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NCS TIB 89-11

NATIONAL COMMUNICATIONS SYSTEM

TECHNICAL INFORMATION BULLETIN
89-11

4 ESS™ SWITCH
ELECTROMAGNETIC PULSE
ASSESSMENT

VOLUME 1

TASKS 1 AND 2
TEST-BED DESIGN
INSTALLATION, AND BASELINING

SCIENTIFIC AND TECHNICAL
FINAL REPORT

AT&T TECHNOLOGIES
FEDERAL SYSTEMS
CONTRACT: DCA100-88-C-0027

JUNE 19, 1989

SUMMARY

The content of this report is defined by paragraph 3.1 of the Statement of Work for contract DCA100-88-C-0027. This report documents Task 1 and 2, Test-Bed Design, Installation, and Baselining of the 4 ESS™ Switch Electromagnetic Pulse (EMP) Assessment Program.

AT&T has engineered an operational digital 4 ESS switch for the purpose of testing the susceptibility of 4 ESS switch systems to high-altitude EMP. The switch is installed in two specially designed trailers that are transparent to electromagnetic radiation and is located in Colorado Springs, Colorado, where current-injection testing and further performance baselining is presently underway. Batteries, air conditioning, and spare parts are housed in two additional trailers. AT&T Bell Laboratories has developed and implemented a test system for generating current pulses, monitoring the pulses, generating calls, and measuring switch performance. Digital traffic has been successfully generated and switched for three signaling systems: Multifrequency (MF); Common Channel Signaling System 7 (CCS7); and Q.931 (used on direct Integrated Services Digital Network connections). Due to problems in acquiring properly engineered signaling-translation software, however, the CCS7 and Q.931 signaling systems have not yet been implemented with a full complement of trunk assignments. Subsequent tasks will entail further baselining, provisioning of backup methods for the operating software, and current-injection testing of the switch.

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1. PROGRAM INTRODUCTION

In response to Presidential Directive/NSC-53, "National Security Telecommunications Policy," and its reaffirmation in 1983 as National Security Decision Directive 97, the National Communications System (NCS) has undertaken a series of contracts to assess the performance of various Public Switched Network (PSN) telecommunications systems to the effects of nuclear weapons. AT&T has performed nuclear weapons effects assessments of its T1 Carrier System, the FT3C Fiber Optic Transmission System, the D4 Channel Bank, and the 5ESS® Switching System under funding from NCS. The 4 ESS Switch is the dominant switching vehicle in the AT&T Switched Network (ASN). As such, its performance in nuclear weapons environments is crucial to certain NCS national level programs and has been identified as a key to the success of the NCS EMP mitigation program.

A program has been outlined to determine the effects of Electromagnetic Pulse (EMP) on the 4 ESS Switch. The results of this program may be used by NCS to model the performance of the ASN in nuclear weapons environments. The test program designed for the 4 ESS Switch EMP assessment is divided into four tasks:

a. Design and installation of the experimental test bed including the switching system to be tested, the portable enclosures, the EMP test data acquisition system, and the traffic, signaling, and maintenance interfaces to the system under test.

b. Determination of the system performance baseline that will characterize the test-bed performance specifications in an unstressed condition. This data will form the basis of comparison for information gathered during the EMP testing.

c. A laboratory test phase to be performed at the installation site in Colorado Springs, Colorado, which will identify potential vulnerabilities in both hardware and logical operation. The method of testing during this phase will involve isolated electrical stimulation of switch elements through techniques such as current injection. The information obtained in this controlled environment will provide the opportunity for developing solutions to problems that might be encountered under the Air Force Weapons Laboratory (AFWL)/Los Alamos Scientific Laboratory EMP Calibration and Simulation (ALECS) simulator at AFWL in an atmosphere conducive to prompt and economical resolution.

d. Threat-level field testing of the 4 ESS Switch at the ALECS threat-level field simulator.

Tasks a through c are funded under contract DCA100-88-C-0027. This report is limited to the first two tasks: Test-bed design, installation, and baselining.

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2. TEST-BED DESIGN

2.1 DESIGN CONSIDERATIONS FOR THE TEST 4 ESS SWITCH

Each digital 4 ESS Switch is specially engineered prior to manufacture to meet the particular requirements of the network application for which the switch is intended. In order to obtain a switch suitable for EMP testing, designing and engineering a particular switch for this purpose was necessary. The design and engineering procedure was guided by two principal considerations: the purpose of the 4 ESS Switch EMP assessment program, defined within the context of the broader goals of the NCS, and the manner in which the program was to be structured pursuant to these goals.

2.1.1 Program Objectives

The objective of an EMP assessment of the 4 ESS Switch is to gain information about how the PSN might perform when subjected to the electromagnetic environment resulting from a nuclear exchange. Because the role of the 4 ESS Switch is central to the PSN, knowledge of its response to EMP is vital to understanding the response of the network. The metric for the 4 ESS Switch performance must be pertinent to deriving measures of the connectivity and capacity of the PSN as might be used by NCS to program computerized simulations of network functions in various hypothetical scenarios (refer to paragraph 4 for particular measures).

The equipage and construction of the switch must be germane and provide some verisimilitude to real network installations. These requirements suggest particular features the switch should incorporate, such as the types of signaling protocols supported, and therefore, place some constraints on the physical layout of the switch. Moreover, the test switch should also provide for new features that might assume greater importance in PSN traffic than occurs presently.

Finally, the test program must prove credible and supply useful data upon completion which can be correlated with possible network-damage scenarios in a meaningful fashion.

2.1.2 Program Structure

The exigencies and cost of EMP assessing a system as complex as the 4 ESS Switch dictate a multistage program. The difficulty involved in simulating several types of network activity, developing the tools for controlling and recording this activity, and finally distilling the data into a sensible measure of switch performance makes a lengthy baselining period critical. The expense of EMP simulator time, coupled with the inimical work environment at a simulator, renders a preliminary current-injection test phase essential; wherein, the component hardware can be stressed piecemeal in an operational switch and the response modes sorted out.

Clearly the previous considerations can be addressed reasonably only if installation, baselining, and current injection are done somewhere other than the EMP simulator facility. However, the switch must be readily transportable to permit simulator testing. This constraint presented an engineering challenge that had never been attempted for a 4 ESS Switch previously and became the guiding principal in engineering the switch.

2.2 DESIGN GUIDELINES

2.2.1 Size

Since accepted standards in the defense community mandate exposure of an electronic system under a threat-level EMP simulator as the only credible indication of EMP performance, AT&T designed the 4 ESS Switch with this goal in mind. Environmental concerns have limited the choices of EMP simulation to AFWL, while economic considerations suggest the ALECS facility as the simulator of choice. This selection places further limitations on the switch. The switch must be transportable and the office sized to fit within the ALECS test volume, corresponding to a central office equivalent to two 48-foot trailers positioned side by side.

