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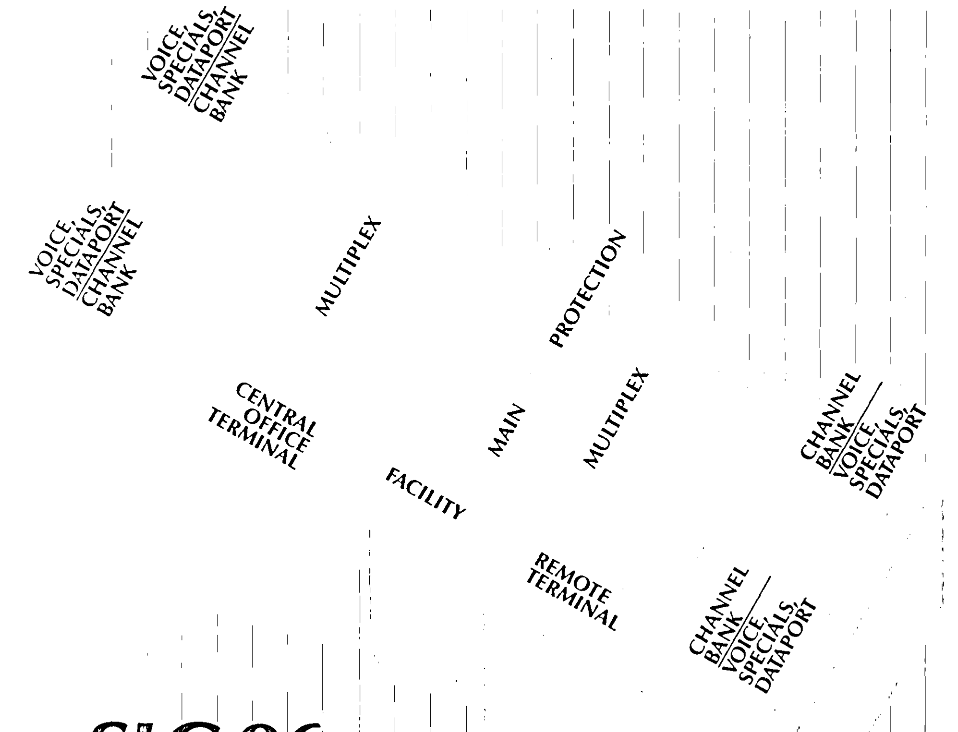

SLC 96 CARRIER

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THE *SLC* 96 SUBSCRIBER LOOP CARRIER SYSTEM

R. C. Chapman, Jr., *Guest Editor*

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The SLC *96 Subscriber Loop Carrier System:*

OVERVIEW

By T. A. ABELE and A. J. SCHEPIS*

(Manuscript received September 23, 1983)

Like all digital transmission systems, digital subscriber loop carrier seems destined to play an ever-increasing role in modern communication networks. This trend derives its strength from basic and pervasive factors: (1) the great ease with which digital transmission can support new services, particularly those related to any form of data transmission; (2) the seemingly inexhaustible potential of digital integrated circuit technology to realize ever-decreasing cost, size, and power-per-circuit function; (3) the great promise digital transmission holds for synergy with digital switching. This paper provides an overview to a series of papers that describe in detail AT&T Technologies eminently successful entry in this market, the *SLC*® 96 Subscriber Loop Carrier System. Emphasis is placed on the background leading to the development and the forces that shaped the system's architecture.

I. INTRODUCTION

The first digital carrier system was introduced into commercial exchange office service in 1962 as an alternative to using multipair metallic interoffice trunks. This first generation digital channel bank was designated the D1 bank. In 1971, the first digital loop carrier system was introduced to provide service to rural subscribers using T1-type digital lines to expand the capability of the existing cable

* Authors are employees of AT&T Bell Laboratories.

plant. This vintage system was designated the *SLM*™ Subscriber Loop Multiplexer System. Three years later, in 1974, a low-cost, high-performance replacement for the *SLM* system called *SLC* 40 Subscriber Loop Carrier System was introduced, which has made a major penetration into rural areas.[1] Each of the above loop carrier systems offered single- and multiparty Message Telephone Service (MTS)* and coin service. Meanwhile, four generations of digital trunk carrier systems culminated in the introduction of the D4 system in 1976.[2] This is where the *SLC* 96 Subscriber Loop Carrier story begins, because its development can be traced directly to the D4 system with which it shares its physical format and technology.[3]

The *SLC* 96 carrier system is a digital system that uses μ255 Pulse Code Modulation (PCM) and time-division multiplexing to consolidate message channels onto four 24-channel digroups for transmission over T-carrier links. The basic system, consisting of a central office terminal interfaced by the T1 lines to a remote terminal, was introduced in 1979 and is presently being manufactured by AT&T Technologies, Inc. Figure 1 is a photograph of a *SLC* 96 carrier system central office channel bank. In November 1982, the basic system was equipped with enhanced features, such as fiber optics, to facilitate increased services and system performance.

II. THE MOVEMENT OF TECHNOLOGY

The continually decreased cost and ever-expanding capability of electronic technology is leading to the rapid development and deployment of a completely integrated digital network. This network, which will ultimately lead to end-to-end digital connectivity, can support a wide range of both voice and nonvoice services, fully integrated on the same basic access to the customer. Digital loop carrier systems like the *SLC* 96 carrier system can handle today a broad range of telecommunications services for both voice-message and special services and represent a significant step toward bringing a basic digital capability to the local network.

The basic *SLC* 96 carrier system synthesizes the essential attributes of an interoffice trunk system with the special features required for operation in the loop environment. It consists of two terminals, the Central Office Terminal (COT) and the Remote Terminal (RT). The COT is located in the central office and interfaces with a local switching machine; the RT is located remotely in the outside plant and serves a cluster of customers in a locality. The terminals contain channel banks that are interfaced by T1 carrier transmission equipment to form distinct channel group operating systems.

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* Acronyms and abbreviations used in the text are defined at the back of the *Journal*.

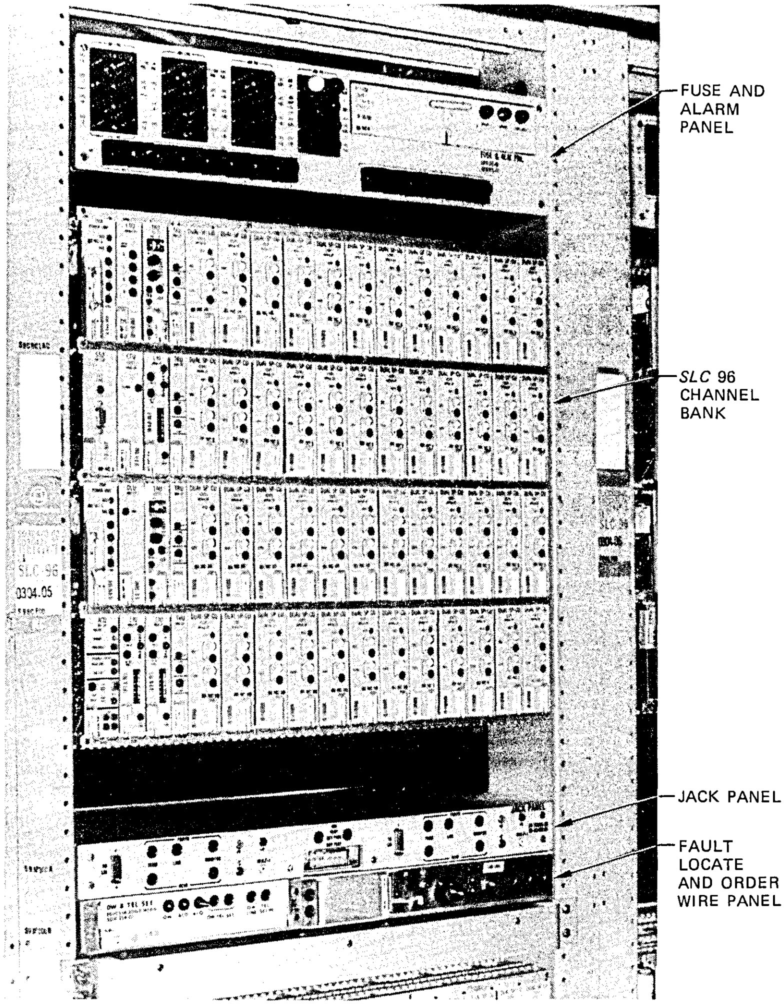

Fig. 1—*SLC* 96 carrier—central office channel bank.

The channel bank organization, containing common units and channel units and being patterned after the D4 channel bank, allows considerable flexibility in its use. Newly designed dual-channel units provide low-cost message telephone service. In addition, the *SLC* 96 carrier channel banks can accommodate coin service and most D4 trunk and special-service channel units, including new dataport units. The resulting system has the versatility to serve the rapidly growing suburban areas, in addition to rural areas, to lower the cost of evolving the loop plant and to provide new digital services to the business community.

The addition of light fiber interfaces and multiplexing equipment to the *SLC* 96 carrier system[4] has provided the impetus to further accelerate the penetration of digital loop carrier by bringing a wide-band capability practically to the customer's doorstep. The enhanced lightwave feature associated with the basic T1 *SLC* 96 carrier system is designated the Fiber *SLC*® carrier. These interfaces, consisting of fiber optics and Optical Line Interface Units (OLIUs), are integrated directly into the *SLC* 96 carrier channel banks to provide the DS2 rate (6.3 Mb/s), while transmission at the DS3 rate (44.7 Mb/s) requires the addition of a companion, higher-bit-rate multiplexer called the LM23 multiplexer.

Figure 2 is a photograph illustrating how the DS2 lightwave multiplexing equipment integrates into the *SLC* 96 carrier channel bank. Three plug-in units (highlighted), a main and protection OLIU, and a Line Switch Unit (LSU), displace existing plug-in units that are normally used to provide service over standard T1 digital lines. Figure 3 illustrates how the *SLC* 96 carrier channel banks interface the digital loop hierarchy to provide voice frequency, data, or special services.

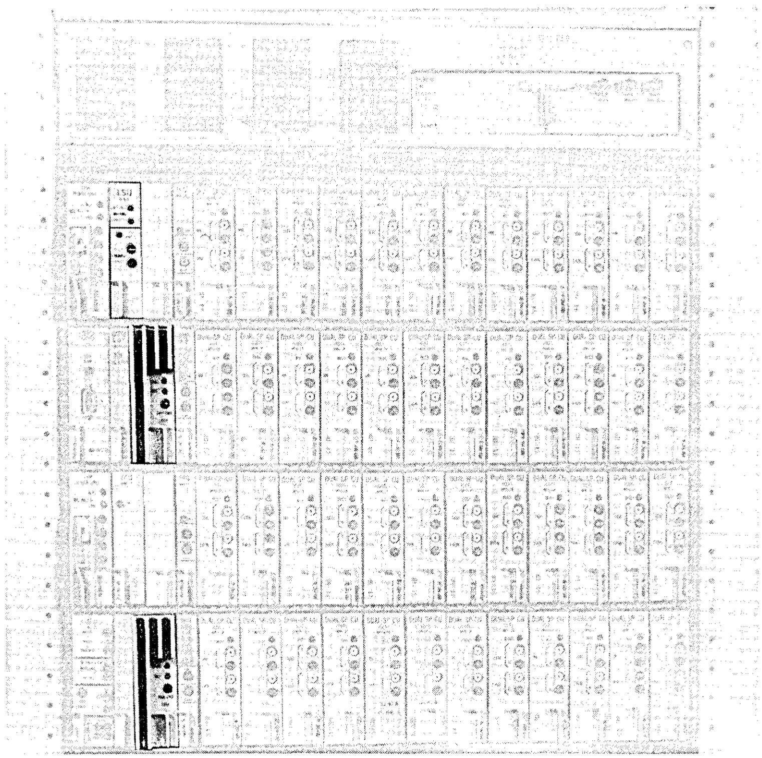

Fig. 2—Fiber *SLC* carrier—central office channel bank.

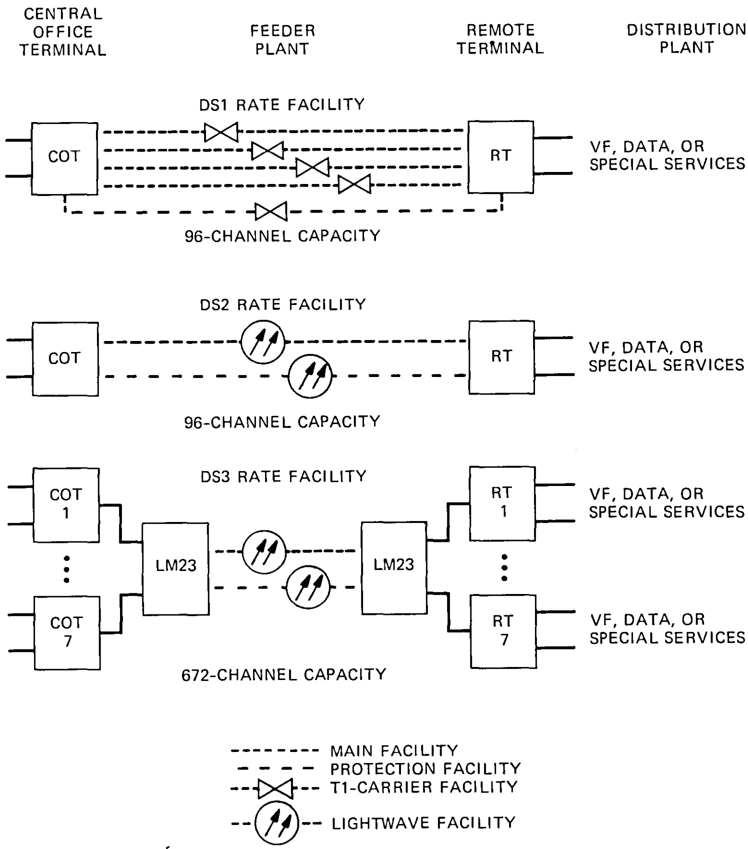

Fig. 3—Standard *SLC* 96 carrier channel bank interfaces.

III. THE EXPANDING MARKET

The penetration of the *SLC* 96 carrier system in the Regional Bell Operating Companies was approximately 20,000 installed systems by the end of 1983. A gross, first-order view of the potential market for digital loop carrier sales worldwide through the end of this century is shown in Fig. 4 and is based on the following premises:

1. The establishment of Carrier Serving Areas[5] by operating companies as a planning strategy for effectively deploying digital loop carrier in the loop network. A carrier serving area, as a planning entity, is a distinct geographic area served by digital loop carrier remote terminals whose outer boundaries are determined by the distance limitations of 64-kb/s digital service without the need for repeaters, and voice-frequency service without the need for load coils.

2. Projections of more than 50 percent of all loop growth to be electronically derived via digital loop carrier by 1990.

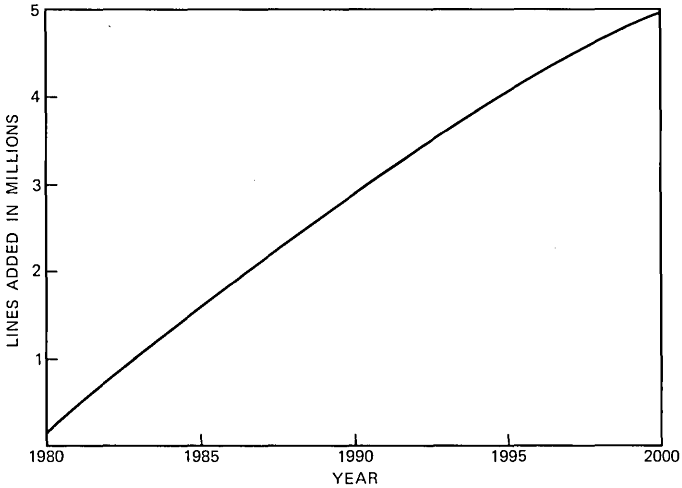

Fig. 4—Worldwide digital loop carrier market.

3. Projections of more than 75 percent of all loop growth installed on digital loop carrier in the year 2000 to be placed on light fiber and not metallic cable.
4. Projections of more than 50 percent of all loop growth via digital loop carrier to be integrated on a digital switch by the year 2000.

The operating companies in the United States are already planning the transformation to a digital network by ceasing to install loaded or coarse-gauge cable in the outside plant by the mid-1980s. This paves the way for all digital transmission directly to the customer's premises over ordinary telephone pairs. In urban areas, where nonloaded, short loops are encountered, digital loops may be provided directly from the central office without using digital loop carrier. In suburban and rural areas, digital loop carrier deployed in a carrier serving area can accommodate digital transmission to the customer over nonloaded pairs in the distribution portion of the loop plant. The loaded feeder cables, which presently streamline voice-frequency services to suburban and rural areas, are gradually giving way to placing digital loop carrier on T1 lines on this portion of the loop plant. The use of existing copper feeder for T1 transmission does require the conditioning of pairs to accommodate a high-bit-rate repeatered line. As continued growth is encountered and new feeder cables are required, the long-term telecommunications needs for a carrier serving area may be provided by using the new light fiber technologies that are emerging.

The new lightwave feature of the *SLC* 96 carrier system employs a light fiber design for efficient repeaterless transmission using LED/PIN diode technology at the long wavelength of 1.3 μm, where dispersion and loss are minimum. The use of light fiber in the feeder portion of the loop plant is significant in the evolution of an all-digital network with a wide-bandwidth capability.[6] Digital loop carrier on light fiber links is also finding increased usage in urban areas to serve commercial and residential complexes.

Digital loop carrier will become even more attractive as digital switching begins to penetrate the central office, since the direct interface of a digital loop carrier remote terminal with a digital switch will lower costs.

IV. THE PHYSICAL ENVIRONMENT

The widespread use of a digital loop carrier of necessity introduces electronic subsystems into an area of the loop plant, commonly referred to as the "outside plant," which is located away from the central office and its protected environment. While the central office provides a generally controlled environment, the outside plant, on the other hand, exposes the remote terminal apparatus of a loop carrier to a hostile environment. This is an environment that includes exposure to lightning, power line induction, temperature and humidity extremes, and possible vibration and atmospheric pollutants.

The *SLC* 96 carrier remote terminal consists of one or more channel banks supported by ringing supplies, battery plants, and power distribution/jack panels, all of which have been designed to operate reliably in an environment to which equipment in the outside plant may be subjected. The channel banks and support apparatus are connectorized for easy installation and turn-up in the field, and these connectorized assemblies can also be rapidly replaced for maintenance reasons. This collection of apparatus can be mounted in a variety of cabinets or on frames suited to small equipment buildings and underground vaults.

One of the goals in designing the *SLC* 96 carrier system has been to provide a variety of structures to accommodate the remote terminal arrangements in widely varying line sizes (from 100 to approximately 4000 lines) and in rural as well as suburban/urban areas. These structures or enclosures have been designed with aesthetic considerations in mind so that they can be functional and yet provide an appearance that is acceptable to the immediate neighborhood. In addition, the remote terminals can also be mounted in customer-owned facilities.

It is important to recognize that the truly low-cost potential of digital loop carrier can only be fully realized if the variety of remote terminal mounting arrangements are standardized and become commonplace in the main stream of the planning, engineering, and operations of the operating companies. For that reason, pre-engineered, turn-key installations of most remote terminal structures are offered for both cabinet and small building arrangements including underground vaults.

V. TRENDS

There is a rapidly growing market for new telecommunication services that can be offered by integrating services on a new digital telephone network. This all-digital network concept is referred to worldwide as the Integrated Services Digital Network (ISDN),[7] and it is causing a complete revolution to take place in the loop plant. The series of articles in this issue will focus on the present-generation digital loop carrier system, the *SLC* 96 carrier system, which may be equipped for operation using T1 digital lines at the DS1 rate, or which may interface directly to lightguides at the DS2 rate using new optical plug-ins in the latest version of the Fiber *SLC* carrier channel banks. A development to complement the Fiber *SLC* carrier channel banks by adding high-capacity multiplexing at the DS3 rate to the architecture is under way. A loop lightwave multiplexer, called the LM23 multiplexer, will multiplex up to seven DS2 streams from Fiber *SLC* carrier banks to use lightguide cables efficiently.

Initially, these new digital facilities are being used to expand the service capability of the present cable network and to defer new capital expenditure. As new cable facilities are required, optical fiber systems will find application in the loop plant to economically establish high-capacity feeder facilities to remote terminal sites through installation of long, repeaterless fiber spans. These lightguide facilities will also provide a wide-bandwidth capability for future services. For example, development is under way to expand the *SLC* 96 system lightwave features to include DS1 port offerings, DS2 optical extensions, and T1-carrier extensions beyond the remote terminal. In this way, the local network may evolve such that no real barriers will prevent the offering of a wide variety of information services needed by businesses and homes.

The *SLC* 96 system, with its added lightwave features, has begun to seed the network with a basic digital capability to the customer while at the same time providing immediate low-cost means of coping with the growth in general message telephone service in the operating telephone companies.

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The SLC 96 Subscriber Loop Carrier System:

Channel Bank

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(Manuscript received September 22, 1983)

The *SLC*® 96 carrier system has been developed to bring digital capability to the local loop network, and ultimately it may be a component of a completely integrated digital network. It uses two unique channel banks: one located in the central office to interface to the local switching machine, and the other located remotely in the vicinity of a group of subscribers. The *SLC* 96 carrier can provide, through the use of different channel units, message telephone service, coin service, special services, and data services. For digital transmission, it interfaces to standard T1 lines or optical fibers. The design is patterned after the D4 channel bank, and many of D4 carrier's channel units can be used in the *SLC* 96 carrier system. The resultant system has the versatility to serve both rapidly growing metropolitan, as well as rural, areas. Features that provide highly reliable service and easy maintenance have been included in the design of the system.

I. INTRODUCTION

The continuously decreasing cost and improving capability of digital technology coupled with the need to enhance the capability of the loop plant to provide new services has led to the development of the *SLC* 96 carrier channel bank.[1-3] Digital loop carriers in the operating companies have been primarily oriented to the rural subscriber.[4] For

* Authors are employees of AT&T Bell Laboratories.

this service, the *SLC* 40 carrier channel bank uses delta modulation to pack 40 subscriber channels onto a T1 line. Earlier, the *SLM*™ (Subscriber Loop Multiplexer) multiplex system had used delta modulation and concentration to pack 80 subscriber channels onto a T1 line. As the cost of digital carrier decreased, while the cost of metallic facilities with their attendant construction and labor costs increased, it became evident that a more versatile loop carrier was needed. Such a loop carrier would serve rapidly growing suburban and urban areas with new communication arrangements for business complexes, while providing such cost-effective benefits as conventional facility relief, wire center deferrals and replacements, and improvements in the transmission quality provided by the previously mentioned loop carrier systems. The *SLC* 96 carrier was introduced to bring to the loop plant toll-quality channels that are compatible with digital trunk carriers. It is a digital system that uses $\mu 255$ Pulse Code Modulation (PCM)* and is patterned after the D4 channel bank used for interoffice trunks. Many of the D4 channel units may be used in the *SLC* 96 carrier channel bank, thereby providing a synergy between trunk and loop equipment. Recently, optical fiber interfaces and multiplexing equipment have been added to the basic *SLC* 96 carrier to further enhance its range of application. This paper describes the *SLC* 96 carrier channel bank, emphasizing the innovative features that differ from those of an interoffice channel bank.

II. BASIC SYSTEM ORGANIZATION

2.1 General description

The channel bank used at the Central Office Terminal (COT) differs from that at the Remote Terminal (RT). The COT channel banks have been designed to be factory mounted in bays and supported by a common fuse and alarm panel. All assemblies are rear mounted in standard 26-inch unequal flange frames, and the wiring to and from these frames is from the rear. The RT channel banks and their support apparatus have connectors for easy installation in the field and are front mounted in frames with wiring at the front to conserve floor and cabinet space. In addition, the loop testing features are different at the COT and RT. With the exception of the above physical and test access differences, the COT and RT channel banks are electrically identical, and they are referred to as the *SLC* 96 carrier channel bank in the descriptions that follow.

The *SLC* 96 carrier employs 7-5/6 bit, $\mu 255$ companded PCM encoding for voice transmission, identical to that used by D4. Many

* Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

of the silicon Integrated Circuits (ICs) developed for D4 have been incorporated into the *SLC* 96 carrier design. There are, however, differences between D4 and the *SLC* 96 carrier in framing, in the number of channels per plug-in, in channel counting, and in signaling. The framing bits for the *SLC* 96 carrier are arranged to provide both frame alignment and a 2.2-kb/s data link between the COT and RT. This data link provides communication for an optional channel concentrator feature and for maintenance. The *SLC* 96 carrier uses a new, dual-circuit channel unit to provide low-cost message service, while single-circuit channel units are used in D4 for special service and trunk circuits. Channel counting differences exist because D4 normally uses a sequential channel count and the *SLC* 96 carrier uses the D1D sequence (1-13, 2-14, etc.). The alternating D1D sequence provides time slot separation for the dual-circuit channel units that reduces crosstalk between adjacent circuits on the same physical unit. Multiparty and coin service requires additional signaling states beyond those required for the special service and trunk circuits used in D4. A new A and B bit-signaling protocol is used that extends the number of signaling states from four to a total of nine.

Figure 1 is a block diagram of the *SLC* 96 carrier channel bank. The channel bank is partitioned into common circuits and channel units with a maximum capacity of 96 message service channels when using the dual-circuit channel units. The channel units connect to the common circuits via Pulse Amplitude Modulated (PAM) buses, one for Receive (RPAM) and one for Transmit (TPAM). A plug-in, called the Transmit/Receive Unit (TRU), holds the codec and framing circuits for a 24-channel digroup. For operation with T1 lines, the TRUs normally connect directly to associated Line Interface Units (LIUs) that can power and serve T1 repeaters. Four LIUs provide 96 time slots at the DS1 rate (1.544 Mb/s) to serve the four digroups that make up a channel bank. A protection LIU is included, activated by a plug-in called the Line Switch Unit (LSU), which provides automatic one-for-four protection switching to handle a single failed T1 line. There are two optional plug-ins, called the Time Assignment Unit (TAU) and Multiplex Unit (MXU), that may be inserted in the signal path between a pair of TRUs and an LIU. The TAU provides two-to-one concentration, 48 message service channels competing for 24 time slots on a full-access basis. The MXU allows full use of T1 line time slots when a channel bank is equipped with single-circuit special services or trunk channel units. If either the TAU or MXU is used, it physically displaces an LIU within the channel bank to conserve common unit space.

Optical fiber interfaces and higher bit rate multiplexing circuits are added to the *SLC* 96 carrier channel bank. When arranged for opera-

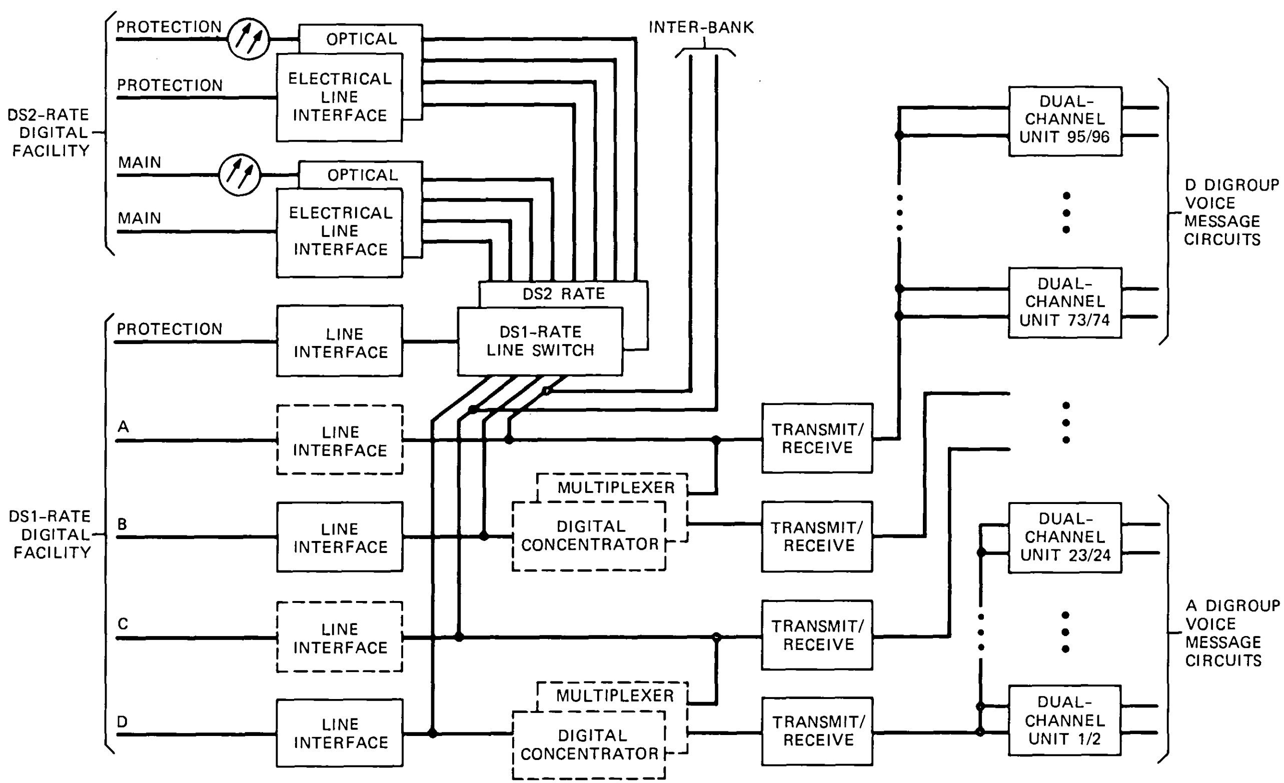


Fig. 1—*SLC* 96 carrier channel bank.

tion on optical fibers, the channel bank is equipped with DS2 rate LIUs, as shown in Fig. 1, and is referred to as the Fiber *SLC* carrier system feature. The light fiber interfaces operate at the DS2 information rate (6.312 Mb/s) to minimize the number of optical fibers needed to interconnect the COT and RT channel banks. The channel bank accommodates the different metallic or optical fiber interfaces through substitution of appropriate line interface and line switch plug-ins. For planning and forecasting of digital loop carrier applications, telephone company administrations may select T1 digital transmission over copper feeder cables or they may choose to install the newer technology optical fiber cables to the RT location. High-capacity multiplexing over optical fibers, which can use the inherent bandwidth capability of lightwave transmission, will be made available through use of a companion DS2-to-DS3 multiplexer, called the LM23 loop lightwave multiplexer. The LM23 multiplexer is designed to interface with up to seven DS2 ports and operate at the DS3 rate (44.736 Mb/s) over the same lightguides as the DS2-rate system.

The *SLC* 96 carrier system includes a digital facility interface module called the Subscriber Loop Interface Module (SLIM) which can sectionalize and manage DS1 interfaces in the local network. Special applications of the *SLC* 96 carrier require a terminal that can terminate a loop span, provide access to system alarms for maintenance purposes, and provide format conversions to allow trunk and loop carriers to interconnect directly at the DS1 information rate. The SLIM can provide interconnection of DS1-level service with higher rate facilities including digital radio and lightwave systems; tandem applications of *SLC* 96 carrier channel banks and D4 banks; customer offerings at the DS1 rate, including economical access to digital Private Branch Exchanges (PBXs); and interconnection to a Digital Access and Cross-connect System (DACS). (A complete description of the variety and use of interface modules in the local network will be described in a future issue of the *Journal.*)

Figure 2 shows the plug-in arrangement of the *SLC* 96 carrier channel bank. The channel bank consists of four equipment shelves, with each shelf having 12 channel unit slots, in addition to 4 common unit slots. Up to 24 time slots may be associated with each shelf, 2 per slot. The backplane design for the channel bank is based on the D4 design to ensure interchangeable use of D4 channel units in the *SLC* 96 carrier. To accommodate the dual-circuit channel units, the two tip/ring appearances required for four-wire circuits in D4 were redefined as two independent two-wire circuits for the *SLC* 96 carrier application. This doubled the capacity of the *SLC* 96 carrier over that of D4, thereby lowering the cost of providing message telephone service.

