The 5ESS-2000 Switch: Exceeding Customer Expectations

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The first 5ESS® switch was deployed in 1982 in Seneca, Illinois, initiating the global presence of AT&T digital switching equipment around the world. Today, the 5ESS switch is an integral part of the telecommunication networks in more than 50 countries. From the beginning, the switch was designed to have a flexible and evolvable architecture. And for more than a decade, it has continued to meet varied and ever-changing customer needs. The 5ESS-2000 platform is one of the switch's most recent and significant evolutions. This platform not only supports today's service needs, it also accommodates future applications requiring enhanced processing capacity, performance, reliability, and OAM&P (operations, administration, maintenance, and provisioning). This paper outlines the switch's current state of refinement, including its architecture and quality improvements. Hardware and software enhancements are discussed, as is the system integration and verification philosophy used in reducing the product-realization interval. The paper also reports on quality and performance data from customer field applications that have deployed the 5ESS-2000 platform.

Introduction

Post, telephone, and telegraph companies (PTTs), as well as other telecommunication carriers, require highly reliable switches that can accommodate a wide variety of needs. These include local/toll, operator-services, wireless, intelligent-network, integrated services digital network (ISDN), and packet-switching applications. A switch must also be economical across a broad range of line sizes, compatible with older equipment, and upgradeable to new technology, such as high-speed interfaces and broadband switching. The architecture and design of the 5ESS®-2000 switch platform is driven by a careful analysis of these customer expectations and market needs. The upgraded platform architecture includes a new switching module, high-speed fiber interfaces, remote-access vehicles, and several optimized configurations for small-line-size networks.

Optimum time-to-market and product quality[1] are both essential for success in today's competitive switching marketplace. Many innovations, therefore, were introduced into the 5ESS-2000 switch development process to shorten the product-realization interval and minimize defects, facilitating rapid product deployment. These innovations are discussed in detail in the following sections. Performance of the 5ESS-2000 switch in the field is also covered.

Meeting the Marketplace

Table I on page 31 shows the range of switching-system services and capabilities needed in today's diverse market. The 5ESS-2000 switch platform—designed with modularity and flexibility in mind—can support all these current switching applications, and it is evolvable to meet future needs.

Targeted to General Market Needs. Switch customers—telephone-service providers—continually face the challenge of minimizing the cost of providing services. The flexibility of the 5ESS-2000 switch platform allows these services to be provided

Panel 1. Abbreviations, Acronyms, and Terms

AM — administrative module
ASIC — application-specific integrated circuit
ATM — asynchronous transfer mode
BIST — built-in self-test
BRI — basic-rate interface
CDX — compact digital exchange, the international version of which is called 5ESS-2000 switch Communication Module 2 - Compact (CM2C)
DNU-S — Digital Networking Unit-SONET/SDH
EF&I — engineering, furnishing, and installing
EMC — electromagnetic compatibility
FCC — Federal Communications Commission
HRISLU — hardened RISLU
IN — intelligent network
ISDN — integrated services digital network
ISLU — integrated services line unit
ISO — International Organization for Standardization
OA&M — operations, administration, and maintenance
OAM&P — operations, administration, maintenance, and provisioning
OSPS — Operator Service Position System
OTC — operating telephone company
QLPS — quad-link packet switch
RISLU — remote integrated-services line unit
RLG — remote line group
RSM — remote switching module
SDH — synchronous digital hierarchy
SM — switching module
SONET/SDH — synchronous optical network and future evolution to SDH
TSI — time-slot interchange
TSIU — time-slot interchange unit
VCDX — Very Compact Digital Exchange, the international version of which is called 5ESS-2000 switch Administrative Work Station (AWS)
XSM-2000 — Extended Switching Module - 2000

