

The 5ESS Switching System:

Maintenance Capabilities

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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-

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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.

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

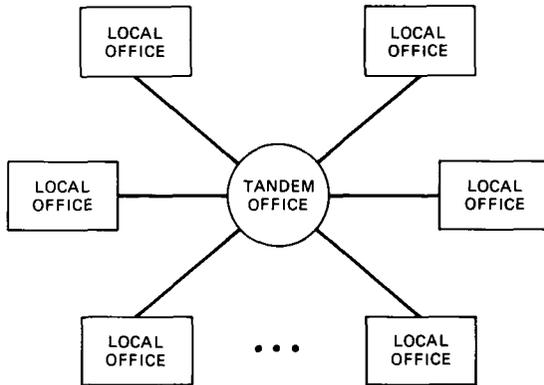


Fig. 1—Network of offices.

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

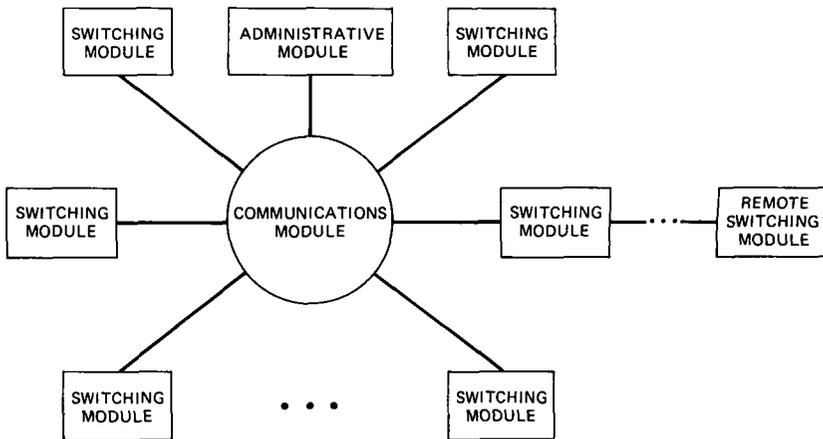


Fig. 2—5ESS switching system.

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

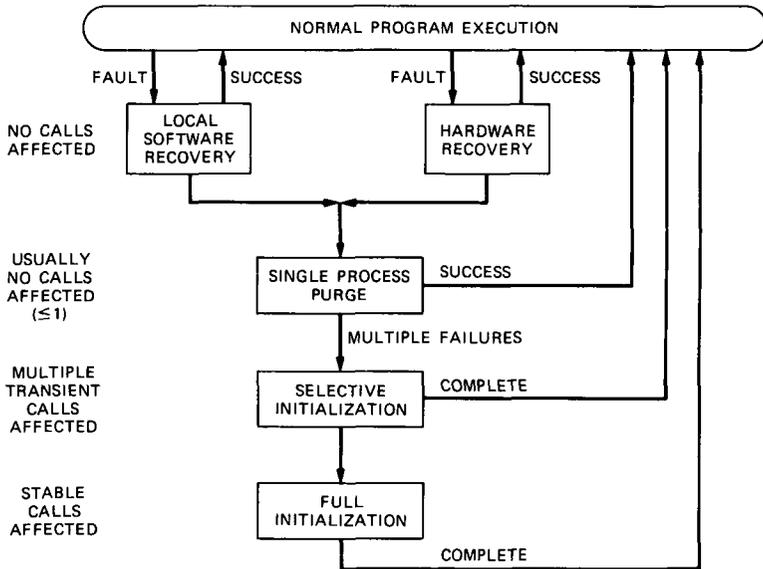


Fig. 3—Switching module recovery and escalation.