Column 1	Column 2	Column 3	Column 4		
PU	LSU	LIU TAU MXU	TRU	12 CHANNEL UNITS (24 SUBSCRIBER CHANNELS) SHELF D	TWO-SHELF GROUP
SSU	CTU	LIU OLIU ELIU	TRU	12 CHANNEL UNITS SHELF C	
PU	DLU	LIU TAU MXU	TRU	12 CHANNEL UNITS SHELF B	TWO-SHELF GROUP
ACU	LIU	LIU OLIU ELIU	TRU	12 CHANNEL UNITS SHELF A	

ACU – ALARM CONTROL UNIT
CTU – CHANNEL TEST UNIT
DLU – DATA LINK UNIT
ELIU – ELECTRICAL LINE INTERFACE UNIT
OLIU – OPTICAL LINE INTERFACE UNIT
PU – POWER UNIT
SSU – SPECIAL SERVICES UNIT

Fig. 2—Plug-in arrangements for the *SLC* 96 carrier channel bank.

There are three line interface plug-in groupings that can be used in the *SLC* 96 carrier channel bank. A detailed description of the first interface grouping, the T1 line interface and protection switching circuits, will follow in this paper. The second interface grouping uses a pair of Optical Line Interface Units (OLIUs) in the channel bank. The OLIU includes an integral M12 multiplex function to multiplex the four digroups in a channel bank to the DS2 rate. Also used is an optical LSU that provides automatic one-for-one protection switching. The third interface grouping substitutes Electrical Line Interface Units (ELIUs) for the OLIUs to provide a DSX-2 cross-connect interface* to a companion LM23 multiplexer. The details of the new plug-ins needed for optical fiber service are discussed in a companion paper in this issue.[5]

2.2 Modes of operation

The channel bank is organized into two groups, with each group consisting of two shelves, as shown in Fig. 2. Each two-shelf group is capable of operation in any of three modes, referred to as Mode 1, Mode 2, or Mode 3. The modes of operation are defined as follows:

Mode 1—This is a nonconcentrated mode requiring four DS1-rate

* AT&T Technical Advisory 34, Issue 3.

interfaces or one DS2-rate interface per channel bank plus one protection interface that can serve the channel bank. This mode can mix message service, special service, trunk, coin, and dataport units; however, service has been optimized for the dual-circuit message service channel units. If all 12 physical slots on a shelf are equipped with dual-circuit channel units, then the 24 time slots associated with that shelf may be fully utilized. For each single-circuit channel unit that is used, one time slot is wasted because the second time slot allocated to that physical slot cannot be used.

Mode 2—This is a concentrated mode that applies to a two-shelf group (one-half channel bank) using two-to-one channel concentration. Up to 24 dual-circuit channel units may be plugged into a two-shelf group, resulting in 48 lines being concentrated onto 24 time slots. This mode requires the use of the TAU plug-in. When DS1-rate interfaces are being used, each two-shelf group requires one main LIU, while the TAU is substituted for the other LIU. One protection LIU can serve the entire channel bank. When a DS2-rate interface is being used, four two-shelf groups are needed to fully utilize the 96 time slots on a DS2 interface. To provide this mode of service, two paired, interconnected channel banks are used at both the COT and RT. Connectorized interbank wiring is used to transfer appropriate clock and data signals between the two paired banks. Main and protection OLIUs (or ELIUs) are equipped in only one of the two banks to interface to the facility. Either dual- or single-circuit channel units may be used in Mode 2; however, only the dual units are concentrated, while the single-circuit units have a "nailed-up" time slot. To maintain sufficient traffic capacity, the number of single-circuit units is restricted to a maximum of eight in any two-shelf group.

Mode 3—This is a special nonconcentrated mode whereby a two-shelf group is dedicated to serving only single-circuit channel units that include special service, trunk, dataport, or coin channels. The 24 channels that make up a digroup occupy two shelves and are multiplexed onto a single DS1 stream by the MXU plug-in. When using T1 lines, an MXU replaces an LIU in each two-shelf group, leaving one main LIU to serve the group. For the optical fiber case, the paired, interconnected bank arrangement, similar to Mode 2, is used.

Figures 3 and 4 illustrate how the channel banks interface to the digital loop hierarchy at the DS1, DS2, and DS3 information rates showing all modes of operation. The DS1 rate is implemented over metallic loop feeder facilities (T1 lines), while the DS2 and DS3 rates use optical fiber facilities. When a DS1 rate interface is used, each two-shelf group in a channel bank may be configured in any mode without restriction. When a DS2-rate interface is used, however, there are some restrictions. For Mode 1, the entire bank must be operated

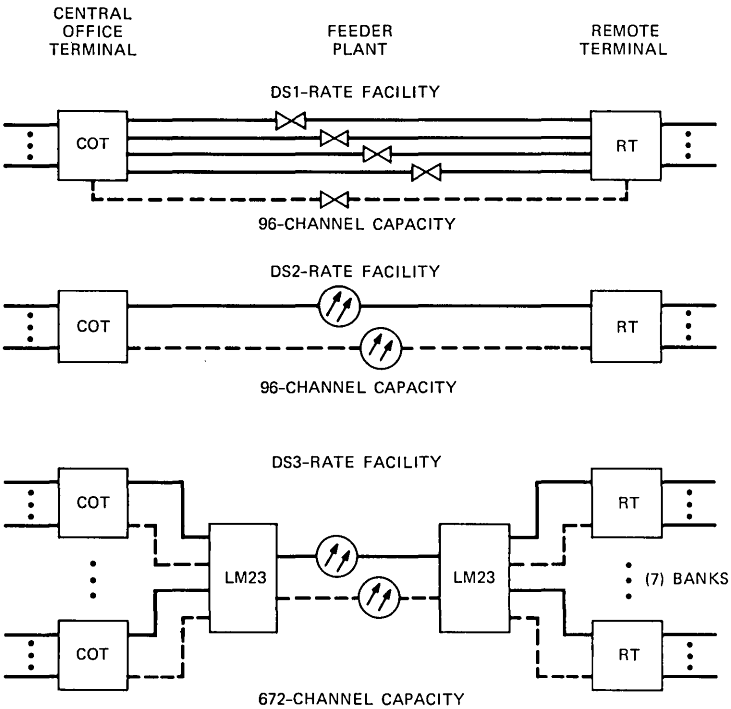


Fig. 3—*SLC* 96 carrier channel bank interfaces—Mode 1.

in Mode 1, and the TAU or MXU cannot be used. For Modes 2 and 3, a paired-bank arrangement is necessary, and each two-shelf group (there are four) may be operated in either Mode 2 or Mode 3, but not in Mode 1, using a TAU or MXU as required.

III. DIGITAL LOOP CARRIER FEATURES

A digital loop carrier has the basic attributes of an interoffice trunk carrier, and it must also have certain special features in the loop environment. These differences arise from having to support local subscriber services from an RT that is located in the outside plant away from the central office. While the central office provides a controlled environment and easy access to maintenance personnel, the RT is often in a hostile, unattended environment. High reliability and a single-ended maintenance philosophy has been emphasized in the *SLC* 96 carrier design. A list of several of the unique system features included in the design are:

- A digital facility protection line with automatic transfer.
- Single-ended fault locating of digital facility troubles.
- Remoting of alarms to centralize maintenance operations.

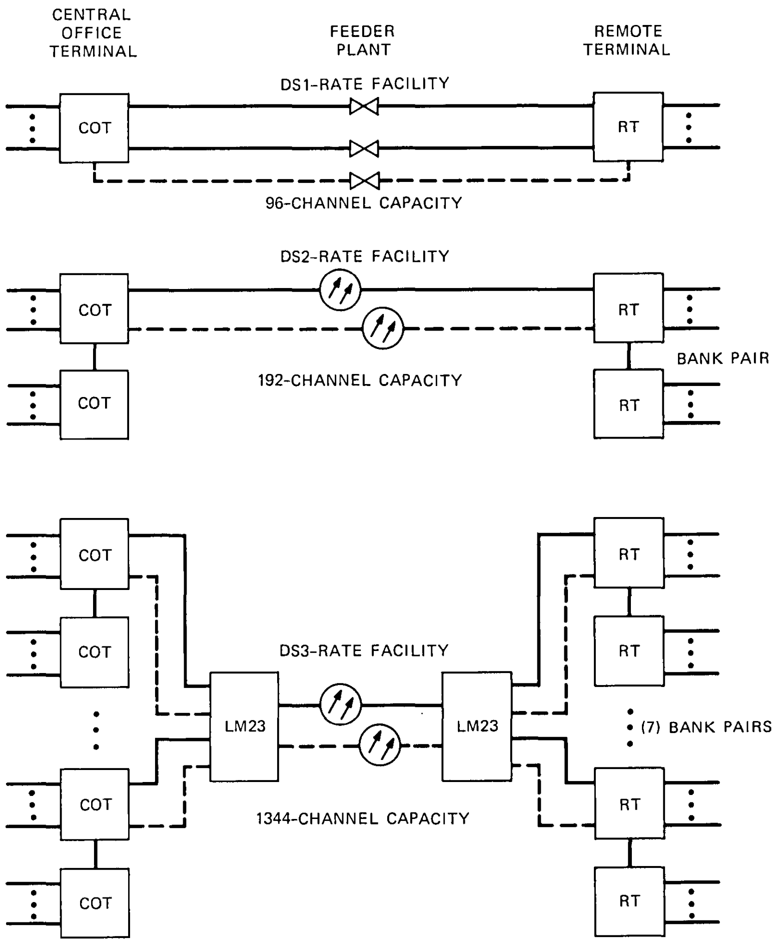


Fig. 4—*SLC* 96 carrier channel bank interfaces—Modes 2 and 3.

- Optional channel concentration to reduce the requirements on interconnecting digital facilities.
- A means of testing customer loops terminating on the RT from a repair service bureau applicable to single-party, multiparty, and coin services.
- A compact, integrated battery plant for the RT that permits a minimum 8-hour system operation when local ac power is lost.
- RT assemblies that are connectorized so they may be rapidly replaced, if needed.

As stated earlier, the channel bank is partitioned into common units and channel units. The common units provide the digital line interface, the Analog-to-Digital (A/D) and Digital-to-Analog (D/A) conversion, channel multiplexing, and optional channel concentration. This is the primary functional path through the channel bank. Other common units provide the support functions, which include handling of alarms, trunk, and channel processing in the event of trouble; automatic protection line switching; and a data link to handle the bank-to-bank communication function. The bank also contains common circuitry to handle the channel testing feature. The following sections will focus on a detailed description of the common units.

3.1 Primary functional path

The primary functional path, exclusive of the channel units (which will be described in Section V), consists of the transmit/receive unit, the time assignment and multiplexer units, and the digital line interface units. The inputs to the transmit/receive function are Pulse Amplitude Modulated (PAM) buses from the channel units for voice frequency services and digital data buses for data service units. The outputs of the transmit/receive function are PCM data streams in the form of unipolar clock and data signals at the basic DS1 information rate. The time assignment or multiplex units may be optionally placed in the path of the transmit/receive unit bit streams. When either of these units is used, bit streams from two transmit/receive units are combined into a single, DS1-rate information stream. These streams may be routed directly to DS1-rate line interface units, or they may be multiplexed to the higher bit-rate DS2 streams for optical fiber applications. The basic common unit plug-ins that provide the DS1-rate primary path through the channel bank will be described in this section.

3.1.1 Digital line interfaces

The channel banks terminate T1 lines, which are the transmission pipes for bipolar signals at the DS1 rate. Line interface units (LIUs) are the circuit packs that receive and transmit the bipolar signal and perform the conversion to a unipolar clock and data format suitable for further processing within the channel bank. In the transmit direction, they provide either a free-running or synchronized clock, and in the receive direction, the clock is recovered from the incoming signal. In addition to this primary function, LIUs provide the following:

- A source of line current to power digital line regenerators or a path to loop line current
- Detection and measurement of bipolar violations or loss of incoming signal to initiate a switch request to a protection line
- Loopbacks in both directions of transmission to facilitate maintenance and line fault locating

- Bipolar signal level administration to interface the T1 line directly or to interface through a DSX-1 cross-connect frame.

Five types of LIUs provide subsets of these additional functions. Bipolar signal conversion, violation detection, and loopbacks are always provided, but sourcing or looping line current and level administration require different circuit pack arrangements. Backplane connections to a single connector accommodate all five types of LIU. A generic block diagram of the LIU circuit is shown in Fig. 5. Option switches on the circuit pack select a range of line powering capability and one of three thresholds for bipolar violation detection. Another option allows selection of 7.5-dB loss pads in both transmit and receive directions on the four basic codes. Equalizers that plug into the circuit pack can be selected to match cable lengths from the bank to the DSX-1 cross-connect frame for the code that is used for transmission within the central office. The five types of LIU codes and their distinguishing features are:

1. WN2—Interfaces Polyethylene-Insulated Cable (PIC)/Pulp cable digital lines directly and loops line current
2. WN3—Interfaces DSX-1 frame with selectable equalization in the transmit direction and 7.5 dB of loss ahead of the receive regenerator
3. WN4—Interfaces PIC/Pulp cable digital lines directly and sources line current
4. WN5—Interfaces MAT/ICOT (Metropolitan-Area Trunk/Inter-City Outstate Trunk) cable digital lines directly and loops line current
5. WN6—Interfaces MAT/ICOT cable digital lines directly and sources line current.

Bipolar conversion in the receive direction uses the same Hybrid

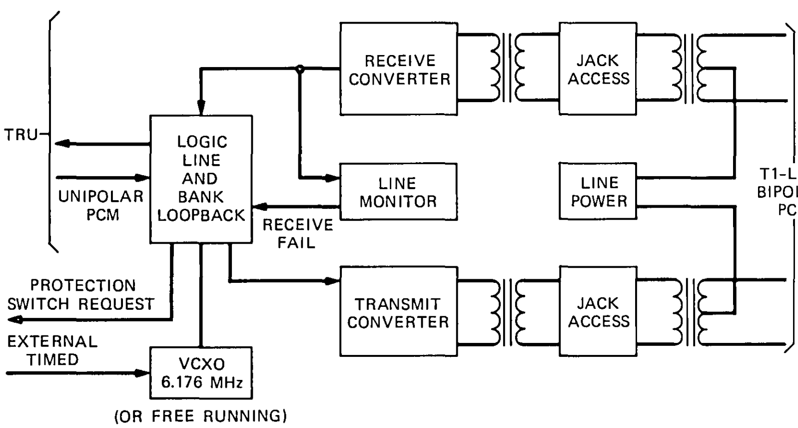


Fig. 5—Line interface unit.

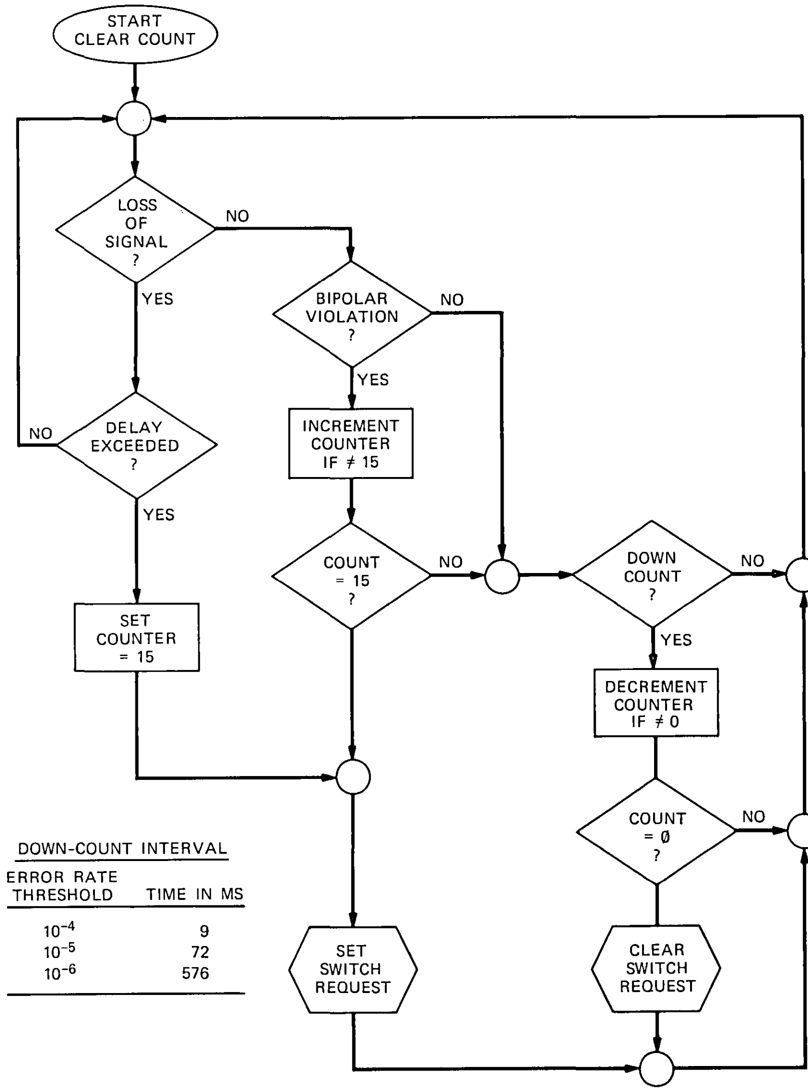
Integrated Circuit (HIC) regenerators used in T1-carrier low-power repeaters. The received balanced signal is coupled to the regenerator through an input transformer. When the LIU interfaces directly to outside plant cables, a second transformer is used to simplex power to the repeatered line. Current surge and lightning protective components are included in this part of the circuitry. The regenerator output, which is dual-rail, is retimed using the recovered clock and combined to form the unipolar Transistor-Transistor Logic (TTL)-compatible received PCM signal. The clock is recovered using the regenerator's preamplifier output and a resonant circuit tuned to the line clock frequency.

In the receive direction, each LIU type has the ability to equalize from 7.5 to 35 dB of line loss measured at 772 kHz. Different receive regenerator HICs accommodate either PIC/Pulp cable or MAT/ICOT cable. The WN3, used to interface the DSX-1 frame, has a 7.5-dB loss pad included ahead of the regenerator to bring the signal level into the effective range of the automatic buildout network. The other four codes also have this 7.5-dB pad as a field option for use at RT sites having short T1 line end sections.

Each type of LIU has a voltage-controlled oscillator that can be optioned to be free running or synchronized to either an incoming or an externally provided clock. The oscillator is controlled by a 6.176-MHz crystal and varactor diode. It is the master clock from which all clocks in the transmit direction are derived.

The transmitted 1.544-MHz signal, in bipolar format, is applied to the line at a three-volt peak amplitude, except for the WN3, where it is six volts. An optional 7.5-dB pad is incorporated for use at RT sites having short end-sections, as with the receiver. In the WN3, a set of lossy equalizers is used to provide a standard level of three volts at the DSX-1 frame through various office cabling distances up to 655 feet.

Line monitoring is accomplished in an IC (Integrated Circuit) gate array where one of three error rate thresholds may be selected. The algorithm for the line monitor is shown in Fig. 6. If Bipolar Violations (BPV) exceed the selected threshold, or if a loss of received PCM is detected, the received line is declared failed and is so indicated by an LED on the faceplate. This also causes a switch request to the protection line. The dual-rail signal from the receive converter is monitored for BPVs and these are counted in a four-stage counter. One count is subtracted every 9, 72, or 576 ms, dependent on the threshold selected. The down-count clocks are derived from the data link unit. At the time of development, little was known about the error characteristics of T1 lines, particularly in the loop environment. Observations[6] showed sensitivity to traffic and pulse density. Due to



DOWN-COUNT INTERVAL

ERROR RATE THRESHOLD	TIME IN MS
10^{-4}	9
10^{-5}	72
10^{-6}	576

Fig. 6—Line monitor algorithm.

the uncertainty in line behavior, the line monitor device was designed with access to the BPV signal ahead of the counter to provide burst protection, if needed. Down-count clocks were supplied to the line monitor at the backplane to allow for future changes. For example, reducing the clock rate after the threshold is exceeded will increase the hysteresis and the cycle time of the protection switch algorithm. Table I gives the characteristics for various thresholds when the average error rate is equal to the threshold.

Table I—Characteristics for various thresholds when the average error rate is equal to the threshold

Error Rate Threshold	Average Response Time	
	Set	Clear
10^{-4}	350 ms	13 min
10^{-5}	7.5s	7 min
10^{-6}	15 min	1.4 min

The threshold of the protection line is normally set one decade higher than the main lines, which are set at 10^{-5} for message telephone service. The times given are the intervals for setting and clearing a protection switch request. The actual time required to complete a switch is not included; however, it is small in comparison to the above and is given in Section 3.2.2, which describes the line switch unit.

Two types of loopbacks may be exercised within the LIU for maintenance purposes. One is the bank loopback, where the transmitted PCM is looped back to the receive side of the channel bank. This loopback occurs within an IC gate array on the LIU and is initiated by a pin-plug switch available on the faceplate of the alarm control unit. Logic in the LIU enforces the condition that a bank loopback can only be done if the digroup is in trunk processing due to loss of received framing. While looped, the fault can be isolated to the local bank or the remote facility by observing the condition of the receive framing lamp on the transmit/receive unit. While the bank is looped, transmitted PCM continues to be sent on the outgoing line.

The line loopback switches the incoming signal, after conversion from bipolar to dual-rail, to the transmit converter where it is returned on the outgoing line. The normal bank-generated PCM is inhibited during line loopback. Line loopback is initiated from the remote end via the data link by a pin-plug switch on the LIU faceplate. Logic circuits prevent operating the line loopback at both ends. Operating lines can be looped without affecting service because service is switched to the protection line, providing it is available. This allows for maintenance of the digital lines without the need for service interruption. With the line loopback, single-ended fault location may be accomplished. Signals may be accessed with a patch cord from the LIU faceplate to the jack panel and fault-locate panel located in the same or adjacent bay.

The T1 digital line is powered in simplex fashion at a 60-mA regulated level. Normally, power is sourced from the COT and looped at the RT. Source voltages are either −135 Vdc maximum, or +135 Vdc outgoing and −135 Vdc returning, for a 270-Vdc maximum range, doubling the span length. The span length can be doubled again by feeding from both the COT and RT while looping at a mid-span repeater.

The powering circuit is a dc-dc converter driven by a −48 Vdc battery. The line interface is effectively floating off ground, which minimizes ac-induced line currents. A voltage-limiting circuit protects the powering transistors when the line is broken or disconnected. A second personnel protection circuit limits the maximum line-to-ground fault on the opposite side pair. Standard lightning protection is provided by gas protector tubes, series current-limiting resistance, and varistor diodes.

Protection against ac power faults has recently been enhanced by an order of magnitude over usual T1 line powering circuitry. This was accomplished by redesigning and hardening the current-limiting resistors and the line feed transformers, and by changes to other power circuit components. In addition, the gas protector tubes are being changed to a balanced type to prevent longitudinal-to-metallic conversion of ac fault currents. These changes have been essential for survival in the more exposed loop plant, as compared to the exchange trunk plant.

3.1.2 Transmit/receive function

The Transmit/Receive Unit (TRU) performs exactly the same function as its separate counterparts in the D4 bank and is designed using the same devices developed for that system. Descriptions of the D4 transmit and receive units have been published,[7] and this section will describe only those aspects that are related to the *SLC* 96 carrier application.

Signal flow in the transmit section converts a pulse amplitude modulated signal, TPAM, into a digitally encoded signal, TPCM, using a common channel encoder with signal compression following the μ225 law. Framing, signaling, and channel-counting clocks are derived from the 6.176-MHz clock supplied by the associated LIU. Four custom IC devices make up the transmit section.

A feature of these devices, used in the *SLC* 96 carrier application, is the ability to implement a low-speed data link by sharing of the signaling-frame bit. This capability, although not used in the D4 system, was designed into the transmit-framing logic and put to use in the design of the *SLC* 96 carrier to provide for a bank-to-bank communication link. Within the device is a frame-bit generator providing the alternate 101010 pattern for terminal framing and the interleaved 111000 pattern to identify signaling frames used to transmit the robbed-bit channel signaling (A and B bits). The capability was provided on the device to allow substituting external data in place of the signaling-framing pattern. This allowed the design of a low-speed data link between the carrier terminals with a data transfer rate of 2.2 kb/s (see Section 3.2.1). When the external data are substituted for the signaling-frame bits, the normal robbed-bit signaling continues to be transmitted in the six and twelfth frames.

Signal flow in the receive section recovers a pulse amplitude modulated signal, RPAM, from the incoming PCM and its recovered clock using a common channel decoder. Framing, signaling, and channel-counting clocks are derived from the recovered incoming clock. Three custom IC devices are used in the receive section. The receive-framing logic will continue to supply signaling-frame clocks even in the absence of the signaling-frame pattern, as is required for the low-speed data link.

In the D4 system, bit 2 of the 8-bit word in each of the 24 transmitted channels is cleared to declare a "yellow alarm", which occurs if the received signal from a far-end connecting terminal is out-of-frame for longer than 2.5 seconds. Bit 2 is detected in the receive framing device and results in the processing of channels at both ends of the D4 system when framing is lost. This feature was not initially implemented in the *SLC* 96 carrier channel banks because the reporting of connecting terminal failures is normally over the data link. With the introduction of the Subscriber Loop Interface Module, SLIM, the need for bit 2 alarm detection and generation is required because the SLIM allows tandem arrangements of the *SLC* 96 carrier with D4 channel banks. This feature is implemented in the MXU used in Mode 3 and is described in Section 3.1.4.

Early TRUs, coded WM1, provided only the 1 to 13, 2 to 14, etc., alternate sequence of channel counting, also known as the D1D sequence. This sequence separates the PAM samples of the two channels sharing a dual-circuit channel unit by six physical slots in the bank, thereby reducing crosstalk between message service channels. Applications that interconnect a *SLC* 96 carrier, operating in Mode 3, to a D4 channel bank have need for sequential counting. TRUs, coded WM1B, allow the selection of either counting sequence with the selected option displayed on the faceplate.

3.1.3 Digital concentration

The channel banks may be configured in Mode 2 to digitally concentrate two digroups into a single DS1-rate bit stream.[8] To perform this function, Time Assignment Units (TAUs) displace LIUs in the channel bank and concentrate the 48 channels in a two-shelf group onto 24 time slots. This DS1-rate stream may be routed directly to a T1 LIU within that shelf group or it can be multiplexed up to the DS2 rate, along with other DS1 interfaces within a paired channel bank arrangement, for Mode 2 optical fiber applications. This can reduce by 40 percent the required number of T1 lines, and for the optical fiber case, the savings in fiber facilities can be 50 percent. For the T1-carrier case, this results in direct savings in structure, repeaters, and apparatus cases and can help to avoid installing new cables, which can be significant, especially for rural systems. For the light fiber case, the savings are in the number of fibers needed to reinforce a feeder route and their associated optical receivers and transmitters.

Figure 7 is a simplified block diagram of the time assignment unit in the primary functional path of a pair of channel banks. There are two codes of TAU, one for the COT-coded WN12 and one for the RT-coded WN13. Each TAU contains a pair of identical Time Slot Interchange (TSI) memory ICs and a *WE*™ 8000 microcomputer. The central office TAU acts as the master controller and assigns an active channel to a specific time slot on the DS1 interface and communicates that assignment to the remote terminal TAU over the data link. The active channel will keep its assigned time slot, which will be referred to as a trunk, for the duration of the call. Concentration is full access such that any of the remaining channels that become active may be assigned to any of the remaining inactive trunks, until all trunks are active.

The method of interchanging time slots in the TSIs, to carry out the concentrator function, is accomplished by loading and unloading a pair of RAM sections, as shown in Fig. 8. One RAM section is loaded while the second RAM section is unloaded. The roles of the RAM sections are reversed every frame. This organization adds a fixed end-to-end delay of two frames in the bit stream. On the transmit side, data streams from two TRUs, serving 48 channels in a shelf group, are written into one RAM section of the transmit TSI. These streams include PCM data from active channels and idle code from inactive

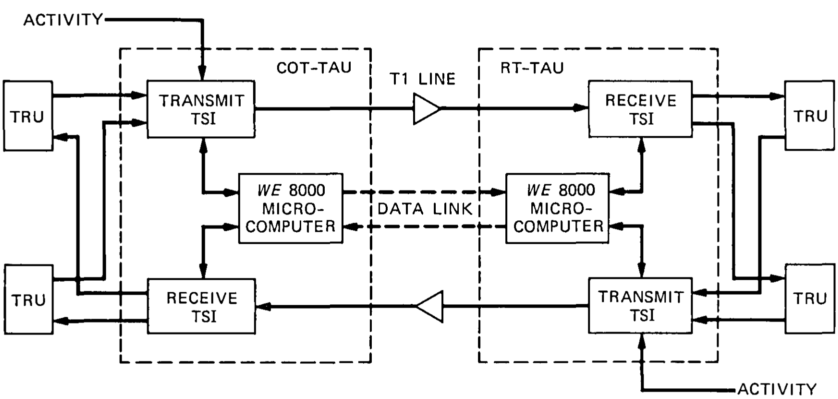


Fig. 7—Time assignment unit.

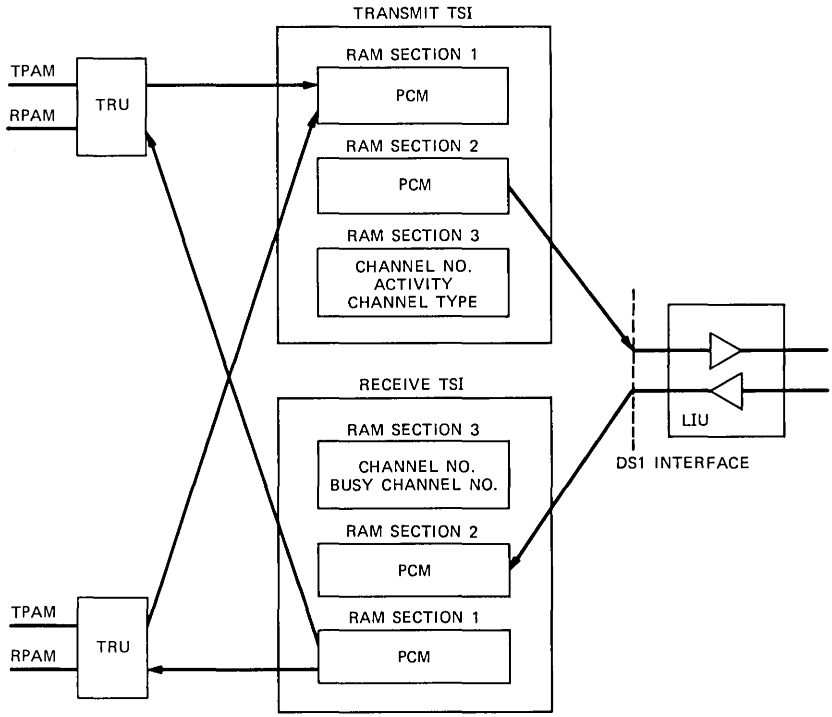


Fig. 8—Data flow through the time slot interchangers.

channels. While this is going on, PCM data from the previous frame are selectively read from the second RAM section and transferred to the appropriate LIU. Selective reading means that the PCM word for a particular channel assigned to a particular trunk is transmitted in proper time sequence to the LIU. Trunks not assigned will transmit an idle code. On the receive side, incoming PCM words are selectively written into a RAM section of the receive TSI. For the case of a blocked call, a busy tone is also selectively written into this same RAM section, at the COT only, to provide a fast-busy signal to terminating calls. Again, a second receive RAM section is simultaneously unloading data that was collected in the previous frame to the TRUs where these data are decoded and multiplexed to the channel units.

A third RAM section provides storage for the real-time housekeeping functions of the TSI. This RAM section holds the active trunk assignments, that is, the actual channel number assigned to a particular trunk. This channel number is used as an indirect address, in both TSIs, to selectively transfer PCM data between the RAM sections and the LIU. The third RAM section is also used to collect and buffer activity and channel-type information in the transmit TSI at both the COT and RT. These data are retrieved by the microcomputer and are used to determine channel/trunk assignments as channels become active. For the receive TSI, at the COT only, this RAM section stores busy trunk assignments. This assignment is the actual number of a channel that is being accessed as a terminating call but is blocked because all trunks are busy. For this case, a means of providing a fast-busy (overflow) tone to blocked COT channels is required. This is done digitally by feeding a PCM busy tone to each blocked channel via the RAM. The PCM busy tone is updated once each frame by the microcomputer and buffered in the RAM for subsequent use in the following frame. Signaling information is also included in these busy tones to allow the blocked channel to trip ringing without charge to the customer.