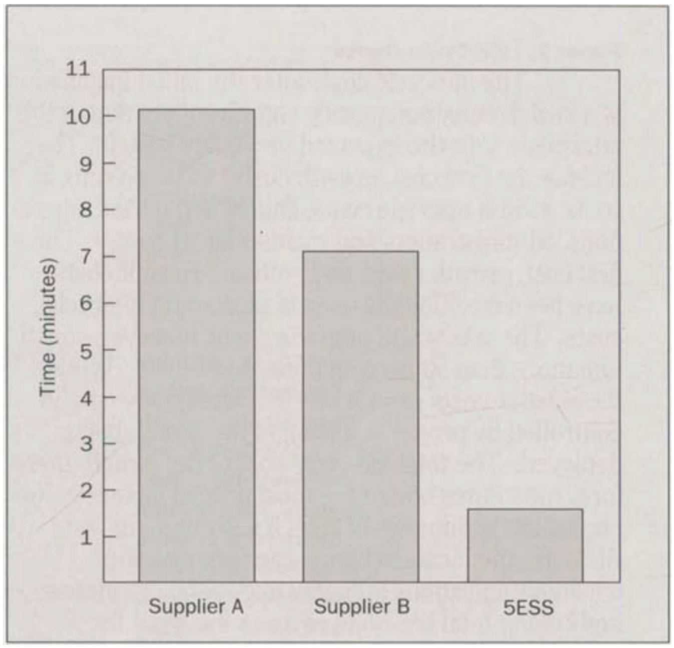

Figure 1. Telephone service traditionally has high reliability standards. This bar chart, which shows switch downtime per 10,000 lines, is based on publicly available data from the Federal Communications Commission. It compares current 5ESS switch reliability with two of its major competitors in the United States.

most economically for each application. While the first costs of engineering, furnishing, and installing (EF&I) switching equipment are crucial, equally important is the total life-cycle cost of owning and operating a network switching system (see Panel 2).

Service providers require switches that can efficiently handle a wide number of lines and calling rates. The 5ESS-2000 switch can support more than 200,000 lines and one million calls per hour.[2] Most switches in the United States typically accommodate several tens of thousands of lines. In the international market, the average number of lines supported tends to be somewhat smaller, although there are a wide range and variation of needs. Small switches, remote units (serving as few as several dozen lines), and remote switching modules (serving as many as 20,000 lines) are also available. Remotes have become more economical and practical with the advent of fiber "umbilicals" installed between central offices and the remotes.

Telephone service traditionally has high reliability standards. Figure 1, which is based on publicly available data from the Federal Communications Commission, compares current 5ESS switch reliability with two of its major competitors in the United States. Besides meeting service objectives, high reliability also reduces the cost of maintaining a switch. Consistent with its advanced design philosophy, the 5ESS-2000 switch platform is duplicated, self

Panel 2. Life-Cycle Costs

The life-cycle costs after the initial installation of a switch constitute a very significant portion of the total costs over the expected life of any switch. They include the first cost, growth costs, software-retrofit costs, switch upgrade costs, and switch OA&M (operations, administration, and maintenance) costs.[8] The first cost, growth costs, and software-retrofit costs have been traditionally used in evaluating life-cycle costs. The OA&M and upgrade costs, however, constitute more than 50 percent of the total costs. While these latter costs cannot be eliminated, they can be controlled by proper selection of the switch being deployed. The total life-cycle cost of the switch, therefore, constitutes one of the most crucial factors influencing the economics of switch selection. In fact, Bellcore, the local exchange carriers, and the telecommunications industry in general are increasingly using total life-cycle costs as the basis for product-deployment decisions.

Following are the key architecture, hardware, and software attributes of the 5ESS-2000 switch that minimize the total life-cycle cost:

- *Modular architecture.* This design allows cost-effective growth of a switch. In addition, network architecture having a powerful remoting capability facilitates deployment of a single switch that can support a wider area, minimizing life-cycle cost.
- *DNU-S.* The OA&M capabilities in the SONET/SDH interface, such as performance monitoring and provisioning, significantly reduce trunk-provisioning and maintenance costs. The SONET/SDH interface reduces trunk-maintenance costs, leading to a significant reduction in life-cycle cost.
- *Large time-slot interchange (TSI) in SM-2000.* The large, modular TSI in the SM-2000 will result in a significant reduction in the need for hardware and, hence, maintenance costs. Also, due to the smaller size of the 5ESS-2000 switch, floor-space requirements, and associated costs, will be reduced.
- *Energy-saving technology.* 5ESS-2000 switch hardware design reduces power consumption, resulting in lower electricity costs.

AT&T conducted several joint studies with PTTs and OTCs in comparing the total life-cycle costs of the 5ESS switch and switches marketed by competing vendors. The ten-year "net present value" for a 40,000-line 5ESS-2000 switch was about 15 percent lower than the closest competitor's switch.

testing, and interconnected in such a way that any faulty components are automatically detected and removed from service. Because the 5ESS-2000 switch platform is common across all applications, system reliability is generally not a function of the application. The switch, however, benefits from the common development and quality improvements invested in all its applications.