To achieve the goal of a two trailer office, AT&T made every effort to reduce the size of the switch. Partly to this end and partly to establish a uniform standard for switch components, AT&T ordered only the latest generation hardware, such as the cost-reduced Signal Processor (SP) and the newest generation of memory boards for the AT&T 3B20 Attached Processor (AP). This technology will be representative of the hardware present in the network for the near future as switching nodes are consolidated and updated.

2.2.2 Features

Size constraints further militated in favor of a strict distinction between central-office transmission termination equipment and switching equipment. By this definition, the 4 ESS Switch begins functionally with the Digital Interface Frame (DIF), where the incoming (DS1) digital traffic enters the switch. Consequently, the test switch incorporates neither lightguide nor digital radio frames, for example, that might otherwise be found in a toll office.

To meet the network applicability requirement, AT&T engineered the test 4 ESS Switch as a complete stand-alone switch that would operate under unmodified generic software. Features such as Automatic Message Accounting (AMA) that provides billing information for toll calls were eliminated, as was the increasingly obsolete Network Management frame, whose function has been largely obviated by Dynamic Nonhierarchical Routing.

The greatest latitude in the selection of features offered by the test switch is provided by the choice of traffic types the switch is to carry, as reflected principally in the signaling protocols. To account for the bulk of normal toll traffic into and out of the AT&T network, the switch was outfitted to accept MF traffic. Because of the considerable importance of common channel signaling to present and future network architectures, the switch was engineered with a Common Network Interface (CNI) ring, which not only allowed installation of a CCS7 node for Integrated Services Digital Network (ISDN) User Part trunks, but also allowed the inclusion of a D channel node for direct ISDN trunks to the 4 ESS Switch. ISDN will play an increasingly important role in data communications in the next decade.

2.3 SWITCH ENGINEERING

2.3.1 Engineering Methodology

Digital 4 ESS Switch production progresses according to the following procedure. First, engineers at AT&T Communications in Bedminster, New Jersey, develop a list of special features and general service requirements (such as the number of incoming trunks, etc.) based on discussions with the customer, which is then fed into a special computerized high-level design tool known as 4 ESS Switching Equipment Engineering System (4ESEES). The output is a relatively complete listing of the constituent hardware needed to build a 4 ESS Switch to the customer's specifications. AT&T Bell Laboratories conducted the switch specification procedure in this case in consultation with the NCS.

The hardware inventory is subsequently turned over to AT&T Network Systems in Atlanta, where the actual engineering is done. The Network Systems engineers first ensure that all of the core components necessary and appropriate to the customer's application are included. The engineers then draw up a highly detailed listing of required hardware, accounting for subtleties in switch engineering that includes consideration of the specific type and number of circuit packs in a given frame based on knowledge of the variations tolerated within the structure of the operating software of the 4 ESS Switch. The engineers subsequently run a program known as Trunk Assignments Generation System that electronically configures and equips a virtual 4 ESS Switch identically to the specifications to see whether such a machine can support the generic software.

After ensuring that the switch's design is functionally sound, the Network Systems engineers then attend to the physical design of the switch. This design includes apportioning the equipment within each bay, laying out the bays within the available floor space, establishing the interbay and cross-aisle cabling appropriate to the configuration of the switch, determining detailed power loads and air-conditioning requirements and other minor details. When finished, Network Systems releases a blueprint of the floor plan of the switch and the cable routing for the installation crew, and sends an exhaustive compilation of the switch components to AT&T Technologies for manufacture.

Actual 4 ESS Switch assembly proceeds piecemeal, beginning with the shipment of the power plant, followed by switching equipment and site hardware, and finishing with the installation of the Office Data Assembler (ODA) software. The true assembly of the switch is performed by Network Systems installers during the installation phase (paragraph 3).

2.3.2 Engineering Details

The original inspiration for the EMP test 4 ESS Switch is the new 4 ESS Switch in Tampa, Florida, that features exclusively cost-reduced and down-sized new-generation equipment in a compact arrangement that differs from older offices. The AT&T 1A processor lineup of the test 4 ESS Switch mimics the Tampa office and uses what is referred to as the "Tampa" (or "standard, nonstandard") cabling option.

Because the switch will be transported in two semitractor trailers, the layout of the test switch was chosen so as to minimize the number of cross-aisle connections between trailers, connections that must be broken during transport. One trailer contains the 1A and 3B20 processors along with the equipment that interfaces the processors to the rest of the switch, while the other trailer contains the switch units with the equipment that interfaces the switch to the network and the power plants. This trailer also contains the Master Control Console (MCC), which is hardwired to the 1A interface, and consequently, must be moved to the other trailer before transporting.

Because of backup features in the 4 ESS Switch generic software, a functioning switch must contain two SPs and two Time-Multiplexed Switching (TMS) units, although single Timeslot Interchangers (TSIs) and DIFs are permitted. The DIF was engineered to accommodate as many MF receivers and transmitters as possible (32 each), requiring 4 specially located Digital Interface Units (DIUs). Attaching the DIF to the single TSI in a standard cabling arrangement permits only two additional available DIUs in the DIF, yielding a total of 720 usable trunks. Although SPs normally comprise both a left and a right matrix, in growing existing offices to accept additional trunks, left-matrix only SPs are frequently added incrementally. The small size of the 4 ESS Switch EMP office permits the single-matrix SP size reduction for the primary SPs. Moreover, the absence of AMA record-keeping needs permitted a reduction in the Call Store/Program Store capacity, shortening the processor lineup. The Ring Node (RN) cabinet necessitated by the inclusion of the CNI ring is situated at the end of the processor lineup.

2.4 SWITCH DESCRIPTION

2.4.1 Functional

A 4 ESS Switch can be thought of as a digital computer that has the capability to intermingle data streams and switch the data streams among ports. The core of this device is the 1A processor, and the Central Control (CC) may be thought of as its Central Processing Unit, the Call Store is its Random Access Memory, and the Program Store is its Read Only Memory, where the "operating system" and information about trunk-group timeslot assignments, etc., is contained. Because of the enormous memory demands on the processor, a separate AP, the 3B20, is added as a more permanent memory management module. The AP also happens to be the host processor for the CNI ring.

The processor accomplishes its switching tasks by spatially and temporally interchanging the digital data assigned to particular timeslots in different data streams. If the TMS and TSI frames that perform this switching are thought of as processor peripheral devices, then the SPs and DIFs may be thought of as the buffers and device drivers for the 1A processor.

Communication between the 1A and its peripherals (SPs, TMS, etc.) is carried by the Peripheral Unit Bus, which passes through the Processor Peripheral Interface (PPI) and is distributed to the peripherals through the Peripheral Unit Branching Bus (PUBB). Direct communication between the 1A and the external world is effected through the Input/Output Processor (IOP). The Attached Processor Interface (API) handles communication between the AP and the 1A.