Activity is determined by monitoring the A and B signaling buses on the system backplanes. The A and B bits are the nomenclature for per-channel signaling that indicates channel status such as off-hook or ringing. Activity at the remote terminal is transmitted over the data link to the central office where channel/trunk assignments are established.

To function in real time, the TSIs must synchronize to the TRUs they serve, following initial power up or after a reframe. In the transmit mode, the transmit TSI establishes its own reference based on internal count-down circuits driven from the system T6 clock (6.176 MHz) and provides superframe synchronization to the TRUs.[8] The receive mode is just the opposite, whereby the reframe circuit of each TRU searches for, and locks onto, the incoming bit stream, which, in turn, provides superframe synchronization to the receive TSI. Since the TSI is situated between the line interface and the TRUs, the receive TSI must assume a special mode during reframe. In this mode, the bit stream is passed unchanged through the TSI until framing is established first at each TRU. To assure that the TRU is not thrown out of frame when the TSI assumes its normal sequencing, the TSI, in its special reframe mode, inserts the same number of cycles of delay as it will when operating normally.

For Mode 2 operation, the two-to-one, full-access concentration provides a traffic-handling capability sufficient to allow full or block loading of single-party channels. There are some restrictions for coin, special services, and multiparty channels. A maximum number of eight coin or special service channel units is allowed in each two-shelf group. These units must be mounted in the four rightmost slots on the two shelves. There is an indicator of the front face of the TAUs, labeled SPEC, that lights if a special services or coin unit is plugged into the wrong slot. Multiparty channels must be limited to 16 to allow block loading of channels without regard to load balancing. Recall that coin and special service units are single-circuit units and each of these units used in a physical slot in a channel bank reduces the number of lines to be concentrated by two. One time slot is nailed-up for each of these units and the concentration ratio for the dual-circuit units remains fixed at two to one. The trunk group size is reduced for each nailed-up channel, up to the maximum of eight, which slightly decreases the traffic-handling capability of the remaining concentrated channels. The Mode-2 traffic carried by a shelf group at 0.5-percent probability of blocking and 25-percent intrasystem traffic is presented in Table II.

The TAUs are significant in their traffic-carrying capability and when used as recommended above, they do not require traffic administration and load-balancing at the RT. However, the TAUs have been designed with several traffic monitoring features, as listed:

1. A two-digit numeric display on the faceplate of COT-TAU displays, upon demand, the peak traffic in ccs (hundred call seconds) per concentrated line. This is the highest traffic that has been encountered on a cumulative basis. The internal traffic register that stores this number is manually cleared by a pin-plug switch on the front face of the unit.
2. The above display will also indicate, upon demand, the number of blocked calls, up to maximum of 15, that have occurred on a cumulative basis. The internal blocked calls register that stores this number is manually cleared by a pin-plug switch on the front face of the unit.
3. A traffic overload alarm, called TRAF, is displayed on the faceplate of the COT-TAU. This alarm lights if there have been two or more blocked calls, for two out of three weeks running. This alarm is manually cleared by a pin-plug switch of the front face of the unit.
4. A relay closure is provided to convey the blocked-call state to electronic switching system machines. In nonelectro-mechanical central offices, the COT-TAU will provide an internally generated reorder tone for terminating calls.
5. A second relay outpulses peak weekly traffic in ccs, once per week, to a remote traffic monitoring register at the rate of one pulse per second.

Table II—Traffic carried at $P(B) = 0.005$ versus number of lines with 25-percent intrasystem calling

Number of MTS lines	48	44	40	36	32
Number of COIN/SS lines	0	2	4	6	8
Carried MTS load (ccs/line*)	12	11.7	11.4	11	10.6

* Hundred call seconds (ccs) per line.

6. A third relay outpulses the number of blocked calls as they occur to a remote blocked calls monitoring register at the rate of one pulse per second.

The TAUs have considerable diagnostic capability in the microcomputer software to detect malfunctions and can generate both major and minor alarms and display these alarms on its faceplates. Some of the diagnostic routines include a ROM checksum test, a processor maze test, continuous testing of the RAM, a sanity time-out, and consistency checks of the database related to line and trunk status. In addition, whenever a trunk assignment is made, a PCM looping test is always made prior to cut-through of the line to the trunk. This test consists of disabling the channel requesting service and circulating PCM test codes that fully test the data path from the COT to RT, and return.

3.1.4 Multiplexing special services

When a D4 special service channel unit is assigned to a *SLC* 96 carrier digroup, only one of the two PCM time slots associated with the channel position is used. If service demands are such that many specials are required, use of the transmission facilities are not efficient because of wasted time slots. To recover this lost efficiency, Multiplex Units (MXUs) may be equipped in place of LIUs on the B and D shelves. When equipped in this manner, the bank is operating in Mode 3. Each two-shelf group in a channel bank may be equipped with D4-type or coin channel units, up to 12 on each shelf. Twenty-four of these channels are interleaved by an MXU to fully utilize the 24 available time slots on a T1 line.

Time slot assignments of the channel unit positions are shown in Fig. 9 for the A and B shelf group. A similar scenario applies to the C and D shelves. The D1D alternate sequence of channel counting places the 8-bit PCM word from the first channel slot into the first time slot, and the word from the seventh channel slot into the second time slot, and so on. The transmit encoding logic in the TRU can select either an 8-bit encoded PAM signal or an 8-bit digital data signal (normally used by dataport channels) to be inserted into a time slot of a PCM bit stream. Selection is determined by the logic state of a backplane bus called TNEN that provides channel-type information to the TRU. The channel positions are addressed by a channel counter in the TRU and as the time slot associated with a channel position occurs, the TNEN bus is pulled high for digital data and low for PAM voice samples.

The D4-type channel units, which are single-circuit units, have access only to the odd time slots at channel positions in the bank. The even time slots are therefore unused at the TRU. By operating two

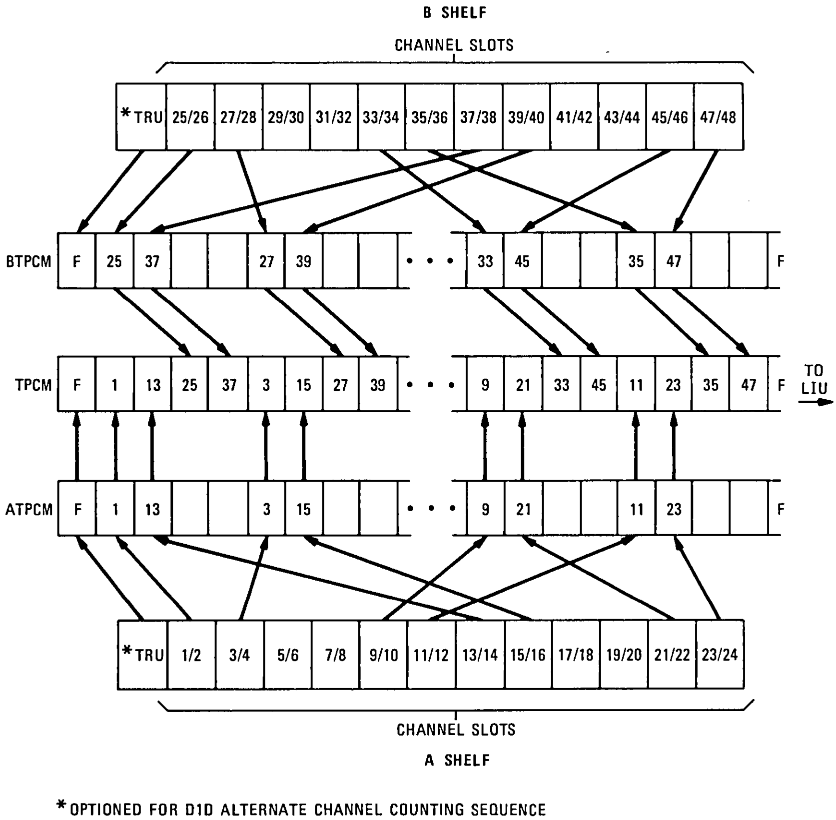
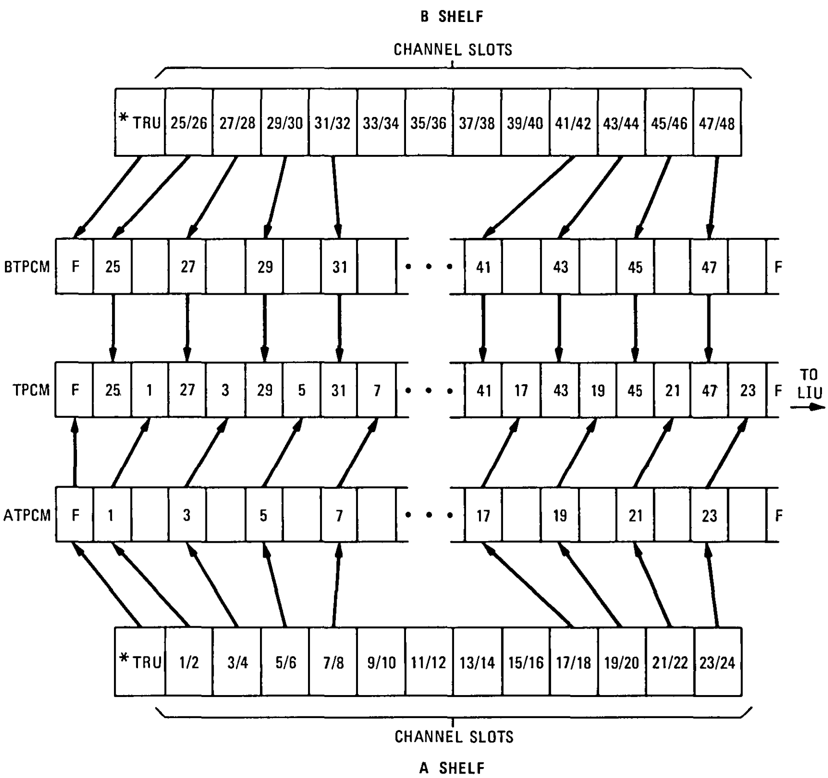


Fig. 9—Multiplexing *SLC* 96 carrier time slots in Mode 3.

TRUs in tandem, the time slots from the B shelf can be multiplexed through the unused time slots of the A shelf. The valid time slot information from the B TRU is routed through the digital data input of the A TRU by appropriate control of the TNEN bus. The pair of TRUs are bit-for-bit aligned within a superframe (12 frames) by synchronizing circuitry in the MXU. This feature eliminates the need for an elastic store and allows a simple realization of the multiplexing function for Mode 3. The MXU provides an alarm indication on its faceplate if synchronization of the bit streams fails, thereby simplifying trouble isolation. The frame bit of the combined transmit bit stream from the two shelves is from the A shelf, which maintains the data link capability. In the receive direction, the incoming bit stream is connected directly to the A shelf TRU. Circuitry in the MXU reconstructs a proper PCM bit stream for insertion into the B shelf by delaying the frame bit by two time slots.

The introduction of SLIM allows for applications of the *SLC* 96 carrier operating in Mode 3 and connecting with a D4 channel bank. To realize this possibility it was necessary to add some features to the MXU. A second version of the circuit pack, coded WN14B, has an option that changes the assignment of time slots to make the channel unit positions indentical in both types of banks. Time slot assignments for transmission to a D4 bank are shown in Fig. 10, and Fig. 11 shows the recovery of these time slots at the D4 bank. The capability of detecting and generating the yellow or bit-2 alarm state has also been included in the latest version MXU. The latest version MXU is backward compatible and can function with a WN14 equipped in a connecting *SLC* 96 carrier bank, avoiding the need to coordinate circuit packs with the introduction of the second version.



* OPTIONED FOR D4 SEQUENTIAL COUNTING SEQUENCE

Fig. 10—Multiplexing *SLC* 96 carrier time in Mode 3 for connecting to a D4 bank via SLIM.

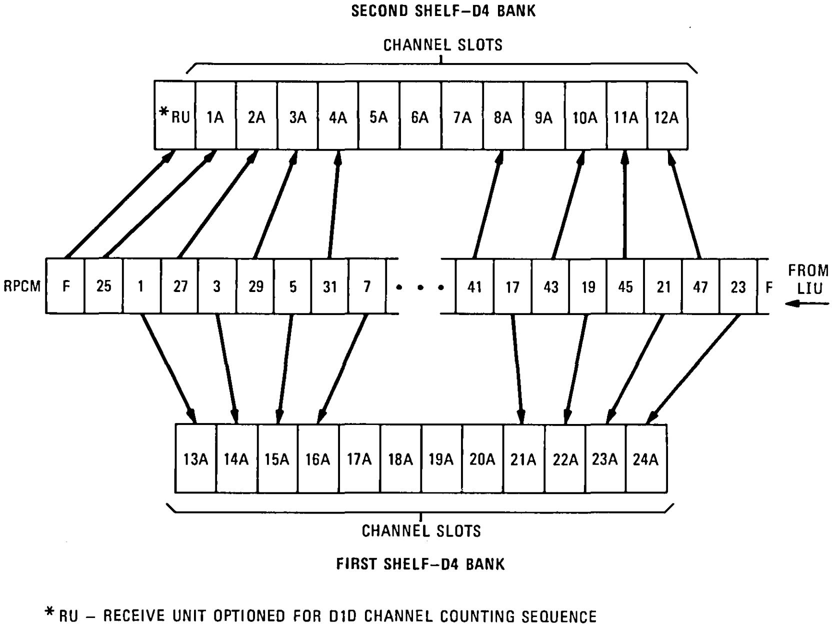


Fig. 11—Demultiplexing time slots at a D4 bank from a connecting Mode 3 *SLC* 96 carrier via SLIM.

3.2 Additional digital loop carrier features

3.2.1 Data link

The *SLC* 96 carrier contains several maintenance features, in addition to the channel concentrator feature, that require a common data channel between terminals. The Data Link Unit (DLU) is a circuit pack that provides a 2.2-kb/s data path by time sharing the signaling frame bit with data link bits. This can be done because the TRU stores the signaling frame location when it has successfully framed on the terminal framing bit. Signaling framing then remains intact until terminal framing is subsequently lost either due to loss of signal or high error rate. If terminal framing is lost, the signaling frame pattern must be restored. To provide a simple reframe algorithm, the signaling frame pattern is refreshed once every 9 ms. This is a total of 72 frames, 36 of which are signaling frames. The signaling pattern is repeated twice within each 9-ms interval (12 bits with the pattern 111000111000) to secure the frame position. Of the 36 signaling frames, 24 contiguous bit positions are available to form a data block. Spoiler bits and data code restrictions are required to prevent a data pattern that may cause false framing. The assignment of bits in the data block is given in Table III.

Within the channel bank, the DLU provides a data link on the A

Table III—Assignment of data link bits

Bit Number	User
01–11	Time assignment unit
12–14	Spoilers (101)
15–17	Channel test unit
18–19	Alarm control unit
20–23	Line switch unit (restricted code)
24	Spoiler (0)

digroup with all bank configurations and on the C digroup when Mode 2 is optioned for the C and D shelves. The C digroup data link uses only the time assignment field of the data block to handle the concentrator function in the upper half bank.

The DLU, coded WN9B, contains two identical transmit and receive sections to provide data links on both the A and C digroups. Appropriate clock and control signals are generated to distribute the data link fields among the common functions within the bank and the DLU interfaces with the TRU for insertion and retrieval of the data link from the framing bit stream. The DLU also generates slow clocks required by the bipolar violation monitor circuits on the LIU and by the A and B signaling state circuitry on the channel units.

3.2.2 Automatic protection line switching

The Line Switch Unit (LSU) was designed to automatically protect against individual T1-carrier line losses due to repeater failure or high error rate conditions, and also including failures of the LIUs within the channel bank. Logic to control a one-for-four protection line switch is included on the LSU circuit pack, as shown in Fig. 12. Failure of any one of the main lines results in switching the associated digroup to the protection line, in both directions of transmission. The LSUs at both terminals coordinate the transfer to the protection line by communicating with each other over the A-line data link. Cross-connection of digroups is prevented by the use of unique 4-bit codes to control the switching of the protection transmit and receive gates.

When no failure exists, the A digroup is transmitted on both the A and protection lines. This provides a "keep alive" signal on the protection line and it allows a "receive only" switch in the event of a failure on the A line, which is carrying the data link. Contentions due to multiple line failures are resolved by assigning a priority to the digroups, with the A digroup having the highest priority. At the receiving terminal, the receive gates in the main LIUs are normally enabled, while the receive gates on the LSU are disabled. The gates have high-impedance outputs in the disabled state.

When the A line causes a switch request, initiated by the violation monitor circuits on the A LIU, the A receive gate on the LSU is turned

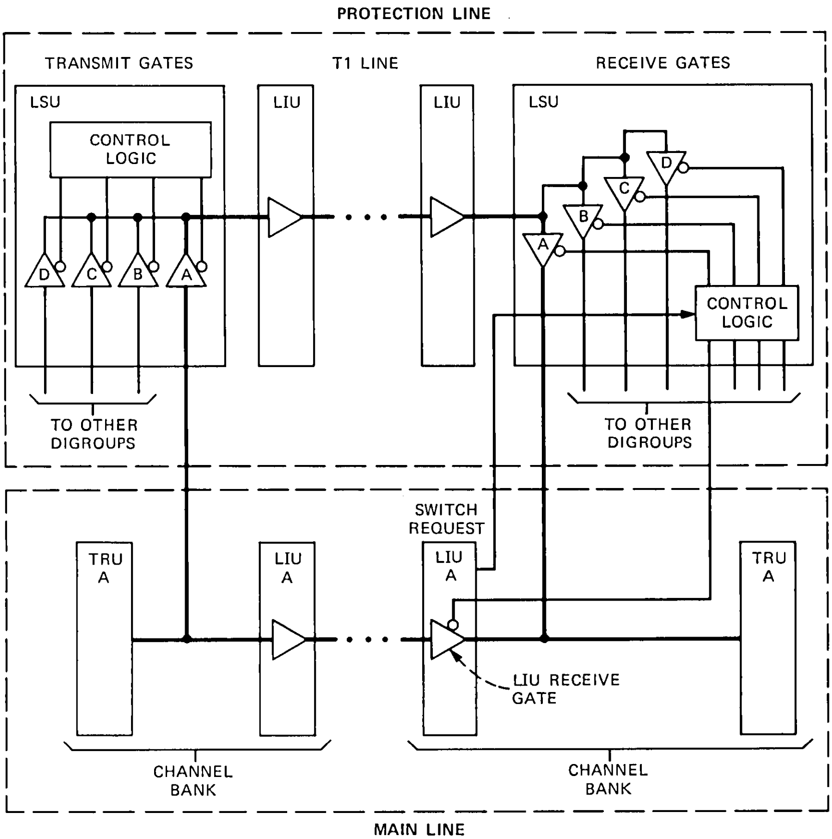


Fig. 12—Protection line switching with one direction shown.

"on" while the associated receive gate on the A LIU is turned "off", thereby restoring an error-free bit stream to the A TRU via the protection line. The failed end then puts up a 4-bit code on the data link that commands the far-end (nonfailed) terminal LSU to switch its A line receive data to the protection line. Both directions of the protection line are then connected through to the TRUs at either end. Before the far-end terminal LSU switches its A line to the protection line, the 4-bit code is compared for three successive data blocks to provide error protection. The time to complete a bidirectional switch due to an A-line failure is a maximum of 36 ms.

When a line other than A causes a switch request, logic in the failed-end LSU puts out a code that commands the far end to switch the B, C, or D transmit circuit to the protection line. After testing for three consecutive data blocks, the appropriate B, C, or D transmit gate is enabled and the A-line feed is disabled. The protection line now carries the far-end B, C, or D digroup. The far-end LSU also puts up a code that is transmitted to the failed-end digroup which causes it to switch its receive and transmit circuits to the protection line. At this point the failed direction of transmission is restored over the protection line, which occurs within a time interval of 54 to 72 ms after the switch request was initiated. The failed-end LSU begins to transmit over the protection line and puts up one last code to command the far end to switch its receive circuits to the protection line. This causes the nonfailed direction of transmission to experience a transfer hit. Most often it is not audible in voice circuits and may not even cause a loss of frame indication. The entire switch cycle is completed in typically 100 ms.

The 4-bit data link commands that control protection line switching are listed in Table IV.

The algorithm described above is symmetrical and results in needing but one code of LSU, WN8C, for either terminal end.

Additional features of the LSU are:

- Switch commands are not transmitted if the protection line is failed.
- A switch to protection may be disabled by inserting a pin-plug into a faceplate switch on the LSU at either terminal.
- A digroup can be forced to switch by inserting a pin-plug into the faceplate switch of the LIU at either terminal end.
- An indication to cause a minor alarm is given to the alarm control unit.

3.3 Maintenance and testing functions

The *SLC* 96 carrier maintenance features center on its automatic monitoring and reporting circuits—its alarming system. Two levels of alarm reporting are used. The first level returns remote terminal alarms via the data link and the second level adds central office terminal alarms to a composite that can be transmitted to a remote, centralized maintenance center responsible for the dispatch of craft personnel, as shown in Fig. 13.

Table IV—Protection line switching commands

Code	Command
0000	All is well
0001	Switch A receive gates
0010	Switch B transmit gates
0011	Switch C transmit gates
0101	Switch D transmit gates
1010	Switch B transmit and receive gates
1011	Switch C transmit and receive gates
1101	Switch D transmit and receive gates

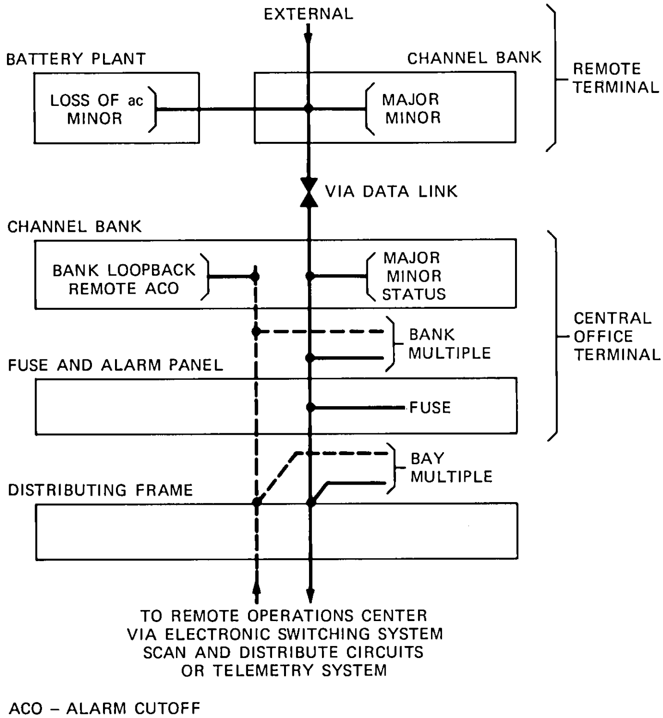


Fig. 13—Alarm reporting.

The alarm control unit is the focus for the execution of this function in the channel bank. This unit processes and displays local alarms and transmits this information to the corresponding unit at the far-end over the data link. At the central office, the fuse and alarm panel collects alarms from up to six *SLC* 96 carrier systems and makes these available to the office alarm system and to remote telemetry systems via contact closures. The alarm control unit also handles the channel processing function for the single-party, multiparty, and coin channel units whenever a digroup major alarm exists, to deny loop closure toward the central office and ringing toward the customer. The special services unit provides the trunk processing function when the D4 family of channel units is used in a *SLC* 96 carrier channel bank.

An important maintenance feature associated with the *SLC* 96 carrier system is its capability to test customer loops terminating on the RT from the repair service bureau. The channel test units in the channel bank handle this function and work with the pair gain test controller in the central office. This feature provides the capability to connect an incoming test trunk at the central office to the customer loop on a dc basis. This section will describe the plug-ins that provide these functions in the channel banks.

3.3.1 Channel processing and alarm control

Economic utilization of the *SLC* 96 carrier system in the subscriber loop requires not only a high degree of reliability, but also the ability to quickly isolate and repair troubles if they do occur. Automatic protection line switching reduces the probability of loss of the transmission facility. If line failures do occur, they are easily identified and appropriate repair procedures may be directed, even from a remote maintenance location. If the primary functional path common to a digroup within either bank fails, an alarm is generated and the failed end may be identified either from the COT, RT, or from the remote maintenance center. Also, during common digroup failure, each of the individual channels within the digroup is processed in a way to prevent excessive noise or crosstalk to the connected subscribers. Channel processing and alarm identification are functions of the Alarm Control Unit (ACU). A block diagram of the ACU is given in Fig. 14. The ACU, which is coded WP1, interfaces with the following units:

- DLU—With two bits in the data link, a subrate frame containing a frame pattern and 12 alarm codes that are exchanged between ACUs in both terminals. A later version of the ACU, coded WP1B, that is compatible with the SLIM has a 15-code field.

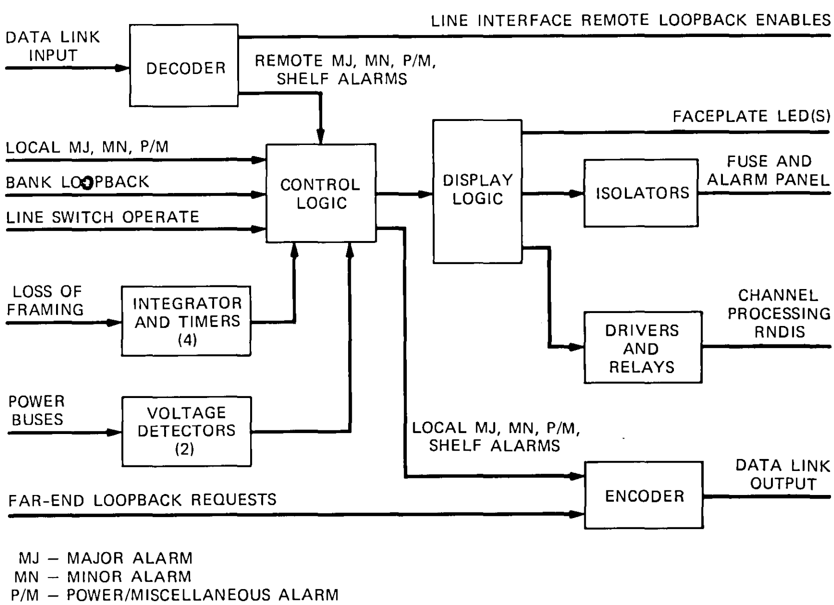


Fig. 14—Alarm control unit.

* TRU—Receives an indication of loss of framing from each TRU.
* TAU/MXU—Receives an indication of loss of synchronization and framing (and also detection of "yellow" alarm from the MXU).
* LIU—Receives the request and provides the command for line loopbacks.
* CTU—Alerts the Channel Test Unit of a major alarm condition.
* LSU—Receives an indication that a line switch has operated.
* Channel units—Provides a switched −48 Vdc to control channel processing.
* Power units A and B—Monitors power unit voltages for out-of-range conditions.
* RT battery charger/ring generator—Receives major, minor, and power alarm indications.
* Local—Allows local control of minor and miscellaneous alarms at the RT.
* Fuse and alarm panel—Provides data for connection to local office alarms and remote telemetry.

The faceplate of the ACU contains a pin-plug switch to operate a bank loopback, a pushbutton switch to cut off office audible and visual alarms, and an array of indicators showing the following:

* Major alarm
* Minor alarm
* Power/miscellaneous alarm
* Digroup shelf alarms (4)
* Alarm cutoff enable
* Near-end fail status
* Far-end fail status.

The ACUs in both terminals exchange alarm data over the data link using a 2-bit field and a subrate frame. The subrate frame indicator is located by a double 11 pattern in the two data link bits. The inactive state for each of the other alarm indications is a 01 pattern with the active state being 00. The subrate frame of the alarm data link field of a WP1 is repeated every 117 ms. Within the subrate frame, the transmitted alarm codes are assigned in the following sequence:

1. Subrate frame indicator
2. Major
3. Minor
4. Power/miscellaneous
5. A digroup fail
6. B digroup fail
7. C digroup fail
8. D digroup fail
9. A line loop request

10. B line loop request
11. C line loop request
12. D line loop request
13. P line loop request.

For applications connecting a *SLC* 96 carrier channel bank to a D4 bank via the SLIM, it is necessary to inform the SLIM that a bank loopback is in effect at the *SLC* 96 carrier channel bank. This allows the SLIM to transmit a yellow alarm to the D4 bank. To accommodate this, the substrate frame is expanded to include bank loopback as an alarm code. Two additional alarm codes have also been included for use in a tandem SLIM-to-SLIM connections. The three new alarm codes are assigned, in the expanded subrate frame, immediately following the frame indicator. The expanded subrate frame time is increased to 144 ms and the leading alarm sequence for the new ACU, coded WP1B, is:

1. Subrate frame indicator
2. Bank loopback (transmitted to a remote SLIM)
3. Pseudo bank loopback (used in tandem SLIM connections)
4. Incoming alarm (used in tandem SLIM connections)
5. Major (same as alarm indication 2, shown in above sequence), etc.

The data link decoder IC in the ACU is designed as a 12-bit shift register enabled by detection of the subrate frame indicator. Hence, the added SLIM alarm field bits are shifted in and overwritten, leaving only the original 12 bits needed for basic *SLC* 96 carrier operation. This method of adding new states to the alarm field without disturbing normal system operation avoids the need to coordinate the introduction of the new WP1B ACU code, since it will function properly with the previous WP1 code.

The timers shown in the ACU block diagram provide a delay function in the detection of out-of-frame conditions in a manner consistent with the D4 system. Step responses are in the order of 2.5 seconds to set and 5 seconds to clear. A lead called receive disable, RNDIS, which is bused from the ACU to the channel units, is used to disable the PAM sampling gates associated with a digroup whenever an out-of-frame condition is detected by the TRU. The response time to RNDIS is immediate at the channel units, while it takes 2.5 seconds to disable the −48 Vdc signaling voltage used to busy out the channels in the event of a steady failure. This allows signaling state storage, which prevents channels from being dropped during an intermittent period.

Near-end and far-end status indicators, used either directly or in conjunction with bank loopback, can identify whether many troubles are either in or out of a particular bank. Maintenance procedures using the features built into the ACU circuitry provide a means to isolate many troubles expediently and accurately.

3.3.2 Trunk processing for special services

Special services, including data port and program channel units, may be included in the digroup structure of a *SLC* 96 carrier channel bank. Backplane connectors are arranged to accept a variety of D4 channel units. The trunk nature of these services requires processing and treatment that is different from the loop channel units. The Special Service Unit (SSU) provides these additional features.

Data ports require a trilevel clock synchronized to a Digital Data System (DDS) network timing system. Conversion from the bipolar composite clock takes place within the SSU. It also regenerates the composite clock for further distribution, if required. Since this circuit is common to all digroups in a bank, and because this clock is also used to drive a power converter in the coin units, a redundant supply circuit is provided to power the SSU. If either power unit in a bank fails, the SSU will continue to function.

Trunk processing on certain D4 channel units requires a −48 Vdc signal, which is delayed 2.5 seconds beyond the declaration of a "red" or major alarm by the ACU. Another set of −48 Vdc signals with a timed wink pulse is also required. The SSU provides these functions and also the carrier group alarm contact closures necessary for offices with electronic switching systems. Buffers to distribute the recovered line clock and the received PCM from the LIUs are contained on this circuit pack. These signals are used by data-type channel units.

3.3.3 Channel testing feature

The *SLC* 96 carrier has the capability of providing test access to customer loops served from the RT. Test access is now provided for single-party, multiparty, and coin units via test access relays mounted on these channel units. The Pair Gain Test Controller (PGTC), working with channel test units (CTUs) in the COT and RT channel banks, establishes a dc bypass path around the carrier system.[9,10] This allows the repair service bureau to perform standard dc tests on the customer's loop. While this is going on, the PGTC is automatically performing a series of transmission and signaling tests on the derived channel. This section describes the CTUs and their interaction with the PGTC and the channel units in the channel bank.

