volatile growth and turnover rates. Consequently, installation, provisioning, and testing functions are, in general, more involved, leading to higher operating expenses. The *5ESS* system with its direct digital interfaces to interoffice T-carrier and to subscriber-side *SLC* 96 systems, together with a planned semipermanent connection mechanism (nail-up) for full-time circuits, will allow it to eliminate and reduce many of the problems associated with special services.

V. SUMMARY

The *5ESS* system incorporates sophisticated new technologies in its design. These technologies include GDXs, digital signal processors, fiber optics, and distributed control elements. Its modular, distributed architecture creates a reliable and flexible system for continued evolution of new capabilities and services. The *5ESS* system uses state-of-the-art techniques to provide a modern software architecture built upon layers of carefully structured virtual machines. The resulting software system is implemented using the C language high-level programming language and provides a high degree of modularity and extensibility appropriate for feature additions for years to come.

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The 5ESS *Switching System:*

Operational Software

By J. P. DELATORE, R. J. FRANK, H. OEHRING, and L. C. STECHER*

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The operational software of the *5ESS*™ switching system has been designed to meet specific objectives for capacity, functionality, and reliability. It has also been designed to accommodate changing technology, changing system applications, and an ever-increasing feature application set. Structured programming techniques, high-level languages, and modular design techniques have been used to obtain these objectives. Specifically, the operational software architecture is organized as a set of functional software components utilizing the advantages of a generalized operating system and database manager to achieve a high degree of hardware independence. A primary cause for hardware churning is the introduction of new peripheral units in support of new feature applications. The peripheral control software shields the majority of the operational software from these changes. Standardized and locally well-defined interfaces to the operations support systems provide information to the customer for the administration and maintenance of the switching system.

I. INTRODUCTION

The operational software of the *5ESS* switching system has been designed to meet specific capacity, functionality, and reliability objectives. It has also been designed to accommodate changing technology, divergent system applications, and an ever-increasing feature application set. To meet these objectives the design stresses structured programming techniques, use of high-level languages, and modular design techniques.[1]

In this paper we describe the operational software architecture within the overall *5ESS* system design. We show the organization of the software as functional components (see Fig. 1) and discuss the

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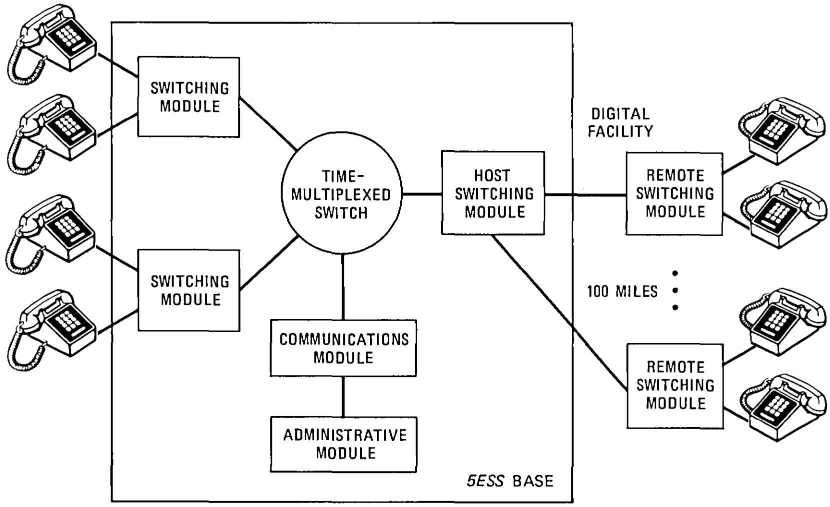

Fig. 1—Architecture of the *5ESS* switching system.

advantages of using a generalized operating system and database manager to achieve a high degree of hardware independence.

We also discuss control of the peripheral hardware and administrative services such as measurements and billing. The call-processing scenario ties these design components together. Finally, we demonstrate how the remote switching capability extends the design.

II. SOFTWARE ARCHITECTURE

The software system of the *5ESS* switching system (see Fig. 2) comprises subsystem modules that communicate with each other using concisely defined message protocols and logically based primitives. The subsystems are designed to be loosely coupled, and almost all subsystems are largely independent of the system hardware and the internal data structures.

An operating system isolates the application programs from the specific processors and allows portability of these programs across processors. The operating system is designed to present a single virtual machine environment to application programs operating in a distributed and decoupled multiprocessor environment.

The data base management subsystem provides the interface between the other subsystems and the physical data. Using a relational database design, it shields the application programs from the actual implementation of both dynamic and static data.

Similarly, the peripheral control subsystem serves the hardware-independent subsystems by managing and controlling the switching

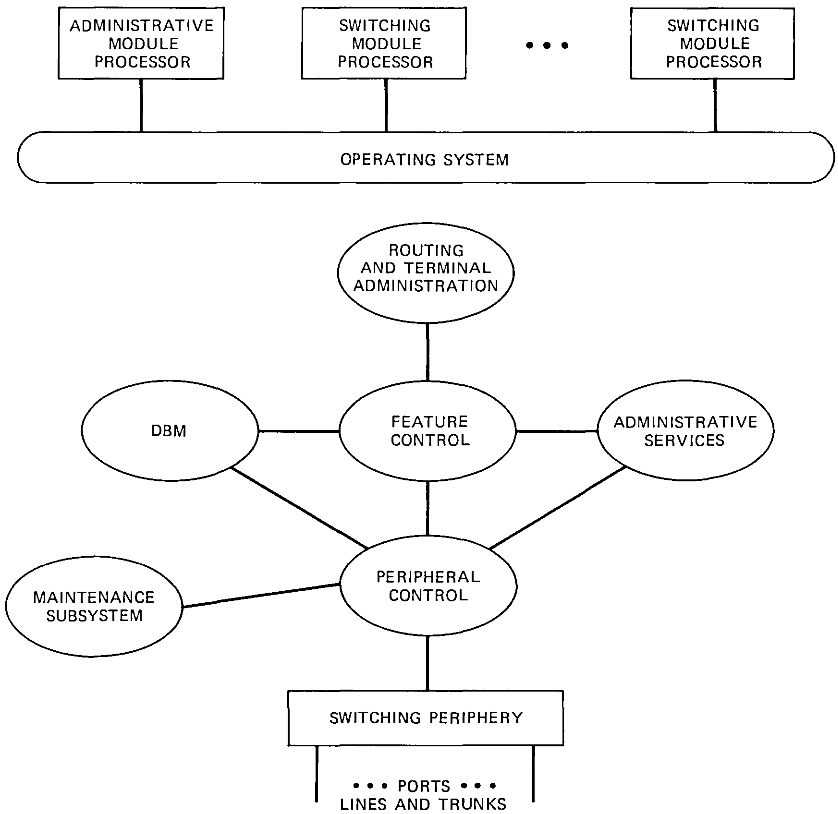

Fig. 2—Software architecture of the *5ESS* system.

periphery. The periphery includes the switching networks, service units, and line and trunk units. Lines and trunks terminate at the line and trunk units, respectively, and are referred to as *terminals* in this paper. The peripheral control subsystem performs all signaling, supervision, alerting, digit reception, and outpulsing functions. A change in a peripheral unit usually requires program changes only in this subsystem and is not propagated into the application software. All the programs to control the switching periphery are resident in the Switching Module (SM)* except for programs that control the Time-Multiplexed Switch (TMS), which are resident in the Administrative Module (AM).

The feature control subsystem is responsible for sequencing all logical call-processing actions associated with residential, business,

* Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

toll, and system features. This subsystem receives terminal inputs in the form of supervision changes or dialed digits, interprets this input based on the terminal's current state, and, when needed, obtains more information from the Data Base Manager (DBM). It then requests that the peripheral control subsystem perform the required actions. Programs of the feature control subsystem that perform basic line and trunk call-processing functions are resident in the switching modules. Optional features or features invoked less frequently are implemented by program modules that can reside in either the administrative or switching module. Placement of these program modules is determined based on how frequently they are used and the resulting trade-offs of processor capacity and memory resources. This can be accomplished with minimal program modification. The software architecture and design philosophy permits the flexibility to best match feature usage with processor placement, thus assuring that the total system resource utilization can be balanced properly.

The routing and terminal administration subsystem provides central routing and screening functions in support of the other subsystems. For example, the feature control subsystem passes a set of dialed digits to this subsystem, which in turn determines the destination of the call. The call destination is characterized by the switching module and terminal to which the call will be completed. In addition to the central switching resource allocation and routing function, the subsystem provides supporting functions, such as terminal status information, for other subsystems. Because of the global nature of these functions, this subsystem resides primarily in the administrative module.

The administrative services subsystem provides message accounting or billing; traffic and plant measurement collection and outputting; network management functions; and interfaces to the external operations support systems, such as the Remote Memory Administration System (RMAS) and the Engineering and Administrative Data Acquisition System (EADAS). The programs in this subsystem collect data from the other subsystems on a per-event basis, and perform analysis and storage for delivery at prescribed intervals or on demand to the external support system via data links. In addition, queries and commands from these external systems are distributed by this subsystem to the appropriate operational subsystem for action. The administrative services program modules are principally resident in the administrative module with data collection programs placed in the switching modules to retrieve per-event descriptions.

The maintenance subsystems perform fault recovery and system integrity functions and are resident in the appropriate module. Various audit programs are automatically brought into play when inconsistencies or hardware failures are detected. They are also scheduled on demand when the integrity of dynamic data is suspect.

III. OPERATING SYSTEM

The Operating System for Distributed Switching (OSDS)[2] provides the processing environment required by operational, switch maintenance, and system integrity software resident in the different modules. OSDS performs five major functions:

1. Processor isolation
2. Concurrency control
3. Intra- and interprocessor message communication
4. Resource scheduling
5. Timing.

The operating system is designed to support the decoupled network view of the *5ESS* switching system design, i.e., it allows the view of the switching system as a collection of independent processors with well-defined interfaces via a concise message protocol. In essence, the design can be viewed as a collection of independent switches administered as one switching center.

A common machine-independent portion of OSDS includes the implementation of process management, interprocess communication, timing services, and scheduling. The machine-dependent portion, a small part of the total operating system, interfaces with the hardware processor and the host operating system supplied with the administrative module processor. It includes interrupt handling, process dispatching, basic memory management, interprocessor communication, and communication to the host operating system.

3.1 Processor isolation

The *5ESS* switching system architecture is designed to have a long lifetime. As hardware technology evolves, it is desirable to upgrade a processor without affecting the design of the software to any measurable extent. OSDS is designed to provide a virtual machine environment whose interface to the operational software remains constant through processor evolution. The fact that the operating system hides the unique hardware configuration from the operational software assures the expeditious porting of such software and preserves the investment in software development.

3.2 Concurrency control

The operating system concept of a process was adopted to facilitate understanding of the large number of concurrent activities in the switching environment. Concurrency is a significant design consideration owing to the large number of active terminals or phone calls at the same time. The software structuring concept of a process enables an operational software designer to program each activity (e.g., providing dial tone or ringing a line) as a sequence of separate tasks in a process. Multiple instances of this process are then executed concurrently by the operating system to provide the concurrency control necessary to simultaneously process a multitude of telephone calls. This approach reduces the complexity of the design, since the designer can focus most of his/her attention on the external behavior of the process and its interaction with the environment and not on the interactions of the processes with each other. The process concept also structures the software system as highly modular parts with limited and well-defined interfaces. Communication with other processes takes place via messages routed to the appropriate destination by the operating system.

3.2.1 Structure of processes

Within the scope of OSDS there are two process types: terminal process and system process.

3.2.1.1 Terminal process. All the activities on an active terminal are controlled by at least one terminal process. A typical call has two terminals and two associated terminal processes controlling the originating and terminating party. Each terminal process thus keeps a partial view of the call and responds only to well-defined inputs from its associated terminal or other processes.

This terminal-oriented process approach reduces programming complexity because it allows the designer to concentrate on the events specific to an individual terminal, the action necessary for processing such events, and interaction with other processes. The terminal-oriented process approach is more natural because the designer can assume the terminal user's point of view in designing a program to control the terminal. Feature enhancements can be implemented by a simple addition to feature control programs that are callable by terminal processes. This approach is also well matched to the distributed aspects of the call-processing job when a call originates in one module and terminates in another. Having one terminal process in each module permits a natural division of the processing between the two modules.

Terminal processes are created and terminated on demand. Typically, these processes are created on origination and terminated at disconnect time. They are activated by the arrival of an external stimulus or input signal from the terminal or another process. After processing a signal, the terminal process takes a "real-time" break by releasing control to the operating system and waits for further input. There are separate control programs for different terminal types. For example, there are residential, coin, and multiparty terminal control programs. These programs determine the control sequence required for their particular terminal type. The majority of the processes in the system are terminal processes, sharing the use of the various control programs.

3.2.1.2 System process. There are also some long-standing processes that function as servers within or outside of call processing. Examples are dispenser processes, which distribute inputs to terminal processes; the routing and terminal allocation process, which assists in routing the call; the data base manager process, from which a terminal process can request data characterizing the physical terminal; and the system audit process, which performs the routine software sanity checks. These are called *system processes* since they provide services on a systemwide basis. They are typically created at system initialization and remain active indefinitely. Each system process carries out a specific function and handles requests from more than one terminal process. In general, a system process is a self-contained program and does not share programs with other processes.

3.3 Message communication

Message communication is the major communication mechanism between processes. Basically, a sender prepares a message in a message buffer and then invokes the operating system using a message communication primitive to transmit the message. The operating system determines the destination of the message. If the message is addressed to a process within the same processor, the operating system copies the message to the receiving buffer and schedules the receiving process. In case the message destination is external to the processor, a communication control program is invoked to transmit the message through a physical link. In a similar fashion, incoming messages are received by the communication control program and transferred for proper routing to OSDS.

3.4 Resource scheduling

Resource scheduling involves the central allocation and assignment of memory resources and processor time. When the operating system schedules a process, it assures that sufficient memory resources are available for that process to run. The operating system is designed in a self-regulating manner intended to meet system performance at the rated call-carrying capacity and to satisfy stringent response times to the craft personnel. It also responds to external stimuli from an overload control program to take corrective actions, if necessary, and preserve system throughput.

The scheduling is done at different priority levels with each type of process assigned a specific priority. Overload control reacts to momentary bursts of traffic input or resource shortages and provides input to the scheduling algorithms. A sanity timer protects the system against any process taking control of the processor for longer than a maximum allowable time. A cyclic timer interrupt assures that high-priority jobs with stringent timing requirements are executed with the appropriate frequencies.

3.5 Timing

The operating system administers two classes of timing services. The first, essentially a time of day clock, is used for billing purposes and for time-stamping events. Second, each OSDS processor maintains a clock used in conjunction with an ordered queue of timing requests that allows each process to request control from OSDS at specified time intervals.

IV. DATA BASE MANAGEMENT SYSTEM

The Data Base Management System (DBMS)[3] promotes the overall *5ESS* system objectives of modularity, portability, and system evolution by providing a single access to the data which is totally at the logical level as viewed by the users of the data. The DBMS supports the distributed architecture of the system by providing distributed data and distributed management of the data. Most data required by a particular processor are contained within that processor. The DBMS makes the location of all data transparent so that other programs need not be concerned about on which processor the data actually reside. The DBMS is a specialized distributed system based on the relational data model and is subject to stringent performance and reliability requirements. The balance between real-time constraints and reliability requirements is largely achieved by a concurrency mechanism that provides the necessary real-time access while maintaining a consistent view of the data.

The Data Base Management System provides:

1. Data definition
2. Data access
3. Concurrency control
4. Memory partitioning and write protection
5. Data backup and recovery
6. Data administration.

4.1 Data definition

Any database management system should provide a measure of data independence. In the *5ESS* switching system, data are defined off-line and changes can be introduced by redefining database relations and automatically recompiling user programs. The goal is to introduce database changes with a minimum number of client program changes. Because the schema remains stable during a given software release, it is not necessary to define the database on line. A data definition language accepts user definitions of the relations and their domains and generates user header files, data dictionaries, and documentation. Figure 3 shows the data definition process and the major software components in a switching module. The administrative module contains

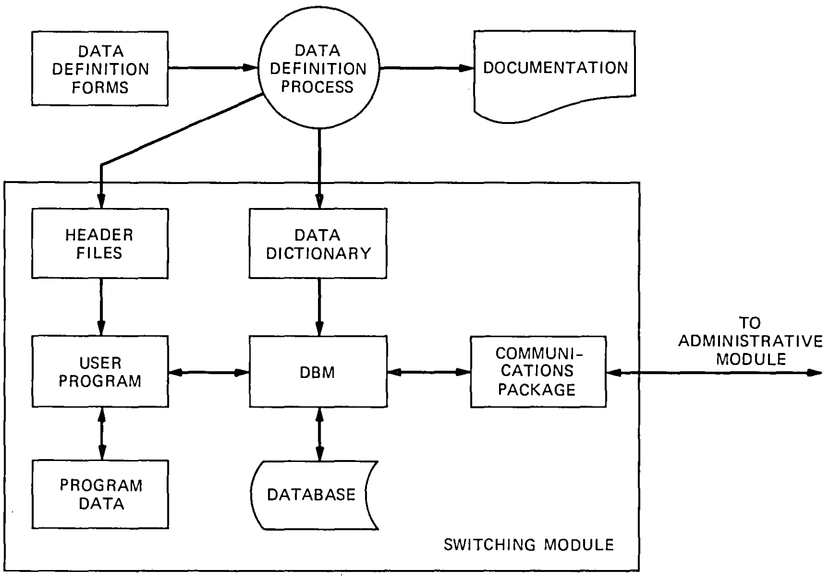

Fig. 3—Overall DBM architecture.

similar components. The user header files contain the C-structure layout (or template) of the relations and are used to compile the client programs. The data dictionaries describe all the relations, attributes, and domains in the database. They are used internally by the DBMS software.

4.2 Data access

The DBMS provides two levels of interface in accessing the database. The two levels of interface achieve different degrees of data independence for users with different performance and data usage requirements. The basic interface is the tuple-level access, which is employed by real-time critical users, e.g., call-processing programs. The user at this level can retrieve tuples of the base relations. The base relations are designed from an operational point of view and are used by all internal subsystems. The base relations represent the actual physical data stored in the database. A higher level of interface, called the view-level access, is designed to provide a higher degree of data independence for users with less stringent real-time requirements. The view-level access operates on view relations, which are virtual relations formed at execution time by combining information from one or more base relations. The view-level access provides an interface to administrative operating telephone company personnel in a *5ESS* switching system and also to Operations Support Systems through external data links.

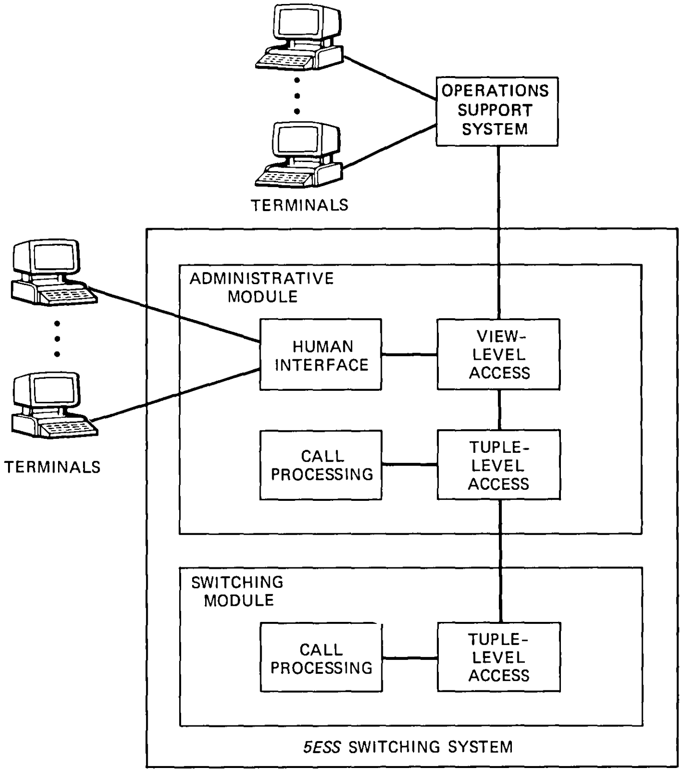

Fig. 4—DBM interfaces.

Since the view-level access is used to interface with the external users, it is only available in the administrative module. Figure 4 depicts the database management interfaces in the *5ESS* switch. All of the resident application programs access data through the DBMS on the processor on which they are executing via a set of interface primitives. These primitives are function calls, as opposed to messages, which are the communication mechanism between processes. For accessing the data on a remote processor, the DBMS automatically generates all the necessary interprocessor queries (in terms of messages).

The database is isolated from application programs. A function call causes some data to be copied from the database to a user buffer instead of providing a physical pointer to the database. This is done to ensure integrity of the data in the database. To fulfill the real-time requirement of call processing, the capabilities of the interface primitives are somewhat restricted. Only single tuples within base relations can be accessed.

4.2.1 Data access primitives

The DBM provides a basic set of primitives that serves all users. The set of primitives is "complete" so that the user can access any part of the database, but it is "basic" enough so that the DBMS does not have to perform any part of the application for the user. The tuple-level access provides control and protection functions in addition to data access. It manages transactions, controls concurrent access, and handles data distribution.

4.3 Concurrency control

Concurrency control in the DBMS is a mechanism that allows multiple users to access the data and protects them from getting inconsistent data due to concurrent updates. The policy on concurrency control has a great influence on the design of the concurrency mechanism. It determines the efficiency of shared data usage or, in other words, the degree of concurrent access.

Call processing is primarily a reader of the relatively permanent data and it contributes a large portion of the data access activity. Since call processing requires rapid real-time response, its access to the data has priority. Most changes to the database are not real-time critical and the frequency of such activities is rather low in comparison to call processing. Concurrency control is designed to provide efficient access to read-only users with potentially delayed access to update users.

The concept employed to control concurrent changes is based on data duplication. All updates are performed on a copy of the real data. During the update period, all readers of the database can still access the original version of the data. When the update is completed, the updated copy will become the real data for future users. The old copy will be discarded when all current read transactions on this relation are completed.

This mechanism allows only one writer to the database in the system to update the same relation. This, however, does not restrict the number of readers who have read-only access to the relation. Furthermore, it does not restrict the number of writers who are operating on the disjoint parts of the database. This situation fits quite well in the *5ESS* switching system's environment, where there are many readers and relatively few, infrequent writers. Simultaneous writers of the same data page are queued internally to the DBMS, so virtual concurrent update operation is still seen by the user in this case.

Since the concurrency control scheme is based on duplication of data, it is desirable to organize the storage structure in such a way that the amount of duplication is minimized. A tree-like storage structure is most suitable for this kind of application. The amount of data duplication required to perform an update in a relation consists of all the blocks along the path from the root node to a leaf node. All relations are in a tree-like structure, regardless of what kind of access method is employed.

When an update transaction terminates, the old data are replaced by the new data by changing the pointers to the control data structures. If the update process terminates abnormally (e.g., owing to software asserts or hardware reset) before the commitment of update, the current version of the data remains intact. The memory for new data that are never committed will be reclaimed immediately if possible, or will be subjected to garbage collection through data audits.

4.4 Memory partitioning and write protection

Write protection is a mechanism to protect the database against "wild" writes by any process. If an area of the memory is write protected, a process writing into this area must first turn off the write-protection mechanism. Otherwise, an interrupt will be generated and appropriate action will be taken on this process. Most unintentional writes to the database can be caught by this mechanism. Providing write protection for the whole database would create unacceptable real-time penalties for the telephone switching operations. To achieve a balance between real-time response and reliability, the memory is partitioned into a write-protected area and a non-write-protected area.

Relatively permanent data are stored in write-protected memory. Examples of write-protected data are the data dictionaries that store the schema of the relational database, and information specific to the individual office: hardware configuration, telephone line and trunk data, digit dialing analysis data, and routing data. Another class of data that is more dynamic in nature is stored in the non-write-protected memory. This class of data is used to define system dynamics such as the state of a phone call, the status of hardware equipment, work queues, etc. Dynamic data do not rely on disk backup for data recovery. Instead, data are recovered through a system of audits that either recover the data from the office-dependent data or from program initialization.

4.5 Data backup and recovery

For access efficiency, most of the data are stored in main memory. Since a power failure can destroy the entire main memory content, secondary disk storage units are utilized to back up all main memory. The disk backup is also used to restore main memory data whose integrity is suspect. An elaborate set of audit programs are used to constantly check the data integrity. The DBMS continually keeps the disk data logically equivalent to the main memory to prevent loss of the latest data updates in the event of data recovery from disk.

4.6 Data administration

A data administration capability is provided by the *5ESS* switch to enable the operating telephone company and the telephone subscriber to dynamically change the feature capabilities available to them. The programs used to provide the data administration capability are called Recent Change and Verify (RC/V) programs. The primary design objective is to provide a user-friendly, interactive interface with maximum flexibility. A comprehensive set of error checks are made on all data entered, with particular emphasis on identifying the exact cause of the error and the specific steps required to correct the error. All error checks must pass successfully before the data in the *5ESS* switch will be updated, thereby ensuring a high degree of data integrity.

The RC/V program provides the ability to add, delete, update, or verify the database using

1. A menu select/mask interface
2. A text interface
3. An operations support system interface (see Fig. 4).

The menu select/mask interface is supported from multiple recent change terminals (CRTs), which can be utilized concurrently, while the other two interfaces are associated with unique terminals. All interfaces are provided over dedicated facilities. The user specifies one of two levels of menu select. The first level of RC/V menu select allows the user to specify which form (user view) is being used. These can be verify only, or a combination verify and recent change forms. The second level requires the user to select the type of operation to be performed (i.e., recent change—new, out, change, or verify) on that form. After the user specifies both the form and the operation, the form is displayed and the RC/V data interpretation and processing subroutines are invoked.

The menu-select program also determines if a particular user terminal is allowed to perform the requested RC/V operation. Following is a list of valid terminal types and a description of the allowed RC/V operations:

Description	*Operations Allowed*
Local–RC/V	All
Remote–maintenance	All
Repair service bureau	Verify only
Network administration	Verify all data Network, administrative data

Line administration	Verify all data Line group data

A user may obtain a permanent copy of all recent change activities by specifying an auxiliary printer. In this case the menu program will generate a print file that consists of a serialized record of the RC/V operations that occurred in a terminal session. Each time the database is recent changed or verified, a copy of the completed form is written, along with the time and view transaction identifier and an indication of the time the transaction was actually committed in the database.

As an additional option, a scratch print file contains a copy of the input forms used, along with any error messages obtained. The file is written whenever the user specifies. This allows the user to obtain a paper copy of his or her input and allows errors in input to be resolved off-line.

The RC/V program performs range and syntax checks on each attribute put into the system. In addition, data consistency checks are made by comparing all attributes of a particular form when the user indicates that input for a particular form is complete. Finally, before committing any database changes, a data integrity check is made so that the data input on a particular form does not conflict with any data already in the database.

V. PERIPHERAL CONTROL

In the *5ESS* switch software architecture, it is the function of the peripheral control subsystem to isolate application programs from the details of switching machine hardware. It provides the sequencing and control for operations on the switching network, service units, and line and trunk units that comprise the switching periphery. As a result, other subsystems can view the switching hardware as a collection of logical resources, unencumbered by the details of the particular hardware implementation.

The abstract resources that peripheral control provides are logical ports, paths, bridges, and connectors. A logical port is an abstraction of the customer terminal's attachment to the system. Bridges and connectors represent the various types of conferencing capabilities. Paths represent the interconnections of logical ports, bridges, and connectors.

The peripheral control subsystem is divided into four parts:

1. Port control—implements the concept of logical ports and provides a set of primitives to operate on them.

2. Switching resource allocator—controls allocation of various switching resources, such as time slots and service units.

3. Network control—coordinates path operations in the digital and metallic access networks.

4. Peripheral I/O—provides low-level sequencing and control of the switching periphery, including the handling of time-critical I/O.

Each of the four major components of the peripheral control subsystem is described in more detail in the following sections.

5.1 Port control

Port control software resides only in the switching module and provides a set of primitives to operate on logical ports. Through these primitives, the application software can deal with line and trunk terminations as conceptual entities, unconcerned with the detailed sequence of operations required to control the hardware. For example, a primitive is provided to "activate" a line termination port by establishing a path through the line concentrator, performing false cross and ground tests, and initializing the associated software data structures. Another primitive is available to apply dial tone (or other appropriate signal) to a logical port. This approach provides an abstract view of the switching periphery that leads to higher productivity in the development of new features. It also allows for the periodic introduction of improved, lower-cost hardware units without modification of the application software.

5.2 Switching resource allocator

The switching resource allocator provides a set of primitives to allocate and deallocate switching resources. These resources can be divided into two categories: (1) paths in the switching network, and (2) service units. Path resources include line concentrator paths, peripheral-side Time-Slot Interchanger (TSI) time slots, and metallic access paths.*

Service units include the High-Level Service Circuit (HLSC), the Local Digital Service Units (LDSUs), and conference circuits in the global digital service units. The HLSC is a circuit in the line unit that is used to verify concentrator paths, provide cadenced ringing, and perform the needed operations for coin phones. The LDSUs are used to generate and decode digital tones used in call processing. Conference circuits are used for bridging and three-way calling.

In addition to allocation and deallocation of switching resources, functions are provided to queue for, or preempt, resources. Queueing would be used, for example, when circuit diagnostics must be run on a hardware unit that is currently in service. Preemption allows a client to gain control of a resource regardless of its current status. Preemption is not a routine activity. It is used primarily in support of high-priority maintenance actions.

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* Metallic access paths are used by the terminal maintenance subsystem for testing lines and trunks.

5.3 Network control

Network control coordinates the actions required to set up and release call paths. It presents a high-level abstraction for feature control to operate on the switching network. It is through the network control software, which resides both in the switching and administrative modules, that the abstractions of paths, bridges, and connectors are realized.

Central network control software coordinates path operations, such as path setup, path teardown, and network reconfiguration, that involve the Time-Multiplexed Switch (TMS) or multiple modules. Through interactions with local network control, it determines what new paths and conference circuits are needed, reserves the appropriate resources, and sends orders to the TMS to connect the paths.

Local network control software is responsible for making connections between the originating or terminating port and the module network control and timing link. It also plays an essential role in coordinating the sequence of path operations required for establishing and releasing an intermodule path, and in inserting or dropping bridges and connectors. The coordination required is a function of the characteristics of the network and is transparent to application software such as feature control.

5.4 Peripheral input/output

Peripheral input/output software is responsible for the sequencing and control of the switching periphery. Of all the peripheral control components, it operates at the lowest level, closest to the hardware. It performs both time-critical I/O jobs (10-ms interrupt level) and base-level I/O jobs whose time constraints are not as stringent. Peripheral I/O software typically performs these jobs at the request of port control or network control programs and provides isolation from the details of the peripheral hardware.

Interrupt-level (foreground) processing is responsible for handling those tasks that require an immediate response. Examples of jobs that fall into this category are

1. Service requests from the periphery
2. Line origination scanning
3. Dial pulse and multifrequency outpulsing.

Base-level (background) processing has less stringent timing constraints. Background processing is started on a 50-ms cycle or on the reception of a report from foreground. It provides such services as

1. Dispatching digit reports to port control
2. Sending origination reports to origination-handling software
3. Implementing the overall scheduling strategy for I/O jobs.

The foreground and background peripheral I/O functions provide a fundamental set of services for controlling the peripheral hardware and responding to external stimuli. These programs interact with the other components of peripheral control to provide the application software with an easy to use, abstract interface to the switching periphery.

VI. CALL-PROCESSING SOFTWARE

Call processing[4] is principally the responsibility of three subsystems: Feature Control (FC), Routing and Terminal Administration (RTA), and Peripheral Control (PC). The roles and interactions of these three subsystems can be better appreciated by considering the flow of a simple line-to-line call. For this purpose let us assume that customer A originates a call to customer B (see Fig. 5). When customer A originates a call, the off-hook is detected by the peripheral control foreground program. Peripheral control, in turn, calls the RTA programs, which create a feature control terminal process to control the call. Checks are made to determine the identity of the line, the type of service offered (individual, two-party, coin, etc.), the type of features offered, and the type of signaling used. A path through the concentrator is set up, a power cross test is run, a digit receiver is attached, and dial tone is returned to the customer. When the first digit is received, dial tone is removed. For the first digit and for each of those that follow, messages are sent to the terminal process, and the digits are subsequently analyzed. If there is no permanent signal, partial dial, or disconnect, the call continues as normal.

At this point a request to terminate to the selected party is sent to the administrative module using a route request message. Here the RTA software determines the terminal associated with the called number (customer B). A path is then allocated between the originating and terminating terminals, the required time slots are identified, and the TMS is ordered to provide the connection. A termination message is sent to the interface module of customer B, and RTA then creates a terminating terminal process after checking for special features on the terminating line. A path through the concentrator is established, a power cross test is run, the appropriate ringing signal is started, and audible ringing is connected through the terminating Time-Slot Interchange (TSI), the TMS, and the originating TSI, back to the originating party.

When customer B answers, an off-hook is detected by the PC foreground program, which informs the terminating terminal process after checking for special features on the terminating line. Ringing is removed by the hardware when customer B goes off-hook; subsequently, the audible ringing is removed and the terminating line is cut through. The parties are now talking.

Assume that the terminating party, customer B, hangs up or disconnects. In this instance, the peripheral control program sees the

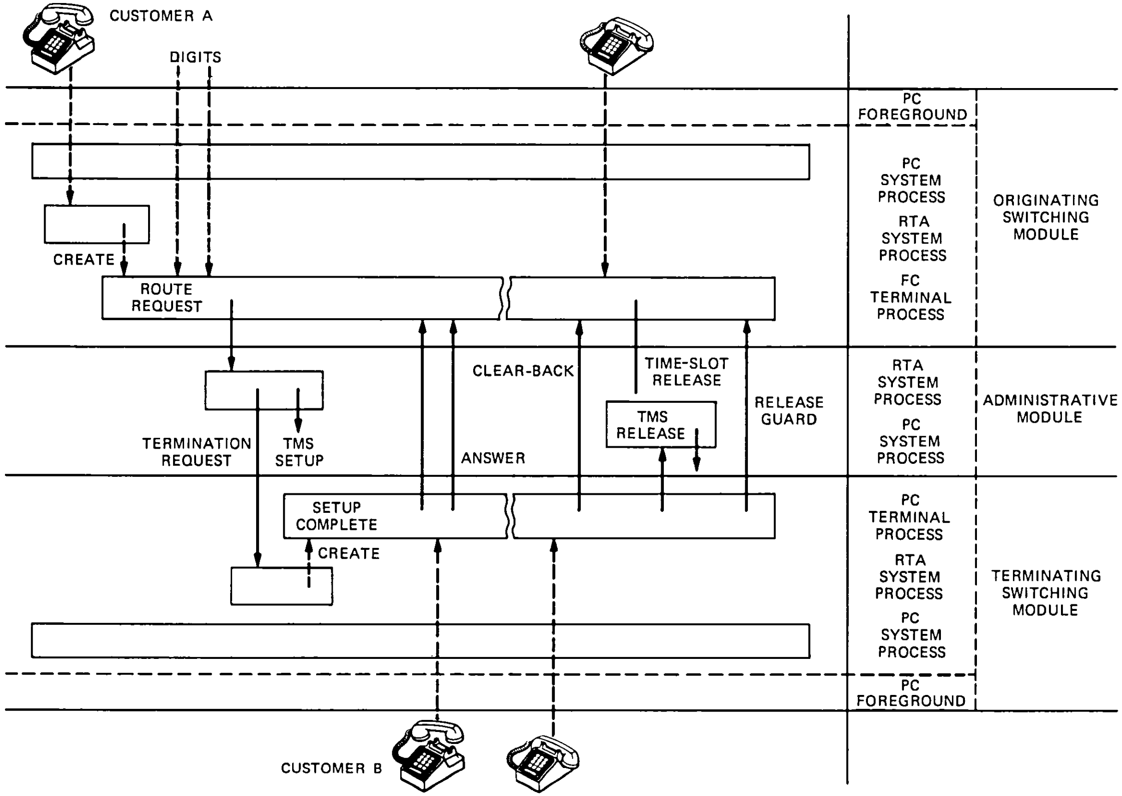

Fig. 5—Line-to-line plain old telephone service call.

on-hook and reports it to the terminating terminal process, which in turn sends a clear-back message to the originating terminal process. The originating process then begins disconnect timing. At this point, if either the originating party hangs up or the disconnect timing expires, the originating terminal process releases the call's time slot by sending a path release message to the administrative module. The terminating terminal process is also notified to release the path. It responds by idling the appropriate time slot, sending a message to the administrative module, sending a release guard message to the originating terminal process, idling customer B's port, and terminating itself. When the originating terminal process receives the release guard message, it idles customer A's port and terminates itself. Meanwhile, after the administrative processor receives the path release message from each process, it instructs the TMS to idle the path, thereby completing termination of the call.

There are many variations of this basic sequence, but the above description is the typical flow for a simple line-to-line call. In the case of three-terminal calls, such as call waiting or three-way conferencing, there is still only one terminal process associated with each terminal, and one of these terminal processes is responsible for providing the overall coordination required during the call. Even with multiterminal calls that are made up of two or more three-terminal calls, only one terminal process is required for each terminal and overall coordination responsibilities rest with one of the terminal processes. Only with interactive multiterminal calls is there a need for a separate call-coordinating process.

VII. ADMINISTRATIVE SERVICES

Administrative services[5] encompass collecting data, processing or formatting data, and outputting data to Operations Support Systems or local crafts people in the office. These wide-ranging data operations include billing, measurements, network management, and service evaluation. Much of this administrative services software is based on the processing of events—call events and system events. Call events are associated with an individual call. Examples are answer or disconnect time, called number or origination data. System events, on the other hand, are not associated with an individual subscriber, but instead consist of such things as traffic or maintenance usage data or processor utilization data. Events are stored on a per-switching-module basis, with each module processor having a call-event buffer and a system-event buffer.

It is the task of the call-processing and maintenance programs to recognize and report events to the administrative services subsystem using primitives that increment counters and associate data on a per-

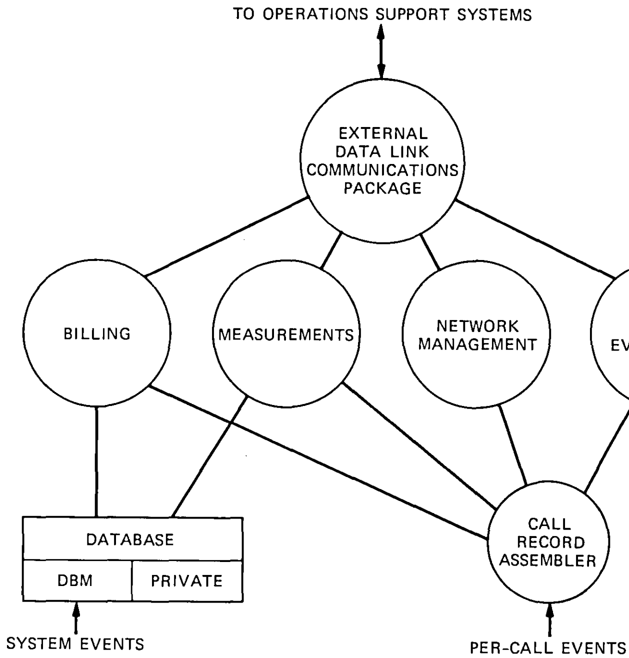

Fig. 6—Structure of administrative services software.

call basis. For example, the feature control subsystem reports the end of dialing, answer, and disconnect. The peripheral control subsystem recognizes that a circuit has been seized or a dial tone applied. The terminal maintenance subsystem recognizes line or trunk troubles, or per-call failures. In all instances, however, the event data collection and processing have been separated as much as possible from the call-processing and maintenance programs, and the data from a single event may be used for several administrative purposes. Only the event data needed are collected, and as new data are required, new administrative primitives are defined.

All the temporary data associated with an individual call are stored in a call record. The data are reported to the Call Record Assembler (CRA), which correlates the data, stores them in the proper call record, and makes the information available to the administrative services software. The memory for this record is dynamically allocated as needed.

The administrative services software is functionally organized as shown in Fig. 6. Per-call events are received by the CRA and system events are generally handled by the data base management subsystem. These data are then made available to the billing, measurements, network management, and service evaluation programs for appropriate

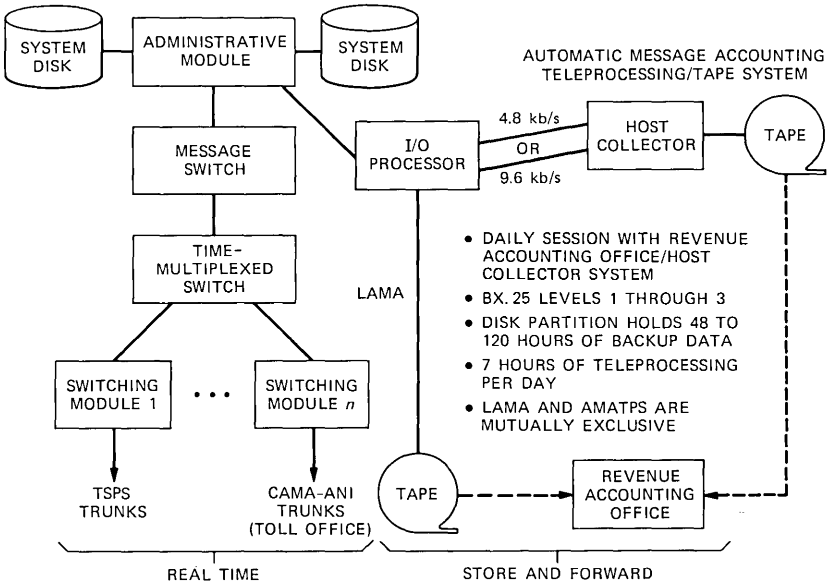

Fig. 7—Billing options.

processing and formatting of output records. These programs, in turn, interface with the external data link communication package, which provides a path to the many external data links that interconnect the *5ESS* switch with the operations support systems.

7.1 Billing

The Automatic Message Accounting Teleprocessing/Tape System (AMATPS) provides stand-alone Local Automatic Message Accounting (LAMA) tape operation and/or teleprocessing of automatic message accounting data to a centralized Host Collector system (HOC). The *5ESS* switch supports many different billing configurations. Alternatively, the *5ESS* switch can support Centralized Automatic Message Accounting (CAMA) operation with Traffic Service Position System (TSPS) or with toll offices such as the *4ESS*™ switching system.

These billing configurations involve either real-time operation or a store and forward arrangement. Real-time operation implies that billing information is moved out of the office as quickly as possible. CAMA operation satisfies this definition. The possible real-time configurations are illustrated in Fig. 7, where Automatic Number Identification (ANI) information is output to TSPS or to a toll office for CAMA operation.

With the store and forward arrangement, billing data are stored in a single-entry format on a disk. These data can be forwarded on demand to a LAMA tape, as shown in Fig. 7. Alternatively, the data may be teleprocessed on a polled basis to a HOC. The interface to the HOC can be a 4.8-kb/s dial-up link or a 9.6-kb/s dedicated link.

7.2 Measurements

A second major portion of administrative services is the measurement package. These measurements fall into three different categories: plant, traffic, and service evaluation. Some of these measurements are peg counts, others are usage counts, still others are overflow counts. All of these counts are processed and subsequently provided to the craft either locally or remotely through operations support systems in a very human-oriented form. All craft reports are appropriately formatted with titles provided so that no templates are required to decipher the data.

The measurement package provides data to EADAS, the No. 2 Switching Control Center System (No. 2 SCCS),[6] and the Master Control Center (MCC). Twenty-four-hour plant measurement data are provided to the SCCS and the MCC; 30-minute traffic reports and Division of Revenue data are sent to EADAS, and a 15-minute traffic report is always sent to the MCC, while the 30-minute report is provided on demand. Optionally, this information is available on a local printer.

7.3 Network management

The *5ESS* switch provides a very powerful network management package, essentially as robust as that available with the *4ESS* toll switch. The package provides real-time surveillance data and implements an assortment of network management controls. All of this is intended to optimize the call-handling capacity of the switch and to maintain external network sanity during periods of traffic overload or failure.

The *5ESS* switch interfaces used to support network management are shown in Fig. 8. They include interfaces with EADAS/Network Management (NM), the No. 2 SCCS, and a local terminal. The communication with EADAS/NM in the Network Management Center (NMC) takes place through the No. 1A EADAS, and the *5ESS* switch interfaces with EADAS through a dedicated 2400-b/s X.25 synchronous link. EADAS/NM is provided with data that includes five-minute surveillance data and thirty-second discretes. The crafts people, in turn, can invoke a variety of trunk group controls, including skip, cancel-to, cancel-from, and reroute. The reroute control allows out-of-chain routing during failure or overflow. Also available are code

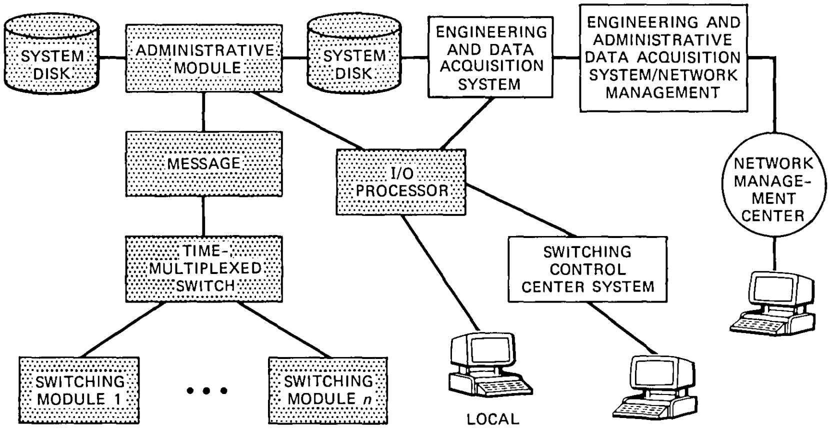

Fig. 8—Network management interfaces.

controls and call gapping. All network management controls that have been invoked can be retired with a single command from any of three different locations: the network management center, the switching control center system, or from a local terminal in the office.

7.4 Service evaluation

Service evaluation is a feature used to determine the quality of service experienced by the telephone customer. The process is now fully automated with the advent of the No. 2 Service Evaluation System (SES). The *5ESS* switch interface with the No. 2 SES consists of a dial-up 2400-b/s X.25 synchronous data link and from one to four monitoring links. The arrangement supports dial-line service evaluation, as well as Mechanized Evaluation of Call Completion Anomalies (MECCA). The latter involves monitoring outgoing calls that have long holding times without answer supervision. The process helps to detect fraud and to find trunks that are faulty from a billing standpoint. MECCA can be used for all line-to-trunk calls and up to four calls can be observed simultaneously.

VIII. REMOTE SWITCHING

The Remote Switching Module (RSM) is the first of a series of digital remote switching products realized within the basic architectures of *5ESS* switching system hardware and software. It provides to customers at the remote site the same services as those served by the host, and it meets the same demanding reliability requirements. The RSM, which can be located up to 100 miles from its host, permits economic replacement of Community Dial Offices (CDOs) with up to

4000 lines and the establishment of new wire centers with a smaller size than previously economical.

8.1 Remoting facilities

The RSM is a standard switching module that uses essentially the same hardware and software as an existing Switching Module (SM). It is connected to an SM at the host office using 4 to 20 digital facilities (see Fig. 1). Two or four of the digital facilities carry permanently reserved control time slots over which the RSM processors communicate with the rest of the system.

8.2 Operational software design for remote switching

The operational software for the RSM supports two modes of operation. The normal linked mode occurs when there is proper functioning of the communication channels between the RSM and the Administrative Module (AM) through an SM at the host. During linked operation, the RSM provides all of the calling features of the host office. The stand-alone mode is entered when communications over the digital facilities is lost owing, for example, to a cable cut. In the stand-alone mode, it provides normal handling of intramodule calls, including most custom calling services, and special handling of emergency and operator calls that would otherwise be routed to the host.

The operational software design for the RSM takes into account three factors introduced by remote switching operation:

1. Intermodule calls involving the RSM require an extra stage of time-division switching beyond that used for local switching modules. This stage is provided by the time-slot interchange unit of the SM in the host.

2. Intramodule calls must continue to be served during stand-alone operation. Thus the call-processing design must handle intramodule calls independently of the AM.

3. Special treatment of emergency calls is required during the stand-alone mode. In addition, intermodule calls must be given an appropriate failure treatment.

8.2.1 Call connections for remote switching

A major portion of the RSM-specific operational software controls the path allocation and path setup mechanisms necessary to incorporate the additional stage of switching into the call connection software. This software is completely within the peripheral control subsystem and, consequently, the application-level software, such as Feature Control (FC), is unaware of the changes required to interface with the expanded switching network. In all, five additional path types are supported (see Fig. 9).

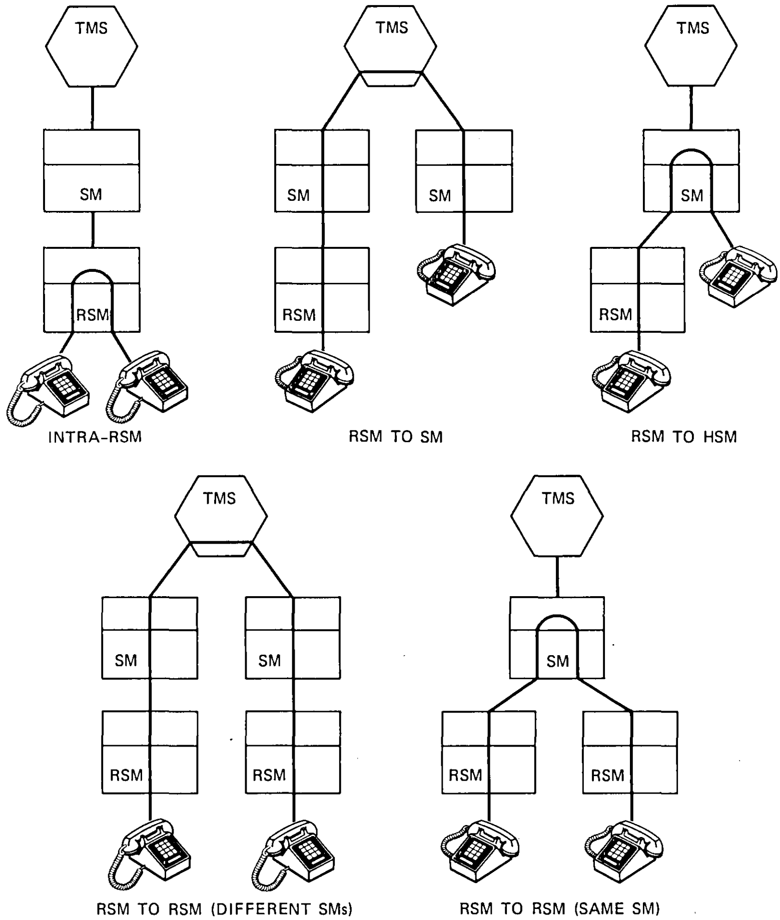

Fig. 9—Remote switching module path configurations.