Finally, numerous support functions for power supply, conversion, and distribution; switch telemetry and maintenance; and various miscellaneous activities such as ringing and tone generation are required for the 4 ESS Switch to operate and switch traffic intelligibly. These functions are provided for by the remaining bays.

2.4.2 Physical

The floor plan of the EMP test 4 ESS Switch appears on Figure 1, and a list of frame-by-frame abbreviations is given in Table 1. Briefly, there are four lineups, the MCC, the 415 (140V) power plant and the 3B20 processor. The first lineup, starting from the bottom, may be thought of as the processor lineup; the second, the switching-device interface; the third, the switching lineup; and the fourth, the power lineup.

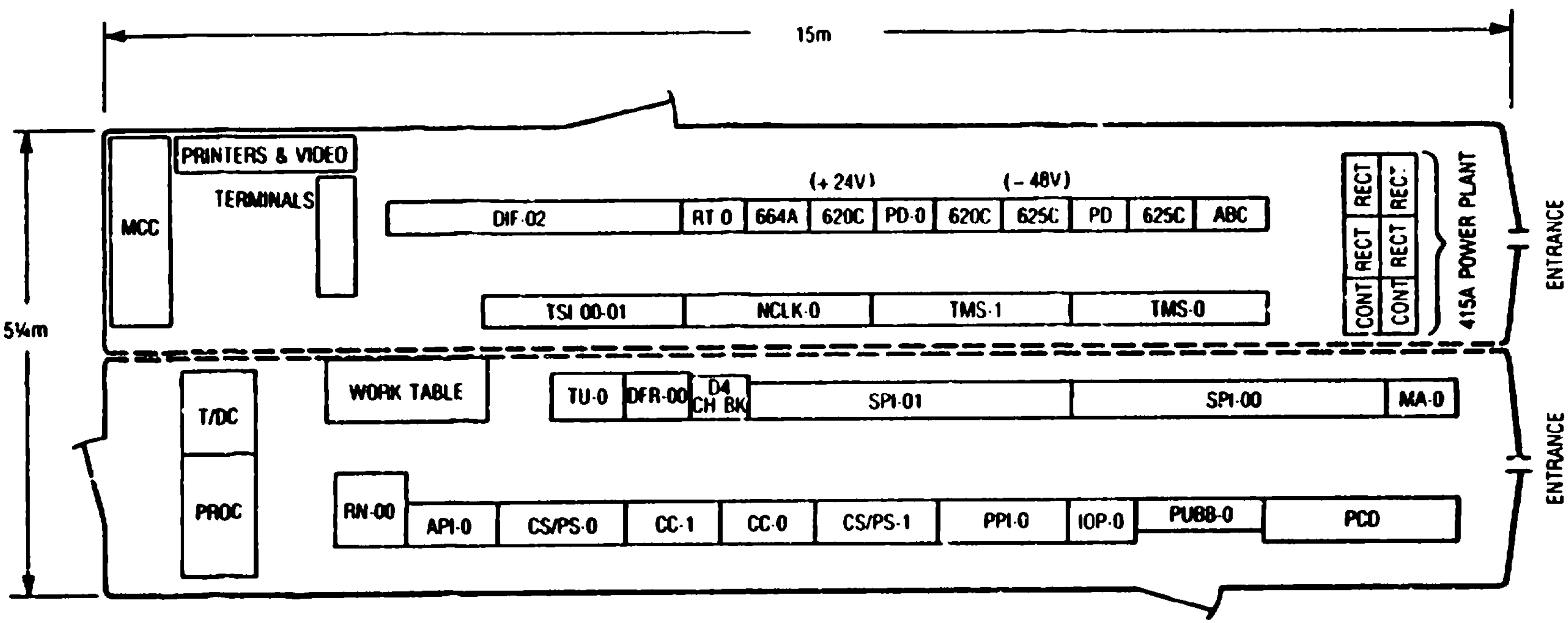

Figure 1. Floor plan of the 4 ESS Switch test trailers.

TABLE 1. Frame-By-Frame Abbreviations.

ABBREVIATION	DEFINITION
ABC	Area Bus Center
API	Attached Processor Interface
CC	Central Control
CONT	Power Control and Distribution
CONV	Power Conversion
CS/PS	Call Store/Program Store
D4	D4 Channel Bank
DFR	Digital Facility Rack Frame
DIF	Digital Interface Frame
IOP	Input/Output Processor
MA	Miscellancous A Frame
NCLK	Network Clock
PCD	Power Conversion and Distribution
PD	Power Distributing
PPI	Processor Peripheral Interface
PROC	3B20 Processor
PUBB	Peripheral Unit Branching Bus
RECT	Rectifier
RN	CNI Ring Node Cabinet
RT	Ringing and Tone Frame
SP1	Signal Processor 1
T/DC	Tape/Disc Cabinet
TMS	Time-Multiplexed Switch
TSI	Timeslot Interchange
TU	Tape Unit

3. INSTALLATION

The installation plan for the 4 ESS Switch EMP Assessment Program involved consideration of many significant aspects. This paragraph will attempt to highlight those areas, provide the rationale for the decisions reached, and report the end results or current status.

3.1 EQUIPMENT SHELTERS

The Statement of Work required the preparation of a switch for current-injection testing that could later be transported to ALECS for EMP testing. To provide the required portability and to incorporate experience gained on the 5ESS Switch EMP program, a series of trailers was used.

3.1.1 Switch Trailers

The floor space required for the 4 ESS Switch exceeded the area available in a standard trailer. In order to accommodate the switch and eliminate any special transportation handling required for oversized loads, two trailers were modified so that the trailers could be mated to provide a large floor area. Discussions were conducted with a trailer fabricator to verify that the mating was a viable alternative. Two 48-foot long, fiberglass reinforced plywood, air-ride trailers were then ordered and delivered to TRAFCO, Trailer Repair and Fabricating Company, Inc., for modification.

TRAFCO was contracted to modify the trailers per AT&T Bell Laboratories specifications and to construct all necessary hardware required for mating and hoisting the trailers. The mating of the two trailers required the trailers be parked parallel to each other with roughly 3 feet of space between the trailers. Special hardware was then installed on the underside of the trailers to accommodate 20-foot long roller conveyers. The air-ride suspension was overinflated to allow sufficient clearance so that the long roller conveyers could be positioned within the hardware on the underside of both trailers.

The air ride was then deflated so that the weight of the trailers was supported by the roller conveyers. Each trailer had one wall that was modified into nine removable panels which were removed. The trailers were then pushed across the rollers until butting against each other, at which time the trailers were attached together to provide a continuous floor area.