There are two versions of CTU-coded WM20 (or also WN10B) for the COT and WM21 (or also WN11B) for the RT. The COT–CTU does the handshaking and interfacing to the PGTC in the central office. It must also switch one-of-four tester unit interfaces from the PGTC to the bypass pair. The RT–CTU is in the path of the dc bypass and allows cut-through to the customer loop under test. In addition, it provides termination circuits to the derived channel for the automatic transmission and signaling tests conducted by the PGTC. The RT–CTU interacts with the channel units via bused signals in the channel bank.

There are two phases to channel testing; the first is the set-up and cut-through of the dc bypass path; and the second is the test of the derived channel. These phases can be described relative to the overall simplified schematic shown in Fig. 15. At the central office, this schematic shows only one Repair Service Bureau (RSB) test trunk interface, of which there can be many, and one-of-four tester unit interfaces to the PGTC.

Assuming that a customer line has been dialed over one of the RSB test trunks, the process starts when the positive station potential is activated over the test trunk. This initiates an involved microcomputer controlled handshaking procedure to connect an incoming test trunk to a customer loop. A time sequence of events at the central office PGTC interface to the CTU and channel unit under test is shown in Fig. 16. The interface between the PGTC and the CTU is a bused interface to all channel banks in the wire center. The positive station potential, +116 Vdc behind 8 kΩ, is applied to the tip conductor of the COT channel unit. This causes TONE (a 333-Hz test tone) to be returned to the PGTC and TEST CODE to be sent to the RT channel unit via the A and B signaling bits. The 333-Hz tone is sensed by the PGTC and used to identify which, of many test trunks, is requesting a connection. A signal called SEIZE is returned to the PGTC via the *SLC* 96 carrier data link and the CTUs. The SEIZE signal is the result of two channel bank signals at the COT and RT, called NSEIZE, which are generated by the channel units under test. The COT–CTU will look at the state of the INHIBIT lead to check the availability of the dc bypass pair. If the INHIBIT lead is not grounded, the dc bypass is not in use and the CTU will return a SEIZE. If the INHIBIT lead has been previously grounded, then the bypass is busy and the CTU will return a SEZBY. During the processing of the SEIZE signal, the CTU will also look at the COT channel bank major alarm bus and, if present, a TMAJ signal will be returned to the PGTC. If either the SEZBY and TMAJ is received at the PGTC, all attempts to test through a *SLC* 96 carrier will be aborted and an appropriate indication will be returned to the RSB test facility by the PGTC. In addition, if all of the PGTC test facilities are busy, the PGTC will send a signal called TSTALM (test alarm) to the COT–CTU, which will return all test connections to normal in the *SLC* 96 carrier and an appropriate indication will be returned to the test facility.

Assuming success during the test set-up phase, when both SEIZE

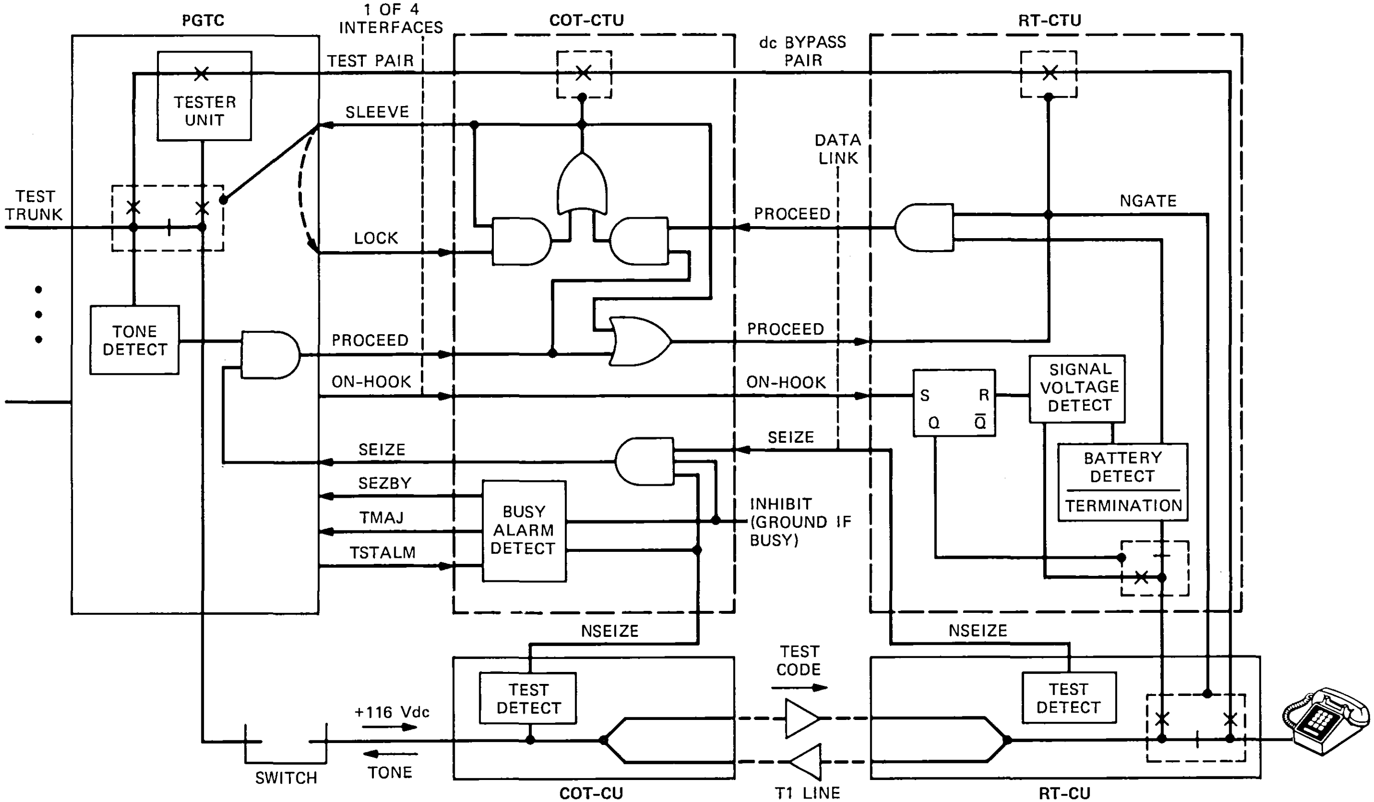


Fig. 15—Simplified schematic of COT and RT channel test units.

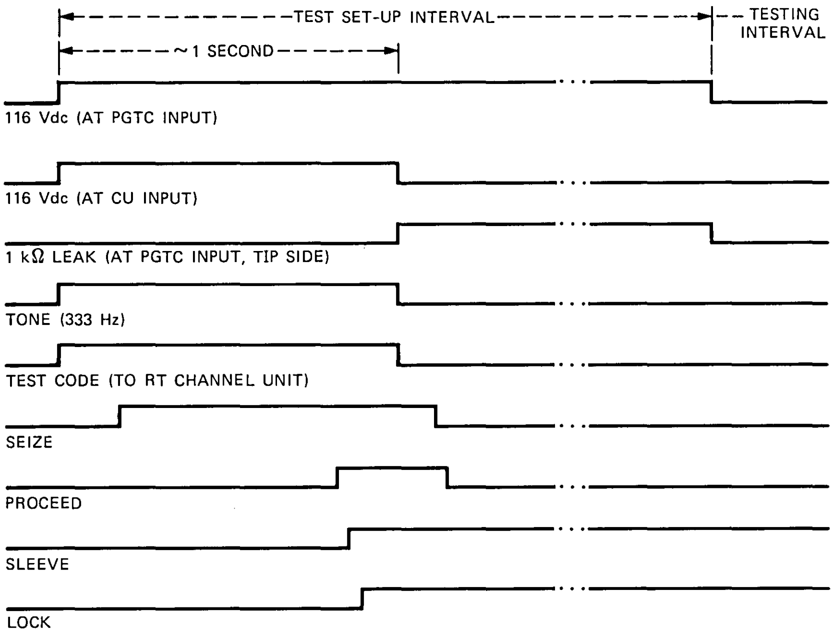


Fig. 16—Time sequence of events at interface between the PGTC and the COT channel test unit and channel unit under test.

and TONE are present at the PGTC, a signal called PROCEED is sent to the RT–CTU via the COT–CTU and the data link. This enables a signal bus at the RT channel bank, called NGATE, that enables the cut-through relays in the RT–CTU and the channel unit under test. The dc bypass pair is thereby connected to the customer's loop and the RT channel unit is connected to the CTU. A battery monitor circuit in the CTU detects the talk battery supplied by the channel unit indicating proper operation of the test relay thereby allowing a return of the PROCEED signal to the central office via the data link.

When the PROCEED signal returns to the COT–CTU, it generates a signal called SLEEVE, which causes cut-through of the bypass path at the COT–CTU. The SLEEVE signal is sent to the PGTC, where it enables the cut-through relay on the RSB trunk card of the PGTC. This drops the 116-Vdc input to the COT channel unit under test and connects the tester unit to this channel. In addition, this action causes the following events to occur: (1) stop the transmission of TONE and TEST CODE by the channel unit, (2) allow the NSEIZE buses in the COT and RT channel banks to return to normal, and (3) subsequently allow the SEIZE and PROCEED leads to return to normal at the PGTC interface. A final signal called LOCK is sent from the PGTC to the COT–CTU to hold up the connection until all testing is complete, at which time, removal of LOCK will drop the entire connection at the *SLC* 96 carrier.

Final cut-through of the RSB test trunk to the bypass occurs when the 116-Vdc station potential is removed by the testing facility. This causes a relay in the tester unit to fully connect the bypass pair. Execution of the test set-up sequence requires approximately one second, and when complete, this is indicated to the testing facility by placing a 1-kΩ leakage resistance from the tip conductor to ground. This leakage is also removed when the station potential is removed.

While normal testing of the customer's drop is occurring, the PGTC is testing the derived channel. This test requires only two seconds for single-party and four seconds for multiparty and coin channels. To start the testing interval, the RT–CTU will complete the test set-up sequence and come up in the off-hook state with a 900-Ω absorptive termination together with an ANI (Automatic Number Identification) ground presented to the channel under test. The ANI ground is poled through diodes to allow current to flow from either a positive or negative battery, depending on the test being conducted. For some tests, a reflective, short-circuit termination is presented to the channel. As the various return loss, channel loss, and idle channel noise measurements are made, the CTU must return an on-hook termination to the channel under test, by responding to commands from the PGTC transmitted over the data link. The CTU will present off-hook terminations again, as it detects the various ringing and coin collect voltages presented by the channel under test. In this manner, all significant transmission parameters may be measured and all signaling states may be recognized appropriate to the channel under test.

The CTUs are alarmed for abnormal conditions and will light an indicator on the front face of each unit when detected. These alarms are also connected to the system minor alarm bus in the channel bank. A minor alarm was considered appropriate because, at most, one customer will be adversely affected should the test logic within the channel bank malfunction.

IV. SYSTEM TIMING AND SYNCHRONIZATION

System timing in the *SLC* 96 carrier is controlled by Voltage Controlled Crystal Oscillators (VCXOs) located on each of the LIUs in the system. These VCXOs may be configured to be either free running or they may be synchronized to other signal sources. Two 4-kHz signals, one derived from the receive count-down timing circuits called RIFT and one derived from transmit timing called TMF, will synchronize a 6.176-mHz crystal oscillator if the lead, LCKLT, is grounded at an LIU output. Otherwise, a stable voltage will set the oscillator free-running frequency to be within the T1 digital line requirements. RIFT may be derived from the received line clock (called loop time) or from the external composite clock used to synchronize data port channel units. The selection of the synchronizing source is an option setting on the special services unit, SSU. The backplanes in the COT and RT terminals are wired differently with the RT forced to loop time from the received line clock. A simplified diagram of the clock control is shown in Fig. 17.

Case 1—Internal synchronization. In this case, the SSU option INT is selected for internal timing at both terminals. At the COT, the LCKLT lead is not grounded in the A digroup LIU, allowing that LIU clock to free run. All other LIUs have their LCKLT leads grounded through insertion of the SSU plug-in and all LIUs reference the same 4-kHz RIFT signal, also provided by the SSU. As a result, all LIU clocks at the COT are frequency locked to the A LIU clock. Because the RT is loop timed, this also causes all RT clocks to be synchronized to the A LIU clock at the COT. If the B (and/or D) LIU is replaced with either a TAU or MXU plug-in for Mode 2 or 3 operation, synchronization is not affected.

Case 2—External synchronization. In this case, the SSU option EXT is selected for synchronization to an external clock at the COT.

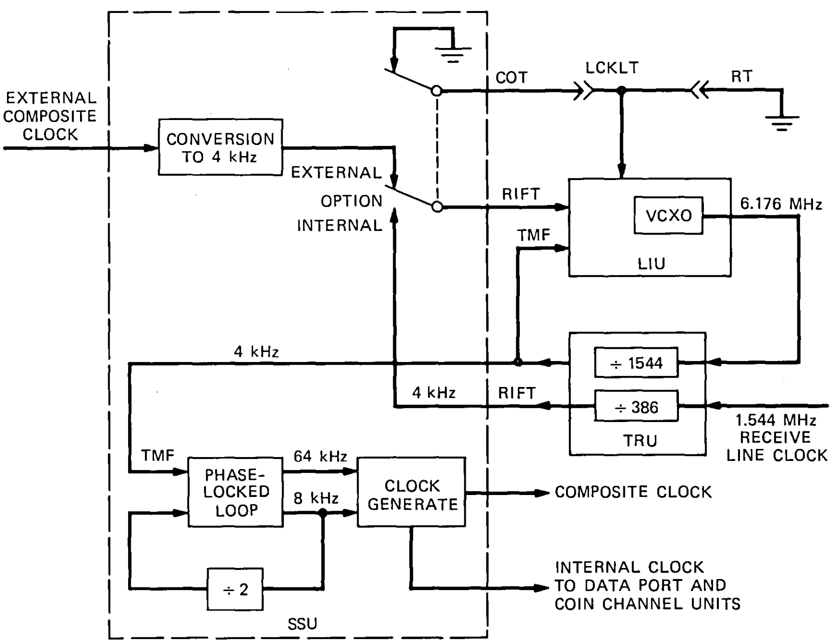


Fig. 17—System synchronization.

An office clock, which is a composite of 64 and 8 kHz, is distributed to all channel banks to be synchronized. A RIFT signal is derived from this clock by the SSU and distributed to all four digroups in the bank. Selecting this option also grounds the LCKLT lead of the A LIU and all digroups are thereby synchronized to the external clock. The SSU at the RT should remain optioned for internal timing.

Should the SSU plug-in require removal from the channel bank for maintenance reasons, message telephone service will continue; however, some services will be disrupted and system synchronization may be lost. For example, dataport service and the RT coin channel units, which receive clock signals from the SSU, will be out of service. If the SSU is removed at the COT, the LCKLT ground is opened, and each digroup will free run in the transmit direction. Nonsynchronous operation of the digroups will degrade voice-frequency idle channel noise performance to some degree. Because the RT is loop-timed via backplane connections, removal of the SSU at the RT will not affect synchronization.

V. THE CHANNEL UNITS

5.1 Overview

Of the many characteristics that make the *SLC* 96 carrier system attractive for loop applications, possibly the most important is its pair gain or pair saving. Ninety-six POTS (Plain Old Telephone Service) subscribers can be served over ten pairs in Mode 1 and six pairs in Mode 2. These ratios can apply to the cable cross section if essentially all services can be accommodated within the system. Services not handled must remain on copper pairs, reducing the efficiency and pair gain potential of the cable. The system, at present, can handle a broad variety of POTS services, including all Regional Bell Operating Company party lines and frequency-selective ringing for the independent companies. In addition, coin-first and dial-tone-first coin service, most special services, and multiple-rate dataports for the DDS network are all standard options. A number of units providing new features are added each year.

This flexibility is provided by equipping the banks with appropriate channel units. These may be interchanged with no interaction with the common units or change of powering considerations. Most units, the analog ones, interface with the TPAM and RPAM buses in their designated time slot. Timing, synchronization, and power is also provided via the common backplane buses. The digital units such as dataports interface through digital data buses for direct access to the T1 bit stream. Many units have jack access to the baseband signals and channel busy lamps for maintenance purposes. All channel units are designed, as are the common units, for "hot" replacement. That is, they may be removed and replaced without interrupting power that would affect service on other channels.

5.2 POTS channel units

5.2.1 General description

These units, providing switched message telephone service, are the most common. They can be conveniently considered in four groups:

1. Single-party with forward disconnect
2. Multiparty with superimposed ringing and tip-party ground (ANI).
3. Multiparty with frequency selective ringing
4. Coin for dial-tone-first and coin-first.

All but coin have two channels per plug-in, a COT unit, and two RT units, one for the 900Ω conductor range and another for the 1500Ω conductor range. All have 900Ω impedances at the central office line port.

The circuitry can be considered generically, as shown in Fig. 18.

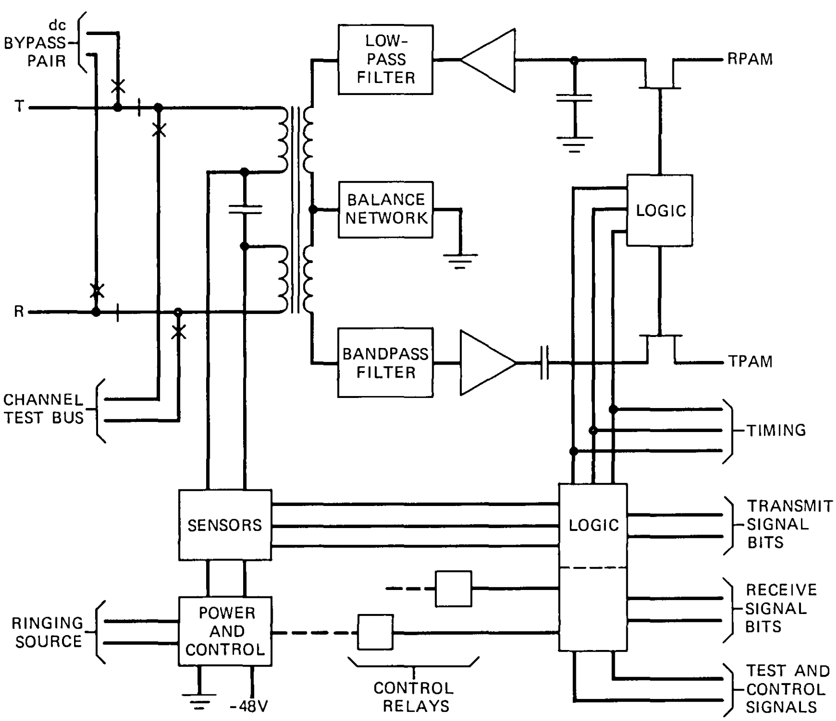


Fig. 18—Message channel unit.

The voice frequency transmission circuits, shown in the upper portion, include the hybrid transformer for coupling the 2-wire line to the 4-wire filters and PAM buses, the filters which bandlimit and reconstruct the speech, and the sampling gates for inserting and removing pulses from the PAM buses in the proper time slots. Also shown is the test relay which, when operated, ties the subscriber line to the metallic bypass pair and eventually to the RSB test facility. The test relay, used on RT units only, also connects the channel unit to the Channel Test Unit (CTU) for the automatic transmission and signaling tests, as described in Section 3.3.3.

The lower portion of Fig. 18 shows the signaling and logic circuits. All COT units sink dc current at the line port, and all RT units source dc current of various levels to bias the telephone set transmitter. These terminations or sources are applied to the center tap of the line hybrid through power and control circuits and various sensors. Ringing voltage in the RT units is also applied here. The sensors measure voltages or currents at the line interface. For COT units, they are ringing voltage detectors, which include the varieties of multiparty ringing, detectors for the test signal from the RSB, open loop sensors indicating forward disconnect actions, and detectors for the various coin control voltages. For the RT units, they are off-hook current detectors for dial-pulse sensing, ring-trip detectors, and tip-party ground ANI detectors.

The line control circuits are normally relay contact closures that affect line powering in some manner. For the COT units, these are off-hook relaying and tip party ground signaling. At the RT, the controls are for the various kinds of ringing voltages, the test relay control, the forward disconnect control of loop voltage, and the coin collect and return functions.

Sensor outputs are normally digital, as are control inputs. These both interface with a logic circuit whose function is to convert the sensor and control signals to and from A and B bits that are applied to or received from the backplane signaling buses. Timing signals are obtained from other buses. Their function is to gate the A and B bits into or out of the proper bus time slots. These same timing signals clock the PAM samples to and from the PAM buses in the proper time slots. The A and B bits are encoded every sixth and twelfth frame in the least significant bit of the PAM words. This bit stealing is effected in the TRU, as discussed in Section 3.1.2.

A few other miscellaneous signals are processed in the channel units. Should the T1 line fail or get excessively noisy, the *SLC* 96 carrier digroup will go into a trunk processing sequence. The first action taken is to kill the channel unit receiver through a RNDIS (Receive Disable) signal from a backplane bus. Also, in response to a test signal, the COT units will apply a 333-Hz tone to the line port for identifying the test trunk to the PGTC. Two other signals from the backplane are part of a handshaking and control process with the CTU.

5.2.2 Single party

In addition to the preceding general characteristics of the POTS family of channel units, a few specific features should be noted. The single-party units are designed to relay a forward disconnect signal from COT to RT. A momentary break in current from the office switch is sensed, signaled to the RT channel unit, and results in removal of current to the subscribers key set. This momentary break in current flow will release a line accidently left on "hold".

Two single-party RT units exist. The standard unit operates to 900Ω of loop resistance and has a net 2 dB of loss from COT to RT and also from RT to COT. This loss maximizes grade-of-service and improves echo return loss. The extended-range RT unit has a lower resistance current feed capable of providing 20 mA to 1500Ω loop resistance. This unit is not recommended for use below 900Ω. Loss is set to 0 dB for optimum service. There are no adjustments on any unit.

5.2.3 Multiparty superimposed ringing

There are a COT and two RT multiparty units that have the same transmission and current feed characteristics as the single-party units. They do not have forward disconnect. They are designed to serve the Regional Bell Operating Company four party, superimposed ringing service, where ringing is divided (tip conductor or ring conductor to ground) and the trip battery is either positive or negative. These options allow full four party selective ringing at 20 Hz. In addition they are capable of detecting a tip party ground and relaying it to the office switch to provide two-party ANI.

Channel signaling via A and B bits requires two master frames, as more than four patterns are required from the COT. By alternating the bits each frame, a third state is added providing nine possible commands.

5.2.4 Multiparty frequency selective ringing

These units for the independent telephone companies were developed in 1983. They provide full selective ringing to four parties by using a different ringing frequency for each party. A tuned ringer in the telephone set responds only to its frequency. Ringers are only bridged and the three types of ringing are supported as follows:

1. Decimonic: 20, 30, 40, and 50 Hz.
2. Harmonic: 16.7, 25, 33.3, and 50 Hz.

3. Synchromonic: 20, 30, 42, and 54 Hz.

Square-wave ringing is used, which restricts the harmonic series from supporting both 16.7 and 50 Hz on the same pair because of cross-ring problems. The proper frequency type is set by an option switch on the RT unit; no option is required at the COT. Again, transmission characteristics are the same as for the single-party units.

5.2.5 Coin channel units

There are a COT and two RT coin units, which have the same transmission characteristics as the other POTS units. Both coin-first and dial-tone-first service are offered with the same plug-ins. The coin-first or dial-tone-first service is automatically selected without any option switches. No postpay option is available. These units are packaged one channel per plug-in in contrast to dual channels for all the other POTS units. As in the multiparty units the use of alternating A and B bits is required from the COT to provide sufficient commands.

5.2.6 Special service units

A set of almost 40 different plug-ins allows the *SLC* 96 carrier to provide essentially the same full range of special services as offered with the D4 trunk carrier system. In fact, the majority of the units are the identical D4 plug-ins. All "specials" are packaged one channel per plug-in, which wastes one of the two time slots available per plug-in in Mode 1 operation. Consequently, Mode 3 is normally used for "specials," with Mode 2 being used where only a few special channels are required per bank.

In general, the special service plug-ins used in the *SLC* 96 carrier channel bank are common to the D4 channel bank and the functions represented are also common to many other systems such as the Metallic Facilities Terminal. The coverage given here will be restricted to a brief description of each family compatible with the *SLC* 96 carrier. The family of special service units will be considered in the categories of voice frequency units, analog special services, and dataports.

5.2.7 Voice frequency units

These units are similar to the POTS units in many ways and Fig. 18 is useful to describe the similarities and differences. Many units, such as the 2FX0, 2DPO and 2DX/GT, are two-wire transmission circuits as are the POTS units. They contain a three-port hybrid transformer as in Fig. 18 for interfacing the two-wire external voice frequency port with the four-wire interface to the PAM buses. Others, such as the 4W E and M, 4FX0, PLR, and 4 TDM, are full four-wire circuits, where transmitting and receiving paths are separate. These may have battery isolation and impedance matching transformers but no three-port hybrid. None of the special service units have a test relay as do the POTS units, and therefore none are compatible with the PGTC. Some units have added gain in the transmitting and/or receiving amplifiers and are usually known as Gain Transfer (GT) units. Gain or loss is usually adjustable over a broad range in 0.1-dB steps. The higher gain units frequently have adjustable equalization in the transmit path to complement cable pair losses. Most two-wire units have network buildout capacitors at the two-wire port for optimum line matching. These are also adjustable in many steps. The balance networks used tend to be more complex circuits than POTS because of more critical return loss requirements. These also have many adjustments in some cases. The channel bandwidth extends from 200 Hz to 3300 Hz at 3 dB down with high attenuation at 60 Hz to suppress power line interference and at 4.0 kHz to prevent aliasing where higher frequency signals could appear in band because of the sampling process.

The signaling path circuits are composed of sensors and control elements, as in POTS. Their nature is different in many cases. Some units such as Transmission Only (TO) and Equalized Transmission Only (ETO) are transmission-only units with no signaling. Others such as DPO are two-state signaling units, meaning they have one signal path with two states (e.g., off-hook, on-hook) in each direction. Others, such as E and M units have four-state signaling. In general, the sensors are voltage or current detectors, the control elements are relays. A and B bits are used for the digital interbank signaling. As with POTS, the receiving control elements are latched to maintain continuity of the signaling state during momentary T1 line faults.

5.2.8 *Analog special service units*

Broader band analog transmission units are available for commercial radio station transmission. These are known as Program Channel Units (PGCU) and have either 5-kHz or 8-kHz bandwidths. The 5-kHz PGCU samples the PAM bus at twice the normal rate and therefore requires two time slots per 24-slot frame. The 8-kHz PGCU samples at three times the normal rate and requires three time slots per 24-slot frame. Each 5-kHz PGCU in use requires one other physical bank position to remain empty, while each 8-kHz PGCU requires two other empty slots.

5.2.9 *Dataport channel units*

Six channel units are designed for digital transmission only for the DDS network.[11,12] These have bit rates of 2.4, 4.8, 9.6, and 56 kb/s, as seen at the subscriber interface. All are compatible with the *SLC* 96 carrier system.

VI. POWERING ARRANGEMENTS

The *SLC* 96 carrier has been designed to be very efficient in its utilization of space regarding powering arrangements at both the COT and RT. At the COT, bay space has been maximized by use of a compact fuse and alarm panel that distributes central office −48 Vdc battery to up to six channel banks in an 11-1/2 foot bay. In addition to handling all alarms for the six channel banks, the fuse and alarm panel also includes an integral talk filter to supply filtered battery to off-premises stations that may be served from a COT bay.

The digital carrier interface to the outside plant has been integrated into the channel banks at the COT, thereby avoiding the need for office repeater bays. Versions of LIUs have been coded to include the line feed converters that power the repeaters on the T1 repeatered line. A constant 60 mA is simplexed onto the carrier pairs from the LIUs. For many applications, the length of digital line is short enough that the 60-mA constant current can be merely looped at the RT. Where the length of digital line exceeds the length that can be powered from the COT, added powering spans are needed. The added powering spans may be provided by back powering from the RT using a powering LIU, or by using an intermediate remote power feed terminal.

A remote power feed terminal has been designed to complement the *SLC* 96 carrier by providing a means of powering long distance digital lines. The remote power feed terminal uses the *SLC* 96 carrier cabinet types and RT battery plant; and it also requires apparatus shelves that hold constant current dc-to-dc converters and power insertion transformers. This hardware is suitable for frame mounting in small equipment buildings.

The *SLC* 96 carrier remote terminals may be powered by an integrated, compact battery plant that is mounted with the remote terminal apparatus, or they may be powered from an external standalone battery plant. In either case, local ac power with battery backup is used. A minimum of eight hours of battery is usually provided during loss of commercial ac power. Additional RT power apparatus items include power panels that house ringing generators, talk battery filters, and distribution fuses for the channel banks.

6.1 Remote terminal battery plant

The *SLC* 96 carrier RT is powered by an integrated battery plant that provides power for one or two RT channel banks, depending upon the type of RT housing. The 3A battery charger is designed to charge up to two 25 AH (Ampere Hour) battery strings, in addition to the channel banks. The battery strings are mounted on shelves designated 128A apparatus mountings. Four KS-21906 List 4 battery packs, employing rechargeable, sealed, lead-acid cells, are connected in series to form a nominal 48-volt string. Each battery pack supplies a nominal 12 volts and is connectorized for plugging directly into the battery shelf. The battery charger and shelves, along with the battery packs, have connectors to provide easy installation and to allow compact integration with the channel banks they power. Connectorization also allows for safe installation of batteries by the telephone company craft. The battery charger needs 7 inches of vertical mounting space and each battery shelf 8 inches, for a total of 23 inches of space in a standard, 23-inch, unequal flange frame. To conserve floor space, the battery plant requires front access only.

Sealed, lead-acid cells were chosen to provide a battery pack that exhibits long life, maintenance-free operation, and the capability to operate over the wide range of temperatures encountered at a remote terminal. These cells are sealed to prevent acid vapors or electrolyte spillage, and they utilize gas recombination to prevent significant loss of water over long periods of float operation. The cells have been packed, six to a pack, and connectorized to guard against shorting during installation. The sealed, lead-acid battery pack exhibits very low internal impedance, which permits very high current to flow, if short circuited.

The capacity of a battery string is 25 AH at a temperature of 25°C, however, the capacity has been derated to 20 AH for reserve calculations to account for ac power failure during winter months. The battery shelves are equipped with thermostatically controlled heaters designed to keep the batteries relatively warm at the outset of an ac outage. The KS-21906 cell has an expected life of five years when used in float-standby applications in the outside plant environment. Battery life is an inverse exponential function of temperature above 25°C. Calculations of battery life using U. S. Weather Bureau data, accounting for both mean daily high and low temperatures throughout the year in several regions of the United States, support the above-expected life.

