The FT-2000 OC-48 Lightwave System

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Next generation terrestrial lightwave terminals must do more than transport digital information from one location to another. FT-2000, AT&T's newest high-capacity lightwave transmission system, is designed to meet the needs of customers into the next century. It combines a flexible hardware platform and a powerful software-based architecture. As an intelligent lightwave system, FT-2000 can operate in sophisticated self-healing networks, and is managed by an advanced control system that simplifies installing, provisioning, monitoring, and maintaining it. It is fully compliant with the American National Standards Institute (ANSI) optical interface standard, the Synchronous Optical Network (SONET). We explore the broad range of applications and customer needs that drove the specification of FT-2000, and present the architectural solution that achieves the flexibility to meet those specifications.

Introduction

FT-2000 is AT&T Network System's new intelligent lightwave system, designed for high-capacity transport of voice, data, video, and special services. Using the latest fiber optic technologies, and operating at a line rate of 2488.32 megabits per second (Mb/s), a pair of FT-2000 terminals configured in a point-to-point application can transport 32,256 voice circuits over a distance of 2,600 kilometers (Km) when FT-2000 repeaters are used. Besides being an efficient medium for information transmittal, FT-2000 has a sophisticated microprocessor-based control system for automatic failure detection and isolation to the failed circuit pack. It reports this information locally through light-emitting diodes (LEDs), a user-friendly personal computer-based craft interface terminal, and office alarms. FT-2000 allows remote reporting through embedded operations channels and operations support (OS) interfaces. The control system also can perform automated self-testing, circuit pack inventory, and automatic circuit pack provisioning.

FT-2000 has been designed for automatic recovery from single-event equipment and fiber-line failures, depending on the equipment configuration and application. In most configurations, the transmission signal paths are protected, so service interruptions are limited to less than 60 milliseconds (msec) when failures occur.

Users of FT-2000

FT-2000 has been designed to meet the network needs of a broad user base. By employing a flexible modular architecture, FT-2000 will meet the needs of local exchange carriers (LECs), interexchange carriers (IECs), independent telephone companies (ITCOs), and private network providers.

Across this customer base, FT-2000 can be configured for each user's particular network needs, whether access, metropolitan, outstate/suburban, or long haul.

- The expanding *access* market segment needs self-healing rings and hubbing capabilities.
- The *metropolitan* market segment, characterized by high-capacity spans over relatively short distances, needs point-to-point systems with protection access and diverse routing, in addition to self-healing rings.
- The *outstate/suburban* market segment has longer routes where small cross sections of traffic are added on and dropped off, and needs add/drop configurations and repeaters. Self-healing rings are also needed.
- Finally, the *long-haul* market segment, characterized by long spans with high cross-sections of traffic, needs repeaters and 1xN protection line switching.

For all types of customers and their special needs, FT-2000 has been designed to replace earlier equipment in existing routes, and to operate in growth applications where new circuits are needed.

The SONET Standard and User Requirements

Several factors have influenced marketplace demands for a next generation high-capacity lightwave system. These factors include a move toward standardization among suppliers, a need for complete network solutions, a desire for more flexibility, better survivability, and attractive economics.

The chief factor has been the development of the SONET standard. SONET was developed before any product introduction, and it applies to a broad range of telecommunications equipment. It has been embraced by most users of FT-2000 as a standardized approach to optical interface specifications, frame formats, payload mappings, protection switching, synchronization, and operation, administration, maintenance, and provisioning (OAM&P).

Because SONET is so encompassing, it satisfies a long-standing need for end-to-end applications and complete network solutions. Thus, FT-2000 must work smoothly with other members of AT&T's family of SONET products. Initially, interworking with AT&T's DDM-2000 multiplexers and DACS-III/IV-2000 cross connects will be required. Later, FT-2000 will have to interwork with other vendors' multiplexers, cross connects, and lightwave systems.

A next-generation lightwave system must be flexible in the payloads and services it can transport. This prevents obsolescence as the network evolves from being dominated by asynchronous payloads such as DS1 and DS3, and moves toward to new SONET-defined payloads such as STS-1 and STS-3c. These payloads will then be able to transport new services such as broadband Integrated Services Digital Network (B-ISDN), Fiber Distributed Data Interface (FDDI), and Asynchronous Transfer Mode (ATM), in an unbroken SONET path from origination to termination.