In addition, TRAFCO installed electrical outlets and lighting, access doors, and a raised floor. The raised floor was installed to ensure that any equipment mounted in the trailer would be isolated from the steel structure on the underside of the trailer. Upon completion of all work, TRAFCO loaded the trailer with 20,000 pounds of ballast to simulate the weight of the switch, and performed the junctioning procedure and hoisting procedure. Both procedures were performed successfully, demonstrating that the sectioning of the trailer wall did not compromise its structural integrity.

3.1.2 Battery Trailer

The 4 ESS Switch requires a 140-volt battery plant, supplied by 70 2-volt round cells. In order to transport these batteries and keep setup time to a minimum, AT&T mounted the batteries permanently in a separate trailer. For this purpose, a used 46-foot long insulated trailer was purchased. This trailer also contains a chilled-water tank and serves as a transport vehicle for the air-conditioner compressor unit. (Refer to Figure 2.)

3.1.3 Equipment Trailer

This trailer serves as a storage trailer for spare circuit packs and other equipment. AT&T purchased a used 48-foot long trailer in which shelves were built to hold circuit packs. This trailer can also serve as

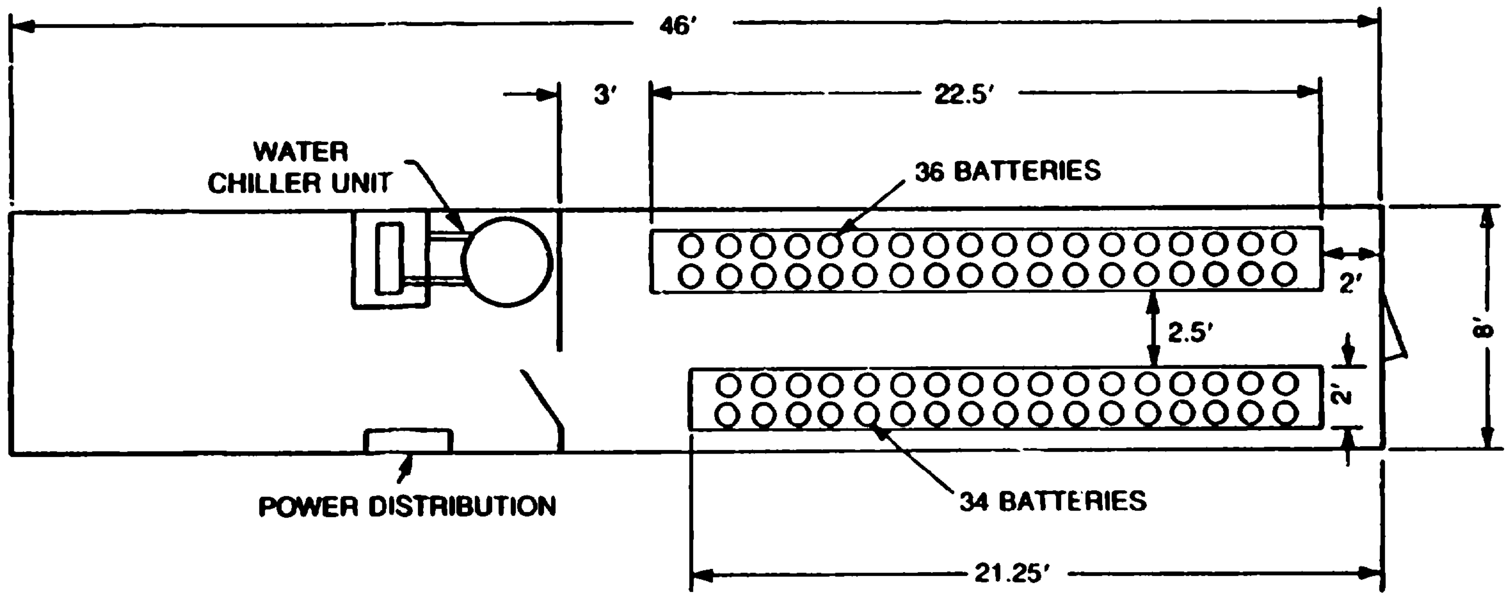

Figure 2. Floor plan of the air-conditioning and battery trailer.

a transport vehicle for the switch trailer junctioning and hoisting hardware, tools, and the test and monitoring equipment.

3.2 INSTALLATION SITE

Colorado Springs, Colorado, was determined to be the optimal location for installation. The Network Systems installation group based in Colorado Springs has experience in EMP and lightning assessments. This experience enhances the ability to cope with nonstandard installation requirements. Through experience in the 5ESS Switch assessment, this group has developed relationships which often quickly enable the acquisition of materials or technical assistance.

In addition, Colorado Springs was chosen because of its proximity to Kirtland Air Force Base, thus eliminating costly cross-country trailer transportation, and a lower cost of warehouse space than New Jersey or Illinois.

A group from AT&T surveyed a number of warehouses in the Colorado Springs area. The warehouse had to be large enough to facilitate driving in four trailers and provide enough space for offices and to set up call generation and data-gathering equipment. The facility chosen was a 9800-square-foot warehouse at 760 Geiger Court in Colorado Springs. (Refer to Figure 3.)

3.3 PREINSTALLATION PREPARATION

3.3.1 Switch Floor Plan

Prior to delivery of the trailers and switch to Colorado Springs, Bell Laboratories and Network Systems developed a floor plan for the 4 ESS Switch to be mounted in the switch trailers. The switch floor plan was arranged to keep cabling between the two trailers to a minimum. This floor plan reduced the number of cables requiring connectorization, and thus will expedite the tearing down, reassembly, and powering up procedures. The floor plan also offered a smooth flow through the office's limited space and a small work area. (Refer to Figure 1.)

3.3.2 Air Conditioning

The 4 ESS Switch generates a great deal of heat, and without some type of air-conditioning equipment, overheating could become a problem. Bell Laboratories personnel, in conjunction with AT&T-Network Operations Group Western Region engineers, consulted with W. D. Moreland Contracting to engineer an effective air-conditioning system around the set floor plan. Moreland suggested a chilled-water system which would circulate cold water through fan coil units mounted in the switch trailer and would not interfere with the equipment. Moreland was contracted to acquire and install this system, and floor space was allocated in the battery trailer to accommodate the chiller and compressor. (Refer to Figure 2.)

3.3.3 Warehouse Power

Based on the power requirements of the 4 ESS Switch, the outside power to the warehouse had to be modified. Berwick Electric was contracted to provide the warehouse with two 208-volt, three-phase, 400-ampere disconnect panels.