Service providers prefer a highly versatile switch—one that can satisfy all their network needs today, and one to which new services and capabilities can be added as technology advances. Updating a switch should minimize the purchase of additional equipment and changes to hardware. Moreover, switch customers want a single-system solution to their application needs. The 5ESS-2000 switch is a single platform having an extensible and evolvable architecture. It is capable of providing a uniform set of features across a wide number of lines and range of applications.

Enhanced Services Provided. The local switching of calls, and toll connections between switches, are the basic functions performed by a telephone switching system. Many additional services and applications, however, are now routinely performed by the 5ESS-2000 switch.

The switch's platform is ideally suited to the unique characteristics of wireless technology[3], including its high capacity and distribution over a wide geographic area. Major wireless standards are supported. Interfaces to intelligent network (IN) features—where information from external data bases is used for call processing to enhance services—are also supported. AT&T Advanced Intelligent Network[4] products, which include the 5ESS-2000 switch, are an example of such features.

As with wireless and IN applications, the 5ESS-2000 switch also provides a "rich" set of gateway, ISDN, and OSPS (Operator Service Position System) services. Gateway switches serve as the international point of

Table I. Switching System Marketplace Requirements

General Market Needs	Services and Applications	Distributed and Small Switches	Emerging Services
• Low cost • Wide capacity range • Reliability • Flexibility • Single system solution	• Local/toll • Wireless • Intelligent network • ISDN • Gateway • Operator services	• Varying size needs • Service transparency	• Multimedia • Hybrid fiber/coax • Integrated ATM capability

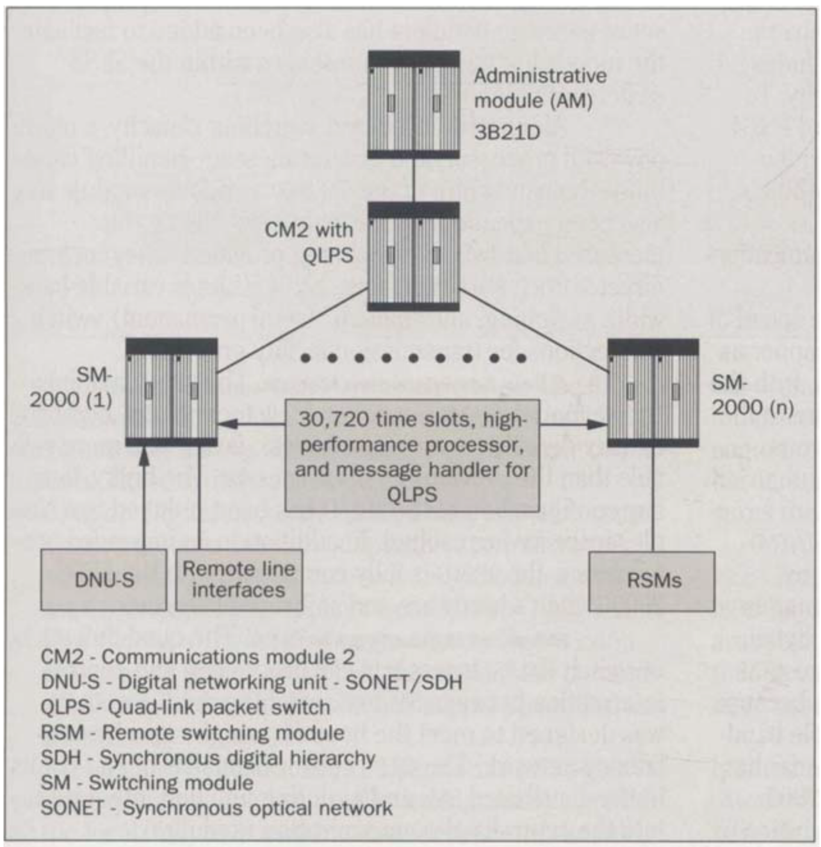

Figure 2. As shown by this illustration, the new elements of the 5ESS-2000 switch are generally independent, allowing them to interwork with those that were previously available. Although much has changed, the basic architecture elements remain the same for both hardware and software. No matter which configuration is selected, the OAM&P interfaces and the subscriber feature-set remain the same.

entry for national networks. Gateway switches must be extremely reliable because of the substantial revenue generated from international calls. They must also support a wide variety of signaling interworking between national and international networks. The 5ESS gateway switch, with its proven reliability and rich feature set, is selected by an increasing number of PTTs and telephone administrations, and is now deployed in approximately 30 countries.

The 5ESS-2000 switch supports ISDN standards throughout the world, and offers ISDN accessibility on a variety of remote-access vehicles. All these capabilities can coexist economically on the same 5ESS-2000 switch.

