LIGHTGUIDE APPLICATIONS IN THE LOOP

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Traditionally, the telephone network has been dominated by voice traffic. With the rapid growth in computers, integrated workstations, automated banking machines, digital PBXs (private branch exchanges), etc., today's voice network must evolve to a wideband network that can support voice, data, and video. This changing environment puts new demands on the telephone network, especially the local access portion. Accurate forecasts for new services and the mix of services are difficult to obtain. Therefore, a network must be developed that can accommodate a wide range of services and, at the same time, change as rapidly as new services evolve. Lightwave systems and digital loop carrier offer many of the characteristics necessary for this flexible network. This article describes AT&T's DDM-1000 lightwave multiplexer and SLC® Series 5 carrier system for loop applications.

Perspective

Since the early 1980s, the Bell Operating Companies (BOCs) have been actively deploying lightwave technology in the loop. Initially, systems used light emitting diodes (LEDs) transmitting on multimode fiber cables.[1] With the rapid advances in lightwave technology, it is now possible to use lasers or edge-emitting LEDs transmitting on single-mode fiber. Today, almost all systems in the loop use lasers or edge-emitting LEDs and single-mode fibers.

With this capability, the BOCs can deploy single-mode fiber media with almost limitless capacity and simply upgrade the end-point electronics to meet demand. Many BOCs are planning to deploy fiber media directly to the customer's location, which will give them the bandwidth necessary to provide a wide range of services that range from voice through video.[2] However, with today's technology, it is not economically possible to take fiber directly to most customer locations.

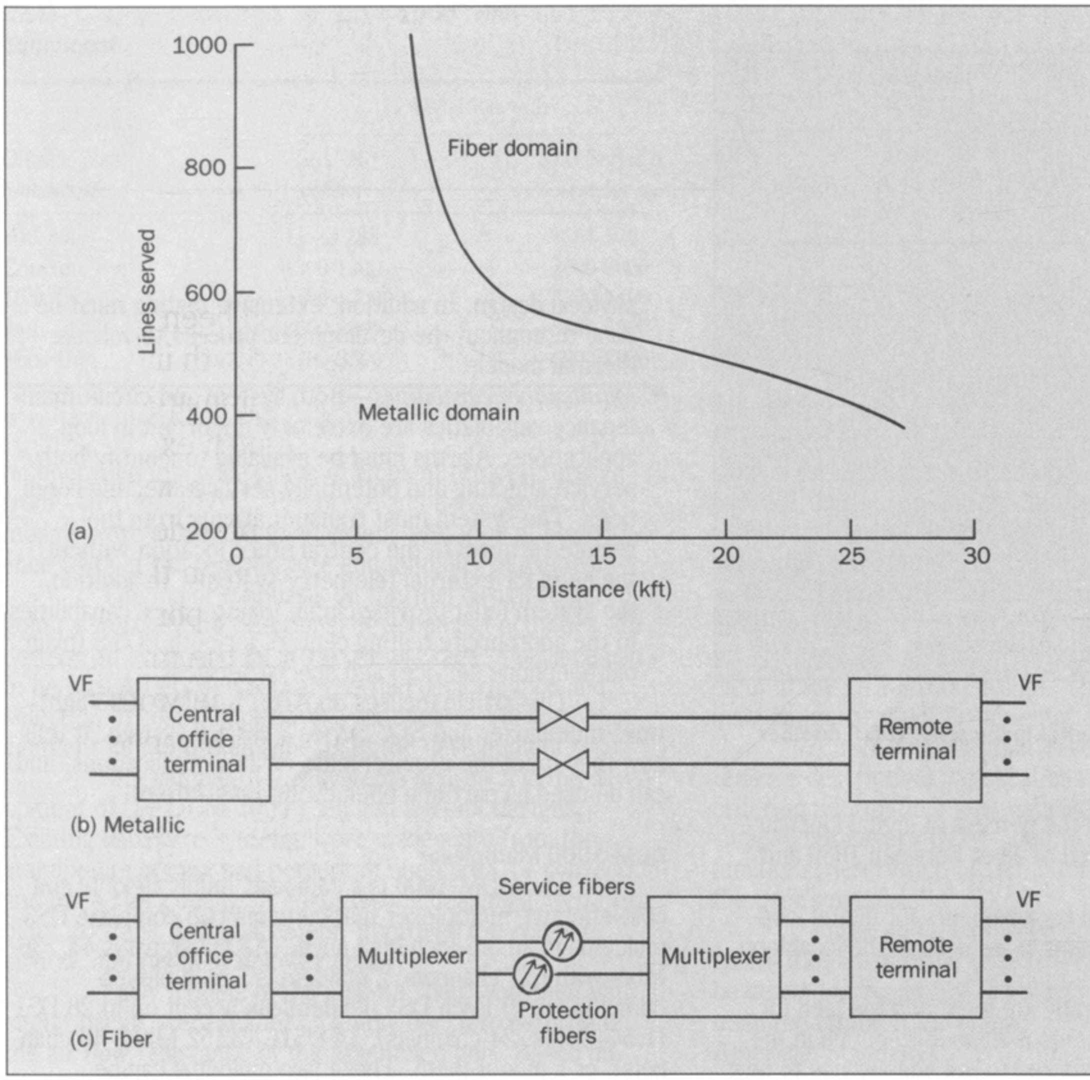

Figure 1. Economics of fiber as feeder cable. The curve shows crossover distance versus lines served for fiber loops. (COT = central office terminal; MUX = multiplexer; RT = remote terminal; VF = voice frequency signal.)