3.3.4 Maintenance and Support

Prior to installation, various maintenance and support items were identified to ensure that the test switch was operated at the most efficient level. Network Systems arranged for the switch to be on distribution for all ongoing Change Notices and Broadcast Warning Messages in order to remain

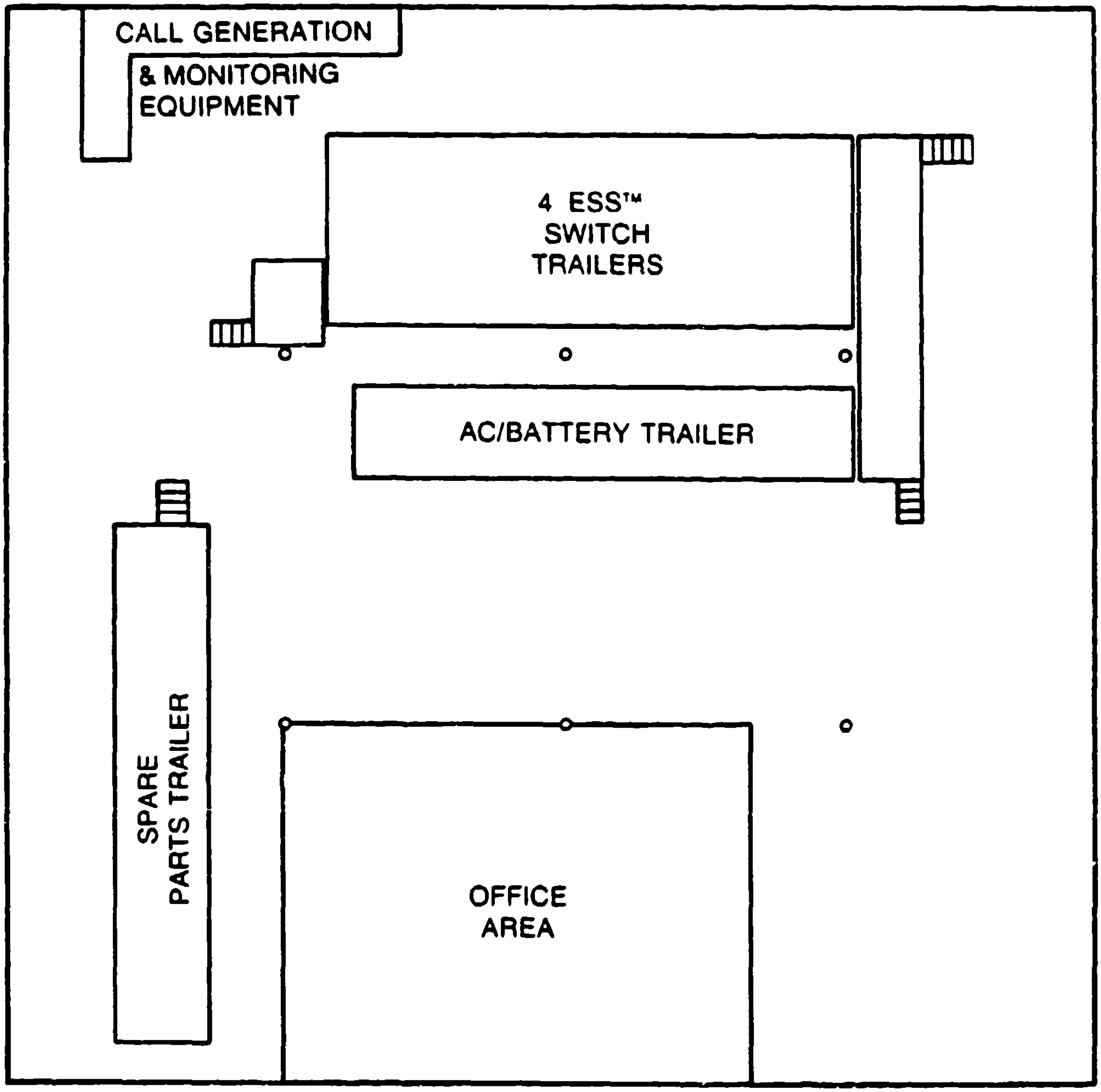

Figure 3. Layout of test system in warehouse.

appraised of any solutions for problems discovered in the field. In addition, phone lines were arranged to link the test switch with the Regional Work Center in Denver, Colorado, in order for technical support personnel to access and monitor the output of the switch. Finally, a technician was assigned to be onsite as part of the test team.

3.4 EQUIPMENT INSTALLATION

On September 26, 1988, the trailers were delivered to the warehouse. The switch trailers were positioned in the warehouse and assembled. The battery trailer was positioned followed by the equipment trailer.

By October 13, 1988, switch delivery and installation began. Because of the limited space within the trailers, the switch equipment was loaded and installed in a sequential manner corresponding with the floor plan. Fork lifts, frame dollies, and brute force were used to get the equipment in the trailers. After all equipment was loaded and secured in the trailers, installation of the air conditioning and frame and power cabling began.

3.5 SWITCH POWER UP

By November 28, 1988, full power was applied to the switch and the basic 4 ESS Switch software and hardware troubleshooting began. Correcting all detectable problems before the generic software was loaded was necessary. The generic software was loaded on January 26, 1989. The ODA tape was received and loaded February 6, 1989. Office translations were entered onsite and that work was completed by March 24, 1989. Though the office was turned over on March 10, 1989, troubleshooting continued on D channel and CCS7 links until April 13, 1989.

Befo. current-injection testing begins, the switch backup system will be tested. The switch will be taker out of service and then restored to service using the backup tapes. This feature will ensure that, in the event of a complete shutdown, the switch can be brought back to its original state.

3.6 TEST MONITOR AND DATA-GATHERING EQUIPMENT

On February 15, 1989, all test-monitoring, call-generating, and data-gathering equipment was delivered to the warehouse from Holmdel, New Jersey. The equipment was arranged in the warehouse (refer to Figure 3) and integration into the switch began. Phone lines were installed so that the computers could be accessed and monitored from Holmdel.

4. BASELINING

The purpose of the baselining period is to measure the performance of the switch in a nonstressed state and to form a set of responses against which the responses of the switch in a stressed environment can be compared. Some of the measurements depend upon the system used to make the measurements actually characterizing the switch – test equipment system. General parameters may be derived from the parameters measured directly, but the raw characterizations of switch performance may depend on the testing system. Thus, this period is also used as a shakedown of our test system.

A nonstressed switch is being characterized, before being subjected to current injection. The parameters being measured are indicative of the switch's operation. However, as in any experimental program, the data generated during the current-injection phase may suggest other parameters, not mentioned here, that may better describe the switch's performance. Those parameters will then be measured and reported in the current-injection report.

This paragraph describes the system used to measure the performance and response of the switch and the parameters to be measured. At this time, not all of the testing has been completed for full baseline characterization of two of the three signaling methods.

4.1 CALL GENERATION AND DATA ACQUISITION SYSTEM

The call generation and data acquisition system is based on a network of AT&T 3B2 computers. One computer is dedicated to the acquisition and analysis of the physical quantities (current, field level, etc.), while the other two share the tasks of generating and monitoring calls on the 4 ESS Switch. The computers are interlinked so that information contained in any one of the computers is accessible to any other. While optimal performance is obtained with all three computers, the system might be able to operate at reduced capacity with only two of the three.