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-

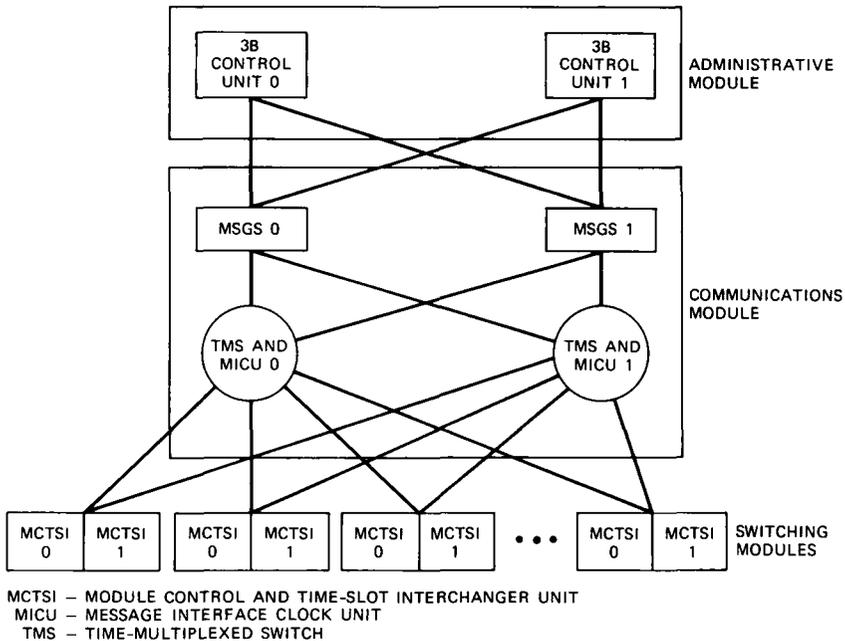


Fig. 4—5ESS switch duplicated hardware architecture.

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

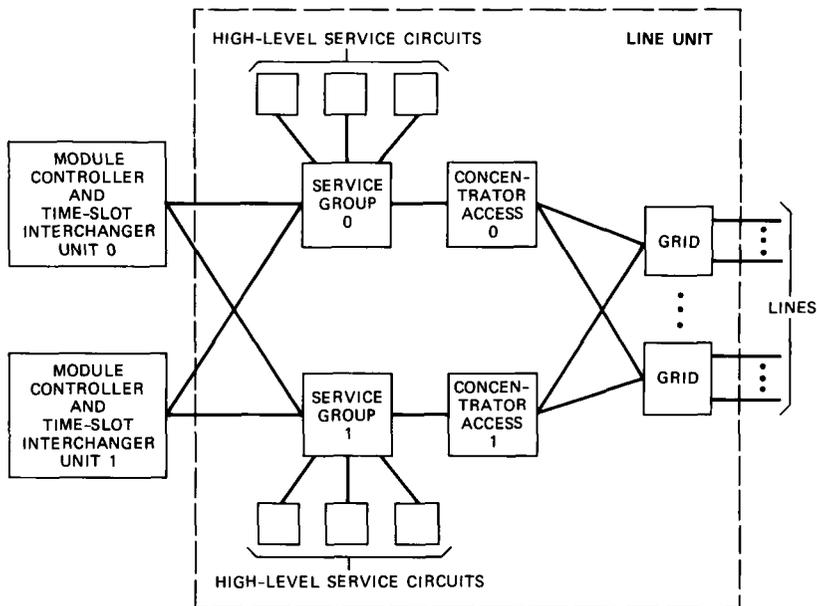


Fig. 5—Line unit redundancy.