Another significant factor, independent of SONET, has been the move toward more data traffic being transported through the network. Much of this traffic cannot be interrupted without incurring economic penalties. This evolution has caused a demand for lightwave equipment that will resist not only hardware failures, but also fiber cable cuts and catastrophic events such as fires, floods, and storms.

Panel 1. Terms and Acronyms in This Paper

ANSI	American National Standards Institute
ADM	add/drop multiplexer
ATM	asynchronous transfer mode
DCC	data communication channel
DS1	Digital signal at the first level in the digital hierarchy. It is made up of 24 digitally encoded voice and/or 64 Kb/s data channels.
DS3	Digital signal at the third level in the digital hierarchy. It is made up of 28 DS1 signals.
FDDI	fiber distributed data interface
IEC	interexchange carrier
ISDN	Integrated Services Digital Network
ITCO	independent telephone company
LEC	local exchange carrier
LED	light emitting diode
OA	optical amplifier
OAM&P	operations, administration, maintenance and provisioning
OS	operations system
PC	personal computer
SONET	Synchronous Optical Network
WDM	wavelength division multiplexing

Fiber optic ring solutions have emerged as a way to offer fast (<60 msec) circuit restoration in case of complete fiber cable cuts or office failures. However, beyond supporting standalone ring sub-networks, FT-2000 must also evolve to interwork with adjacent rings and other network-level restoration schemes.

Another significant factor is the need to save on operating expenses by making more efficient use of maintenance personnel. A next-generation lightwave system must allow for enhanced operations, administration, maintenance, and provisioning OAM&P capabilities that permit increasingly centralized maintenance centers, reduced installation and turn-up intervals, and fewer hours needed to operate and maintain the equipment.

FT-2000 Applications

FT-2000 will meet the application needs of a broad base of customers, who will use FT-2000 in vastly different ways. Many customers will use FT-2000 in standard applications such as point-to-point, add/drop, and hubbing, summarized in Figure 1. But there is a growing demand for lightwave products that offer enhanced

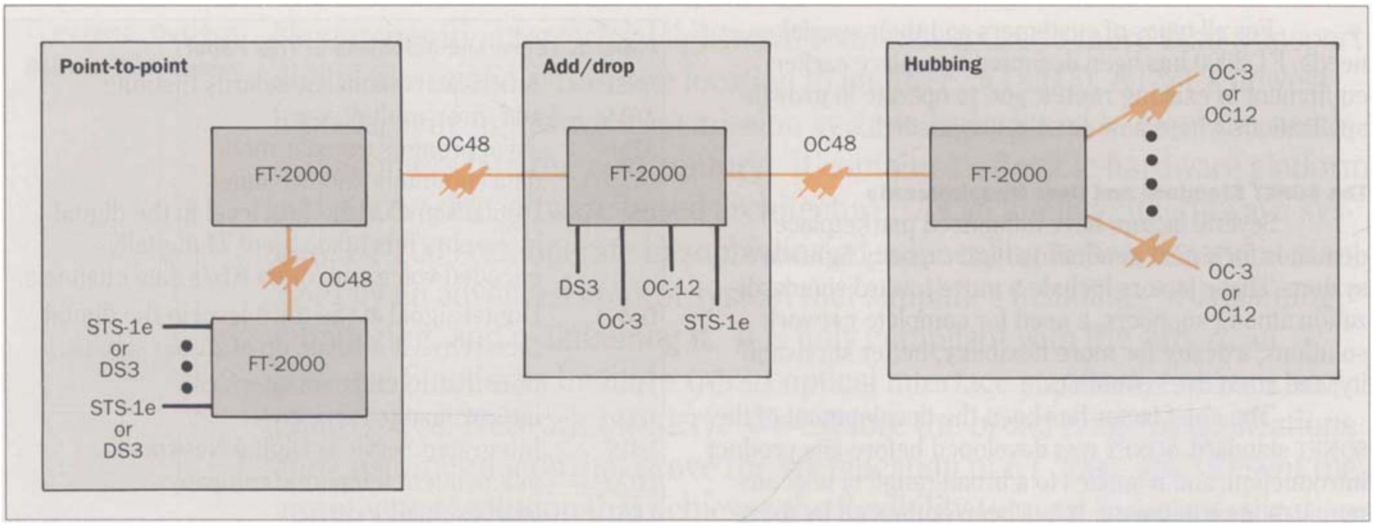

Figure 1. Point-to-point, linear add/drop, and hubbing applications. In point-to-point, up to 48 DS3 equivalents are transported bidirectionally between a pair of FT-2000 terminals. In linear add/drop, two 1X1 protected OC-48 lines terminate on a single FT-2000. For the initial add/drop offering, up to 48 DS3 equivalents can be added/dropped from either side and assigned to any low speed slot, while the remaining circuits are passed through with out transversing low speed interfaces. FT-2000 can also be used as a *hub* or concentration point for 1X1 protected OC-3 or OC-12 optical lines that come from geographically separate locations.