For a call between local switching modules, path setup is accomplished through interaction with network control in the AM. In a case involving the RSM, the procedure is very similar (identical from the feature control point of view). The roles of the originating and terminating terminal processes and the path setup protocol remain essentially the same. There are, however, some differences, which are hidden within peripheral control. The connection through the TMS must be made to the RSM's Host SM (HSM). This is different from the local SM case, where the TMS connection is always made to the originating or terminating module itself. Also, the setup of the originating or terminating portion of the path involving an RSM is more complicated since two modules, the host SM and the RSM, are involved. The primitive, which is used to set up the originating or terminating end of the path, determines if it is executing in an RSM and, if so, coordinates with software in the host SM to establish the required connections. This coordination function is placed within the existing call connection procedure so that this activity is transparent to the call-processing actions on the other end of the call.

8.2.2 Distributed routing for remote switching

The administrative module provides the call-routing function for ordinary calls, and routing data therefore reside in the AM. Stand-alone operation in the RSM requires a more distributed approach. In this case, the local routing algorithm in an RSM proceeds through data accesses and manipulations relating to resident destination addresses. If the destination of the call is an RSM terminal, defined in the extracted routing data stored in the RSM, all routing is handled by the RSM. If the data stored in the RSM are insufficient to determine the termination address, control is forwarded from the RSM to the AM, which completes the routing process.

The call connection and distributed routing techniques provide a full complement of services to lines served by the RSM. They also provide the basis for stand-alone call processing, a mode that may be assumed (a telephone company option) when communications with the host fail.

8.2.3 Stand-alone mode

In the stand-alone mode, the RSM continues to handle intra-RSM calls normally and provides for special treatment of other calls. Normal intermodule calls, originating at the RSM and terminating on another module (including outgoing calls), are automatically routed to either an announcement or a reorder tone (telephone company option) at the RSM. Emergency calls, originating on the RSM and normally handled as intermodule calls, may be routed to designated lines on the RSM during stand-alone operation. Up to ten directory numbers may be specified in the emergency category. Global hunt groups (hunt groups with appearances on the RSM and one or more other switching modules) are reconfigured to permit hunting over the local subset of the global group during stand-alone operation.

IX. SUMMARY

This paper has described the operational software structure used to provide the major call-processing and administrative function in the *5ESS* switching system. It demonstrates the functional decomposition of the software through use of a general operating system and DBM, as well as a high degree of hardware independence achieved by use of the operating system and the peripheral control subsystem.

X. ACKNOWLEDGMENTS

The authors wish to acknowledge the efforts of those designers, too numerous to mention individually, who contributed to the successful operational software system design.

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The 5ESS *Switching System:*

Maintenance Capabilities

By G. HAUGK, F. M. LAX, R. D. ROYER, and J. R. WILLIAMS*

(Manuscript received November 3, 1983)

In developing the *5ESS*™ switching system, a digital switch with distributed control, major emphasis has been placed on reliability, quality of service to the customer, and efficiency of the human interface for the telephone operating companies. To achieve a high-reliability design for this system, a robust hardware/software architecture has been developed with emphasis on a networking approach to functional maintenance organization. Building on this approach, a highly effective set of capabilities is provided for the detection and sectionalization of errors, and for recovery from software and hardware faults. Complete diagnostic aids are available, and flexible video display terminals provide an efficient and attractive means for telephone operating company personnel to interface to the system. Further, a wide range of automated, as well as manual, trunk and line test features are integrated into the system design; and interfaces to both local work stations and operational support systems provide a variety of options for efficient maintenance operation.

I. INTRODUCTION

Reliability and maintainability are of critical importance in the design of high-availability switching systems. Design for high reliability requires capabilities that provide continuity of service when failures or problems occur, be they hardware, software, or human induced. Maintainability issues center around the provision of capabilities that support prompt and accurate repair and control operations by the telephone operating company maintenance personnel (crafts people).

In developing the *5ESS* switching system, reliability and maintain-

* Authors are employees of AT&T Bell Laboratories.

ability have been integrated into the total system architecture.[1] In addition, features that support the maintenance of trunks and lines terminating on the *5ESS* switch have been integrated into the system design. These include a comprehensive set of capabilities that permit interactive, automatic, routine, and remote testing of lines and trunks.

The human interface has been designed for both performance and flexibility. Using the CRT-based Master Control Center (MCC)* and other optional test positions, maintenance operations can be efficiently performed in a manner that supports high-reliability operation in a user-friendly environment.

From the operations point of view, considerable flexibility is provided in the design of these interfaces. For example, color is an option for the MCC video display terminal, and the telephone operating company can select one of two available human interface languages.

Overall, the maintenance capabilities for the *5ESS* switch can be categorized into the following five principal areas:

1. System integrity and software recovery
2. Hardware fault recovery
3. Hardware diagnostic and repair aids
4. Trunk and line maintenance
5. Maintenance crafts people interface.

Subsequent sections further describe these capabilities.

II. SYSTEM INTEGRITY AND SOFTWARE RECOVERY

The *5ESS* switch has a distributed-processing architecture that consists of a network of modules, each performing a variety of tasks autonomously. Software-recovery actions for such an architecture offer new challenges not encountered in previous systems.

The software architecture is based on a strategy that only loosely couples the various modules. Combining fault-tolerant software with a robust set of automatic module recovery actions sets the stage for a distributed network approach to software recovery.

The network approach to software recovery places a heavy emphasis on the stability and recoverability of each module. Software data-structure design and single-module recovery actions are major elements supporting system stability. These elements, coupled with recovery actions stimulated by a set of techniques including in-line run-time error detection and periodic checks of functional system components, lead to high reliability for both the individual modules as well as the total *5ESS* switching system.

This section highlights the software-recovery techniques used in the *5ESS* switch to attain a high degree of reliability.

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* Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

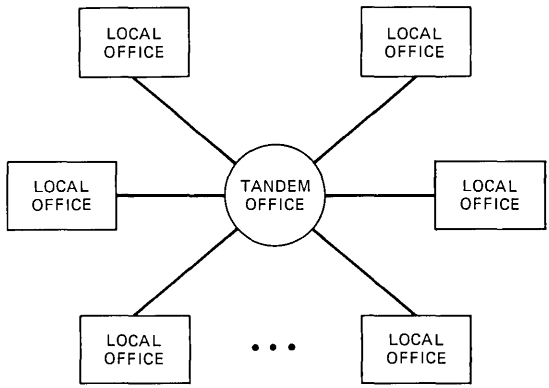

Fig. 1—Network of offices.

2.1 Loosely coupled network of modules

A solid software fault-recovery strategy is a fundamental building block to the reliable operation of any Stored Program Control (SPC) switching system. The software-recovery strategy for the *5ESS* switch is based on localized, autonomous, module recovery. Within this decoupled recovery strategy, an error is confined and recovered within the boundary of the physical module where the error was originally detected. Hence, when a high-level recovery action is required in one module, only the module experiencing difficulty is recovered, without adversely affecting the operational capabilities of the other modules. This strategy allows normal operation to continue in the rest of the *5ESS* switch while one module is undergoing recovery, resulting in a minimal system outage. The *5ESS* switch decoupled recovery strategy is in contrast to a monolithic approach wherein a high-level recovery action affects all of the modules, resulting in a total system outage. This decoupled approach to software recovery enhances the stability and recoverability of each module within the network, and thus increases the system's overall availability by limiting error propagation between modules.

The attributes of such a strategy can be compared to the classical network of offices in which a tandem office is used to interconnect several local offices, as shown in Fig. 1. Since the signaling interface between offices uses a standard high-level protocol, an error condition in one office is autonomously recovered while the remainder of the network continues to operate normally. The architecture of the *5ESS* switch can be compared to the network of offices described above by replacing the tandem office with a Communications Module (CM), the local offices with Switching Modules (SMs), and adding an Administrative Module (AM). In this network of modules, depicted in Fig. 2, the AM directs the CM to set up connections between the modules in

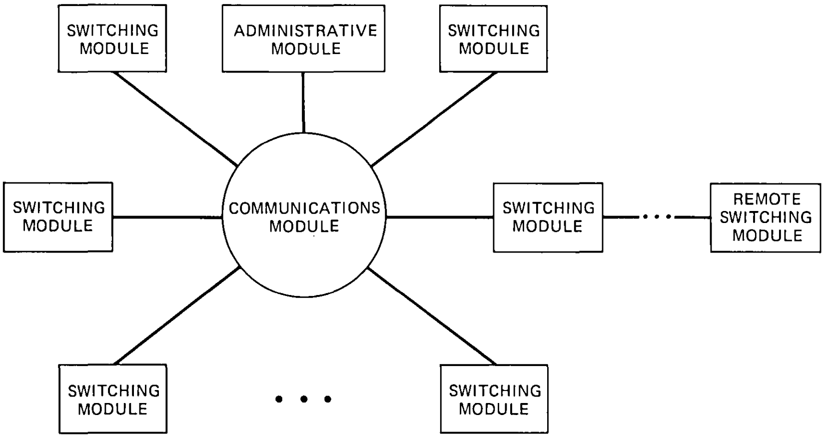

Fig. 2—*5ESS* switching system.

response to call requests, while each SM provides an intelligent switching interface to the customer. Similar to the network of offices, a given module within the *5ESS* switch may undergo software-recovery actions while the rest of the system continues to operate normally.

2.2 Software error detection

Reliable fault-tolerant software is an integral part of a reliable switching system. Fault-tolerant software should detect errors before they can degrade the system's performance, permitting recovery from errors with a minimum degradation of performance. Faults may be due to crafts people's procedural errors, hardware failures, or software defects. Fault tolerance is an absolute necessity if system downtime objectives are to be met.

The *5ESS* switch software fault-tolerant design strategy employs several techniques to detect, contain, and recover errors with a minimum impact on system operation. Specifically, this strategy embodies the concepts of software error detection, error containment, independent processor initialization, and interprocessor data consistency. Fault-tolerant software in the *5ESS* switch is characterized by the following features: in-line defensive checks, recovery from interrupts, initialization, and escalation.

2.2.1 Defensive checks

In-line defensive checks are extensively used throughout the system. This software fault-detection mechanism consists of comparing data relationships, or checking for specific data values at intermediate points in a program.

The objective of the defensive check is to detect software faults or bad data at the earliest possible time, and then to signal for recovery.

In this manner, faults are detected early and prevented from propagating throughout a module as well as throughout the system. A common systemwide approach is used for detecting, reporting, and recovering from these errors.

2.2.2 Audits

Reliable fault-tolerant software data-structure design is a key element supporting system stability. Audit programs are an essential form of error detection and correction within these software data structures. They are designed to detect, confine, and recover software data errors before system performance is adversely affected. Both intramodule and intermodule audits are interleaved with call-processing activity and routinely executed to ensure data integrity. In the event an error is detected that is so critical that normal call-processing operation cannot reasonably be expected to continue, an audit may be run in a special uninterrupted mode. These actions provide localized recovery to correct the error, and prevent escalation to a more severe level of recovery.

2.2.3 Software and hardware checks

Various types of resource checks are employed to ensure that a proper allotment of real time and a balanced distribution of system resources are provided among program clients. Such checks include hardware sanity-timer checks, process-activity checks, and tight-loop-detector checks. Additional software checks are made on resource availability, resource limits and throughput, and lost resources. In addition, several event-driven internal-hardware functional checks are used to detect and recover faulty communications between modules. An external sanity monitor is utilized as an overall backup to periodically test the system's ability to process calls.

2.3 Initialization strategy

Initialization levels in the *5ESS* switch are hierarchical in nature. Each higher-level recovery action takes more severe actions. This recovery escalation philosophy takes advantage of the loosely coupled architecture to confine software-recovery actions to within a single module. Recovery actions initially are focused only on that portion of a module in which the error occurred. If unsuccessful, broader recovery actions are taken until eventually the entire module is initialized. During some high-level module initializations, it may be necessary to ensure interprocessor data consistency. In these cases, resynchronization of cross-module redundant data is performed if any inconsistencies are detected under both normal and recovery situations.

The following sections provide an overview of the recovery actions taken at each of the levels of recovery. Although slightly different specific actions may be taken at each level in the AM or the SM, the strategy and objectives of each initialization are the same. The various initialization levels within a module include return to point of interrupt, Single Process Purge (SPP), directed audits, selective initialization, and full initialization.

2.3.1 Return to point of interrupt

A Return to Point of Interrupt (RPI) is the lowest level of software initialization. It is performed automatically in response to in-line, program defensive-check failures, and when restarting from maintenance interrupts. Actions associated with this level include local initialization of user-owned global data, scheduling of deferrable recovery actions such as audits, and escalation to the next highest level of recovery if appropriate. Control flow is usually returned to the previously interrupted point. This level of initialization is noncall affecting.

2.3.2 Single process purge

The SPP level is used whenever an error is detected that is severe enough to make it unsafe to return to the point of interrupt. The primary objective of the initialization action is to restore a software configuration that can support resumption of normal processing.

The initialization is usually confined to a single process entity within the operating system environment, such as a system process, a terminal process, or a demand process. The recovery actions associated with an SPP include killing or restarting, if appropriate, the running process or task, restoration of any associated global data, and recovery of hardware and software resources.

Control is reestablished at a safe point. Normally, this level of initialization is noncall affecting.

2.3.3 Directed audits

Directed audits are used as an initialization action whenever inconsistencies are discovered in critical data structures that prohibit continued normal system operation. This level is generally invoked from either a routine audit or a user-program, in-line, defensive-check failure.

The action taken by this initialization level is to recover, in an unsegmented mode, enough of the data structures to ensure that normal system operation can resume, and to schedule on a deferred basis any audits that are further needed.

2.3.4 Selective initialization

The second highest level of initialization in any module in the *5ESS* switch is selective initialization. This level preserves all stable talking calls associated with that module.

2.3.5 *Full initialization*

The highest level of initialization in any module in the *5ESS* switch is full initialization. This level will clear all calls from that module, and will restore it to normal operation regardless of the software configuration at the time the full initialization is invoked. The general strategy of this level is to completely initialize all of the memory and peripherals associated with that module, and then restore data synchronization with the other modules in the system.

Before running a full initialization in the SMs, hash-sum checks are made over portions of memory that are backed up on the system disk. If any region of memory is found inconsistent with its hash-sum record, that region is pumped from the disk image before the main portion of the initialization is begun. In the AT&T 3B20D computer-based AM,[2] the full initialization level is accompanied by the *UNIX* Real-Time Reliable (RTR) operating system initialization, which results in a complete rebooting of all text and data portions of memory.[3]

Mechanisms are provided to preserve recent changes and generic program updates that have not yet been committed to the system disk across full initializations. Any of the mechanisms for maintaining recent changes or program updates across initializations can be overridden by crafts person commands. This facility allows manual actions to remove temporary changes in the event that they may be interfering with the recovery of the system.

All levels of initialization provide reports, following the initialization, that describe the state of the module at the beginning and end of the initialization, its cause, and other information useful for determination of the conditions surrounding the initialization.

2.3.6 *Escalation*

The escalation philosophy takes advantage of the loosely coupled architecture and confines software-recovery actions to within a single module. Abnormal events are recorded in error history tables on a module basis. Based upon preestablished threshold values, the escalation programs determine if the current error events, based on recent history only, warrant an escalation of recovery action to the next highest level. For each module there are several levels of initialization, as illustrated in Fig. 3, with impacts ranging from minimal to a complete clearing of all stable calls associated with that module.

The escalation strategy is designed to recover the system in the shortest possible time with the least adverse affect on the total system. Furthermore, the escalation strategy also guarantees forward progress towards recovery. If the focused, low levels of recovery fail to recover normal operation to a failed module, recovery actions automatically escalate to more severe levels. This escalation occurs whenever a

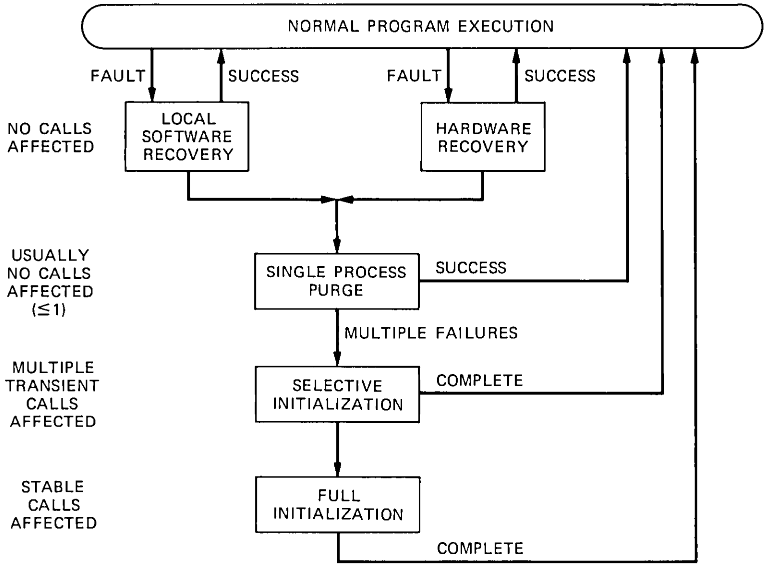

Fig. 3—Switching module recovery and escalation.

recovery action fails to complete within a predetermined time interval, or when failure events recur during a postrecovery time interval. Repeated initializations will escalate to the level necessary to recover the system. All critical initialization/recovery constraints are parameterized to permit easy modification and fine tuning of the escalation strategy.

2.3.7 Intermodule data synchronization

A relatively small amount of SM-AM intermodule redundant data exists in the *5ESS* switch. Whenever the AM and any SM are out of communication for an extended period of time, their shared data are resynchronized once intermodule communication has been restored.

Intermodule data synchronization is triggered whenever a loss of communications occurs between an SM and the AM. The AM is capable of resynchronizing all SMs concurrently.

III. HARDWARE FAULT RECOVERY

The ability to recover promptly and efficiently from hardware faults is another requirement for meeting the reliability objectives for a high-availability system. In designing the *5ESS* switching system, substantial attention has been given to hardware fault recovery—in the system architecture, in hardware design, and in software design. Hardware redundancy, configuration switchability, built-in error-detection mech-

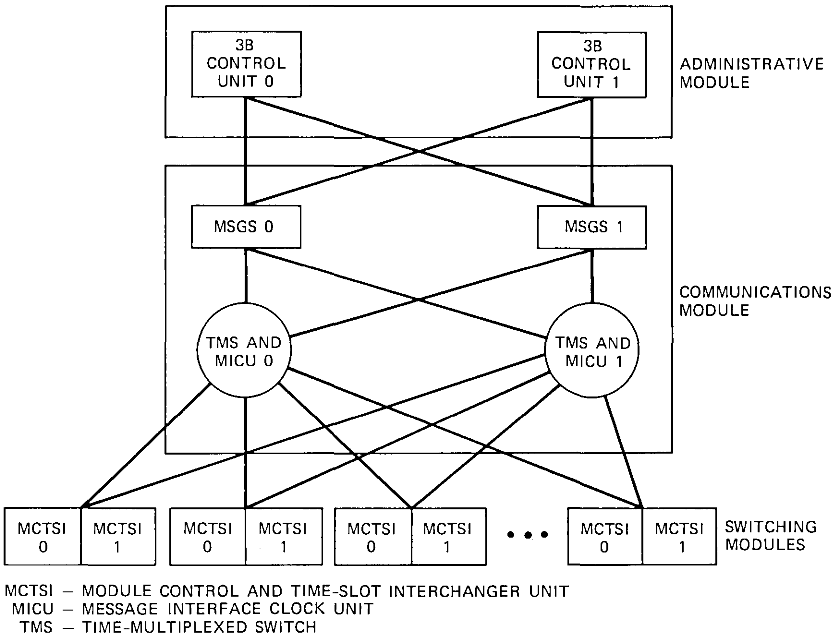

Fig. 4—*5ESS* switch duplicated hardware architecture.

anisms, and deterministic software-implemented recovery strategies are specific examples that are discussed in this section.

Guiding principles in developing the *5ESS* switch, as mentioned earlier, were to fully pursue the concepts of distributed control and loose coupling between system modules. These principles have also been vigorously followed in hardware fault-recovery design. For example, error detection and recovery actions for an SM are carried out in that module. For this example, the role of the AM is to report the recovery actions to the system maintenance personnel.

3.1 Hardware considerations

A significant part of the *5ESS* switch hardware exists for the purpose of meeting system reliability objectives.[4] Redundancy, error-detection logic, and circuitry that permits configuring around faults are prime examples. These are all prerequisites to attaining the reliability of objectives set for telecommunication switching systems.

3.1.1 Redundancy

Duplication is widely used in the *5ESS* switch architecture to permit operations to continue unhindered in the presence of a hardware fault. Figure 4 illustrates some of the redundancy employed in the system

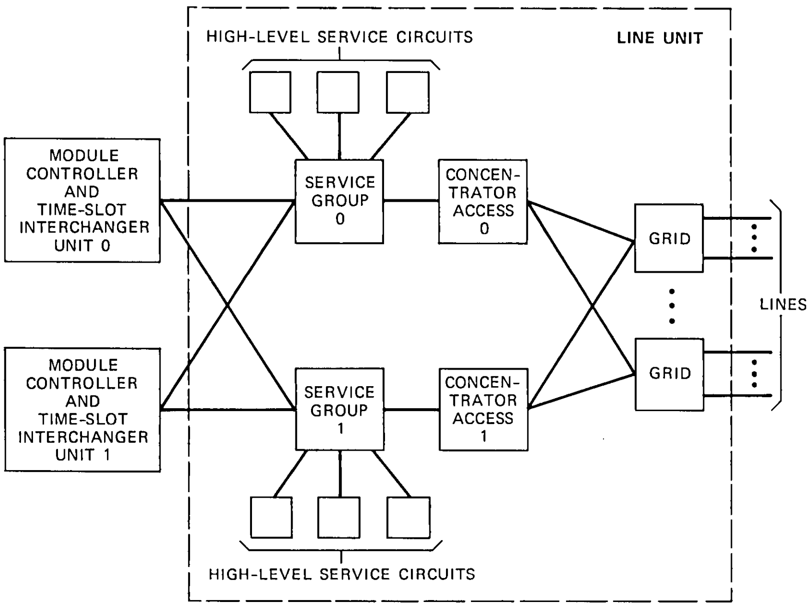

Fig. 5—Line unit redundancy.

design. As can be seen, full duplication is employed for all major control and switching elements. In the case of the SM, redundancy is also carried beyond the module control to the Time-Slot Interchange Unit (TSIU), since it is needed to provide highly reliable operation. For example, in the line unit (see Fig. 5), combinations of duplication and redundancy are employed in achieving the required level of reliability.

3.1.2 Error detection and containment

The abilities to detect and report errors are vital parts of a hardware fault-recovery plan. In the *5ESS* switch design, a self-checking strategy has been widely used in the hardware architecture. A variety of specific mechanisms are used, including

1. Parity/hamming checks
2. Operation code, address, and data validity checks
3. Sanity timers
4. Background-level exercise tests run by microprocessors
5. Synchronous Data Link Control (SDLC) and BX.25 protocol checks for link transmissions
6. Buffer overflow detection.

Error containment is also an important factor in the development of fault-recovery systems, and further, it is an important factor in the degree of "external" impact that results from a recovery action. Special attention was devoted to error containment in the *5ESS* switch design, which has enabled the loosely coupled module approach to be achieved. To illustrate, parity checking and regeneration at various points in the switching network provide prompt and localized detection of errors in the switching path. This permits ease in identifying an offending unit, and, just as importantly, prevents error signals from being broadcast throughout the system. In turn, this allows straightforward recovery actions to occur without impact to the remainder of the system.

3.1.3 Error reporting

Several levels of error reporting are employed to notify fault-recovery software of errors detected in hardware operation. For the more significant error types, high-priority interrupt mechanisms are used. For less serious errors, lower-level report messages are launched to the appropriate module for processing. Finally, for nontime-critical events, error source registers (set by error detectors) are periodically polled by software to determine if any errors have occurred. For each unit, specific reporting mechanisms have been chosen to achieve a good balance between

1. Impact on overall system performance
2. Impact on the specific unit involved
3. Economics (system cost).

Figure 6 illustrates typical error detection and reporting schemes employed in the SM control and TSIU.

3.2 Software functions and strategies for hardware fault recovery

The *5ESS* switch fault-recovery strategies and the logic for configuring the system are principally contained in software. To achieve the loosely coupled design intent, major portions of the system's fault-recovery software are resident in the administrative and switching modules. The AM, based on the 3B20D computer, is fully self-recoverable.[3] Similarly, the SM is designed for self-recoverability, both from simplex failures in the module controller and TSIU, as well as from failures in the SM's peripheral units (e.g., line units, trunk units, and service circuits). This is achieved by having fault-recovery software resident in the SMs at all times. For the CM, recovery actions are principally orchestrated from the AM.

A variety of hardware fault-recovery strategies are employed in the *5ESS* switch design. Unit-specific strategies cover the majority of faults. For these, recovery actions are invoked in response to unique errors, i.e., errors that trigger a specific detector that in turn implicates a specific unit. Another strategy, error thresholding, is commonly used to filter out transient errors. Other strategies, including error analysis,

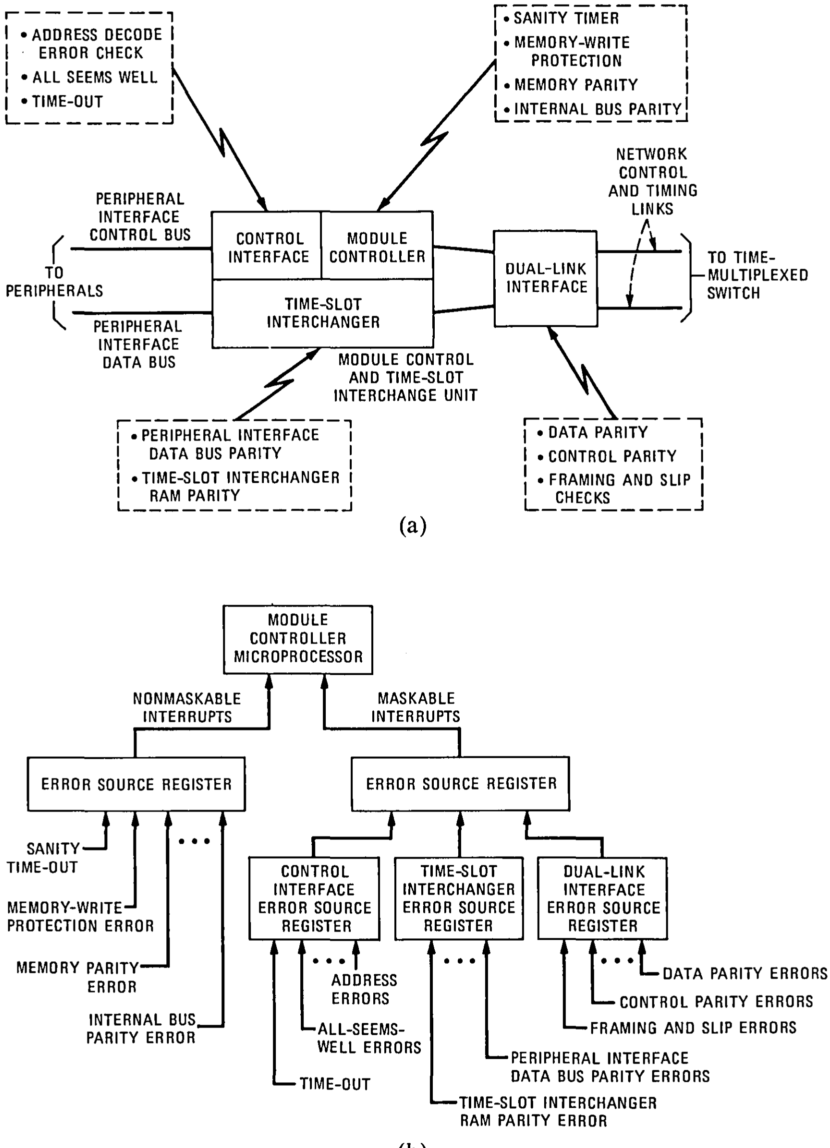

Fig. 6—Typical error-detection and reporting mechanisms for the switching module controller and TSI unit: (a) error detection; (b) error reporting.

are used to handle the more complex faults. Moreover, high-level hardware recovery strategies are also in place to support the more global system-level recovery strategies discussed previously in Section II.

Provisions have also been made for handling recurrences of error reports for which the primary recovery strategy is ineffective. Alternate strategies have been provided in the *5ESS* switch design to handle these cases. This mechanism provides an effective way to deal with low-probability failures, including multiple faults.

The ability to have graceful degradation is another characteristic of the *5ESS* switch design. This is particularly important in multiple fault situations involving opposite sides of the duplicated hardware architecture. Although infrequent, these faults could otherwise cause significant impact on system performance. One area where significant attention has been given is in the central stage of the switching network, the time-multiplexed switch, which is part of the CM.

To provide telephone company maintenance personnel with ultimate control of the system, the ability to manually inhibit error reports and force specific configurations is also provided in the design. These capabilities override normal recovery actions and thus permit maintenance personnel to establish working configurations under highly unusual failure conditions.

IV. HARDWARE DIAGNOSTICS AND REPAIR AIDS

The purpose of diagnostic programs is to verify that circuits being tested function according to their requirements. If a circuit under test does not function accordingly, the diagnostic process should readily guide the user to the faulty hardware for repair.

4.1 Objectives

In real-time systems designed for continuous operation, diagnostics must be run in a time-shared noninterfering mode with the application software and hardware. The *5ESS* switch is such a system. In this system it is unacceptable to deny service to communications customers for fault isolation, repair, or routine testing.

Maximum fault detection of all faults is desired. While practical and economic constraints prevent the detection of all possible faults, it is clear that high coverage can be achieved by addressing testability at the very beginning of the design process.

Diagnostic fault resolution is defined as the ability of a diagnostic program to pinpoint the location of a faulty circuit in the system. Upon fault detection, and when tests in a diagnostic fail, the diagnostic program should provide a rank-ordered list of hardware items that are candidates for replacement or repair. These rank-ordered lists are called Trouble Location Procedure (TLP) lists. In addition to removable circuit boards, the TLP lists may include other hardware, such as cables and power supplies. It is desirable that the vast majority of all faults encountered by operating personnel be on a TLP list. Indeed, it is an objective that, in the majority of failure instances, the replaceable unit containing the fault be high (i.e., first or second) on the appropriate TLP list.

Diagnostic run time is measured from the time a diagnostic is requested until the diagnostic result is available. Short run time is often in conflict with high fault-detection coverage and high resolution. It is important to note that a diagnostic that runs fast, but does not detect or locate many faults, does not support a short repair time. Diagnostics that balance all diagnostic objectives prove most useful to maintenance personnel.

Measures of fault-detection coverage, fault-location performance, and run time can be made. This is accomplished by the examination of data obtained from physical fault insertion, simulation, and system operation, both in the laboratory and in the field. By use of these means, diagnostic performance is measured, improved, compared to, and balanced against objectives.

4.2 Design approach

The diagnostic subsystem of the *5ESS* switch is aligned with the system's high-level distributed-control architecture. The diagnostic software structural philosophy includes the minimization of internal messages to maximize system performance. Diagnosis of a given piece of equipment is generally performed by the nearest processor in the system having sufficient software capability. Diagnostics run from these locations tend to minimize run time and have a better ability to control and monitor the circuits being tested.

The AM processor, the Foundation Peripheral Controller (FPC), which is part of the CM and SM processors, execute the diagnostics for at least one additional system component and are referred to as diagnostic hosts.[1–4] The approach used in diagnosing hardware peripherals associated with a diagnostic host generally depends on the nature of that hardware.

A peripheral that contains no processing capability of its own is tested entirely by its host, from which stimuli are applied and responses are measured.

A peripheral that has a microprocessor of its own, but insufficient software power to act as a diagnostic host, is approached in a different manner. Such circuits are typically diagnosed from the nearest host by a combination of direct tests of the peripheral-host interface, firmware-resident tests of additional portions of the circuit, and possibly down-loaded, RAM-resident tests of the remainder.

The AM and SM processors are the major duplex processors in the system. The active member of a major duplex pair is generally used to execute the diagnostic of the other member. Diagnosis is accomplished by an appropriate combination of direct tests by the active mate, firmware-resident self-test, and RAM-resident tests loaded from the mate.

In all of the cases outlined, the technique of using only active or previously tested circuitry in the hardware under test is followed.

Conceptually, diagnostic programs may be considered to be resident in the host processor in which they are executed. In actuality, they are generally loaded into a host's memory from the system disk on demand under the auspices of diagnostic control software. This loading process is known as paging. Therefore, while a large fraction of the total software generic consists of diagnostic programs, only a relatively small amount of processor memory is required for their execution.

4.3 Diagnostic environment

The diagnostic environment for the *5ESS* switch was designed such that the diagnostic program developers can concentrate on the hardware and the hardware interfaces being tested, as opposed to system software interfaces. This isolation is provided through the environment software consisting of diagnostic supervisors and special-purpose diagnostic functions and macros.

The diagnostic supervisor's role includes controlling diagnostic execution, providing hardware read/write access, managing resources, and preventing the diagnostics from interfering with normal system operations.

The Peripheral Diagnostic Language (PDL/5) was developed for the *5ESS* switch to formalize the interfaces between the diagnostic program and the system software. Special-purpose functions, called by means of corresponding macros (PDL/5 macros), allow the diagnostic to access hardware, use special resources, and, at the same time, isolate the diagnostics from the system. The language is specifically designed as an augmentation of the C programming language. Among other things, the use of the PDL/5 macros in diagnostic programs detects as many diagnostic coding errors as possible at compile time, and provides a C comment labeling for each segment and each test. This labeling is an aid in reading diagnostic listings and for use in the rare case of manual troubleshooting.

4.4 Diagnostic structure

Typically, there is a unit diagnostic for groups of major functions contained on one or more circuit boards. The unit diagnostics are used to diagnose the hardware set that has been removed by fault recovery because of a problem. This hardware set is called a repair group, because if any piece of hardware in the group fails, the entire set of hardware is removed from service for diagnosis (repair). In some instances, the repair group and the unit diagnostic are "identical" (e.g., the FPC), while in others, the repair group is diagnosed by the use of several subunit diagnostics.

Each diagnostic consists of several diagnostic phases. A typical phase diagnoses a set of functionally related hardware on one or more circuit boards. The following criteria are among those used to determine what tests are to be included in the same phase:

1. Each phase should contain tests that are associated by virtue of some common property. A common property can be physical, such as a circuit board, or logical, such as when a phase tests a circuit subfunction.

2. Phases may be run independently, and, because of this, they are designed so that the results are independent of the order in which they are run.

3. Phases should be homogeneous in their use of helper circuits so that tests requiring dissimilar helpers are not in the same phase. A helper circuit is any other circuit used to help diagnose the unit that is under test. Use of these criteria ensures that tests requiring unrelated resources are not skipped by keeping related tests together.

Each diagnostic phase is composed of segments. A segment is defined to contain the set of tests necessary to test a single board function or operation. Diagnostic segments have system-dependent requirements such as run-time limits, real-time breaks, and critical region requirements. Specific segment execution time limits are restricted to ensure that diagnostic execution does not impact other system activities, e.g., call processing.

Each segment is composed of one or more tests. A test is a minimum exercise that produces observable results.

4.5 Routine exercises

The *5ESS* switch diagnostic software has an important capability known as Routine Exercise (REX). The REX capability allows operating personnel to schedule periodic diagnostic and other testing of the system hardware. By this means, the office equipment is tested routinely to detect latent faults before they can affect service.

The implementation of the REX capability utilizes the *5ESS* switch distributed architecture to an advantage. Once started by an AM process, the per-processor processes diagnose their hardware units autonomously.

A scheduling table in the AM is used for these purposes. Using this table, operating personnel can, if desired, specify or change the days, the times of day, and the length of time REXs are to be run on the various modules comprising the system's hardware. Duplicated circuits are tested and switched, and simplex circuits are tested and restored to active service if the diagnostic passes. When faults are encountered,

```
(Input)
DGN: LUHLSC (2,3,0,1) TLPI

(Output)
DGN LUHLSC (2,3,0,1) FAIL PH 2 SEG 7 TEST 2
DGN LUHLSC (2,3,0,1) SUSPECTED FAULTY EQUIPMENT

     AISLE    FRAME    BAY    CODE     EQL     NOTE

     0101       2       2     TN333    43-46    -
     0101       2       2     TN343    43-22   On Line
     0101       2       2     TN331    43-90   On Line
```

Fig. 7—Diagnostic printout TLP list.

diagnostic results are both printed out and displayed. Also, as testing progresses, each control process maintains a table of statistics including the numbers of circuits of each type tested, passed, and failed. Once each day, or, asynchronously, on demand by maintenance personnel, a summary report on the current results from REXs can be printed out and displayed.

4.6 On-line trouble location

In the *5ESS* switch, TLP lists are provided on-line immediately following diagnostics to the various output locations. These output locations include the MCC at the switch, operating company switching control centers, and, if needed, at support centers at AT&T Technologies and AT&T Bell Laboratories. A TLP list is provided by the diagnostic program when it detects a failure of one or more of its tests.

In the *5ESS* switch, the TLP list generation is an integral part of the diagnostic program design. The designer uses special PDL/5 macros to specify how the TLP hardware list is to be built and adjusted dynamically as the diagnostic progresses through its sequence of tests. With this approach, the TLP capability can easily be kept in step with diagnostic and hardware evolution.

This on-line approach in the *5ESS* switch is convenient for operating personnel with switch maintenance responsibilities. Because of the extensive use of Large-Scale Integration (LSI) circuitry, the typical unit or circuit being diagnosed is composed of only a few circuit boards. In fact, the majority of the hardware is covered by individual diagnostics, where the reconfigurable unit or circuit is contained on a single board. In many cases, the suspect-board list contains the single board and one or two of the boards with which it interfaces. In these cases, the diagnostic designer need only be concerned with the optimum rank ordering of the two or three boards on the TLP list. A very large percentage of the expected hardware faults are first on the rank-ordered TLP lists.

4.7 Typical output

A typical input request to run a diagnostic and a typical failure output response are shown in Fig. 7.

4.8 Additional features and capabilities

The diagnostic system for the *5ESS* switch has many desirable features and capabilities beyond those discussed in this brief section. Several examples follow.

1. More than one diagnostic can be run in an interleaved time-shared mode concurrently in an individual SM. This is in addition to the capability of running diagnostics simultaneously in several SMs.

2. Simple visual displays of system status and craft interfaces are provided. User-friendly, menu-driven selections are displayed to assist the craft in maintaining the switch.

3. Diagnosis of links between major units (e.g., SMs and time-multiplexed switches) is provided for routinely and on demand by cooperative use of diagnostics at each end, plus link-specific diagnostics.

4. Testing of the solid-state line concentrators is accomplished using two programs: the concentrator diagnostic and a network fabric test program. The role of the concentrator diagnostic is to determine the health of the concentrator as a whole. The role of the fabric test program is to verify that each and every crosspoint and link works properly and that no shorts or opens exist. The fabric test is run routinely or on demand with the concentrator in service and coexists with call processing.

V. TRUNK AND LINE MAINTENANCE

Maintainability considerations for trunks and lines are also important factors in the design of telecommunications systems. Automatic detection of faults, administration of service status, and facilities for running tests and making measurements are capabilities required for the maintenance of trunks and lines. Over the years, a number of methods have been employed in this area and many are currently in use. Some methods depend on capabilities either built into or appliqued onto a switching system, while other methods center on remoting of maintenance functions. Centralized maintenance approaches are also widely used.

5.1 Facilities

For the *5ESS* switch, a complete set of trunk and line maintenance facilities have been integrated into the system design, and interfaces have also been provided for remote testing. The goal is to provide flexibility to the telephone operating companies to best meet their individual needs.

The principal hardware parts of the *5ESS* switch related to trunk and line maintenance are shown in Fig. 8. Coupled with software control, these provide a complete feature set and flexibility for both local and remote maintenance operations.

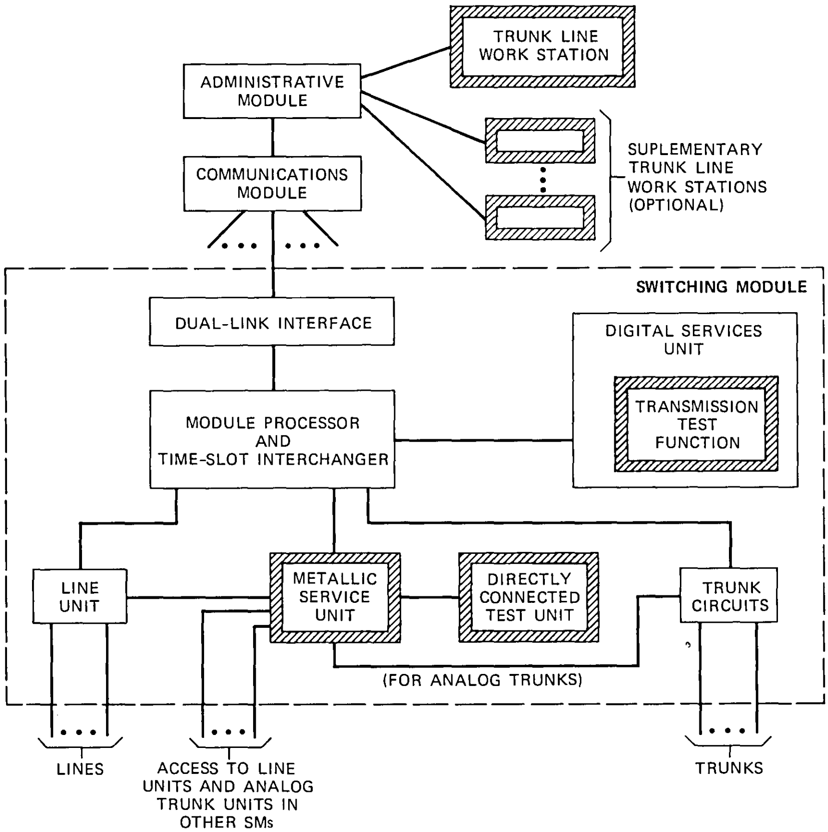

Fig. 8—Principal hardware units supporting trunk and line testing capabilities.

The Trunk Line Work Station (TLWS) is integrated into the MCC of the *5ESS* switch. As shown in Fig. 9, key TLWS facilities include a CRT video display terminal, a receive-only printer, a key telephone set for voice and monitor connections, and a test access unit with ac and dc jacks that provide access for testing with portable test equipment. The CRT terminal at the TLWS is the principal human interface for trunk and line testing. For larger offices, up to six supplementary TLWSs can be equipped as needed.

The Transmission Test Function (TTF), via switched digital Pulse Code Modulated (PCM) access, provides all capabilities needed for voice frequency testing. Tone sources and detectors, power and noise measurement capabilities, and features needed for a variety of standard test lines [100, 102, 104, Remote Office Test Line (ROTL) and Touch-Tone signaling test lines] are incorporated in the TTF design.

Metallic access for trunk and line testing is provided by the Metallic

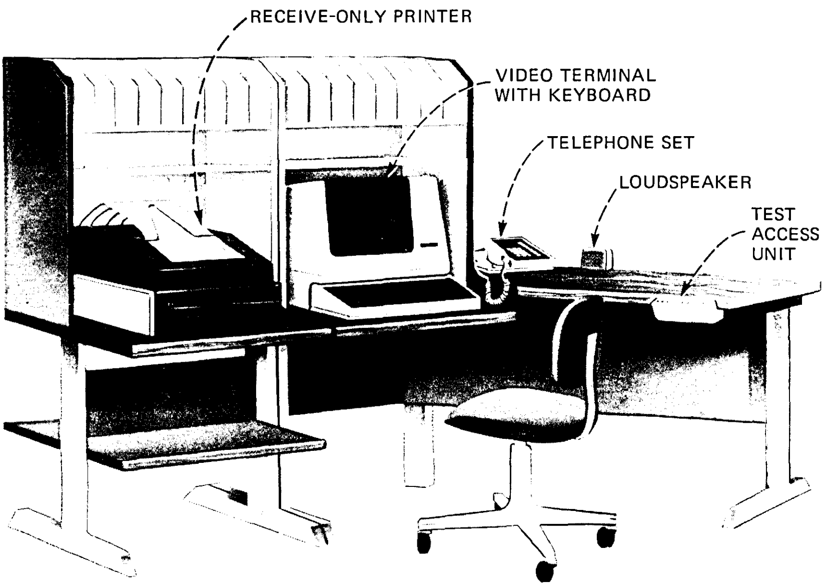

Fig. 9—Master control center with integrated trunk and line work station capabilities.

Service Unit (MSU). In addition, the MSU hardware contains the capabilities needed for Automatic Line Insulation Testing (ALIT).

The Directly Connected Test Unit (DCTU) is used for testing where metallic access is needed. A variety of testing capabilities are provided, including foreign Electromotive Force (EMF), resistance, capacitance, and coin station tests.

The TTF, MSU, and DCTU units are resources shared across SMs in the *5ESS* switching system.

5.2 Trunk and line test features

Using the hardware facilities described above, a comprehensive set of test features are provided by *5ESS* switch software. Part of these features permit maintenance personnel to interactively perform tests at the video display terminal of the TLWS. To illustrate, maintenance personnel can, using convenient commands, request specific line/trunk accesses, tones, and measurements (e.g., voltage, noise, resistance, and capacitance). Results are quickly displayed on the terminal.

A standard set of automated test capabilities are also integrated into the system design. These include the standard 100 series test lines and test calls (e.g., milliwatt, and two-way noise, and loss measurements) and ALIT. These automatic test capabilities permit maintenance personnel to request specific tests to be run in a prepackaged fashion without the need for any human interaction. Removal from service, sequencing of tests, and restoral to service are all accomplished automatically by the associated trunk and line maintenance software, without the need for any manual intervention. Should maintenance personnel in the course of testing remove from service a significant number of trunks within a trunk group, alarms are activated to aid in protecting office performance.

Routine test capabilities built into the *5ESS* switch design provide an efficient detection mechanism for trunk and line problems. These tests are run periodically with no human involvement. For trunks, the Automatic Progression Testing (APT) feature is provided. Tests to be automatically run can be prespecified by the telephone operating company and can be selected from the set of operational tests built into the *5ESS* switch design, i.e., signaling capability tests. For lines, ALIT tests are similarly run. For flexibility, the starting time and duration of routine tests can be scheduled by the telephone operating company in order to best coincide with an office's nonbusy period. Protection is again provided to prevent routine test software from automatically removing an excessive number of trunks within a single trunk group.

5.3 Trunk and line status

Administrative software is provided to efficiently and reliably handle the maintenance status of trunks and lines terminating on a *5ESS* switch. Call and carrier failure events as well as any failures detected during routine tests are reported to this software for appropriate processing. High and wet, blocked, and power cross lists are maintained, and the status of the included lines and trunks are supervised in order to return them to service when the problem is removed. Capabilities are also provided at the TLWS for querying and changing the status of lines and trunks.

5.4 Remote facilities

As shown in Fig. 10, flexibility is provided in the *5ESS* switch to interface with both the traditional and newer remote maintenance facilities. For both trunks and lines, the test capabilities available on the TLWS CRT terminal are also available at the serving Switching Control Center (SCC). For trunk testing, the *5ESS* switch also provides integrated interfaces to the Centralized Automatic Reporting On Trunks (CAROT) system and the new Central Trunk Test Unit (CTTU). The CAROT operations support system provides, on a centralized basis, the means for initiating and evaluating routine transmission tests on trunks. This capability is fully supported by the *5ESS* switch with its integrated ROTL capability. The CTTU provides, on a dial-up basis to the *5ESS* switch, the ability to run tests on

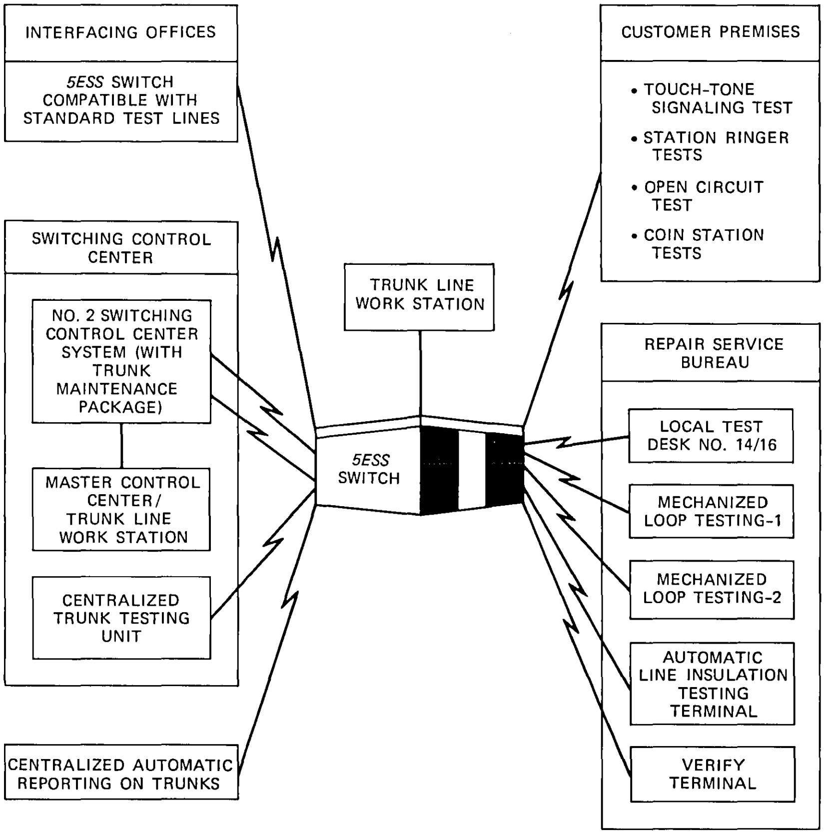

Fig. 10—Trunk and line maintenance remote interfaces.

requested trunks and lines. The *5ESS* switch is also compatible with the Trunk Maintenance Package (TRUMP) capability provided in the No. 2 System Control Center System (SCCS) System located at an SCC. TRUMP monitors trunk error messages, performs error analysis functions, requests appropriate trunk tests to be run at the *5ESS* switch, and has the ability to request removal from service of any failed trunk.