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,

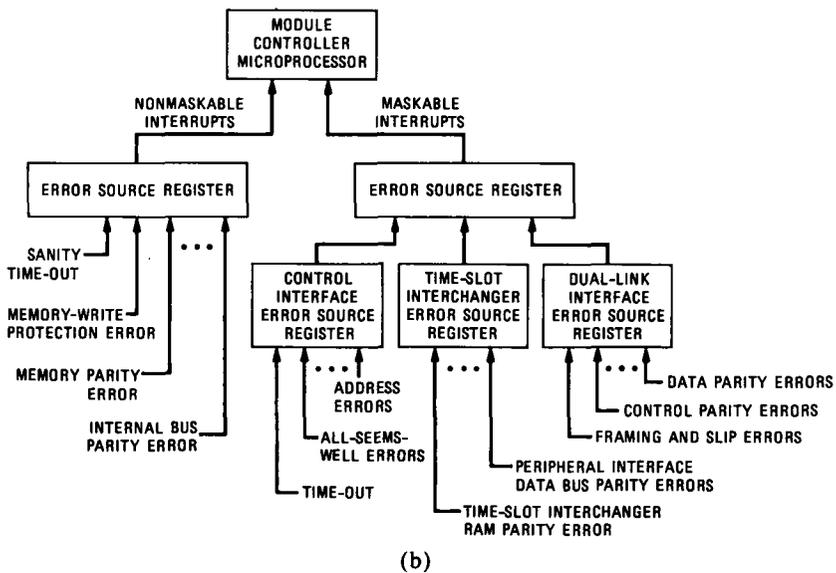
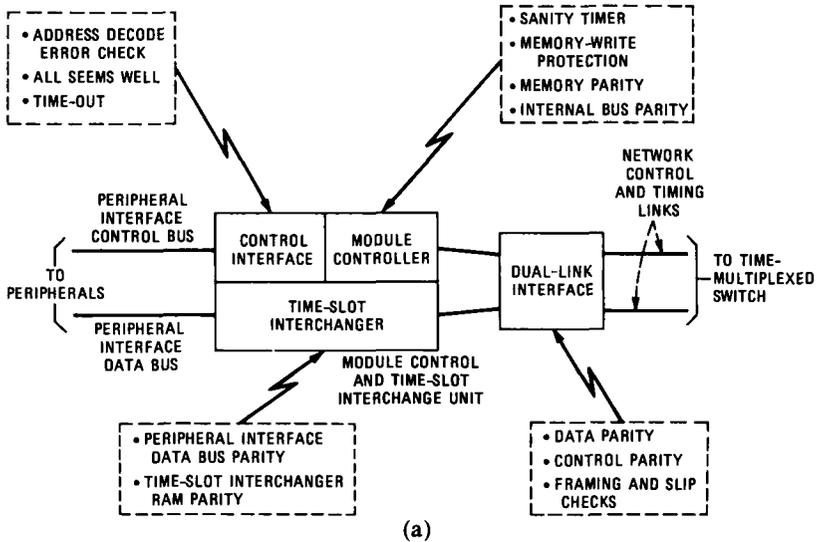


Fig. 6—Typical error-detection and reporting mechanisms for the switching module controller and TSI unit: (a) error detection; (b) error reporting.

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,

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(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

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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 applied 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.