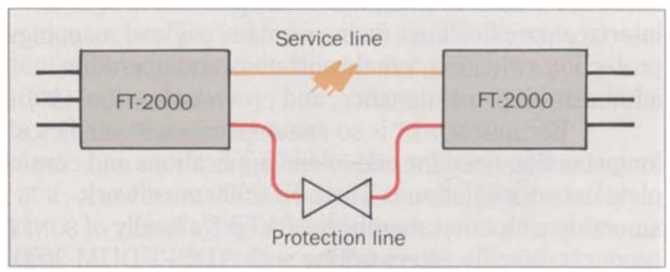

Figure 2. Route diversity application. The protection line is routed over a geographically different path from that required for the service line. A regenerator is sometimes needed on the protection path.

survivability. Although the applications shown in Figure 1 will gracefully recover from internal equipment failures and single-fiber breaks, if an entire fiber cable is cut or an FT-2000 node fails, additional configurations are needed to restore service quickly. Two such configurations supported by FT-2000 are *route diversity* and *bidirectional line-switched rings.*

Route Diversity. Route diversity is a protected configuration that provides additional tolerance to fiber cable cuts by routing the service and protection fibers over geographically separate paths (see Figure 2.) This configuration reduces the probability that a single event, e.g., accidentally digging up a fiber cable, will simultaneously cut the protection and service fibers. Although route diversity is extensively deployed to protect critical circuits, it does *not* protect against node failures.

Rings. A ring is a network topology that provides fast restoration from fiber cable cuts and node failures by using a more efficient form of real-time route diversity. While several ring types have been proposed, Figure 3A conceptually illustrates the bidirectional line-switched rings used in FT-2000. *Line-switched* means that all circuits on a service line are simultaneously switched to the protection line when a failure is detected between any two nodes. *Bidirectional* refers to the way circuits are routed around the ring. In a bidirectional ring, transmission from node A to node B (A-B) is routed in the opposite direction from B-A transmissions. This is the normal assignment method for most circuits today.

Finally, the ring type used in FT-2000 shares the diversely-routed protection path among all nodes on the ring. This shared protection property of FT-2000 rings is a more economical alternative to other types of rings, especially when the traffic is more evenly distrib-