For line maintenance, provisions are made for testing remotely from customer locations and from remote centers. From the customer premises, tests such as Touch-Tone signaling, station ringer, and connections to an open circuit or coin station test line can be made. For the remote repair service bureau, *5ESS* switch interfaces are provided for testing from a Local Test Desk (LTD) or from the Mechanized Loop Testing (MLT) System. ALIT tests can also be requested from the repair service bureau.

5.5 Flexibility

The trunk and line maintenance design for the *5ESS* switch is inherently flexible. With the basic testing facilities integrated into the system architecture, provisions are made for a comprehensive set of interactive, automatic, and routine test capabilities. Remoting is a natural ability with flexibility in interfacing to a variety of external systems and facilities. The video display terminal-based TLWS offers a user-friendly interface that also provides substantial flexibility for future developments.

VI. MAINTENANCE CRAFT INTERFACE

Maintenance activities in the *5ESS* switch are controlled via a modern, user-friendly craft interface system. The craft interface is built from basic components provided by the 3B20D computer craft interface package[5] enhanced with specific craft programs for the *5ESS* switch. The crafts people maintain the *5ESS* switch from work stations supported by the AM. This architecture centralizes and consolidates the craft interface while permitting effective maintenance of the loosely coupled elements of the *5ESS* switch architecture. When the crafts people need access to a terminal anywhere in the office, interframe wiring permits access from a work station at a remote site.

6.1 System architecture

Work stations in a *5ESS* switch office may contain both a video display terminal with keyboard and a hard-copy Read-Only Printer (ROP). The main work station is called the Master Control Center (MCC). This work station is the primary interface to the switch, and consists of a video display terminal, a ROP to print a paper copy of all major system events, and trunk and line maintenance features as discussed in Section V. A view of a typical MCC position is shown in Fig. 9. Other work stations that may be equipped in an office are for recent change, multiple Trunk Line Work Stations (TLWSs), and a belt-line terminal to assist crafts people in larger offices. All of these work stations may use video display terminals.

Since a large number of *5ESS* switches will be remotely maintained, an interface to the Switching Control Center (SCC) is provided which allows MCC control functions to be performed remotely. For reliability, the links to the SCC are duplicated and use the BX.25 protocol.

6.2 Video display terminal

The heart of the *5ESS* switching system's craft interface is the video display terminal. Several different terminals are supported that may be either black and white or color. The video display terminal in

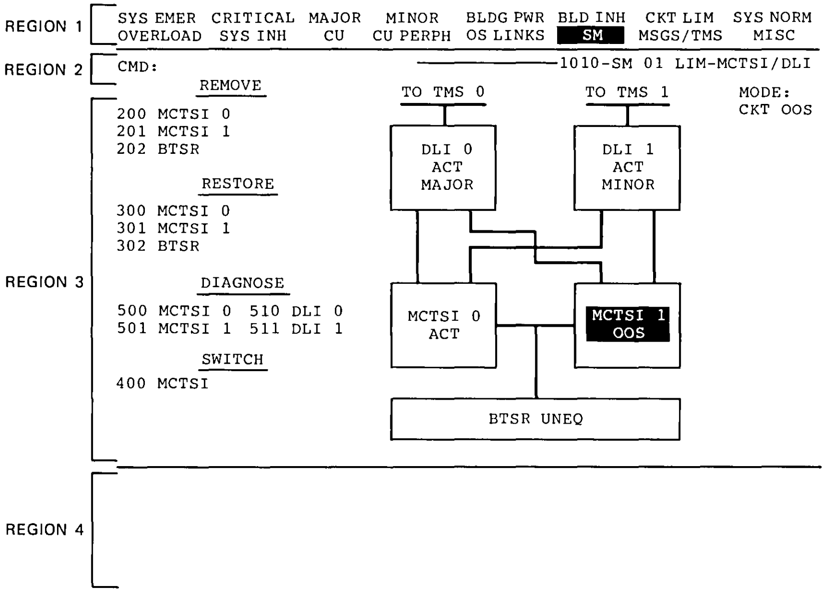

Fig. 11—Video display regions.

the *5ESS* switch combines the capabilities of the primary I/O device and the status display and control panels of previous systems to minimize cost and provide flexibility.

To accomplish all of these functions, the video display unit screen is divided into four separate regions or *windows* (see Fig. 11). The first window contains a high-level system summary status as well as system summary alarm levels. This display provides a constant high-level picture of the status of the switching system.

The second window is the system command area, which is reserved for entering abbreviated system commands called *pokes,* as described below. These numerical pokes are used to change the displays or to execute menu commands.

The third window is the display area. This area can be used for several purposes. In many displays, it is used to give detailed status of specific hardware units. These pages use block diagrams to represent the various hardware subsystem units. Blocks in the diagram are labeled with the name of the units and their system states. Connecting lines represent the functional relation between units in the diagram. Color or backlighting and flashing are used to highlight status information. Most pages also contain a menu of commands that can be executed to change the state of units on the page. The commands are invoked by multiple-digit pokes that are entered from the keyboard in the system command region.

```
SYS EMER  CRITICAL  MAJOR    MINOR     BLDG/PWR   BLDG INH  CKT LIM   SYS NORM
OVERLOAD  SYS INH    CU    CU PERPH  OS LINKS      SM      MSGS/TMS   MISC

CMD:                                   ----------------------100-PAGE INDEX
                  USE EA DISP FUNCTION KEY TO DISPLAY EAI PAGE

100 PAGE INDEX                    117 IOP 0 & 1               160 TRUNK & LINE MAINT
101-104 NOT ASSIGNED
105 BLDG/PWR & ALARM CONTROLS     119 MISC ALARMS             190 C/D UPDATE
106 BLDG/PWR & ALARM CONTROLS     120 MESSAGES                191 OS STATUS PAGE
107 CIRCUIT LIMIT                 121 MICU 0 & 1              197 CUTOVER
108 NOT ASSIGNED                  122 TMS 0                   198 ODD RCV
109 OVERLOAD                      123 TMS 1                       (NOT FOR USE BY SCC)
110 SYSTEM INHIBITS               124 MSGS 0                  199 ECD/SG RCV
111 CU, CU PERIPHERALS            125 MSGS 1                      (NOT FOR USE BY SCC)
112 CU, CU PERIPHERALS            126 LOGICAL LINK MAP
113 OS LINKS                      127 MTIB STATUS             1950 PROG UPD MAINT
114 EQUIPPED SM STATUS SUMMARY                                1960 BWM INSTALLATION
115 MSGS/TMS SUMMARY              130 NM EXCEPTION            1999 NO. 5 STATES
116 MISCELLANEOUS                 131 HARDWARE CALL TRACE
```

Fig. 12—Page index video display.

The fourth region on the screen is reserved to input messages to the system and to display system output messages. Input and output messages are formatted in either the conventional syntax used for AT&T Technologies electronic switching systems or the International Telegraph and Telephone Consultative Committee (CCITT) MML. The customer has the choice of which language to use on a per-office basis.

6.3 Controlling the 5ESS *switch*

Figure 12 shows one of the high-level MCC displays for the *5ESS* switching system. This display (page 100) is the page index, which contains a reference list of all pages available to the crafts person for displaying status of any part of the switch. The SYS NORM indicator at the top of the display signifies that all hardware units are in service and are operating normally.

To illustrate how crafts people would use these displays to control the system, assume that a trouble exists in one of the switching modules. The crafts person would be given a high-level view of this problem via the SM summary indicator in region 1 of the CRT screen. At this point, the page index could be used by the crafts person to step through the display hierarchy to display increasingly more information about the trouble. By entering `114` in the system command area of the page, summary status information for all equipped SMs can be displayed (see Fig. 13). This display points to a circuit out-of-service condition in SM 1. Instructions on this page inform the crafts person of subsequent commands to be entered. In this case, the command `1010, 1` would cause more detail about SM 1 to be displayed. As indicated in Fig. 14, SM 1 has a problem with the duplicated Module Controller Time-Slot Interchanger/Dual-Link In-

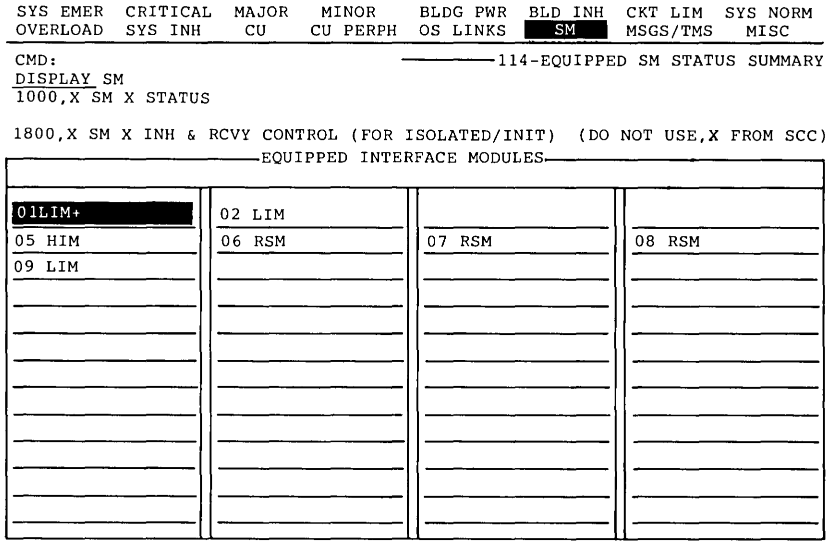

Fig. 13—Status summary display for switching modules.

terface (MCTSI/DLI) complex. At this point, the command 1010 would cause this complex's complete status to be displayed. Figure 11 shows that the specific hardware trouble is in MCTSI 1.

Using automatically generated trouble-locating information provided on the ROP by system diagnostics, crafts people would locate and replace the faulty circuit board. After the repair is completed, a single menu poke command will cause the *5ESS* switch software to retest the hardware and automatically restore normal operation if all tests

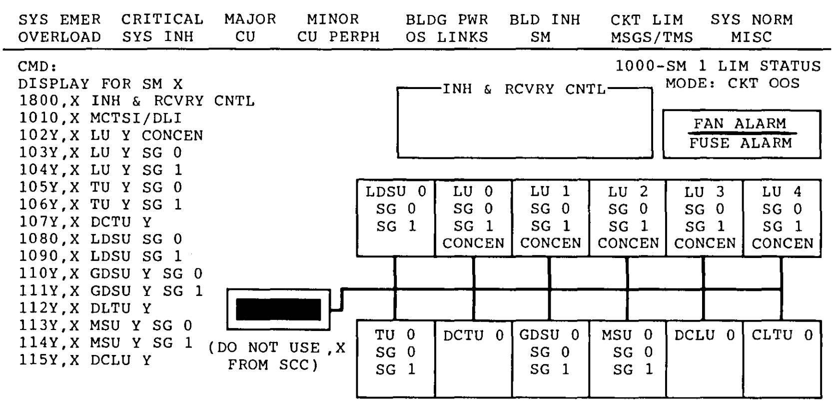

Fig. 14—Switching module status display.

pass. The successful execution of these tests would result in the MCTSI being restored to the active state.

Experienced office crafts people could have immediately entered the `1010, 1` command to display the status of the MCTSI/DLI complex, since automatically generated reports on the ROP would have pointed directly to this complex. Thus, the hierarchy of displays allows all crafts people, from the inexperienced to the experienced, to be guided through simple commands to the exact trouble. In this way, all maintenance situations can be resolved quickly.

6.4 Trunk line work station capability

As described in Section V, the TLWS provides the capability for performing trunk and line maintenance tasks at a *5ESS* switch office. In many earlier systems, these tasks were performed using a specially designed hardware panel. The *5ESS* switching systems, however, utilize standard video display terminal-based work stations to perform the TLWS function. The MCC includes full TLWS capabilities, and the MCC, remoted through the SCCS, also includes TLWS features. For large offices, up to six supplementary TLWSs can be equipped.

6.4.1 Base TLWS menu

An interactive TLWS task is initiated and controlled by the crafts people through a base menu referred to as a test position. There are eight test positions so that up to eight interactive tasks can be simultaneously in progress. The test position menus are simultaneously available at all TLWSs. A crafts person can choose to have more than one task active at a given work station. However, only one test position menu is displayed on a TLWS CRT at a time. The crafts person can move from task to task by entering commands to change the test position currently displayed. Each test position is kept up to date with the status for its task whether or not it is currently displayed.

Figure 15 shows an example of a test position menu page. At the top, in the system summary alarm region, are office critical indicators common to all MCC pages. In the general display area, the upper portion of the display shows test parameters and task status indicators. Sufficient information is displayed to allow the craft to control and follow the progress of any task.

The lower portion of the test position display area is used to display menus that give instructions and commands for all TLWS interactive task capabilities. Figure 15 shows page 170 displayed in this area. This menu gives an index of the other menus that can be requested for display in this area. The menus are listed in three groups corresponding to the three steps of a task. These include entering test parameters, requesting connection of a line or trunk to test equipment, and finally,

```
SYS EMER  CRITICAL  MAJOR    MINOR     BLDG PWR  BLD INH   CKT LIM   SYS NORM
OVERLOAD  SYS INH    CU     CU PERPH   OS LINKS    SM      MSGS/TMS    MISC
------------------------------------------------------------------------------
CMD: 170 OK                                    ----------161 - TEST POSITION 1
 IN      PORT    TALK  MNTR  E   M   RING ROH
 PROG    ACC

    POSITION DATA              STABLE CONDITIONS          RESULTS
PORT:                     TYPE ACC:
TYPE:                     FUNCTION:
JACK:
OPDN:
FREQ:
LEVL                IN PROG ACK:
-----------------------------------------------------170 - TEST MENU INDEX

TEST DATA MENUS           TEST ACCESS MENUS:         TRANS TEST MENUS:
 171 POSITION DATA         172 TLLWS JACKS            177 MEASUREMENT
                           173 MNTR BUSY TRK/LINE     178 SEND TONE
                           174 TRANS TEST            MET MEAS MENUS:
                           175 METALLIC MEAS          176 METALLIC TESTS
------------------------------------------------------------------------------
```

Fig. 15—Sample test position page for TLWS.

the execution of specific tests. For example, instructions for entering test parameters are displayed with command 171. The crafts people need not call up these displays if they are familiar with the menu commands. A TLWS task command can be used when a test position is on the video display whether or not the menu containing the command is currently on the display.

6.4.2 A sample TLWS task

The following example shows how a crafts person would check for foreign voltage on a line. First, the crafts person would enter the directory number of the line to be tested in the command area of the screen. In this example assume the directory number of 357-0001. After being accepted by the system, this information is redisplayed under POSITION DATA in the center screen area (see Fig. 16). Next, a

```
SYS EMER  CRITICAL  MAJOR    MINOR     BLDG PWR  BLD INH   CKT LIM   SYS NORM
OVERLOAD  SYS INH    CU     CU PERPH   OS LINKS    SM      MSGS/TMS    MISC
------------------------------------------------------------------------------
CMD: 176 OK                                           161 - TEST POSITION 1
 IN      PORT     TALK MNTR  E   M   RING ROH
 PROG    ACC

    POSITION DATA              STABLE CONDITIONS          RESULTS
PORT:3570001              TYPE ACC: MET MEAS
TYPE:LINE — DN            FUNCTION:
JACK:
OPDN:
FREQ:
LEVL:               IN PROG ACK:
------------------------------------------------------176 - METALLIC TESTS
REQUEST:             REQUEST: (COIN LINE): REQUEST (LINE):   ADDL CMDS:
 952 FEMF             964 HOME TOTALIZER    956 DIST TO OPEN  900 RELEASE
 953 RESISTANCE       965 DETECT COIN       957 RNGR COUNT    905 PRNT RESULTS
 954 CAPACITANCE      966 COLLECT COIN                        (MENU 175)
 955 AV,DV,Ko,uF      967 RETURN COIN
------------------------------------------------------------------------------
```

Fig. 16—TLWS display page with setup for metallic testing.

```
SYS EMER  CRITICAL  MAJOR   MINOR     BLDG PWR  BLD INH  CKT LIM  SYS NORM
OVERLOAD  SYS INH    CU     CU PERPH  OS LINKS    SM     MSGS/TMS   MISC
--------------------------------------------------------------------------
CMD: 952 OK                               ------------161 - TEST POSITION 1
  IN    PORT       TALK  MNTR  E  M  RING ROH
  PROG  ACC

     POSITION DATA            STABLE CONDITIONS              RESULTS
PORT:3570001               TYPE ACC: MET MEAS          OC VOLTAGE (VOLTS)
TYPE:LINE-DN               FUNCTION:                              AC      DC
JACK:                                                  TG          0       0
OPDN:                                                  RG          0       0
FREQ:                                                  TR          0       0
LEVL:              IN PROG ACK:
-----------------------------------------------------176 - METALLIC TESTS

REQUEST:           REQUEST (COIN LINE):  REQUEST (LINE):     ADDL CMDS:
 952 FEMF           964 HOME TOTALIZER    956 DIST TO OPEN    900 RELEASE
 953 RESISTANCE     965 DETECT COIN       957 RINGR COUNT     905 PRNT RESULTS
 954 CAPACITANCE    966 COLLECT COIN                          (MENU 175)
 955 AV,DV,Ko,uF    967 RETURN COIN
```

Fig. 17—TLWS display page with metallic testing results.

connection between the measurement hardware and the line is requested with the appropriate command in the command area of the screen. Figure 16 shows the display after the crafts person has completed this activity by indicating the connection to measurement hardware. The PORT ACC indicator is also backlit to remind the crafts person that a connection is in place. As also shown in Fig. 16, page 176 contains a list of measurements that can now be requested. Finally, the crafts person requests a voltage measurement, as shown in Fig. 17, by entering the appropriate system command. The requested measurements are displayed under RESULTS. Note that the ac and dc voltages in the tip-to-ground, ring-to-ground, and tip-to-ring configurations are normally displayed and dynamically updated until another measurement is requested.

6.5 *Flexibility*

Every effort has been made in the design of the *5ESS* switch craft interface to make it easy and efficient to use. The use of the video display unit as a combination I/O device and display panel puts all critical office information in one place, decreasing the incidence of errors.

The use of windows on the display screen allows the crafts person to see both overall system status and the status of a particular subsystem simultaneously. The use of graphics to depict hardware units and the connectivity between hardware units enables the crafts person to instantly understand the impact and scope of an equipment outage. Color (as an option) has been used to highlight system status in a natural, intuitive way. For example, green indicates in-service units and red indicates out-of-service units.

The use of a single soft terminal for many functions reduces the initial cost of the system and makes it easier and cheaper to implement new features. In previous systems, new keys and lamps were required in addition to system software to provide new features. With the *5ESS* switch, only new software is normally required. The use of terminals, rather than dedicated keys and lamps, also allows easy remoting of these functions. Finally, the use of pokes to replace wordy input commands reduces the amount of typing the crafts person must do, increasing efficiency and reducing the number of errors made.

VII. SUMMARY

With the described maintenance capabilities, the *5ESS* switching system is fully capable of providing the highly reliable service demanded of switching nodes in telecommunications networks. The system maintenance features provide a friendly interface for telephone operating company personnel that in turn further supports the reliability of the system and its associated trunks and lines. Building on the distributed processing concept inherent in the *5ESS* switch design, maintenance actions are focused within an individual module, thus minimizing perturbations to the overall system. This loose coupling approach is a key ingredient in providing the *5ESS* switching system's resiliency to malfunctions, be they induced by hardware, software, or human procedural errors. Further, the coordinated maintenance functions are capable of handling multiple failures and severe malfunctions.

Substantial flexibility is provided in the *5ESS* switch design for the telephone operating companies and for system extensions. Interfaces are provided to a wide variety of operations support systems, and an integrated set of capabilities is provided for all aspects of maintenance. Thus, the *5ESS* switching system is well suited for all applications ranging from stand-alone installations to offices remotely maintained on a centralized basis. This flexibility, coupled with the fault resilience and user-friendly maintenance capabilities described in this article, contributes significantly to making the *5ESS* switching system an outstanding choice for telecommunications switching applications.

VIII. ACKNOWLEDGMENTS

In planning and developing the maintenance capabilities for the *5ESS* switching system, many people in many organizations have been involved. The strong team work and individual contributions of all have made this a highly successful and interesting endeavor. The authors gratefully acknowledge all our colleagues who participated in this work.

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The 5ESS *Switching System:*

Hardware Design

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(Manuscript received November 23, 1983)

This paper gives a general description of the *5ESS*™ switch hardware design. A significant amount of new hardware, including numerous very-large-scale integration circuits, microprocessors, signal processors, and memory devices, is used in the *5ESS* switch design to accomplish its operational and maintenance design objectives. By adhering to the distributed and modular architecture in all the hardware designs, the incorporation of advancing technologies and new functionality is accomplished with ease.

I. INTRODUCTION

The *5ESS* switch hardware architecture is composed of the Administrative Module (AM),‡ one or more Switching Modules (SMs), and a Communications Module (CM) as major system elements. Control of the office is distributed between the AM, which consists of a single AT&T 3B20D computer complex, and one or more SM processors. Communication among all these processors is performed by the Message Switch (MSGS) contained in the CM. Switching in the office is performed with a time-space-time Pulse Code Modulation (PCM) digital switching network. This network consists of a Time-Slot Interchanger (TSI) in each SM and a single Time-Multiplexed Switch (TMS) within the CM. The TMS, MSGS, and SMs are interconnected with high-speed optical-fiber links that carry network data, control

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‡ Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

messages, and timing information. Interfaces to lines, trunks, and pair-gain systems are provided by a variety of digital and analog interface units. Numerous other circuits, such as the Signal Processor (SP), Digital Service Unit (DSU), and Metallic Service Unit (MSU) provide the resources and functionality necessary for call processing and maintenance of the office. SMs can be located up to 125 miles from the office, and connected by T-carrier facilities.

The hardware design, which used sophisticated machine aids extensively, has taken advantage of many technological advances. A new high-voltage Gated-Diode-Crosspoint (GDX) technology is employed in a solid-state, low-cost, and efficient line concentrator. Very large scales of integration are used in 64K-bit memory chips, custom logic, digital signal processing, and time-slot interchanging. A single-chip codec/filter is employed. Optical-fiber links pioneer an interframe interconnection media. Extensive use is made of microprocessors to realize the design of the *5ESS* switch's distributed processing architecture.

The major hardware design objectives included a highly reliable system, functionality for numerous switching applications, the ability to accept gracefully the introduction of new technology and low cost. In addition, minimizing power consumption and floor space and providing for short installation intervals are included as design objectives.

The physical design of the *5ESS* switch is covered in a companion paper.[1]

II. CONTROL STRUCTURE

The switching network of the *5ESS* switch is controlled, as shown in Fig. 1, by the AM and the SM. The AM performs the switching network path-selection function, whereas the SM performs most of the call-processing functions. Control information among the processors within these modules is communicated via messages that are transferred from the sending processor to the receiving processor by the MSGS. Messages that originate or terminate at the SM processor are transmitted by the MSGS over optical-fiber links.

2.1 Message switch

All interprocessor message transfers are performed by the MSGS. For a message to be transferred from one SM processor to another, the originating processor, illustrated in Fig. 2, transmits the message on a dedicated control time slot over its Network Control and Timing (NCT) link to the TMS. The message is switched from the TMS onto another NCT link that connects to the MSGS. Within the MSGS, an MSGS peripheral controller known as the module message processor

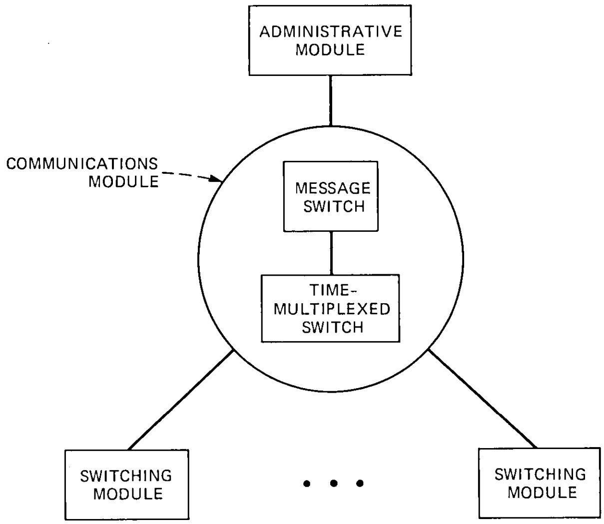

Fig. 1—*5ESS* hardware architecture.

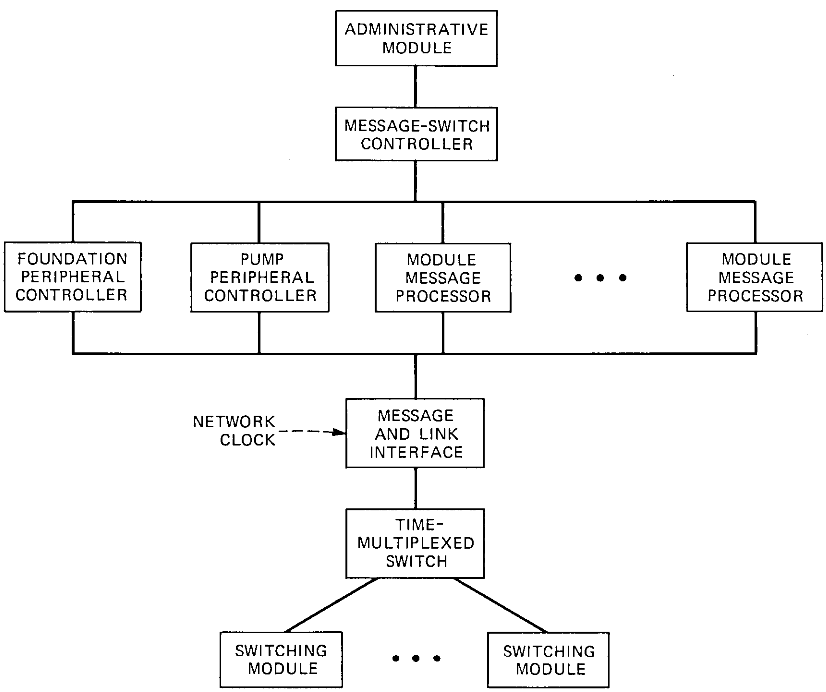

Fig. 2—Message-switch interprocessor communication.

receives the message and, with the help of the MSGS controller, transfers the message to the dedicated control time slot of the destination SM processor. If the message is destined for the AM, the MSGS controller transfers the message from the module message processor to the AM over a high-speed serial bus.

In addition to the messages associated with normal operation of the switch, the MSGS is designed to transfer large quantities of bulk data and program text from the AM to an SM processor. A pump peripheral controller is used for this operation. The effective data rate of this type of transfer is 192K bytes per second. At this data rate an SM processor can be loaded with 4M bytes of program text and data in about 40 seconds (including protocol overhead time).

The MSGS is also capable of transferring special maintenance messages from the AM to an SM processor. These messages, known as processor-intervention messages, travel through the MSGS in parallel with normal messages and are sent by the AM to force the SM processor into a particular state.

Messages from the AM that control the operations of the MSGS can be transferred over the high-speed serial bus to the MSGS controller. Depending on the type of message, either the MSGS controller will be the destination of the message, or an MSGS peripheral controller will be the destination. Control messages from the MSGS controller or an MSGS peripheral controller to the AM can also be transferred.

One specific MSGS peripheral controller, known as the foundation peripheral controller, processes AM control messages that are destined for, or originate from, the network clock, the TMS, and the MSGS's message and link interface circuitry. The foundation peripheral controller communicates with the network clock, the TMS, and the message and link interfaces over a standard dedicated bus known as the control and diagnostic access link.

2.1.1 Message-switch controller

The MSGS controller is designed around four bit-sliced microprocessor chips. The design includes circuitry to interface with the AM's dual serial channel that allows direct memory access transfers of data between the AM's processor and the MSGS controller.

Also included in the design is a microprocessor I/O bus. This bus allows the MSGS controller to communicate via direct memory access with up to 14 MSGS peripheral controllers that may be handling message traffic for up to 48 SM processors.

Up to 5 million, 30-byte messages can be handled per hour by this design. Microcoded algorithms are used to achieve this message throughput. The design includes nearly nine thousand 40-bit instructions of microcode. About one-half of these instructions are for maintenance functions and the rest are for message-processing functions.

2.1.2 Message-switch peripheral controllers

There can be a total of 14 MSGS peripheral controllers equipped in the MSGS. One of these is the foundation peripheral controller and another is the pump peripheral controller. The remaining 12 controllers are module message processors that are available for communication with SM processors. Each of these 12 module message processors handles eight BX.25 links. To provide interprocessor communication with high reliability, the entire complex of 14 MSGS peripheral controllers is duplicated and four BX.25 links (two from each duplicated side) are interconnected for communication with each SM processor.

Each MSGS peripheral controller is designed around a microprocessor chip that is operated at an 8-MHz clock rate. The design's memory system supports 128K bytes of dynamic RAM for software text and data. An additional 16K bytes of ROM is provided for initialization programs. In addition, 8K bytes of RAM is specifically designed for message queues. This special "mailbox" memory includes arbitration circuitry to control access in a prioritized way by the processor itself and the MSGS controller.

2.2 Switching module processor

The SM processor performs most of the call-processing functions that control the *5ESS* switching network. The design supports up to 16M of RAM for program text and data and up to 128K bytes of ROM for initialization programs. To achieve high reliability the processor and memory system are fully duplicated. Special circuitry is included to provide the required maintainability and real-time performance.

2.2.1 Processor core functions

The SM processor is designed around a single microprocessor chip that is operated at a 9-MHz clock rate. Circuitry to provide interrupt handling, address mapping, bus control, power-up sequencing, alarming, and several other special functions is included as part of the processor's core design, as diagrammed in Fig. 3.

Three interrupt levels are used in the SM processor: one for operational and routine maintenance, the second for reconfiguration messages, and the third for reset errors. There are several different sources of interrupts at each of these levels. They may all be masked under software control with the exception that critical maintenance

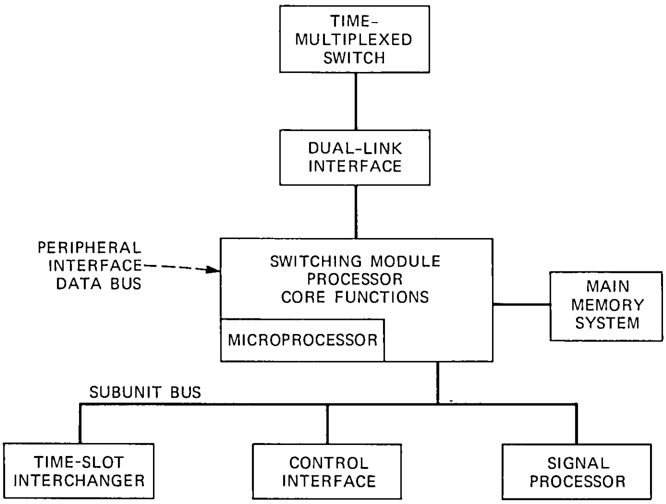

Fig. 3—Switching module processor connectivity.

messages, such as reset, sanity-timer time-out, and test system interrupts, may not be masked.

2.2.2 Processor I/O

I/O operations for the SM processor consist of either interprocessor message transmissions or communication with the other circuitry in the SM, such as the TSI.

Interprocessor messages are formatted and queued for transmission by software routines. The SM processor transfers these messages by direct memory access circuitry to a synchronous data link control chip that applies BX.25 protocol to the messages. The messages are then transmitted in the appropriate control time slot by the dual-link interface circuit.

Large quantities of data and program text may be loaded into the SM processor's memory system. This operation, known as "pump," requires special circuitry in the SM processor and a connection to the Peripheral Interface Data Bus (PIDB).

The SM processor communicates with other units within the SM on the subunit bus. The subunit bus allows 16 bits of data and 6 device address bits to be transmitted to the subunits. Each unit on this bus receives its own unit-select signal and is capable of specifying the number of processor wait states needed to complete its operation. There are currently three different subunits: the TSI, the SP, and the control interface.

Of particular importance, the control interface circuitry provides an interface for control information to all the SM peripheral units. This interface is over a standardized bus known as the Peripheral Interface Control Bus (PICB). By using this bus peripheral units can evolve independently of the SM processor.

In addition to interprocessor messages and subunit I/O operations, numerous (about 100) special-function and status-register operations are performed. These operations, as with the message and subunit bus functions, are memory-mapped operations. One class of special registers is known as the shadow registers. These registers capture the state of various bus levels and other machine registers when certain maintenance interrupts occur. The captured information allows for higher resolution of the source of the interrupt that may have been caused by either a hardware or software failure.

2.2.3 Processor main memory system

The SM processor's I/O total address spectrum encompasses 16 million locations. Memory-mapped I/O uses 8K addresses, leaving the remaining locations available for program text and data. The main memory system provides up to 128K bytes of ROM for processor initialization programs, and 8K bytes of fast static RAM for operating system stacks and special diagnostic functions. The remainder of the memory spectrum may be populated with dynamic RAM as needed. Currently, about 4 megabytes of RAM are required, 64K bytes of ROM, and 8K bytes of fast static RAM.

The dynamic RAM portion of the memory system uses memory planes that are organized as 40-bit words by 256K locations. The 40 bits per location are addressable by the memory system's controller as 4 bytes. The remaining 8 bits contain the Hamming function code for that location.

The memory system controller includes Hamming function circuitry. This circuitry is capable of detecting double-bit errors and correcting single-bit errors. This circuitry is implemented in custom gate arrays.

The memory system includes both write-protection and stack-protection circuitry. The write-protection circuitry inhibits mutilation of software text and protected data. The stack-protection circuitry inhibits a software function from writing into another function's stack frame and guards against stack overflows.

III. SWITCHING NETWORK

The network of the *5ESS* switch, a time-space-time network, is depicted in Fig. 4. The time-division portion consists of distributed, concentrating TSIs that each multiplex up to 1024 time slots from the network's periphery (lines, trunks, and service circuits) to 512 time slots toward the space-division portion. The CM contains a TMS that is a very fast space-division switching fabric that makes and tears

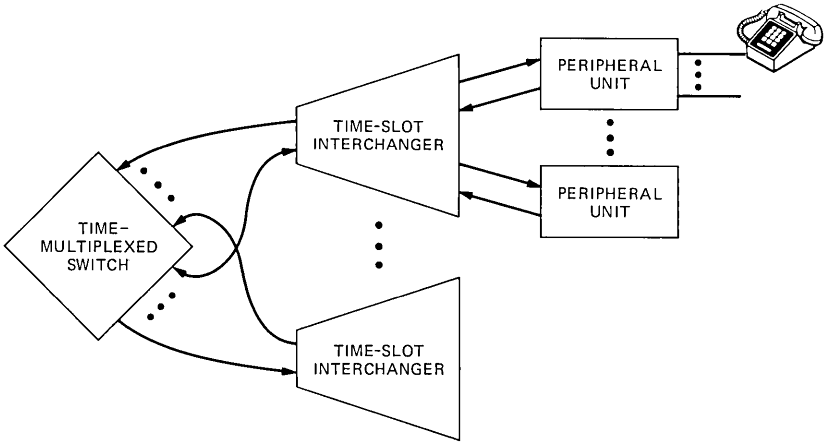

Fig. 4—Time-space-time digital switching network.

down connections between TSIs on an individual time-slot basis. The TSIs and the TMS are interconnected by optical-fiber links. Timing for the *5ESS* switch is provided by the CM's network clock and is distributed by the TMS to the TSIs over the optical-fiber links.

Within the *5ESS* switch the signaling and control information is carried along with data throughout the switch. The TSIs, the TMS, and the optical-fiber links are designed for 16-bit time slots in which 8 bits are data and 8 bits are signaling and control information. The signaling bits are used in a variety of ways. For example, one signaling bit typically carries on-hook/off-hook status and therefore can be used to detect switchhook "flashes." Another signaling bit is used within the *5ESS* switching fabric to mark the status of each time slot as idle or busy. Yet another bit, the parity bit, is important to the detection of hardware faults. Some signaling is contained within the data band, for example, tone-dialing signals and dial tone. The above examples are intended to convey the idea that a considerable amount and variety of signal processing must occur within the switch. Signal processing is performed in either of two units: an SP that is closely associated with each TSI and is used for functions that must be performed on a per-time-slot basis; and a digital service unit that performs more complex signal processing that can be shared over several active time slots.

3.1 Design considerations

Although implementation cost is a design consideration, an even more important consideration for the switching network hardware is reliability. Several of the approaches taken to ensure operational reliability for the switching network are listed below.

1. All the major switching units are duplicated, and selected units are cross coupled.

2. Circuitry that can detect, contain, and report hardware faults is included. In this circuitry, error containment is a major consideration that must be provided so that hardware errors propagate as little as possible and never to the duplicated portion of the network.

3. Although software can completely control the hardware configuration, certain classes of serious faults are handled autonomously by the hardware.

Another major design consideration is to provide for potential design evolution. For the lifetime of the switching network to extend over decades or more, it is essential for the hardware design to be capable of evolving to take advantage of technology evolution and market needs. This consideration led to careful partitioning of functions with attention to interfaces. The following examples are illustrative.

1. The optical-fiber links that connect the TMS to the TSIs carry all interconnection information (data, control, and timing). With technology evolution it is expected that the maximum distance possible for the optical-fiber link connection will be many miles. This will result in a widely distributed switching network.

2. The connection of the TSI to the SM peripheral units that interface to lines and trunks is over a standardized data bus known as the PIDB. This bus carries timing, data, and signaling. Peripheral units can evolve independently of the TSI by using this bus.

3. Evolution was also considered in the design of the interfaces to the software system. For example, the TMS controller was designed so that software can communicate with it via high-level messages that are independent of a particular hardware implementation of the TMS.

3.2 Design descriptions

3.2.1 Optical-fiber links

Multimode optical-fiber links interconnect the TSIs and the TMS. Information is transmitted in nonreturn-to-zero format at 32.768 Mb/s framed into two hundred fifty-six 16-bit time slots at an 8-kHz frame rate. Separate fibers are used for each direction of data flow. Therefore, four links are required in each direction to support each TSI. An LED serves as the optical transmitter and a pin photodiode is used as a light transducer in the receiver. Clock and frame timing is extracted from the data stream by the receiver-associated circuits to accomplish synchronous data transmission. Up to a full frame of buffer storage is provided at the receiving end to remove any constraint on cable-length matching.

3.2.2 Time-multiplexed switch

A simplex TMS is composed of two independent switching fabrics and a common microprocessor controller. Each 32×32 switch unit interfaces to one NCT link from as many as 30 SMs, a test input, and a link from the MSGS. Optical-fiber links carrying even-numbered time slots connect to the "even" switch unit, while odd-numbered time slots connect to the "odd" switch unit. Data from the link interfaces are divided into dual 16-Mb/s data streams for transmission through the switch multiplexers. Error reporting and analysis, path request handling, and initialization are tasks of TMS controller firmware, which provides an intelligent interface between the AM and the switch unit hardware. Link time slots passing through faulty circuitry will have their busy/idle status bits forced to the idle state for interpretation by special maintenance circuits in the TSI.

3.2.3 Time-slot interchanger

Within each SM, dual 512 × 512 TSIs perform the switching function in each direction of the path connection (periphery-to-network or network-to-periphery). Special loopback paths within each TSI establish peripheral-to-peripheral and network-to-network connections. Each slide of the duplicated TSI is able to select automatically network data from either side of the duplicated TMS by examining "valid data" markers on every incoming network time slot.

The digital service unit tone generators and decoders have switched access so that the unit can be the source of or receive data on any peripheral or network time slot. The SM processor also has switched access, which allows it to be the source of and to observe data on any TSI time slot.

A 2:1 concentration function allows up to 32 peripheral data buses of 32 time slots each to access the 512 time slots of the TSI.

Data going from the TSI to the periphery can be optionally attenuated by a digital attenuation function in the TSI. This function is individually controllable on a per-time-slot basis to provide a selectable attenuation level of up to 15 dB.

The TSI also provides dedicated signaling bit access to and from the SP for all signaling and control bits on each of the 512 peripheral time slots in the TSI.

3.2.4 Signal processor

The SP can be the source of signaling and control bits on each of the 512 peripheral time slots in the TSI. In addition, the SP monitors all incoming signaling and control bits from the 512 time slots for state changes and reports all transitions that last longer than 6 ms. The SP is controlled by the SM processor so that reports of signaling changes on any time slot can be inhibited or allowed.

3.2.5 Digital service unit

The DSU provides the *5ESS* switch with digital signal processing capabilities. The capacity of a DSU is engineered to meet peak service demands so that the digital processing resources can be shared across all active channels. The *5ESS* switch requires two applications of the DSU. The first application, known as the local DSU, provides heavily used services by locating a DSU within each SM. A local DSU is responsible for creating and transmitting call-progress tones, multifrequency signals, tone-dialing signals, and common channel interoffice signaling continuity check tones. It also does dial-pulse collection, tone-dialing decoding, and detection of multifrequency signals. The second DSU application, called the global DSU, provides low-runner services such as three-party conferencing and special transmission test functions. A global DSU is shared across all SMs in an office.

To provide reliable operation the DSU is composed of two service groups that share the load so that a single fault can at most reduce DSU capacity by 50 percent. The DSU uses AT&T Technologies digital signal processing chips for almost all its required services.

IV. SUBSCRIBER INTERFACE AND METALLIC TESTING

4.1 Line unit

The *5ESS* switch Line Unit (LU) interfaces to analog subscriber lines. In particular, this includes conventional loop-start, ground-start, and PBX trunks. Since these analog terminations typically constitute most of the terminations in an office, the LUs represent a large fraction of the total equipment and cost of the *5ESS* switch. Thus, an important engineering consideration in the design of the LU is its manufacturing and maintenance cost.

Since the LU interfaces with conventional subscriber loops, it must be capable of withstanding lightning surges and power crosses, and it must interface with a large variety of station equipment. In addition, it is desirable to minimize the amount of engineering required for any given LU within an office, since equipment terminations and traffic patterns tend to change and evolve with changing communication needs in an area.

Finally, the reliability and maintenance of the unit are prime considerations in the design. It is essential that the unit require minimal maintenance, and it is also highly desirable that the equipment be designed such that faults and problems can be isolated without denying service to the connected subscribers.

These design objectives are provided in the *5ESS* switch LU by joining a new high-voltage silicon technology (used to achieve a concentrating network function on ceramic hybrids) with state of the art low-voltage complementary metal-oxide semiconductor silicon technology (used to provide the analog-to-digital conversion function). This combination of technologies gives the advantages of low cost and digital device technology for the *5ESS* switch LU.

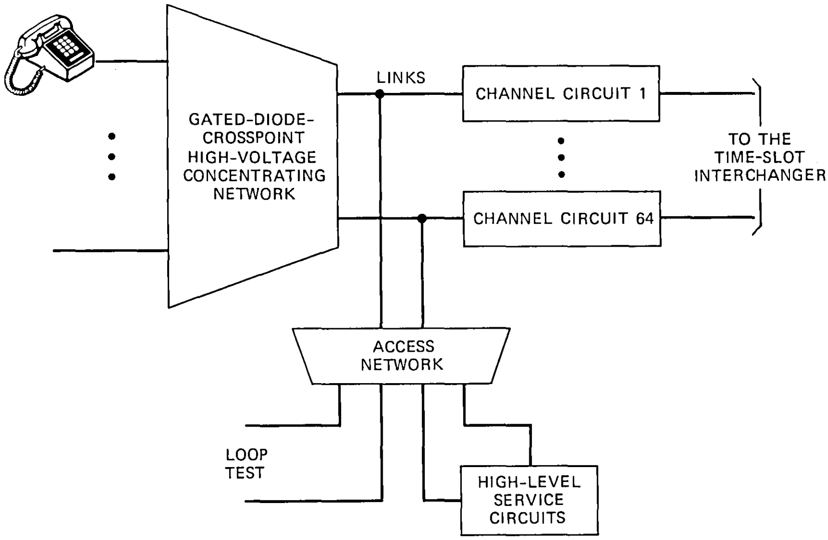

Fig. 5—Subscriber line unit.

4.1.1 Concentration network

Subscriber appearances terminating on the LU are switched to channel circuits that provide battery feed, analog-to-digital conversion, and other functions, as indicated in Fig. 5. The concentration ratio of lines to channel circuits is a function of the expected traffic level in the application. Ratios of 8:1 and 6:1 are achieved by simply removing optional plug-in circuit packs. Ringing and loop-testing functions are provided through an access network that further concentrates the 64 links to six high-level service circuits and two test ports.

The fundamental building block of this space-division concentrator is the GDX device. This 590V silicon technology device was initially developed to meet the needs of the *5ESS* LU application. The device itself is configured as a 2 × 2 switch that serves both the tip and ring conductors of a connection.

The GDX device is packaged in a hermetically sealed chip carrier that, in turn, is mounted on a ceramic substrate that interconnects several GDX devices. This hybrid integrated circuit also has control circuitry for the local GDX devices. Since large voltages can be present on the tip and ring conductors (±265V), special hybrid integrated-circuit technology and high-voltage control circuits were also specially developed for this application. Five hybrid integrated-circuit codes were developed for the space-division concentrator network.

These GDX hybrid integrated circuits are placed on conventional double-sided printed wiring boards along with the power supplies, alarm circuits, overvoltage protection circuits, and the required control logic. Sixty-four customers are served by three circuit packs that constitute a grid. For maintenance and control purposes, the three circuit packs are handled by software as a single unit.

The origination detection circuits do not use the usual "balanced" detector design, but, rather, they use a detector/filter combination on the ring conductor only. This arrangement with separate cutoff crosspoint control on the 1400-ohm scan resistors to ground and battery allows the same electrical circuit to work for loop-start or ground-start applications. This option can be selected in system software and requires no special equipment rearrangements.

An LU can be equipped with six to eight grids, depending on the expected traffic level. When equipped with eight grids, the unit serves 512 lines with traffic levels up to 3.2 CCS/line. When equipped with six grids, the unit serves 384 lines with up to 5.2 CCS/line.

4.1.2 Access network

The space-division network as depicted in Fig. 5 provides switched paths between two classes of service circuits. Sixty-four channel circuits provide battery feed, two-wire to four-wire conversion, loop supervision, and analog-to-digital functions for the subscriber terminations. The access network connects high-level service circuits that provide ringing voltages, coin control pulses, and network test functions.

4.1.3 Channel circuits

Since the channel circuits serve the connected subscribers through a GDX network, several new requirements are placed on them. The GDX device exhibits a nonlinear characteristic when the current through the device reverses direction. To prevent this device characteristic from interfering with telephone calls in the talking state, the battery-feed current is supplied differentially to the tip and ring conductors but floating with respect to earth ground. To prevent loop conductors from corroding as a result of positive potentials on the conductors, a special circuit on the channel pack detects cable corrosion conditions and biases the loop conductors negative. The GDX network also has a finite series resistance for which the channel circuit must compensate with added gain. Finally, the channel circuit's hybrid circuits must appropriately terminate both loaded and nonloaded customer loops. The appropriate balance network is selected by system software from information stored in the SM processor's memory resulting from on-hook loop tests done periodically by system maintenance software.

Since the *5ESS* system is intended for international as well as domestic applications, several different versions of channel circuits are available. Termination impedances, battery-feed-current profiles, and A-law or μ-law codec versions are available. The modularity of partitioning in the system allows this critical function to take advantage of rapidly changing technology in planned product evolution for future applications.

4.1.4 High-level service circuits

The subscriber loop plant requires a variety of signal voltages, including 20 Hz, 88V rms ringing, ±130V coin-control pulses, and others. In addition, the LU itself must check its operations and be capable of further diagnostic tests that detect faulty circuits. Previous systems have met these requirements by terminating a variety of special-purpose circuits on the switching network. These special-purpose circuits in general were engineered for each application.

In the *5ESS* LU, special signaling requirements are met by a universal high-level service circuit that is configured under software control. Because each circuit can handle a variety of tasks and the holding time for a particular task is short, six circuits can meet the needs of 512 lines independent of the particular service mix on that unit.

The high-level service circuit itself is a dc-to-dc converter capable of 15W and 200V. The output of this converter is fed to the switching network through a full-wave bridge-type switching circuit that acts as an amplifier to low-level signals produced by the signal generator on the circuit pack. The low-level signal generator produces 20-Hz signals and other required signal voltages, and the bridge switch amplifier produces at the high-level service circuit output a signal amplified 50 times. This circuit pack also contains an accurate current-sensing circuit that is used to verify proper operation of the LU and to detect the presence of the ring trip condition during ringing on the subscriber loop.

High-level service circuits are time shared among various system processes under software control. The circuit can be reconfigured quickly (100 ms) to provide a burst of ringing, do a power-cross check, collect a coin from a coin phone, or do a network integrity check.

4.2 Metallic service unit

The MSU provides a two-wire metallic switching matrix that interconnects dc and low-frequency test equipment to subscriber lines and metallic trunks. It is a highly concentrated resource that accommodates service circuits that are traffic engineered for each office. The service circuits do basic test, test interconnection, and alarm-reporting functions. The service circuit functions have been packaged into five circuit pack codes that provide metallic access, GDX compensation, automatic line insulation testing, and general scan and distribute functions. To perform a typical test the system software configures the service circuits into the switching network as appropriate.

For reliability purposes, an MSU contains two service groups, each with its own common control circuit and interface to the SM processor. In large offices several MSUs may be needed to accommodate all the necessary service circuits. These units are interconnected by a metallic test interconnect bus that enables any single test resource to access any line or trunk in the office.