Distributed and Small Switching Needs Met. Switch user groups are not always large, and they may be geographically scattered. These user groups can be served in a number of different ways by using:

- A small 5ESS-2000 switch;
- A remote switching module (RSM);

- An Extended Switching Module-2000 (XSM-2000); or
- A "remoted" line interface.

A recent addition to the 5ESS-2000 switch platform is a set of options aimed specifically at the small switch market. These options are discussed in the next section.

With RSMs, XSMs, and remoted line interfaces, the switch is effectively extended to be near the telephone subscriber. As a result, service providers can reduce their plant investment required for local access. Full-feature service is still available, and even though a small 5ESS switch option or remote-access vehicle may provide it, such equipment is transparent to end-users.

Emerging Services. Multimedia, which includes teleconferencing, is a rapidly advancing technology. To support it, the 5ESS-2000 switch features ISDN and Nx64 Kbits/s switching. This combination is ideal for video teleconferencing, where 384-Kbits/s and 1.5/2-Mbits/s transmission rates are commonly used.

The use of fiber-optic cable in telecommunication networks—less expensive than copper cable per circuit-mile—significantly increases the interface speed of switches. As a result, fiber is rapidly displacing copper as the industry standard for most interconnections, with the exception of end-user equipment. The architecture of the 5ESS-2000 switch provides for efficient Synchronous Optical NETwork (SONET) and future Synchronous Digital Hierarchy (SDH) transmission interfaces.

Interest in asynchronous transfer mode (ATM) transmission and switching is high in the telephony industry. ATM offers an attractive standard for transmission and switching, with a uniform cell size of 53 bytes. The higher the information flow desired, the more ATM cells that are sent and switched. ATM is attractive because of its inherent ability to handle constant or variable bandwidth as needed. ATM—now just emerging—thus far has had very limited use. The flexibility of the 5ESS-2000 switch architecture, however, allows for full integration of the ATM capability.

Overview of Switch Components

The new units and modules, shown in Figure 2, are generally independent, allowing the interworking of all old and new components. Although much has changed, the basic architecture elements remain the same for both hardware and software. No matter which configuration is selected, the operations, administration, maintenance, and provisioning (OAM&P) interfaces and the subscriber feature-set remain the same. Together, these enhancements offer an economical, total switching solution having the widest practical range of configurations, capacities, applications, and interfaces.

A New Switching Module. Switching modules (SMs)—the "building blocks" of the 5ESS switch—are its fundamental distributed elements. The number of 64-Kbits/s time slots in each SM has been increased from 512 to 30,720 for the Switching Module-2000 (SM-2000). A more powerful, duplex processor complex has been added to handle the increased call-processing capacity. A set of message handlers has also been added to facilitate the increasing number of messages within the 5ESS switch architecture.

Along with increased switching capacity, a more powerful processor, and greater message-handling capability, the bandwidth of the SM-2000 switching module has also been expanded. New capabilities—using this increased bandwidth—are being provided. They include direct SONET/SDH interfaces, Nx64 Kbits/s variable-bandwidth switching, and "nail-up" (semi-permanent) switch connections for transmission-facility grooming.

A New Administrative Module. The 3B21D administrative module (AM) is smaller (new technology, higher density disk drives and tape drives), faster, and more reliable than the previous 3B20D processor. The bulky, four-bay configuration of the 3B20D has been reduced to a single, space-saving cabinet. In addition to its improved performance, the 3B21D is fully compatible with the 5ESS-2000 switch's hardware and software platforms.

Enhanced Messaging Via QLPS. The quad-link packet switch (QLPS) transports call-processing and control information between SM-2000 switching modules. QLPS was designed to meet the need for a high-capacity, low-latency network. The QLPS network consists of end-points in the distributed SMs and a routing function integrated into the centralized communication module.

High-Capacity Interface. The Digital Networking Unit - SONET/SDH (DNU-S) provides a direct, integrated interface to the 5ESS-2000 switch for both the SONET and future SDH standard interfaces. The DNU-S currently supports up to 12 SONET STS-1 interfaces (51.84 Mbits/s or 672 time slots), with higher-rate interfaces planned for the future. It uses the large time-slot capacity and fiber interface of the SM-2000 switching module. With this merging of switching and transmission equipment at a higher bandwidth, overall maintenance costs are reduced.