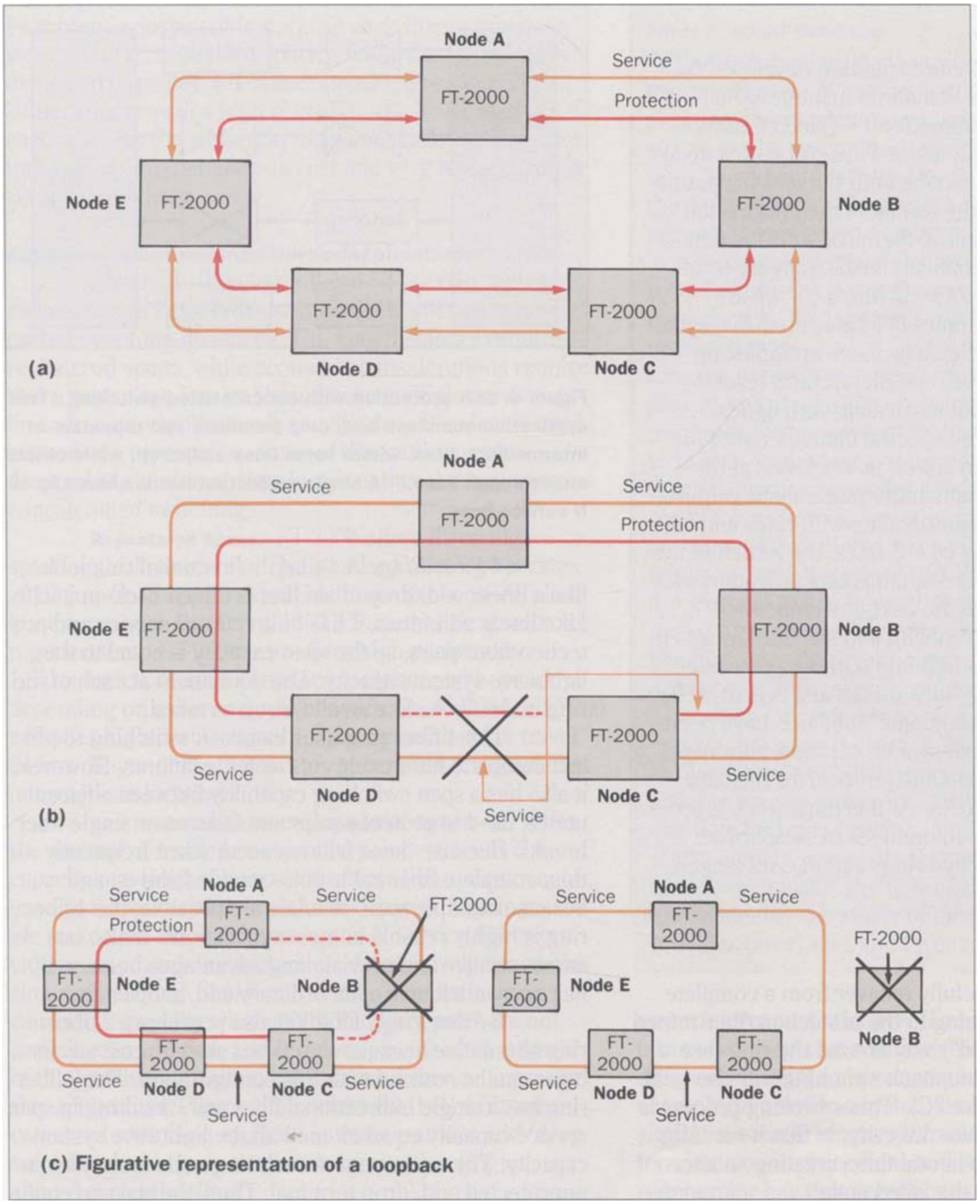

Figure 3. Bidirectional ring application. Bidirectional rings use FT-2000 add/drop-ring terminals (A/D-R) in a closed topology, as shown in Figure 3A. Each terminal has bidirectional service and protection capacities which are realized by using individual fibers in the case of 4 fiber rings, or by sharing fibers in 2 fiber rings. When a cable cut occurs, as shown in Figure 3B, service between nodes C and D is restored via a protection path established the long way around the ring. This is done by looping the traffic back at nodes C and D. Figure 3C illustrates how a node failure is healed using loopback switches. When a node failure occurs at B, nodes A and C detect loss of incoming signal, and each initiate loopback switches. These actions establish connections which bypass failed node B.

Panel 2. What Is SONET

SONET is an optical interface standard developed by the American National Standards Institute (ANSI) under the Standard Committee T1-Telecommunications. The standard is contained in several ANSI documents that together describe both the optical parameters of the signal and the format of the information carried within. The central theme of SONET is that a hierarchy of standard optical signals, ranging from 51.84 Mb/s (OC-1) to 2488.32 Mb/s (OC-48) are defined as integer multiples of a basic modular signal. SONET also describes a synchronous multiplexing technique for going from one hierarchical level to another. The specifications dealing with optical parameters describe the spectral characteristics for both 1310 and 1550 nm lasers, power levels at the interface points, and transmitter pulse shape requirements. The specifications dealing with rates and formats describe the allowed OC rates, the format of the basic modular signal, the multiplexing procedures for going from one level to the next, the embedded SONET overhead (see Panel 3), and standard means to map existing digital signals into SONET payload signals. Defined mappings include DS1 and DS3, as well as 2.048 Mb/s signals. Additional standards have been described for timing and synchronization, automatic protection switching, and the protocol for the data communications channels. At this time, work is progressing in several T1 committees to standardize bidirectional line-switched rings and DCC messages, among other things.

uted among nodes.

A ring can gracefully recover from a complete fiber cable cut by switching to the protection fiber routed the long (or "loopbacked") way around the ring (see Figure 3B). This same loopback switching will also heal a node failure (see Figure 3C). This switching process is similar to repeatered route diversity, in that it reconfigures the protection loop in real time, creating an alternate path that bypasses the failed node.

FT-2000 supports two types of line switched bidirectional rings, 4-fiber and 2-fiber. These labels refer to the number of physical fibers traversing the ring. Each type has attributes best suited for particular applications and planning objectives.