Therefore, an evolutionary strategy is being followed.

Most BOCs are deploying fiber in the feeder portion of the loop. They are taking economic advantage of the technology available today, while building a backbone network to support future digital services.

Figure 1 shows the economics of deploying fiber in the feeder portion of the loop. It compares the relative cost of installing new metallic T1 cables or fiber optic cable and multiplexers to provide the facilities for a digital loop carrier system, such as AT&T's SLC® Series 5 carrier system. For example, Figure 1 shows that, at 15 kft from the central office, it is more economical to use fiber if more than 550 lines are to be served.

The model used to generate Figure 1 did not include:

- Additional revenues that might be obtained from the fiber's bandwidth
- Maintenance benefits that occur from stabilizing the outside plant facilities
- The cost of rebuilding manholes to accomodate T1 repeaters
- Allocated cost of conduit.

Inclusion of these factors will move Figure 1's curve down and to the left, increasing the region of application for fiber.

This economic picture explains why, in Figure 2,

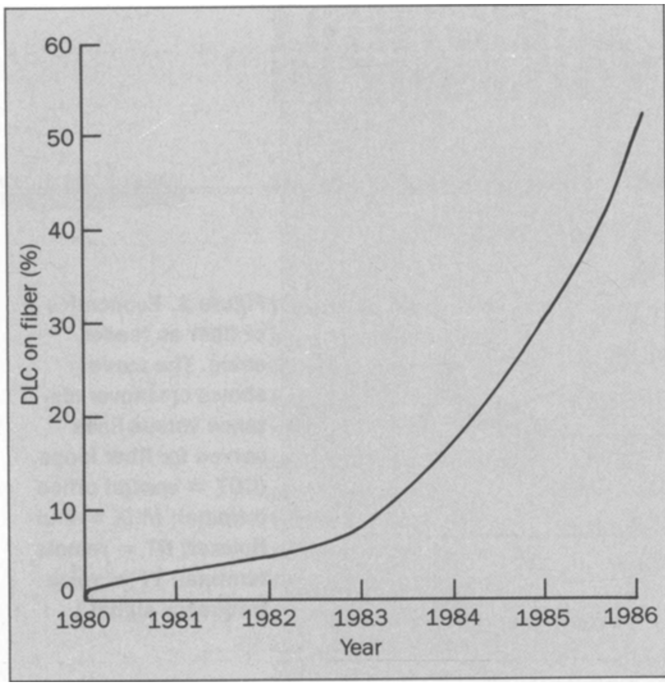

Figure 2. Deployment of digital loop carrier (DLC) on fiber since 1980.

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we see a rapid increase in the percent of digital loop carrier systems being deployed on fiber between 1980 and 1986.

The key technical requirements for digital loop carrier and lightwave systems to be used in the local loop are:

- *Size*—Land costs generally are high, and the land for remote terminal enclosures is difficult to obtain in the short intervals often required to provide service to new residential areas or industrial parks. Component systems permit the use of cabinets on the existing right of way, reducing service intervals and lowering overall costs.
- *Flexibility*—Forecasts for the quantity and mix of services are difficult to obtain. Flexible systems that can support a wide range of services and data rates reduce the risk associated with inaccurate forecasts.
- *Environmental robustness*—Because many loop applications are in uncontrolled environments, the equipment must be environmentally robust. Operation from –40°C to +65°C at up to 100-percent humidity (noncondensing) must be assured. This requires special component selection and specification, as well as unique circuit and physical design. In addition, extensive testing must be done throughout the development process to validate thermal models.
- *Maintenance capabilities*—Both system and circuit maintenance capabilities are extremely important in loop applications. Alarms must be available to identify both service-affecting and potentially service-affecting conditions. The system must transmit alarms from the remote terminal to the central office location without the need for external telemetry systems. In addition, the system must provide circuit maintenance capabilities to the appropriate testing centers for both POTS (plain old telephone service) and special services.

This article focuses on AT&T's DDM-1000 lightwave multiplexer and SLC Series 5 carrier system. It tells how they meet the requirements for loop applications, and can be used as part of a fiber-evolution strategy.

DDM-1000 Multiplexer

The DDM-1000 is a compact, highly flexible and cost-effective multiplexer that contains two complete DS3 muldems in an 8.5-inch high shelf. (A DS3 signal is 44.736 Mb/s with 672 channels; a muldem is a multiplexer-demultiplexer.) Each DS3 muldem can accept up to 28 DS1 (1.544 Mb/s, 24 channels), 14 DS1C (3.152 Mb/s, 48 channels), or a mix of them. These two muldems can be connected to transmission systems through a DSX-3 cross-connect, or connected internally to a 90-Mb/s lightwave transmitter/receiver. Figure 3 shows a fully equipped DDM-1000 assembly.

The DDM-1000 was designed to meet the requirements of loop applications. Its extended temperature and humidity capabilities and rich feature set that combines central office and remote terminal functions provide flexibility in planning and implementing digital loop carrier installations.

Thermal Design. Early in the development, model and empirical analyses generated benchmarks for thermal design of the DDM-1000. Component selection, fan unit, and shelf design requirements were established, all focused

Table I. Line Capacities of DDM-1000 with SLC Carrier Equipment

Outside plant structure	DDM-1000 with SLC-96 carrier	DDM-1000 with SLC Series 5 carrier
80C/80D	Up to 288	384-576
Concrete hut	1300-1400	2600-2800
16-ft CEV	1500-1700	3200-3400
24-ft CEV	2600-2800	5200-5600
Maxi-Hut	3400-3500	6800-7000

NOTE: CEV = controlled environment vault.