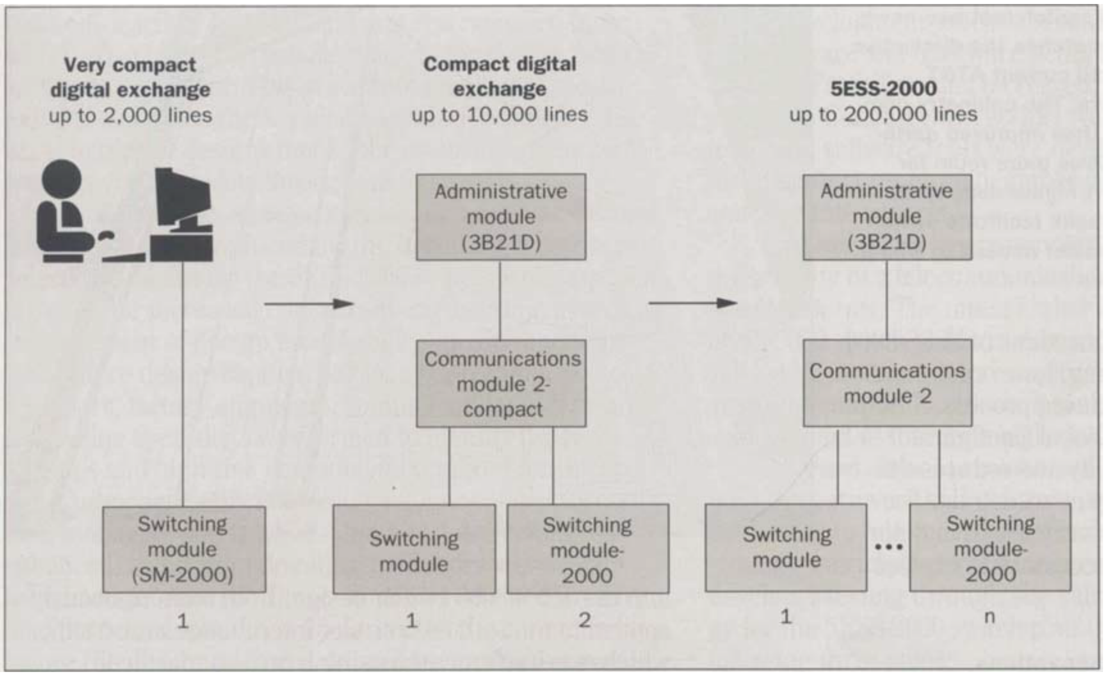

Figure 3. This drawing depicts the family of 5ESS-2000 switches with representative capacities, ranging from small to large applications. The two smaller configurations provide all the local/toll, ISDN, and business services of the full-size configuration. These smaller switches complement remote switching modules, remote line groups, and remote integrated-services line units, offering customers more alternatives for optimizing switch size.

Small Switches with Full-Feature Design. The 5ESS-2000 switch is now available in two new, small-line-size configurations having all the features of the larger configuration. These switches include the:

- *Compact Digital Exchange (CDX).* Using a small communication module called the CM2C, the CDX interconnects a combination of SM/SM-2000 switching modules, and the AM. CDX switches can support from 2,000 to 10,000 lines.
- *Very Compact Digital Exchange (VCDX).* This version uses a work station to replace the AM and the communication module. These switches support from 100 to 2,000 lines.

Figure 3 illustrates a comparison of 5ESS-2000 switch capacities. The two smaller configurations provide all the local/toll, ISDN, and business services of the full-size configuration. These smaller switches complement RSMs, remote line groups (RLGs), and remote integrated-services line units (RISLUs), offering customers more alternatives for optimizing switch size.

Remote Units and Switching Modules. Lines up to 600 miles from the host 5ESS-2000 switch may be served cost effectively with RSMs, RISLUs or RLGs.[5] The same full-feature service is provided on these lines. With these units, it is also possible to create an overlaying network in a geographical area to provide advanced services without replacing the existing switch network. The remote integrated-services line unit (RISLU) has been available for some time, serving up to 1,024 lines. New, however, is the hardened RISLU (HRISLU), which can be used in enclosures that are not environmentally controlled.

The RLG is an extension of the integrated services line unit (ISLU) architecture, serving either analog or ISDN lines in 64-line groups. It allows rapid, country-wide availability of ISDN by "remoting" ISDN basic-rate interface (BRI) access to distant, small clusters of fewer than 250 ISDN subscribers.

The Extended Switching Module-2000, an optically remoted SM-2000, provides the same capabilities as an SM-2000 at a remote location. It also has stand-alone capability if the umbilical is severed.