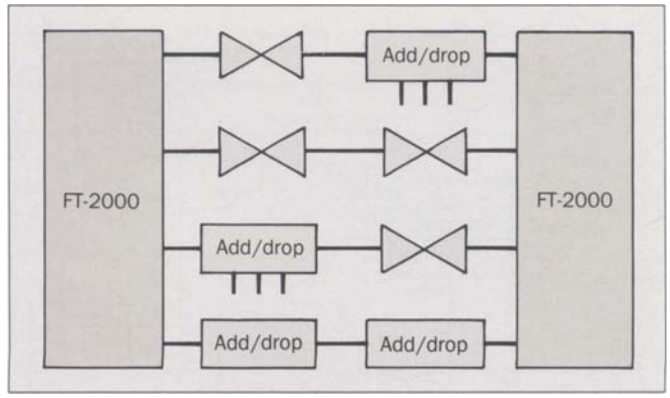

Figure 4. 1xN protection with concatenated switching. This application combines add/drop terminals and repeaters at intermediate sites, where some lines add/drop, while others are "through lines." A single protection line is shared by all N service lines.

4-Fiber Rings. A 4-fiber bidirectional ring looks like a linear add/drop chain that is folded back on itself. Like linear add/drop, it has bidirectional service and protection fiber pairs, so the span capacity is equal to the lightwave system capacity. The equipment at each of the ring nodes looks like an add/drop terminal.

The 4-fiber ring uses loopback switching to protect complete fiber cable cuts or node failures. However, it also has a span switching capability between adjacent nodes, used to protect equipment failures or single fiber breaks. Because these failures occur more frequently than complete fiber cable cuts or node failures, and because multiple span switches are possible, the 4-fiber ring is highly reliable in most applications. It also has administrative and provisioning advantages because it has many attributes of an ordinary add/drop chain.

2-Fiber Rings. FT-2000 also provides a 2-fiber ring alternative because significant start-up cost advantages can be realized with this configuration. The 2-fiber ring has a single bidirectional fiber pair, resulting in span service capacity equal to one-half the lightwave system capacity. The equipment at each ring node looks like an unprotected add/drop terminal. Thus, the start-up equipment configuration is roughly half as expensive as the 4-fiber configuration.

The 2-fiber ring uses loopback switching to recover from equipment failures, single fiber breaks, node failures, and complete fiber cable cuts. Span switching is not possible because each fiber carries service on half its available capacity, while the other half is dedicated to protection in the opposite direction. The 2-fiber ring provides high reliability at a lower start-up cost, whereas the 4-fiber, in most applications, offers the trade-off of a higher start-up cost and very high reliability via span switching.

Additional Interexchange Carrier Applications

Generally, the IECs will use FT-2000 in applications where large cross-sections of traffic are transported over long distances. The long distances require repeatered spans, while economic considerations require that a protection line be shared over multiple service lines. In some applications, an add/drop terminal is used instead of a repeater, so some of the traffic may be dropped at an intermediate location, thereby requiring concatenated switching.

Repeatered Spans. FT-2000 offers three high-speed optical interfaces. The standard offering operates at 1.3 μm (micrometers) and, with nominal outside plant losses, can span distances of 53 kilometers (km) without regenerators. FT-2000 also offers high-performance 1.3 μm optics, capable of spanning 60 km and beyond, depending on cable and splice losses. In addition, FT-2000 will offer high-performance 1.5 μm optics that can travel 84 km. Beyond this distance, regenerators are needed at intermediate locations.

1xN Protection with Concatenated Switching. When the amount of traffic between two points exceeds the capacity of a single fiber pair, multiple fiber pairs may be used to increase the overall route capacity. Sharing a single protection fiber pair among the N service fibers provides economical line protection. Alternatively, wave division multiplexing (WDM) can also be used to increase capacity, especially when additional fiber pairs are not available. In addition, add/drop may be needed at some of the intermediate sites, but not on all service lines. For this application, Figure 4 illustrates the 1xN with concatenated switching application that combines add/drop terminals and regenerators in a span with a single shared protection line.

The FT-2000 Architectural Solution

Clearly, with such a variety of applications needed by several important classes of customers, the architecture of the FT-2000 system must be flexible and powerful, yet cost effective. To provide the high-capacity transmission system solutions required, several possibly different FT-2000 components must be put together. For example, to provide a system that can transport 96 DS3 signals across 90 km, two terminals are needed that can terminate two service lines and one protection line. One regenerator bay that regenerates those three lines would also be needed. However, if there is a need to terminate some DS3s at the intermediate site, the repeater bay would be replaced by an add/drop terminal. The combinations of equipment needed are as limitless as the number of possible applications.