V. TRANSMISSION INTERFACES

There are three different transmission interface units that may be provided in an SM for connection to analog trunk facilities, a T1-carrier, and subscriber line carrier equipment. These units make extensive use of custom Very-Large-Scale Integration (VLSI) devices to achieve cost-effectiveness and dense packaging.

5.1 Trunk unit

The trunk unit provides the interface for all analog trunks on the *5ESS* switch. This includes both metallic and analog carrier trunks. The trunk types provided include E&M (both two-wire and four-wire), loop (both incoming and outgoing), and a test trunk interface.

Although many types of trunks are supported, the trunk circuits differ only in the type of signaling and transmission scheme that they use. These differences are provided by trunk facility interface circuitry. The control and voice interface is common on all *5ESS* switch trunk circuits and provides the analog-to-digital conversion (codec) function and trunk circuit control functions.

5.2 Digital line trunk unit

The Digital Line Trunk Unit (DLTU) is designed to interface digital trunks on the *5ESS* switch. The primary function of the DLTU is to convert the bipolar T1-carrier format into a unipolar format and distribute the T1-carrier frame onto the 32-time-slot PIDB frame of the SM.

The DLTU contains up to ten Digital Facility Interface (DFI) circuits, a power-start circuit, and an equalizer circuit. The power-start circuit controls power to a DLTU, and the equalizer is used to guarantee that the DSX-1 is at an equal-level point in the office.

The key circuit in the DLTU is the DFI circuit that provides all the functions required to terminate a T1 line. Four custom VLSI devices provide the functions of bipolar-to-unipolar conversion, framing, slip control, signaling extraction, and insertion and line formatting. The 24 PCM time slots from the T1 line are evenly distributed over the 32 time slots available on the PIDB. Idle code is used to fill the eight remaining time slots.

Control information from the SM is interfaced by two custom VLSI devices to a microcomputer. These devices provide the protocol conversion needed and a buffered communication interface to the SM processor. The microcomputer guarantees the integrity of the messages passed between it and the SM processor. The microcomputer also maintains the facility. For example, it estimates error rates, performs facility alarm processing, and measures the quality of the other circuitry in the DLTU by running in-service tests.

A second type of DFI circuit uses an additional VLSI device and additional memory to provide a 4-kb/s BX.25 data link. This type of DFI circuit is used to interface between a Host Switching Module (HSM) and a Remote Switching Module (RSM) (see Section VI). It uses the extended framing format in a mode that provides 23 clear channels for PCM and a 24th channel that carries network signaling information.

Recognizing that the *5ESS* switch plays an important role in the emerging integrated services digital network and taking advantage of firmware control and VLSI technology, two new capabilities not found in the existing network were added to the DFI circuit. They are 64-kb/s clear-channel capability and compatibility with the new extended framing format. Consequently, as the integrated services digital network evolves, the *5ESS* switch can evolve without changing its digital interface hardware.

For international applications a 30-channel DFI circuit is provided by using the same VLSI devices used on the interface for digital message trunks with modified firmware and front-end circuitry.

5.3 Digital carrier line unit

The Digital Carrier Line Unit (DCLU) provides direct interfaces for up to six *SLC®* 96 or *SLC* 5 carrier remote terminals. Except for control and data multiplex functions, it is similar to a DLTU.

Up to 9:1 digital concentration is provided by terminating 576 lines through *SLC* carrier remote terminals spread over two service groups on up to four PIDBs. Each service group under normal operation will interface 288 lines. If a service group fails, the nonfaulted service group can share the load of the faulted service group, thus maintaining customer access to the switch. Consequently, the DCLU operates in an active/active shared mode. Digital concentration is provided by a data multiplex circuit, while distribution of control information from PICBs is done by a control multiplex circuit.

To mitigate the blocking that could occur from digital concentration, a TSI function and on-hook/off-hook supervision are included in the

DCLU. A VLSI device is used for TSI and signaling functions to prevent severe blocking.

VI. REMOTE SWITCHING MODULE

The objective of the *5ESS* switch RSM is to provide the capability within the *5ESS* switch architecture to connect a remotely located SM over T-carrier transmission facilities to a host *5ESS* switch. This capability enables *5ESS* switches to be geographically extended from the host switching machine.

6.1 Design considerations

The applications for RSMs include the replacement of small community dial offices and large clusters of digital loop carrier systems. These applications place certain implementation constraints on both the design and its cost. Some of the principal considerations of the design of the RSM are as follows:

1. The RSM hardware design is constrained to share as much hardware from the SM as possible to maximize commonality and minimize overall hardware cost.
2. Reliability is a major consideration that requires duplication of all major switching units and adherence to all the reliability constraints placed on a nonremoted SM. In particular, the RSM, during a loss of T-carrier facilities, must operate in a stand-alone mode.
3. The RSM is designed to accommodate both domestic and international applications.

6.2 Design descriptions

The remote switching capability consists of an RSM connected over T-carrier facilities to an HSM. As depicted in Fig. 6, the HSM is located in the host office with the CM and AM. Each HSM can support up to a maximum of five RSMs. The RSM can be located as far as 100 miles away from the HSM.

6.2.1 Host switching module

Digital facilities from an RSM are terminated on a DLTU located in the HSM. The termination of these digital facilities is treated by the HSM in the same way as any other nonconcentrated facility. The HSM provides access to the TMS for the data channels on these facilities. Each RSM requires from 4 to 20 T1 lines. An RSM used for community dial office consolidation is expected to require only 6 T1 lines. Since an HSM can support traffic associated with at least 20 T1 lines, the HSM's excess capacity can be shared over several RSMs, T1 trunks, digital loop carrier systems, or analog facilities.

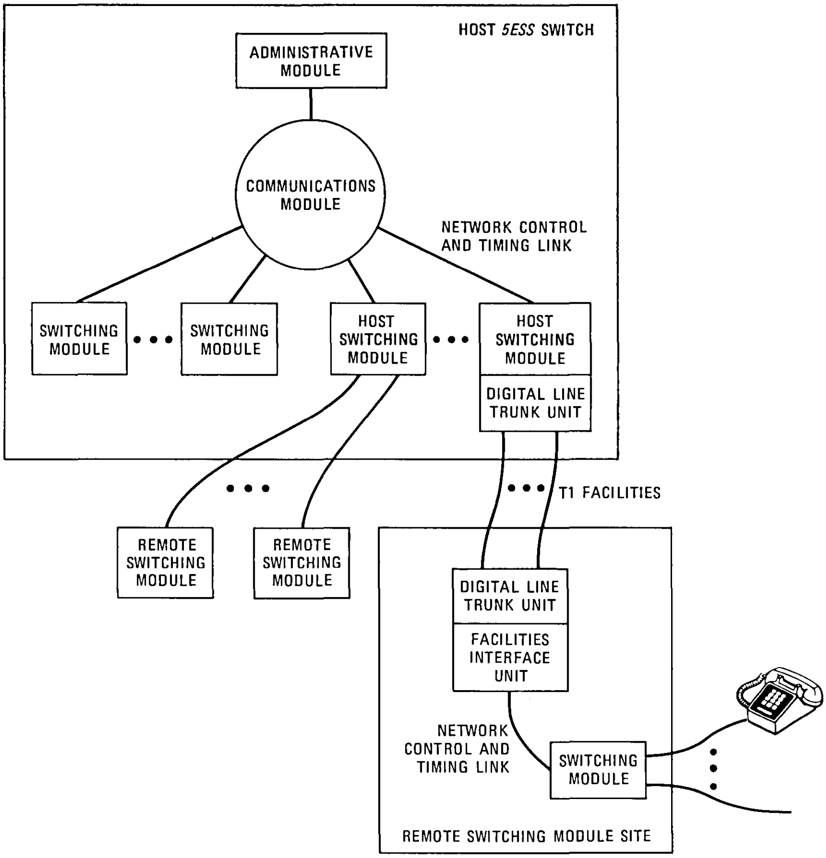

Fig. 6—Host switch with remote switching modules.

Control links for an RSM are routed through the HSM as nailed-up data channels that are assigned cooperatively by the AM and the HSM software. The two required control links are established on the active side of the TMS and duplicated on the standby side. They appear on separate facilities between the HSM and the RSM to minimize the probability of a single failure taking out both control links.

6.2.2 Remote switching module

An RSM is equipped in a way similar to a *5ESS* SM except for the addition of a Facilities Interface Unit (FIU). The FIU connects the RSM's SM processor and time-slot interchange unit to the digital trunk facilities provided by the HSM. Data, control, and timing are recovered from the T1 lines, and this information is reformatted into a pair of NCT link signals, which are routed to the time-slot interchange unit over optical-fiber links. The subunits of the FIU are controlled by peripheral control channels from the active SM processor. Each peripheral control channel is realized through a PICB. A maximum of 22 peripheral control channels are required to support up to 20 DFI circuits and the duplex FIU hardware. Through the peripheral control channels, RSM maintenance software initializes each subunit, receives reports of hardware failures, and does diagnostic testing.

The FIU interface with the trunk facility is through one or two DLTUs that are equipped with DFI circuits. Each T1 line must be terminated on an office repeater that supplies signal equalization, regeneration, and, if needed, line powering. The resultant signals are routed to a DLTU through a standard DSX-1 cross-connect that provides test access to the facility. The DFIs are configured to operate in the RSM mode, whereby they provide 23 clear data channels. In this mode the DFIs also provide T-carrier clock signals to the FIU. These signals are used to lock a local crystal oscillator within the FIU to the network clock provided by the HSM. This oscillator, in turn, determines the data rate on the NCT links, thus assuring synchronization of the RSM to its HSM. This same oscillator provides accurate timing for the RSM during stand-alone operation.

Data through the FIU are multiplexed from up to 20 DFI subunits into two 256 time-slot frames that are formatted into two service groups of two NCT links. Data are similarly demultiplexed in the reverse direction. This multiplex/demultiplex function is performed under a fixed address and time-slot mapping scheme that is driven by time-slot clock and frame synchronization signals produced by the FIU control circuitry.

The hardware of an RSM includes a standard SM with its peripheral circuits, an FIU, and associated DFI(s) for interfacing to the T-carrier facilities. The FIU itself contains only two different circuit pack codes and takes advantage of commonality with other *5ESS* switch equipment by using some of the NCT circuits.

As a result of the flexibility built into the FIU, certain expansion capabilities may be attained through little effort. For example, the RSM hardware can be configured for international applications by simply altering the ROM information stored in the FIU.

VII. SUMMARY

The *5ESS* digital switching system is highly reliable, modular, compact, and low in cost. Its architecture will permit rapid deployment of new services. The modular hardware design allows switching capacity, processing power, and peripheral units to be added incrementally. In addition, this hardware modularity allows the *5ESS* switch hardware units to evolve independently and take maximum advantage of the advances in semiconductor technology.

VIII. ACKNOWLEDGMENTS

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The 5ESS *Switching System:*

Physical Design/Hardware

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(Manuscript received November 23, 1983)

The reliability, availability, and versatility of the *5ESS*™ switch are highly dependent on the physical design of the hardware. We present a comprehensive description of the system and equipment designs, with particular emphasis on the advanced interconnection technology used, such as the fine-line, multilayer, printed wiring boards; ceramic substrates for functional modules; and high-performance, device-level packaging. The system design features described include new cabinet and office arrangements, the use of *Fastech*™ equipment, and new power and alarm systems. The office layout is flexible to allow growth in any size installation, and the modular architecture of the *5ESS* switch makes it easy to install. We also present various testing and installation methods and summarize the physical design requirements and objectives for all equipment in the *5ESS* system.

I. INTRODUCTION

The *5ESS* switch physical design emphasizes a wide range of system sizes, high packaging density, modular architecture, and advanced interconnection technology. The system design features minimum office interconnect and a variety of shipping modes, including block unitization, hot slide, and full unitization. Substantial floor-space reductions occur over predecessor analog switching systems. Equipment designs emphasize ease of engineering and growth, simplified human engineering, and distributed power conversion. Standardization of apparatus design is a keystone to a highly manufacturable design. In

* Authors are employees of AT&T Bell Laboratories.

addition, advances in the interconnection technologies of hybrid integrated circuit, fiber optics, and printed wiring board have resulted in a highly reliable, small-size-equipment realization. The high standards of reliable field performance have been assured through the distributed nature of the architecture and the use of redundancy where needed. Sparing costs have been minimized through application of reliability data to sparing calculations. The physical design, when taken with the flexible architecture, maintenance system design, and circuit design, offers a digital switch that is compact, easy to engineer and enlarge, highly maintainable, and reliable.

II. *5ESS* SWITCH INTERCONNECTION TECHNOLOGY

The *5ESS* switch achieves low cost, high reliability, and high manufacturability by using a standardized, state-of-the-art interconnection technology coupled with forced air and convection cooling systems. High packaging density and optimum performance are made possible by fine-line, multiple-layer printed wiring boards, thin- and thick-film ceramic substrates for functional modules, and high-performance, device-level packaging. These technologies are optimally merged in minimum design time through the extensive use of Computer-Aided Design (CAD)* tools. Later sections deal with the four major levels of interconnection within each *5ESS* switch unit design.

2.1 Unit-level interconnection

The *5ESS* switch uses the *Fastech* packaging system,[1] which provides a dense, high-performance, standardized interconnection technology. Each *Fastech* unit consists of one or more apparatus mountings and backplane printed wiring boards to support and interconnect the circuit packs (see Fig. 1). Each apparatus mounting contains about 20 to 22 circuit packs, and typical *5ESS* switch units use one or two apparatus mountings.

The apparatus mounting is designed to support circuit packs and alignment to backplane pin fields. Circuit pack location is highly flexible. Pack spacing in *5ESS* switch units varies from three-quarters of an inch to one and one-half inches. The apparatus mounting is also designed to minimize resistance to vertical airflow, thus increasing the effectiveness of the forced air cooling system.

The backplane printed wiring boards vary from two layers to six layers, and are interconnected by plated-through holes. All backplanes provide printed power and ground interconnection and some backplanes also provide printed signal paths. Pins are placed on a 0.125-inch grid and extend on both sides of the printed wiring board. On the side of

* Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

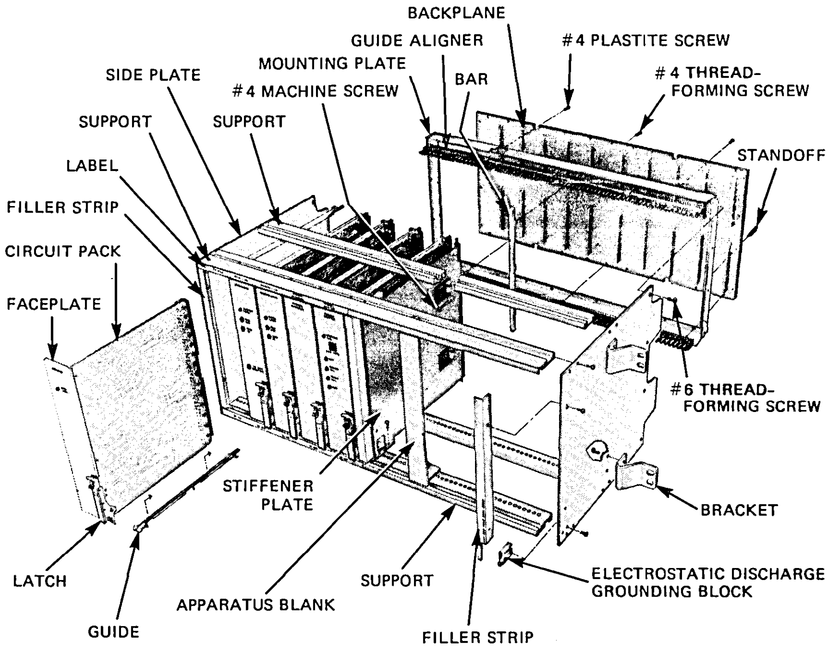


Fig. 1—*Fastech* hardware.

the backplane away from the circuit packs, intraunit connections are made by automatically wrapped discrete wiring. Connectorized cables are also terminated on these pin fields to connect interunits. The cable connectors are guided and retained on the backplane by cable apparatus mountings. On the component side of the backplane, pin length is varied to improve the sequencing of power, ground, and signal connections on pack insertion. Each circuit pack code is individually "keyed" to prevent insertion into the wrong pack location.

2.2 Circuit-pack-level interconnection

The system uses a single-size circuit pack, 7.67 by 13.375 inches, to maximize manufacturability and design uniformity. These circuit packs represent the smallest replaceable module within the system. Both double-sided and multiple-layer printed wiring board structures are used. The typical multiple-layer boards contain two or four signal layers, a single power layer, and a single ground layer. These boards are designed with a standard 0.100-inch grid of plated-through holes for interconnection and component placement. The standardized hole grid simplifies computer-aided design and automated assembly. Multiple-layer printed wiring boards are used for high-density, high-performance applications within the switch (see Fig. 2).

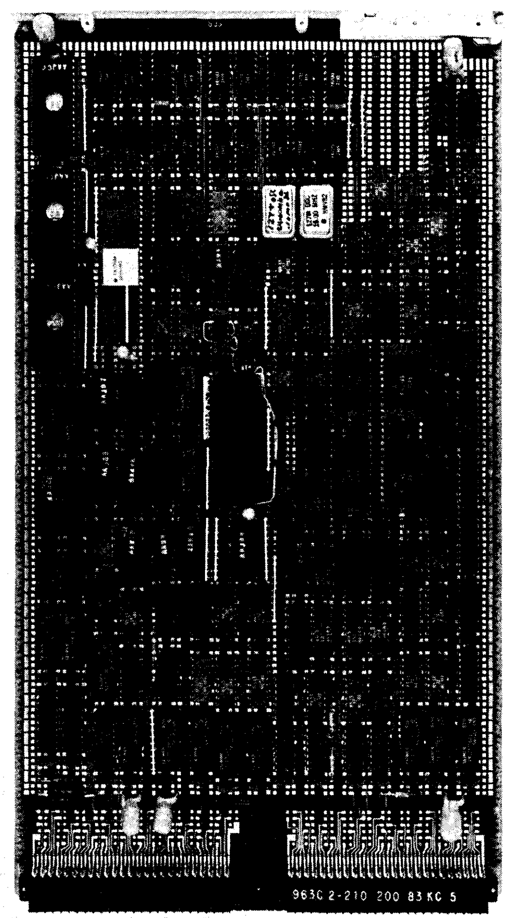


Fig. 2—Multilayer printed wiring board.

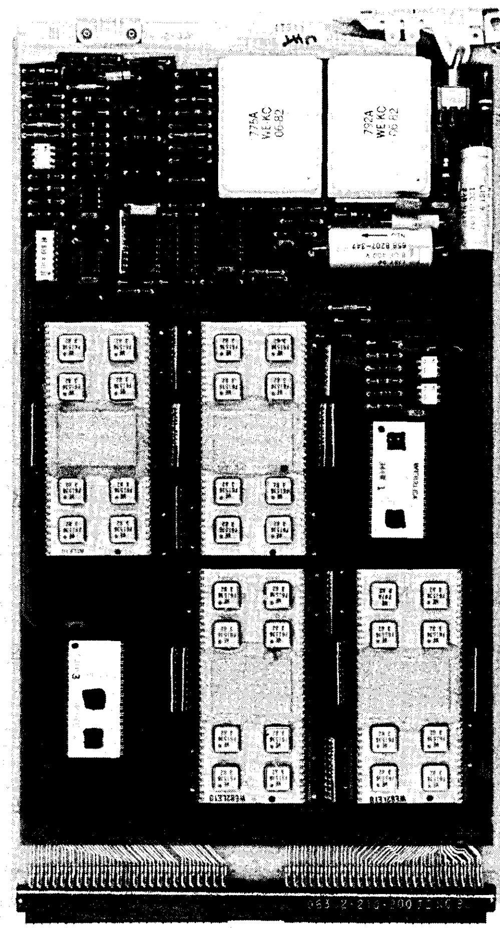


Fig. 3—Double-sided printed wiring board.

The double-sided printed wiring board structure is typically used for high-volume circuit packs associated with line or trunk termination circuitry of the *5ESS* switch (see Fig. 3). This structure allows a more flexible grid for the plated-through hole placement and results in a lower-cost interconnection medium.

The circuit packs use either 200-contact or 300-contact connectors for interconnection to the unit backplane. These connectors provide a matrix of contacts designed to engage the backplane pin-field grid on 0.125-inch centers. Contacts are of a highly reliable bifurcated and selectively gold-plated design to ensure design life. Because of the high insertion force required for the high numbers of interconnections, a latch is provided on the edge of the circuit pack to engage the apparatus mounting, thereby easing insertion.

Circuit pack designs allow testing either through the edge connector or through direct contact with pads on the noncomponent side of the printed wiring board. In certain cases, component locations are printed on the printed wiring board to simplify circuit pack assembly, inspection, and testing.

2.3 Functional-module-level interconnection

To improve density, testability, and cost of certain functions, particularly analog trunk and analog subscriber line terminations, numerous functional modules are used. These modules are based on ceramic substrates with both thin- and thick-film interconnection technologies. The provision of precision resistors, controlled impedance, a high conductivity, and the resulting high density significantly enhance the performance of each of these modular functions. The *5ESS* switch uses over 20 active and 100 passive ceramic modules. An example of this module is shown in Fig. 4.

The ceramic module technology used in the *5ESS* switch is designed to be a highly reliable package capable of withstanding the stresses due to high-voltage transients of an analog subscriber line (600V), and the stresses of the central office environment. Floating surface crossovers and programmable vias enhance routing density and provide the equivalent of two layers of interconnection on each of the sides of the ceramic. An extensive CAD system simplifies the layout of the module and evaluation of performance criteria. Silicon integrated circuits are either beam leaded and thermocompression bonded to the ceramic or placed in leadless chip carriers and reflow soldered to the ceramic. Edge-clip lead frames, reflow soldered to the ceramic, provide connection to both sides of the ceramic.

2.4 Silicon-integrated-circuit-level interconnection

The device-level packaging strategy was established to avoid proliferation of packages, to provide both printed wiring board and ceramic

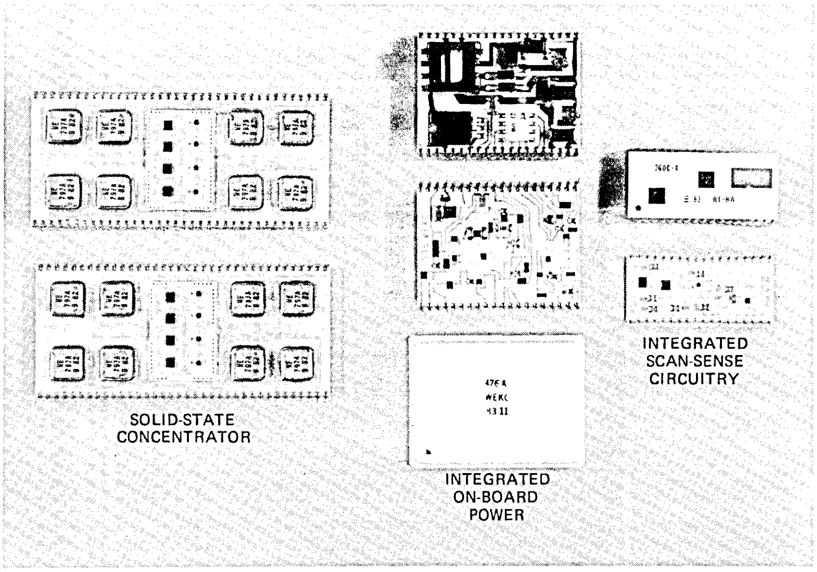


Fig. 4—Typical ceramic modules.

module compatibility, to provide a reliable interconnection medium, and to use an extensive postmolded plastic packaging capability. This strategy calls for use of the following three elements: (1) Dual In-Line Packages (DIPs) for devices requiring from 2 to 40 interconnections to printed wiring boards, (2) pin-grid arrays or surface-mounted leaded chip carries for devices requiring greater than 48 interconnections to printed wiring boards, and (3) either beam-leaded or leadless ceramic chip carrier packages for use on ceramic modules. Many devices in the *5ESS* system do not require hermetic seals; therefore, plastic packages are used. For those devices requiring hermetic seals for reliability, ceramic packaging is used.

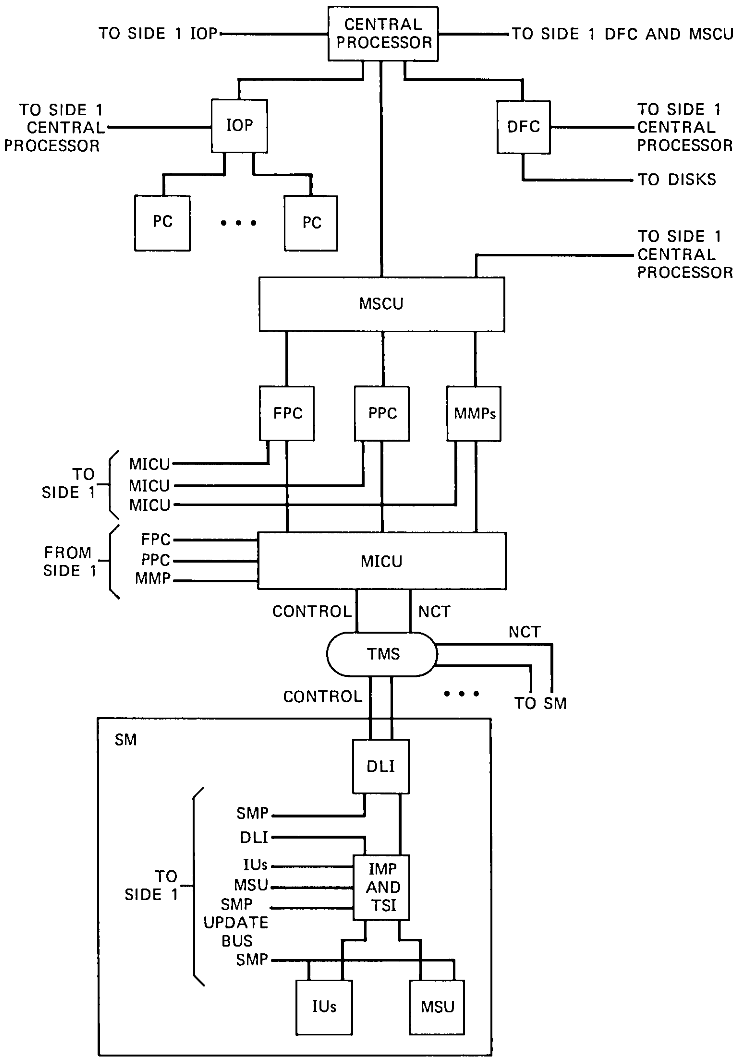
III. RELIABILITY

3.1 Hardware reliability

The *5ESS* switch has been designed for a robustness and availability that is the industry standard. High availability is achieved, as a principle, early in the design phase by paying attention to hardware reliability requirements, and by evolving architectures that are the most feasible engineering solution.

3.2 System architecture

The architecture of the multimodule *5ESS* switch is shown in Fig. 5. The basic units of the switch are organized into four primary communities, the Administrative Module (AM), the Communications



DFC – DISK FILE CONTROLLER
DLI – DUAL-LINK INTERFACE
FPC – FOUNDATION PERIPHERAL CONTROLLER
IMP – IMPROVED MODULE PROCESSOR
IOP – INPUT/OUTPUT PROCESSOR
IU – INTERFACE UNIT
MICU – MESSAGE INTERFACE CLOCK UNIT
MMP – MODULE MESSAGE PROCESSOR
MSCU – MESSAGE SWITCH CONTROL UNIT
MSU – METALLIC SERVICE UNIT
NCT – NETWORK CONTROL AND TIMING
PC – PERIPHERAL CONTROL
PPC – PUMP PERIPHERAL CONTROLLER
SM – SWITCHING MODULE
SMP – SWITCHING MODULE PROCESSOR
TMS – TIME-MULTIPLEXED SWITCH
TSI – TIME-SLOT INTERCHANGER

Fig. 5—Multimodule architecture.

Module (CM), and the Switching Module (SM). An important feature of the *5ESS* switch is its modularity; a wide range of switch configurations, from the single module office to the large multimodule system, can be developed with the basic building blocks of the system. Thus, by the graceful introduction of additional hardware, any office can grow from its initial size into a large system. This feature accounts for the high availability of this local digital switch, with each unit in the system having been improved with respect to function and availability. This section presents an overview of the long-term hardware reliability estimates for the system. It shows that the system reliability is well within the requirements for electronic switches.

3.3 System reliability

Hardware faults that can affect the operation of large segments of the system are mitigated by duplexing of subsystems. System outage, and, hence, the cessation of call processing, occurs with duplex hardware failure in the Message Switch (MSG) and the Time-Multiplexed Switch (TMS) in the AM or the CM. The above two subsystems are the core equipment in the *5ESS* switch; all intermodular communications rely on the successful operation of these core units.

Figure 6 is the reliability block diagram for the *5ESS* switch, which is obtained from Fig. 5 by associating subunits that interact as a failure group and by identifying the cross-couplings in the system architecture. The SMs are shown in the last block for completeness only. They are not to be construed as part of the TMS reliability subblock.

3.4 Interface module reliability

The core units in the SMs are the Switching Module Processor Unit (SMPU), the Time-Slot Interchange Unit (TSIU), and the Local Digital Service Unit (LDSU). These units maintain intramodule communications; in combination with the Dual-Link Interface (DLI) and the TMS, they improve intermodule communication. The outage of the SM occurs on any duplex hardware failure within its core equipment SMPU-TSIU-LDSU.

Other than during system outage, any SM may become isolated when the hardware dedicated to the SM is unavailable. Module isolation may occur during simplex operation of the TMS with the loss of the DLI, or with the loss of the core units in the SM.

3.5 Interface units reliability

Each Interface Unit (IU), except the Digital Line Trunk Unit (DLTU), has two service groups operating in the active-active load-sharing mode. The service of an interface unit is lost on the occurrence of coincident critical hardware failures of both service groups. Because of load sharing, the loss of a service group increases blocking or degradation of service. In general, noncritical hardware outages in the

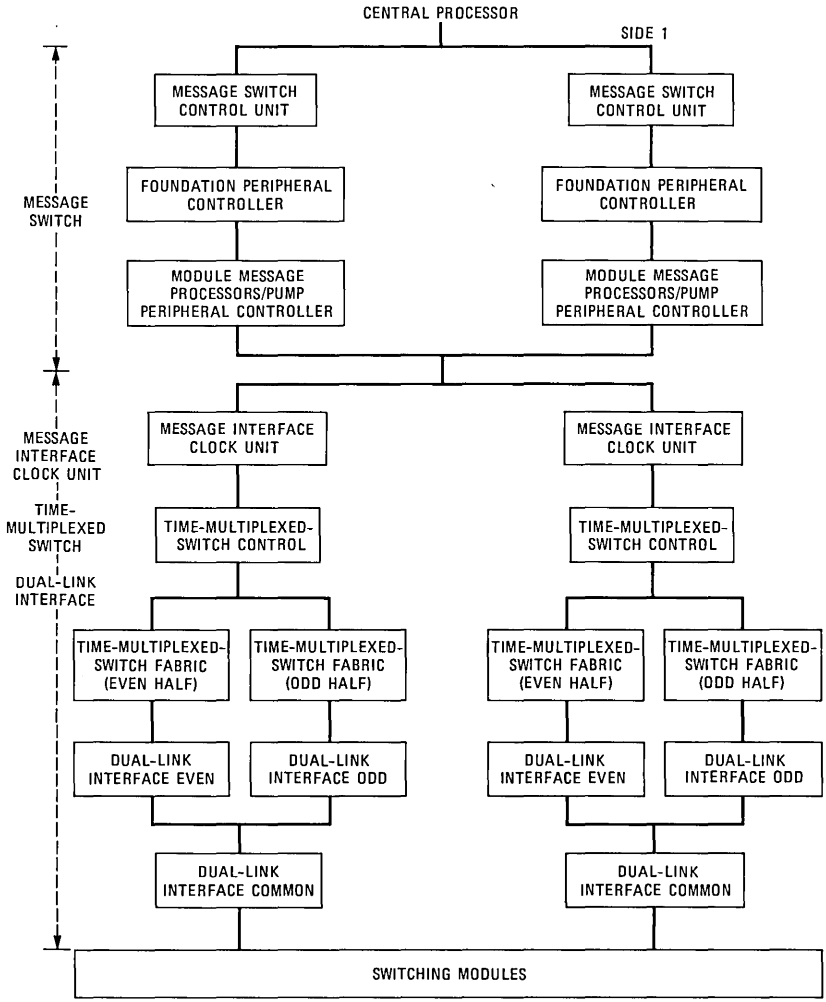


Fig. 6—Reliability structure of *5ESS* multimodule.

IUs affect service quality to a small community of customers. On the Digital Service Units (DSUs), the analog Trunk Unit (TU), and the DLTU, the service circuits and trunk are randomly assigned according to traffic loadings. The circuits that fail in these units are taken out of service, while surviving circuits share the load.

IV. SYSTEM DESIGN

4.1 Cabinets

The system uses a newly designed four-posted cabinet to house the equipment units. The cabinets are 6 feet high, 2 feet 6 inches wide, and 1 foot 9 inches deep (see Fig. 7). Each blue and white cabinet will

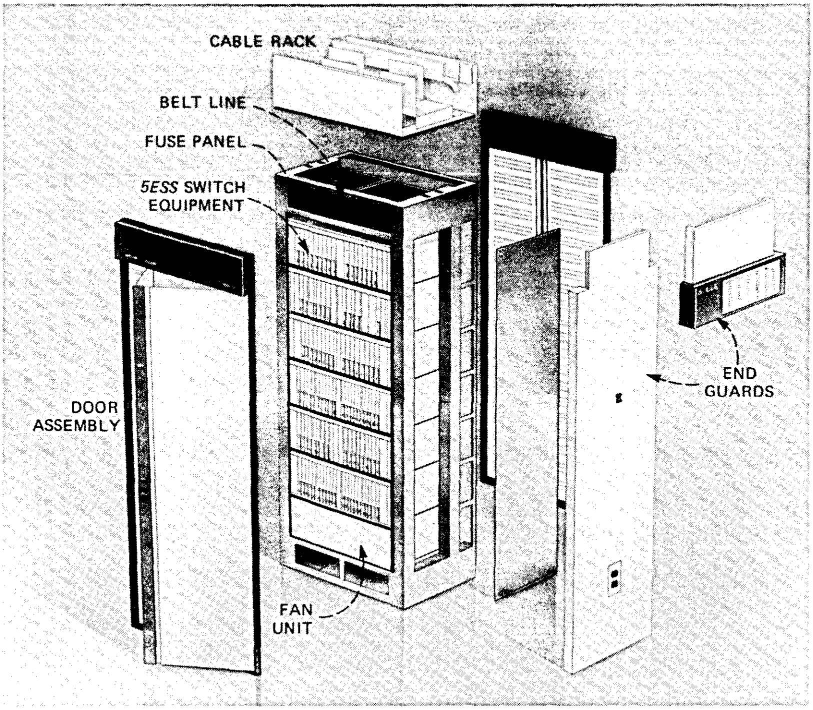


Fig. 7—Exploded view of 6-foot cabinet.

accommodate six 8-1/2 inch high *Fastech* equipment shelves. To maintain system integrity, forced air cooling is used, provided by a fan unit located at the bottom of each cabinet (not one of the six mounting positions). Fans are triplexed per cabinet, deliver 250 through 300 Cubic Feet per Minute (CFM) of filtered air, which is drawn from the wiring aisle. An arrangement of fan flaps prevents loss of air flow if a fan fails. Alarms detect individual fan failures. The cabinet design also includes two fuse/filter units for power distribution at the top of each cabinet. The 6-foot design precludes the need for external earthquake bracing in any office location.

4.2 Teletypewriter and telephone jack access

Teletypewriter (TTY) and telephone jack access is provided by the fuse/filter units located in the message switch and Switching Module Control (SMC) cabinets. These access points are multiplied throughout the office. Access is also provided at the Master Control Center (MCC), at each Supplementary Trunk Line Work Station (STLWS), and at the distributing frame for connection to other areas of the central office and to remote switching modules.

Table I—Cabinet configurations

Cabinet	Acronym	Number required
Switching module control	SMC	1 per switching module
Line interface	LNI	As required
Line trunk peripheral	LTP	1 to 4 per interface module
Master control center	MCC	1 per office
Message switch	MSG	2 per office
Miscellaneous	M	As required
Power distribution	PCFD3	1 to 6 per office
Supplementary trunk line work station	STLWS	1 to 6 per office initial TLWS provided as part of MCC
Time-multiplexed switch	TMS	2 per office

4.3 Cabinet arrangements

The system uses a limited number of cabinet arrangements for simplicity and ease of office engineering, as shown in Table I.

4.4 Office arrangements

4.4.1 Floor plans

Standard cabinet arrangements have been developed to minimize engineering and installation costs. A universal plan has been developed that permits natural, yet flexible, growth from the smallest to the largest installation. Other plans are also available for single module and remote switching module applications. Figure 8 depicts a typical multimodule office floor plan, and Fig. 9 shows a remote module plan. Some constraints on cabinet placement must be observed.

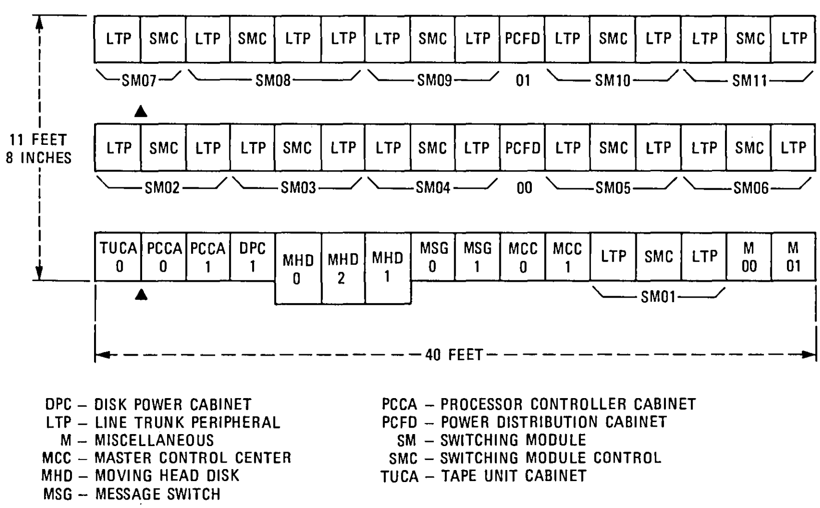
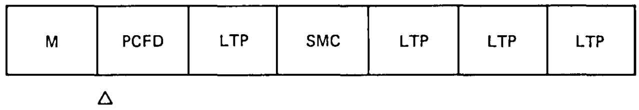


Fig. 8—Typical multimodule office floor plan.



LTP – LINE TRUNK PERIPHERAL
M – MISCELLANEOUS
PCFD – POWER DISTRIBUTION CABINET
SMC – SWITCHING MODULE CONTROL

Fig. 9—Remote module floor plan.

1. The SMC and Line Trunk Peripheral (LTP) cabinets comprising a given switching module must be arranged in a specific pattern to minimize intercabinet cable lengths.
2. The message switch cabinets must be located within 50 cable feet of the AT&T 3B20D2 computer to maintain the integrity of the signals between these equipment entities.
3. Power distribution cabinets are to be placed in line with one another and should be centrally located with respect to the cabinets they serve.
4. To minimize cable congestion, the distributing frames should grow perpendicular to cabinet lineups; however, other layouts can be accommodated.
5. The system floor plans have been designed to fit the New Equipment-Building System (NEBS) building bay standards. The system's modular design makes it readily adaptable to existing buildings.

4.4.2 Cable rack, end guards, and office lighting

The system uses a newly designed overhead cable rack system. Cabinet-supported cable racks, 10 inches high and 21 inches deep, are positioned in 90- and 30-inch increments. Unlike previous systems, it has only two cable compartments, one of which provides separation and mechanical protection for the fiber optics, while the other contains all other intercabinet cables. Interlineup connection uses telescoping cross-aisle cable racks to simplify engineering and installation.

There are end guards at the ends of each cabinet lineup and at each exposed cabinet position within the lineup. Aisle directories naming the cabinets in each lineup, and lighting control switches are on the ends of lineup end guards.

The cabinet-supported cable rack is also arranged to support the via cable rack system and an optional overhead lighting system.

4.4.3 Distributing frames

4.4.3.1 Conventional or open type. The Low-Profile Conventional Distributing Frame (LPCDF) or similar conventional mainframes may be used with the *5ESS* switch, particularly in office sizes up to 6000

Table II—Cosmic II mainframe arrangements

COSMIC II Type	Termination Field (Pairs) Facility	Termination Field (Pairs) Equipment
Mini	6,000	7,600
Combined	30,000	48,000
Subscriber	100,000	100,000
Trunk	30,000	36,600

lines. This conventional-type distributing frame meets the needs of the NEBS standards and is a floor-supported, earthquake-resistant, low-profile version of the early distributing frames. Standard equipment arrangements are available to minimize jumper congestion.

4.4.3.2 COSMIC II. The COSMIC II distributing frame is a modular mainframe that can meet the wide range of office configurations. Depending on the best planned office size in terms of total terminations, one of the arrangements shown in Table II can be used.

4.4.4 Protection

The first stage of protection is provided by a new distributing-frame-mounted gas tube protector. Most newer connectors will accept the plug-in unit, although older connectors, such as the C50 and 300 type, will not.

For single-entity wire centers, all exchange cable pairs should be terminated on Distributing Frame (DF) connectors that accept the new protectors. Some retrofitting may be required in existing wire centers that reuse older DFs. A secondary strategy is used in multientity wire centers where retrofitting costs could be prohibitive. In these applications, two options exist:

1. Use of a newly designed horizontal mainframe connecting block, which provides gas tube protection as well as equipment termination and jumper access.

2. Placement of the Line Interface (LNI) cabinet between the mainframe and the equipment cabinets. The LNI cabinets may be installed in the equipment lineups or may be placed in a separate area to meet local requirements. Each LNI cabinet provides protection for 2048 pairs at an 8:1 Line Concentration Ratio (LCR).

4.5 Office alarms

Office alarm equipment reports hardware conditions such as fuse operation, voltage and current levels, and software triggers such as diagnostic failures. Such alarm conditions are reported by the system to the MCC, where a video display identifies the exact location of the reported trouble. The alerting function of the office alarm plan is provided by an audible and visual alarm system. Distinctive audible devices alert the user to the trouble, indicating the particular level of importance. Visual indicators may also be provided at switch room exits. The traditional aisle pilot lamps are not provided, to ensure that the user begins the search for the trouble location by using information at the MCC and not by following visual indicators.

4.6 Power

4.6.1 Overview

The *5ESS* switch requires only −48V power from a dc power plant. The individual voltages required by each circuit are provided by dc-dc power converters equipped in each unit or by on-board power converters. Ringing and tone voltages are provided within each switching module. Common system equipment requiring other than −48V or ring and tone voltages must be supplied via bulk converters or separate plants provided by the customer.

4.6.2 Power plants

The power plant used with the system is a −48V plant with a voltage range at the power distribution cabinet of −42.75 to −52.5V. The −48V power may be obtained from any modern power plant with the required voltage range, including the 111A, 151B or C, 153A or 155A plants, or the new *Lineage*™ 2000 plant. Power plants can be operated in parallel to supply power for large offices.

Existing power plants using Counter-Electromotive Force (CEMF) or end-cell switching (one or two cells) may be used, as long as they do not violate the system grounding constraints. Older plants incorporating SCR-type rectification will require additional protection to prevent damage to the *5ESS* switch from lightning or power transients.

4.6.3 Battery reserve plant

A battery reserve plant is required to continue service during outages of commercial power and to provide proper filtering for the power plant. Typically, there is a three-hour reserve for attended offices, and an eight-hour reserve for unattended offices. This plant should be designed to meet local job conditions using parallel strings of rectangular or round cells.

4.6.4 Standby power

A standby alternator can operate the central office if a prolonged commercial power outage occurs. For small offices, a receptacle may be provided to connect a portable ac generator, whereas a stationary engine should be used in larger offices. Local conditions will dictate the configuration of this reserve system.

4.6.5 Power sharing

In some applications it may be economically attractive to share a battery plant between the *5ESS* switch and other central office equipment. The rules for power sharing are the same as those defined in previous electronic switching systems. Power for the non-*5ESS* switching equipment must be supplied from a separate power distribution cabinet/frame located in the non-*ESS*™ switch area. Power feeders supplying the frame must be run via the ground window and have the ground side of the feeders bonded to the single-point ground. All shielded cables running between the two areas must have their shields grounded at the *5ESS* switch end and be isolated from the ground at the other end.

4.6.6 Power distribution

Power distributing cabinets are used to distribute the −48V power to the equipment cabinets. They are centrally located in the area of the cabinets they serve in order to minimize feeder congestion and to maintain the required voltage drops in the feeders. Typically, one power distribution cabinet is required for 36 equipment cabinets.

4.6.7 Grounding

The *5ESS* switching equipment is connected to an isolated ground plane that has no contact with building ground or other foreign ground planes except for a single connection to the floor central office ground. The single-point ground system eliminates the possibility of transient current flow through the *5ESS* switch ground plane from the sources outside the system.

4.7 Office interconnection

All connections between equipment entities in the *5ESS* switch are fully connectorized. All signal and tip and ring leads are terminated on the unit backplanes using *Fastech* backplane connectors. Connectorized mainframe blocks are used to terminate tip and ring leads from the line units, as well as leads from the trunk units, metallic service units, and the Trunk Line Work Station (TLWS).

Control and data signals between the SMC and its peripheral units are completed using double-ended connector cables that run directly between cabinets as opposed to being run in the overhead racking system. Optical fibers are used to complete the highly critical connections between the switching modules and the TMS or MSG.

This high degree of connectorization greatly reduces the installation interval, simplifies the growth procedures, and eases factory assembly and testing.

4.8 Factory testing/installation

The system is tested in the factory in segments called blocks. A core system, consisting of the 3B20D computer, the CM, and one or two SMs, is tested and shipped as a unit. Individual SMs are tested and shipped as separate blocks to the office site, where full system testing is completed by the installer. This method eliminates duplication of tests and minimizes the cost of factory testing.

The system can also be installed on site in a temporary facility, tested, cut into service, and then moved into its final position after the replaced equipment has been removed from service. This method, known as "hot slide-in," can be done in several ways. Figure 10 depicts the sequence followed in hot slide-in of an office. The entire system can be moved in three lineup blocks, or the core system can be moved independently of the switching modules. The switching modules need only be located within 1000 cable feet of the TMS/MSG before or during the hot slide-in procedure. These methods greatly simplify installation and add another dimension of flexibility to the *5ESS* switch.

V. EQUIPMENT PHYSICAL DESIGN

5.1 Switching module

The SM terminates lines and trunks, and converts their signals into the digital format of the *5ESS* switch. The SM also performs much of the call-processing function.

Physically, the SM consists of two to five cabinets, which may be configured to suit the type and quantity of lines and trunks the particular SM serves. A distinction is made between the types of cabinets that comprise the SM, the SMC, and the LTP, as described below.

Equipment that is common to all SM designs is housed in the SMC. This common equipment consists of the SMPU, the TSIU, and the LDSU. The SMC cabinet equipped with these common elements is shown in Fig. 11. Only one SMC cabinet exists for each SM. Later paragraphs describe the units of the SMC.

5.1.1 Time-slot interchange unit

The TSIU is a two-shelf unit that provides time-slot switching, Network Control and Timing (NCT) link interface, signal processing, data interface, and control interface. The unit is fully duplicated, with each simplex half associated with the corresponding simplex half of the SMPU. The halves are referred to as side 0 and side 1, as viewed

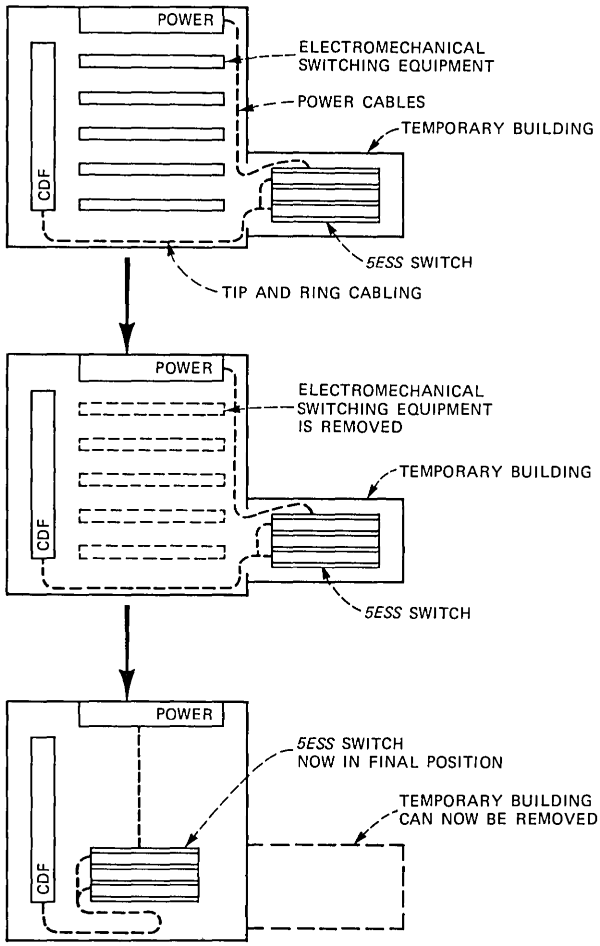


Fig. 10—Hot slide-in sequence.

from the front of the unit. At any given time, only one side is active and the other is in a standby mode.

Figure 12 is a physical layout of the unit, showing the physical partitioning of the TSIU's function. Note that the TSIU halves are mirror imaged. A brief description of these functions follows.