Distinctive Look and Streamlined Ordering. The 5ESS-2000 switch features newly designed cabinetry (Figure 4) that matches the distinctive color and appearance of all current AT&T Network Systems products. The cabinetry complies with International Organization for Standardization (ISO) guidelines, has improved earthquake protection, and allows more room for internal cabling in order to support higher density electronics. Improved cable racks facilitate switch installation and provide easier access to wiring.

Figure 4. The 5ESS-2000 switch features newly designed cabinetry that matches the distinctive color and appearance of all current AT&T Network Systems products. The cabinetry complies with ISO guidelines, has improved earthquake protection, and allows more room for internal cabling to support higher density electronics. Improved cable racks facilitate switch installation and provide easier access to wiring.

Standard configurations of 5ESS-2000 switches simplify ordering, lower costs, and accelerate the manufacturing process. A helpful ordering tool—the Global Configurator—increases design flexibility and reduces the effort needed to develop new central-office configurations. It is also very useful in determining the equipment necessary to expand existing systems.

Development-Process Innovations

Timely delivery and high quality are essential ingredients for success in today's competitive environment. Numerous innovations were introduced into the 5ESS-2000 switch development process to shorten the product-realization interval and improve quality, thereby achieving rapid product deployment. The following subsections summarize these innovations.

Global Design Specifications. The 5ESS switch is sold throughout the world. Significant delays due to costs and scheduling could occur if customization for each application was required. The 5ESS-2000 switch platform requirements, both at a high level and at the detailed level, were formulated to include all global customer requirements to avoid any customization for specific applications.

Improved Hardware Simulation. With the increase in the level of circuit complexity (for example, larger ICs with higher speeds), circuit simulation at the device, pack, and multicircuit pack level became an integral part of the development process to ensure design functionality on first-model delivery. One circuit-pack development cycle was eliminated by simulation, test planning, and execution, thereby reducing the development interval and overall cost.

Built-In Self-Test (BIST)/Boundary Scan. A special effort was made to incorporate BIST and boundary scan into the 5ESS-2000 switch design. Both were rigorously applied to the SM-2000 time-slot interchange unit (TSIU), which was implemented using large, standard cell, application-specific integrated circuit (ASIC) devices. All devices—and most of the circuit packs—use BIST, which significantly reduces device and pack test-development effort while increasing fault coverage. This initiative significantly reduced the cost of testing and the test-development interval. System diagnostics were greatly enhanced by taking advantage of BIST at the pack and unit levels.

Refined Robustness Testing. Robustness was designed into the 5ESS-2000 switch hardware through component selection, timing and signal-integrity analysis, simulation, and thermal analysis. The robustness of the design was thoroughly checked by means of environmental stress testing (voltage and temperature extremes), prolonged operation of diagnostic tests, and special software routines designed specifically to exercise the hardware beyond normal operating limits. Faults found were documented, vigorously investigated, and corrected. By eliminating faults early, the high cost usually associated with fault discovery and remediation in the field, as well as pack change-out, were virtually eliminated.

Electromagnetic Compatibility Training. A trial of the 5ESS-2000 switch development initiative was conducted to address electromagnetic compatibility (EMC) during the early design phases for circuits and hardware. Development engineers were trained in the principles of EMC containment. Each circuit pack and unit was reviewed by an AT&T expert, and corrections made to the design, before proceeding to layout. This procedure resulted in greatly reduced electromagnetic radiation and susceptibility. The initial hardware designs met all the electromagnetic compatibility requirements throughout the world.

Hardware-Component Engineering Initiatives. Several initiatives were introduced for the hardware-component selection process for the 5ESS-2000 switch project, which provided for increased concurrent engineering, as well as enhancement of design for reliability, quality, and logistics. Before design-capture began, a team comprised of designers, factory engineers, component engineers, and supply-line specialists was formed to identify the technologies and high-risk components required for the project. Component-selection risk management was formalized, managed, and tracked. Qualification tracking was enhanced, and design de-rating guidelines were established and monitored. These strategies resulted in full qualification of more than 95 percent of the components before the design release date, and few problems were discovered during the development cycle. Early stock-list transmission to the factory resulted in a smooth product transition to production.

Design-Realization Interval Reduction. One of the major elements in shortening the hardware-development cycle is the reduction of the design-realization interval. The 5ESS-2000 switch project defined the many steps throughout the printed-wiring design process. Clear entrance and exit requirements were defined and documented at each step in the process. This procedure provided a means to manage, comprehensively, both the production schedule and product quality. Such management control minimized process variation, reduced schedule delays, shortened production intervals, and greatly increased product quality.