Panel 3. SONET Overhead

The SONET standard defines a frame format rich in overhead bytes. What are overhead bytes? To multiplex and demultiplex the multiple payload data streams to be transmitted, additional framing bytes must be added to identify the order and placement of the payload bytes. To make the equipment and the network that it is part of more maintainable, other overhead bytes are included as well. The overhead bytes fall into three categories, per the SONET standard: section, line and path. *Section overhead* refers to overhead bytes used in the spans between regenerators and between regenerators and end terminals. *Line overhead* refers to overhead used between end terminals. *Path overhead* refers to overhead between terminals originating and terminating SONET signals. Section overhead includes two bytes for framing, one parity for performance monitoring (of the section), one for section orderwire, one for network provider (user) use and three for a 192 Kb/s data communication channel. (It is this DCC that is used to transport the OAM&P information among terminals.) Line overhead includes three for pointers (defined to allow multiplex payloads of slightly different frequencies), one parity byte for performance monitoring (of the line), two for automatic protection switching signaling, nine for line based DCC, two reserved for future growth, and one for line orderwire. Path overhead includes one byte for trace (used to identify the source of the SONET signal), one parity for path performance monitoring, one to label the type of signal in the payload, one to identify the status of the path, one for network provider (user) use, and three for future growth.

FT-2000 is meeting this wide variation in applications by offering five basic types of terminals: 1x1 End Terminals, Add/Drop-Rings Terminals, 1xN End Terminals, 1xN Add/Drop Terminals, and Repeater Bays connecting them.

- The 1x1 End Terminal is a single-bay product optimized for 1x1 operation (see Figure 5).
- The Add/Drop-Rings Terminal is designed for linear add/drop, 2-fiber rings and 4-fiber ring applications. The shaded portions in the upper third of Figure 6 represent the upgraded 4-fiber ring product.
- The 1xN End Terminal is designed for the higher capacity needs of IEC customers.
- The 1xN Add/Drop Terminal, also aimed primarily at the IEC market, provides high-capacity add/drop functionality.
- Repeater Bays are used to extend the distance between terminals.
- System solutions are arrived at by combining variations of these five terminal types.

These terminal types are, in turn, made up of three basic shelves: a Low Speed Shelf, a High Speed Shelf, and a Repeater Shelf.

- The Low Speed Shelf holds the circuit packs that provide the necessary processing for the terminal's low speed interfaces, i.e., DS3s, STS-1Es, and OC-3s.
- The High Speed Shelf holds the packs that interfaces with the fibers and operates at the OC-48 rate.
- The Repeater Shelf holds the regenerator packs.

The above descriptions take an input-output perspective on the transmission functionality. Another important perspective is timing and synchronization. To multiplex and demultiplex the low speed interface signals according to the SONET standard, a sophisticated timing architecture also must be provided. FT-2000 can be synchronized to external DS1 references, to incoming OC-48 lines, or to an internal oscillator. As with the transmission packs, fault detection and protection switching (of both the timing references and timing packs) are provided so the FT-2000 reliability requirements are met.

These emphasize the shelves' transmission functionality. Though high-capacity transmission is indeed the basic function provided by FT-2000, a system providing only transmission would be inadequate. Reliability and maintainability are essential qualities of today's SONET-based transmission systems. Because of these requirements, FT-2000 has a powerful and sophisticated