5.1.1.1 Time-slot switching. The TSIU performs the switching of 512 time slots per 125-μs frame from IUs to the TMS, and from the TMS to the IUs. It also can switch peripheral time slots with peripheral time slots (i.e., for intramodule calls), and TMS time slots with TMS time slots (for maintenance). This Time-Slot Interchanger (TSI)

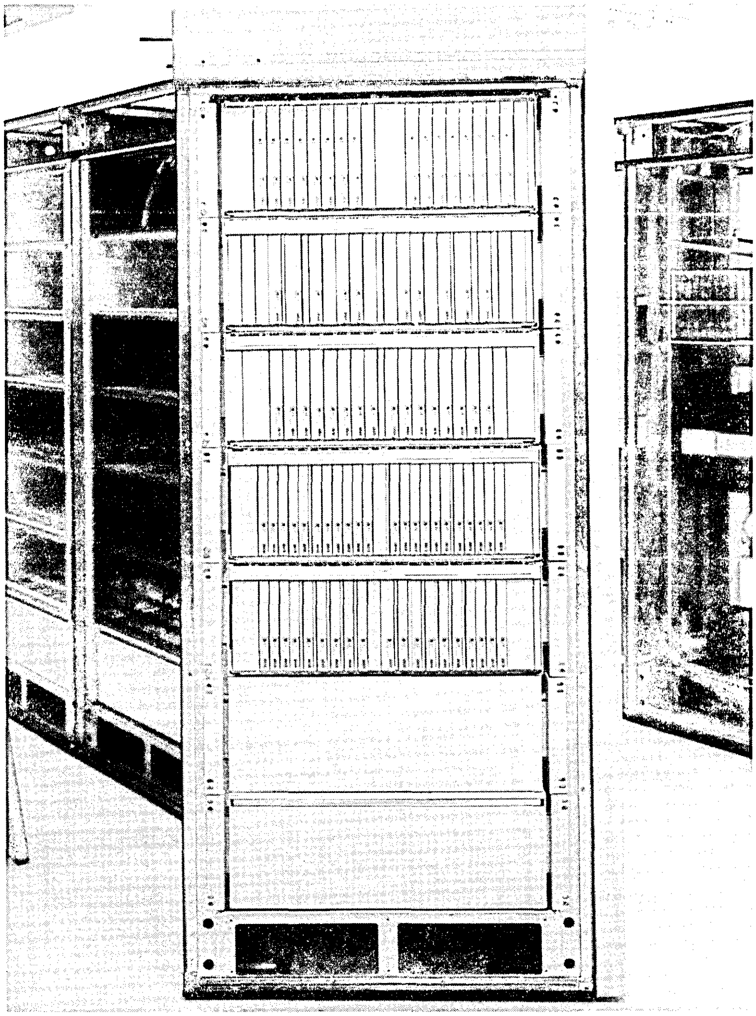


Fig. 11—SMC cabinet.

function is provided on five TN-type multilayer circuit packs in the unit.

5.1.1.2 Dual-link interface. The TSIU provides an interface to the NCT links with its DLI circuits. The DLI extracts timing from the NCT links for the SM, accommodates the optical transmit and receive circuits required to terminate the fiber-optic NCT links, and provides the SMPU with a message time slot from the 256 time slots of the NCT links. Two DLI circuit packs are equipped in the TSIU, but are associated with the TMS from a reliability group standpoint. Because

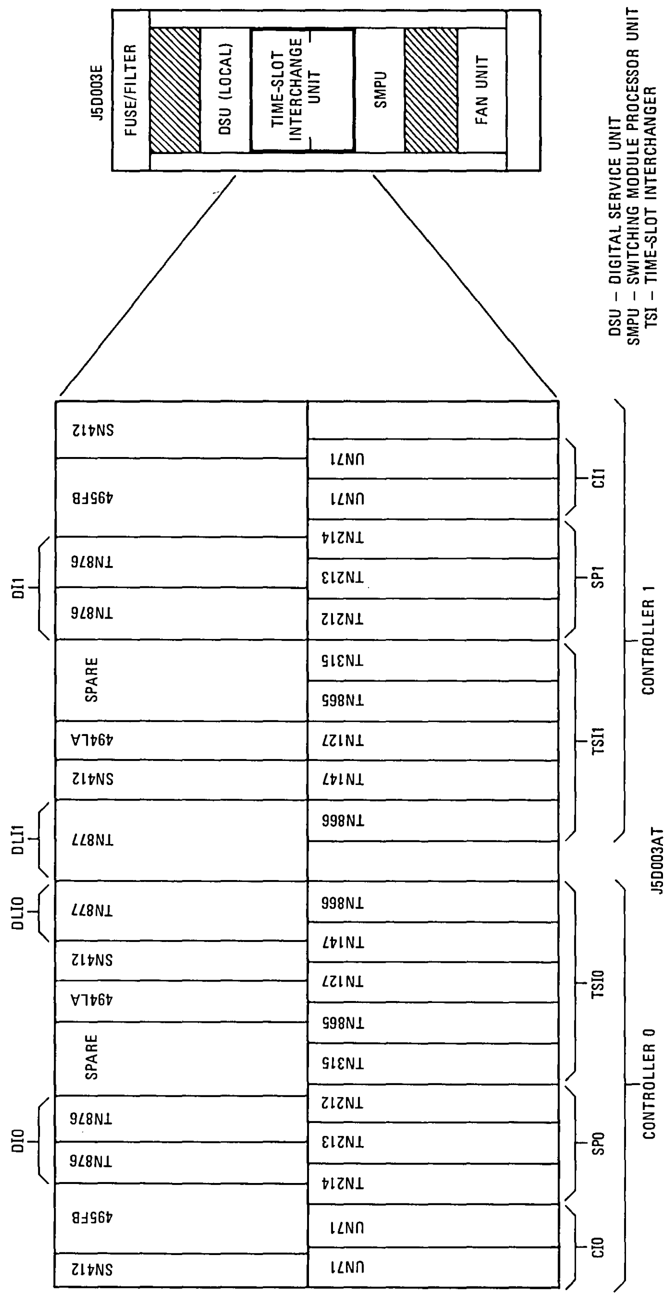


Fig. 12—Time-slot interchange unit.

of this relationship, each DLI is coupled to each TSIU/SMPU simplex half, and each DLI has its own power converter.

5.1.1.3 Data interface. Two data interface circuit packs are equipped on the TSIU to provide up to 32 Peripheral Interface Data Buses (PIDBs) from the TSIU to the IUs of the SM.

5.1.1.4 Control interface. The TSIU provides up to 46 Peripheral Interface Control Buses (PICBs), which deliver control information to the IUs from the SMPU. Each control interface circuit pack has 23 control ports available.

5.1.1.5 Signal processing. The signal processor, housed in the TSIU, is a three-board complex that transmits and receives address and supervisory signaling from the IUs.

5.1.2 Local digital service unit

The LDSU is a one-shelf unit located in the SMC cabinet. It is divided into two service groups, each of which requires 32 time slots, which are not a subset of the 512 TSI internal time slots. The LDSU provides each SM with tone decoding and tone generation functions. Figure 13 depicts the LDSU. Each service group has its own power conversion and common circuit, and is then equipped with tone generators and decoders as required.

5.1.2.1 Tone decoding. The Universal Tone Decoder (UTD) of the LDSU recognizes Touch-Tone (16-tone pairs) and multifrequency (15-tone pairs) signals. The UTD circuit pack contains four decoders.

5.1.2.2 Tone generation. The Universal Tone Generator (UTG) of the LDSU is capable of generating the following tones:

1. Audible ring
2. Dial tone
3. High tone
4. Low tone
5. Call waiting
6. Preemption
7. Multifrequency signals (15-tone pairs)
8. Touch-Tone signals (16-tone pairs)
9. Common Channel Interoffice Signaling (CCIS) continuity check tones (1780 and 2012 Hz).

The UTG has 32 channels of tone generation per Multilayer Board (MLB)-type circuit packs.

5.1.3 Switching module processor unit

The SMPU is a one-shelf unit housing the SM memory and microprocessor complex. The SMPU performs most of the call-processing and maintenance functions for the lines and trunks terminating on the IUs of the SM. The SMPU is fully duplicated and operates in

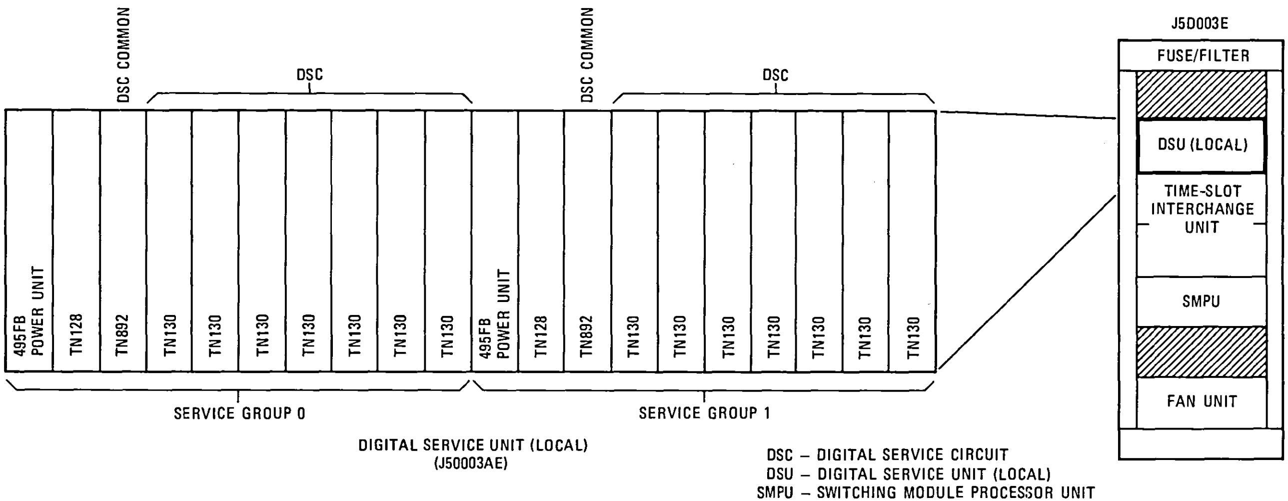


Fig. 13—Local digital service unit.

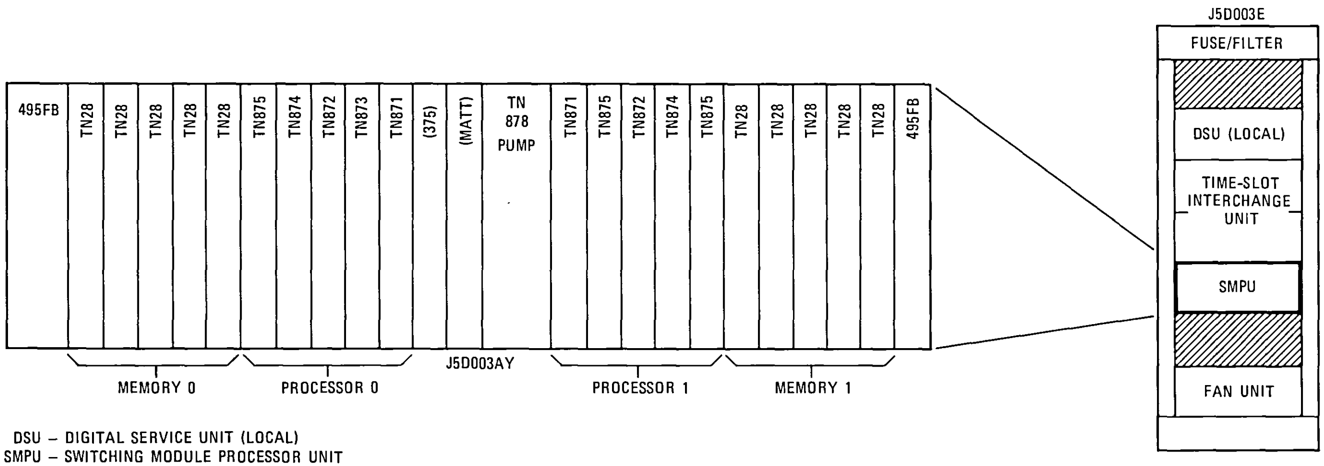


Fig. 14—Switching module processor unit.

an active/standby mode, as described in Section 5.1.1. The active simplex half has total control over the entire SM, and also updates the standby side's data. Figure 14 is a physical layout of the SMPU.

5.1.3.1 Microprocessor. The SMPU is based on the microprocessor. The entire processor complex is accommodated on five multilayered circuit packs.

5.1.3.2 Memory. Most of the SMPU program text and data are kept in RAM with backup on the moving head disk of the 3B20D computer. Five memory planes can be housed within each service group of the SMPU. At this writing, 1M-byte planes are used, with 2M-byte planes planned for the near future, allowing 5M bytes or 10M bytes for the SM.

5.1.3.3 Fast pump. The SMPU also contains the fast-pump controller circuit, which enables the central processor to down load memory to both sides of the SMPU in an expeditious manner. One PIDB is used as a channel to provide the means for data transfer.

5.2 Line trunk peripheral cabinet

The LTP cabinets house all the IUs of the SM. There may be up to four LTPs associated with one SM, and each LTP has six unit positions available for equipage. LTPs equipped with IUs are shown in the SM configured in Fig. 15.

5.2.1 Line unit

The *5ESS* switch line unit provides the interface to virtually all types of analog subscriber lines (see Fig. 16). The unit's modular design allows smooth growth from termination for 256 lines at a 4:1 concentration to termination of 512 lines at an 8:1 concentration. The line unit is a functionally partitioned, two-shelf unit containing up to 50 circuit packs at the 512-line capacity. The line unit provides all line interface functions, including battery feed, overvoltage protection, ringing, supervision and scan, analog-digital encoding and decoding, the hybrid function, two stages of line concentration, and test access. Unit 5V power is derived from one fully duplicated bulk dc-dc converter. Control interface to the peripheral interface control bus and control fanout is provided by two additional fully duplicated circuit packs.

5.2.1.1 Concentrator. The line unit concentrator is partitioned into grids, each of which terminates 64 analog lines. A minimum of four and a maximum of eight grids may be equipped in each line unit. The grid is contained on three circuit packs, two of which perform overvoltage protection, scan functions, and the first stage of concentration for 32 lines each. The third circuit pack performs second-stage concentration, and provides −48 Vdc to +300 Vdc power conversion and control for the grid. Each 64-line grid is configured in a simplex arrangement, whereas all other line unit functions are fully duplicated.

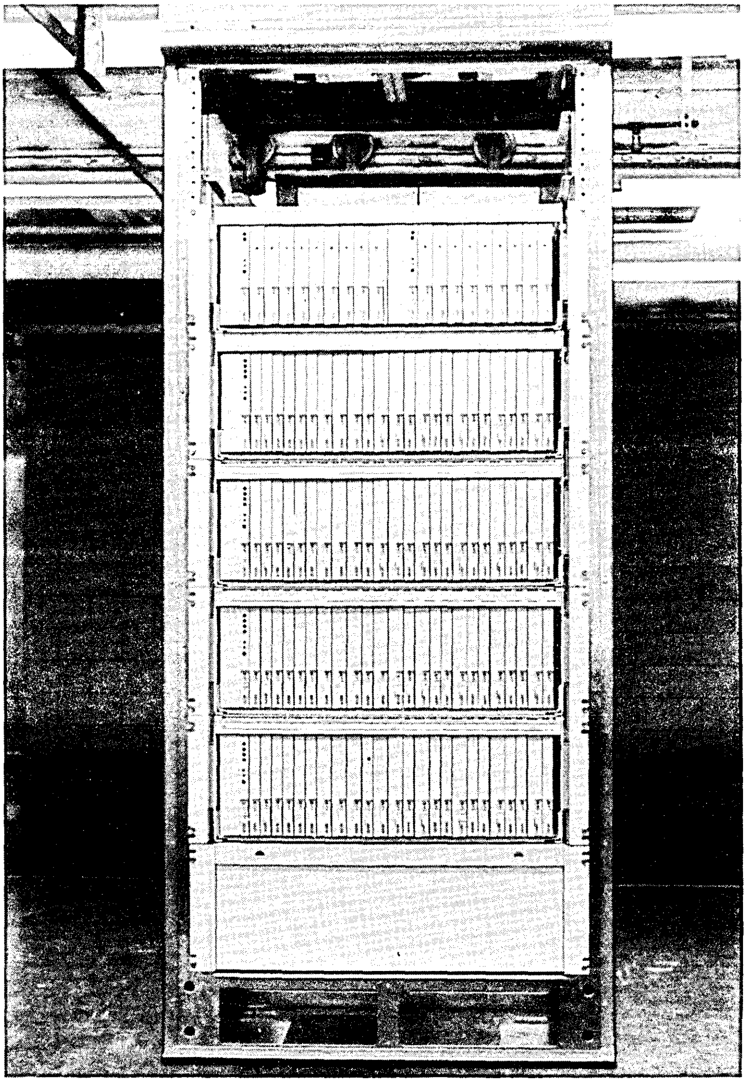


Fig. 15—Line trunk peripheral cabinet.

5.2.1.2 Channel. The battery feed, encoding-decoding, and hybrid function is provided on the channel circuit packs. Eight channel packs, each containing circuitry for eight individual channel circuits, are equipped in all line units. These packs provide 64 Pulse Code Modulation (PCM) outputs, which may be accessed by any of the 512 analog line terminations through the concentrator. The interface of these PCM channels to the peripheral interface database structure is performed on one fully duplicated circuit pack.

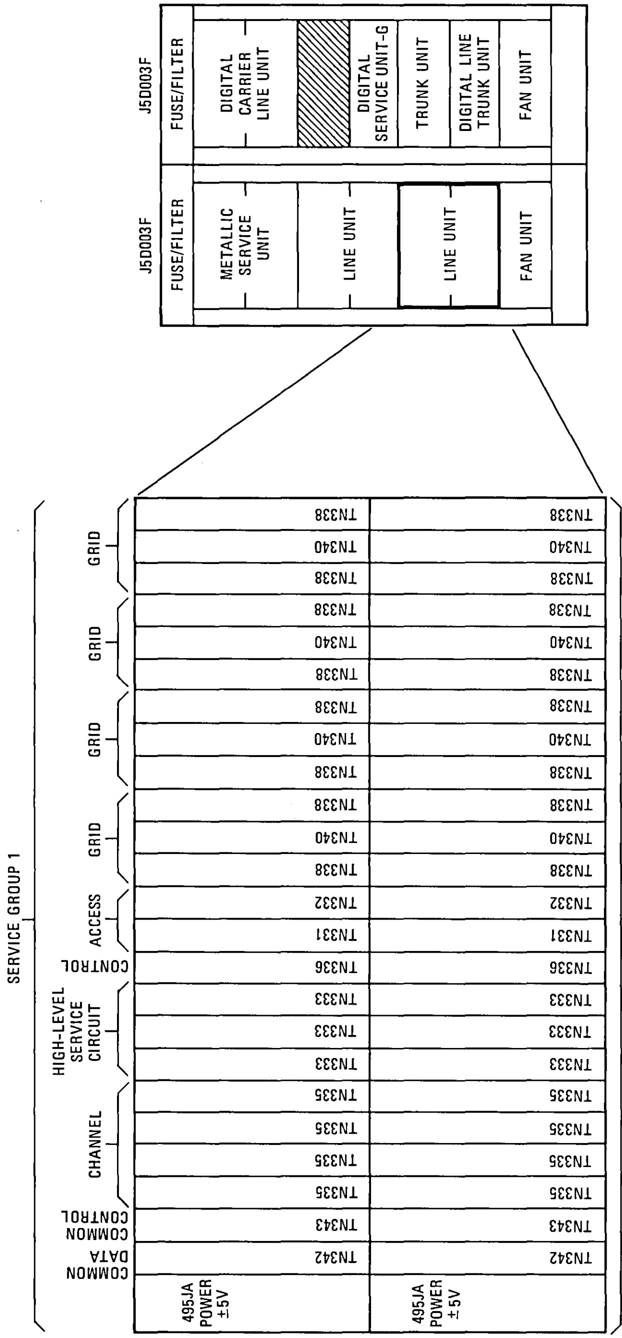


Fig. 16—Line unit.

5.2.1.3 ***Ringing and test.*** Ringing and test functions are provided from the high-level service-circuit pack. A minimum of four and maximum of six of these high-level service circuits may be equipped in each line unit. The ring and test functions are connected to individual subscriber lines through the ring and test access network and the concentrator. The access network, contained on two circuit packs, is fully duplicated for high availability, and allows access of any of the ringing or test circuits to any subscriber line.

5.2.2 Digital line trunk unit

The DLTU of the *5ESS* switch will interface with a large number of existing digital transmission terminals. It is a single-shelf unit that contains up to ten Digital Facility Interface (DFI) circuit packs, each of which terminates a single T1 line. These circuit packs use the MLB technology.

5.2.3 Digital carrier line unit

The Digital Carrier Line Unit (DCLU) is used to terminate T1 lines from integrated *SLC®* 96 carrier systems, where up to 96 subscribers without concentration at the remote terminal are provided with 96 channels to the *5ESS* switch. Mode II is the carrier-concentrator mode, where up to 96 subscribers share access to 48 channels to the *5ESS* switch. The DCLU is a two-shelf unit equipped with DFI, data multiplexers, control multiplexers, equalizers, and power units. Each DCLU terminates up to 30 T1 lines and consists of two service groups. A maximum of six *SLC* 96 carrier remote terminals may be terminated on a DCLU. These circuit packs use the MLB technology.

5.2.4 Trunk unit

The TU provides for the termination of high-traffic voice-frequency trunks. Specifically, it can terminate interoffice trunks and trunks to switchboards, operator positions, and announcement machines. Simplex equipment can terminate up to 64 trunks. A TU is a single-shelf unit divided into two separate service groups, each with its own power and common circuitry. Each service group terminates up to 32 trunks. Each trunk circuit pack is double-sided and contains four trunk circuits. The TU provides an interface for the following multipurpose trunk types:

1. Loop supervision, outgoing, two-wire local
2. Loop supervision, outgoing, two-wire toll
3. Loop supervision, incoming, two-wire local
4. Loop supervision, incoming, two-wire toll
5. E&M supervision, two-wire local
6. E&M supervision, two-wire toll

7. E&M supervision, four-wire local
8. E&M supervision, four-wire toll
9. Local test desk.

5.2.5 Modular metallic service unit

The Modular Metallic Service Unit (MMSU) consists of a one-shelf basic unit and up to three additional growth units. Each shelf is split into two service groups, and each service group has its own power and common circuitry. It can also accommodate up to nine metallic service packs whose functions are outlined below.

5.2.5.1 Metallic access. The MMSU provides the metallic access function on one circuit pack. Metallic access provides an access network that can interconnect analog facilities to test equipment.

5.2.5.2 Scan and signal distribution. A scan circuit pack and a signal distribute pack in the MMSU monitor the power supply status and maintenance status of the periphery.

5.2.5.3 Gated-diode-crosspoint compensation. The Gated-Diode-Crosspoint (GDX) compensator pack corrects leakage during testing of analog lines.

5.2.5.4 Automatic line insulation testing. One Automatic Line Insulation Testing (ALIT) circuit pack performs internal testing functions, such as insulation of all customer lines, short circuit, and foreign potential, and other specific tests on individual lines.

5.2.6 Global digital service unit

The Global Digital Service Unit (GDSU) is a one-shelf unit with two service groups. The unit design (i.e., backplane) is identical to the LDSU design, but is equipped with a different set of circuit packs, which perform lower-usage digital service functions. Each service group has its own power, common circuit, and space for up to eight service circuits, whose type and quantity are equipped as the needs of the office require. The GDSU may be shared among SMs in an office, being accessed by the switching network. GDSUs connect to the TSIU in the SM by way of PIDBs. The primary GDSU functions are described below.

5.2.6.1 Universal conference circuit. The Universal Conference Circuit (UCC) double-sided circuit pack of the GDSU contains five three-port conference circuits. At this writing six-port conferencing is planned for 1985.

5.2.6.2 Transmission test function. The Transmission Test Facility (TTF) of the GDSU performs all the voice-frequency tests required in the office. Four circuit pack codes provide

1. Facility testing
2. CODEC testing
3. Noise, loss, and frequency response measurements

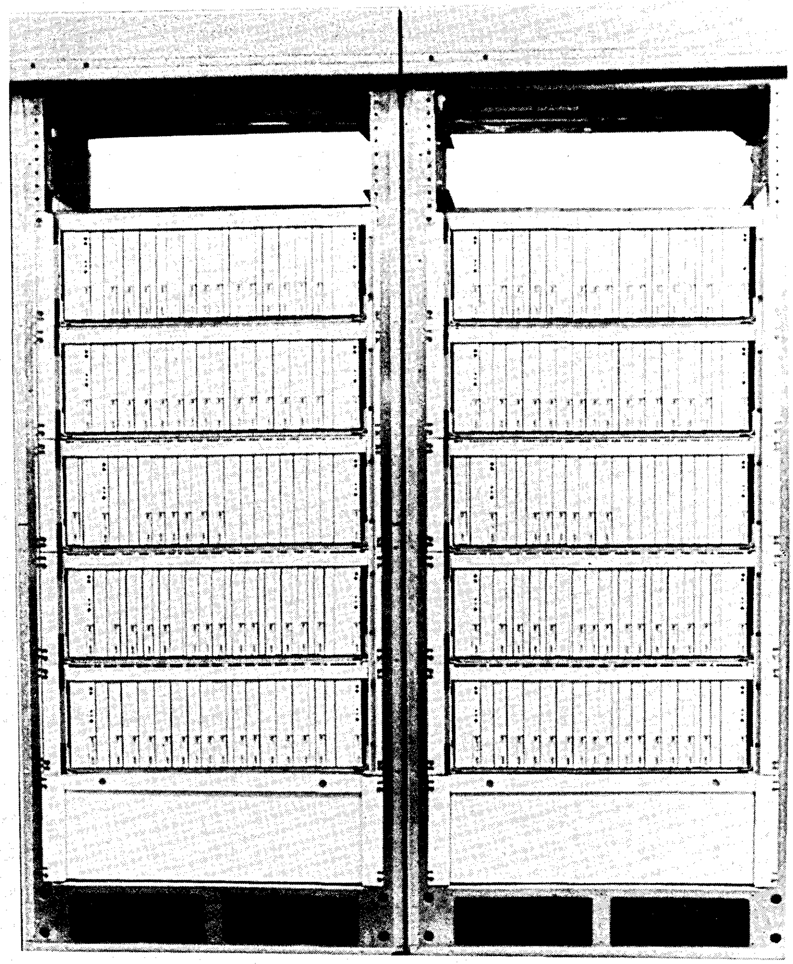


Fig. 17—Time-multiplexed switch cabinet.

4. 100 test line
5. 102 test line
6. 105 test line
7. Remote office test line
8. Touch-Tone test line.

5.3 Time-multiplexed switch

A *5ESS* switch equipped with more than one SM requires a TMS. The TMS cabinet (see Fig. 17) provides space-division switching of time slots between two or more switching modules. The TMS routes control, data, and PCM-encoded voice between the switching modules over fiber-optic links called NCT links. The equipment in a TMS cabinet is arranged to accommodate from 2 to 30 switching modules. For reliability, the TMS equipment is duplicated in a second TMS cabinet and operates in a duplex two-cabinet configuration. Equipment units within the TMS cabinets are job engineered with respect to the number of SMs in the office. Each TMS simplex cabinet contains two TMS Units (TMSUs) and one TMS Control Unit (TMCU). These units are provided for the minimum TMS configuration (two SM offices). The TMS (office) capacity can be smoothly increased to 30 SMs by populating the TMSUs with additional circuit packs, NCT links, and power converters. The TMS can be expanded quickly and easily in the field in this manner.

5.3.1 TMS switch unit

The TMSU is a single-stage space switch with 32 input ports and 32 output ports. There are two TMSUs in each simplex TMS cabinet separated by a TMCU. The TMSU located above the TMCU switches "even" time slots, and the TMSU located below the TMCU switches "odd" time slots. The even and odd TMSUs are connected to the TSI, which handles both even and odd time slots and is fully duplicated, by full-duplex optical-fiber data links. Each link carries even or odd time slots only. The exception to this even/odd arrangement is the link to the MSGS unit, which must carry both even and odd message time slots.

A TMSU is a two-shelf unit arranged to mount a total of 4 power converters (2 per shelf) and 27 *Fastech* multilayer circuit packs. The power converters supply power to all the circuit packs within their shelf. The capacity to switch 2 to 30 SMs is determined by the arrangement of circuit packs, NCT links, and power converters in the even and odd TMSUs.

5.3.1.1 NCT links. Fiber-optic transmitters and receivers, along with fiber-optic cable, make up the NCT links that are positioned on the backplane of the TMSU. They connect directly behind the Link Interface (LI) circuit packs that are housed on the equipment side of the backplane. Figure 18 shows a typical fiber-optic connection.

5.3.1.2 Fanout, fabric, and link interface. TMSUs are configured with the clock and data fanout circuit packs in the center of each shelf. Located on each side of the fanout pack are the fabric circuit packs, and outside the fabric are the LI packs. This scheme allows for the shortest path switch nets and better timing control.

5.3.2 TMS control unit

The TMCU provides the control path setup and the craft interface for all units in the TMS cabinet. The TMCU is a single-shelf unit

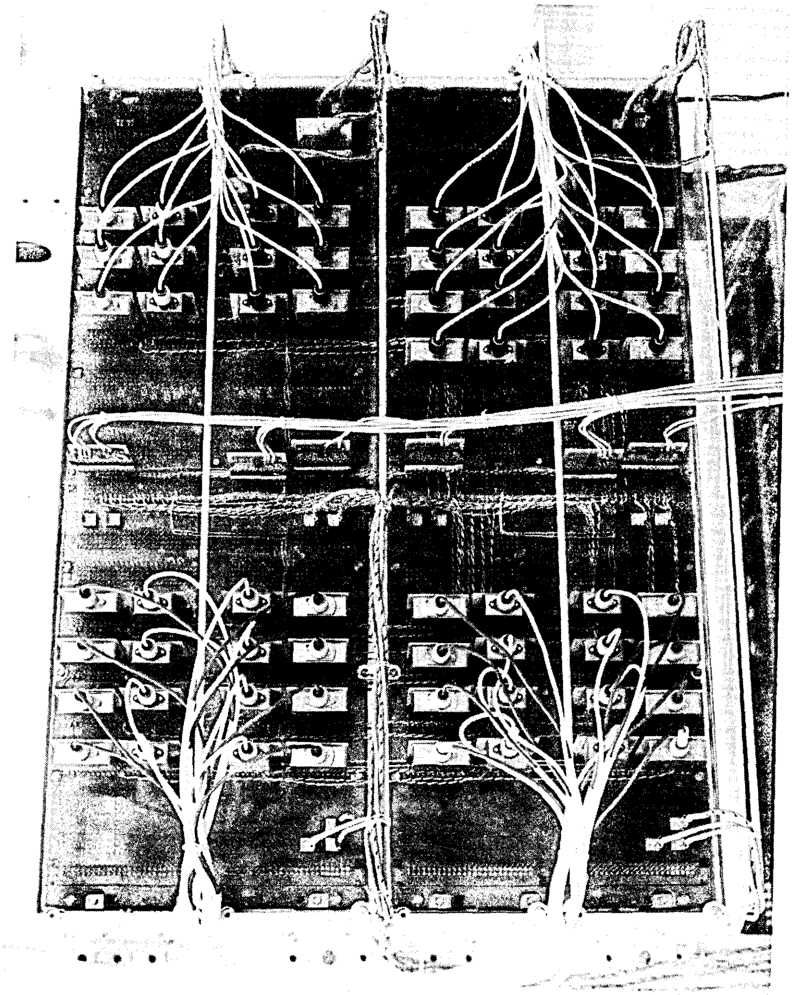


Fig. 18—Fiber-optic connections.

containing two power converters and seven circuit packs, including the control and display pack. The TMCU is equipped with a full complement of circuit packs and power converts regardless of the multimodule office size. The circuit pack complement contains one of each of the following packs:

1. Message Link Interface (MLI) pack
2. Test pack
3. Clock interface pack
4. TMS maintenance pack
5. TMS control pack
6. TMS interface pack
7. Control and display pack.

5.4 Message switch cabinet

The MSG in the *5ESS* switch provides synchronous control-data paths between the AM and the SMs, provides a synchronous control-data path for module-to-module communications, and timing to the rest of the *5ESS* switch; it also synchronizes the switch to the switching network. For each simplex cabinet, the MSG contains one Message Switch Control Unit (MSCU), three to four Message Switch Peripheral Units (MSPUs), and one Message Interface Clock Unit (MICU). For high reliability, the MSG equipment is duplicated in a second MSG cabinet and operates in a duplex two-cabinet configuration. Equipage of the units within the MSG cabinets is job engineered with respect to the number of SMs in the office. Growth procedures will be described in the sections that follow. Figure 19 shows a message switch cabinet.

5.4.1 Message switch control unit

The MSCU is an interface between the AM and the peripheral controllers in the MSPU. The MSCU is a single-shelf unit that houses in its normal configuration one power converter, one Control and Display (C/D) circuit pack, and either six or seven MSCU circuit packs. Two additional positions have been reserved in the MSCU for a test circuit pack and its converter. Since the MSCU has its own power converter and C/D circuit pack, it can be powered down without affecting other units. The circuit pack complement in the MSCU consists of

1. One control and display
2. One duplex dual-serial bus selector
3. One bus interface controller
4. One peripheral interface controller
5. Two Microcontrol Stores (MCSs)
6. One or two input/output microprocessor interfaces.

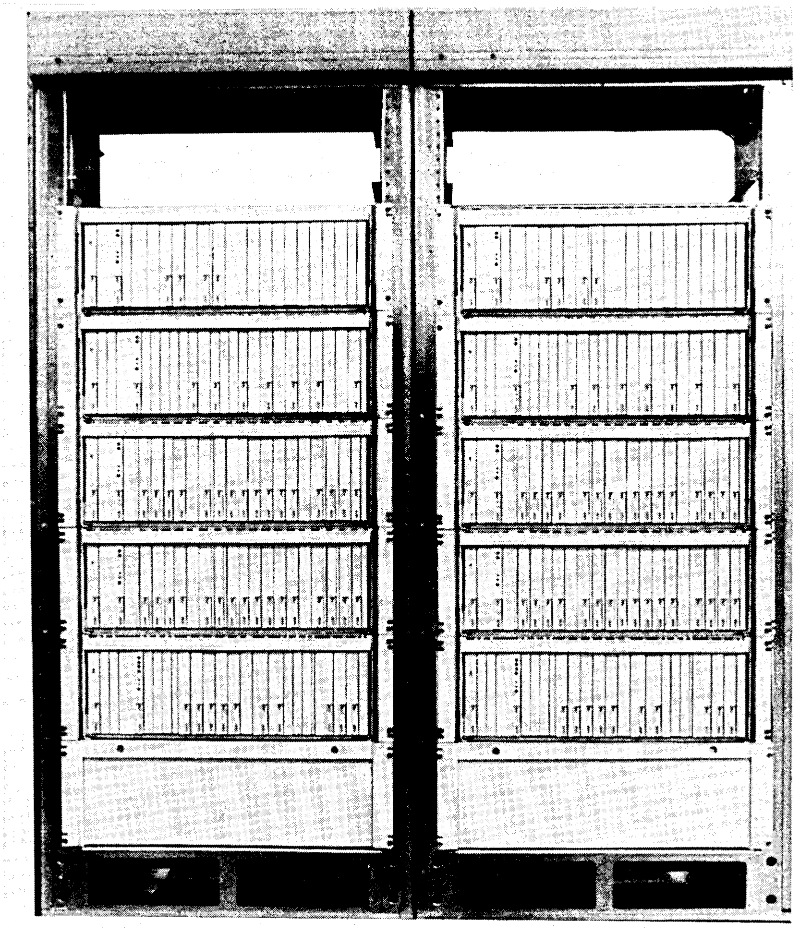


Fig. 19—Message switch cabinet.

The quantity of input/output microprocessor interfaces depends on the office size. All these circuit packs, except the C/D and MCS, are MLB types. The C/D and MCS are Double-Sided Rigid (DSR) types.

5.4.2 Message switch peripheral unit

The MSPU is a single-shelf unit that houses the Module Message Processor (MMP), Foundation Peripheral Controller (FPC), and Pump Peripheral Controller (PPC). The MMPs handle message traffic between the MSCU and the modules via the MICU and TMS. The FPC passes control data over the control and diagnostic access link from the AM via the MSCU to control the configuration of the MICU, as well as to control the TMS. The PPC can quickly initialize the module memory.

In the minimal multimodule MSG configuration, three MSPUs are required for a simplex MSG cabinet. Two of these units house MMPs and one houses the FPC and PPC. Each of the units is equipped with its own power converter and C/D circuit pack. Thus, one MSPU can be powered down without affecting other MSG hardware.

5.4.2.1 Module message processor. Up to four MMPs can be housed in one MSPU. With two units fully equipped with MMPs (MMPs must be added simultaneously to two MSPUs per simplex MSG), the MSG can support 32 modules. For offices larger than 32 modules, a dual-community version (growth unit) of the MSPU is added to the cabinet. This unit contains two separate power groups (two power converters and two C/D circuit packs) and allows growth to 48 modules.

The MSG grows by adding MMP circuit packs. An MMP contains

1. One Message Switch Peripheral Processor (MSPP)
2. One module message processor 1
3. One or two module message processors 2.

These packs are added simultaneously to each of two MSPUs per simplex MSG for support of up to 32 modules (see Fig. 20). When an MMP consists of four circuit packs, it can handle one time slot for as many as eight modules. An MMP may also consist of three circuit packs. In this configuration, up to four modules can be supported. Thus, in summary, three MMP circuit packs are required in each of the two MSPU communities to support up to four modules, four packs are required to support up to eight modules, seven are required to support up to 12 modules, eight packs are required to support up to 16 modules, etc. When MSPU communities 2 and 3 are fully equipped, 32 modules can be supported. In a similar way, MMP circuit packs can be added to each community in the dual-community (growth-unit) version of the MSPU for growth to 48 modules. All circuit packs of the MMP are MLB-type packs.

5.4.2.2 Foundation peripheral controller. Each MSG cabinet has one FPC, which contains one each of the MSPP or FPC codes of MLB-type circuit packs.

5.4.2.3 Pump peripheral controller. Each MSG cabinet has one PPC, which contains one each of the MSPP or PPC codes of MLB-type circuit packs.

5.4.3 Message interface clock unit

The MICU is a single-shelf unit that houses the Message Interface (MI), LI, and Network Clock (NCLK). The MICU provides system

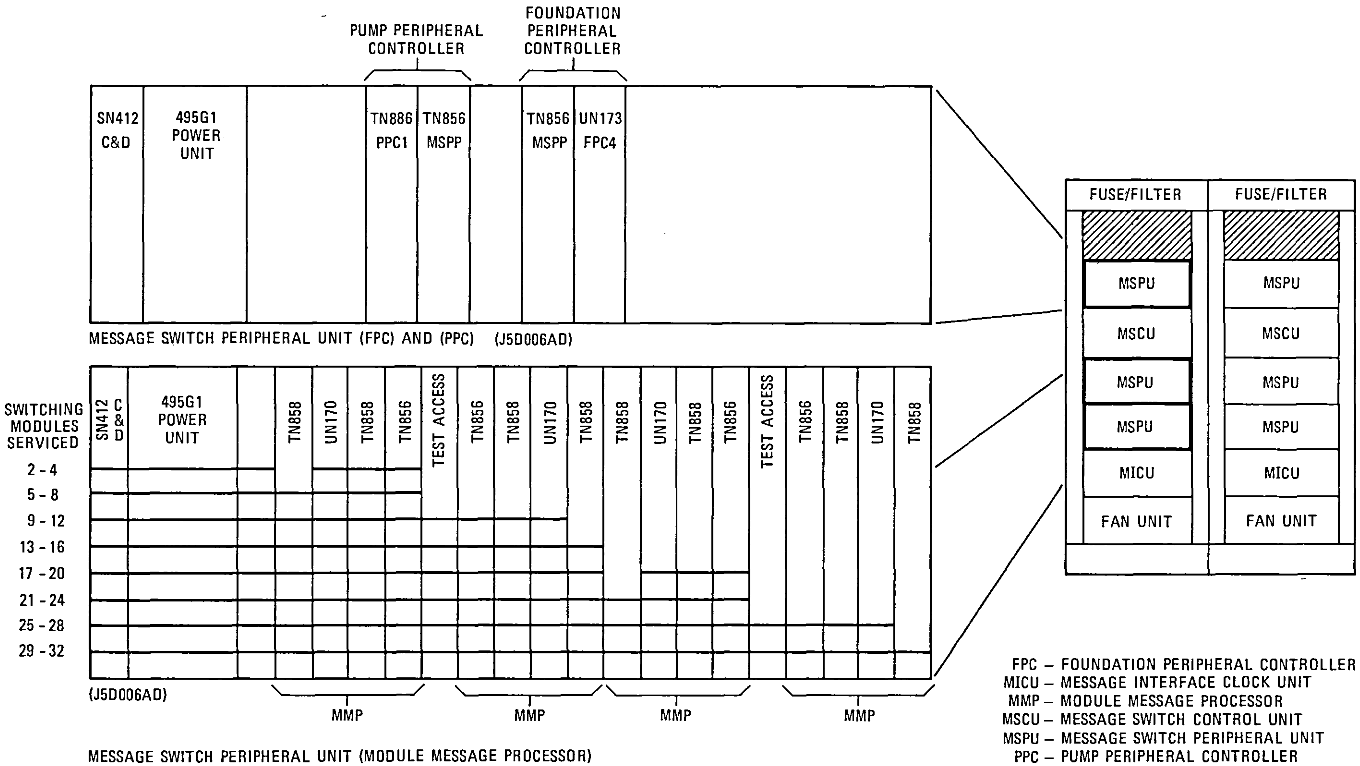


Fig. 20—Message switch peripheral unit.

synchronization and the interface for transmitting message time slots between the module controllers via the TMS and the AM.

5.4.3.1 Message interface. The MI consists of one each of the four MLB-type circuit packs listed below:

1. Message interface 1
2. Message interface 2
3. Message interface 3
4. Message interface 4.

It multiplexes and demultiplexes the message time-slot information between the MMPs and the LI.

5.4.3.2 Link interface. The LI consists of two MLB-type link interface circuit packs (link interface 1 and link interface 2). It provides the termination for the NCT link in the MICU. The LI transmits and receives data as 256 control time slots over the link to and from the TMS.

5.4.3.3 Network clock. The NCLK comprises three circuit packs—the controller, the digital phase-locked loop, and the synchronizer. Two versions (two different circuit packs) of the synchronizer are available—one for use in offices that are tied to T1 lines (slaved offices), and one for stand-alone offices. The NCLK provides master system timing and synchronization for the *5ESS* switch. The NCLK always contains three MLB-type circuit packs per MICU.

5.5 Miscellaneous cabinet

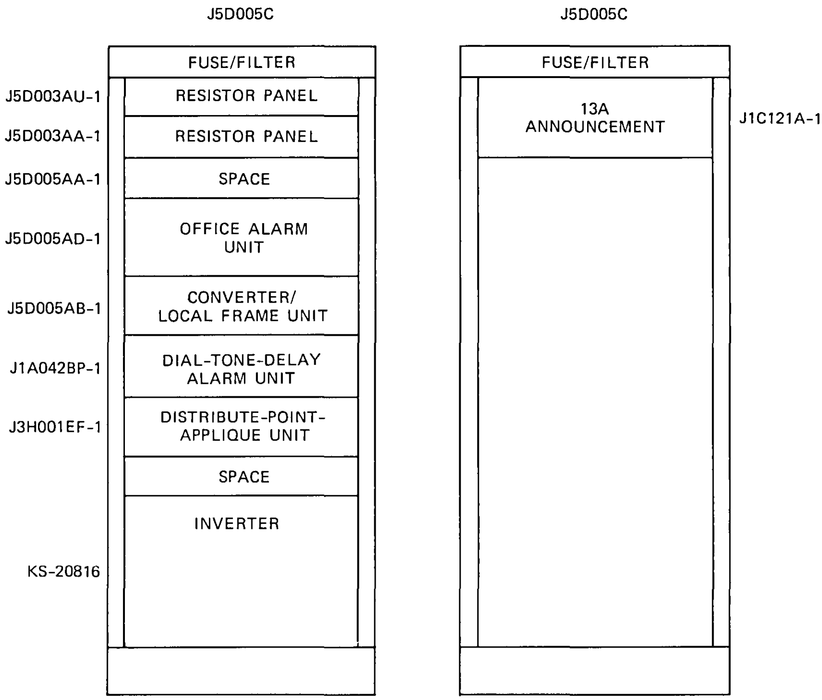
The miscellaneous cabinets, two of which are required for minimum equipage, house peripheral units that do not require module time slots or control ports. Each cabinet is equipped with two fuse and filter units but does not require fan units. The miscellaneous cabinets are equipped with the following units: inverter, office alarm unit, converter and local frame (tel jack) unit, resistor panel, 13A announcement system, external sanity monitor, and inductor unit. Figure 21 shows a maximum configuration of the two cabinets, and each unit is described in the paragraphs below.

5.5.1 13A announcement system

The 13A announcement system is a multichannel system allowing one to eight channels to provide recorded announcements of various lengths. Each channel can record and play one message. A maximum of four units can be mounted in one cabinet.

5.5.2 Inductor unit

The inductor unit provides a filter for the powering of the 13A announcement systems. This 4-inch by 2-foot 1-inch unit is required only when 13A announcement systems are used.



NOTE: A MINIMUM OF TWO CABINETS ARE REQUIRED FOR MISCELLANEOUS EQUIPMENT. A MAXIMUM OF FOUR 13A ANNOUNCEMENT CIRCUITS CAN BE MOUNTED IN A MISCELLANEOUS CABINET.

Fig. 21—Miscellaneous cabinet.

5.5.3 Resistor panel

The resistor panel is a 4 inch high, 23-1/4 inch wide unit that provides a mounting for cables and current-limiting resistor assemblies.

5.5.4 Inverter

The inverter unit is required to provide emergency 117V ac to the data-set cabinet and equipment at the master control center. This unit is 26-1/4 inches high, 23 inches wide, and 15 inches deep.

5.5.5 Converter and local frame (tel jack) unit

The converter unit is a 4-inch high, 2-foot 2-inch wide mounting plate equipped with a housing for a 131-type dc-to-dc power converter that supplies the external sanity monitor. Also mounted on this unit is the circuitry required for interframe communications.

5.5.6 External sanity monitor

The external sanity monitor provides a test of the call process that establishes a call between two switching modules. The equipment required to do this is mounted on the

1. Dial-tone-delay alarm unit, which is 4 inches high by 25 inches wide;
2. Distribute-point-applique unit, which is 2 inches high by 25 inches wide; and the
3. Converter and local frame (tel jack) unit, previously described.

5.5.7 Office alarm unit

The office alarm unit is a *Fastech* 8-inch-high apparatus housing equipped with the following functions:

1. Office alarm circuit
2. Scan-applique circuit
3. Remote alarm unit
4. Broadcast dynamic control.

5.6 Data-set cabinet

The data-set cabinets are used to house various operational support systems that interface with the *5ESS* switch. These cabinets are equipped with shelves and various styles of apparatus mountings to accommodate these systems. Two cabinets are required; one cabinet has backup ac power (protected ac), and the other is supplied with conventional ac power (essential ac).

Each 6-foot-high, 21-inch-deep, 30-inch-wide cabinet contains a cooling unit. The following list details by function which systems are in each cabinet.

5.6.1 Protected ac cabinet

The protected ac cabinet contains the following systems:

1. Automatic Message Accounting Teleprocessing System (AMATS)
2. Automatic Message Accounting Recording Center (AMARC)
3. 2 Switching Control System Center (2SCCS).

5.6.2 Essential ac cabinet

The essential ac cabinet contains the following systems:

- Central Trunk Test Unit (CTTU)
- Engineering and Administrative Data Acquisition System (EADAS)
- Remote Memory Administration System (RMAS)
- Service Evaluation System-2 (SES-2)
- Recent Change and Verify Local (RC/V LOCAL)

- Software Change Administration and Notification System (SCANS)
- Automatic Line Insulation Testing Repair Service Bureau (ALIT RSB)
- Verify Repair Service Bureau Local Test Desk (VFY RSB LTD)
- Belt Line (TTY A&B)
- Recent Change and Verify Switching Control Center (RC/V-SCC)
- Recent Change and Verify Network Administration Center (RC/V-NAC).

5.7 Remote switching module

The Remote Switching Module (RSM) is an SM located remotely from a host *5ESS* switching equipment office and connected via T1 carrier facilities. An RSM is a *5ESS* switching equipment SM connected by digital facilities through a Facilities Interface Unit (FIU) to a host *5ESS* switching equipment multimodule office. The RSM is capable of terminating lines and pair gain systems. The RSM can be divided into the following equipment types.

5.7.1 Digital facility interface

The RSM Digital Facility Interface (R-DFI) consists of a group of circuit packs that plug into a DCLU and act as an interface between the T1 lines from the host office and the FIU.

5.7.2 Facilities interface unit

The FIU consists of several subunits. These subunits are Multiplexers (MUXs), LIs, and a Clock Control (CLK CNT). The FIU recovers data, control, and timing from the T1 line and formats this information into a pair of NCT link signals that it routes over fiber-optic pairs called NCT links to the RSM SM (see Fig. 22).