A simplified schematic of the 3A battery charger is shown in Fig. 19. The rectifier circuit in the battery charger produces two dc voltages. The primary output is 48-Vdc signal grade with 8.5A capacity to power the channel bank loads, and the secondary output is 64 Vdc with 2.5A capacity to supply the battery charging circuits. The battery charger is dual-rate designed to return full charge to one or two battery strings in 24 hours using a high-rate constant-current charge. A temperature-compensated float will then retain this capacity indefinitely. The rectifier uses the principal of controlled ferromagnetic resonance of a

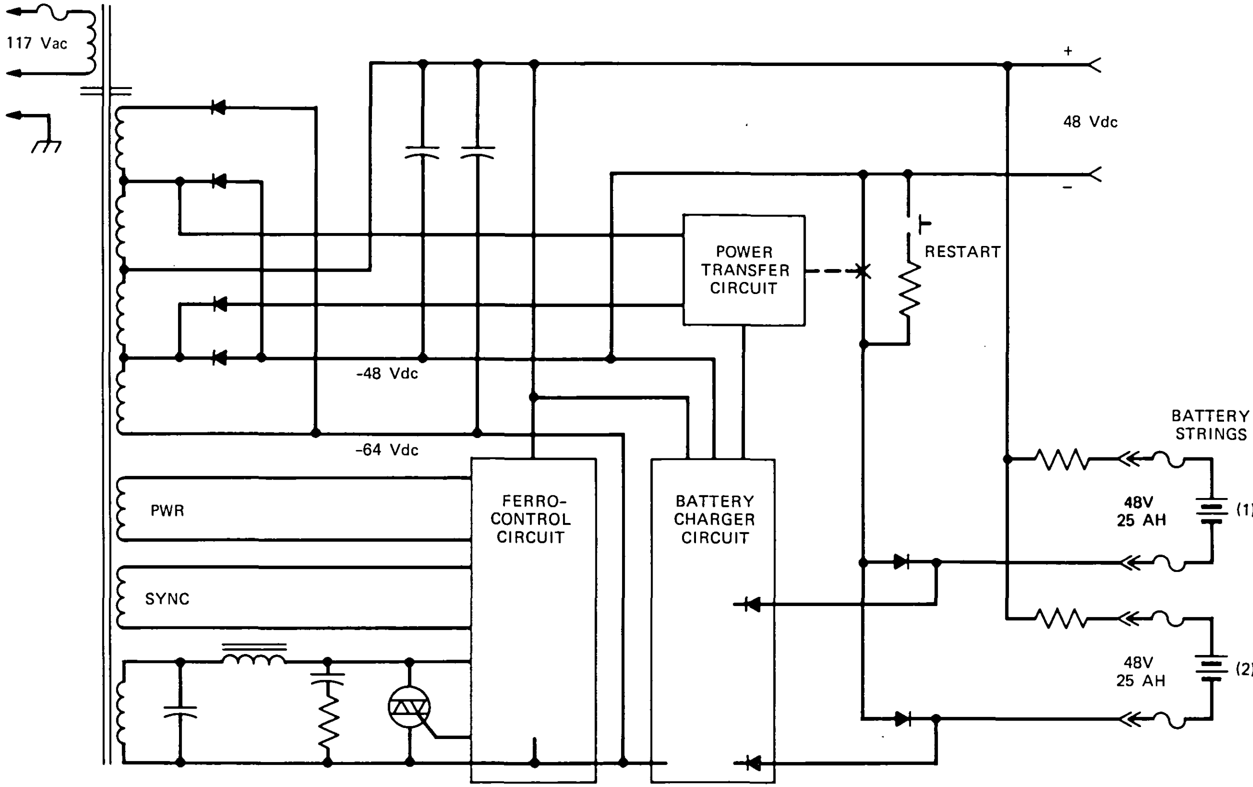


Fig. 19—Battery charger.

transformer to achieve regulation. To maximize availability of the rectifier, the ferromagnetic transformer is designed to be open loop stable producing a system voltage of less than 60 Vdc (typical 56 Vdc) should the regulator circuit fail. All of the sensitive electronics, including the ferro control circuit, are mounted on a plug-in unit, coded the YL1B. As discussed above, replacement of this plug-in does not shut down the rectifier.

The battery charger is provided with two alarm closures that are monitored by the RT channel banks. The first alarm produces a POWER MINOR at the COT, via remoting of alarms, and is caused by the detection of loss of ac power. This also causes the power transfer circuitry to connect the batteries to the load. The batteries will remain connected to the load until ac power returns or until the system load bus drops to 42.5 Vdc. At this point, the power transfer circuitry disconnects the batteries from the load to avoid damage to the batteries due to excessive discharge. If the loss of ac power was momentary (a few seconds), the minimum connect time of the power transfer relay is 24 seconds to guard against possible chatter.

The second alarm produces a MINOR alarm which is caused by:

- Detection of high voltage on the load bus due to failure of the regulator circuit.
- Detection of very low float current through a battery string. This is an indication of a blown fuse or possibly a corroded cell in the battery string.
- Detection of low voltage across the battery string on float. This is an indication of inadequately charged batteries on float or it may be an indication of shorted cells in the battery string.

The remote terminal battery plant has proved to be a compact and versatile subsystem. Because it has been designed to integrate with the electronic assemblies that it powers, the battery plant is finding wide application in the outside plant.

VII. SUMMARY

The *SLC* 96 carrier channel bank, with its ability to accommodate both metallic and optical fiber facilities, is playing a vital role in enhancing the digital transmission capability of the local loop network in a cost-effective manner. This is leading the way to providing many new digital data services in addition to traditional message telephone service. Digital loop carrier can also meet the transmission needs of many special service circuits with considerable flexibility and fast response by eliminating the distance constraints associated with all metallic facilities. The *SLC* 96 carrier system design approach, which has combined many attributes of an interoffice trunk system with the unique requirements of a digital loop carrier, has become a dominant vehicle in bringing new technology to the loop plant.

VIII. ACKNOWLEDGMENTS

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The SLC 96 Subscriber Loop Carrier System:

Physical Design

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The successful deployment of digital loop carrier systems by the operating companies is highly dependent on the physical and mechanical design of the electronics. A comprehensive description of the *SLC®* 96 subscriber loop carrier system central office and remote terminal equipment design is presented. Particular emphasis is placed on the loop plant electronics enclosures developed for operation in uncontrolled outside environments. Remote terminal thermal design guidelines are also presented, since thermal control of the environment surrounding the electronics is essential to long-term reliable operation. Throughout this paper, physical design requirements and objectives for digital loop carrier design are summarized.

I. INTRODUCTION

The introduction of digital loop carrier systems into the loop plant has made servicing more efficient and flexible. Deployment of the *SLC* 96 subscriber loop carrier system has reduced costs and accelerated the introduction of digital technology in the loop. Digital technology has greatly enhanced the loop's capability for voice telephone and data transport services.

Successful physical design of the *SLC* 96 system was necessary to its rapid deployment. *SLC* 96 equipment design has given the operating

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companies rugged, reliable, flexible, and economical mounting arrangements that were engineered for both the central office and the uncontrolled environments of the outside plant.

The aim of this paper is to highlight the physical design of the Central Office (CO)* and remote outside plant terminal equipment. The paper also summarizes the thermal design and evaluation, which have been valuable in ensuring reliable system operation.

II. PHYSICAL DESIGN REQUIREMENTS

The *SLC* 96 system was designed primarily to serve the suburban loop market. Applications in rural and urban areas were considered as secondary markets. This approach required a modular carrier system that could be flexibly deployed in both small and large line sizes. Aboveground and below-ground Remote Terminal (RT) mounting and aesthetically pleasing RTs were necessary to satisfy suburban and urban market pressures. Other specific requirements included:

1. Operation in outdoor environments that had ambient temperatures from −40° to +120°F and could accommodate maximum solar heating and internal equipment heat dissipation of about 155 watts.
2. Operation in outdoor environments of up to 100 percent relative humidity. The electronics also had to be protected from airborne particles and pollutants like salt, dirt, hydrocarbons, and industrial smog.
3. Installation and assembly by operating company technicians. Simple installation and operation methods using standard hardware, whenever practical, were required.
4. A modular system with plug-in assemblies and connectorized cables to permit easy installation and flexible change-out of units for feature enhancements. This area is highlighted in the design of the Fiber *SLC* carrier system feature introduced in November 1982, about three years after the original product was manufactured.

III. SYSTEM PHYSICAL DESIGN

As described in Ref. 1, a *SLC* 96 system comprises a central office terminal connected to a remote terminal via a standard T1 repeatered line. Distribution pairs from customers are cross-connected to the remote terminals to complete the service path. Figure 1 illustrates a complete system. The succeeding sections provide details of the physical design of the central office and remote terminal equipment.

3.1 Central office

The central office terminal equipment for the *SLC* 96 system con-

* Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

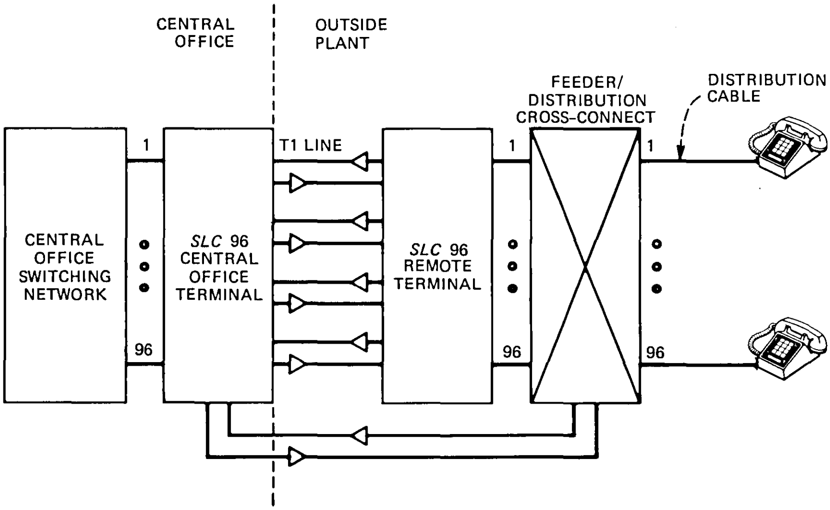


Fig. 1—*SLC* 96 carrier system configuration.

sists of a channel bank, a fuse and alarm panel, a jack panel, and a fault locate and order wire panel. Figure 2 illustrates this equipment mounted in a central office bay. As Fig. 3 shows, three bay arrangements are available to give flexibility to all operating company central offices. AT&T Technologies, Inc. *SLC* 96 bay shipments show a 50-, 25-, and 25-percent market split for 11-foot 6-inch, 9-foot, and 7-foot bays, respectively.

The format of the *SLC* 96 bank was derived from the D4 channel bank, a high-production trunking system introduced in 1977. The *SLC* 96 bank is 19 inches high and 12 inches deep, and it is flush-mounted on a 23-inch-wide, unequal flange, duct-type bay. There are four shelves in each bank. Like the D4 system, each shelf contains up to 12 plug-in channel units plus common equipment plug-ins that are located on the left side of each shelf. Figure 4 illustrates a 7-foot bay arrangement. Although many new plug-ins were designed for the *SLC* 96 system application, such as single and multiparty channel units and new common equipment, many special service channel units developed for the D4 channel bank can also be used in the *SLC* 96 bank. The support shelves are die-cast aluminum, with the plug-in unit guides cast into the top and bottom surfaces, as shown in Fig. 5. As with any high-production runner, the die-cast shelves have been reduced in cost and optimized for easy assembly. The most recent shelf design has also been optimized for strength, weight, castability, and maximum thermal cooling capacity. Approximately 45 percent of the shelf area is open for air flow. (Details of this shelf design are described in Ref. 2.)

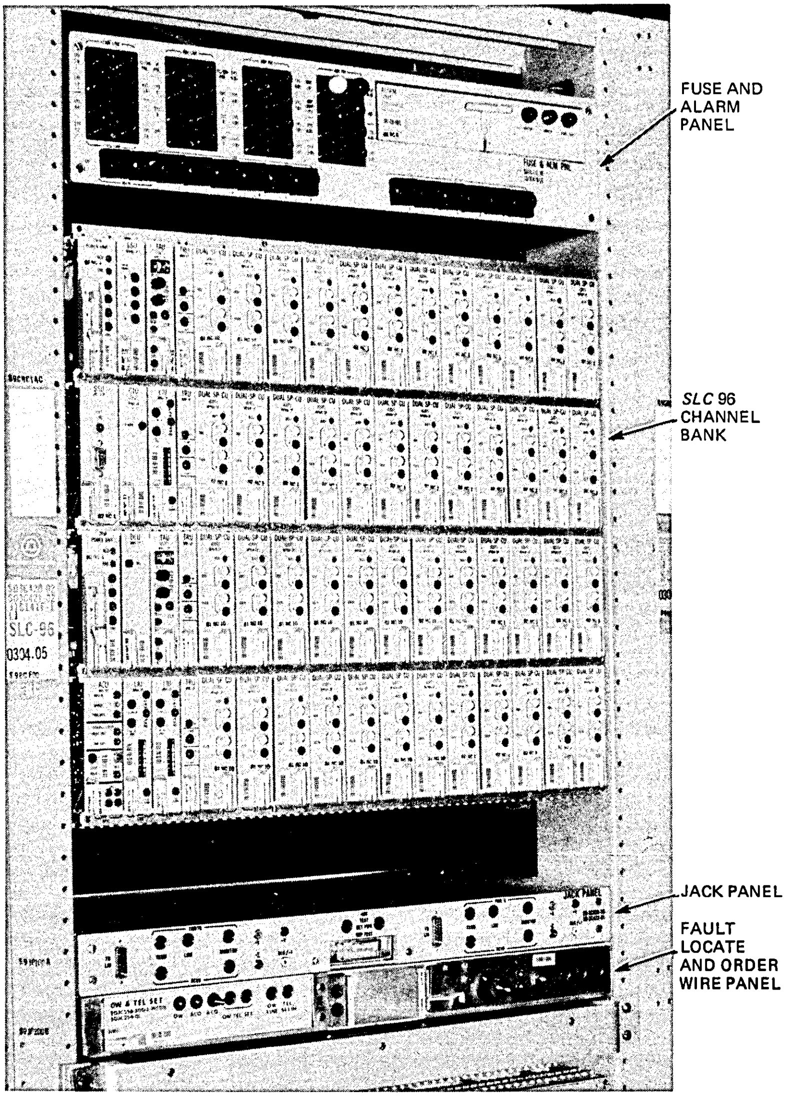


Fig. 2—Central office terminal equipment.

The interconnection of plug-ins with the shelf assembly is achieved with gold-fingered contacts that mate with connectors mounted in a rigid, printed wiring backplane. The connector pins are a compliant section design, pressed into plated-through-holes in a double-sided, epoxy-glass backplane. Approximately 70 percent of the backplane is printed; the rest is hard-wired, using standard wire-wrap technology. Figures 5 and 6 show the backplane technology.

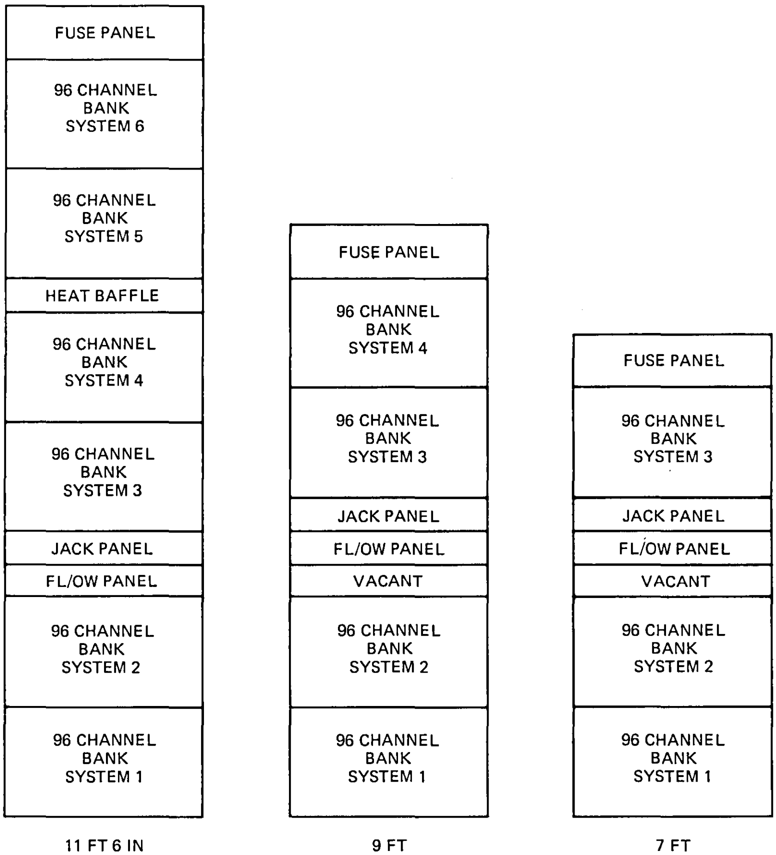


Fig. 3—*SLC* 96 central office bays.

The bank is fully connectorized for simple installation in the central office. Bank connectorization permits prewiring bays and simplified installation when equipment is added later. These features shorten service intervals.

All plug-in units use epoxy-glass, double-sided, rigid, printed wiring boards that are 9.9 inches long and 4.3 inches high. Each unit has a die-cast faceplate and a latching mechanism that locks the unit into the shelf. A lever mechanism in the latch aids in extracting the plug-in. The plug-in and shelf assembly are carefully designed to facilitate connector mating and plug-in insertion/extraction over a wide tolerance range.

The integrated circuit technology is primarily medium-scale integration, using Dual In-Line Packages (DIPs) and many Hybrid Integrated Circuits (HICs). (Details of the hybrid technology are summarized in Ref. 2.) Large-scale integration was used in one plug-in, the

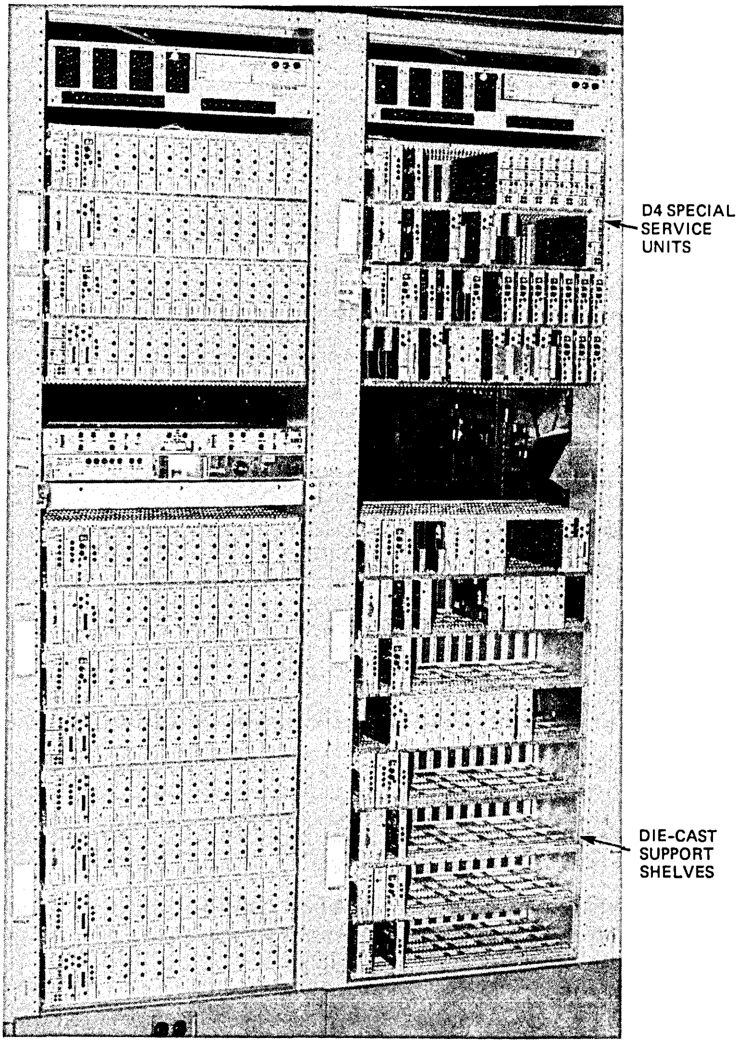


Fig. 4—Seven-foot central office flush-mounted bay arrangement.

Time Assignment Unit (TAU). (Ref. 3 describes the application of the TAU unit.)

The fuse and alarm panel is 4 inches high and mounts at the top of the central office bay, accommodating up to six *SLC* 96 systems. The panel provides fused power to the banks, local visual alarms, and connections that are wired to office and remote alarm systems. The jack panel, two inches high, provides access to the digital lines via cord jacks on the front panel. The jack panel is located at a convenient working height. The fault locate and order wire panel is optional for

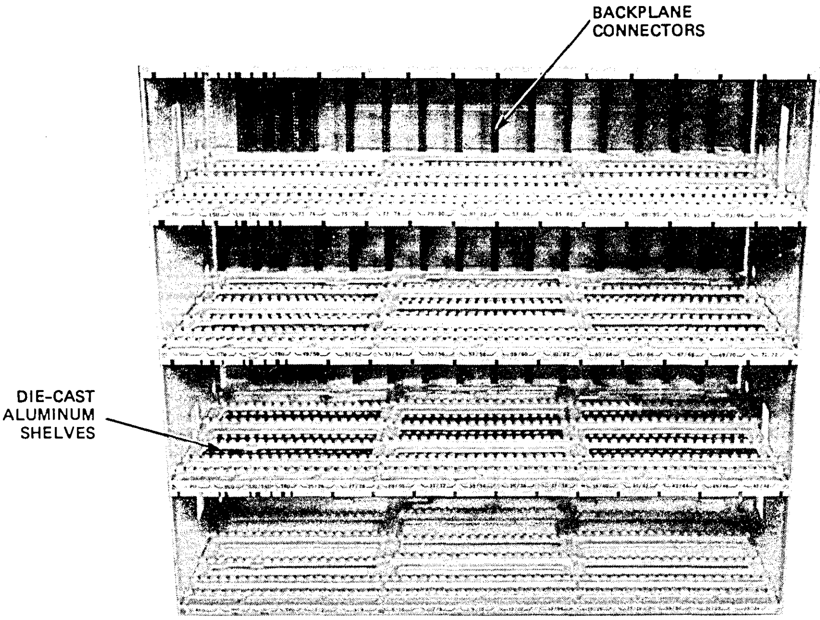


Fig. 5—*SLC* 96 die-cast shelves and backplane.

T1 line turn-up and troubleshooting. It also provides an independent communications path between the central office, and the remote terminal and digital repeaters.

3.2 Remote terminal equipment

The *SLC* 96 remote terminal equipment consists of a remote terminal bank, a protector block, a ringing generator, a power and jack panel shelf, a battery charger shelf, and emergency backup batteries. Figure 7 illustrates the equipment mounted in a remote terminal hut.

The remote terminal bank is similar to the central office bank. Differences exist in the complement of channel unit plug-ins among some common units, in the connectorization method, and in the additional surge protection hardware.

The remote terminal electronics is protected on both the T1 line side and the voice-frequency side. Two protection hardware schemes are available. One is a bank-mounted protector unit for cabinets and small line-size configurations, illustrated in Fig. 8. The other is a building entrance configuration called "bulk" protection, for large remote terminal installations, where the protection is provided at the building entrance rather than on the bank. This configuration is explained in greater detail in Section 4.3. The standard, 3B-type, central office protector unit and the existing technology of the 300

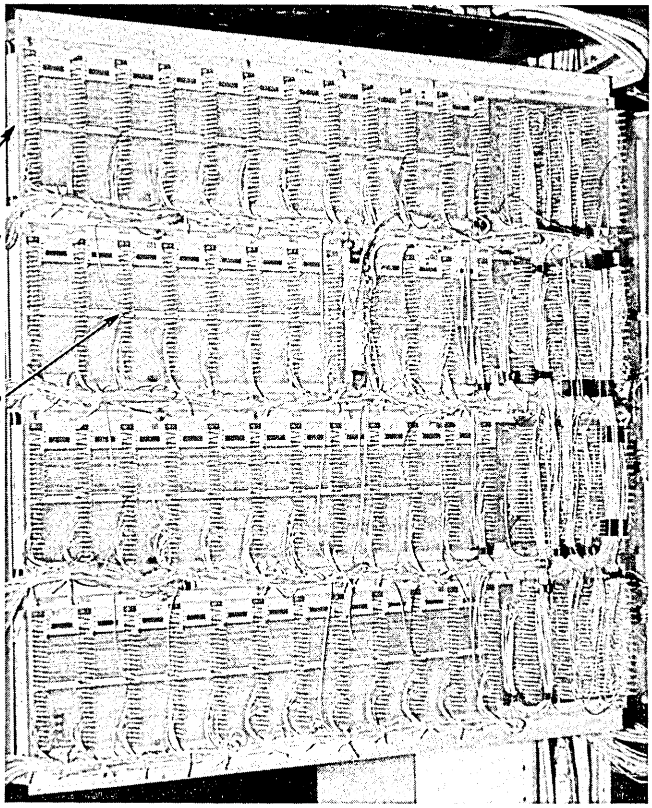


Fig. 6—*SLC* 96 backplane wiring.

series AT&T Technologies, Inc. main distributing frame connectors are currently utilized in the protector block design.

Like the CO bank, the remote terminal bank is fully connectorized. It uses AT&T Technologies, Inc. 710 connectors, which are standard in the outside plant. To simplify stocking and ordering, the remote terminal bank is equipped with connectors that plug into the protector block. This permits the same bank to be used with local, bank-mounted protection or with bulk protection. In addition, E&M signaling leads are provided on all banks for use in customer premises applications. Overall, connectorization speeds field installation and greatly reduces the probability of errors.

The battery plant, which includes the battery charger and battery shelves, mounts in a standard, 23-inch-wide frame, as shown in Fig. 7. The battery charger requires 7 inches of mounting space; each battery shelf requires 8 inches. One battery shelf is required for each 96-line remote terminal system. However, one battery charger can

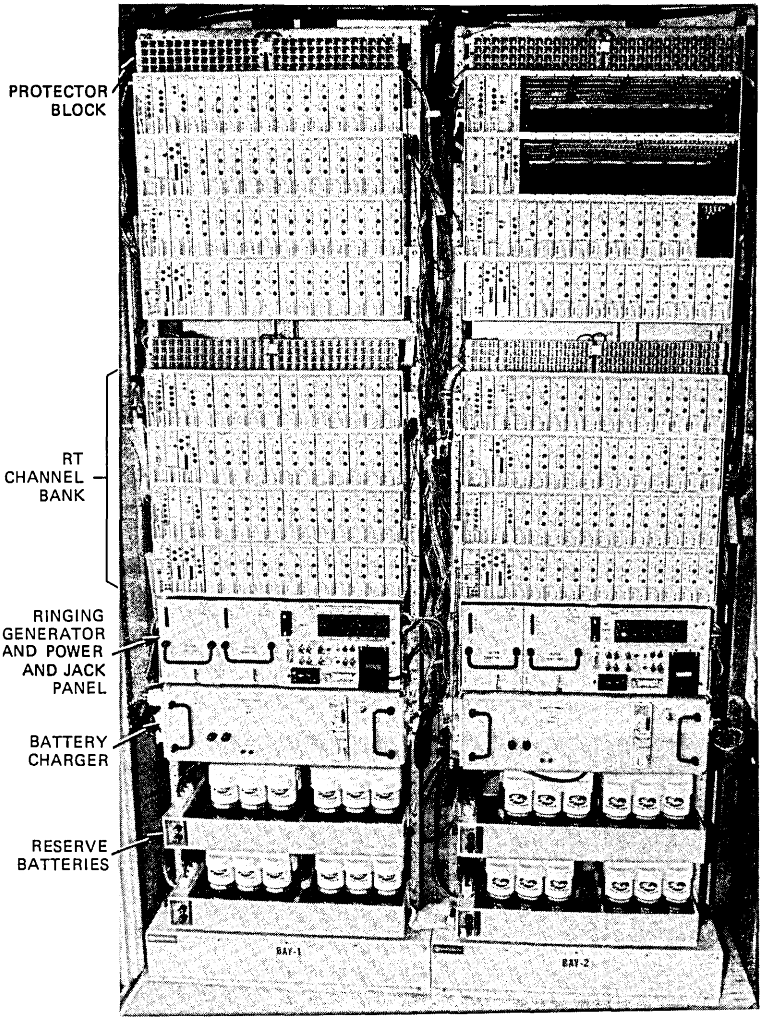


Fig. 7—Remote terminal equipment mounted on a 7-foot bay.

serve two *SLC* 96 banks; only an additional battery shelf is required when a second bank is added. Figure 7 illustrates this concept. Each battery shelf contains an ac-powered, thermostatically controlled heater to ensure adequate battery capacity in cold weather. Both the charger and batteries are connectorized for easy installation. The battery plant uses rechargeable, sealed, lead-acid batteries to provide at least eight hours of backup if commercial ac-power fails. Details of this system, including operational temperature extremes, are discussed in Ref. 3.

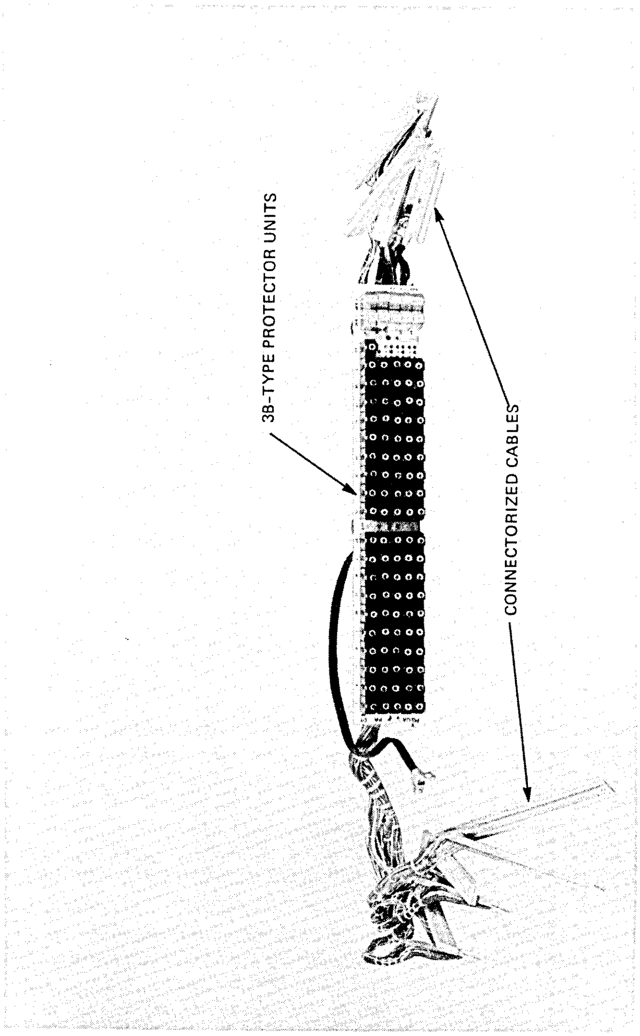


Fig. 8—Bank-mounted protector assembly.

The power and jack panel shelf, shown in Fig. 7, provides system fusing, power, alarm distribution, and talk filter functions. The panel uses the standard bank die-cast shelf to support the equipment. One or two ringing generators plug into the shelf, providing capacity for one or two 96-line remote terminal banks. The panel contains indicating fuses for supply voltages, connectorized cables for interfacing with the banks, termination connectors for alarms, connectorized leads for local battery supplies other than the *SLC* 96 batteries, terminal strips on the front of the unit for wiring in additional alarms, and a 48V terminal for powering small, miscellaneous loads. Jacks on the front of the panel also provide access to the digital, fault locate, and order wire lines. A connector port for a 238A repeater is also provided for digital line testing.

3.3 Fiber SLC *equipment (CO and RT)*

The introduction of lightwave cables to replace the copper T1 feeder span requires a lightwave interface in both the CO and RT banks. A major feature of the Fiber *SLC* bank design, which went into production in January 1983, is its alternative use for either T1 copper or lightwave cables with only a simple interchange of plug-ins. Despite the detailed changes described below, all bank installation procedures remain the same as the original *SLC* 96 system design. (The detailed operational features are described in Ref. 4.)

The significant physical design contributions to the Fiber *SLC* system design are the optical connector to the bank backplane and the integration of optics into a new plug-in, the Optical Line Interface Unit (OLIU). The OLIU plug-in is illustrated in Fig. 9. It consists of a double printed wiring board mounted to an aluminum die-cast faceplate, which fits into the standard *SLC* 96 bank. The plug-in contains the optical Light-Emitting Diode (LED) transmitter and the optical receiver. The lightwave connectors are mounted between the printed wiring boards to provide mechanical protection. Connections to the backplane lightwave connectors are made simultaneously with electrical connections when the OLIU circuit pack is plugged in. The LED transmitter had to be specially mounted to provide a very low thermal resistance path to the finned faceplate. Heat-sinking was required for satisfactory and reliable operation of the LED device in the hostile loop plant environment. In the worst-case environment, the LED will not exceed a temperature of 75°C.