Table II. Optical Line Interface Unit Requirements

OLIU	Environment (°C)	System gain (dB)	Span length (miles)
16E	0 to +50	24.0	0 to 18
16F	−40 to +65	28.5	0 to 28
16G	−40 to +65	34.5	28 to 37

on operation in a wide range of ambient temperatures, from –40°C to +65°C. Prototype and early production models were subjected to an extensive series of performance tests at the temperature and humidity extremes.

The major emphasis on thermal design required going a step beyond traditional development activities. To develop an economically attractive package, a balance had to be struck between robust thermal performance and selection of cost-competitive components. Thermal management influenced all aspects of the development.

An example of this systems approach is the development of the DDM-1000 shelf and fan unit designs. Existing hardware systems were inadequate from the standpoints of cost and percent of open area for convection and forced air cooling. A custom shelf design allowed flexibility in circuit pack placement, improved the cooling airflow, and resulted in lower cost.

Early models of the custom shelf, equipped with circuit packs, were tested on a flow bench to determine the air flow resistance of the assembled unit. Based on these results, we selected forced air cooling for uncontrolled environments.

The overall compact size of the DDM-1000 permits installing eight shelves in a standard network bay frame in a controlled environment. Three 3-inch high baffles are installed in this configuration, one between every two shelves, to keep the circuit-pack temperature within established limits. In the free-convection mode of operation, cooling air is drawn in from the front of the equipment and exhausted to the rear.

Thermal management also included specific design of many components. This was especially true in the design of the optical line interface units (OLIUs) that operate in uncontrolled environment applications. A custom gate array required a special heat sink that clips on the ceramic substrate and keeps junction temperatures within limits.

The laser transmitter package (Astrotec® laser transmitter system) has both heating and cooling capabilities for the laser. During manufacture, a single setpoint control temperature is established within the Astrotec package. During operation, temperatures above the setpoint start thermoelectric cooling, while temperatures below the setpoint initiate heating. With this arrangement, the laser temperature is not subjected to the wide temperature variations that other components experience.

Operation. Simplicity of operation was a key ingredient in the DDM-1000 design. This extends to installation, turn-up, documentation, and maintenance.

A user's manual that covers functional and maintenance descriptions, applications engineering and ordering information, and installation procedures is shipped with every DDM-1000. Appendix A presents a functional description of DDM-1000 operation, taken from the user's manual.

Three automated turn-up procedures reduce DDM-1000 installation time to a minimum. These tests can be started using an ASCII terminal or push buttons mounted on the front of the equipment. (ASCII is the American Standard Code for Information Interchange.)

The first procedure, the local test, verifies operation of the assembly as an isolated entity. The second procedure checks the wiring to the cross-connects, while the third procedure—the system test—verifies end-to-end operation of the facility.

The DDM-1000 provides an ASCII terminal interface that can be used to obtain detailed maintenance information and control the advanced features of the assembly. Many portable terminals and most display terminals can be used directly. Installations with more than one DDM-1000 per bay can share a link between shelves that allows the ASCII terminal to communicate with other shelves.

When the DDM-100 is installed in a central office/

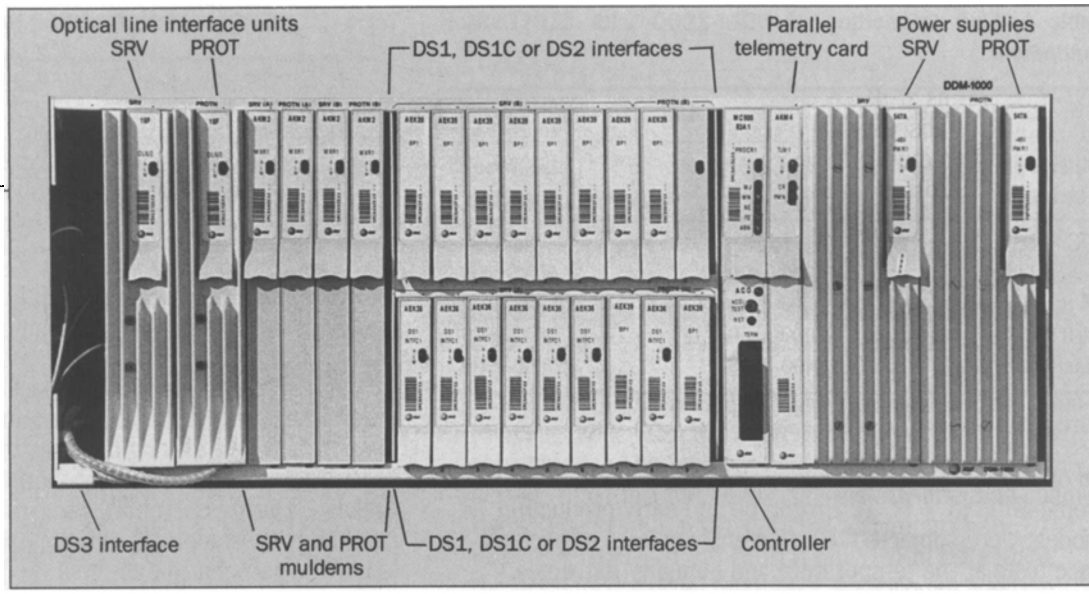

Figure 3. Fully equipped DDM-1000 assembly. SRV = service; PROT = protection.