Rigorous Stability Runs. The 5ESS-2000 switch platform project introduced major new hardware and software continuously throughout the development interval. In order to maintain an environment within which developers can efficiently test and verify their designs, periodic *stability runs* are established. These runs help identify the potential difficulties affecting basic system integration. Stability runs place the system under a heavy, simulated call load, with many of the maintenance activities normally carried out at in-service central offices.

The frequency of these runs was increased early in the development process because of the amount of new software and hardware being introduced. As the frequency of stability runs increased, the level of automation also rose. Concurrently, scripts were written to automate tests, and software tools were developed to reduce the manual effort required to gather data, analyze results, and generate reports.

One of the key parameters used in calculating the stability of a telecommunication system is the *call-completion rate.* The much higher call capacity of the 5ESS-2000 switch platform demands more powerful call-load generators, more sophisticated system-test environments, and a rigorous analysis process to ensure achievement of the same high quality as before.

Verification and Customer Delivery. To verify that both the hardware and software meet customer requirements and to minimize any difficulties, a rigorous test strategy was implemented for every step from initial developer testing through site validation. The test strategy for the 5ESS-2000 switch platform is comprised of the following three steps:

1. Project breakout into smaller subfeatures;
2. Developing and verifying each subfeature individually; and
3. Integrating subfeatures back into a final product.

A subfeature is an identifiable, functional area of a system. It is also a logical, intermediate product resulting from integrating other subfeatures. A final system subfeature is responsible for the complete recomposition and validation of the total 5ESS-2000 switch platform.

Total Requirements Coverage. In order to ensure that the developed product met or exceeded customer expectations, all customer requirements (hardware and software) needed to be tested and verified. Complete coverage of the platform requirements was ensured by explicitly mapping each requirement to one or more of the tests to exercise the requirement fully.

On-Site Developer and Initial Applications. Rapid deployment of 5ESS-2000 switches required the quick resolution of any lingering faults and a fast learning curve for factory test engineers, field-support personnel, and installers. To facilitate rapid switch deployment, a *best-in-class process* is used. This procedure recruits system experts in hardware and software from the AT&T Bell Laboratories development community, and places them in rotational assignments at the factory and various customer field sites. This enhanced the training of factory and field personnel as the product was manufactured and brought into service.

Initial Customer Sites. Each of the following features that comprise the 5ESS-2000 switch is a platform change to the switch's basic building blocks:

- A new processor for the AM;
- A new communications module for small offices;
- A new SM; and
- A number of new peripherals (for example, DNU-S).

To introduce this new hardware and software, the following first-office applications were defined to provide final system verification of the new platform:

- *Santo Domingo, Dominican Republic – Gateway.* This application, a new gateway office, handles C7 signaling to the United States and C5 signaling to many locations in the rest of the world. Four SM-2000 switching modules were installed to meet the customer's need for trunk connectivity throughout the world.
- *Wuhan, China – Local/Toll.* This application is a new office with national C7 signaling and local/toll features. Nine SM-2000 switching modules were installed to service 37,000 lines and 9,900 trunks.
- *sGravenhage Marnix 1E, Netherlands – Local/Toll.* In this application, one SM-2000 was integrated into the switch to verify hardware and craft equivalence with the previous software release.
- *Kecksburg, Pennsylvania, USA – Local/Toll.* This application is a new CDX office with a mix of SM and SM-2000 switching modules.
- *Harmon, Guam – OSPS.* A new office with two SM-2000 switching modules, this application hosts many operator and supervisory positions.
- *Qingdao, China – Local.* This application is a new VCDX office.
- *Leidschendam, Netherlands – Local/Toll.* Many RLGs are hosted on a switch in sGravenhage to provide ISDN service in this application. PTT Telecom in the Netherlands (see Panel 3) evaluated the hardware and software through a rigorous testing process.
- *Malaysia.* This application is a wireless-system verification on a 5ESS-2000 switch.

Customer Integration and Acceptance. Such platform developments as the 5ESS-2000 switch should be transparent to any application software. The customer integration teams, associated with each site, worked together to define a test set that validates this. The test set is comprised of *common tests* and *unique tests*. Common tests, to be executed at all the sites, are written to verify the 5ESS-2000 switch hardware and associated software (initialization, fault recovery, diagnostics, and craft interface). Unique tests for call processing, billing, traffic measurements, line and trunk maintenance, and signaling are written to verify the country application.