Designing the mating half of the lightwave connector into the bank backplane required careful attention. Space was limited by existing backplane printed-wire paths and electrical connectors. Minimum bending radii requirements for the cable leaving the bank, and worst-case tolerance buildups among the OLIU plug-in, the die-cast shelf,

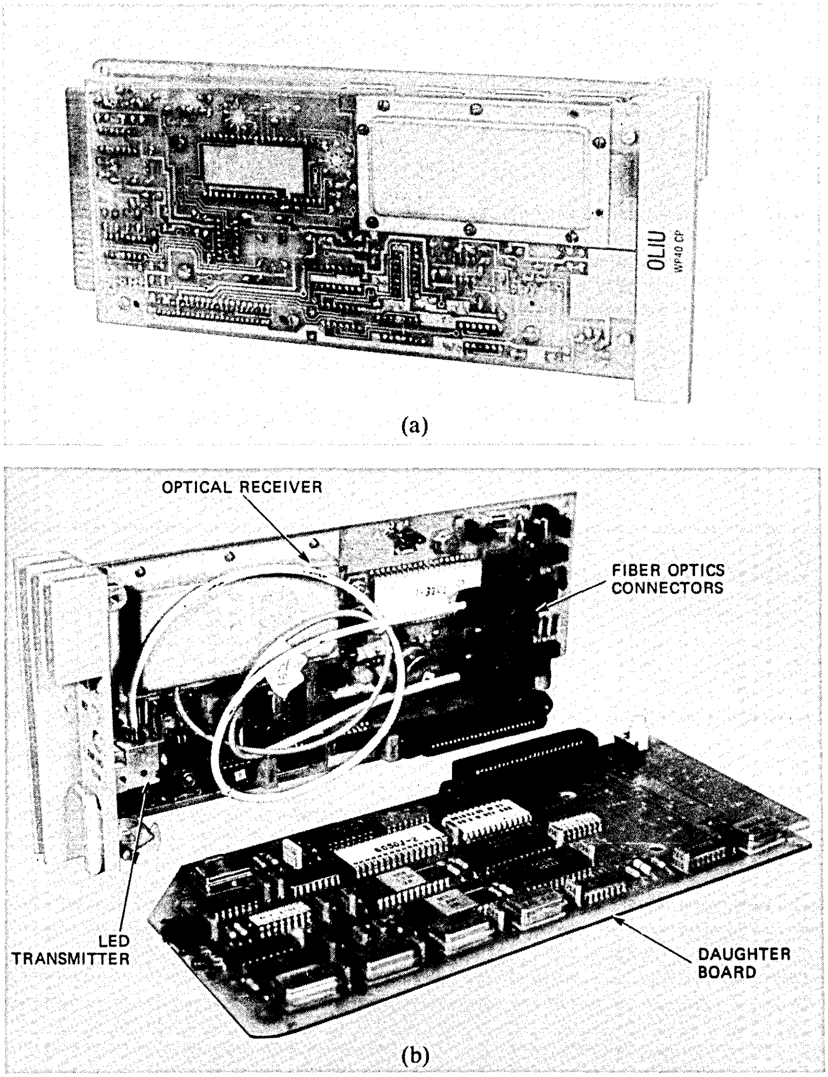


Fig. 9—Optical line interface unit: (a) assembled, and (b) unassembled.

and the backplane assembly required careful design. The mounting arrangement is illustrated in Fig. 10. The male end of the lightguide connector, which is the standard AT&T Technologies, Inc. FT-3 lightguide system design, is mounted to a metal bracket between the electrical connectors. Printed wiring backplane mounting area was minimized by using the bracket mount illustrated in Fig. 10.

Mechanized connector float is also provided by the mounting arrangement.

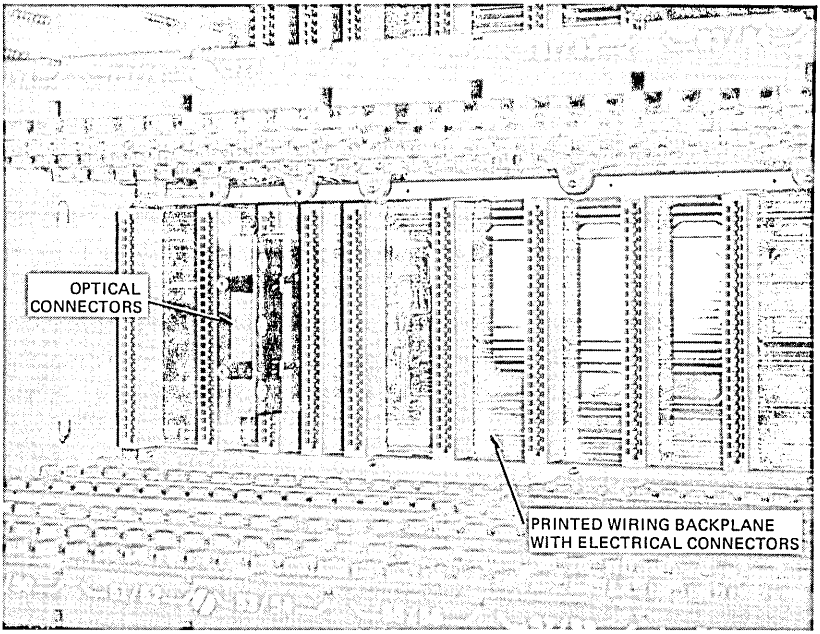


Fig. 10—Fiber *SLC* backplane.

IV. REMOTE TERMINAL ENCLOSURE DESIGN

Urban, suburban, and rural applications of the *SLC* 96 system require flexibility among the remote terminal enclosures in size, appearance, and the manner in which the structure interfaces with the outside plant network. *SLC* 96 systems have been designed into enclosures that house from one to forty systems.

4.1 Remote terminal design requirements

The most important and obvious design requirement is that the enclosure provide the proper environment for reliable operation of the electronic equipment in ambient temperatures from −40° to 120°F and humidities up to 100 percent. The equipment must not overheat because of high ambient temperature, solar heating, or its own heat dissipation. It also must be protected from corrosion caused by air pollution and high humidity. To keep the enclosures simple, the goal has been to provide this protection with the minimum active environmental control systems. Extensive analysis and testing has been done, as described in Ref. 5, to determine the maximum temperatures under the wide variety of conditions the electronics will be exposed to across the country.

Another important requirement is that the enclosure be part of a complete system package, capable of being shipped to the field as a preassembled unit. This requires that all the enclosures be transportable with *SLC* 96 remote terminal equipment installed and capable of immediate connection to outside plant cables.

Appearance has become the most controversial of the requirements on the enclosures. AT&T Bell Laboratories arrived at design guidelines after consulting with the Henry Dreyfuss Company, an industrial design firm. The first is to keep the lines of the structure clean and simple. The structure should be attractive, but should not attract attention. The second guideline is to use earth-tone colors rather the traditional green shades. Over most of the country, for a majority of the year, the natural backgrounds are predominantly brown rather than green. The third is to maintain as low a profile as possible. The aspect ratio of width to height should be kept somewhere around 2:1.

4.2 Remote terminal cabinets

An early cabinet design for the *SLC* 40 system, described in Ref. 6, has become a standard enclosure for single-system loop carrier applications in rural and semirural environments. This cabinet, currently coded by AT&T Technologies, Inc. as 36D, has enjoyed wide usage for rural applications of the *SLC* 96 system. It is illustrated in Fig. 11 in a clustered arrangement, with a separate cable cross-connect cabinet as part of the installation. This cabinet is not adequate, however, where enclosure appearance is important. To improve appearance, a single-system, low-profile cabinet, painted earth-tone colors and referred to as the AT-8908M cabinet (see Fig. 12) was designed. It has a bell jar cover that rises when unlatched, to allow access to the electronics. An additional feature is the option for an internal feeder-distribution interface or cross-connect facility. In many applications, this additional feature eliminates the need for a second cabinet at the remote terminal site and significantly improves the appearance of the installation.

For sites requiring a few more systems and where appearance is also a significant factor, the 80-type, Community Service Cabinet (CSC) was developed. Designed for industrial parks and suburban areas, it can house up to four remote terminals, or two remote terminals and a 2700-pair feeder-distribution interface. Figure 13 illustrates the cabinet. This cabinet has also been designed with earth-tone colors to blend with natural surroundings. It can also be used as an attractive sign at entrances to an industrial park or a housing development, for example.

4.3 Remote terminal huts

One thing we observed from the applications of the *SLC* 40 system

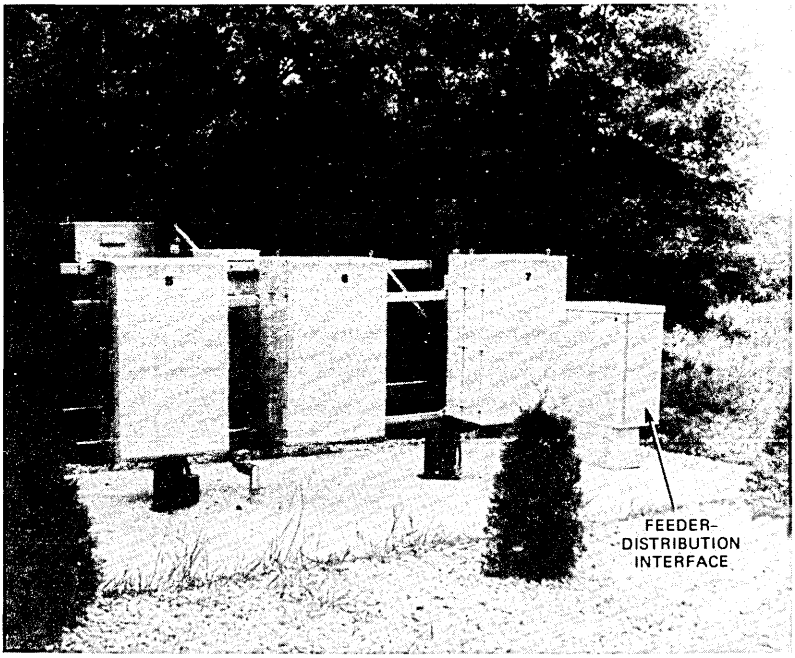
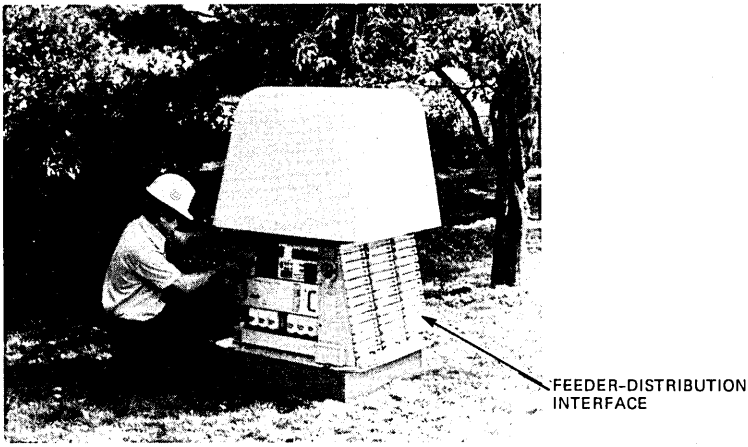


Fig. 11—Configuration of 36-type cabinets mounted on crossarms.

was the operating companies' tendency to cluster systems at a single site. They did this because it was difficult to find, establish, and maintain suitable remote terminal sites. Purchasing land or acquiring right-of-way slows installation and generates high costs for the operating companies. Difficulty designing T1 lines for distributed remote terminals also stimulates clustering.

The tendency to cluster remote terminals led to the design of several building-type structures. The first of these was the Minihut, which can house ten *SLC* 96 systems in central-office-type equipment bays. Again, appearance was a critical factor, so the Henry Dreyfuss Company was selected to do the architectural design. Again, earth-tone colors were chosen, and the goal was to keep the appearance clean and simple (see Fig. 14).

Another important requirement was that the structure be transportable, with *SLC* 96 equipment already mounted. Drawing from *SLC* 40 system experience with huts, we found that telephone companies preferred having AT&T Technologies, Inc. install the remote terminal equipment in the huts at a central location and ship them to the field as preassembled units. AT&T Technologies, Inc. service centers provide all *SLC* 96 equipment and cabling on a standard- or custom-order basis for the telephone companies. Minihuts are shipped as pre-



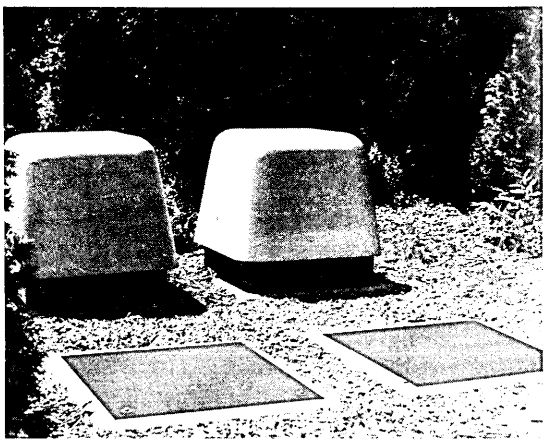
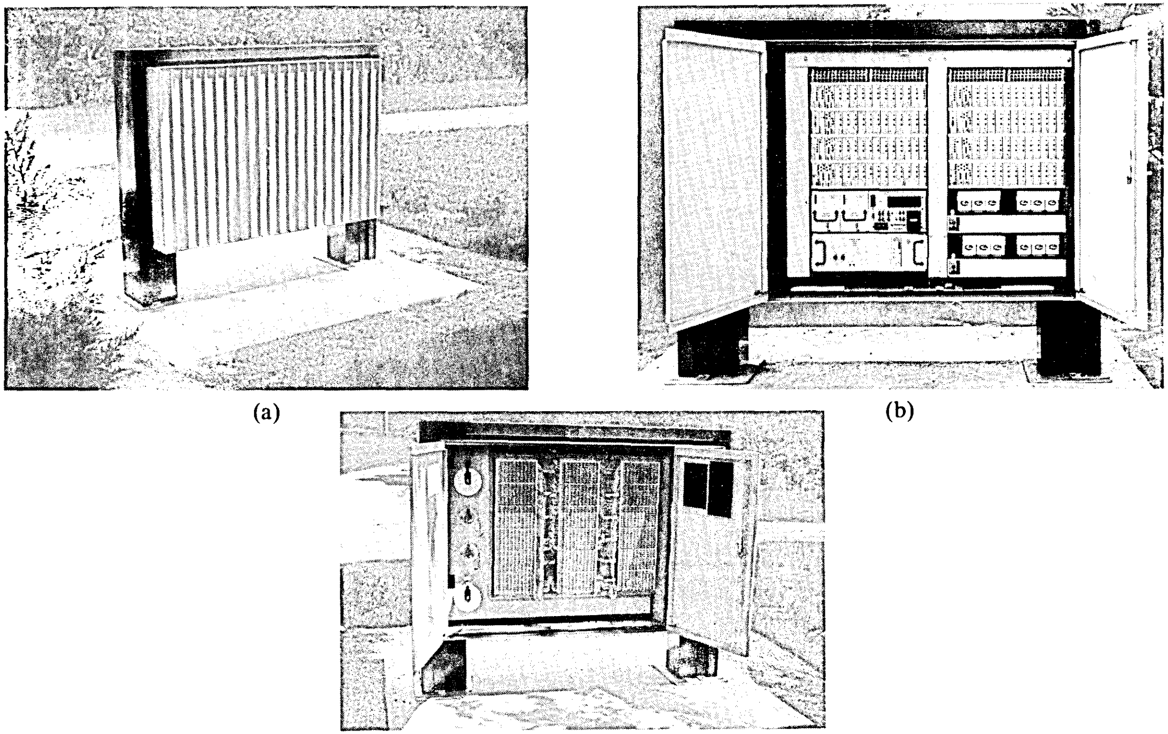


Fig. 12—Low-profile AT-8908M cabinet with integrated electronics and cross-connect.

engineered, pre-equipped structures, without batteries and plug-ins. The only on-site work is setting up the structure, connecting the ac-power, and splicing in the outside plant telephone cables.

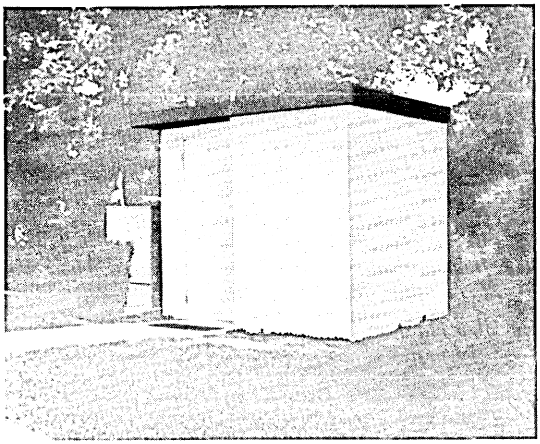
The minihut is 6 feet wide × 10 feet long × 8 feet high and weighs 2000 pounds. It can be handled by a medium-sized forklift truck or a small crane and can be shipped on a standard flatbed trailer with no travel restrictions.

The minihut has a minimum of environmental controls, to keep the structure simple and maintenance-free. It is not insulated, so no active

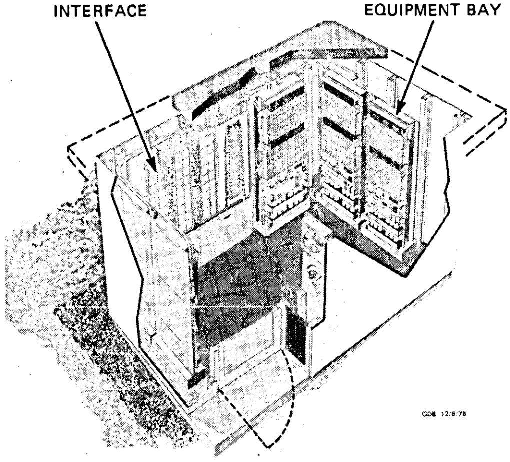


(a) (b) (c)

Fig. 13—(a) Community service cabinet illustrating packaging of (b) two *SLC* 96 systems on one side, and (c) a feeder-distribution interface on the other side.



(a)



(b)

Fig. 14—(a) Field installation of a minihut. (b) Arrangement of equipment inside a minihut.

cooling system such as a blower or air conditioner is required to maintain the prescribed operating temperatures.

Shortly after the minihut was offered, the telephone companies announced that a significant number of their remote terminal sites that would grow beyond the ten systems accommodated by the minihut. In response to this, the Electronic Equipment Enclosure (EEE), or Maxihut, was adopted for the *SLC* 96 carrier system. The EEE was originally developed for the 10A Remote Switching System (RSS).

The maxihut houses up to forty *SLC* 96 systems. The EEE is shown in Fig. 15.

Again the Henry Dreyfuss Company handled the architectural design for the EEE, using earth-tone colors. Like the minihut, the EEE is transportable, and the *SLC* 96 system equipment is installed at a central location before being shipped to the field site. The building is 10 feet wide × 20 feet long × 12 feet high and is constructed of sheet steel and honeycomb panels in a stressed-skin structural design. The honeycomb panels make the EEE a moderately well-insulated building, which had been optimized for minimum energy usage when used by the RSS. A major concern in making this building suitable for the *SLC* 96 system was to accommodate a three-fold increase in heat dissipation for the 40 *SLC* 96 systems it houses. This required larger air conditioners and a ventilation system for emergency cooling if the air conditioning failed. Because the building is sealed and insulated, unacceptably high temperatures could otherwise result. The ventilation system became the primary cooling method, with air conditioning an option for craft comfort in warm areas of the continental United States. Using the combined, electronically controlled ventilation/air conditioning system saves about $800 per year in a fully equipped EEE.

The temperature controller easily varies the building temperature. For example, when the building is unoccupied its temperature can be allowed to rise or fall to extremes that would not provide acceptable craft working conditions. By operating a switch, the craftsperson can reset the operate points of the controller to comfortable working temperatures. The controller will automatically reset to the wideband temperature settings after a specified time.

Several state governments require that both the minihut and the EEE be certified to meet certain state and national building codes. Structural analysis and/or structural testing were required to ensure that the buildings met national building code requirements. The EEE was tested, as shown in Fig. 16, for snow and ice loading on the roof.

A third building, a concrete hut (Fig. 17), fills the size gap between the minihut and the EEE. It uses precast concrete construction but is still transportable. It is 8 feet wide × 13 feet long × 8 feet high and can contain 16 *SLC* 96 remote terminals in eight equipment bays. The hut is also optimally sized for the DS-3 rate Fiber *SLC* system. In that configuration, 14 remote terminals in seven bays, and two LM23 multiplexers and one LCIT in the eighth bay are accommodated.

The ventilation system provides for the worker the best cooling short of air conditioning. This enhanced ventilation system limits heat stress on personnel to no worse than would be experienced standing outside but exposed to direct sunshine—see the following section on

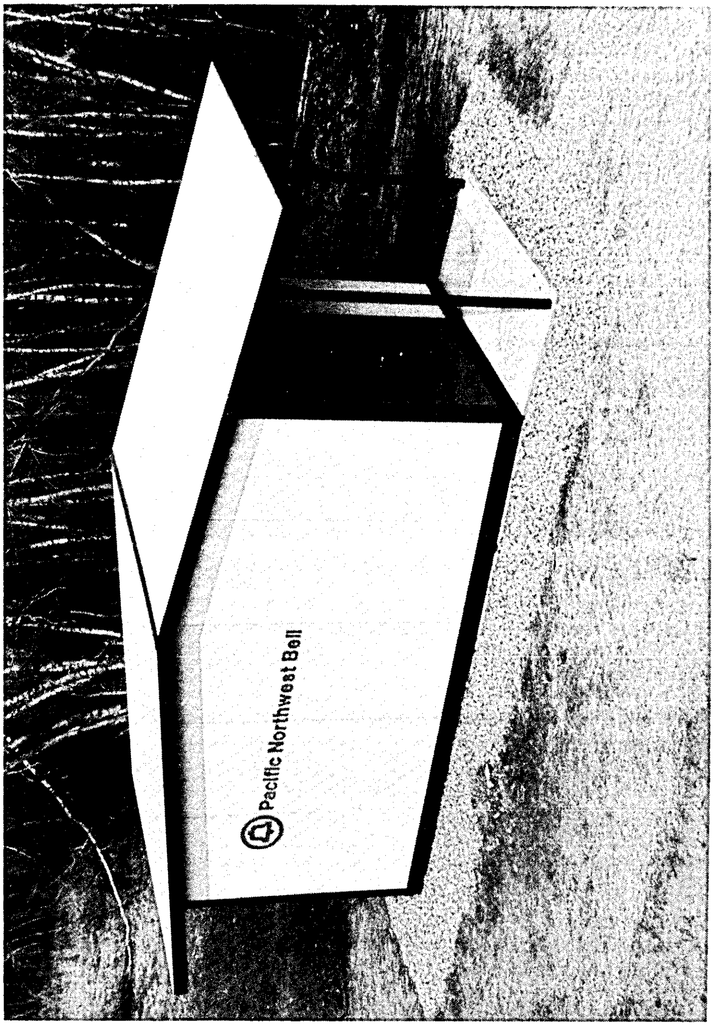


Fig. 15—Electronic equipment enclosure.

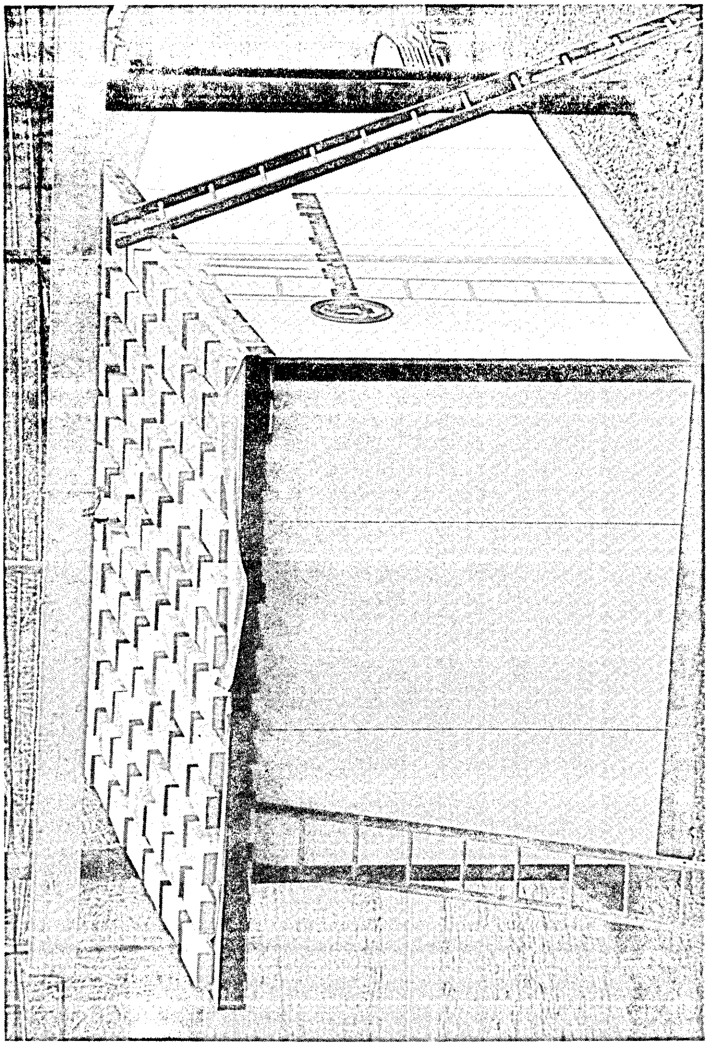


Fig. 16—Load testing of an electronic equipment enclosure.

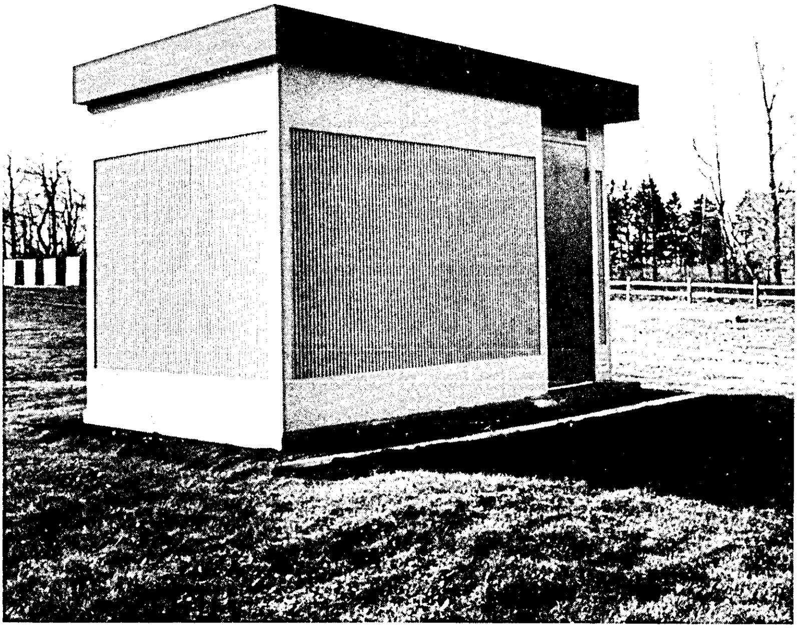


Fig. 17—Precast concrete hut.

the Controlled Environment Vault (CEV) for detailed description of the enhanced ventilation system. For extreme environments, an optional air conditioner, which is not required for the *SLC* 96 equipment, can provide a suitable working environment for the craftsperson. It will also provide lower temperatures for other miscellaneous equipment that might be placed in the hut.

The surge protection hardware for all the wire pairs connected to the remote terminal bank was originally provided as part of the channel bank for all applications not on customers' premises. Later we judged that bulk surge protection near the cable entrance was preferable for building structures. Bulk protection provides more flexibility for the installation of equipment other than *SLC* 96 remote terminals in these structures and was more consistent with the way surge protection was provided in other telephone company buildings. The bulk protection arrangement in the EEE is shown in Fig. 18.

4.4 Below-ground remote terminal enclosures

As use of the *SLC* 96 system grew in suburban areas, two anticipated

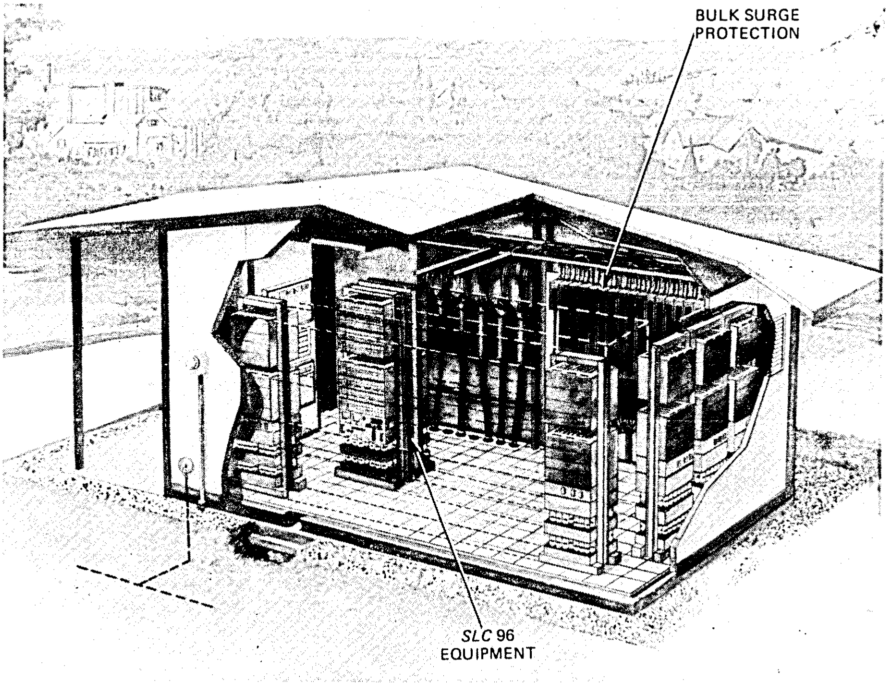


Fig. 18—Bulk surge protection arrangement in an electronic equipment enclosure.

phenomena have occurred: The appearance of the remote terminal structure has become a more critical issue, and land costs have become very high. Often the only solution to placement dilemma has been to put the remote terminals underground and out of sight. Two structures have been designed to accomplish this: the Controlled Environment Vault (CEV) and the Below-ground Electronic Remote Terminal (BERT).

The two structures have quite different design approaches. The CEV is much like an underground buiding, with many active environmental controls, the BERT is a flush-mounted housing, with minimum of active environmental controls.

The CEV is a two-piece, precast concrete structure, 6 feet wide × 16 feet long × 9 feet high inside, that will house 20 *SLC* 96 systems in ten equipment bays. Only the 2-1/2 foot × 4-1/2 foot × 1-1/2 foot high entrance hatch protrudes aboveground (see Fig. 19). Because the CEV is a two-section structure, with each section weighing about 16 tons, installing the *SLC* 96 equipment before the structure is shipped to the field is not as easy as it is with the minihut and EEE. To avoid piece-by-piece field installation of the *SLC* 96 systems, a shipping and installation module, coded the B equipment platform, was developed.

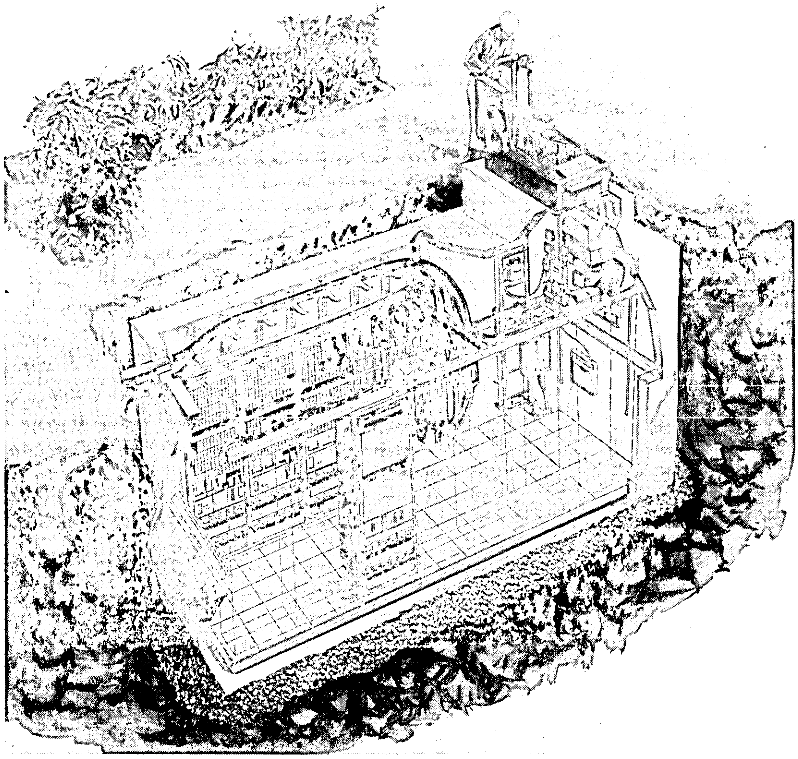


Fig. 19—Controlled environment vault.