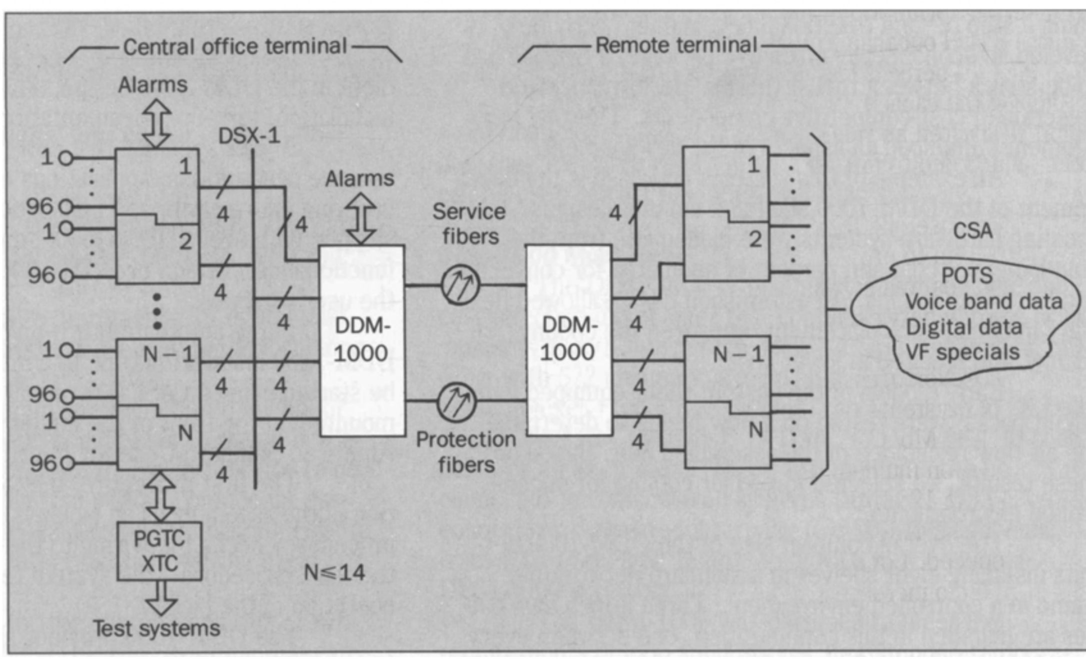

Figure 4. Typical SLC Series 5 carrier system application with DDM-1000 (for N ≤ 14). The pair gain test controller (PGTC) and extended test controller (XTC) provide test capabilities for all services. The carrier serving area (CSA) encompasses POTS (plain old telephone service), voiceband special services, and digital data services.

remote terminal application, an optional telemetry pack provides additional maintenance interfaces. This package includes additional alarms; an extensive, parallel telemetry set; and a bidirectional, overhead telemetry capability.

Various outside plant structures are available to house the DDM-1000 and SLC carrier equipment. Table I lists the approximate line capacities of these structures, using DDM-1000 together with SLC-96 carrier or the SLC Series 5 carrier system.

Applications of DDM-1000 in its optical mode are based on the operating environment of each assembly and the approximate span length between assemblies. Table II specifies the operating environment, system gain, and span length for the various OLIUs.