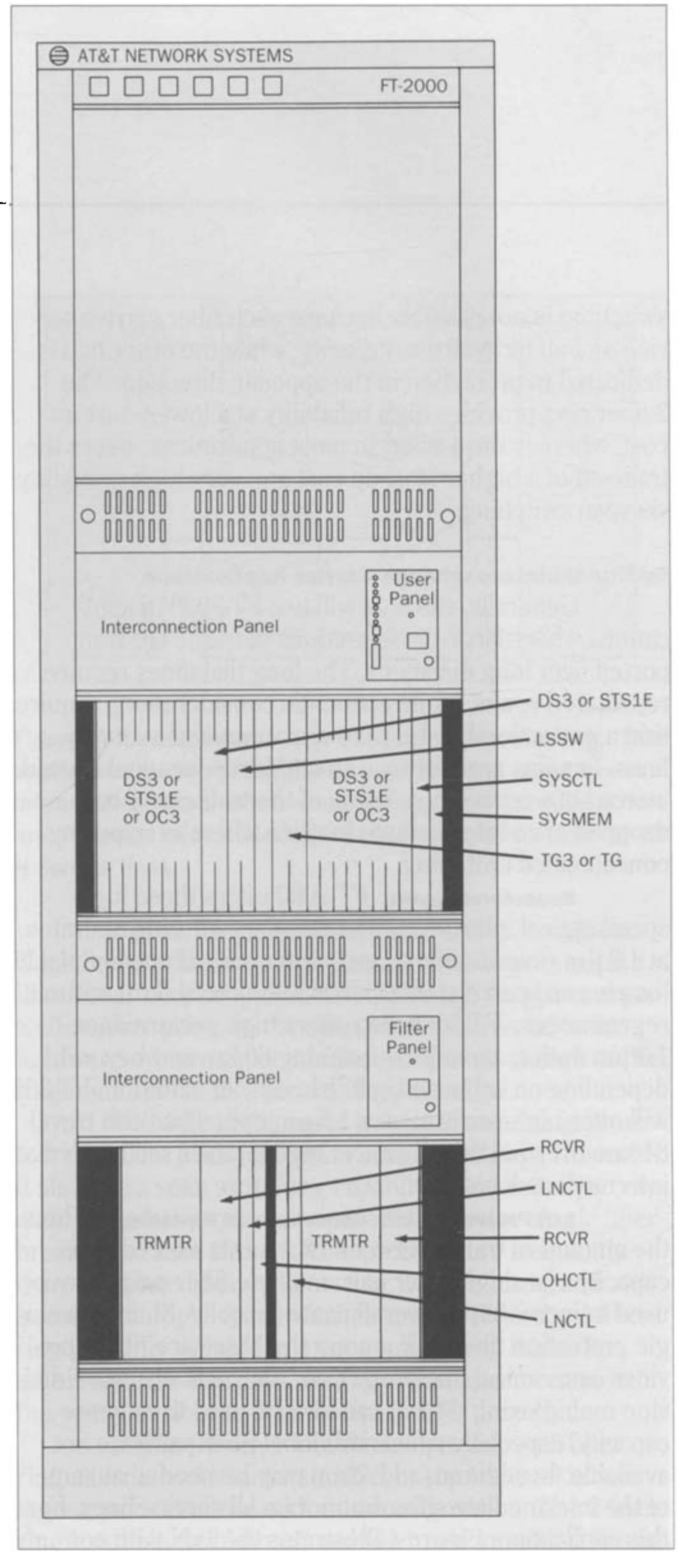

Figure 5. FT-2000 OC-48 1x1 End Terminal.

microprocessor-based control system. It must automatically detect and protect failures, measure transmission performance, run automated self-tests, keep circuit pack inventory, and automatically provision its circuits. It must provide user interfaces, including faceplate LEDs, a