This module includes all of the *SLC* 96 equipment and is installed directly in the lower CEV section after it has been placed in the excavation (see Fig. 20). The top section is then lowered into place to form a complete remote terminal structure.

Because the CEV is an enclosed below-ground structure, additional Occupational Safety and Health Administration (OSHA) and operating company regulations apply to environmental control. To satisfy these regulations, the CEV is constantly monitored for toxic or explosive gases and is continuously ventilated to ensure good air quality. If toxic or explosive gases are detected, warning lights are illuminated at the entrance and additional ventilation is provided. The ventilation system is also used to remove the heat generated by the electronics.

A significant design effort produced an "enhanced" ventilation system to provide the best possible environment for the craftsperson, without using air conditioning. This was done by designing an air duct and blower system to envelop the work space with a gentle shower of

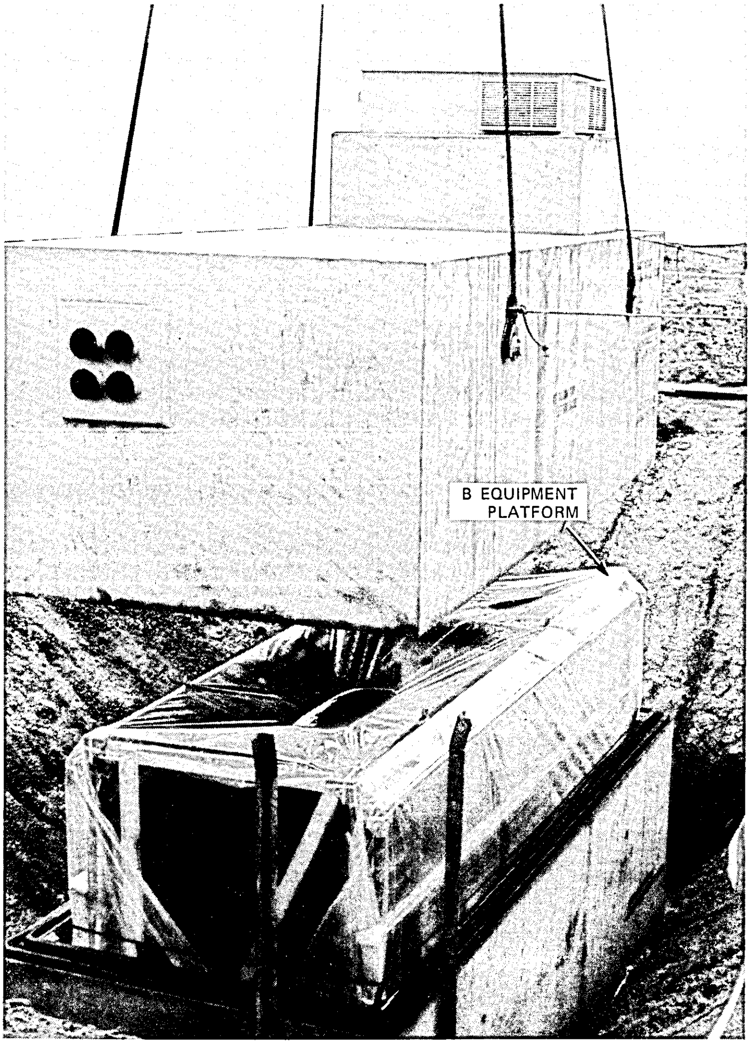
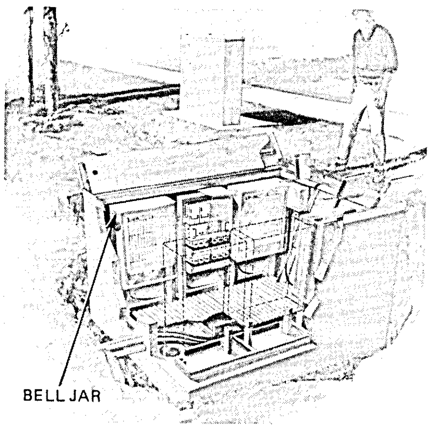


Fig. 20—Placement of a controlled environment vault with a B equipment platform.

outside air. This air surrounds the worker before the air temperature is raised by the heat from the equipment. At high ambient temperatures, a gentle breeze is more effective at cooling a person than a strong blast of air. At air temperatures above body temperature, the only cooling modes for the body are from radiation and evaporation. Any convection heat transfer adds heat to the body. We learned from laboratory experiments that there is little increase in evaporation rates for air velocities over 150 feet per minute (1.7 miles per hour). Thus, at high air temperatures, a very low air velocity provides optimum cooling of the body and anything above that only adds heat to the body.

The other below-ground structure, the BERT, houses four *SLC* 96 systems. While the CEV has an entranceway extending 2 feet above ground, the BERT is installed flush with the earth and extends 4 feet below the surface, as shown in Fig. 21. The top of the BERT is covered with doors to uncover the entire structure for access to the equipment. Exposing the entire structure and maintaining a maximum 4-foot depth was necessary so that the craftsperson would not be working in an enclosed underground space. Because of that, many OSHA and



(a)

(b)

Fig. 21—(a) Below-ground electronics remote terminal. (b) Field installation of a below-ground remote terminal.

operating company regulations regarding air quality that are specified for enclosed underground spaces do not apply to the BERT.

Active environmental controls to protect the electronics are not required in the BERT. The equipment is protected from flooding and high humidity by bell jars. The bell jar is like an inverted glass, set over the equipment. During a flood air is trapped in the bell jar, which prevents the water from rising to the level of the electronics. The BERT can experience very high humidity for long periods, but the equipment is protected by the heat trapped by the bell jar.

4.5 Summary

A series of structures to house *SLC* 96 remote terminals have been developed to satisfy a wide range of applications. The number of *SLC* 96 systems required at site varies from one to several dozen. Placement locations vary from rural to urban in any geographic area of the country. These structures must reliably protect the equipment from a wide range of environments, for many years, with minimum maintenance and downtime.

V. REMOTE TERMINAL THERMAL DESIGN AND EVALUATION

5.1 Overview

As we previously described, digital loop carrier equipment is located in both the central office and the outside loop plant. The central office environment is usually well controlled, as specified in AT&T Technologies, Inc. New Equipment Buildings Standards (NEBS). Outdoors, however, ambient temperature extremes of −40° to 120°F occur with ambient relative humidities up to 100 percent. The design of loop electronics equipment must consider both indoor and outdoor conditions. This section highlights the thermal design and evaluation of the remote terminal equipment.

5.2 Thermal design guidelines

Loop electronics hardware consists of a wide variety of both dissipating and nondissipating electrical devices, printed wiring boards, batteries, connectors, and miscellaneous hardware. Systems are packaged so that no components exceed or fall below manufacturers' recommended operating temperature ranges.

Figure 22 provides a graphical representation of the maximum temperatures in an RT cabinet. The equipment is designed to a maximum outdoor ambient temperature of 120°F. The 120°F represents a temperature that will be exceeded less than 1 percent of the time in the warmest locations in the continental United States. Solar radiation adds an additional temperature rise, depending primarily upon the structure's color, external finish, and shape. A 30°F temper-

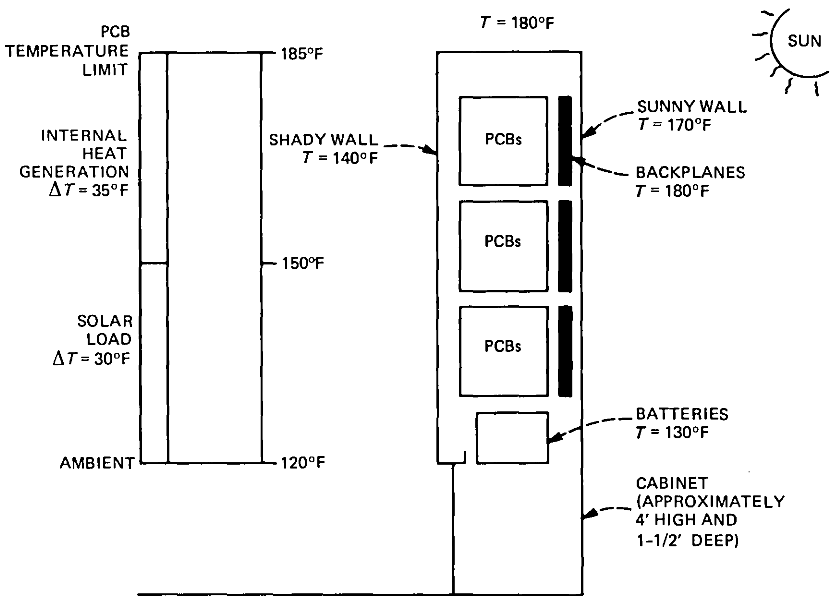


Fig. 22—Maximum temperature rises in a remote terminal cabinet.

ature rise for loop electronics equipment is a typical worst case for solar heating. The effective ambient temperature within a cabinet is, therefore, approximately 150°F. Using a 185°F maximum operating temperature for nondissipating devices mounted to Printed Circuit Boards (PCBs), this allows a maximum temperature rise of 35°F in the equipment design because of internal heat dissipation. Heat dissipating components like integrated circuits and resistors are selected to operate reliably on printed circuit boards that can reach 185°F. Of course, localized temperatures of heat dissipating devices can exceed 185°F. Placing passive devices away from these hot spots is part of the design process.

Cabinet structures have a large variation in temperature within a relatively small volume, as shown in Fig. 22. Designing and testing electronics equipment for this environment is essential for long-term reliability. Details of the *SLC* 96 cabinet designs are discussed in the next section.

Larger structures will be subject to the same ambient effects as the cabinet. Their color, construction (whether insulated or uninsulated), and placement above or below ground will affect the maximum effective ambient temperature the equipment sees and the amount of heat removal equipment necessary to maintain a reliable working environment. As we previously noted, ventilation systems of varying complexity are used in larger structures.

5.3 Thermal design—SLC 96 cabinet

Before the *SLC* 96 system was introduced, free, convective cooling sufficed to maintain proper temperatures of electronic systems packaged in cabinets. Increased packaging density and a concomitant increase in heat dissipation required additional, forced air cooling. Transient and steady-state analysis and testing without forced air cooling showed serious hot spots in the common equipment area of the *SLC* 96 RT bank, with heat dissipation temperature rises up to 60°F. These rises were reduced to acceptable levels by a small fan mounted over the common equipment. The thermostatically controlled fan blowing on the hotter common equipment effectively spread the heat within the bank, holding all areas within the required temperature limits. Convective cooling from the equipment to the walls of the cabinet still provided the basic heat transport mechanism to the outside environment.

All of the *SLC* 96 system's cabinet designs were thermally analyzed and tested. Sophisticated analysis tools predicted temperatures down to the printed circuit board level. Each design was analyzed and evaluated under worst-case conditions to ensure that all components and circuits operated within their design limits.

Thermal analysis is only one of many testing and evaluation procedures in the development of a loop carrier system. Thermal performance is becoming increasingly more important as new generation carrier systems become smaller and heat dissipation densities increase. Developing simple and efficient cooling techniques for outside plant equipment continues to be a critical part of packaging new digital carrier systems.

VI. SUMMARY

The physical design of the *SLC* 96 system has been one of the significant factors supporting its widespread deployment. Several aspects of the physical design have led to this success. The modular equipment design allows quick installation and provides flexibility to meet the wide range of sizes of system applications, including the introduction of a fiber-optic system. The remote terminal structures have also been designed for a wide range of demands in both size and appearance, while reliably providing necessary environmental protection.

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The SLC 96 Subscriber Loop Carrier System:

Maintenance and Operation

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(Manuscript received April 20, 1983)

The success of digital loop carrier depends not only on economic considerations, but also to a great extent on the ability of the operating companies to maintain, administer, and operate this technology. This paper discusses a generalized digital loop carrier operations plan and describes the *SLC*® 96 carrier system features that satisfy the requirements of the operations plan. A thorough explanation of the *SLC* 96 carrier maintenance features is included. The paper covers system maintenance philosophy, alarm structure, and line testing methodology.

I. INTRODUCTION

One of the most critical aspects in the design of a Digital Loop Carrier (DLC)‡ system is the maintenance and operational features. With the proper features, systems will be reliable, easy to maintain, and amenable to craftspeople. The *SLC* 96 carrier system was designed from the beginning with maintenance and operations in mind.[1] The design of the maintenance and operations features was based on a thorough understanding of the loop operations environment and how digital loop carrier can best be used within that environment.

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‡ Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

This paper will first describe a generalized operations plan for digital loop carrier. This plan was developed in conjunction with AT&T and the Regional Bell Operating Companies and represents a widespread consensus on the most efficient operating procedures for digital loop carrier. The operations plan covers craft responsibility, circuit testing, system maintenance, and circuit assignment issues.

In the subsequent sections of this paper, we will show how the features designed into the *SLC* 96 carrier system allow implementation of this operations plan. We will describe the innovative circuit testing arrangements utilizing the "pair gain test controller" concept, describe the basic system maintenance philosophy, and discuss the feature capabilities that allow system alarms to be remoted to centralized maintenance bureaus.

II. DIGITAL LOOP CARRIER OPERATIONS PLAN

An operations plan consists of three basic elements. Process flows describe the sequence of events, functions to be performed, and operations center and system interfaces necessary to accomplish a specific task. Center descriptions summarize the responsibilities of each operations center involved, with particular attention to data inputs, outputs, and interfaces. Similarly, system descriptions describe the Operations Support System (OSS) requirements necessary to implement the process flow. Because the latter two elements are derived from the first, only process flows will be described in this section.

Three basic operations process flows must be defined for a transmission system such as the *SLC* 96 carrier system. They are (1) resource provisioning, (2) service provisioning, and (3) maintenance. Resource Provisioning is concerned with the planning, design, and construction operations. These functions determine how to economically select the timing, sizing, and location of a transmission system; how to design the system and its support facilities; and how to order, construct, turn-up, and record the system and its components on property records. Service Provisioning is concerned with operations necessary to assign customer services to the constructed system in response to a service request. This includes the maintenance and use of equipment inventory and capability databases. Unlike resource provisioning, which is often a lengthy process, service provisioning is a real-time process often requiring completion within 24 hours. As a result, resource provisioning flows are usually designed to optimize the efficiency of capital expenditures, while service provisioning flows are usually designed to optimize labor efficiency.

The Maintenance process flow has two components. The first deals with response to individual Customer Trouble Reports (CTRs) and involves individual circuit access and test functions, as well as the administrative functions required to track, dispatch, clear, and close out a CTR. This customer-stimulated component flow requires labor efficiency similar to that needed in service provisioning. The second component process deals with the response to whole system troubles. This involves detection of failures, sectionalization of troubles to system components, transmission of alarm data, analysis, response, tracking, and closeout. Since this flow should occur less frequently and may require more analysis, it is similar in some ways to the resource provisioning flows. Of course, response here must be much faster. The two component flows interact since system failures will usually precipitate multiple CTRs. Furthermore, database requirements in the maintenance OSS for these two component flows will overlap.

The maintenance processes are the only processes that require direct electrical interfaces to the transmission system. Although the provisioning processes surely depend to some extent on the architecture and feature set of the transmission system, it is the maintenance processes that are the most influenced by and have the greatest influence on system design. The remainder of this section will, therefore, explore further the maintenance processes developed for DLC systems such as the *SLC* 96 carrier system. We will take particular note of those parts of the process flows that have a definite impact on the design of the DLC system.

2.1 Some basic principles

The development of a maintenance process flow can be assisted by adherence to some basic principles. Several apply in this case:

1. Because of the volume expected, the CTR flow for DLC should be integrated as much as possible into the normal CTR flow. Special operations should be kept to a minimum. The fact that a DLC is involved should be kept as transparent as possible to the craft force. (Of course, the hands-on repair force will often know the difference.)

2. System failure information (alarms) should be sent to the organization (a) most closely associated with the CTR flow and customer contact and (b) in control of the predominant hands-on repair force.

3. The choice of the repair force should be independent of the technology employed in the DLC and of the force currently trained in that technology. Since deployment of DLC greatly increases the need for a trained force, currently trained forces and their organizations will be inadequately staffed. Thus, the decision on organization can be based on other factors, since more trained force must be created.

4. The flows must take maximum advantage of currently planned or available OSS capabilities and should minimize major OSS overhauls. As operations centers become more and more dependent on

OSS, it becomes very expensive (often impossible) to backtrack to a manual work around. This fact puts a premium on OSS capability for the new processes, but OSS overhauls are often very lengthy and expensive. Thus, OSS inertia is an important driving force.

The following sections will show how these basic principles have been applied to develop CTR and system failure operations flows for DLC.

2.2 Customer trouble report operations

On the surface, the operations plan for responding to a single carrier channel failure and associated CTR is indistinguishable from the plan for responding to a metallic pair failure. Both plans fit into the scheme developed for the Automated Repair Service Bureau (ARSB)[2] and depend on the use of the Loop Maintenance Operations System and Mechanized Line Testing (LMOS/MLT). However, some important differences are present. Basically, the steps are:

1. Receive a CTR and access customer circuit data.
2. Access the loop through the switch train (no-test trunk).
3. Perform a series of electrical tests to verify the trouble and to sectionalize as best as possible.
4. Screen results and perform more tests, if needed.
5. Dispatch proper craft to the fault location.
6. Clear trouble and close out.

These steps are identical for a DLC circuit or metallic circuit with the following exceptions.

1. Customer circuit data must include information pertaining to the DLC system, including type, channel or line unit number, and location.
2. Electrical access must be provided to MLT to test the circuit.
3. Capability must be provided to test both the carrier channel and the metallic portion of the circuit extending from the Remote Terminal (RT) to the customer.
4. Sectionalization capabilities must be sufficient to determine if the trouble is in the Central Office Terminal (COT) or RT channel unit. If the trouble is sectionalized to the metallic extension, the same level of fault localization as in a completely metallic circuit must be provided.

Because we try to minimize the impact on OSS design, most of the burden of satisfying these requirements falls to the DLC designer. Exceptions to this include the creation of new data fields (or the specialized use of rarely utilized fields) on the customer line record in LMOS and the use and recognition of various test signals and responses on the part of MLT. In particular, access and channel test capability cannot be provided by the OSS and must therefore be a part of the design of the DLC system. Section III will discuss the specific design features of the *SLC* 96 carrier system that satisfy these requirements.

2.3 System failure operations plan

The deployment of DLC in the loop, along with its many frequently stated benefits, has one often overlooked benefit. It adds intelligence to the loop and, in the words of one operating company maintenance supervisor, "alarms the plant." This creates an operations problem, however, since widespread alarming in the loop is a new capability and a new operations plan is required to take advantage of it. Instead of fitting into an existing operation with minimal visibility, a system failure operations plan must, therefore, start from scratch. However, one cannot ignore the existence of the OSS supporting the centers that are candidates for inclusion in such a plan. Good use of existing OSS features and minimization of new OSS developments is clearly dictated by the economics.

2.3.1 The DLC system maintenance plan

The following plan was originally developed as part of the Total Network Operations Plan (TNOP effort in 1979).[3] Minor changes and clarifications have been made through the present to keep the plan current and to take advantage of new developments. A simplified process flow diagram is shown in Fig. 1.

The plan requires that system alarm information be transmitted to two centralized operation centers, the Switching Control Center or Network Terminal Equipment Center (SCC/NTEC), and the Maintenance Center (MC). This requirement is consistent with the basic principle that alarms should be sent to the centers associated with the CTR process (the MC) and the centers associated with the hands-on repair force (both SCC/NTEC and MC).

The alarms should have the following attributes:

1. The alarms should indicate the severity of the trouble. For example, in the *SLC* 96 carrier system a *major alarm* usually means 24 or more customers (12 for special service circuits) have been simultaneously put out of service. A *minor alarm* indicates that a failure has occurred but customer service is not affected (e.g., switch to the protection of T1 line).

2. The alarm data should be "system specific". That is, an alarm should indicate which DLC system and, by association, which customers are affected.

3. The alarm data should be "location specific". That is, the data received at an MC or SCC/NTEC should allow those centers to make dispatch decisions with reasonable assurance that both the location

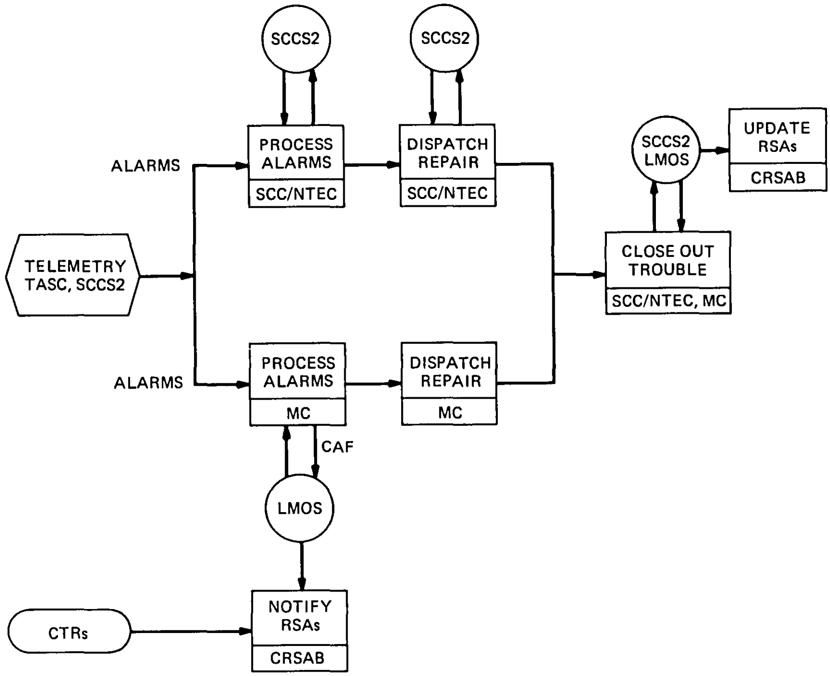

Fig. 1—DLC System Maintenance Plan.

the craft is sent to and the skill and test equipment the craft carries is sufficient to repair the fault.

Section III will describe how the *SLC* 96 carrier system meets these alarm requirements. Figure 1 shows that an alarm is sent to the SCC/NTEC or MC via a telemetry system. Telemetry systems can include the Telecommunication Alarm Surveillance and Control (TASC) system, the Switching Control Center System No. 2 (SCCS 2), the maintenance channel of an electronic switch—e.g., the Automatic Line Insulation Test (ALIT) channel—or a commercial telemetry system. Choice is often dictated by local economics and spare capacity on systems already in place. The key point is to provide instantaneous alarm visibility in these centers.

The SCC/NTEC responds only to system troubles localized to the COT of a DLC system. Therefore, the SCC/NTEC can choose to screen out all alarm data other than COT failures. When a COT alarm is received, however, the SCC/NTEC dispatches a technician under their control. The SCCS 2 is used to log the trouble, monitor the repair, and close out the report upon completion. Since the SCC/NTEC and NTEC traditionally respond to other alarmed equipment failures, these operations are not new and impose very few new requirements on SCCS 2. Thus, an economical and very rapid deployment of this part of the plan is possible.

The MC is assigned responsibility for repairing system failures localized to the RT or to the Carrier Line (CL). The MC also is responsible for notifying the Repair Service Attendants (RSAs)—the 611 clerks—that a system failure is in progress. Both of these functions are shown in Fig. 1.

It is of the utmost importance that RSAs be notified as soon as an alarm is received. This notification allows an RSA to inform affected customers who report troubles of the approximate clearance time and also avoids having the RSA initiate circuit tests with MLT. It also assures that no repair technician will be dispatched in response to a received CTR while a system repair is in progress. Prompt notification of the RSAs can avoid many false dispatches.

RSAs are notified through a sequence of LMOS transactions. When an alarm is received, accompanied by the system ID, a Display Line Record (DLR) transaction is performed to retrieve the DLC system data. These data are stored on a "dummy" line record, with the usual telephone number access key replaced by the system ID. The retrieved "dummy" line record is examined for the identity of the derived cable pairs connected to the DLC system. This information is then used in a second transaction, a Cable Failure (CAF) transaction. The CAF searches LMOS data for the circuit IDs (usually telephone numbers) assigned to the indicated cable and pair count and flags those circuits. When an RSA accesses an affected circuit ID, the proper failure information is displayed.

These transactions were not new to LMOS. The only new item needed for this sequence was the creation of the "dummy" line record. Since an existing record format was used, no new LMOS developments were required to implement this plan. Of course, future ARSB developments will enhance this process by completely automating the sequence, from alarm receipt to RSA terminal update.

Since a system failure is treated as a CAF in LMOS, standard LMOS tracking, jeopardy reporting, and completion routines apply. The fundamental difference is only that, in the case of DLC, the presence of a failure is known instantaneously.

2.3.2 A word on the choice of centers

DLC systems are based on T-carrier technology. Since this technology is not new to the operating companies, it is reasonable to ask whether the existing centers and OSS that currently maintain interoffice T-systems could be used. In particular, the T-Carrier Administration System (TCAS) seems a likely candidate to receive DLC alarms and administer the repair operation.

Upon further investigation, however, it can be shown that TCAS is not an appropriate system for DLC. The major value added by TCAS is its ability to sectionalize a T-carrier failure to a particular span. (A span is a T-carrier line between two Central Offices [COs], including the terminations.) In case of DLC, however, only one span exists—from the CO to the RT. Furthermore, the interoffice T-carrier forces, although trained in the technology, are not geared to routinely respond to service outages, since most trunk failures result in service degradations but not in complete outages. When a DLC system fails, many customers may be out of service.

The MC, which is normally responsible for the maintenance of the loop plant, seemed the better placed center for DLC responsibility. Although, traditionally, MC forces have not been trained in T-carrier technology, it was observed that many additional technicians would have to be trained in any case to handle the increased volume created by DLC deployment. The issue was thus reduced to the question, to whom should these newly trained technicians report? The MC seemed the most reasonable answer.

III. *SLC* 96 CARRIER MAINTENANCE PHILOSOPHY AND FEATURES

A key element in the maintenance of a DLC is the recognition that the RT and the COT have different maintenance needs. The COT is located in the sheltered central office environment and is easily accessible to craftspeople. In many situations the central offices are staffed during working hours, and attention of the craftsperson to a COT can be rapidly obtained. On the other hand, the RT is often located some distance from the central office. It may be in a cabinet exposed to the elements or in a small hut without any heat or air conditioning. Therefore, not only is craft access to the RT more difficult and time-consuming because of its location, but the RT is also a more difficult environment in which to work.

Since the operations plan specifies that different craft groups will maintain the COT and RT equipment, it is necessary for the system to provide fault alarms that indicate the location of the trouble. In the *SLC* 96 carrier system, all common system failures (that is, failures affecting 24 or more channels) are alarmed. As will be described below, these alarms are specific about the severity of the problem and the location of the failure. In this way, the proper maintenance forces can be dispatched to the right location in the minimum amount of time, thus minimizing the duration of any customer outages.

Failures of the *SLC* 96 carrier system that are not alarmed occur in channel units and typically affect only one or two customer lines. In these cases, customer trouble reports are received by the Repair Service Bureau, and the *SLC* 96 carrier circuit testing feature is used to diagnose the failure. This feature utilizes the pair gain test controller in conjunction with capabilities in the *SLC* 96 carrier system to provide the ability for the Local Test Desk or the Mechanized Loop Testing (MLT) system to access a customer line and determine if the failure is in a *SLC* 96 carrier channel unit, the central office line equipment, the cable pair beyond the RT, or the customer's terminal equipment (e.g., station set). A feature of the *SLC* 96 carrier system that has proven to be essential to the reliable performance of digital loop carrier is the protection T1 line with automatic switching. The system provides one protection T1 line for either two or four main T1 lines, depending on the mode of system operation. Both the main and protection T1 lines are continuously monitored for faults. Failure of a main T1 line results in rapid and imperceptible switching to the protection T1 line, thereby maintaining customer service. The switching action also raises a minor system alarm. If the protection line fails, its outage is detected and a minior alarm is also indicated.

3.1 SLC 96 carrier alarm plan

The alarms associated with an individual *SLC* 96 carrier system channel bank are displayed in detail on the Alarm Control Unit (ACU) plug-in shown in Fig. 2. The same ACU is used in both the COT and RT. On the ACU, the upper three indicators show the classification of the alarm. A MAJOR alarm indicates that between 24 and 96 customers are out of service. The MINOR alarm is displayed when

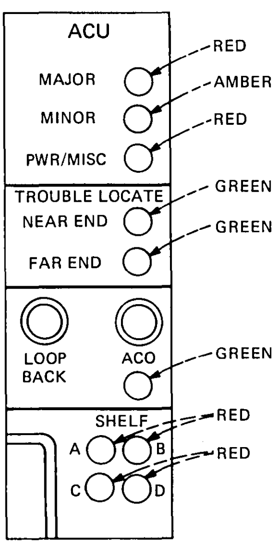

Fig. 2—Alarm control unit alarm indicators.

nonservice-affecting failures occur such as a switch to the protection T1 line. The PWR/MISC (Power/Miscellaneous) alarm indicates that either commercial ac power has failed at the RT or that a miscellaneous alarm point at the RT has been activated. The miscellaneous alarm point frequently is tied into hut alarms such as an open door.

The NEAR END and FAR END indicators on the ACU reveal the location of the trouble. For example, if you are observing the ACU at a COT and the FAR END indicator is illuminated, a remote terminal problem is indicated.

The LOOP BACK switch activates a channel bank loopback at the front end of the line interface units on any failed digroup. This control is frequently used from the COT to help determine if troubles are located in the COT or outside in the T1 lines or RT. The Alarm Cutoff (ACO) switch is used to retire alarms after their status has been read and recorded. The last four indicators—SHELF A, B, C, or D—on the ACU show which shelf (that is, a digroup of 24 channels) has failed under a major alarm condition.

Other failure displays are contained on the Transmission/Receive Unit (TRU), Line Interface Unit (LIU), Data Link Unit (DLU), Channel Test Unit (CTU), Time Assignment Unit (TAU), and Multiplex Unit (MXU). These local displays are keyed to maintenance flow diagrams contained in the system documentation and allow for rapid diagnosis and repair of system failures.

In the central office, six COTs are grouped together and connected to a fuse and alarm panel. This panel provides a source of 48V power and fusing to the COTs and also serves as the interface to the central office audible and visual alarm system. The fuse and alarm panel provides for supplemental alarm relay contacts that can be used to interface the *SLC* 96 carrier system alarms to telemetry systems.

The operations plan discussed in Section II dictates that the alarms be remoted from the COTs to a centralized maintenance bureau. The telemetry interface capabilities of the fuse and alarm panel allow the operations plan to be satisfied with common telemetry systems. In certain cases, *ESS*™ switching equipment scan and distribution points can also be used for telemetry. The alarms, status indicators, and remote command interfaces present on the fuse and alarm panel are given in Table I. With the exception of the system ID status indicator, alarms and status indicators for all *SLC* 96 carrier systems in a central office are multiplied together and then connected to the telemetry system. The sytem ID indicators, however, are individually carried through the alarm telemetry system. In this way the number of telemetry points required in the central office are kept to an absolute minimum, and the system ID signal is used to indicate which system has caused the alarm. The Bank Loopback and Alarm Cutoff allow

Table I—Summary of *SLC* 96 carrier alarm and telemetry connects

Alarms	Status Indicators	Remote Commands
Major	Near end	Bank loopback
Minor	Far end	Alarm cutoff
Power minor	Carrier line failure	
Fuse	System ID	
	Power/miscellaneous	

those system features to be operated over the telemetry system from a remote maintenance center. These command points are multiple across the office.