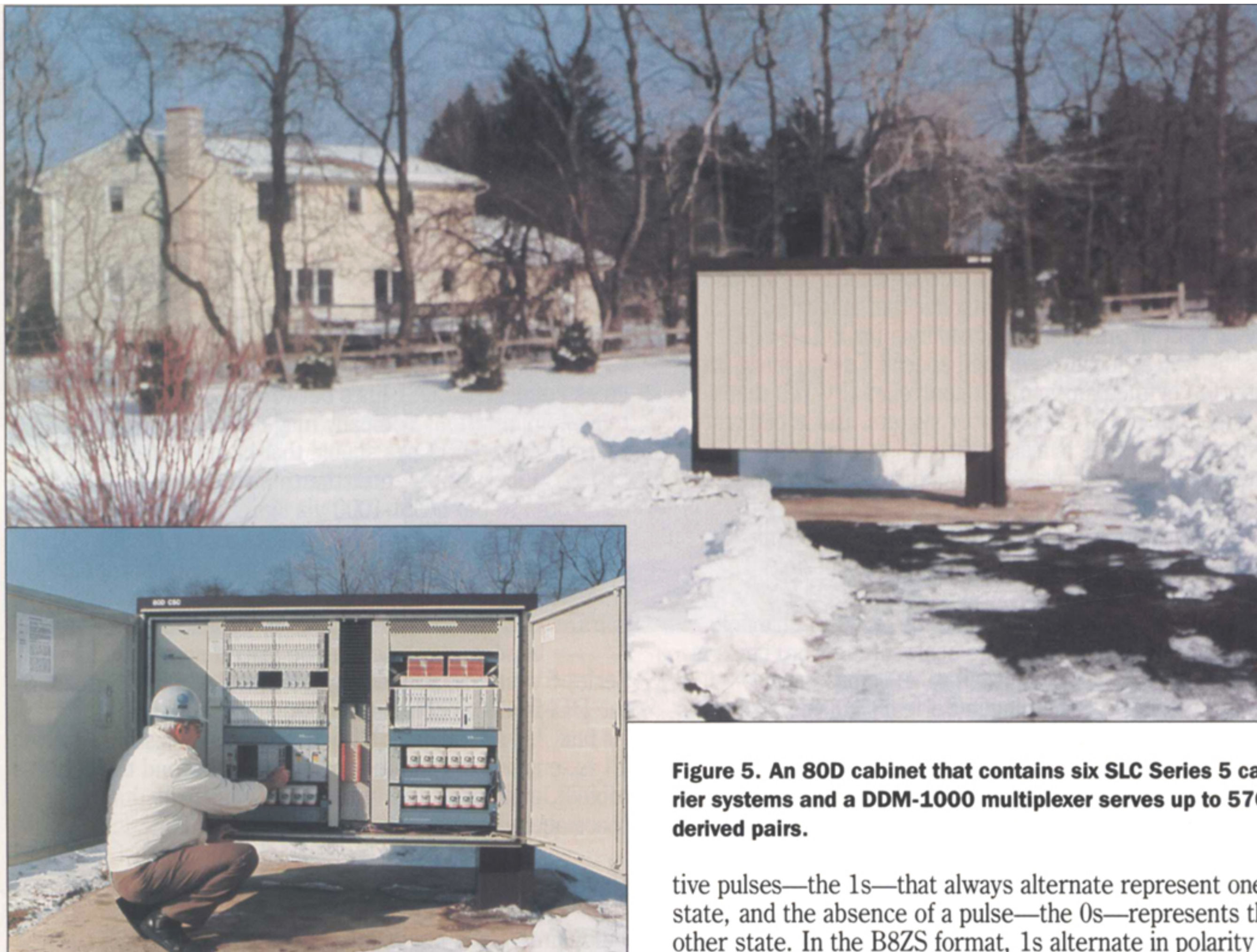

Figure 5. An 80D cabinet that contains six SLC Series 5 carrier systems and a DDM-1000 multiplexer serves up to 576 derived pairs.

SLC Series 5 Carrier System

The SLC Series 5 carrier system is a microprocessor-based, digital loop carrier system that supports a full range of voice and digital services in one-fourth to one-half the space that the SLC-96 system requires. (Hereafter, we will refer to the SLC Series 5 carrier system as Series 5.) The Series 5 architecture permits upgrading service capability with simple plug-in changes. Figure 4 shows a typical arrangement of Series 5 with DDM-1000. The interface between the two systems is at the DS1 rate (1.544 Mb/s).

Both Series 5 and DDM-1000 support traditional bipolar, alternate mark inversion (AMI) line coding or bipolar with eight zero substitution (B8ZS) for clear channel capability. (In the bipolar AMI format, positive and negative pulses—the 1s—that always alternate represent one state, and the absence of a pulse—the 0s—represents the other state. In the B8ZS format, 1s alternate in polarity but a special code word replaces eight 0s in a row in the original signal.) Line coding is selected with dip switches on the respective line interface units.

Appendix B discusses the internal architecture of the Series 5 channel bank.

Maintenance and Testing. System maintenance is accomplished by the internal system intelligence and the overhead message-oriented data link between the Series 5 remote terminal and the corresponding central office equipment (central office terminal or digital switch). Use of this data link enables the terminals to perform automated maintenance actions that sectionalize trouble to either the central office terminal, the remote terminal, or the facility. Alarms are available at the central office equipment for transmission via standard telemetry systems to the appropriate operations centers.

Circuit maintenance is accomplished via the bank microprocessor and a test controller that is located at the serving central office. Test capabilities for POTS-type lines, as well as locally switched special service lines, are supported by the pair gain test controller (PGTC) that was developed for the SLC-96 carrier system. Enhanced testing for all services is available through the extended test controller (XTC) that was developed specifically for the Series 5 system.

With the XTC and Series 5, all services may be tested. This enhanced testing capability is possible because of the microprocessor technology in the XTC and Series 5, the test access relays on the Series 5 channel units, and the VLSI (very-large-scale integration) chips in the channel bank that permit full splitting bit-stream access. System programming in Series 5 and the XTC initiates sequences and interprets results.

Thermal Design. As with the DDM 1000 development, thermal management was considered at all stages of Series 5 development. Extensive modeling and testing were done to assure operation in an uncontrolled environment. Heat baffles were developed to aid convection cooling at the central office terminal, and a fan unit and associated controls were designed for forced convection in remote terminal applications. Thermal setpoints for fan operation were established to maximize system reliability.

80D Cabinet Arrangement

The size and service capabilities of the DDM-1000 and the Series 5 provide increased opportunity for the BOCs to deploy fiber. In the arrangement shown in Figure 5, six Series 5 systems and a DDM-1000 multiplexer are placed in a single 80D cabinet, providing capability for 576 derived pairs (equivalent cable pairs).

The 80D cabinet, which is factory assembled and prewired for the Series 5 systems and the DDM-1000, is 66 inches high, 84 inches wide, and 27 inches deep. The DDM-1000 is powered from the Series 5 power shelf, and Series 5 fan units supply forced air cooling for both electronic assemblies. Three battery strings on each side of the cabinet provide eight hours of operation if ac power fails.

The tie block above the DDM-1000 is used to cross-connect the DS1 lines between the two systems. The telecommunications company may use the tie block to rearrange the DS1 lines should that be necessary.

Fiber cables enter the cabinet on the left and are connected to the DDM-1000 via lightguide interconnect hardware. The derived pairs are spliced to the distribution cables inside the cabinet, and protector blocks in the middle of the cabinet provide electrical protection for the pairs.

A second cabinet can be placed nearby with eight Series 5 systems, permitting full use of all 56 DS1 ports of the DDM-1000.

To provide flexibility for DS1 services or permit T1 extensions to remote terminal sites beyond the 80D cabinet, office repeater shelves can be provided in the space above the tie block (Figure 6).