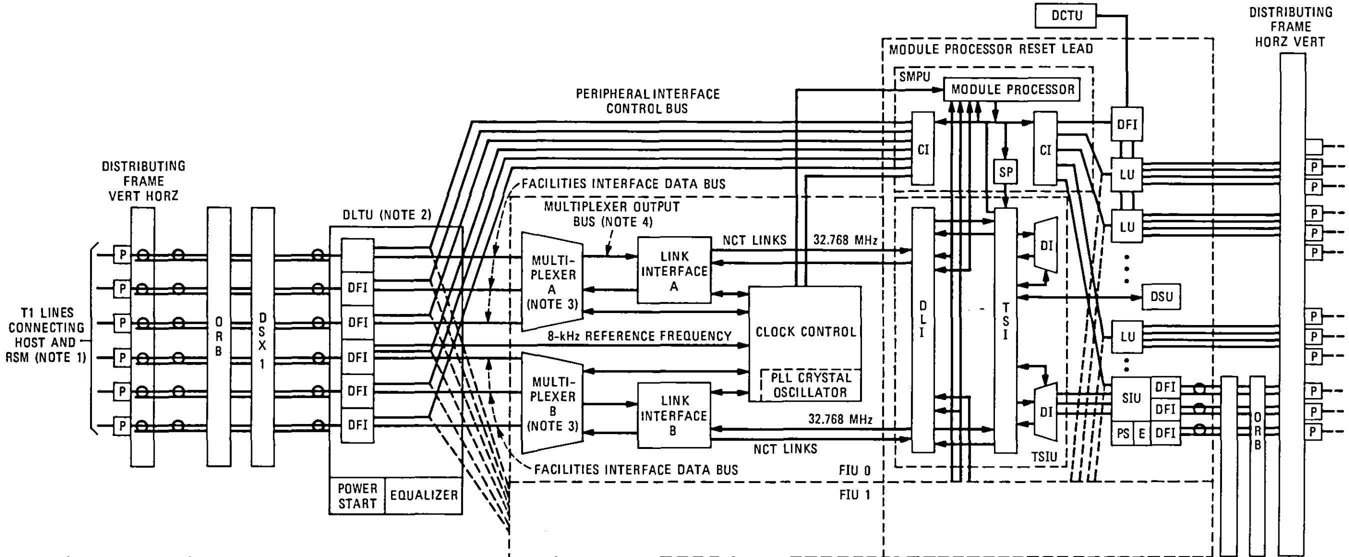
5.7.3 Switching module

The RSM SM consists of the following units:

1. Time-slot interchange unit
2. Switching module processor unit
3. Modular metallic service unit
4. Digital service unit
5. Interface units—line units, trunks units, and DCLU, as required.

5.7.4 Optional equipment

Optional equipment for the RSM includes the 13A Recorded Announcement Unit (RAU) and Directly Connected Test Unit (DCTU).



CI – CONTROL INTERFACE
DCTU – DIRECTLY CONNECTED TEST UNIT
DFI – DIGITAL FACILITY INTERFACE
DLTU – DIGITAL LINE TRUNK UNIT
DI – DATA INTERFACE
DSU – DIGITAL SERVICE UNIT
DSX – DIGITAL CROSS-CONNECT
E – EQUALIZER
FIDB – FACILITIES INTERFACE DATA BUS
FIU – FACILITIES INTERFACE UNIT
LU – LINE UNIT
NCT – NETWORK CONTROL AND TIMING
ORB – OFFICE REPEATER BAY

P – PAIRS
PICB – PERIPHERAL INTERFACE CONTROL BUS
PLL – PHASE-LOCKED LOOP
PS – POWER START
RSM – REMOTE SWITCHING MODULE
SIU – *SLC* CARRIER INTERFACE UNIT
SMPU – SWITCHING MODULE PROCESSOR UNIT
SP – SIGNAL PROCESSOR
TSI – TIME-SLOT INTERCHANGER
TSIU – TIME-SLOT INTERCHANGE UNIT

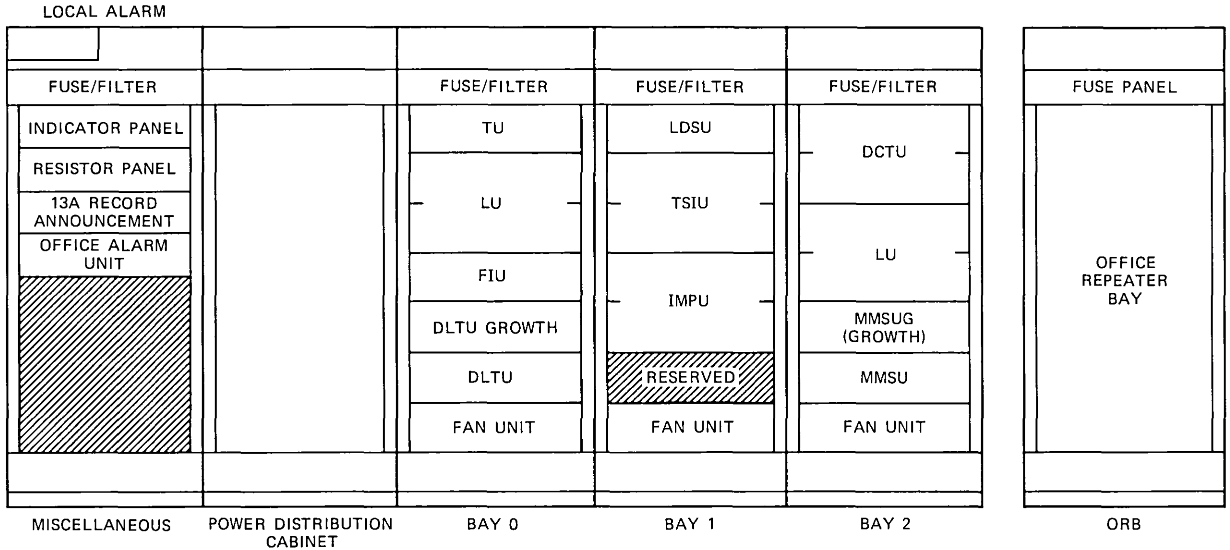
NOTE 1: A T1 DIGITAL CARRIER LINE IS A TRANSMISSION FACILITY THAT OPERATES AT A DS1 RATE (1.5444 MHz). A T1 LINE PROVIDES TWENTY-FOUR, 64-kb/s CHANNELS. TWENTY-THREE OF THE 24 CHANNELS ARE DATA CHANNELS, WHILE THE 24TH CHANNEL CARRIES CHANNEL-ASSOCIATED SIGNALING FOR THE OTHER 22 CHANNELS.

NOTE 2: ONE DLTU CAN BE EQUIPPED WITH 10 DFIs. A MINIMUM OF 4 AND A MAXIMUM OF 20 DFIs ARE REQUIRED FOR NORMAL OPERATION OF AN RSM.

NOTE 3: MULTIPLEXER A OR B CAN RECEIVE DATA FROM A MAXIMUM OF 10 FIDBs. EACH PIDB TRANSMITS/RECEIVES 32 TIME SLOTS OF 16-BIT SERIAL DATA TO/FROM THE DFI DURING AN NCT FRAME.

NOTE 4: THE MULTIPLEXER WILL TRANSMIT AND RECEIVE DATA WORDS OVER 2 FOUR-WIRE BUSES IN FOUR SEQUENTIAL 4-BIT NIBBLES.

Fig. 22— 5A remote switching module.



DCTU – DIRECTLY CONNECTED TEST UNIT
DLTU – DIGITAL LINE TRUNK UNIT
FIU – FACILITIES INTERFACE UNIT
IMPU – IMPROVED MODULE PROCESSOR UNIT
LDSU – LOCAL DIGITAL SERVICE UNIT
LOCAL ALARM – REMOTE SWITCHING MODULE STATUS ALARM UNIT

LU – LINE UNIT
MMSU – MODULE METALLIC SERVICE UNIT
MMSUG – MODULE METALLIC SERVICE UNIT GROWTH
ORB – OFFICE REPEATER BAY
PDC – POWER DISTRIBUTION CABINET
TSIU – TIME-SLOT INTERCHANGE UNIT
TU – TRUNK UNIT

Fig. 23—5A remote switching module with 1024 line terminations.

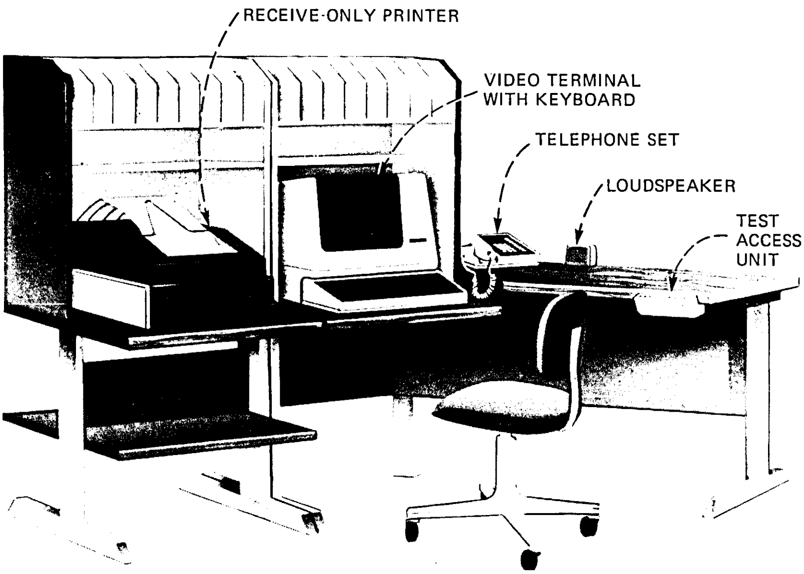


Fig. 24—MCC/TLWS console.

5.7.5 Other equipment

Other equipment includes an Office Repeater Bay (ORB), DSX-1 digital cross-connect facility, battery plant, distributing frame, etc. (see Fig. 23 for 1024 RSM equipment). The ORB supplies signal equalization, regeneration, and T1 line powering. The ORB is connected to a DSX-1 facility that provides test access to the T1 lines.

5.8 Master control center/trunk line work station

The MCC provides the interface capability for both administrative and maintenance tasks. The MCC is the primary communication link between maintenance personnel and the *5ESS* switch. The Master Control Center/Trunk Line Work Station (MCC/TLWS) console (see Fig. 24) and MCC/TLWS 6-foot cabinet (see Fig. 25) contain the following major components:

1. Video Display Terminal (VDT) with keyboard (color terminal option is also available)
2. Receive-Only Printer (ROP)
3. Multiline Telephone Set (MLTS) equipped with loudspeaker
4. Test Access Unit (TAU).

The video display terminal provides the means to communicate with the system during performance of a maintenance task. Maintenance requests are input through the keyboard, and the receive-only printer prints a hard copy of input and output messages for future reference.

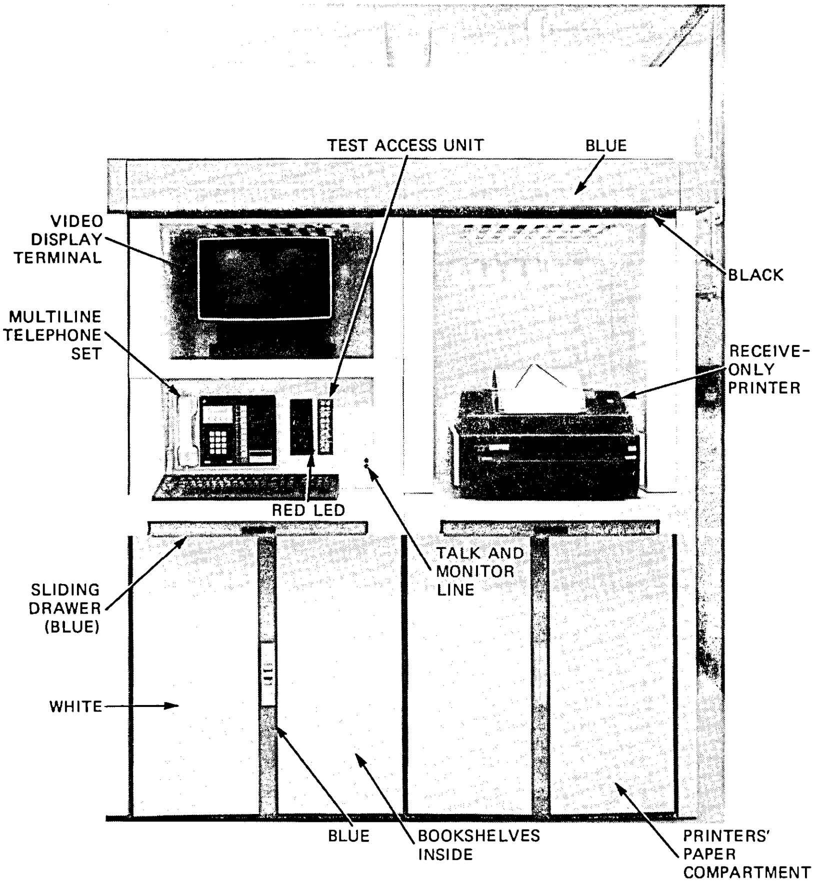


Fig. 25—MCC/TLWS/STLWS cabinet.

The MLTS is used to provide a general-purpose business line, and a TEL A Mon and TEL B Mon line, which is used to provide testing of the network. The MLTS can be used independently of the same central office, thereby ensuring outside communication during office outage. The MLTS is equipped with a loudspeaker to provide voice communication when maintenance personnel require hands-free operation.

The MCC/TLWS shares the same physical equipment as a fully equipped Supplementary Trunk Line Work Station (STLWS). The ROP, MLTS, and TAU are optional equipment for the STLWS only.

The STLWS enables a *5ESS* switch to be equipped with additional TLWSs (maximum of six) that are separate from the MCC. The operating company can then separate trunk and line testing activity from the MCC so that several crafts people can work simultaneously at different work stations to speed up the precutover testing.

Additional test equipment can perform some TLWS functions. The TAU provides several plug-in type jacks, which are used with portable test equipment and system software control to gain trunk or line access and perform tests. The MCC input/output and display conventions are also used by the TLWS. Although the TLWS and MCC share the same equipment, functional differences exist between them. These differences include the MCC functions mode and the TLWS functions mode. The TLWS functions are subfunctions of the MCC. Normally, the equipment is in the MCC mode. When performing TLWS functions, the equipment is switched automatically to the TLWS mode.

VI. ACKNOWLEDGMENT

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The 5ESS *Switching System:*

System Development Environment

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(Manuscript received October 13, 1983)

This article describes the elements of the system development environment that support each phase of the *5ESS*™ digital switching system product development. The elements themselves are complex hardware/software systems that are specialized to meet the particular needs of the different phases of development but integrated to smooth the transition through the phases. The requirements and design phases are supported by general-purpose *UNIX*™ systems that provide a rich set of tools for document preparation. The design is transformed into executable software for the *5ESS* system, primarily in the C programming language, augmented by C-based extension languages to support the special needs of database and diagnostic programming. This software is created, compiled, combined, and packaged for the *5ESS* switch test models by large *UNIX* systems running on IBM System/370-compatible hardware. Unit testing of developed software takes place on smaller support computer systems in an environment that closely resembles the test model. The test models, actual *5ESS* switching systems, are used for the integration and system test of the product. A dedicated computer system for each test model supports testing at the C language level. A number of actual and simulated load generators are used to stress and regression test the system. All the support systems are interconnected with high-speed data transmission networks that support remote command execution as well as file transfer.

I. INTRODUCTION

Since the early 1960s AT&T Bell Laboratories has been developing and introducing large software packages that operate, maintain, and

* Authors are employees of AT&T Bell Laboratories.

administer the many types of electronic switching systems that make up the major portion of the telephone switching network in the United States. As these packages have grown in scope and complexity, there has been a parallel growth in the use of computers and computer-based aids to support each system. For the *5ESS* digital switching system, this collection of computer aids, with its development elements, is known as the System Development Environment (SDE).* The elements are complex hardware/software systems that are specialized to meet the particular needs of the different phases of development but integrated to smooth the transition through the phases. The requirements and design phases are supported by general-purpose *UNIX* systems that provide a rich set of tools for documentation preparation. The transformation of the design into executable software for the *5ESS* switching system is done primarily in the C programming language, augmented by C-based extension languages to support the special needs of database and diagnostic programming. This software is created, compiled, combined, and packaged for the *5ESS* switch test models by large-scale *UNIX* systems. A dedicated *UNIX* system for each test model supports testing at the C language level. All elements are tied together with high-speed data-transmission networks.

The *5ESS* system architecture and the development approach provide new challenges that are met by the SDE. The software in the *5ESS* system is distributed over several different types of processors, and the architectural design is such that as new processors are developed they can be substituted into the basic system. This means that the development environment must be able to assign software to the designated processors and must make it easy for existing software to be applied as technology changes both during development and after the system is released for commercial service. Software may be located in writable memory or in read-only memory. The development environment must always associate the correct software and firmware (software in read-only memory) for each load or release of the system. The development plan provides for many organizations to be generating software simultaneously for different releases of the system. This means the development environment must allow for parallel developments with overlapping content and independent schedules for actual releases.

The environment operates under a formal methodology for each step in the process and supports the generation of complete documentation for all phases of development from requirements to system release. All source and object code is controlled and tracked for each development version of the system as well as for each officially released

* Acronyms and abbreviations used in the text are defined at the back of the *Journal*.

version. The environment allows the *5ESS* system design to evolve by sequentially adding capabilities that can be independently developed and tested. The environment also allows continued maintenance of the system by applying incremental updates to the software. Overall, the SDE gives the programmers their individual, personal contact to the system under development without the programmers being hindered by the hundreds of other programmers and developers accessing the system.

II. PROGRAMMER SUPPORT SYSTEM

The Programmer Support System consists of all components needed to facilitate the work of the software developer during the requirements, design, and software-generation phases of the development life cycle. In the *5ESS* SDE the requirements and design phases are supported on medium-scale, general-purpose computing facilities, and the software-generation phases are supported on large-scale computing facilities. The medium-scale systems are either AT&T 3B20S or VAX-11/780* machines running the *UNIX* operating system and are typically referred to as general-purpose *UNIX* systems. The large-scale software-generation machines are IBM 3033AP, IBM 3081K, or Amdahl 5860 systems, also running the *UNIX* operating system. These are referred to as Large-Processor (LP) machines.

2.1 General-purpose UNIX *systems*

The *5ESS* switch methodology relies on a series of well-defined specification documents to guide the development process. These documents include architecture, requirements, capability design, development unit design, and test-plan specifications. A standard template outline has been defined for each document, and the developer uses the general-purpose *UNIX* facilities to create and maintain these documents.

Several sophisticated tools exist in the *UNIX* environment to support this document generation. The Programmer's Workbench and *Writer's Workbench*™ systems provide tools that perform such tasks as spelling verification, double-word detection, sentence structure analysis, and readability analysis. In addition, there are tools that allow the writer to transform text into well-formatted, publication-quality documents. These tools include `nroff`, a macro language for formatting text; `tbl`, a tool to create tables; and `gc`, a tool that formats "typewriter art" into polished figures. The *5ESS* switch project's general-purpose computing resources are supplied through the computer center operations that support the general AT&T Bell Laboratories user community.

* Trademark of Digital Equipment Corporation.

2.2 Large-processor UNIX *systems*

The majority of the Software Generation System (SGS), source control, and Change Management System (CMS) functions are performed on the LP *UNIX* systems. The LP systems run the *UNIX* operating system and, in addition to the standard rich set of tools provided with the *UNIX* operating system, support several major piece parts integrated through well-defined procedures and scenarios. The process of software development proceeds from the initial writing of the software to its official introduction under source control. At this point the source can be compiled and introduced into a product package of varying size for execution and testing in either the Execution Environment (EE) (see Section III) or test-model target machines. It can then be changed in a controlled way throughout its initial development. After being introduced into the field it can be supported and updated. The tools to support these steps in the software life cycle will now be described.

2.2.1 Change Management System

The CMS provides the ability to keep track of the current version of the official program source, isolate test versions of programs, and eventually introduce either new code or corrections into the official version of *5ESS* system software. The CMS provides not just isolation of changes in differing states of development but also independence of one generic from another. It can also provide dependence of one generic on another by allowing pieces of the software to be defined as common between multiple generics. The software for the *5ESS* switch is partitioned into a number of logical subsystems, each of which performs a part of the total switching task. The software for each subsystem is organized in a structure that can be cleanly represented as a subtree of the *UNIX* file system's tree-structured directory hierarchy. These structures, known as nodes, are understood by the CMS system and the load-building tools. The subsystems are spread across several LP *UNIX* machines; however, no single subsystem spans more than one machine. Each subsystem is built (compiled) independently and then collected on a single machine designated as the Program Administration machine for final building (link editing).

2.2.2 Software generation systems

There are several SGSs in use to support cross-compilation to a multiplicity of target machines; System/370 compatibles, AT&T 3B20, VAX-11/780, Intel* 8086, Motorola MC68000, and several smaller microprocessors.

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* Registered trademark of Intel Corporation.

The SGSs consist of preprocessors, compilers, optimizers, assemblers, linkers, and utilities. Preprocessors have been developed to provide enhanced message and data definition capabilities to the developers. They provide a higher level of abstraction and better user interface for the definition of interprocess and interprocessor communications and the definition of database relations. The output of these preprocessors is C language code.

The vast majority of *5ESS* system software is written in C, and the portable C compiler provides the basis for the multiple-target-machine environment support. A tool, `lint`, is provided for syntax, portability, and interface checking of the source code before compilation. Listing production is a separate process and can be accessed on-line. Optimizers have been provided for real-time and memory optimization of code targeted for the AT&T 3B20D Administrative Module (AM) processor and the Motorola MC68000 Switching Module (SM) processor.

2.2.3 Load building and packaging

Using CMS and SGS to create a desired version of the system source and process it into object files, the load-building process brings together the work of developers to produce an official load for testing in the test models. Using an automated Initial Modification Request (IMR) system, developers record their progress during the development of a new capability or the correction of a previously detected problem. When the developer has completed the necessary software changes and tested the changes privately, the developer submits the IMR to the load-building team for inclusion in one or more public loads (a change may belong in two or more load streams because of shared development). Using information recorded in the IMR, the load-building team extracts the desired version of the affected source without interfering with other ongoing change activity. Using a series of recipes for product construction, known as `makefiles`, and a series of node structures that represent the current view of the load, the necessary source-to-object transformations are automatically performed in a selective fashion. Only those transformations that must be repeated because of changes introduced by new IMRs are performed. This process, known as load building, takes place in parallel on all the LP machines for all subsystems. Shared information necessary for all subsystems, such as global header files and common data definitions, are preprocessed and distributed to all LP machines via the interprocessor network (see Section VII), utilizing a set of shipping tools that ensure the integrity of the distributed data. Once the load building on each machine has produced a single object file for each combination of processor type and subsystem, these high-level objects are shipped to a single LP machine and combined to form the final products, which are then delivered to the test models.

A more incremental development process that only reconstructs lower-level products is used by developers to produce private products for testing code before its official introduction. Two methods, called capability build and Quick Fix, allow the developer to build a private test product on a capability basis, rebuilding only those parts of the subsystems needed for the capability and thus introducing a small change into the test model without rebinding entire subsystems.

In addition, a set of tools has been developed that allow fixes to be quickly and efficiently introduced into generics in the field. These tools extract from updated object files the functions and data that have been changed with respect to the field, package the minimal changes with associated installation instructions, and transmit the resulting package via electronic delivery to affected sites. At the field sites the package is further processed and installed in in-service offices, without disruption of service. Associated listings are produced and available for field offices.

III. EXECUTION ENVIRONMENT

The EE for the *5ESS* system uses general-purpose *UNIX* systems to host a simulated *5ESS* system environment. Using a standard library of subroutines to stub off the routines that directly control and monitor hardware in the actual switch, the users of the EE can test the logical behavior of the vast majority of the operational software from their desks. Since the software to be tested is written in C, all that is required to build a load to be tested in the EE, rather than a test model, is to compile the code for the AT&T 3B20S rather than the AT&T 3B20D or Motorola MC68000. To support this mode of testing, the official load-building process produces loads for the EE as well as the test models. Using additional software provided with the EE, the user can test code destined for either the AM or SM or both. The testing language used is identical to that which the developer will use later in the test model. Test scripts can be developed and refined in the EE and then taken directly to the test model for regression testing on the actual hardware. By using the EE for unit and small-scale integration testing, users can isolate and correct logical problems before entering the test model. The use of general-purpose processors to support the EE reduces the complexity of parallel hardware/software development by allowing most software problems to be found and fixed before the code is executed on the switch hardware.

IV. LABORATORY TEST SYSTEM

The Laboratory Test System (LTS) for the *5ESS* system gives software developers a friendly environment in which to test their code. It does this by providing a standardized command language and by interfacing the various test products to the *5ESS* subsystems through a single Laboratory Support Processor (LSP). The software under test is resident on one or more of the processors within the distributed architecture of the *5ESS* switch.

In general, LTS test products have an LSP-resident part and a *5ESS* switch-resident part, some of which require special hardware interfaces to the switch. The LSP part controls the switch-resident part and communicates with it over data links so that the LSP can be located remotely from the switch.

The LTS is an evolving system with multiple capabilities. It is packaged and distributed to users as a single system. Test-product improvements and new test-product capabilities are scheduled and developed based on the prioritized needs of the entire *5ESS* system development community. LTS is provided in tested and scheduled releases. Each release is accompanied by installation documentation and is installed in a *5ESS* system laboratory soak site by an installation team supported by an LTS first-application team. After a suitable soak interval the release is distributed to all system laboratories by laboratory support personnel. Procedures are available to give emergency fixes or interim releases to solve problems identified by the user community. New releases are accompanied by user documentation and by tutorials presented by the LTS developers.

4.1 Laboratory support processor

The LSP, running the *UNIX* operating system, provides the facilities to interface the test products to the users in a standard format. This standardization of format reduces the training required for users to become productive and also reduces user errors.

The LSP controls test resources and may be configured to handle dozens of user terminals that are either dial-up or directly connected. A single LSP can serve several *5ESS* switch test models simultaneously.

Software to be tested is prepared on the LP systems, transferred to the LSP via the Network Systems Corporation network (see Section 7.2), and then loaded into the target *5ESS* switch processor under control of the LSP. A different symbolic debugging tool is needed for each type of *5ESS* switch target processor (AT&T 3B20D, Intel 8086, or Motorola MC68000), but the user interfaces to these tools are essentially identical.

The LSP file system contains copies of all approved *5ESS* switch object code and symbol tables relating it to the C language source code. In addition, the file system contains object modules and corresponding symbol tables for the new code to be tested. The symbol tables are used for symbolic debugging. Any of the software object-level files can be loaded into an appropriate target processor in the

5ESS switch for testing. Frequently a test session will require software to be loaded into two or more target processors, each of which is monitored with a separate user terminal connected to the LSP. Symbolic test results or memory dumps can be transferred to the LSP for detailed analysis.

The LSP supports the use of test scripts for code debugging or regression testing. It makes available test products that allow scripts to generate switching system stimuli in the form of various types of line and trunk calls, high call-traffic volumes, or simulated craft input messages. Switching system response is then monitored via standard system outputs—e.g., traffic schedules or teletypewriter messages—or via special test software loaded into the target processor by the LSP.

Figure 1 is a diagram of the combined *5ESS* switch-LTS configuration showing that the LSP communicates via data links with various hardware subsystems within the distributed architecture of the *5ESS* switch. These subsystems are the AM, the Communications Module (CM), and multiple SMs. Three types of processors are used within the current *5ESS* switch. The AM uses an AT&T 3B20D processor, the CM uses Intel 8086 microprocessors, and SMs use Motorola MC68000 microprocessors. The numbers within each box of Fig. 1 indicate the LTS products that are available for each *5ESS* subsystem.

Four LTS products that reside entirely on the LSP are not shown on Fig. 1. They are the *UNIX* operating system, the software to interface to the Network Systems Corporation high-speed data bus, a C language-level software correction capability (Quick Fix), and an object-level software correction capability (Patch Compiler).

4.2 Test subsystems

The LTS test products fall into three broad categories. The first category is load administration facilities. The second is software debugging tools, which include C language debuggers for each of the processor types, coverage analyzers to determine the percentage of code actually executed, a Communication-Link Monitor (CLM) for recording and analyzing messages passed between *5ESS* subsystems, and a system-pause capability to permit all processors to be halted and restarted simultaneously under control of the software debugging tools. The third category is test products, which provide *5ESS* system stimuli in the form of call traffic, intersubsystem message traffic, or craft input message traffic.

The Debugger for Remote Target (DART) and the Integrated Test System (ITS) are C language debugging tools that allow the user to plant breakpoints, modify memory or processor registers, and provide formatted symbolic dumps of software variables and symbolic traces of software execution. Many of the actions of these debuggers interfere

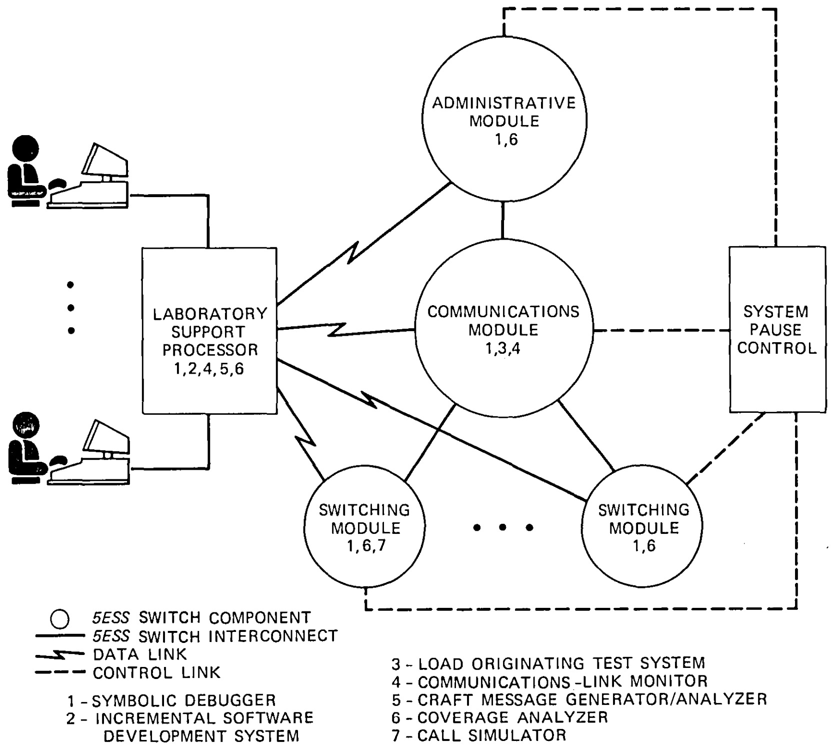

Fig. 1—LTS configuration for the *5ESS* switch.

with the normal real-time execution of *5ESS* system code and are not suitable for use in an in-service environment. ITS, however, does provide extensive debugging capabilities on a noninterfering basis.

Coverage Analyzers (CAs) are provided to determine what percentage of the code is executed. The CAs work in conjunction with compiler options that plant instructions in the object code to flag a specific memory location in a CA map when that code is executed. The LTS part of the CA function then retrieves the memory location map and produces a symbolic display of the code that has been executed. The mapping can be done either on a function-by-function basis or on a line-by-line basis.

The CLM requires a special circuit that taps into the *5ESS* switch message links at the CM and at one or more of the SMs to permit the LTS to capture selected messages or message headers for analysis. The CLM circuit also contains a display for local monitoring of the messages.

System pause is a function not presently integrated into the LSP. It consists of (1) circuits that interface with each processor in the system and (2) an array of switches and lamps. The switches are used to select which processors will be enabled for a specific test, and the lamps display whether the associated processor is halted. A development currently under way will replace the manual switches with ones that can be remotely controlled by the LSP.

Call traffic is generated by programmable call simulators that contain (1) circuits that simulate lines and trunks and (2) circuits that can generate and detect tones and various types of telephone signaling. These line and trunk circuits interface to the *5ESS* system SMs as standard lines and trunks, and calls generated by the call simulator appear to the *5ESS* switch to be normal calls. Test scripts are written in a C-like simulation language and stored in test sequence files on the LSP. A wide variety of line and trunk calls are possible. These test scripts are extensively used for regression testing of the *5ESS* system generics.

The Load Originating Test System (LOTS) generates high-volume message traffic, which appears to the AM as coming from a number of SMs in the *5ESS* switch. In reality, the messages are generated by special software loaded into Module Message Processors (MMPs) in the CM subsystem of the *5ESS* system. The messages generated by LOTS simulate line-to-line, line-to-trunk, and trunk-to-line calls that represent either inter-SM or intra-SM traffic. The messages may represent completed calls, abandoned calls, Custom-Calling calls, or a variety of other call-sequence situations. In addition, the LOTS software generates corresponding traffic data and AMA billing data, which it sends to the AM for processing. Each LOTS MMP can generate messages representing approximately 70,000 busy-hour calls. With four MMPs, LOTS is able to load the AM with message traffic representing close to 300,000 busy-hour calls.

The Craft Message Generator/Analyzer (CMGA) is a test product that interfaces to serial I/O channels of the AM, such as the maintenance channel or service-order channel. The CMGA generates teletypewriter traffic on these serial channels and records the system responses for analysis. Test scripts can be generated and stored on the LSP, and the *5ESS* responses can be matched against the expected results.

V. TEST MODELS

5.1 General description

The fundamental purpose for the test models in the *5ESS* system development environment is to allow programmers to debug their code on the target machine. Subsequent software integration, load stress testing, stability runs, and final generic verification are also accomplished on a configuration that is representative of expected capability interactions in the field. Additionally, the test models integrate the hardware design into the software architecture to satisfy the overall system requirements. In this manner, the test models simulate the latest state of the hardware to allow the software to execute and operate under the expected conditions that will be seen in the field.

The test model simulates an operating local telephone office with as many of the myriad combination of features and capabilities as are required to test the generic being produced. For feature debugging purposes, there is a subscriber test station, which allows manual testing of line features (e.g., dial pulse, Touch-Tone, coin) via the appropriate station set access. The subscriber test station also allows manual access to a variety of trunks for testing of transmission and signaling features of the *5ESS* switch. Automated load test equipment is also provided for simulated traffic effects to test the real-time capacity and system response of the software architecture.

In addition to the target machine and the LTS, the *5ESS* system test models are also equipped with a user area to create a friendly environment. When this space was planned, considerations ranged from furniture to a complete simulation of the field Master Control Center (MCC). Cabinets, tables, computer terminals, phones, and other appointments were considered in establishing an environment conducive to the development effort. Access to the LTS as well as the LP and general-purpose *UNIX* systems is provided via direct lines and dial-up service. Figure 2 displays a *5ESS* system test-model user area, showing the LTS user terminals and the MCC in the foreground with the *5ESS* switch itself behind the glass partition.

5.2 Lab engineering

The detailed configuration of a given test model is generated from requirements provided by the development organization in a fashion analogous to the dial administrator and equipment engineering functions in an operating company. This hardware and the associated engineerable assignments are represented in the executable software in the office-dependent data. Changes to this software abstraction of the peripheral hardware must be coordinated with changes to software tools altered by the target code, changes to the hardware configuration, or changes in assignments within a test model. This interaction of the office-dependent data with the state-of-the-generic development is one major aspect of the test-model work to ensure the integrity of the hardware as viewed by the target software.

5.3 Load procedures

The developing software takes on the character of a generic through addition and update of the various pieces into an integrated whole called a load. The test models provide the environment for maintaining

Fig. 2—*5ESS* system test-model user area.

a load of a particular vintage, termed the public load, and bringing in new loads on a schedule commensurate with developer needs. Each public load may encompass software and, possibly, hardware and firmware changes in the evolution toward a field-grade generic. Additionally, the test models allow altered states of these public loads, termed private loads, to be tested by individual programmers for specific situations.

5.4 Developer testing

The individual developer testing with private loads is the essence of the proof that the capability under development meets the intent of the requirements. The test-model environment provides the necessary hardware and software tools to allow the programmer to test, debug, alter, and retest the code under examination to the satisfaction of the documented test plan. The foundation of these private loads is the previously mentioned public load, against which the private loads are built. The programmer private-load mechanism begins in the LP environment with the public-load structure and manifests itself in the private software under test. As each capability is proven to meet the requirements in this environment, all the individual capabilities are reconstituted together to form the next public load. This synthesis of numerous capabilities into the new thesis of a public load is then regression tested to produce information relating to interactions among the various capabilities added to the developing generic.

5.5 Load testing

A subset of the test models is configured for regression and load testing of the public load. This mechanism of stress testing the software via simulated high-level telephone traffic has consistently generated heuristic information that uncovers latent problem interactions in the generic load. System testers and private-load developers take advantage of programmable call-simulation equipment to provide mixtures of ordinary and feature-activating telephone calls up to and beyond the design capacity of the system to tune system behavior at all traffic levels including overload.

5.6 Lab maintenance

As a final note, the public load is used as the vehicle to maintain the test-model environment at a satisfactory level. Such maintenance time is used to fix problems uncovered throughout a given period, apply official change notices issued against the hardware, evolve and grow the hardware according to agreed-upon development plans, and reaffirm the stability of the test model with the appropriate features in the public load. As always, this maintenance activity is balanced against the need for the test model as a system development resource and trade-offs are constantly being made in the fast-paced development environment.

VI. SPECIAL-PURPOSE SYSTEMS

In a system the size and scope of the *5ESS* switching system, a number of functions require special facilities or benefit from novel uses of computer systems. The applications described in this section are examples of special-purpose systems in use by *5ESS* system development.

6.1 SCANS

The Software Change Administration and Notification System (SCANS) provides a gateway between the *5ESS* SDE and the AT&T Technologies field-support network. Updates to software running on in-service *5ESS* switches are produced as explained above and then sent to the SCANS machine for packaging and transmission to the field. The SCANS machine, interconnected to the other *5ESS* system development systems via an interprocessor network outlined below, focuses the necessary hardware and software for this task in a single machine but gives the whole project access to the field-support function.

6.2 Project management

The coordination and control of a large development project such as the *5ESS* switch requires considerable computer support. Dedicated systems with associated tools are used to track and report on the progress of development; maintain lists of action items and resolutions; and maintain and distribute paper and electronic copies of architecture, methodology, and schedule documents. An ever-increasing variety of graphics applications have been developed to capture and represent the plans and status of the project.

6.3 System-testing support

To ensure a quality product, extensive system-testing activity is performed on the *5ESS* switch. A dedicated computer system is used to store and track the status of the large battery of regression tests that have been developed for the switch. Electronic logging and automated analysis of output messages from *5ESS* switches also are routinely provided.

VII. NETWORKS

The *5ESS* system development involves hundreds of software developers at several AT&T Bell Laboratories locations. Support of this number of developers requires several dozen computer systems that must be connected to both the developers and each other.

7.1 Terminal networks

To interconnect each developer with the computer systems that he or she may require in the course of a day's work is itself a major task. To meet this need the *5ESS* system development presently is using three approaches: *Dimension*® Custom 2000 PBXs, Develcom, and the *Datakit*® virtual circuit switch.

7.1.1 Dimension *Custom 2000 PBXs*

The primary site for *5ESS* system development is a complex of large buildings in a campuslike setting. Each developer is provided with dial-up access to all computers in the complex via a network of *Dimension* Custom 2000 PBXs dedicated to data switching. The most common connection is currently 1200 baud, although faster and slower rates are possible. This network is part of a larger companywide voice and data switching network that provides flexible access to computer systems at all company locations.

7.1.2 Develcom

To provide switched but nonblocking access at higher speeds to replace point-to-point connections previously used, a small data switch has been installed. These lines are used primarily by hardware developers to interconnect proprietary microprocessor development systems and programmable read-only-memory programmers to other computer systems.

7.1.3 Datakit *virtual circuit switch*

To provide widely available very-high-speed access from all potential users to the computer systems, a *Datakit* virtual circuit switch local area network is being introduced. This network will eventually supplant the *Dimension* PBXs as the primary access to all local computer systems and provide gateways to *Datakit* virtual circuit switch networks at other company locations. The bandwidth available with this approach is matched to the needs of intelligent terminals and work stations now finding their way into the project.

7.2 Interprocessor network

File transfer between the development-support computers is provided by the HYPERchannel* network and associated adaptors. The network consists of two dual-coaxial-cable backbones, one in each of the

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* Trademark of Network Systems Corporation.

primary development buildings, interconnected via dual fiber-optic links. Further extension and complete interconnection of the networks is provided by a gateway system, which transships files between subnetworks. Connections are supported to AT&T 3B20S, PDP-11/70,* VAX-11/780,* and System/370-compatible machines. Data rates on the 50-Mb/s buses range from about 3000 to over 100,000 bytes/s, depending on the combination of source and destination machine types and loads. Networking software in each connected processor controls access to the buses and provides for transmission of files, execution of commands on remote systems, and notification of file delivery or command results. The file transfer mechanism is used to propagate changes in the *5ESS* system software being developed across support systems. It is also used to deliver code from the LP systems to the EE or LTS systems for testing. Updates to the *UNIX* operating system and *5ESS* system tools are distributed via the network, and performance data on the support computers and the network itself are collected via the network. Remote execution of commands allows a user on one system to perform activities on another system without logging into the second system.

7.3 I/O network

The *5ESS* switch project uses a network to access high-speed-laser page printers for publication-quality documentation, plotters for graphical data, and specialized resources such as a Cray supercomputer. This network also provides an alternate path between *5ESS* system support machines via the remote-job-entry network. Electronic mail may be routed via this network to any computer system within the company. A form of limited remote command execution also exists for this network.

VIII. CONCLUSIONS

A system development environment that allows generation of high-quality software, ensures high productivity of programmers, and provides administration of all versions of the system has been developed. The environment has been able to evolve as required by the *5ESS* system architecture and development plan. This has been achieved by using a distributed architecture much like the *5ESS* switch itself, where growth can be accomplished by adding computing and testing elements. Contributing to the ability to gracefully evolve is the versatility of the *UNIX* operating system and the C language, which is the base for the environment as well as the *5ESS* switch. The importance of a formal

* Trademark of Digital Equipment Corporation.

methodology cannot be overlooked. The *5ESS* system project can be expected to continue to rapidly add features and capabilities for many years using the SDE.

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The 5ESS *Switching System:*

System Test, First-Office Application, and Early Field Experience

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Comprehensive system testing and verification of feature design at a "first-office"-application site are integral parts of the design and development methodology for the *5ESS*™ system. The strict enforcement of this methodology has led to a product that has exhibited high quality and reliability in the field. This paper describes the activities associated with the integration and system testing of *5ESS* system generics, as well as the procedures used at the first-office-application site to verify operational compatibility prior to release for service. The operational experience with in-service *5ESS* systems is also described.

I. INTRODUCTION

Since the introduction of the first multimodule office in Sugar Grove, Illinois, in 1983, the number of *5ESS* systems in service has increased dramatically (see Fig. 1). In anticipation of this rapid buildup, and the rapid introduction of new designs and features, the system was designed to include steps to ensure reliability during manufacture and installation. These have made it possible to bring systems to the market rapidly.

During the first two years of *5ESS* system service, three major system program releases (generics) plus several minor "point" generics were designed and released by AT&T (see Table I). Each of these generics went through extensive system testing and comprehensive

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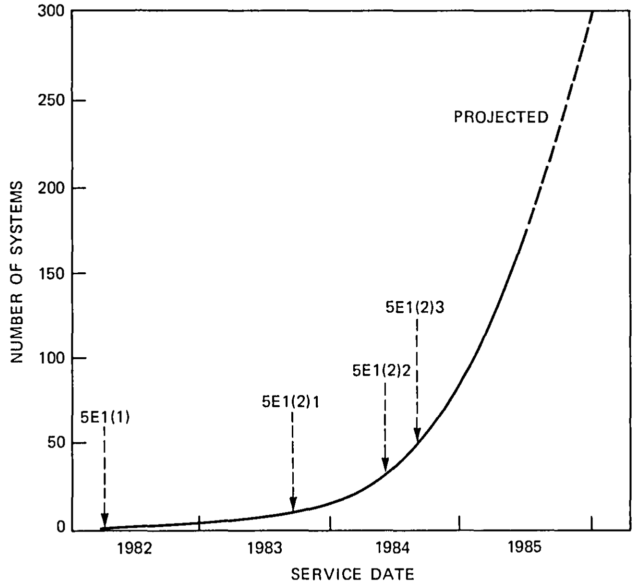

Fig. 1—*5ESS* switching systems in service.

verification of operational performance and customer acceptance at a First-Office-Application (FOA)* site.

This paper describes the activities of system integration, system test, and FOA-site verification. The methodology for *5ESS* system development is briefly described in Section II. System integration activities are described in Section III. Section IV describes the functions of system test, while Section V describes the activities at the FOA site. The field experience with the early *5ESS* switch is described in Section VI.

II. DEVELOPMENT METHODOLOGY

Generics for the *5ESS* system are created following a strict methodology for both hardware and software development. Using this methodology, specific milestones for each of the development and test phases are established for completion within a specified time frame. A representation of the methodology is shown in Fig. 2. The design organizations are responsible for the capability design, design-unit design, coding, unit test, and capability test. System test, regression test, and FOA verification are the responsibility of separate test organizations.

* Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

Table I—Generic development

Service Date	Generic Issue	Principal Features
3/82	5E1(1)	Basic single module
3/83	5E1(1A)	Improved module processor
8/83	5E1(2)1.0	Multimodule system
10/83	5E1(2)1.1	Local/toll
2/84	5E1(2)1.2	Improved network fabric
4/84	5E1(2)2.0	Remote switching, integrated *SLC*® carrier system
6/84	5E1(2)2.1	Module growth, optically integrated Remote Switching Module (RSM)
9/84	5E1(2)3	Frequency-selective ringing, RSM trunking
4/85	5E2(1)	Carrier interconnect, basic Centrex

Early in the planning for a *5ESS* system generic, each feature approved for development is divided into "capabilities." A *capability* is a specific software or hardware function. For example, capabilities needed to implement the feature "three-way calling" would include a conference bridge, a special digit-handling program, and a data-change program for three-way-calling parameters. A specific schedule for completion of the development and test phase for each capability is established. A project management group tracks and reports milestone completions (see Ref. 1).

III. SYSTEM INTEGRATION

System integration plays a central role in the overall development of *5ESS* system generics. System integration includes program change control, software-load building, system-load bringup, and field delivery. System integration teams are formed early in the generic development cycle and work closely with the project management, feature planning, and test groups to establish an integration plan for the generic. This plan includes the requirements for the system-lab test equipment and configuration, program-support environments, and specific schedules for the development, testing, and delivery of the features required for the generic. The integration team's main responsibility is to ensure that a stable development and test environment is maintained as major software functions are added to the generic.

3.1 Program change control

Integration of code added to the generic is overseen by the Program Change Committee (PCC). In this way, the PCC ensures that generic stability is maintained as new features are added. The PCC is chaired by the integration team and has representation from all the software development areas as well as system-test and site-test groups. The PCC approves the software changes introduced into the generic. During the early stages of a new generic development—when major software functions are being coded—the PCC reviews the integration and

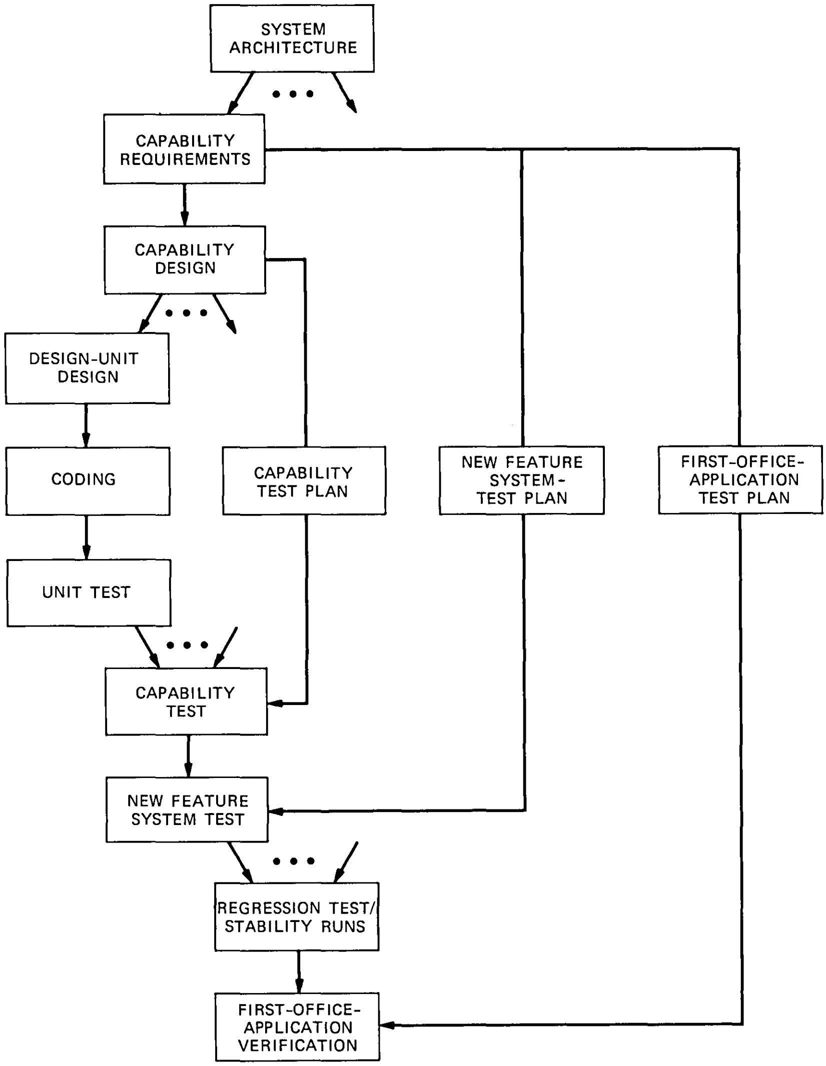

Fig. 2—Development methodology.

testing plans for the new code and any accompanying data changes. Near the end of the generic development cycle, most of the software changes are fixes for bugs uncovered during system and site testing. During this period, the PCC reviews all software changes introduced into the generic.

An automated problem-tracking system allows the PCC to review and manage software-change activity. All software problems or design deficiences that are found or detected are documented by an Initial

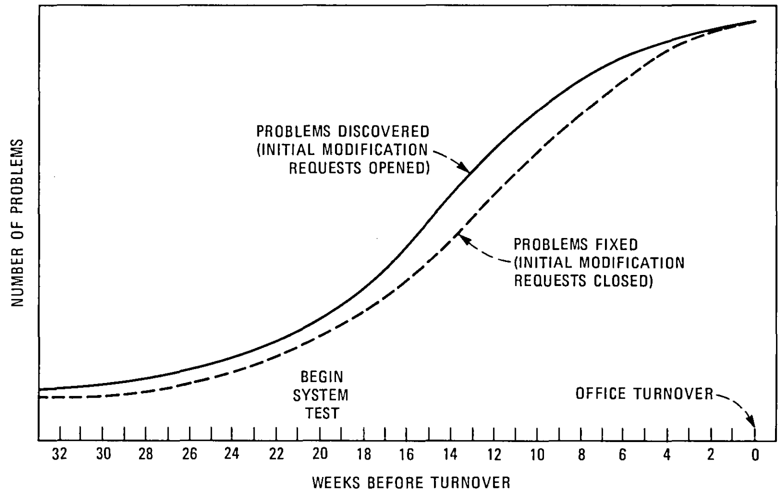

Fig. 3—Problem status history.