4.1.1 Physical Data

The physical data acquisition and analysis system is based on a 3B2 computer contained on a VME card. This card plugs into a VME backplane, into which other modules (disk drives, terminal drivers, etc.) are mounted. The computer accesses the information to record and analyze through an IEEE-488 bus connected to a CAMAC crate. The plug-in modularity of the CAMAC system can be used to tailor the system to suit the requirements of the test. For this test, to record the rapidly changing and transient physical data, 4 LeCroy 6880B digitizers are being used that digitize signals with 8-bit resolution at the rate of 1.3 GHz. A schematic view of this system is given on Figure 4.

The software to control and read back information from the transient digitizers was written by Bell Laboratories. An analysis system was developed which allows the user to access and analyze the data easily.

A much simpler AT&T PC-based data system, without the data analysis capabilities, serves as a backup means of data acquisition, if necessary.

4.1.2 Generating Stress

Currents and voltages will be injected into the system by one of two Marx generators, capable of generating up to 180 kV. The output of these generators will be injected at various points of the switch through direct injection or current transformers. The generators will be triggered by signals from the 3B2 computer through the CAMAC crate (refer to Figure 4).

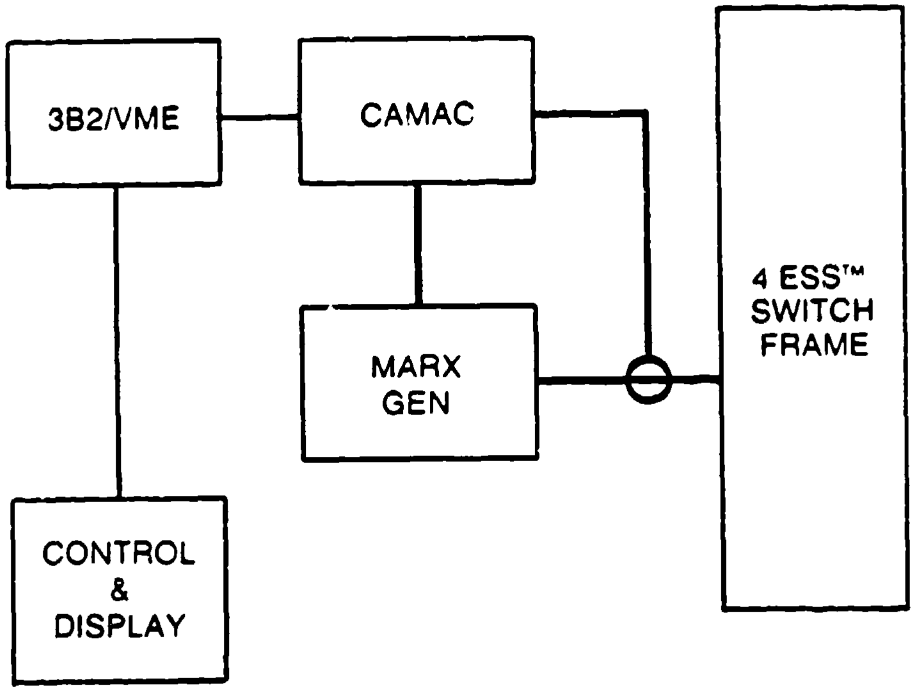

Figure 4. Schematic of data acquisition system.

4.1.3 Call Generation System

Three types of signaling are employed on the switch: MF, CCS7, and Q.931 (used for ISDN). Since the switch communicates to trunks solely at the DS1 rate (1.544 Mbps), the call generators generate the signaling necessary to control trunks at this rate. The point of interface to the switch is at the Digital Interface Frame (DIF), which is where all the trunks controlled by the call generators enter the switch.

The call generators are under the control of two 3B2/600 computers, which direct the call generators to place calls and keep track of information relating to the completion of the calls. A schematic of the call generation system is shown on Figure 5.

4.1.3.1 Multifrequency Signaling. MF signaling is an inband signaling system, similar to touch-tone signaling on local exchanges. Tones, corresponding to the digits of a number, are outpulsed to the switch to identify the desired destination. Seizure of the trunks is indicated by E and M leads. When the 4 ESS Switch seizes a trunk, the M lead is raised, and when the call generator seizes the trunk, the E lead is raised. The particular type of signaling used on the switch is MF Wink Start, in which the switch has to acknowledge a seizure of an incoming line by raising the M lead, and quickly lowering the lead back down (a "wink").

To generate MF calls, five specially modified Ameritec AM1 PLUS-D T1 bulk call generators are used. Each unit can generate up to 30 calls simultaneously on any of the 72 trunks contained in three T1 lines. Calls are made that terminate back on the unit, and voice path checks are made in both directions (originating line to terminating line and terminating line to originating line). Other information relating to call completion is obtained, specifically, the time between seizure of a line and the switch's acknowledgement, and the time between digit outpulsing and seizure on the terminating line.

Two different types of calls will be placed on the switch. One type, called transient calls, will be made to assess the switch's ability to route calls continuously. Once a call has been completed and the connection verified, the call will be immediately torn down and another call placed. The other type of call, called stable calls, will be made to determine the fraction of calls already made that will remain standing after an EMP. These calls will be established at the beginning of a test and will remain connected until dropped by the switch or the end of a test.

To control and receive call data from the call generators, special software was written for the 3B2 computers. This software helps the user choose call parameters for the trunks on which calls will be placed, downloads this information into the call generators, and starts the call generators placing calls. For the transient calls, the units are periodically queried for information on calls that have recently been placed. New telephone numbers and trunks are then chosen randomly for the next period of time, and the units then make more calls. This cycle stops either after a predetermined time limit, or the user stops the process.

For stable calls, the units are continuously monitored for trouble messages indicating that the stable calls have dropped (or been reinstated). The absence of these messages indicates that the calls are still up.

The 15 T1 lines from the five Ameritec units pass into the trailer through a patch panel and then terminate on the DIF. (Refer to Figure 5.) Our initial configuration is to use two units to generate stable calls, while the other three units are to generate transient calls.