Summary

The size, flexibility, environmental robustness, and maintenance capabilities of the DDM-1000 and the Series 5 systems have been designed to meet the requirements of the local loop. When used in structures or the 80D cabinet, they give the Bell Operating Companies a way to implement an economical, evolutionary strategy for fiber deployment. The microprocessor-based architecture of the systems allows upgrades of service and maintenance capabilities as needs are identified.

References

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2. R. K. Snelling and J. Chernak, "The Revolution in the Loop Network: The Evolving Broadband Technology," *Proceedings of the International Symposium on Subscriber Loops and Services*, Tokyo, Japan, September 29 to October 3, 1986.

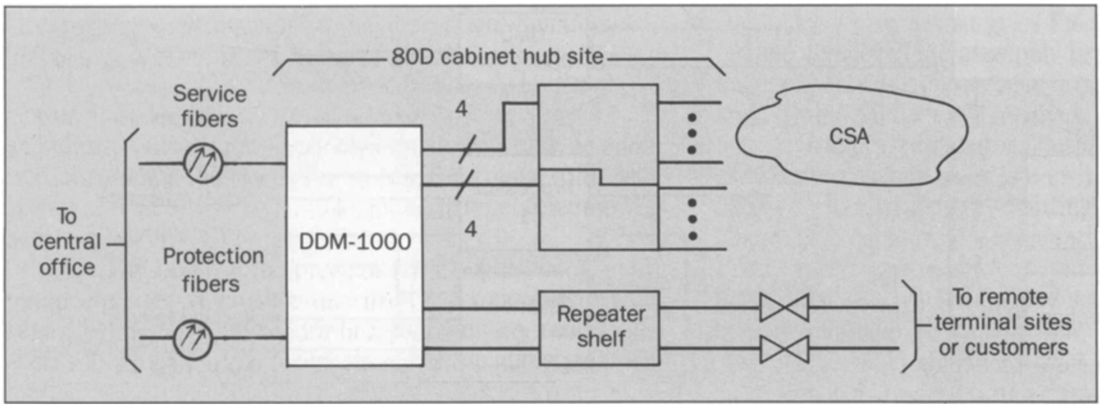


Figure 6. Office repeater shelves placed in the space above the tie block can provide DS1 services or permit extending T1 to remote terminal sites.

Appendix A. DDM-1000 Functional Description

As Figure A-1 shows, two muldems (multiplexers/demultiplexers) share high-speed interfaces, power, and a controller.

If the DDM-1000 is configured for DS3 (44.376 Mb/s) electrical terminations, each muldem is independent. If it is configured for lightwave terminations, Muldem B is synchronized to Muldem A to provide an economical 90-Mb/s lightwave system.

The controller provides all monitoring, protection switching, and display within the assembly. In addition, it contains interfaces for an ASCII terminal; office alarms; and serial, parallel, and overhead telemetry.

Separate optical line interface units (OLIUs) terminate each service or protection 90-Mb/s lightwave line in both the transmit and receive direction. Three codes are available:

- The OLIU1 (16E) can only be used in a controlled environment for short to moderate length spans.
- The OLIU2 (16F) can be used in an uncontrolled environment for short to moderate length spans.
- The OLIU3 (16G) can be used in an uncontrolled environment for moderate to long spans.

Transmission. In the lightwave transmitting direction, an 89.472-MHz clock is received from the function unit—service or protection, as appropriate—in Muldem A and Muldem B (Figure A-2) One of these clocks is selected for the OLIU pack's use as a clock source. This clock is divided by two, and the resulting 44.736-MHz clock is sent to the function units for their use to return synchronous data to the OLIU.

The OLIU also receives a unipolar, scrambled NRZ (nonreturn on zero) data and clock stream from each function unit. These synchronized DS3 signals are combined to form the 88.742-MHz NRZ data signal. However, the DS3 signal from Muldem B is marked to allow the separator at the far end of the system to identify Muldem B's signal.

A single-mode, 1.3-μm laser transmitter converts the electrical signal into information pulses of light that are coupled onto a single-mode fiber pigtail for connection to the transmitting single mode or multimode fiber.

Reception. In the lightwave receiving direction, the receiving single mode or multimode fiber is connected to a multimode fiber pigtail. A PIN (positive-intrinsic-negative) diode based lightwave receiver converts the pulses of light into electrical pulses. The clock is recovered from this 89.472-MHz unipolar, NRZ data stream using a surface acoustic wave (SAW) filter. The signal is separated into two unipolar, scrambled NRZ data and 44.736-MHz clock