For each of the test sites, a six-week interval was arranged: four weeks to execute the test program and to resolve any difficulties, and two weeks to execute customer-acceptance tests in the customer's presence.

Panel 3. Glass-BOX Testing

PTT Telecom, the public telecommunications operator located in the Netherlands, defines Glass-BOX testing to reduce acceptance-testing time and to improve the quality of procured software from different suppliers. There are three phases to the Glass-BOX testing process:

- *Requirements/product specification.* One of the suppliers receives the contract for the main system integrator. The product specification is jointly written by all suppliers. This specification is later used to define acceptance tests.
- *Implementation by suppliers.* Implementation is completed independently by each supplier. PTT Telecom monitors the schedule and quality metrics of each supplier.
- *System Integration.* The main system integrator is responsible for the test and integration of the new software products in PTT Telecom's software-verification environment.

When all exit criteria have been met, the new software is released into the national telecommunications network of PTT Telecom.

Customer Feedback and Field Results

This section discusses the deployment of 5ESS-2000 switches throughout the world, as well as the field data (hardware and software) from in-service offices.

"Ramping Up" on Production. Preparations for shipping the new 5ESS-2000 switch progressed very rapidly. Initial manufacturing of each hardware unit was completed at the AT&T Oklahoma City Works. Once the factory production processes were refined, manufacturing was quickly authorized in other AT&T plants worldwide. So far during

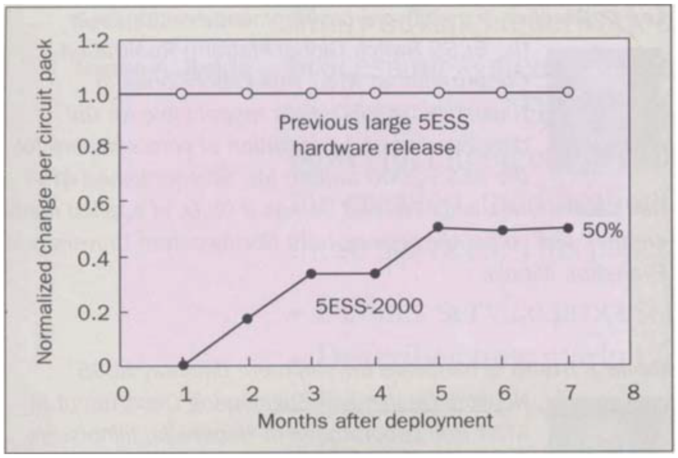

Figure 5. Much effort was expended to ensure that hardware defects were found early—during product development—and not after delivery to a customer. This graph, which depicts customer-affecting hardware changes, indicates that during the first six months following deployment, the 5ESS-2000 switch project showed major quality improvements by reducing the rate of hardware defects by about 50 percent over previous, large-hardware development efforts.

1994, several thousand SM-2000 units have been shipped, along with other 5ESS-2000 switch hardware.

Controlling Software and Hardware Defects. All 5ESS switch software is under a change-control system. With such a system in place, it is possible to monitor fault density at different points in the project. Modeling-analysis tools are used to monitor defects found to date and to project the number of defects remaining to be found. Similarly, other tools exist that monitor defects after a software release is delivered to a customer. In the first six months after the initial release, product quality—as determined by defects found per thousand non-commentary source lines of code—is about ten times better than the previous software release.

Furthermore, much effort was expended to ensure that hardware defects were found early—during product development—and not after delivery to a customer. Figure 5 illustrates that during the first six months following deployment, the 5ESS-2000 switch project has shown major quality improvements by reducing the rate of hardware defects by about 50 percent over previous, large-hardware development efforts.

Downtime Statistics. Because the 5ESS switch has a distributed architecture, two types of downtime are measured and tracked:

- *System downtime* is defined as the length of time ALL subscribers in an office are without service.
- *SM downtime* is defined as the length of time SOME subscribers in an office are without service. These incidents are usually restricted to a particular SM and may only affect transient calls or service on that SM.

In the first seven months after deployment, there have been no reported system or SM downtime incidents for 5ESS-2000 switches.

Summary

5ESS-2000 switch products are the work of a multinational team of engineers and scientists located throughout the AT&T research and development community. The goal of this team is to meet the challenges of the marketplace and to exceed the expectations of customers. Current data indicates this goal has been achieved. Since the completion of its development, all components of the 5ESS-2000 switch platform have been placed in service at many different customer application sites. While continuing to support existing applications, the flexibility and evolvability of the 5ESS switch architecture will make possible a host of new services.[6,7]

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