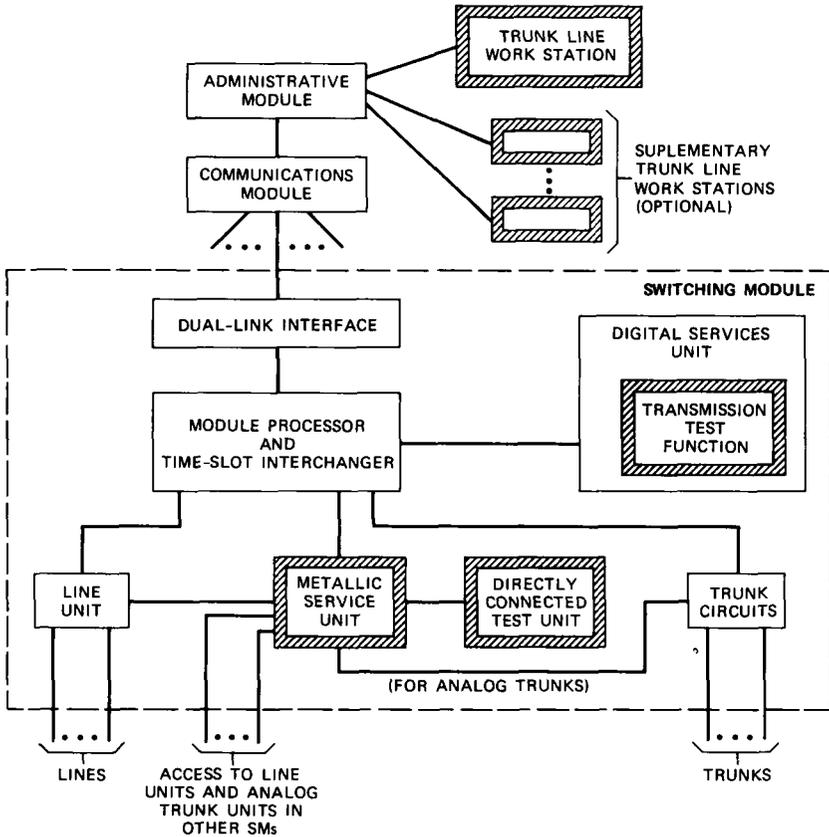


Fig. 8—Principal hardware units supporting trunk and line testing capabilities.

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

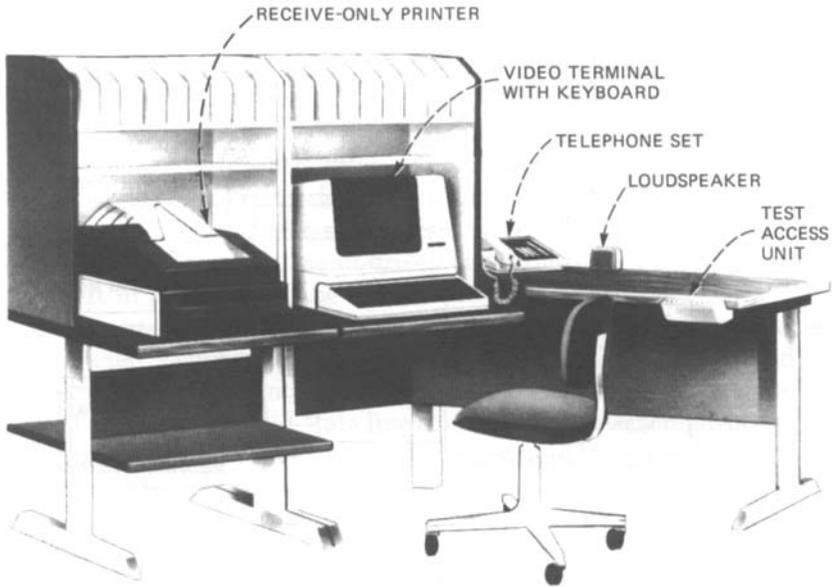


Fig. 9—Master control center with integrated trunk and line work station capabilities.