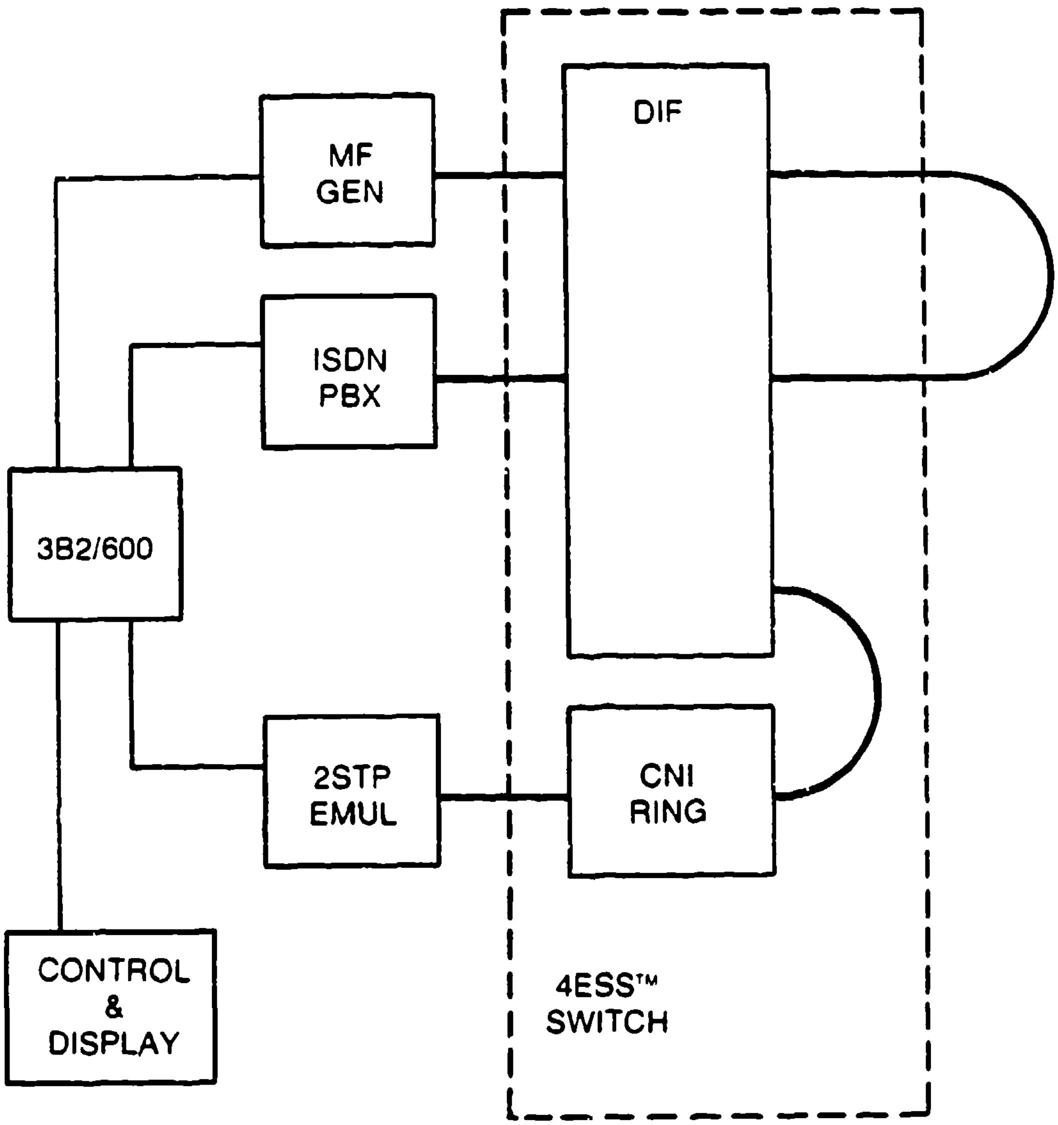

Figure 5. Schematic of call generation and monitoring system.

In order to increase the throughput of the switch, MF calls are routed on only the first three digits. This procedure reduces the holding time of the MF receivers and transmitters, and also reduces the setup time of the call. These units can each generate about 14,000 calls per hour. The three dynamic units should thus be able to generate about 42,000 calls per hour.

4.1.3.2 CCS7. The CCS7 system is an out-of-band signaling system, relying on a network of Signal Transfer Points (STPs) to relay messages from one switch to another. When a switch routes a call to another switch using CCS7, the switch sends messages to an intermediary (the STP), using CCS7 protocol, over a 56 kbps link. The STP forwards the CCS7 messages to the terminating switch and relays back any messages for the originating switch from the terminating switch. If and when the switches agree to set up the call, then the appropriate connection is made over the connecting trunks, and the call proceeds.

In the test system, an STP Emulator, developed by Bell Laboratories at Indian Hill, Illinois, is used. The STP Emulator, when sent a call setup message destined for a terminating switch, will change the contents of the message so that the message appears as if the terminating switch is sending a message back to the test switch to request a different call setup. When the test switch sends back an acknowledgement to this latter setup message, the STP Emulator again changes the message around, making the message appear as if the terminating switch is sending this acknowledgement to the original call setup message. Other messages are treated similarly, so that the 4 ESS Switch under test is fooled into sending all the CCS7 messages needed to complete a call. The DS1 voice trunks controlled by these messages are looped back to each other so that, when the signaling finally establishes the call, audio messages sent out on one trunk will return to the switch via the looped back trunk. (Refer to Figure 5.) Control of the STP Emulator is effected by one of the 3B2/600 computers.

This loopback process is utilized to make CCS7 calls with the MF generators. The MF generator outpulses digits corresponding to a CCS7 trunk and an MF trunk. The switch routes the call based on the CCS7 digits but deletes the CCS7 digits when sending the setup message to the terminating switch. When the STP Emulator routes the call back to the switch, the switch perceives that the other switch is attempting to terminate a call back on the originating switch. With no CCS7 digits, the incoming CCS7 call is then routed to the MF trunk specified by the MF digits remaining. One may imagine this procedure in this way: the MF digits correspond to particular lines on the switch, while the CCS7 digits correspond to a particular area code. If only MF digits are outpulsed, the switch routes the call as a local call in its own area code. If there are CCS7 digits outpulsed, the switch interprets this call as going to an area code specified by the CCS7 digits and routes the call to a trunk going to that area code. Since the far-end switch is aware of its own area code and does not need these digits to route the call, the test switch removes these CCS7 "area code" digits from the number, and sends the call out over CCS7 to the terminating switch. When this call returns via the STP Emulator to the switch, all that remains of the number is the MF (local) digits, which the test switch then proceeds to route in the normal (local) manner to one of the MF call generators.

The information obtained from the CCS7 calls will be the same as that from the MF calls. Hence, the software controlling and monitoring the MF calls will also do the same for the CCS7 calls.

In the initial configuration, the Ameritec call generators will route approximately half of the calls to CCS7 trunks, in the same way as routing the MF calls. Thus, the number of CCS7 calls placed will not be greater than the number of MF calls placed. If one-half of the expected 42,000 MF calls per hour are placed through CCS7, this corresponds to about 21,000 CCS7 calls per hour.