Modification Request (IMR) that describes the specifics of the problem or affected software. The PCC assigns priorities and responsibility to IMRs.

A Modification Request (MR) is used to document the actual software submitted for the generic. When the code represented by an MR is added to the generic, the associated IMR is closed. The PCC regularly publishes reports that summarize the open and closed IMRs. The number and seriousness of open IMRs are used to evaluate the software quality. The history of open and closed IMRs for a typical *5ESS* system generic is shown in Fig. 3.

3.2 Program administration

Part of the integration plan for a generic is a set of regularly scheduled software loads that allow incremental introduction of new software and subsequent software fixes. Each software load contains all the old software plus any new code or corrections approved by the PCC. The generation of these software loads is the responsibility of the Program Administration Group (PAG). PAG incorporates the MRs that are approved by the PCC into the official generic database and recompiles the software source code.

The output of the PAG software-load-building process is a set of software files and associated reference documents such as program listings and address cross-reference maps. The files contain the executable software for both the Administrative Module (AM) and Switching Modules (SMs), plus the Office-Dependent Data (ODD) needed for the system-laboratory configuration.

3.3 Load bringup

Hardware and software integration and testing is carried out in several system laboratories that, as much as possible, replicate a field environment. The process by which a new software load is introduced into the system labs is known as *load bringup*. The integration team is responsible for load bringup. After the system lab is initialized with the new software load, problems with generic operation are documented with IMRs, and, where appropriate, fixes are made to maintain a stable environment. A set of comprehensive baseline test scripts are executed to verify the integrity of major functions, such as system recovery, diagnostics, and basic call processing. At the end of a load bringup, major problems and deficiences with the generic are documented in a user's guide, and the system is released to software developers and testers.

Several system laboratories, each with a slightly different equipment configuration and test environment, are available for *5ESS* system development and testing. After a load is brought up and is sufficiently stable for testing new code, it is copied into each lab and initialized with the lab-specific ODD. Development and test activity then proceeds in parallel in several labs until the next load is introduced.

3.4 Load distribution

The software loads created early in the development cycle are distributed and maintained specifically for the system laboratories to support new software design, testing, and evaluation. About three months before a system is released to the customer (the turnover date), a generic load is needed at the FOA site so that hardware and software verification tests can be started. This generic load is designated as a prerelease version and undergoes a stringent set of tests to ensure its usability in the field environment. Any design deficiences or operating exceptions with this load are thoroughly documented for the site personnel.

At the site, the generic program and ODD are loaded in the system and initialized. The prerelease load is officially supported by the integration team, which provides the fixes designated by the PCC that are needed to continue site testing. If necessary, other prerelease versions of the generic are sent to the site prior to the official turnover load. The official load, along with necessary software documentation, becomes the standard release of the *5ESS* system by AT&T Technologies, Inc.

IV. SYSTEM-TEST DESCRIPTION

The *5ESS* system is a universal switching system with a distributed-hardware architecture and a comprehensive set of features. It is difficult to verify by laboratory testing that the system performs correctly under all possible combinations of circumstances. The goal of system testing is to rigorously stress each new generic release in the system laboratory so that as many errors as possible can be found and corrected. The system-test phase includes three types of testing: new feature testing to exercise new features, regression testing to exercise existing features, and system testing to exercise the system as an entity.

Most system testing takes place in *5ESS* system laboratories that are configured specifically for system-test use. The system laboratories contain a complete, representative set of production hardware so that the proper operation of various combinations of hardware can be verified. By carefully planning and engineering the installation of equipment, an environment can be created that can simulate many typical field configurations with a minimum amount of actual hardware. In particular, maximum-size equipment configurations are engineered whenever possible.

4.1 Feature testing

Each new feature or capability of a generic is assigned to a system tester, who tracks the development of the feature and reviews feature requirements and design. The tester seeks to identify areas where the implementation of the feature adversely affects earlier capabilities, or where the implementation does not work as it was defined to work. To verify a feature, testers use several sources of information, including internal requirements (as defined in feature-specification documents and capability-requirements memoranda), external requirements (as defined in the Local Switching System General Requirements and the *5ESS* System Technical Specification), and user documentation (such as AT&T Practices and Telephone Operating Procedures).

Testers attend appropriate requirements and design reviews and provide feedback on all levels of development. This not only allows the tester to gain an early working knowledge of the feature, but also lets the tester bring a system-level, cross-feature perspective to the development process. While the developers are designing and coding their capabilities, the testers plan and write the tests to be used for each new capability or set of capabilities. The tester also defines and writes specific tests to stress system aspects of the capability. System aspects include real-time performance, human interfaces, interactions with other features, and operation under various abnormal conditions. Developers and testers jointly agree on the testing approach and review each other's test plans.

As part of the testing approach, a set of acceptance tests is defined for each capability. The acceptance tests are typically a subset of the system tests. When the developers are satisfied that a capability is ready for system testing, they formally deliver it to the system-test organization by demonstrating that the capability can pass the majority of the acceptance tests. The delivery package includes documentation of any failing tests and a plan for resolving them. After the capability is delivered, the system tester executes the complete set of system tests and records all problem indications. Possible problems are analyzed to determine what sequence of events caused abnormal responses and whether the problem appears to be an environmental (system-laboratory hardware or data) or generic problem. Possible generic problems are formally documented with an IMR and referred back (through the PCC) to the responsible development organization for resolution.

4.2 Regression testing

In addition to testing new features, system testers must also test existing features to verify that they work as they did in the previous generic. Tests that exercise existing features are collected into a package of regression tests. As additional features are developed, new tests are selected and incorporated into the regression test package. Because regression tests are repeatedly executed, they are automated whenever possible and are usually executed by specially trained batch operators.

Full regression testing is done after all new capabilities have been added to the generic. Regression testing must be done late enough in the development interval to catch most problems, but early enough so that there is time for the problems to be corrected.

4.3 Metrics

System testers keep a detailed account of executed tests and uncovered problems. Status is reported periodically. Testers report on the number of tests planned, the number of tests executed, the number of tests that passed on the first attempt, and the total number of tests passed. All problems are identified and tracked, and the corrections are retested as they are turned in.

Results from the testing of two generics are summarized in Table II. Generic A was virtually a completely new software program; hence, the relatively low number of regression tests. Testing productivity increased significantly for Generic B; about 20 percent for new feature testing and about 50 percent for regression testing. This increase is mainly attributable to a more stable system at the beginning of the system-test phase, additional test automation, more experienced testers, and better test tools.

Table II—System-test metrics

Metric	Generic A	Generic B
Number of new tests executed	10,600	7,500
Number of tests executed per hour of test-model time	2.2	2.7
Noncommentary source lines of code tested per test	23	23
Noncommentary source lines of code tested per hour of test-model time	50	61
Number of regression tests executed	950	2000
Number of regression tests executed per hour	2	3

4.4 System testing

In addition to examining individual features, the system-test organization looks at the overall system. To provide a benchmark for system quality, regular stress tests, or stability runs, are performed. During the development phase, a stability run is performed on every new load. These runs measure the performance of the system and provide data to analyze the change in performance over time.

Stability runs are usually 24-hour sessions in a system laboratory. During the session, the system is operated as if it were a live-traffic telephone office. Routine user and maintenance activities are performed and a heavy call load is generated. Since many activities such as traffic reports and routine maintenance are automatically run on a daily basis, a 24-hour period allows all such regularly scheduled activities to take place. The effect of these regular activities on the system performance is observed and analyzed. Towards the end of the development period, extended (up to a week long) stability runs are used to check for subtle problems whose symptoms may take a longer time to surface. Longer stability runs also incorporate typical telephone-office-acceptance tests (see Section 5.5) such as the half-office test and the integrated-volume test.

During all stability runs, the system is carefully monitored for any abnormal behavior. All potential problems are logged and investigated. The performance of the system is quantified by several metrics, including calls successfully processed per hour, hardware interrupts, software-detected audits and asserts, initializations, and printer output. An overall index is defined by using a weighted average of the individual metrics. For each metric, acceptable thresholds are defined. As thresholds are attained, the criteria are tightened to force continued effort to a higher level of quality. For example, once a phone call completion rate of 99.99 percent is attained, the threshold rate may

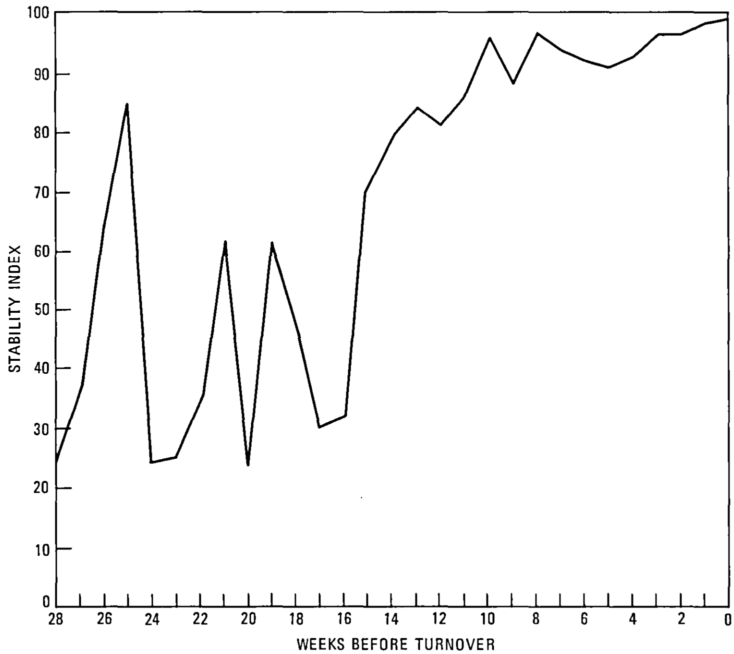

Fig. 4—Stability run index.

be increased to 99.999 percent. The system must meet an acceptable level of quality before it is released for general use.

The high level of quality is attained through continual, close cooperation between developers and testers. Problems uncovered during stability runs are investigated and resolved by developers who staff stability run teams. Each team has a speciality area, such as achieving high call-completion rates or decreasing the number of software audit-error reports. The teams directly support the stability runs during the last several months of the development cycle when generic quality is rapidly improving. Figure 4 shows the trend for a typical index.

4.5 Test tools

Many tools have been developed to increase testing efficiency and productivity. Tools used during system testing include

1. Symbolic debuggers that provide ways to do traces, dumps, conditional matches, and other utilities on C language programs.
2. A call generator that generates Plain Old Telephone Service (POTS) calls at specified traffic levels over standard line connections.
3. An automatic call simulator that can be programmed to generate traffic loads with specified combinations of POTS and more complex call types on both lines and trunks.

4. Load-generation tools that simulate high call loads on the *5ESS* switch to stress the system beyond limits available through other load-generation tools.

5. The switching system automated test set, which performs switching, signaling, and transmission tests under traffic conditions.

6. The automated craft-message interface, which provides automated message input and detailed output analysis for automating user commands and analyzing system response.

V. FIRST-OFFICE APPLICATIONS

As a standard practice, major new releases of *5ESS* system software and major new hardware units are introduced after a FOA verification. FOA verification is under AT&T Bell Laboratories control, and its primary purpose is to test the new hardware and software by operating the *5ESS* system in a field environment. Consequently, most FOA tests use standard input messages and avoid the use of special utilities or other methods of intervention.

The FOA-verification stage follows system testing, but the two overlap. As new software loads are generated, their performance, as measured in the FOA, helps confirm the observations made by system testers.

FOA verification also gives the customer a chance to get hands-on training in the new features. In addition, the customer is assured by direct involvement that the office is ready for service. One of the main benefits to the supplier is an early opportunity to verify product performance in an actual operating environment and in a system configuration that is generally larger and more complex than a system laboratory.

5.1 FOA selection

FOA sites are selected to meet the service needs of certain offices while matching generic program availability dates. New offices that appear to be candidates are analyzed with respect to new features, schedule flexibility, and customer preference for FOA treatment. In some cases, a strong desire by some customers to obtain the use of new capabilities as soon as possible influences FOA schedules. In other cases, feature availability is the determining factor.

5.2 Preparation and planning

FOAs are chosen so all the major new features developed for each generic are verified. In many cases, several FOAs are needed to verify all features. For each selected FOA, an office verification schedule is

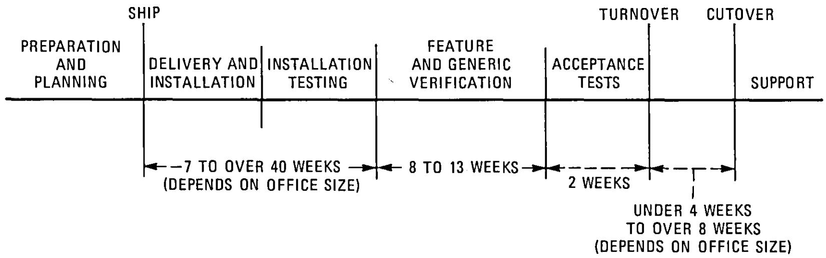

Fig. 5—Typical FOA schedule.

generated. This schedule includes dates for the normal AT&T Network Systems installation activities, FOA verification, and introduction of new software loads. A sample schedule is shown in Fig. 5. Before the *5ESS* system arrives, early planning addresses several topics. The variables considered during early planning include the schedule, the features needed by the customer, office size, and the network interconnection plan. Before system delivery, space is allocated and provisions are made for installing power plant, cable racks, and making other building-support-structure changes. Cutover and transition committees are established, and they coordinate all of the activities associated with placing the new system into service.

5.3 Installation interval

The first parts of the *5ESS* system delivered to the telephone office are the AM, Communications Module (CM), and at least two SMs. Nearly all intramodule cabling is done at the factory and all units are tested before they are shipped. This helps reduce installation time. After the modules are in place, power cabling and intermodule cabling are connected. Nearly all interframe cables for the *5ESS* system are pretested and connectorized. This saves installation time and greatly reduces interframe wiring at site.

The general philosophy of the installation is to concentrate on powering up the core of the switch (AM and CM) as soon as possible. Because the AM and CM can be operated independently from the SMs, the core can be tested while the SMs are still being installed. The installation force is split so that some testers are devoted to the testing of the AM and CM while the others continue doing the cabling and powering up the SMs. Testing the AM and CM takes about three days. These core units are then used to test the SMs. As the SMs are powered up, they may be connected to the core units one at a time, or all at once. In large offices, where SMs may arrive in several shipments, the former is generally done.

As mentioned above, installation testing overlaps equipment installation. Some units are being tested while others are still being installed. The first test on all units is power and ground verification. Next, hardware circuitry is tested, much of it concurrently. Testing proceeds in the following sequence: AM, CM, SM control units, and finally, SM peripheral units.

Hardware is tested using diagnostic programs that are part of the system software. A graphic status display of each hardware unit can be requested on the Master Control Center (MCC) video terminal. The display includes a menu of commands, including diagnostics, that can be performed on the specified unit. Installation testing starts with diagnosis of individual units, and proceeds to subsystems and their interfaces with each other. Finally, subsystem operation with the generic program and ODD is tested.

Call-processing capabilities are tested next by applying a simulated call load to the system, with load boxes that simulate subscribers. A typical load box can simulate up to 64 telephone calls at one time and generates 15,000 calls per hour.

5.4 Verification and software introduction

In major FOAs, test and verification generally spans the next six weeks. Feature verification is planned to mesh with the same sequence established by system test. During the verification interval, the installation teams continue to do office maintenance, apply hardware changes, and complete installation testing. At the end of the verification interval, installation testing continues with acceptance tests.

During the verification interval, new software loads are introduced that contain corrections to problems discovered during system testing. New loads are usually introduced at the beginning of the verification interval and as often as weekly afterwards. Occasionally, new software loads that consolidate important corrections may be introduced after turnover so the corrections can be demonstrated to the customer before placing the system into service.

5.4.1 FOA and feature verification

The verification performed in the FOA includes verifying specific new feature operation; verifying the characteristics of the new software, hardware, and supporting installation; and overseeing customer-acceptance testing. For each FOA site, a list of required and desirable features is created by the customer. FOA-verification tests are designed for each feature. The features that will not be activated in a particular FOA may be temporarily activated or verified in another FOA.

Using previous experience to determine typical test-execution rates, the FOA-verification interval is scheduled for the new features. Feature verification is generally scheduled for 16 hours a day, while office installation and maintenance activities are scheduled for the rest of the day.

Test scripts are generated for each set of features. These are applied in the FOA, and records are kept on which tests pass and which fail. If a failing test reveals a problem, an IMR is generated and referred to a development organization. When fixes are delivered in subsequent loads, the failing tests are rerun to assure the problem is corrected.

5.4.2 Generic verification

In addition to feature-specific verification, the new software release is checked for overall performance by executing a set of regression tests. Performance is verified through weekly stability runs that complement those done by system testers in the system laboratories. The FOA-stability runs help identify configuration and office-database-dependent problems. The results of the stability runs are analyzed with the help of special programs in support computers. While FOA testers continue with their verification tests, members of a special analysis group work with developers to resolve the problems detected by the stability run analysis.

A library of all FOA test scripts is maintained. A set of regression tests is selected from the library to assure that features provided in previous generics continue to function properly in the current generic. In selected FOAs, special performance tests are scheduled. For example, in one FOA, high traffic was generated by additional load boxes so that traffic-handling capacity could be verified. There are also special tests that verify compatibility with the trunk interfaces to connecting offices in the network and with line interfaces to station sets, coin telephones, PBXs, key, equipment, and range extenders.

5.5 Acceptance tests

At the end of the installation interval, tests are run on the switching system to demonstrate stability and performance to the telephone company. Throughout the tests, artificial traffic is applied to the system so that any changes in call-completion rates will indicate problems. Specific thresholds are designated for alarms, maintenance interrupts, and software errors during the tests. The specific tests performed are the half-office test, the heat test, and the integrated-volume test.

In the half-office test, the ability of the system to operate with only half of the duplicated equipment available is established. In this test, one side of all duplicated controllers is powered down for one hour, powered up, and diagnosed. The process then is repeated on the other side. The test takes place with a call load running, and demonstrates that call processing is not affected.

The optional heat test demonstrates the system's ability to operate under high-temperature conditions, such as air conditioning failure. In the test, a plastic tent is constructed around the switching system and the temperature is raised to 118 degrees Fahrenheit. The switch operates for four hours under these conditions while being monitored for correct handling of the applied call load.

The integrated-volume test demonstrates the system stability and call-processing capabilities over a continuous 24-hour period under conditions that simulate a typical day. Again, call-completion statistics and other system measurements are used to help verify performance.

Once installation is completed and all acceptance tests are successfully executed, principal use of the system is turned over to telephone company personnel so they can conduct special tests to verify that each trunk and line operates properly and that office data are correct.

5.6 Metrics

The main FOA-verification metrics used fall into the following categories:

- Verification progress versus schedule
- Verification-test pass rate
- System quality and stability metrics.

The combined results of these metrics are used to help determine that the new generic programs are ready for service and to manage the priority items leading to the introduction of the new generic program.

VI. EARLY OFFICE INSTALLATION AND EXPERIENCE

Installation of *5ESS* systems has occurred according to the curve in Fig. 1. The first four systems were single-SM systems. Two additional single-SM systems have been added and one of the original systems has been converted to an RSM served by a multiple SM host. The rest of the installations have been multiple SM systems. As of November 1984, installed *5ESS* systems contain from 1 to 30 SMs. Plans exist for offices having over 60 SMs to be installed within the next year.

The first *5ESS* system RSM was placed in service in April 1984; others will be installed according to the curve in Fig. 6. RSMs are currently connected to their hosts, using conventional T1 facilities, and T1 over fiber-optic systems as umbilical links. An optically remoted switching module is also in service. This configuration uses a direct fiber-optic link from the *5ESS* system host CM to the RSM.

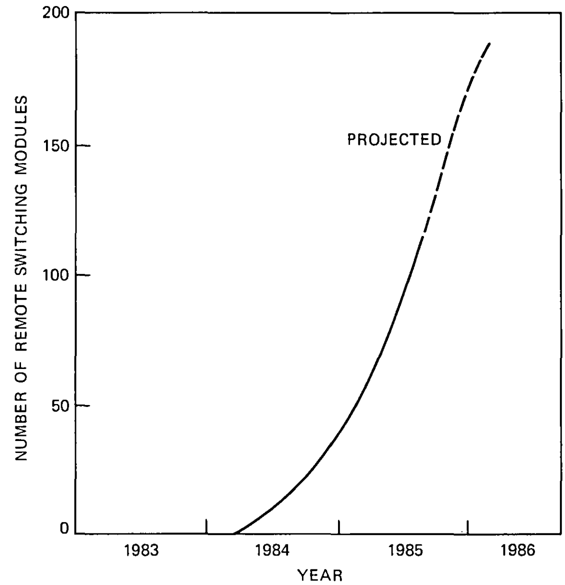

Fig. 6—Remote switching modules in service.

Additional facts about *5ESS* system capacity and installation are given in Table III.

6.1 Customer support

AT&T provides extensive support for the owners and operators of the *5ESS* systems. Problems and requests for assistance are sent first to a Regional Technical Assistance Center (RTAC), then to a centralized Product Evaluation Control Center (PECC), and finally to AT&T Bell Laboratories. Generally, AT&T Bell Laboratories receives only those problems and requests that require design changes or corrections.

Customer support facilities include specialized equipment that allows logging output from systems to help problem analysis, and portable, noninterfering field-test sets to help find any problems that cannot be reproduced in system laboratories. A large diagnostics center at the

Table III—System dimensions

	System Capacity (1985)	Maximum Observed in Service (11/84)
Number of SMs	192	30
Number of lines	100,000	27,000
Busy-hour calls*	300,000	80,000

* Assumes normal maintenance activities and feature use.

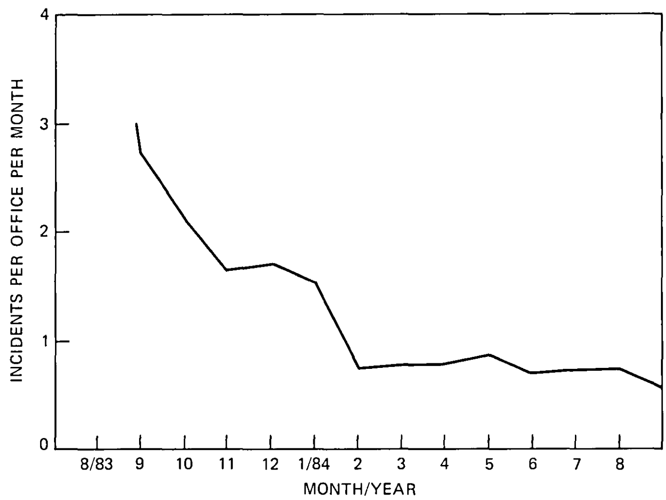

Fig. 7—Unplanned initializations (six-month rolling average).

AT&T Network Systems division in Lisle, Illinois, is available so offices requesting assistance can obtain advice from system experts, and can have their system output displayed for use by the experts.

6.2 Performance measurement

Many different performance measurements are used to evaluate *5ESS* system performance. Measurements of system initializations traditionally have been widely followed. For the *5ESS* system, initializations can occur with varying levels of impact. Most initializations are effectively confined by the system architecture to a single SM, and most do not affect stable calls. Higher-level initializations are available for recovering from more severe problems. Calls in the talking state are generally not affected even by these higher-level initializations. Figure 7 shows the number of unplanned initialization incidents per office per month. Figure 8 shows the trend for SM initialization incidents per module per month. Other system performance data that can be used to forecast potential trouble include measurements of audits, interrupts, software-check failures, and alarms.

The reliability of the *5ESS* system hardware is also tracked by plotting the actual circuit pack replacement rate against the expected replacement rate. The expected replacement rate is calculated at one circuit pack per month per thousand lines. The number of packs returned to the factory for repair is then compared to this value. A plot of the overall replacement rate is shown in Fig. 9. Several Line Unit (LU) codes have had higher replacement rates than expected,

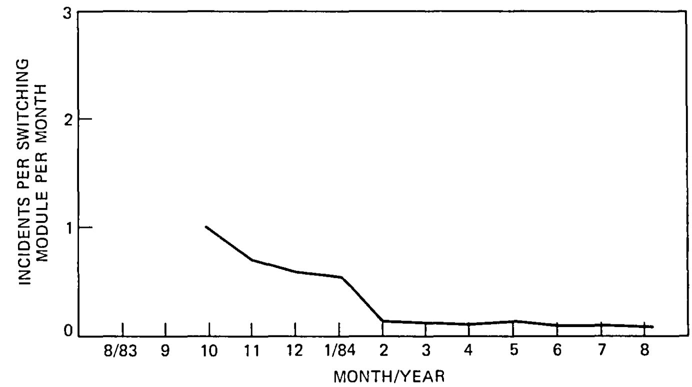

Fig. 8—Unplanned switching module initializations (six-month rolling average).

and a series of improvements in design, manufacturing, and testing have been made. The AM, CM, and the SM (minus the LU) are all showing reliability performance that tracks expectations very closely. The latest improvements in the LU packs are showing favorable early reliability in factory yield and test data.

6.3 Retrofit and growth

Retrofit is the general name for the introduction of new generic issues and their corresponding databases into an in-service *5ESS* system telephone office. Early retrofit methods carefully controlled full-system initializations. The system-initialization time associated

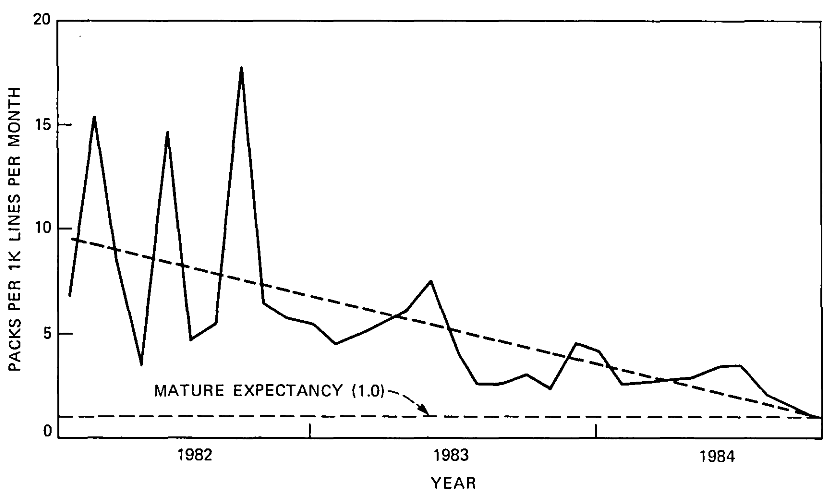

Fig. 9—Hardware replacement rate trend.

with these retrofits was roughly proportional to the number of SMs in the system. Failure of any SM to successfully initialize resulted in an incomplete retrofit.

Beginning with the 5E1(2)2 generic, significant improvements were made to the retrofit procedure. These improvements allow the new generic to be off-line loaded into the out-of-service half of each SM without affecting service. Under control of the active generic and without affecting service, each SM can be preinitialized with the new generic to detect any database or hardware problems. The resulting system-initialization time is independent of office size. In addition, calls in the talking state are saved over the retrofit.

Growth capability allows addition of SMs, RSMs, and units within them, without affecting service. Growth equipment is added and tested in a manner similar to new equipment; however, the growth process is controlled with special procedures to avoid affecting service. Early experience with growth procedures has been very good. A number of SMs and RSMs have been added to in-service *5ESS* systems with growth procedures.

VII. ACKNOWLEDGMENTS

The successful and rapid introduction of the *5ESS* system is the result of the dedicated effort of many people at AT&T Bell Laboratories and AT&T Network Systems. The cooperative team work and continuing high quality of individual contributions of all have made the *5ESS* system a significant success. Performance of initial releases has been excellent. Customers find the *5ESS* system reliable, easy to use, and flexible. The authors wish to acknowledge the efforts of all the many individuals who have participated in this project.

VIII. CONCLUSION

The high quality and reliability of the *5ESS* system depends on a methodology that includes a series of integration, test, and validation phases. The integration, system testing, and FOA-verification procedures described in this paper have been used in the development of several major program releases. They have played a key part in the successful introduction of the *5ESS* system and will continue to be important as the system evolves.

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The 5ESS *Switching System:*

Operations, Administration, and Maintenance Capabilities

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The *5ESS*™ switching system is a digital, time-division switching system that is being introduced into a multiplicity of operating environments—local, toll, private networks, and stand-alone applications. Many of these operating environments are currently dominated by analog, space-division switching systems. Furthermore, the *5ESS* switching system is being introduced into environments in which there have been increasing trends toward centralization and mechanization of operating procedures through the use of minicomputer-based support systems. The *5ESS* switching system has been designed to allow a smooth incorporation into these mechanized operating environments, while still retaining features needed for stand-alone operations in less mechanized environments. This paper describes the operational features, both administrative and maintenance, of the *5ESS* switching system. The emphasis is on the features that differ from those of earlier stored program control switching systems. These include features that represent enhancements over those of earlier systems, differences mandated by a digital, time-division technology, and features designed to more readily adapt to operations support systems.

I. INTRODUCTION

The *5ESS* switching system is the first time-division, digital switching system AT&T has designed to serve in both local and toll offices as well as in private network and stand-alone applications. As such, it is inherently a four-wire system, and includes integrated interfaces for

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digital-carrier-serving message trunks and Digital Loop Carrier (DLC)* systems. In addition, the *5ESS* switching system employs a modular hardware and software architecture. This architecture improves the economics of the switching system, allows more flexibility for growth, and simplifies the development process to introduce new technologies into the switching system and add new features. The operations of the *5ESS* switching system have been designed in concert with this modular architecture.

The *5ESS* switching system has been designed with careful attention to switching system operations. Over the past several years, there has been an increasing trend in the telecommunications industry toward centralized work centers and the use of computer-based Operations Support Systems (OSSs) to support those centers. The *5ESS* switching system has been designed for convenient integration into these centralized, mechanized operating environments, while retaining the features needed to operate in less mechanized or manual environments. In earlier vintage switching systems, these OSSs typically use the same Teletypewriter (TTY) interface that supports the work center in a nonmechanized environment. The *5ESS* switching system's interfaces to these OSSs are designed specifically for machine-to-machine communications and use higher transmission rates and the BX.25 protocol, a modified subset of the CCITT X.25 protocol.

Finally, the *5ESS* switching system also includes new features and improvements to existing features that address the operations of the switching system. These features are designed to take advantage of the new capabilities and economies that improved technology has made possible. These enhancements include improved craft interfaces and the integration of capabilities that had previously been performed by external equipment (e.g., line and trunk test capabilities) into the switching system.

This article is organized into three major functional areas of operations: planning and engineering, administration, and maintenance. Within each of the functional categories, the major operational differences and improvements over previous systems are discussed.

II. PLANNING AND ENGINEERING

2.1 Planning

Two aspects of the *5ESS* switching system have a major effect on planning for applications for the switching system: the digital switching network used by the system, and the modular architecture of the system, including a Remote Switching Module (RSM).

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* Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

A digital switching system, such as the *5ESS* switching system, has economic advantages when interfacing with digital facilities. Thus, having a large proportion of digital facilities in an area stimulates the introduction of digital switching systems. Digital switching systems then in turn serve to increase the movement to digital facilities. This mutually stimulating effect is referred to as digital synergy. Digital synergy applies to both digital interoffice facilities and DLC systems. The *5ESS* switching system's architecture includes an integrated interface for T1-carrier message trunks and RSM umbilicals, the Digital Line Trunk Unit (DLTU), and an integrated interface for *SLC*® 96 carrier systems, the Digital Carrier Line Unit (DCLU). These integrated interfaces eliminate the need for terminal equipment in the central office and couple the planning of digital interoffice facilities and DLC systems with switching system planning.

The modular architecture of the *5ESS* switching system increases the range of applications for which the *5ESS* switching system is attractive. This architecture includes distributed processing so that as the termination capacity is increased, the call-processing capacity is also increased by adding Switching Modules (SMs). This enables the *5ESS* switching system to grow smoothly and economically from small-capacity configurations to large-capacity configurations. Having the same switching system in all applications simplifies operations in a telephone company. The *5ESS* switching system's design enables it to host a single-module or multimodule RSM. This RSM is an enhanced version of the standard SM that has been modified to provide stand-alone switching in the event it is cut off or isolated from the host. RSMs interface with their host using T1 carrier. The RSM is designed to make Stored Program Control (SPC) switching economical for more applications.

A "hot slide-in" procedure has been developed for the *5ESS* switching system. With this procedure, the *5ESS* switching system is installed and cut into service while housed in a temporary shelter. After the old switching equipment is removed, the in-service *5ESS* switching system is put in its place. This procedure reduces costs for offices that would otherwise require a building expansion.

2.2 Engineering

The *5ESS* switching system takes advantage of mechanized traffic data collection and processing systems (see Section III), which make it feasible to use a large amount of data to engineer an office. Most older SPC systems use Average Busy Season (ABS), Time-Consistent Busy Hour (TCBH) engineering methods. These methods require studies to determine the busy hour, and then base their engineering on data gathered during this hour. Because most traffic-sensitive equipment must provide good service when peak loads occur, regardless of the hour in which they occur, ABS TCBH methods based on 1 hour of data per day require conservative engineering. The *5ESS* switching system uses procedures in which data are collected 24 hours a day, and Once A Month (OAM) peak loads are calculated from these data. The *5ESS* switching system then may be engineered to render good service based on either TCBH loads (ABS or high day) or OAM loads.

The *5ESS* switching system's engineering (for both stand-alone *5ESS* switching system and RSM applications) is strongly influenced by the modular architecture of the system. In general, the switching system is engineered to determine the necessary quantities of the lowest-level units. The quantities of these units then determine the necessary quantities of the next higher level unit and so on. More specifically, the number and type of terminations appearing on the switching system in conjunction with their traffic characteristics are used to determine the number of SM subunits (e.g., line units and trunk units) that are required. The time-slot and call-capacity requirements of these subunits then determine the number of SMs required. Finally, the number of SMs determines the equipage of the Communications Module (CM), which is composed of a Time-Multiplexed Switch (TMS) and a Message Switch (MS). This process is mechanized in the *5ESS* Switch Digital Ordering and Planning System (5EDOPS).

The CM equipment used to interconnect SMs and handle messages between SMs and the Administrative Module (AM) is designed to provide full access. This design eliminates the need for CM traffic engineering.

III. ADMINISTRATION

Administration of the *5ESS* switching system is concerned with ensuring objective service levels at optimum cost. It involves provisioning and assignment, data administration, capacity and equipment management, and resolving traffic-related service problems.

3.1 Provisioning and assignment

The *5ESS* switching system incorporates several features intended to enhance the provisioning and assignment process. These features include the structure of the database, the switching system's craft interface for accessing the database, and the interface to the Remote Memory Administration System (RMAS). In addition, the integrated digital interfaces simplify the provisioning and assignment process for services provided off these facilities.

The *5ESS* switching system includes a database management system that supports a relational database structure. This provides the users

```
                    5ESS SWITCH
                   RECENT CHANGE
       TRUNKS—TRUNK GROUP & MEMBER VIEW—32

#1. TGN             —        12. CGASPN          ———
#2. MEMB NBR        —        13. CLCI TRK ID     ——
 3. TEN             ——       14. HOLD BUSY       —
 4. DEN             ———      15. SATELLITE       —
 5. LTP             ——       16. OUT START DIAL  —
 6. CLEI            ————     17. TRF SAMPLE      —
 7. TRANS CLASS     —        18. CAMOPTLK TEN    ———
 8. SUPV            —        19. CAMOPTLK DEN    ———
 9. IDLE STATE      —        20. ACTN            —
10. IN START DIAL   —
11. STOPGO          —

Trunk group number. Enter from 1 to 999.
```

Fig. 1—A recent change view.

(the users may be either operating company personnel or other *5ESS* switching system software) with a logically structured database tailored to their needs, and enables the users to ignore the physical structure of the database. In the *5ESS* switching system, call-processing software accesses the database at a level, called the base relation level, in which the data are organized according to needs of this software. The craft interface is at the view level, which is created through logical operations on the base relations. Views have been designed to correspond to operating company work functions (e.g., add a new line) so that for each function, the necessary information can be obtained by accessing the appropriate views of the database.

The *5ESS* switching system includes its own craft interfaces to the switching system database and an interface to RMAS. Both of these interfaces are at the view level. The *5ESS* switching system's interface is similar in format and uses much of the same software as that used in the office data assembly process to initialize the database of a new office. The *5ESS* switching system has a menu selection routine from which views, the groupings of data at the view level, are accessed. The views of the database are presented in a screen format complete with navigational capabilities and help and error messages. Figure 1 is an example of a view. Database access using the view interface is available on site and remotely via Recent Change (RC) terminal(s). The database can also be accessed over the maintenance channel in a manner suitable for logging by the Switching Control Center (SCC) minicomputer. The *5ESS* switching system also has a 2400-baud, BX.25 link to RMAS. The RMAS interface is similar to that of the *5ESS* switching system. In addition, RMAS provides the *5ESS* switching system with enhanced data administration capabilities and provisioning features. These features include pending and history files to manage the entry of database changes into the switching system. Both the *5ESS* switching system and RMAS can print the switching system's data in tabular format so that paper versions of the office records may be maintained and updated.

Integrated digital interfaces simplify the provisioning process for T1-carrier message trunks and DLC systems. With integrated interfaces, there is no central office terminal equipment. Thus, there are no central office line assignments to be made, and the number of distributing frame cross-connects is greatly reduced. Combined with remote software provisioning, this gives the capability with the *5ESS* switching system to add and modify services on these integrated interfaces without requiring a central office visit.

Assignment for the RSM is accomplished via the host *5ESS* switching system. This enables the RSM to take advantage of the database management features incorporated into the host *5ESS* switching system and share the same craft interfaces. Only the distributing frame cross-connect work must be performed at the RSM site.

3.2 Data administration

Data administration ensures the availability, adequacy, and validity of the collected traffic data. Traditional traffic reports are available in human readable format over the Network Administration I/O channel. The *5ESS* switching system also provides an interface to the Engineering and Administrative Data Acquisition System (EADAS). EADAS provides an interface to the Total Network Data Systems (TNDS).

The administrative interface for the RSM is through the host *5ESS* switching system. Thus, all the administrative features of the *5ESS* switching system are also applicable to the RSM.

The EADAS interface uses the BX.25 protocol and is 2400 baud. EADAS polls the *5ESS* switching system for a half-hourly, hourly, and 24-hour data collection schedules. Data validation is performed by EADAS. For the *5ESS* switching system, EADAS creates C, E, H, and P schedules from the half-hourly data and passes them to the downstream TNDSs for additional processing. The C schedule includes trunking and customer usage data, the E schedule contains the extreme value data for usage-sensitive equipment, the H schedule includes hourly data and half-hourly data for special studies, and the P schedule has the processor capacity estimation data. The downstream TNDSs have been expanded to support the *5ESS* switching system as a new switching system type. These systems perform functions for network management, load balancing, forecasting switching system and facility growth, and indexing system performance. (See Refs. 1 through 3 for additional information.)

3.3 Capacity and equipment management

A primary function of switch administration is to ensure an efficient utilization of equipment. The goal is to maximize equipment utilization and minimize the quantity of equipment needed to provide the desired grade of service. Capacity management ensures that sufficient equipment is available and load balancing ensures that it is efficiently utilized.

The modular architecture and use of distributed processing in the *5ESS* switching system allows both call-processing and network capacity to be added. This is done by adding SMs to a system. Capacity estimation procedures using extreme value methods have been developed to determine and anticipate overload conditions. For the *5ESS* switching system, these procedures are expanded because of the distributed processing scheme, which requires multiple processors to be monitored. While adding SMs increases the call-processing and network capacity, SM subunits are added to provide additional terminations.

Since the design of the *5ESS* switch network is such that blockage can only occur in the line concentrator stage of the network, load balancing is only required to assure that individual concentrators are not overloaded. This is achieved by assigning lines based on their class of service. Trunks may be distributed to optimize reliability without regard to load balance. The *5ESS* switching system has no space-division junctors, hence junctor rearrangements are eliminated.

3.4 Trouble resolution

The switch administrator is responsible for the resolution of traffic-related service problems. The *5ESS* switching system includes an I/O channel—the NAC channel—for this purpose. This channel is a virtual channel over the BX.25 interface to the No. 2 Switching Control Center System (SCCS). This enables the administrator to take advantage of the SCCS minicomputer capabilities (e.g., logging, browsing, filtering, and alarming of messages). Over this channel the administrator has access to the switching system's database, to office status and control information, and traffic information. For dealing with traffic overload conditions, the *5ESS* switching system includes controls to reduce the load offered to the switching system and is designed to dynamically alter the allocations of system real time in response to changes in load. The essential service protection feature may be activated or inhibited to reduce the number of recognized requests for service via this channel. Network management controls are available to control the flow of traffic into and out of a *5ESS* switching system office over trunks. These controls may be activated "on-site" [at the Master Control Center (MCC) or SCC] or via EADAS/NM (network management).

IV. MAINTENANCE

The maintenance features designed into the *5ESS* switching system make it well suited for both highly mechanized environments and other less mechanized environments. Its inherent flexibility allows it to work in a variety of operational environments and configurations. The maintenance interface is a user-friendly one that, by the use of video displays and easy-to-use menus, guides the craft through the control operations used to maintain the system.

4.1 Maintenance objectives

The overall reliability and availability objectives of the *5ESS* switching system are detailed in Ref. 4. From a maintenance perspective, these objectives distill into the following points: First, the *5ESS* switching system should perform as much of the maintenance as it can without the need for craft intervention. Whenever a trouble condition occurs, the crafts people should be notified of it, along with the criticality of the event. When the crafts people must take corrective action, it should be easy to identify and isolate the trouble quickly and unambiguously, and the repair should be quickly effected. Lastly, except for pack replacement and other "hands-on" repair, all maintenance control and display capabilities should be available on-site and at the remote SCC.

4.2 Maintenance capabilities

4.2.1 General

The *5ESS* switching system has a full complement of audits, interrupts, purges, and diagnostics. Details of these may be found in Ref. 5.

4.2.2 Craft interface

The craft interface for system maintenance at the central office is the MCC. Figure 2 shows the most frequently used parts of the craft interface. Instead of having a custom, hard-wired key and lamp panel for each office, as other SPC systems have, the maintenance interface uses a video display and keyboard unit similar to the one discussed in Ref. 6. The displays are software controlled and are easily changed to track the particular *5ESS* switching system's configuration. The upper part of the screen always displays a summary of the critical indicators, including the alarm-level indications `CRITICAL`, `MAJOR`, and `MINOR`, and the "type" indicators such as `BLDG/PWR` and `MSGS/TMS`, which

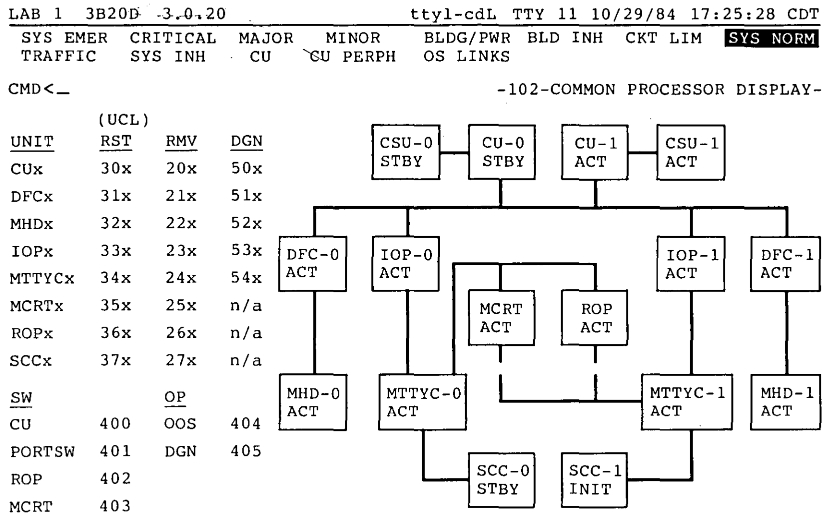

Fig. 2—Parts of a master control center.

indicate the trouble source. On monochromatic terminals, these indicators would be displayed in reverse video or blink to indicate the type and the severity of the trouble. For the optional color terminals, changing status would be shown by a change in color.

Below this area, the crafts people can select different "pages" to be displayed in order to perform the control and display functions similar to other SPC systems. The pages consist of an ordered list (a menu) of control and/or display functions that can be selected by entering a 3- or 4-digit number followed by an execute character. Usually accompanying this menu is a graphical representation of the status and interconnection of equipment. There are separate pages for different types of equipment and for different levels of detail.

As in other SPC systems, the *5ESS* switching system has a "belt-line" function that allows craft at the switching frames to interact with the switching system. By means of a portable TTY, the crafts people can input messages and receive appropriate output and system status messages.

4.2.3 Diagnostics

Flexibility and power are the hallmarks of the *5ESS* switching system's diagnostics. An entire equipment unit, a particular subunit, or all the subunits in a particular community can be diagnosed. Complete tests, a range of test phases, or particular phases may be run. While most requests can be initiated automatically, all requests can be initiated manually. To aid in troubleshooting, interactive features such as stepping, looping, and pausing are provided. Manual requests can be entered from the maintenance terminal by either menu selection or message input.

Diagnostic results can be sent to the maintenance terminal and the printer. Unlike other SPC systems, which print trouble numbers that must be decoded by referencing a Trouble-Locating Manual (TLM), the *5ESS* switching system can be requested to print a list of suspected faulty circuit packs. This Trouble Location Procedure (TLP) option provides an ordered list of packs, including their locations, which simplifies the repair procedure. It is expected that 90 percent of all faults can be cleared by replacing one or more of the boards listed with nearly half of the faults cleared by the first pack on the list.

4.2.4 Emergency action interface

In the unlikely event that the *5ESS* switching system cannot recover from a catastrophic failure, the Emergency Action Interface (EAI) provides manual control and basic status information. The EAI circuit can access the *5ESS* switching system regardless of system configuration or software sanity. Firmware in the EAI controls a display that allows the crafts people to force system configurations, to inhibit error sources and sanity checks, and to initialize the system. In the event of a complete system outage, the EAI provides a gross diagnostic capability in the form of processor recovery messages. The EAI page is displayed on the same terminal as other maintenance displays, and is available at both the central office maintenance terminal and remotely at the SCC.

4.2.5 Initializations

Initializations in the *5ESS* switching system are very comprehensive. The *5ESS* switching system supports a variety of initialization levels from a single process purge to a full initialization and memory reload.[5] The distributed architecture of the *5ESS* switching system permits initializations of separate units of the switching system, often with little effect on the other units. For example, one SM may be initialized without interfering with call processing in other modules. Likewise, some levels of AM initialization have little effect on the periphery. If more drastic actions are required, the entire system may be initialized.

4.2.6 Switching Control Center System interface

The Switching Control Center System (SCCS) provides the hardware and software to control, administer, and maintain SPC systems from a remote centralized location. This is accomplished through a combination of audible and visual alarms, status panels, and video displays for status control. The SCCS also provides analysis and computational tools, office records, and interfaces to other operations systems and centers. (See Refs. 7 and 8 for more thorough discussions of the SCC.)

The *5ESS* switching system is fully compatible with the SCCS. All SCCS functions that can be performed on other SPC systems can be performed on the *5ESS* switching system. All maintenance control center functions are remoted to the SCC, including the emergency action interface page. The displays at the MCC and SCC are identical, which improves craft communications between the central office and the SCC. In addition, the *5ESS* switching system shares a common, standard interface design with other AT&T 3B computer processor-based systems.[9]

Communication between the *5ESS* switching system and the SCCS is via a duplicated data link using the BX.25 protocol. BX.25 is a packet-switching protocol for error-free data communications, which allows for the multiplexing of separate "virtual channels" on a single facility. Thus, savings are realized on facility and terminal costs while promoting a standardized interface to future packet-switched networks.

All alarms, control and display information, input and output messages, and other maintenance data are sent on separate, virtual channels over the same BX.25 link. This is in contrast to other SPC systems, where TTY and telemetry information are sent over separate, nonduplicated links. In the case of a link outage, BX.25 provides for an automatic switch to the standby link. Therefore, the interface to the SCCS is fully duplicated and full functionality is maintained during any single link failure.

4.3 RSM maintenance

The RSM in the *5ESS* switching system's architecture is an SM designed to be used in a variety of remote applications. As discussed in Section 2.1, to minimize the impact of host office troubles and facility failures, when the RSM cannot communicate with the host, its stand-alone mode will provide basic telephone service within the customer community. While in this mode, emergency lines will also be provided to assure access to emergency service.

While the maintenance of the RSM has been designed to be virtually identical to that of the host SM, the remoteness of the RSM implies some differences. Trouble will be sectionalized sufficiently to ensure that craft will be dispatched only when necessary, and that minimum spare parts will be taken to the remote site.

Most RSM maintenance will be controlled from the SCC, where testing will determine if and when a dispatch is necessary. Most tasks requiring craft at the RSM site will be accomplished by one crafts person, using a portable TTY. This TTY will have access to the SCCS via a secure dial-back arrangement, or to the host office as an extension of the belt line. Optionally, a remote MCC terminal may be provided at the RSM site. When necessary, assistance can be provided by a controller or analyzer at the SCC, or by another crafts person at the host office.

The crafts people at the RSM will have a simple status panel that will show RSM alarm information and an indicator that will show when the RSM is in the stand-alone mode.

4.4 Line and trunk testing

The *5ESS* switching system is designed to fit into the existing environment for line and trunk testing, and also to support improved interfaces for these functions. This includes providing testing capabilities within the *5ESS* switching system and supporting interfaces to remote test systems such as the Centralized Automatic Reporting on Trunks (CAROT) and Mechanized Loop Testing (MLT) systems. Thus, to support line and trunk testing, the *5ESS* switching system provides metallic access, built-in test capabilities, and craft interfaces (both local and remote).

The *5ESS* switching system includes a line and trunk testing craft interface called the Trunk Line Work Station (TLWS). This interface shares the same physical equipment as the MCC for switching systems maintenance and accepts two forms of input: menu mode and TTY messages. From this interface administrative actions such as changing the state of the line or trunk, actual line and trunk tests, and miscellaneous functions such as monitor-only connections may be performed. For large offices that require large volumes of testing, as many as six supplementary TLWSs may be equipped.