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

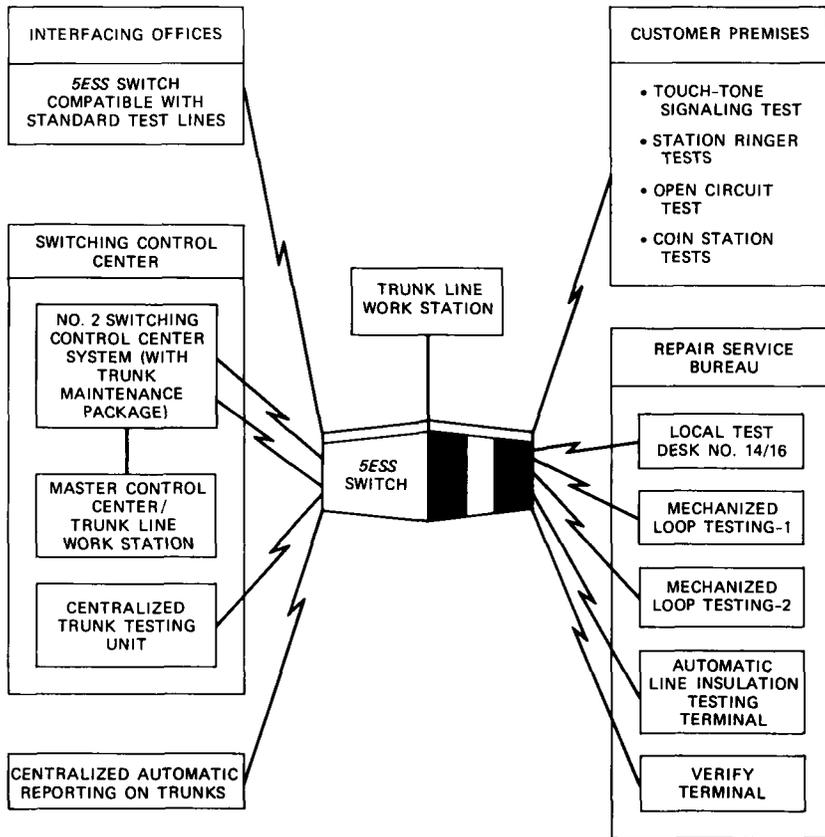


Fig. 10—Trunk and line maintenance remote interfaces.

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 package⁶ 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

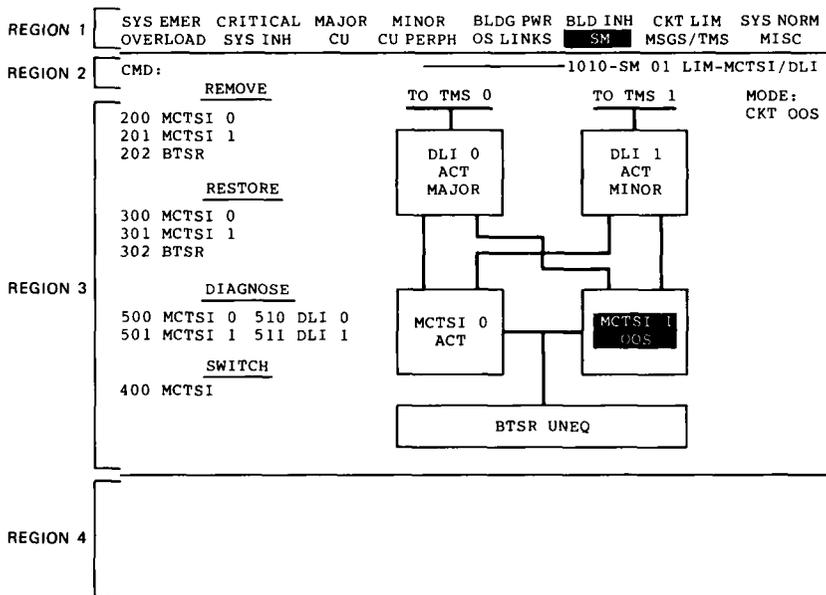


Fig. 11—Video display regions.

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

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 OVERLOAD	CRITICAL SYS INH	MAJOR CU	MINOR CU PERPH	BLDG PWR OS LINKS	BLD INH SM	CKT LIM MSG/TMS	SYS NORM MISC
CMD: 170 OK						161 - TEST POSITION 1	
IN PROG	PORT ACC	TALK	MNTR	E M	RING ROH		
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 OVERLOAD	CRITICAL SYS INH	MAJOR CU	MINOR CU PERPH	BLDG PWR OS LINKS	BLD INH SM	CKT LIM MSG/TMS	SYS NORM MISC
CMD: 176 OK						161 - TEST POSITION 1	
IN PROG	PORT ACC	TALK	MNTR	E M	RING ROH		
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 FEMP	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 OVERLOAD	CRITICAL SYS INH	MAJOR CU	MINOR CU PERPH	BLDG OS	PWR LINKS	BLD INH SM	CKT LIM MSGS/TMS	SYS NORM MISC
CMD: 952 OK								161 - TEST POSITION 1
IN	PORT ACC	TALK	MNTR	E	M	RING	ROH	
PROG								
POSITION DATA			STABLE CONDITIONS			RESULTS		
PORT: 3570001						OC	VOLTAGE (VOLTS)	
TYPE: LINE-DN							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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