4.1.3.3 Q.931 Signaling. The third type of signaling used is the Q.931 signaling for ISDN. Q.931 signaling is another out-of-band signaling used on a channel (called the D channel), which does the signaling for other channels (called B channels). The 4 ESS Switch interface with the Q.931 signaling is at the primary rate interface, 1.544 Mbps, corresponding to one D channel with 23 B channels (23B+D). One D channel may control up to 479 B channels in a format of 479B+D. These channels, all at the DS1 level, terminate on the switch at the DIF. In a normal switch, up to 24 D channels arriving at the DIF are put on permanent routes through the switch ("nailed up") to the CNI ring, where the signaling information is decoded. This information is then forwarded to the 1A to route the other trunks (B channels) through the switch. (Refer to Figure 5.)

In the tests, AT&T is simulating two PBXs with Q.931 signaling into the 4 ESS Switch. The D channel signaling is generated by two cards developed by Bell Laboratories in Denver that plug into the two 3B2/600 computers. These cards generate a DS1 signal with only D channel information. Additional Bell Laboratories software controls these cards, and places and tears down calls.

In order to verify the continuity of the B channel paths through the switch, these DS1 channels are sent through two Coastcom D/I II Drop/Insert Multiplexers. Here, 9600 baud signals from terminal ports of the 3B2 computers are inserted onto some of the timeslots of the DS1 bit stream. When the boards on the 3B2 computers are informed by the switch that a connection exists between two B channels and, therefore, between two terminal ports of the 3B2 computers, these two ports send messages to each other. When these messages are received properly, the continuity of the B channel connection is assured.

In order to generate an appreciable number of calls, not all B channel connections are checked by the 3B2 computers. Checking continuity requires about 20 seconds, and the calls need to be placed more frequently than that. An objective is to check between 5 percent and 15 percent of the connections made, with an anticipated call rate of about 18,000 calls per hour.

4.2 SWITCH PERFORMANCE

4.2.1 Normal 4 ESS Switch

The capacities and capabilities of a "normal" 4 ESS Switch are driven by its preeminence in AT&T's long distance network and in several RBOC's large metropolitan plants. The 4 ESS Switch has been engineered to allow for a maximum of 107,520 trunk connections, enabling a peak call attempt rate of approximately 600,000 calls per hour. The overhead used in reaching this call attempt rate effectively limits the actual number of trunks to about 80,000. Not all 4 ESS Switches have this capacity, since each switch is custom built to meet the actual and prospective demands of its environment. Typical 4 ESS Switches have 50,000 to 60,000 trunks attached, with peak busy hour loads of about 400,000 to 500,000 call attempts per hour. However, there exist smaller 4 ESS Switches with about 20,000 trunks, and peak call loads of about 100,000 calls per hour.

4.2.2 The Test 4 ESS Switch

Engineered so that the switch would fit into a small space, the 4 ESS Switch used in this test has a much more limited capacity than others found in the network. The total number of trunks available is limited by the amount of equipment and the standard configuration used to connect the various components.

The main limitation comes from an objective of maximizing the number of MF receivers and transmitters (32) on the DIF, so that the MF call attempt rate can be maximized. Normally, the DIF can be equipped with up to 32 Digital Interface Units (DIUs), each of which is capable of terminating the equivalent of five T1 lines, thus giving the capacity of 150 T1 lines, or 3648 trunks. However, this load is usually distributed over more than one TSI. Using an available cabling arrangement that is found in some offices between the DIF and the TSI that enabled access to all the MF receivers and transmitters, only two other DIUs are usable, yielding a total of six DIUs, or 720 trunks on the switch.

4.2.3 Call Load Estimates

A normal 4 ESS Switch will route upwards of 100,000 calls per hour on a busy hour. In order to determine the response of a 4 ESS Switch on call switching realistically, the 4 ESS Switch should be switching a similar number of calls. If switching only a few calls per hour, service degrading conditions may not be encountered that would be evident when trying to switch calls at a rate closer to the maximum rate of the switch.

Admittedly, the type of calls seen by the test 4 ESS Switch (short-holding times, on a small number of trunks), is much different from that seen by an actual 4 ESS Switch (long-holding times, on a large number of trunks). However, the activity perceived by the 1A processor is directly correlated to the creation and destruction of paths through the TDN. Therefore, by using a call attempt rate as high as possible, the greatest load is placed on the 1A processor.

In order to generate a realistic number of calls on the switch (on the order of several 10,000's of calls per hour), a large number of calls will be placed with short-holding times. Assuming an average holding time of 10 seconds, and thus a call rate of six calls per minute per trunk, the 720 trunks on the switch should be able to support 260,000 calls per hour. However, limitations in the switch and the test equipment will reduce this number. With the call generation equipment and the present configuration, a peak call load of about 80,000 calls per hour is estimated. However, changes in the configuration of the equipment (using four Ameritec units for dynamic calls, assignment of additional B channels to the D channels, multiple CCS7 loops, etc.) may double this number.

4.2.4 Performance Measurements

The two measurements used to characterize the performance of the switch are the time between a line seizure by a call generator to the switch and the acknowledgement of that seizure, and the time between the reception of the dialed number digits by the switch and the seizure of the appropriate trunk to the terminating switch/call generator. (For MF signaling, one may think of these times as a dial-tone delay and a postdialing delay.) A crude indicator of the time needed to switch calls may be given by the amount of load that can be put on the switch, but with the call generation capability, this indicator is probably more a measure of the test equipment than of the switch. Load dependence of these parameters will be investigated, but again because of the small load (compared to its maximum value) that will be placed on the switch, measurable load dependence may be very small. Table 2 lists the measurements to be made.

TABLE 2. Performance Measurements.

SIGNALING	ACKNOWLEDGE SEIZURE (ms)	COMPLETE CALL (ms)	MAXIMUM LOAD (1,000 Calls/hour)
MF	50	40	42
CCS7	<70	70	21
Q.931	50	125	18

In addition to these measurements, the voice path continuity of the setup calls will be verified, and the fraction of calls that are dropped by the switch after an EMP will be measured.

APPENDIX A

GLOSSARY

TERM	DEFINITION
AFWL	Air Force Weapons Laboratory
ALECS	Laboratory EMP Calibration and Simulation
AMA	Automatic Message Accounting
API	Attached Processor Interface
ASN	AT&T Switched Network
CAMAC	Computer Automated Measurement and Control
CC	Central Control
CNI	Common Network Interface
DIUs	Digital Interface Units
EMP	Electromagnetic Pulse
IEEE	Institute of Electrical and Electronics Engineers
IOP	Input/Output Processor
ISDN	Integrated Services Digital Network
kbps	kilobits per second
kV	kilovolt
Mbps	Megabits per second
MCC	Master Control Console
NSC	National Security Commission
NCS	National Communications System
ODA	Office Data Assembler
PBXs	Private Branch Exchanges
PPI	Processor Peripheral Interface
PSN	Public Switched Network
PUBB	Peripheral Unit Branching Bus
RN	Ring Node
SP	Signal Processor
STPs	Signal Transfer Points
TSIs	Timeslot Interchangers