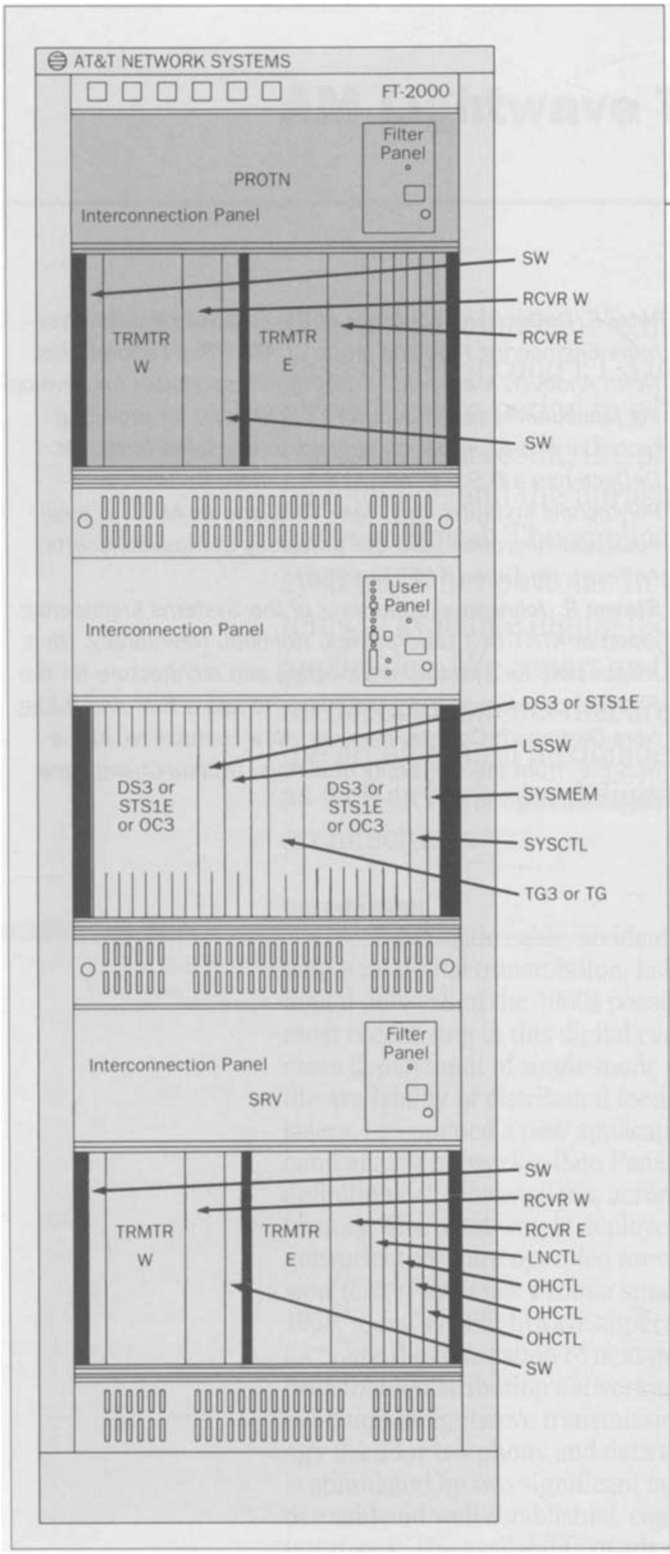

Figure 6. The FT-2000 OC-48 Add/Drop-Rings Terminal for 2-fiber ring and 4-fiber ring applications. The additional equipment needed for the 4-fiber ring applications is shown in the shaded portions in the upper third of the figure.

user panel, office alarms, a user-friendly PC-based craft interface terminal, and several different OS interfaces. It also must provide additional OAM&P features primarily involving communications with other terminals via the data communication channel (DCC).

Though the details of the control system vary slightly with each type of terminal, the basic FT-2000 control system philosophy takes a three-layer approach.

- At the top layer is the *system controller*, which is responsible for system-wide functions such as user interfaces, non-volatile memory, and bulk memory.
- The second layer consists of *line controllers*. There is usually one line controller associated with each OC-48 line. These line controllers are responsible for line level functions such as fault detection and protection switching. There are also overhead controllers to handle the processing needed by the seven layer OSI stack, defined by the SONET standard, for use on the data communications channel (DCC).
- At the third layer are the board controllers. Every transmission and timing pack in FT-2000 has a microprocessor on it that acts as the control system's "eyes and ears." The board controllers monitor and control the transmission hardware and report the results up the control system hierarchy.

The software running on this control system, like its hardware, is flexible, powerful, and modular. Object-oriented design techniques have been used extensively to develop the FT-2000 software. Indeed, because of the numerous combinations and variations of the FT-2000 system, the flexibility offered by the object-oriented design techniques is essential.

Object-oriented design is an increasingly popular software development technique. The essence of object-oriented design is to take the real-world application domain, develop abstractions of the "things" in that domain, and call them *classes*. Those "things" are then "brought to life" in a running system, and are called *objects*. These objects have properties, called *attributes*, and can perform functions, called *methods*. Objects interact by means of messages. The attributes of an object can be changed by invoking a pre-defined method.

This fundamental concept of object-oriented design has several important and powerful implications.

- It forces clean, mutually agreeable interfaces between objects to be defined.
- This defining allows parallel development of objects and reuse of objects in future releases or on other types of terminals.

- It decouples the software from its physical processor, allowing objects to run on different processors within the control system hierarchy, as dictated by the type of terminal.

Conclusion

The first FT-2000 release, a terminal for point-to-point applications, is currently completing customer evaluation and acceptance testing both in laboratory environments and first service applications in the field. Additional releases are planned throughout 1992 and 1993, creating a family of configurations to support all applications discussed in this paper. Beyond 1993, AT&T plans to evolve FT-2000 to provide for more advanced applications. It is considering new levels of wavelength division multiplexing (WDM) aimed at increasing FT-2000's capacity, and optical amplifiers (OAs) to increase the spacing between terminals or regenerators.

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