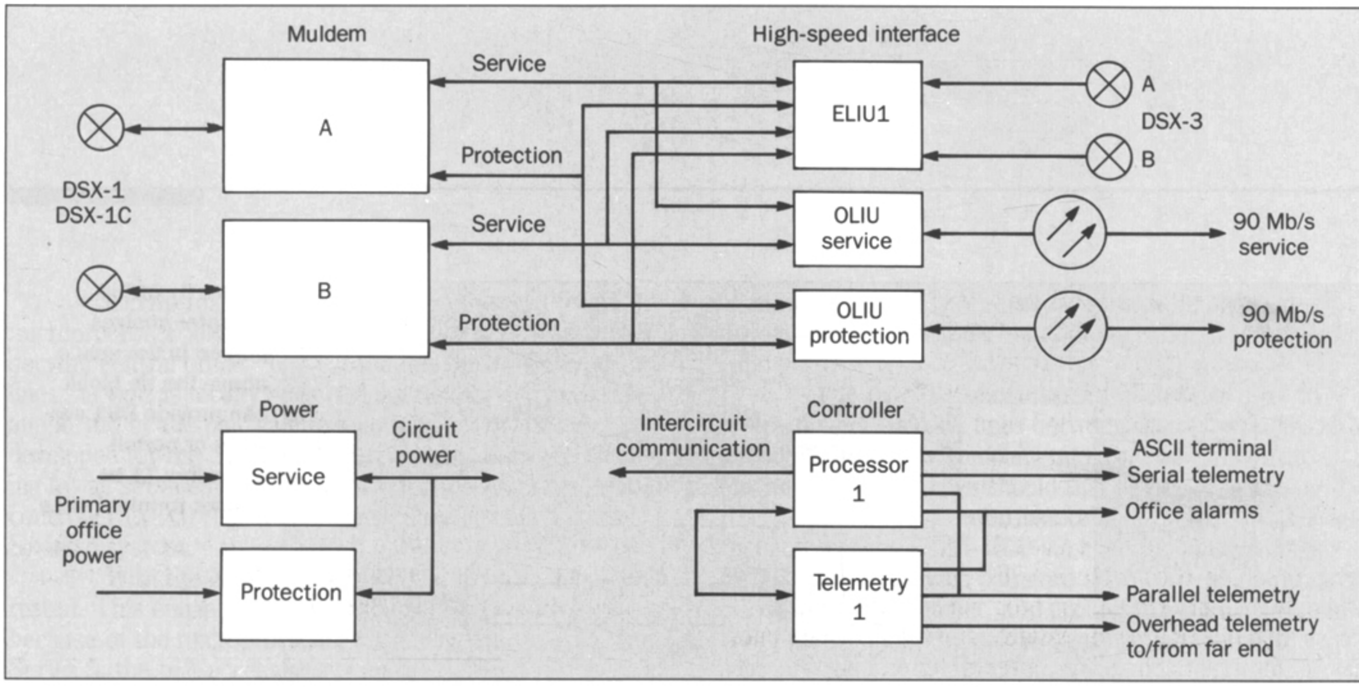


Figure A-1. DDM-1000 block diagram.

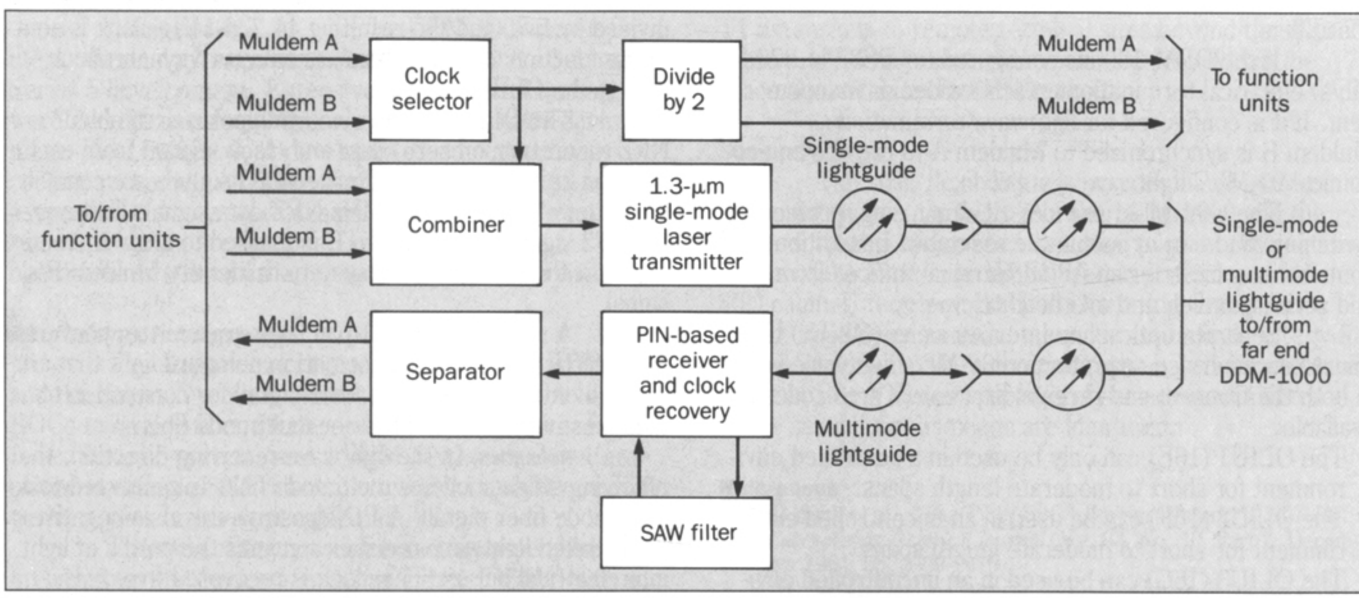


Figure A-2. OLIU block diagram.

streams that are then sent to the appropriate function units.