In addition to the manual tests that may be performed at the TLWS, the *5ESS* switching system performs automatic tests. For lines, these include standard per-call tests and Automatic Line Insulation Testing (ALIT), which includes tests of integrated *SLC* 96 system lines. The ALIT function is performed by equipment integrated into the *5ESS* switching system. Loop segregation tests are run on a periodic basis to differentiate between loaded and nonloaded loops. These tests ensure that the system provides the proper balance network for echo control during calls. For trunks, automatic outgoing transmission and operational test calls are provided.

For line- and trunk-testing OSSs, the *5ESS* switching system, in addition to providing metallic access for the conventional testing interface, is designed to support more sophisticated interfaces and eliminate the need for external test equipment. This permits external testing systems to share these capabilities. The *5ESS* switching system includes equipment called the Transmission Test Facility (TTF) and the Directly Connected Test Unit (DCTU) that, along with system software, perform test functions that external equipment such as the Remote Trunk Test Unit (RTTU) and Loop Testing System (LTS) provided for other switching systems. The TTF implements the loop segregation tests, the various transmission test lines, and the Remote Office Test Line (ROTL) functions. The DCTU provides dc and subaudio measurement capabilities. Thus, as well as providing for remote testing in the same manner as other switching systems, the *5ESS* switching system anticipates an environment where remote test systems (e.g., CAROT and MLT) request a test, and the switching system performs the test and delivers the results. In this environment, the test systems will communicate with the *5ESS* switching system in a manner similar to RMAS and EADAS, using BX.25 protocol.

Finally, in addition to performing tests for remote testing systems, the DCTU also eliminates the need for much of the portable test equipment at the central office. If the loops at the RSM are to be tested, they must also be equipped with their own DCTU.

V. SUMMARY

The *5ESS* switching system has been designed with an operational flexibility that allows it to work in a variety of operational configurations. In particular, the *5ESS* switching system has been designed with a set of enhanced interfaces that accommodate its integration into highly centralized and mechanized operating environments, as well as features that provide for operations in offices that are not as highly mechanized. Thus, the *5ESS* switching system includes a wide range of operational features and enhancements for a wide variety of operational environments.

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The 5ESS *Switching System:*

Factory System Testing

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This paper describes factory system testing for the *5ESS*™ switch. Factory system testing is performed using standard maintenance and diagnostic features of the *5ESS* switch. The design of the factory system testing process is based on the distributed architecture of the *5ESS* switch and is described in this paper. The system-level requirements that each *5ESS* switch must meet before shipment to the field are also discussed.

I. INTRODUCTION

The process of testing hardware for the *5ESS* switch involves several stages, beginning with circuit-pack testing in the factory and progressing to final system acceptance testing in the field. The objective of this process is to give the customer a high-quality system that meets the design requirements of the *5ESS* switch. This paper describes Factory System Testing (FST)‡ of the *5ESS* switch, the final stage of factory testing that ensures that each *5ESS* switch meets stringent requirements before being shipped to the field.

The FST process for the *5ESS* switch is designed to be both effective and efficient, with the specific objective of resolving system-level hardware problems in the factory rather than in the field. This objective is achieved by performing FST with the standard generic program using standard system diagnostics. The required efficiency has been achieved by using the distributed architecture of the *5ESS* switch in the design of the FST process.

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‡ Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

Section II of this article describes the different types of testing performed in the factory on the *5ESS* switch. Section III presents the strategy that has been adopted for FST of the *5ESS* switch. Features in the standard generic program of the *5ESS* switch that are particularly useful in performing FST are discussed in Section IV. Sections V and VI review the activities performed during FST of the *5ESS* switch and summarize the specific test criteria that must be met. Finally, Section VII describes the quality-assurance program for the *5ESS* switch as it applies to FST.

II. FACTORY TESTING PERFORMED ON A *5ESS* SWITCH

Testing performed in the factory for the *5ESS* switch can be divided into component testing, circuit-pack testing, unit testing, and system testing. Circuit-pack testing is performed on all plug-in elements as individual entities before they are inserted into units of the *5ESS* switch. Units are composed of one or more equipment shelves that house the circuit packs. Depending on the function of a given unit within the system, testing may or may not be performed at the unit level before system testing. System testing makes full use of the system environment of the *5ESS* switch to provide final check-out of the system. These four testing phases are described below.

2.1 Component test

5ESS system performance dictates the use of components that exhibit high levels of quality and reliability. To meet quality and reliability requirements, components are procured against rigid specifications that assure both incoming quality and long-term reliability. Exacting standards for ac and dc electrical testing, metallic-lead finishing, and burn-in are specified to eliminate infant mortality. Sample lots of components are screened to determine compliance with these quality standards.

2.2 Circuit-pack test

The *5ESS* switch is composed of both analog and digital multilayered circuit packs, although most of the pack codes are digital. Functional tests for digital circuits are generated by circuit simulation.[1] Further processing of test vectors is provided by a diagnostic retrieval algorithm[2] that converts the vector sets into the proper format required by the circuit-pack test sets.

Before functional circuit-pack testing is performed, many circuit packs of the *5ESS* switch are tested for short circuits, open circuits, device orientation, and device tolerance using an in-circuit test set. The in-circuit test set is less expensive than the functional test set and provides a more convenient method for detecting mechanical faults. Repair facilities are located near each test set so that circuit-pack transport and handling are minimized.

The failure rate of circuit packs in system testing is used as a constant monitor of the effectiveness of circuit-pack testing. The testing objective is to locate circuit defects at the earliest possible stage of manufacture so that defect repair costs are minimized. Emphasis on circuit-pack fault coverage enhances the system-test circuit-pack yield.

2.3 Unit test

Unit testing of subassemblies in the *5ESS* switch takes on two forms. Unit testing was considered a necessity during the manufacturing start-up period of the *5ESS* switch. The unit-testing capability divided the product into functional entities and provided a means for quickly isolating design and manufacturing difficulties. Experience with previous electronic switching system switches, however, showed that as a product reaches maturity, less intermediate testing is required. Early planning for the *5ESS* switch, therefore, scheduled unit testing to be phased out of the manufacturing process where possible. The foremost goal was that the quality of the *5ESS* switch would not be compromised. Unit testing thus existed only temporarily for Switching Module (SM) peripheral units such as line units (LUs) and trunk units (TUs), while other units and subassemblies continue to be tested at the unit level. All equipment of the *5ESS* switch that bypasses the intermediate unit test is tested using system diagnostics and must meet system-level requirements before being shipped from the factory.

Permanent unit-test facilities remain for system elements that are critical for the system-testing operations. The Switching Module Processor Unit (SMPU) is unit tested along with its Time-Slot Interchange Unit (TSIU), since these units are necessary for testing SM peripheral units in system test. Guaranteeing a known good SM controller enhances the ability to easily bring up an SM in a system environment. The Communications Module (CM) parts of the system—the Message Switch (MSGS) and Time-Multiplexed Switch (TMS)—as well as the AT&T 3B20D computer are all pretested before system testing.

Many of the unit-test sets were derived from laboratory test sets used during development of the *5ESS* switch. Most were minicomputer based with custom interfaces designed to communicate with the particular unit to be tested. Software for the test sets was developed primarily on computers running with the *UNIX*™ operating system and often included translated system diagnostics. Much of the test software was compiled on off-line computers and down loaded into the individual test-set computers.

2.4 Factory system test

FST of switching equipment generates a product whose hardware and software have been successfully integrated. This integration and testing eliminates inconsistencies between physical hardware equipage and database hardware equipage. However, the major benefit of FST is its demonstration that while being exercised at full system speed, the equipment meets end system requirements in a nonsimulated environment.

Further benefits of FST include a reduced installation interval, consistency between factory and installation procedures, early identification of hardware and software problems, and greater customer satisfaction. These benefits are achieved because the system is truly operated in its native mode, i.e., under the same conditions that the machine will encounter in field operation, including stress conditions.

To ensure that end requirements are met, all system testing of hardware is performed with the standard generic program. The equipment configuration database that describes the hardware equipage is derived from the Systems Equipment Engineer's specification. Thus, the factory provides system verification using system-level hardware and software configurations while operating in an environment similar to that encountered in the field.

III. *5ESS* SWITCH FACTORY SYSTEM TESTING STRATEGY

Planning for FST of the *5ESS* switch was based on principles of previous electronic switching system switches but was heavily influenced by the modular architecture of the *5ESS* switch. The basic building block of the *5ESS* switch is the SM. The greater part of switch maintenance, and hence system testing, is carried out within each SM through the intelligence of the SM controller. The fact that SMs are loosely coupled to the TMS via the fiber-optic Network Control and Timing (NCT) links led to a modular testing concept. Consequently, a dual-phase FST was proposed and implemented for the *5ESS* switch.

3.1 The SMST/MMST concept

In the first testing phase all SMs are tested in a full-system configuration known as Switching Module System Test (SMST). The SMs under test are served by a factory-installed host complex composed of an Administrative Module (AM), and a CM consisting of a duplex MSGS and a duplex TMS. The second phase is called Multimodule System Test (MMST). In the MMST process the essential elements of each office are assembled and connected. The AM and CM are connected with the first two SMs (previously tested in SMST) to produce a working office configuration. Each MMST office receives a complete system test, including call-volume testing.

SMST provides a parallel process that can intermix and test SMs destined for several different telephone offices. Each SMST test position is assigned an SM, and up to 15 SMs can be tested simultaneously with a single SMST Host System. The standard generic program controls the SMST complex. Therefore, an SMST complex is similar to a 15-SM office and provides a complete FST environment. Likewise, MMST is also performed using the standard generic program. Emphasis in MMST is placed on verifying that a base configuration of hardware will pass all phases of end office requirements, including call-volume testing, to which the remaining SMs system tested in SMST can easily be added in the field.

3.2 Cost-effectiveness of SMST/MMST

The reduction in FST costs through the SMST/MMST concept is achieved for several reasons, which are discussed in the following sections.

3.2.1 Reductions in inventory costs

In-process inventory costs accrue rapidly for offices during the FST process. Offices undergoing FST are complete except for final test verification. SMST provides a highly parallel operation where most SMs for a given office are tested at the same time. The first two SMs for each office are tested earlier in SMST and sent to MMST, where these SMs are mated with the AM and CM while the balance of the SMs for that office are still being tested in SMST. Thus, SMST and MMST taken together form parallel processes and hence a reduced factory interval.

3.2.2 Reductions in unit-test costs

SMST replaces the unit testing of SM peripheral units while providing end requirement tests for SMs of the *5ESS* switch. The capital investment in unit-test facilities is saved, as well as the testers required to operate the test facilities. SMST derives much of its cost avoidance from these two areas.

3.2.3 Floor space savings

SMST and MMST minimize the need for factory floor space. SMST requires less movement and handling of *5ESS* system units and cabinets than do the unit testing operations. In addition, SMST concentrates more product per square foot of floor space than does unit testing. MMST of a fixed-size office configuration allows installation of standard test areas including system power, lighting, test line distribution, and maintenance consoles.

3.2.4 Minimization of redundant testing

Unit testing eliminated by SMST consisted, in part, of tests derived directly from system diagnostics. The SMST application of system diagnostics in a system environment is the preferred method of testing. Although the unit test, if left intact, would generate high unit yields into SMST, many of the same tests would be rerun on the SMs in SMST. The goal for the *5ESS* switch was to eliminate redundant testing of this sort throughout the manufacturing process. Clearly, SMST and MMST fulfill this goal for *5ESS* equipment and system testing.

3.2.5 Diagnostic effectiveness

The requirement is that system diagnostics detect all failures that occur during full operation of the *5ESS* switch. Specifically, if an operational failure occurs during call processing, the normal system maintenance diagnostics should also detect the failing hardware. Both AT&T Bell Laboratories and AT&T Network Systems engineers performed detailed experiments to ensure this requirement was met. Obviously, the end product benefited from this work since the confidence in the overall diagnostic and maintenance capability of the *5ESS* switch was increased. This effort indicates that a thoroughly diagnosed SM is traffic worthy on arrival in the field.

3.3 System testing of growth SMs and remote switching modules

Installed *5ESS* switches are expanded by the addition of new SMs to the CM or by the attachment of Remote Switching Modules (RSMs) to the office. SMST easily accommodates testing of growth SMs using the same procedures that are followed for all other SMs. To test RSMs, helper SMs, consisting of an SMPU, TSIU, and Digital Line Trunk Unit (DLTU), are connected to an SMST host to provide digital trunk communication with the RSM under test.

3.4 Sustaining SMST/MMST test objectives

SMST and MMST represent a modular testing concept designed to complement both the modularity and distributed intelligence of the *5ESS* switch. Robust system diagnostics and maintenance software ensure complete SMST and MMST hardware testing in the factory. However, the factory gives considerable attention to the monitoring and recording of circuit-defect information. SM circuit defects found in MMST provide a constant check of SMST product quality and process reliability. An unacceptable circuit-pack yield in SMST and MMST results in corrective action to determine and fix the problem. In addition, the factory relies on its review of field problems to check factory processes. The factory philosophy is to correct problems at the source rather than provide additional system-testing steps to screen defects.

The SMST and MMST role in the overall factory-test philosophy for the *5ESS* switch is to provide rigorous end requirement verification. But, since SMST and MMST also replace intermediate unit testing steps, this role could not be fulfilled without particular generic software features. These software features provide control of faulty hardware, efficient procedures for hardware check-out, and detailed summaries of the system status. A description of these generic software features is provided in the following section.

IV. USES OF THE GENERIC PROGRAM OF THE *5ESS* SWITCH FOR FACTORY SYSTEM TESTING

FST of the *5ESS* switch is performed using the standard generic program. The FST environment, however, is considerably different from that of an in-service office. The major differences are as follows:

1. Multiple faults commonly occur both in SMST and MMST.
2. Many simultaneous diagnostics are run in SMST.
3. Heavy emphasis is placed on resolving hardware problems both in SMST and MMST.
4. Fifteen test positions operate in parallel and communicate with the system in SMST.

These special requirements for FST are handled by standard features available in the generic program of the *5ESS* switch.

The min-mode feature allows the system to handle multiple faults in both SMST and MMST. Furthermore, min-mode provides the *5ESS* switch with the capability of handling extremely infrequent but critical occurrences of multiple faults in the field.

The execution of many simultaneous diagnostics in SMST is possible because of the diagnostic environment provided by the *5ESS* switch. In addition, the features provided by this diagnostic environment are extremely useful to the installer and after cutover result in improved efficiencies for operating company maintenance personnel. Various system troubleshooting features are also available to help resolve hardware problems both in the factory and in the field.

The capability to support 15 testers working in parallel during SMST is provided by an output message routing feature. Installers in the field also use this feature during the installation interval.

The features of the *5ESS* switch that are particularly useful in SMST and MMST are described in the following sections.

4.1 Min-mode

Min-mode provides a capability for factory system testing hardware containing multiple faults in critical units. Using SM min-mode, it is possible to bring up an SM from an unknown state and test it using the SMST procedure specified in Section 5.4. Using AM min-mode, it is possible to bring up the AM and CM and test this hardware using the MMST procedure specified in Section 6.4.

SM and AM min-mode are invoked separately. Entry to or exit from min-mode can only occur through manual action, and it results in a single initialization. When in min-mode, indicators are displayed on the Master Control Center (MCC) terminal indicating the system's status. All manual requests for system action are honored in min-mode.

Min-mode is the one feature of the *5ESS* switch that allows the standard generic program to be used for FST. Although min-mode is used routinely during FST, it is used to a much lesser extent during the installation interval and is available for emergency use in cutover offices.

4.2 Diagnostic environment features

The capability to efficiently diagnose hardware of the *5ESS* switch is important in achieving the FST cost objectives for the *5ESS* switch. Features provided by the diagnostic environment of the *5ESS* switch are major factors in obtaining the required testing efficiency. These features are concurrent diagnostics in a single SM, the SM global diagnostic request, the diagnostic status report, and the diagnostic test status report. The following sections describe these features.

4.2.1 Concurrent diagnostics in a single SM

The SM concurrent diagnostic feature allows up to four diagnostics to run simultaneously in a single SM. Concurrent diagnostics can result from various combinations of automatic and manual requests. Automatic diagnostic requests are given higher priority than manual diagnostic requests to ensure quick response to fault-recovery actions.

A diagnostic request blocking strategy is used to ensure that in a single SM only one diagnostic is active in each peripheral unit at a given time. This restriction is necessary since diagnostics cannot share certain resources within a peripheral unit. Furthermore, simultaneously diagnosing both sides of a duplicated unit in an SM is also blocked. When a diagnostic request is blocked, however, it is only delayed until the conflicting diagnostic completes execution.

4.2.2 SM global diagnostic request

The SM global diagnostic request allows a system tester to enter a single diagnostic request and diagnose an entire service group in an SM peripheral unit. An option is provided either to diagnose all circuits unconditionally or to stop after the first failure. In some types of peripheral units a single global diagnostic request for a service group can be used instead of specifying as many as 16 individual diagnostic requests. The use of SM global diagnostic requests with the concurrent SM diagnostic feature results in significant reductions in FST intervals for the *5ESS* switch.

4.2.3 Diagnostic status report

The diagnostic status report is a summary report that can be requested and specifies the current status of all AM, CM, or SM diagnostic requests. This report is particularly useful when testing an SM with as many as four diagnostics running at once. The diagnostic status report specifies for each active diagnostic request whether the requested diagnostic is currently queued or executing, the type of request (i.e., normal diagnostic, restore, test, exercise, or routine exercise), and whether the diagnostic was automatically or manually requested.

4.2.4 Diagnostic test status report

The diagnostic test status report is a summary report that can be requested and specifies the complete diagnostic status of all diagnosable units and circuits in either an SM or the CM. For each diagnosable entity, this report specifies the status of either (1) all tests passed, (2) conditionally all tests passed (occurs if a helper circuit is not available for a diagnostic), (3) some tests failed, or (4) no test run. With this information it is possible to easily and accurately determine the work remaining to be completed in testing an SM or the CM.

4.3 Troubleshooting features

Troubleshooting features are provided in the generic program of the *5ESS* switch to supplement the standard system diagnostics. In the factory these features aid in resolving hardware problems that are either intermittent or involve marginal conditions. These troubleshooting features are generic utilities, utility call trace, and the library supervisor. The following sections describe these features.

4.3.1 Generic utilities

The *5ESS* switch provides generic utilities that are used for both software and hardware troubleshooting. These utilities provide debugging capabilities in both the CM and the SM. The generic utilities are used to troubleshoot certain hardware faults not identified by fault-recovery software and not detected by system diagnostics, but resulting in operational failures. They are triggered by conditional or unconditional utility commands.

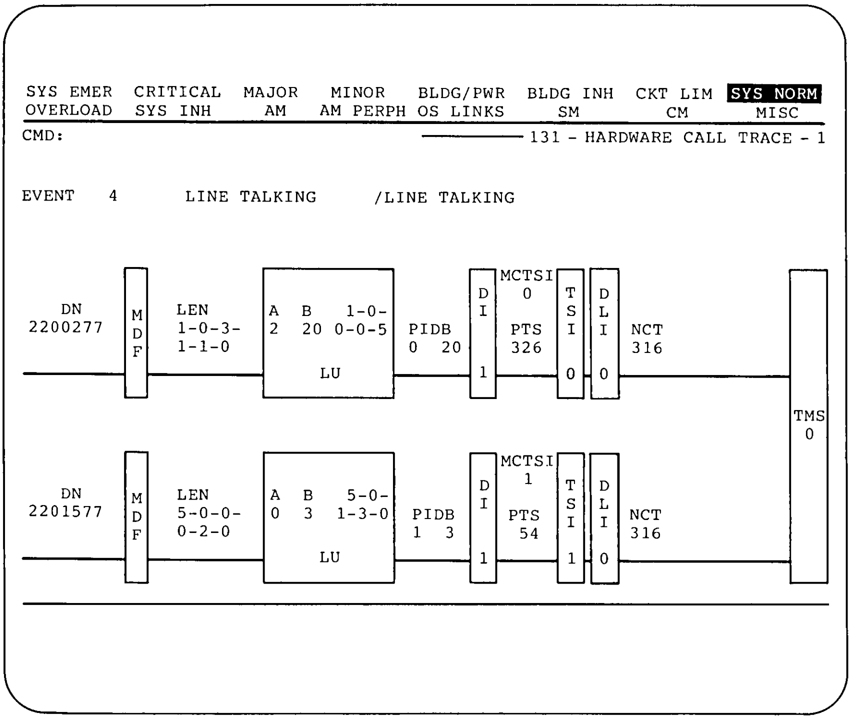

Fig. 1—Utility-call-trace master control center page.

One use of the generic utilities occurs when a fault is detected by system diagnostics and isolated to a circuit pack but the circuit pack still passes all the circuit-pack tests run before system testing began. The utilities can be used to further analyze the failure and isolate the faulty component. Circuit-pack testing can then be improved to include additional tests. A use of the SM generic utilities with the utility call trace is described in the following section.

4.3.2 Utility call trace

Utility call trace provides the capability to identify the specific hardware and software configuration used in processing a call. This feature is used during MMST to resolve problems associated with any calls that fail. All hardware information associated with a call is displayed on an MCC page that specifies the path of the call through the system. Figure 1 shows an MCC page displaying a line-to-line call in the talking state. The dynamic data structures associated with controlling the call are printed on the Read-Only Printer (ROP).

Utility call trace can be activated using either input messages or generic utility breakpoints. The port, circuit, or time slot used by a call can be specified in an input message as the trigger for utility call trace. Furthermore, generic utility breakpoints can be set in the failure legs of either the feature control or peripheral control subsystems to trace a failing call without prior knowledge of the hardware to be used. The programmable call generator used to generate traffic during MMST has a feature to trap on failing calls and hold the call. This feature is used with utility call trace to identify specific hardware problems.

4.3.3 Library supervisor

The library supervisor controls the execution of individual client programs. These client programs are not a part of the standard generic since they are only used for special-purpose functions. Client programs are installed from tape on the AM's disk and are executed and controlled by the library supervisor. Client programs are written in the C programming language and compiled using the development environment for the *5ESS* switch.

Library supervisor client programs can execute in different SM/AM environments. The possible environments are an SM client program running in one or more SMs; an AM client program; an SM client program running in one or more SMs all communicating with an AM client program; an SM client program running in several SMs all communicating with each other; and an SM client program running in several SMs, all communicating with each other and with an AM client program. Input commands are available to load, delete, start, and stop the execution of library supervisor client programs. An additional input command is available that allows the user to pass information to client programs. Individual client programs can generate output messages supplying information to the user.

The library supervisor is used in SMST and MMST for special-purpose troubleshooting. For example, system diagnostics are designed to resolve hardware problems to the circuit-pack level. However, with a library supervisor client program certain failures can be analyzed to a more detailed level such as the device level. Since no unit testing is performed on SM peripheral units, library supervisor client programs can be especially useful in resolving any diagnostic failures that occur in SMST but are not detected in circuit-pack test.

4.4 SM output message routing feature

Multiple terminals are used by the system testers during SMST, where a terminal connected to the AM is provided for each of the 15 SMST test positions. Normally the *5ESS* switch routes all maintenance and diagnostic output messages to the MCC terminal and the ROP. However, a feature of the *5ESS* switch allows autonomous system-generated messages associated with a particular SM to be routed to a specific terminal. With this feature, messages such as interrupts or

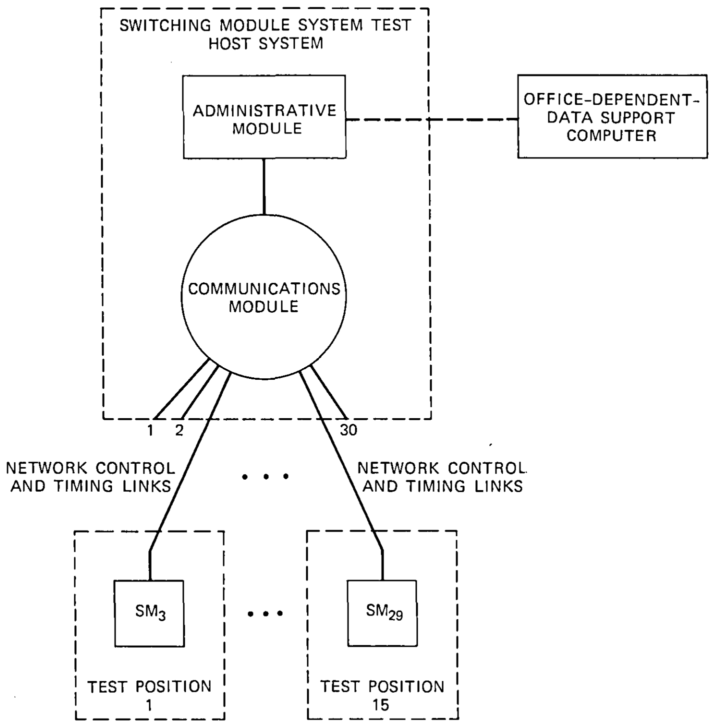

Fig. 2—Switching module system test configuration.

reports on fault-recovery actions from a particular SM can be routed to the terminal at the proper SMST test position. An SM message-routing table is maintained by the *5ESS* switch. This table can be dynamically altered by a system tester to control the routing of messages from a specific SM to a particular terminal. With this feature it is possible to effectively test SMs from 15 terminals during SMST.

The following section describes the SMST process, in which many of the features of the *5ESS* switch described in this section are used.

V. SWITCHING MODULE SYSTEM TEST

The purpose of SMST is to provide an efficient and effective FST of SMs for the *5ESS* switch. The SMST process, which involves testing SMs with the SMST Host System, is described in this section.

5.1 SMST configuration

The SMST Host System consists of a factory-installed AM and CM connected by NCT links to 15 SMST test positions. The CM is equipped to accommodate 30 SMs that are specified in the SMST Office-Dependent Data (ODD). Figure 2 shows the SMST configuration.

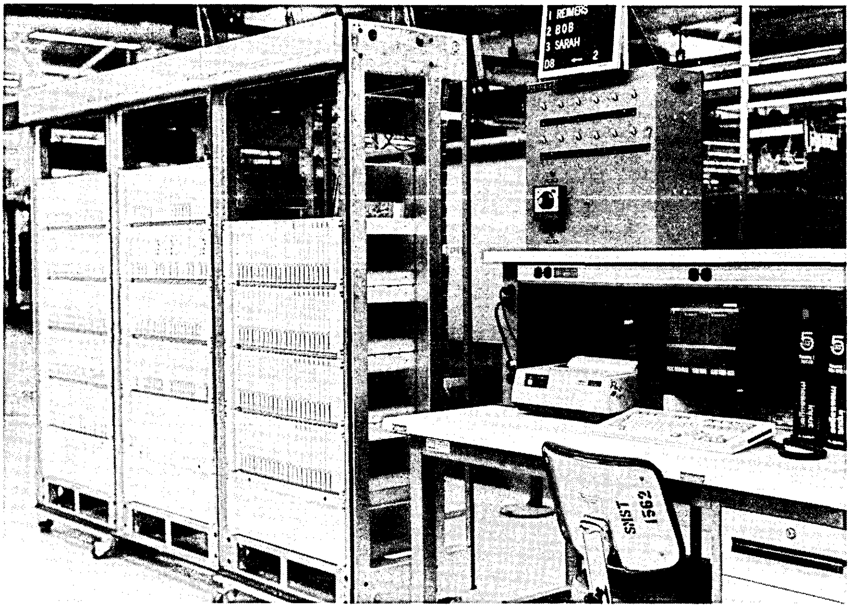

Fig. 3—Switching module system test position.

Two types of communication occur between each SMST test position and the SMST Host System. First, an SM being tested with the SMST Host System communicates with the CM through NCT links. Second, each system tester communicates with the AM via an I/O terminal. One I/O is assigned per test position. This terminal is used for input messages such as diagnostic requests and status requests. Output messages associated with a particular SM are routed from the AM to the terminal at the appropriate SMST test position. A printer is provided at each SMST test position for use whenever a hard copy printout is desired. Figure 3 shows an SMST test position.

5.2 ODD for SMST

The ODD for each SMST Host System defines the database for 30 SMs. This ODD is specifically generated for SMST on a support computer in the factory. The SMST ODD Administrator generates the SMST ODD by specifying on this support computer the next 30 SMs scheduled to be tested with a particular SMST Host System. The SMST ODD generation process combines information from the ODDs for SMs from various *5ESS* switches. Since diagnostics rather than call processing are used during SMST, no call-processing information is included in the SMST ODD. Instead, only information defining the equipment configuration is included. The SMST ODD consists of 30 files for each of the SMs to be tested plus one file containing the ODD for the AM.

A new SMST ODD is installed as soon as testing has begun on the last of the 30 SMs specified in the old SMST ODD. After completion of this process, new SMs can be tested using the SMST Host System. The test requirements each SM must meet before the completion of SMST are summarized in the next section.

5.3 SMST test requirements

The requirements for an SM to complete SMST are stated in a specification developed by AT&T Bell Laboratories. Adherence to these test requirements in the factory is verified on sampled SMs by the AT&T Network Systems quality-assurance organization. These requirements are summarized as follows:

1. All circuit packs, including spares, must meet stress-test requirements before SMST.
2. All SMPUs and TSIUs must have previously passed unit testing.
3. All plug-in units to be shipped with the SM must be tested in SMST.
4. All SMs tested in SMST but not tested in MMST must be able to process call traffic at the completion rate and with quality equal to MMST requirements.
5. All diagnostics, including all demand phases, must pass. The LU grid fabric exercise must also pass.
6. The SMST Host System must be able to pump the memory of each SM.
7. Each SM must pass a heat test.

The next section specifies the SMST testing strategy and contains more details on the SM pump test and SM heat test performed in SMST.

5.4 SMST testing strategy

SMST testing is performed as specified by a detailed FST procedure. The three stages of the SMST procedure are reviewed in the following sections.

5.4.1 Preliminary procedures

The preliminary SMST procedures must be completed before an SM can be tested with the SMST Host System. These procedures are as follows:

1. Equipment in the SM frames is visually checked to ensure that the SM is properly equipped.
2. The message time-slot switches on the SM are set to specify the SM number specified in the SMST ODD.

3. The I/O terminal associated with the test position is initialized so that SM-related output messages from the SMST Host System are directed to the terminal at the proper SMST test position.

4. The system tester next verifies that both power and fusing for the SM have been correctly installed.

5. Circuit packs are inserted. The only circuit packs that will have been installed previously in the frames and unit tested are the SMPU and TSIU packs. All other circuit packs in the SM come directly to SMST from the circuit-pack test and are inserted into the frames at the SMST test position.

6. All SM cables are verified. The final step in the preliminary SMST procedures is the connection of the NCT links. A flexible SM numbering capability in the generic program allows NCT links to be reassigned to the particular SM being connected. Recent change messages provide this reconfiguration capability. Functional testing of the SM with the SMST Host System is now ready to begin.

5.4.2 SM functional test

The process of functionally testing an SM begins by placing the SM into SM min-mode. The SM's memory (both generic program and ODD) is pumped from files on the AM's disk, and the SM is initialized. After the SM has been initialized successfully, units in the SM are diagnosed in the sequence specified below. Preprinted forms for recording diagnostic test results are provided to SMST personnel.

1. SMPUs. The SMPU diagnostic includes the switching module processor, TSIU, control interface, Data Interface (DI), and signal processor.

2. Fast-Pump Bootstrapper. This is the circuit pack used to fast pump the SM's memory.

3. Dual-Link Interface (DLIs). The DLIs are the SM interfaces for the NCT links connecting to the TMS.

4. Peripheral Units. The specific peripheral units in each SM are engineered by the operating companies to meet their individual requirements. With Generic 5E2(1) the possible SM peripheral units are local digital service units, global digital service units, LUs, TUs, modular metallic service units, DLTUs, digital carrier line units, directly connected test units, and facility interface units for RSMs. In addition to diagnosing all peripheral units, the LU grids are exercised using the grid fabric exerciser program. Peripheral units are functionally tested in SMST using many of the features previously described in Section IV. Diagnostics are run using the concurrent diagnostic and global diagnostic features. The current status of SM diagnostic requests can be determined from the diagnostic status report. A cumulative record of all SM diagnostic results can be determined from the

diagnostic test status report. After all peripheral units have been successfully diagnosed, the SM is removed from SM min-mode.

The capability to successfully pump the SM's memory from the SMST Host System using different link combinations is tested. Both control time slot and fast pump are used during this test.

5.4.3 Heat test

The SMST heat test is designed to eliminate marginal circuit packs and at the same time provide complete diagnostic verification of the SM. During temperature elevation the temperature is raised from ambient room temperature to 49°C. As the temperature level is raised, the active SMPU is switched every five minutes. This exercises the SM instead of running system diagnostics during temperature elevation.

After the temperature has been stabilized at between 47 and 49°C, all SM diagnostics and the grid fabric exerciser are run. The standby SMPU is then made active and the diagnostics and grid fabric exerciser are repeated. During the second set of diagnostics no major alarms or initializations can occur because of the SM being tested. No more than one hardware-related interrupt in a two-hour interval is allowed. If these requirements have not been met after completion of the second set of diagnostics, the stabilized temperature interval is continued with diagnostics running until a full two-hour interval occurs that satisfies these requirements.

If at any time a failure is encountered, the failure is resolved and the system is soaked for a 15-minute interval before proceeding. Furthermore, if a failure occurs during either temperature elevation or depression, the temperature is held constant during the 15-minute soak interval following resolution of the problem.

After the SM has passed the heat test requirements, the temperature is allowed to return to the normal ambient level. The active SMPU is switched every 5 minutes while this occurs. When the temperature has returned to normal, all diagnostics and the grid fabric exerciser are run one more time. Any problems encountered are resolved. After this final verification at room temperature, SMST is complete.

The first two SMs for each office are tested in SMST before other SMs for the office so that these SMs will be available for MMST. The following section describes the MMST process.

VI. MULTIMODULE SYSTEM TEST

The purpose of MMST is to simulate field operation of the *5ESS* switch in the factory on a limited scale using the first two SMs from an office. This ensures that there is a known working base configuration when a *5ESS* switch is first installed in the field.

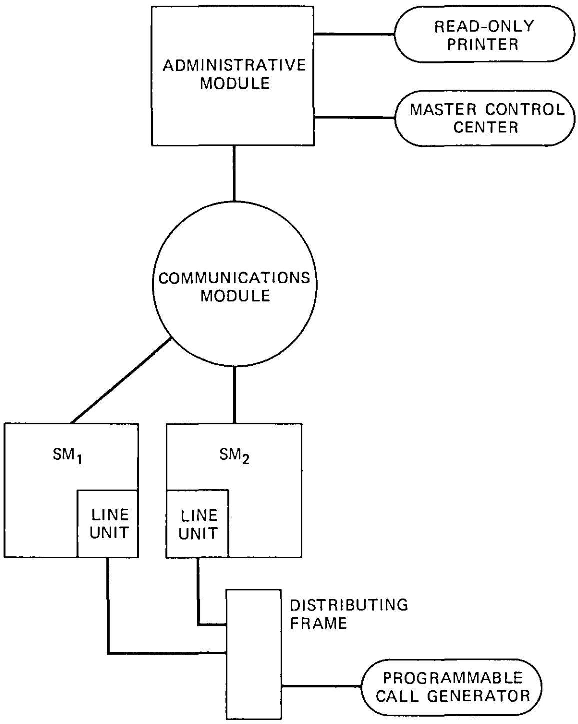

Fig. 4—Multimodule system test configuration.

6.1 MMST configuration

The *5ESS* switching equipment tested at each MMST test position consists of the AM, CM, and SM_1 and SM_2. All the major units in MMST successfully complete either a unit or system test before MMST begins. The AM is fully system tested in the test of the 3B20D computer; in the CM, both the MSGS and TMS are unit tested; and both SM_1 and SM_2 are system tested in SMST.

Each of the pre-MMST unit-test and system-test activities listed above includes a heat test. Therefore no additional heat test is required during MMST. All circuit packs that fail during MMST are replaced with packs that were previously heat tested.

Special test equipment is required for MMST and is permanently installed at each MMST test position. This equipment includes an MCC terminal and ROP that allow factory system test personnel to communicate with the system being tested. A programmable call generator is used to generate calls during MMST call-volume testing. A distributing frame is provided for interconnecting the test lines required for call-volume testing. Figure 4 shows the MMST configuration.

6.2 ODD for MMST

The ODD used during MMST is the same special ODD initially used when a *5ESS* switch is installed in the field. This special ODD, known as Factory and Installation Test Translations (FITTs), contains all equipment-related data required for cutover of the office. The final ODD installed shortly before turnover contains the customer line data. FITTs provides a set of test line data with which both MMST and the installing office perform call-volume testing and operationally test the LUs. Call-volume testing is performed with all LUs in the first two SMs during MMST and with all LUs in the office during installation.

The FITTs database is generated on a support computer in the factory. After MMST the FITTs database is shipped to the field with the system.

6.3 MMST test requirements

The requirements for a system to complete MMST are stated in a specification developed by AT&T Bell Laboratories. Adherence to these test requirements in the factory is verified on sampled MMST configurations by the AT&T Network Systems quality-assurance organization. These requirements are summarized as follows:

1. The AM, CM, and SMs tested in MMST must have successfully passed system testing of the 3B20D computer, CM unit tests, and SMST, respectively.
2. All system cables and cabinets used during MMST must be the same ones shipped with the system. Cabinets tested in MMST must contain the specific plug-in units (including power converters) shipped to the field.
3. All circuit packs, including spares, must meet stress-test requirements before MMST.
4. All diagnostics, including all demand phases, must pass.
5. A call-volume test with the two SMs must be successfully completed.
6. A half-office test must be successfully completed.
7. A full-office link test must be performed for all equipped SM positions.
8. A system-initialization test must be successfully completed.

The next section specifies the MMST testing strategy and contains more details on the call-volume test, half-office test, full-office link test, and system-initialization test.

6.4 MMST testing strategy

MMST testing is performed as specified by a detailed FST procedure. The eight stages of the MMST procedure are described in the following sections.

6.4.1 Preliminary procedures

The preliminary MMST procedures must be completed before MMST testing can begin. The AM, CM, and first two SMs are installed in the MMST test position, and system cables are connected. The MCC terminal and ROP permanently located at the MMST test position are connected to the system. After a complete inspection of the power circuitry to ensure there are no broken fuses, wires, or connectors, a detailed power-up procedure is followed.

6.4.2 AM test

Although the AM has previously completed system testing of the 3B20D computer, additional testing of the AM emphasizing initialization and reconfiguration capabilities is completed in MMST. All AM diagnostics are run with each processor active. After all the AM diagnostics pass, testing can begin on the CM.

6.4.3 CM test

Testing of the CM begins by placing the system in AM min-mode. CM units are diagnosed in the following order: (1) MSGSs, (2) foundation peripheral controller, (3) pump peripheral controller, (4) module message processor, and (5) office network timing control. The office network timing control consists of the message interface and clock unit, TMS, and the DLIs in the two SMs. After all the CM diagnostics pass, testing can begin on the two SMs.

6.4.4 SM test

All diagnostics are run on each SM and any diagnostic failures are resolved. Since the two SMs tested in MMST have already completed SMST, few if any problems are encountered. After both SMs have been successfully diagnosed, the system is ready for the MMST call-volume test.

6.4.5 Call-volume test

The call-volume test is performed in MMST using line-to-line traffic generated by a programmable call generator. Sixteen test lines defined in the FITTs database are connected from each LU to the distributing frame permanently located in the MMST test position. These lines are cross-connected from the distributing frame to the programmable call generator. Both dial-pulse and Touch-Tone signaling calls are generated by the programmable call generator. The hourly call rate used is 750 times the number of line units in the first two SMs. The length of the call-volume test is 12 hours. The following are requirements that must be met before the call-volume test is completed:

1. The call completion rate must be 99.99 percent or greater.
2. There can be no more than one interrupt per 10,000 calls.

3. There can be no more than one audit or single-process purge per 2000 calls.

4. Per-call test failures must be less than 0.1 percent.

5. No more than 0.5 percent of all calls can experience dial-tone delay greater than three seconds.

6. No system inhibits may be set during the test.

6.4.6 Half-office test

During a half-office test the system runs first with one half of the office powered down and then with the other half powered down. All duplicated units in the AM, CM, and SMs are included in this test. The system operates on each half for one hour with a call load. The call-completion rate and system problem counts must meet the criteria specified in Section 6.4.5 for the MMST call-volume test.

6.4.7 Full-office link test

Although MMST only involves two SMs, a comprehensive test of the CM, known as the full-office link test, is performed in MMST to operationally test the CM links associated with all SMs in the office. The NCT links from SM_2 are sequentially connected to each SM position in the TMS from 3 through the maximum SM number. Although the hardware configuration of SM_2 will not necessarily match the ODD for any of the other SMs, the memory of SM_2 can still be successfully pumped while connected to each SM position in the TMS. This link test procedure is repeated as SM_2 is rotated through every equipped SM position in the TMS.

6.4.8 System-initialization test

In MMST the system is tested to ensure that the AM, CM, and SMs can be fully initialized with the generic from either side of the AM using either primary or secondary disk file controllers. No inhibits may be set when this test is performed.

The standard configuration of the *5ESS* switch includes a spare disk drive in addition to the active and standby disk drives. This spare disk drive can be used as a backup for either of the other two disk drives. The final stage of MMST involves testing the spare disk drive and the spare disk. After this test, MMST is complete.

VII. QUALITY-ASSURANCE PLAN

7.1 Quality-assurance requirements

Each *5ESS* switch must meet demanding quality requirements throughout the manufacturing process. The Quality-Assurance (QA) organization applies final factory quality audits following SMST and MMST. Both visual and functional checks are required. A rigorous sampling of *5ESS* switching equipment determines the overall acceptability of the product.

There are two types of operational checks for *5ESS* switches. First, functional audits measure the hardware performance against normal operating criteria. These audits include application of all system diagnostics (SMST and MMST), call-volume testing (MMST), half-office testing (MMST), and system-initialization testing (SMST and MMST). Second, reliability audits measure system performance under stress. Elevated temperatures are applied for 48 hours while the system is heavily exercised using volume traffice (MMST) and system diagnostics (SMST and MMST). The QA organization conducts the audit and it reports statistically derived results based on the equipment sampled.

7.2 Quality-assurance procedures

The QA organization decides randomly which SMs from SMST and which MMST configurations will be audited. The QA organization can perform either a functional audit or a functional audit and a reliability audit. All hardware failures are reported by the QA organization. Additional quality-assurance checks ensure that all equipment to be supplied by the factory is equipped. The factory is responsible for correcting all problems before shipping the system.

VIII. SUMMARY

FST of the *5ESS* switch, the final stage in the factory test process, ensures that each *5ESS* switch shipped to the field meets specific system-level requirements. Consideration of the distributed architecture of the *5ESS* switch in the design of this test process contributes significantly to the cost-effectiveness of FST for the *5ESS* switch. All SMs are tested in SMST, and the first two SMs from each office are tested in MMST with the office's AM and CM. The parallelism that is possible with SMST and MMST results in significant cost savings.

The FST environment provides a more stressful set of conditions for the diagnostics and maintenance software than is normally encountered in an in-service office. However, diagnostic and maintenance features of the *5ESS* switch allow the standard generic program to be used for FST. These features include min-mode, the diagnostic environment, hardware troubleshooting features, and a message routing feature used in SMST.

System-level test requirements that must be met in both SMST and MMST are specified. A quality-assurance program in the factory verifies on a sampling basis that *5ESS* switches either meet or exceed these requirements. Thus, the successful completion of FST for the *5ESS* switch is a major factor in assuring that each *5ESS* switch delivered to the customer will provide high-quality service after cutover.

IX. ACKNOWLEDGMENTS

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ACRONYMS AND ABBREVIATIONS

2SCCS	2 Switching Control System Center
5EDOPS	*5ESS*™ Switch Digital Ordering and Planning System
ABS	average busy season
ALIT	automatic line insulation testing
AM	administrative module
AMARC	automatic message accounting recording center
AMATPS	Automatic Message Accounting Teleprocessing/Tape System
AMATS	Automatic Message Accounting Teleprocessing System
ANI	automatic number identification
AP	administrative processor
APT	automatic progression testing
ASW	all seems well
BORSCHT	battery feed, overvoltage protection, ringing, supervision, coding and decoding, hybrid, and testing
CA	coverage analyzer
CAD	computer-aided design
CAMA	centralized automatic message accounting
CAROT	Centralized Automatic Reporting on Trunks
CCIS	common channel interoffice signaling
CCITT	International Telegraph and Telephone Consultative Committee
C/D	control and display
CDF	combined distributing frame
CDO	community dial office
CEMF	counter-electromotive force
CFM	cubic feet per minute
CI	control interface
CKT	circuit
CLK CNT	clock control
CLM	communication-link monitor
CM	communications module
CMGA	craft message generator analyzer
CMS	Change Management System
COT	central office terminal
CP	central processor
CRA	call record assembler
CTTU	central trunk test unit
DART	debugger for remote target
DBM	data base management, manager
DBMS	data base management system
DCLU	digital carrier line unit

DCTU	directly connected test unit
DF	distributing frame
DFC	disk file controller
DFI	digital facility interface
DI	data interface
DIP	dual in-line package
DL	digital line
DLC	digital loop carrier
DLI	dual-link interface
DLTU	digital line trunk unit
DPC	disk power cabinet
DSC	digital service circuit
DSL	digital subscriber line
DSR	double-sided rigid
DSU	digital service unit
DSX	digital cross-connect
E	equalizer
EADAS	Engineering and Administrative Data Acquisition System
EAI	emergency action interface
EAS	extended area service
ECSA	Exchange Carrier Standards Association
EDLCP	external data link communications package
EE	execution environment
EMF	electromotive force
ESD	electrostatic discharge
ESR	error source register
FC	feature control
FIDB	facilities interface data bus
FITT	factory and installation test translation
FIU	facilities interface unit
FOA	first-office application
FPC	foundation peripheral controller
FST	factory system testing
GDSU	global digital service unit
GDX	gated diode crosspoint
HIC	hybrid integrated circuit
HLSC	high-level service circuit
HOC	host collector
HSM	host switching module
IC	interexchange carrier
IMPU	improved module processor unit
IMR	initial modification request
IOP	input/output processor

ISDN	integrated services digital network
ITS	Integrated Test System
IU	interface unit
LAMA	local automatic message accounting
LATA	local access and transport area
LCR	line concentration ratio
LDSU	local digital service unit
LI	link interface
LNI	line interface
LOTS	Load Originating Test System
LP	large processor
LPCDF	low-profile conventional distributing frame
LSI	large-scale integration
LSP	laboratory support processor
LTD	local test desk
LTP	line trunk peripheral
LTS	laboratory test system
LTS	loop testing system
LU	line unit
MCC	master control center
MCS	microcontrol store
MCTSI/DLI	module controller time-slot interchanger/dual-link interface
MDF	main distributing frame
MECCA	Mechanized Evaluation of Call Completion Anomalies
MHD	moving head disk
MI	message interface
MICU	message interface clock unit
MLB	multilayer board
MLI	message link interface
MLT	mechanized loop testing
MLTS	multiline telephone set
MML	man-machine language
MMP	module message processor
MMST	multimodule system test
MMSU	modular metallic service unit
MMSUG	modular metallic service unit growth
MP	module processor
MR	modification request
MS	message switch
MSCU	message switch control unit
MSG	message switch
MSGS	message switch
MSPP	message switch peripheral processor

MSPU	message switch peripheral unit
MSU	metallic service unit
MUX	multiplexer
NAC	network administration center
NCLK	network clock
NCT	network control and timing
NEBS	New Equipment-Building System
NMC	network management center
OAM	once a month
OA&M	operations, administration, and maintenance
ODD	office-dependent data
ORB	office repeater bay
OSDS	operating system for distributed switching
OSPS	Operator Service Position System
OSS	operations support system
OTC	operating telephone company
P	pairs
PABX	private automatic branch exchange
PAG	program administration group
PC	peripheral control
PCC	program change committee
PCCA	processor controller cabinet
PCFD	power distribution cabinet
PCM	pulse code modulation
PDC	power distribution cabinet
PDL	peripheral diagnostic language
PECC	product evaluation control center
PICB	peripheral interface control bus
PIDB	peripheral interface data bus
PLL	phase-locked loop
PMO	present method of operation
POTS	plain old telephone service
PPC	pump peripheral controller
PPM	periodic pulse metering
PS	power start
PSS	Programmer Support System
QA	quality assurance
R-DFI	RSM digital facility interface
RAU	recorded announcement unit
RC	recent change
RC/V	recent change and verify
RC/V LOCAL	recent change and verify local
REX	routine exercise
RMAS	Remote Memory Administration System

ROP	read-only printer
ROP	receive-only printer
ROTL	remote office test line
RPI	return to point of interrupt
RSB	repair service bureau
RSM	remote switching module
RSS	remote switching system
RT	remote terminal
RTA	routing and terminal administration
RTAC	regional technical assistance center
RTTU	remote trunk test unit
SCANS	Software Change Administration and Notification System
SCC	switching control center
SCCS	Switching Control Center System
SDE	system development environment
SDLC	synchronous data link control
SES	Service Evaluation System
SES-2	Service Evaluation System-2
SGS	Software Generation System
SIU	*SLC*® carrier interface unit
SM	switching module
SMC	switching module control
SMP	switching module processor
SMPU	switching module processor unit
SMST	switching module system test
SP	signal processing, processor
SPC	stored program control
SPP	single process purge
STLWS	supplementary trunk line work station
T&R	tip and ring
TAU	test access unit
TCBH	time-consistent busy hour
TLM	trouble-locating manual
TLP	trouble-location procedure
TLWS	trunk line work station
TMCU	time-multiplexed control unit
TMS	time-multiplexed switch
TMSU	time-multiplexed-switch unit
TNDS	Total Network Data System
TRUMP	trunk maintenance package
TSI	time-slot interchanger
TSIU	time-slot interchange unit
TSPS	Traffic Service Position System

TTF	transmission test facility, function
TTY	teletypewriter
TU	trunk unit
TUCA	tape unit cabinet
UCC	universal conference circuit
UTD	universal tone decoder
UTG	universal tone generator
VDT	video display terminal
VDU	video display unit
VLSI	very-large-scale integration

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