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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.

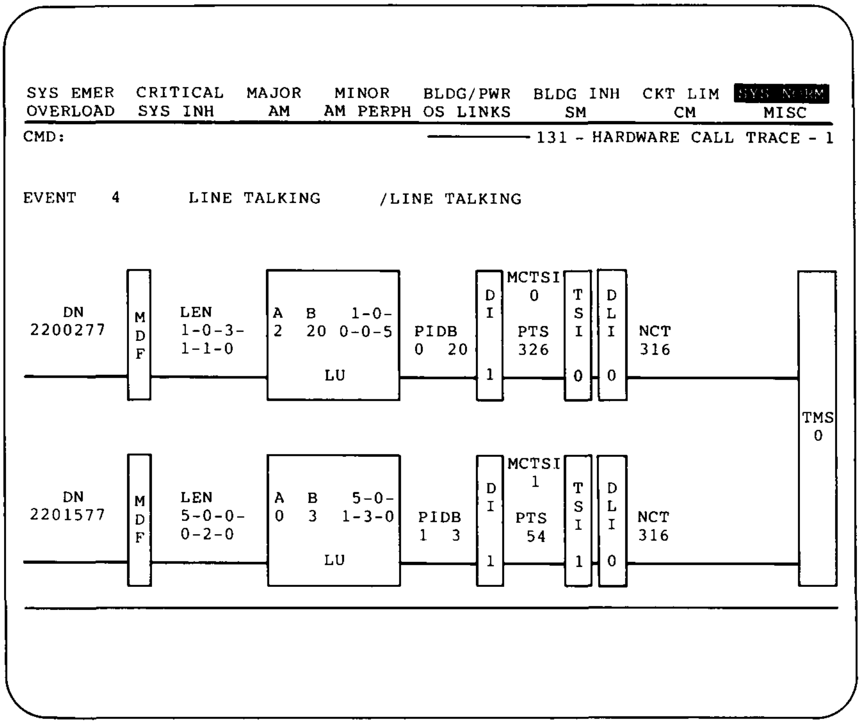

Fig. 1—Utility-call-trace master control center page.

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

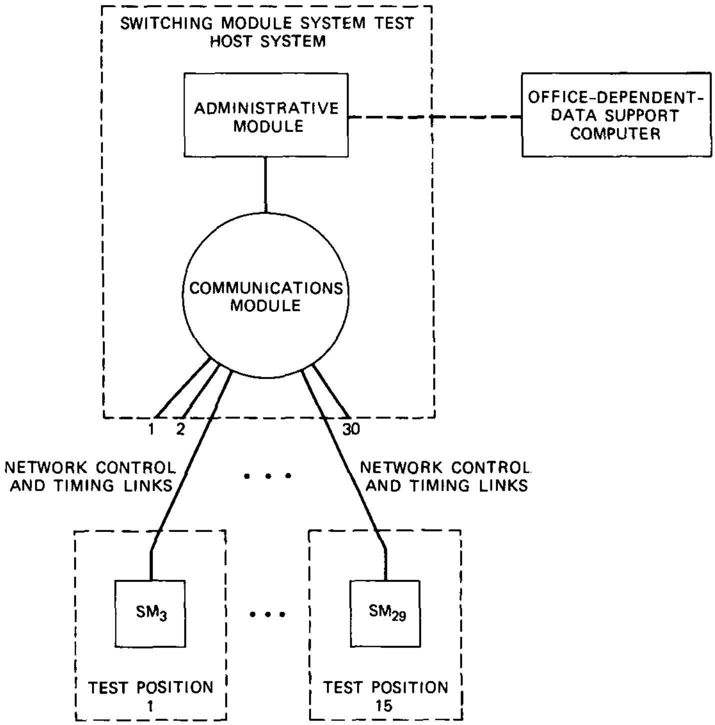

Fig. 2—Switching module system test configuration.

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.

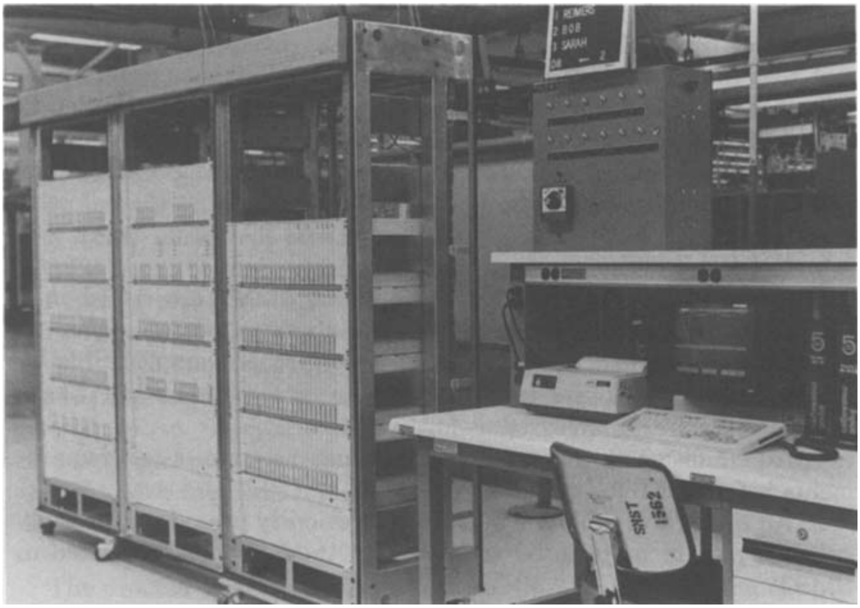

Fig. 3—Switching module system test position.

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.

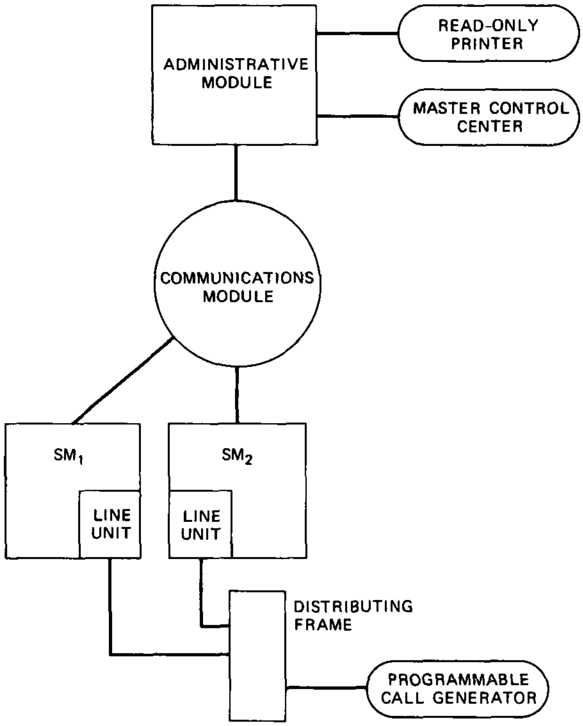

Fig. 4—Multimodule system test configuration.

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.

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