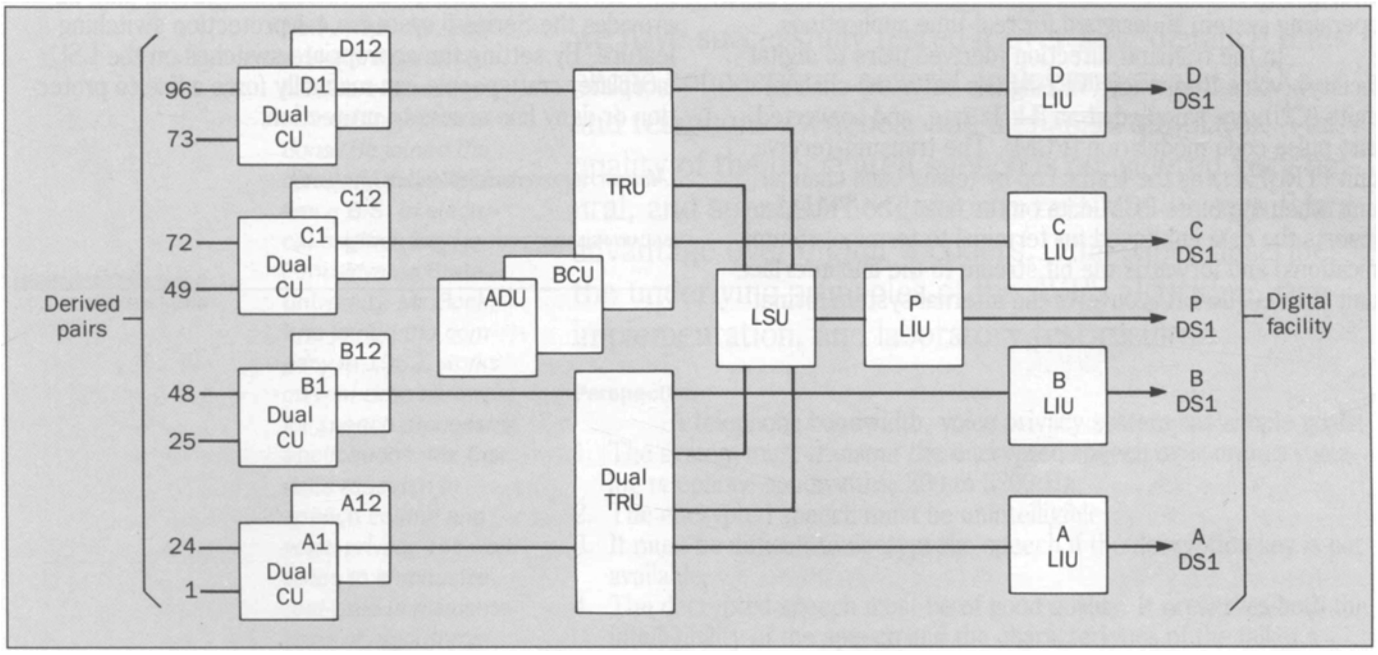
Processor. In the controller (Figure A-1), the processor provides control for all monitors, protection switching, alarms, and display within an assembly. In addition, it contains interfaces for an ASCII terminal, office alarms, serial telemetry, and a limited parallel telemetry set.

The heart of the processor is a sophisticated microcomputer. It consists of a 16-bit microprocessor with read only memory (ROM) for program storage, random access memory (RAM) for variable storage and state information, interrupt controllers, interval timers, an intelligent sanity timer, and an operating system designed for real-time applications.

Application-specific hardware links this microcomputer with the transmission hardware. A high-speed communication link that gives the processor complete status and control of the assembly is provided for each muldem. This link allows access to and control of the far end DDM-1000 terminal for many different features.

Dedicated monitors for parity error and loss of clock/frame ensure quick line switching for the line terminating option. LED (light emitting diode) drivers can turn on any LED to provide easy identification of failures. Primary-pack switch drivers control the protection switching on all packs. Pack-equipped sensors identify new packs as they are added to the assembly.

Figure B-1. Block diagram of a central office terminal for the SLC Series 5 carrier system. (ADU = alarm display unit; BCU = bank control unit; CU = control unit; LIU = line interface unit; LSU = line switch unit; TRU = transmit-receive unit.)



Appendix B. Series 5 Functional Description

As the block diagram (Figure B-1) shows, the channel bank forms the transmission and signaling interface between the derived cable pairs and the DS1 digital facility. It multiplexes 96 derived pairs (channels) onto four active DS1 lines. The alarm display unit (ADU) and bank control unit (BCU) circuit packs contain the system processor, system programming (firmware), memory, and intrasystem interfaces. Together, they form the system controller and control performance monitoring, protection switching, alarming, and testing. New service and maintenance capabilities can generally be obtained through changes in the controller.

The controller is an 8-bit microprocessor with electronically programmable read-only memory (EPROM) for program storage, random access memory (RAM) for variable storage, interrupt controllers, timers, and a serial interface to channel units and common circuit packs. The operating system is designed for real-time applications.

In the transmit direction (derived pairs to digital facility), voice frequency (VF) signals enter the channel units (CU), are sampled at an 8-kHz rate, and converted into pulse code modulation (PCM). The transmit-receive unit (TRU) acts as the traffic cop by telling each channel unit when to put its PCM data on the bus. The TRU also inserts the data link (used for terminal to terminal communications) and forwards the bit stream to the line interface unit (LIU). The LIU converts the internal system format into the standard bipolar (1.544 Mb/s) DS1 format and interfaces with the transmission facility. The reverse process is carried out in the receive direction (digital facility to derived pairs).

The two-way, terminal to terminal data link is used for transmitting status and alarm conditions between the central office terminal and the remote terminal. The data link is message oriented using the X.25 protocol and is transmitted on the A digroup.

The bank controller uses the data link to communicate with the other terminal's bank controller; each controller keeps its own common units informed of alarms and status conditions.

The LIU automatically uses internal bank loopbacks to sectionalize failures so that the bank controller can provide detailed information about failures to craftspeople.

The line switch unit (LSU), an optional plug-in, provides the Series 5 system's 4:1 protection switching feature. By setting the appropriate switches on the LSU faceplate, craftspeople can manually force a line to protection or deny line access to protection.

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