3.2 Channel and drop testing

A system has been developed to permit customer loops served by a DLC, such as the *SLC* 96 carrier system, to be tested from a Repair Service Bureau (RSB).[1,4] This system provides a means of switching that will connect incoming RSB test trunks to a dc bypass around the carrier system to the distribution pair terminating on the RT. The method requires an item of central offie equipment called the Pair Gain Test Controller (PGTC), which will support all carrier systems deployed from a particular wire center. The PGTC is a microcomputer-controlled device that interacts with circuitry in each of the carrier systems to provide metallic access to the customer's drop. This allows the RSB to perform standard tests on the drop, while at the same time, the PGTC performs a series of automatic transmission and signaling tests on the derived carrier channel. This system was chosen because it maintains compatibility with existing test desks and automated test systems such as MLT, while presenting minimal changes to test procedures presently in use at the RSBs. The system can accommodate all types and lengths of loops and test trunks that are presently testable from an RSB. Figure 3 is a representation of the test method showing the functional relationship of all of the system elements.

The PGTC is a compact system consisting of a control shelf that holds the microcomputer, up to four tester units, and trunk cards sufficient to switch up to 12 incoming test trunks. Four expansion shelves may be added, each holding trunk cards for up to 20 additional test trunks. The maximum system capacity is 92 test trunks. The PGTC holds four tester units permitting four simultaneous tests on customer loops, providing that the loops are served from carrier systems not sharing the same dc bypass pair. The actual number of tester units equipped (one to four) is determined by blocking considerations.

Referring to Fig. 3, the PGTC is installed in a wire center with the

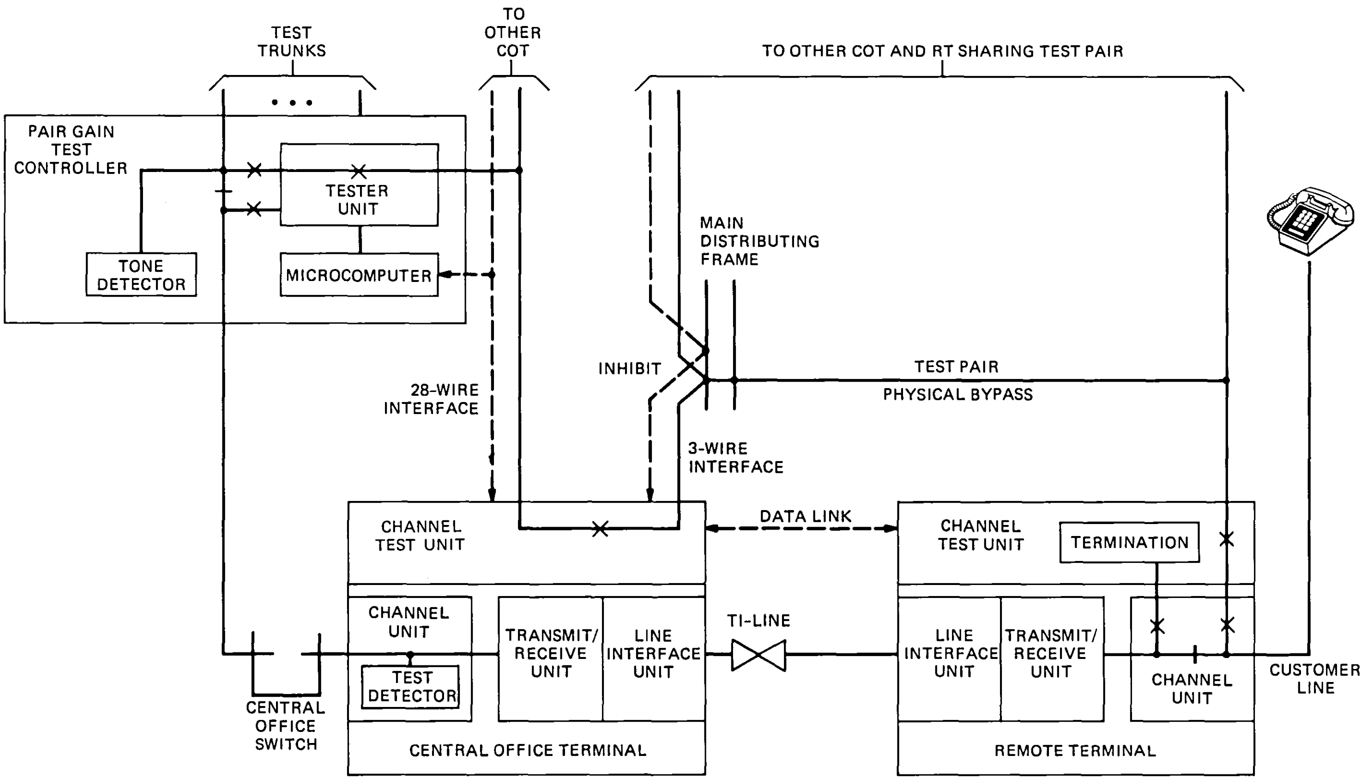

Fig. 3—Pair gain test controller interface to the *SLC* 96 carrier.

associated *SLC* 96 carrier systems and intercepts the incoming test trunks from the RSB prior to their terminating on the CO switch. When the PGTC is inactive, the test trunks pass through unaltered and the PGTC is transparent to the normal dialing and testing activities of the RSB. When the PGTC is activated, the PGTC, in conjunction with the COT and RT, establishes a connection between an incoming test trunk and the customer's drop through the dc bypass pair.

The *SLC* 96 carrier must provide three interfaces to function with the PGTC. The first interface is to the COT channel unit, which is accessed over a test trunk by dialing the telephone number assigned to the line served by that channel. The maximum resistance between the PGTC and the tip or ring of the channel unit after a connection has been established is 65 ohms. The second is a 28-wire interface containing test pairs (up to four) and the test set-up control leads from the PGTC. This interface is bused to all *SLC* 96 carrier systems and interacts with common circuitry in each of the carrier systems. This circuitry is contained in a plug-in called the Channel Test Unit (CTU). There are unique CTU codes for the COT and RT channel banks, respectively. The third is a 3-wire interface between the COT channel banks (connected at the main distributing frame) to allow sharing of dc bypass pairs between systems that are colocated at an RT location. This consists of the dc bypass pair and a control wire, called INHIBIT, which when grounded prevents seizure of this shared pair by more than one PGTC tester unit at a time. The maximum limit of the total test path (which includes test trunk, dc bypass pair, and customer drop) is approximately 3000 ohms of loop resistance. The test trunk portion of this path is generally limited to 1500 ohms when the test facility is not colocated with the PGTC.

3.2.1 Interconnection sequence to set up dc test path

The testing process consists of two distinct intervals: the test set-up interval, where the set-up and cut-through of the dc path from the RSB to the customer are established; and the testing interval, where the PGTC conducts a test of the derived channel while the RSB is testing the customer's drop. The PGTC is activated only when attempting to test a customer loop served from an RT. The test set-up interval is initiated by first dialing the customer's telephone number over one of the RSB test trunks. The RSB test trunk sleeve lead must be in the negative low-current condition when the line is being accessed. The negative low-current condition is the normal state of the sleeve lead for most interactions between the RSB test system and the PGTC unless the RSB is requesting the results of the transmission and signaling tests or unless the RSB is signaling disconnect of the test trunk. Using standard RSB procedures, a tester may verify CO continuity and check for leakage resistance on the connection up to the COT channel unit. To achieve cut-through to the dc bypass pair and customer drop, the RSB applies positive station potential (typically +116 Vdc) to the tip conductor with the ring conductor open. The COT single- or multiparty channel unit recognizes this voltage and starts an interconnection sequence that will cause cut-through of the dc test path upon removal of the positive station potential. For coin lines, the ring conductor must be grounded so that the carrier system coin channel unit can distinguish between a test request and the positive coin collect signal. The RSB test system must maintain the positive station potential until one of the following signals is detected:

1. A 1-kΩ leak to ground interrupted at a 60 Interrupts Per Minute (IPM) rate is applied to the tip conductor of the test trunk at the PGTC. This signal indicates that the carrier system serving the line to be tested is in a major alarm state. The major alarm must first be cleared before line testing will be successful.

2. A 1-kΩ leak to ground interrupted at a 120-IPM rate is applied to the tip conductor of the test trunk at the PGTC. This signal indicates that the dc bypass pair required for this particular test is already in use or that all of the PGTC test circuits are busy. For this case, the tester must disconnect and try again later.

3. A steady uninterrupted 1-kΩ leak to ground is applied to the tip conductor of the test trunk at the PGTC. This signal indicates that all required test connections have been set up by the PGTC and the carrier system and that testing may now proceed.

At this point, the RSB test system must remove the positive station potential from the tip conductor of the test trunk (and on coin lines remove ground from the ring conductor). If the first or second condition above is detected, no further testing may be conducted and a test disconnect must be issued to release the test trunk, the PGTC, and the carrier system. If the third condition is detected, the PGTC will remove the 1-kΩ leak when the positive station potential is removed and the test system will then be connected to the drop.

Before proceeding to a description of the testing interval a description of the handshaking sequence that occurs immediately after application of the positive station potential follows, as shown in Fig. 4. In response to an applied dc voltage greater than +94V (typically +116 Vdc) in series with 8 kΩ on the tip conductor, the channel unit will send a 333 Hz-TONE toward the PGTC and will send a TEST CODE over its channel signaling bits toward the RT. The ring conductor is open except for coin units, where it is grounded. The tone is sensed by a detector bridged onto the test trunk alerting the PGTC that a

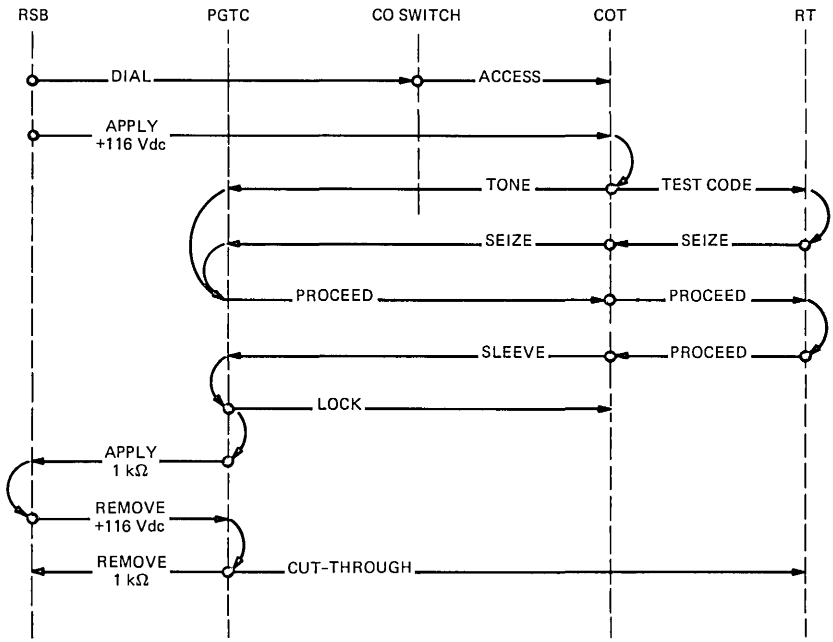

Fig. 4—Sequence to set up dc bypass path to customer's drop.

test connection is requested and identifying the particular test trunk involved. The PGTC will communicate with the COT over the 28-wire bus until the interconnection sequence is completed. The COT and RT, in turn, will communicate via the carrier system data link. When the 333-Hz tone is detected by the PGTC, it waits for an acknowledgment that the carrier system has accepted the test request. The signal from the carrier system that signifies this is called SEIZE.

When tone and seize signals are both present at the PGTC, the PGTC selects a tester unit and associated test pair (one of four) assignment. The tester units are scanned and the first available tester is selected. The microcomputer within the PGTC performs a verification test of the selected tester to assure calibration of the circuits. Having selected a tester, the PGTC will send a signal called PROCEED to the carrier system. Upon receipt of the proceed signal, the carrier system will connect the dc bypass pair to the RT drop and connect a test termination circuit to the tip and ring of the RT channel unit under test. When all connections have been made by the carrier system, the system will return a SLEEVE signal to the PGTC. Upon receipt of the sleeve signal, the PGTC will disconnect the RSB test trunk from the channel unit under test and connect the selected PGTC tester unit to that channel. In addition, the PGTC places the previously mentioned 1-kΩ resistance to ground on the tip side of the RSB test trunk and sends a LOCK signal that enables the carrier system to hold up the connection until all testing is completed. Disconnecting the RSB test trunk from the channel unit causes the station potential to drop at the channel input and this in turn causes the channel to stop sending tone and test code signals. The channel thereby returns to normal operation for the subsequent transmission tests.

Removal of the positive station potential by the testing facility will cause removal of the 1-kΩ resistance and final cut-through of the test path from the RSB to the customer's drop. This is the start of the testing interval. Removal of the lock signal by the PGTC as part of the test disconnect procedure is the indication to the carrier system that the testing interval is over and all connections are to be restored to normal.

3.2.2 Description of transmission and signaling tests

During the testing interval, and while the RSB test facility is performing its normal tests of the customer's drop, the PGTC conducts an automatic transmission and signaling test of the derived channel. This test is conducted immediately after cut-through of the dc test path and is completed within approximately two seconds for single-party and four seconds for multiparty and coin. The results of these tests are stored for later recall by the RSB test facility. The transmission tests check that transmission parameters of the carrier channel are not grossly out of limits. The signaling checks ensure that the carrier system channel can detect and repeat the necessary single-party, multiparty, and coin telephone control and supervision signals.

Figure 5 shows the PGTC tester unit circuitry. The test oscillator, which is swept in frequency from 1 to 2 kHz at a 125-Hz rate, applies a −3 dBm signal through a 900Ω hybrid to the COT channel unit under test. The oscillator is swept to minimize interhybrid reflections. The return signal from a termination at the RT channel unit is separated by the hybrid and passed through a C-message weighted filter. The output of the filter is then amplified, rectified, and compared against known thresholds as part of the transmission tests. Signaling relays apply ringing, coin voltages, positive and negative talk battery voltages, and tip/ring reversal. A current detector senses loop current for on/off hook status and tip or ring current for Automatic Number Identification (ANI) and coin checks.

The transmission tests require that the carrier system RT be able to apply terminations to the RT channel unit under test. For the *SLC* 96 carrier system, as shown in Fig. 6, the RT has three types of terminations that it can apply in response to different ringing signals or to coin collect voltages. These are a reflective termination (short

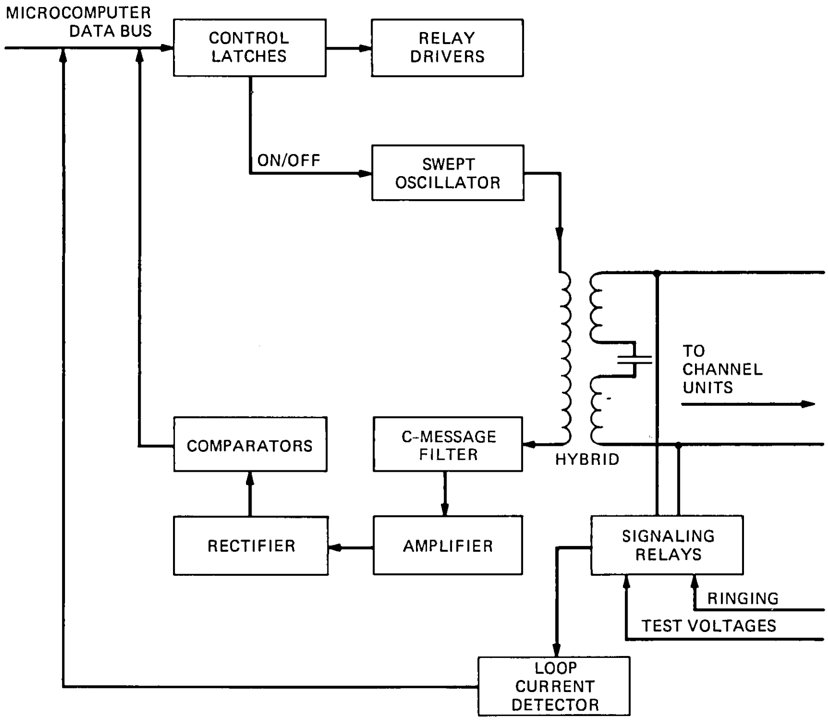

Fig. 5—The PGTC channel tester unit circuitry.

circuit), an absorptive termination (900Ω), and a resistance to ground that is less than 3 kΩ. The resistance to ground is poled through diodes to allow current flow from either a positive or negative battery, depending on the test being conducted. There are several checks of tip or ring current flow that are used to identify the presence of a coin unit, to check operator mode (battery reversal), or to determine the presence of either a coin or ANI ground.

Two types of return loss measurements are performed. The first is a measure of round trip channel loss, including CO switch and wiring losses, and is performed with the RT channel unit terminated by a reflective termination. The measured loss at the PGTC must be less than 7 dB (or 12 dB) if the PGTC is equipped with an SM87B (or SM87C) tester unit plug-in. The second is a measure of echo-return loss and is performed, in this case, with the RT channel unit terminated by an absorptive termination. The measured loss at the PGTC must be greater than 13 dB (or 15 dB), depending on the vintage of tester unit, as above. A round trip idle channel noise test is also made by turning off the swept oscillator while the RT channel unit has an

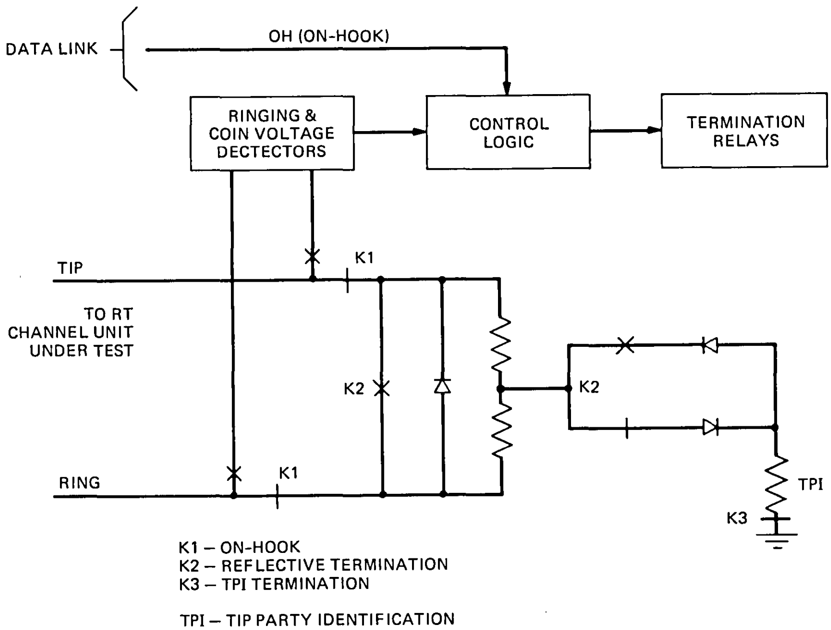

Fig. 6—Remote terminal termination circuit.

ac reflective termination. The resultant C-message weighted signal level should be less than −60 dBm at the PGTC.

The automatic sequences are performed in a manner that exercises all of the signaling states while conducting the transmission measurements. The signaling tests require that the signals applied by the PGTC to the carrier system COT be detected by the COT and duplicated at the RT. The RT CTU is capable of recognizing four types of ringing (positive and negative superimposed ringing on either tip or ring, −R, +R, −T, +T) and +130 and −130 Vdc coin voltages. For each unique signaling state detected by the CTU, an appropriate termination is applied across tip and ring of the RT channel unit, including the presence or absence of a resistance to ground. These terminations are detectable at the COT by the PGTC and each allows a particular transmission measurement to be made. In addition, the RT must detect off-hook, ANI ground, and coin ground from the customer and these signals must be reproduced at the COT where they may be detected by the PGTC.

The state diagram for the sequencing of the RT terminations is shown in Fig. 7. After removal of the positive station potential, the RT CTU initially presents an off-hook, absorptive termination to the RT channel. The echo-return loss test is conducted and a check is made to determine whether the particular channel under test is a coin

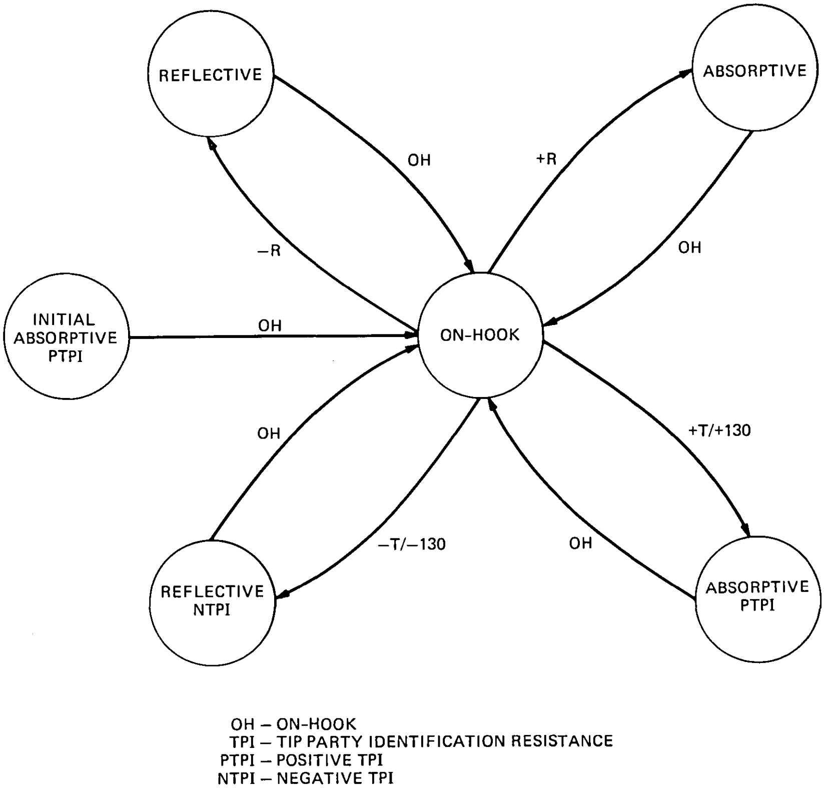

Fig. 7—State diagram for the remote terminal channel terminations.

unit. If so, this is flagged for later use. The RT CTU is then forced on-hook by a signal on the 28-wire bus from the PGTC to the COT CTU called OH (ON-HOOK). This signal is transmitted to the RT CTU via the carrier system data link. The RT CTU can now respond to −R ringing and come off-hook again, however, with a reflective termination being presented this time. The round-trip channel loss test is made and then by turning off the oscillator, the idle channel noise test is made. At this point, the channel has been checked for transmission parameters and its signaling has been verified as sufficient to support single-party service. The flow diagram for this portion of the test sequence is shown in Fig. 8. If all checks have been positive to this point, then a flag is set in the microcomputer noting "channel good–single-party service."

From this point on, the testing will attempt to verify the signaling states for either multiparty or coin channels. For coin channels, the previously set coin flag is checked and, if present, all of the coin signaling states will be checked, as shown in Fig. 9. In this case, the

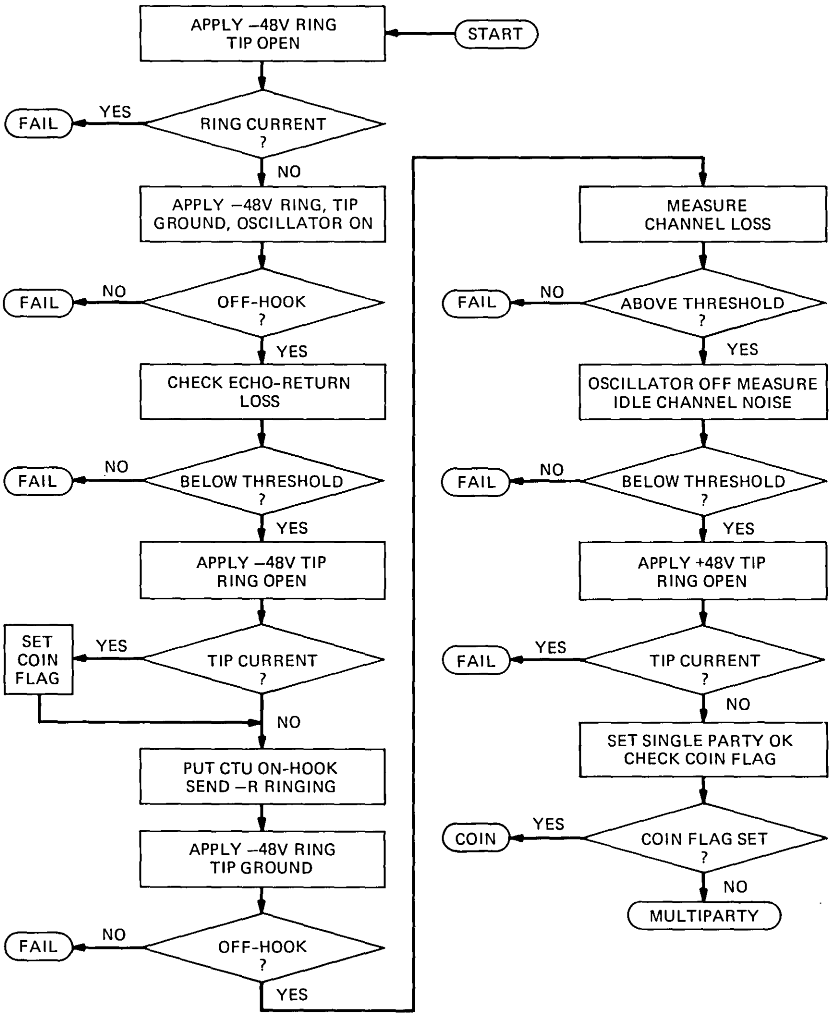

Fig. 8—Single-party test sequence.

+130 and −130 Vdc coin collect voltages, as repeated at the RT channel unit, are detected and used by the RT CTU to apply appropriate terminations. The use of the OH signal from the PGTC is used to remove terminations and sequence to the next step until all checks are complete. If all checks have been positive in this sequence, then a flag is set in the microcomputer noting "channel good–coin service." If the coin flag did not indicate a coin channel, then the multiparty signaling states will be checked, as shown in Fig. 10. For this case, the remaining ringing states (+R, −T, +T) not previously used, and as repeated at the RT channel unit, are detected and used by the RT

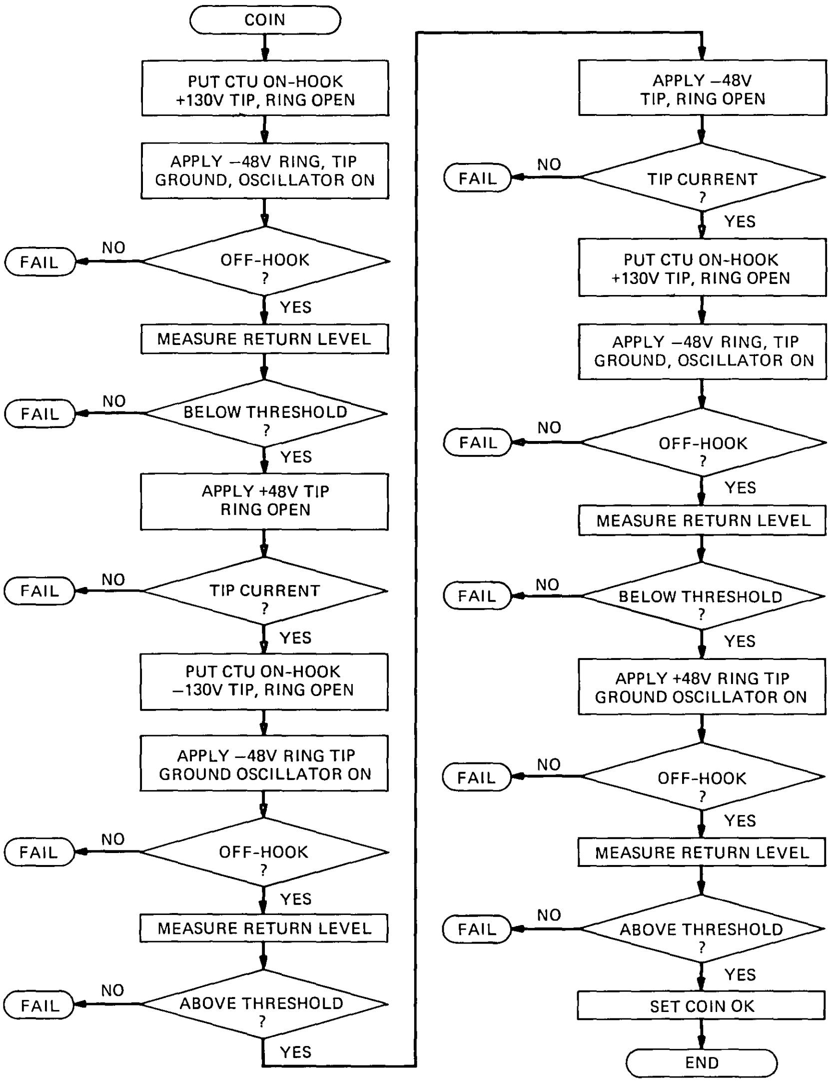

Fig. 9—Coin unit test sequence.

CTU to apply appropriate terminations. Again, the OH signal from the PGTC is used to remove terminations at the RT and sequence to the next step until all checks are complete. If all checks have been positive in this sequence, then a flag is set in the microcomputer noting "channel good–multiparty service."

3.2.3 Test results

The RSB test system can obtain the results of the automatic tests

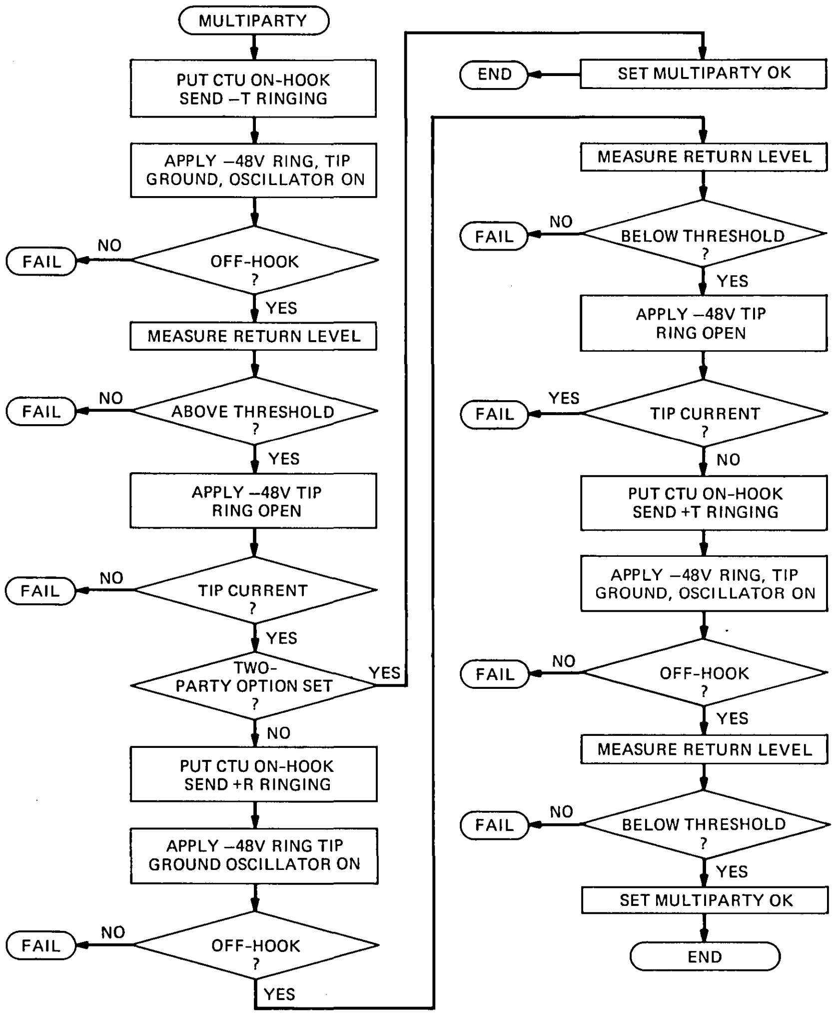

Fig. 10—Multiparty test sequence.

conducted by the PGTC by opening and closing the sleeve lead of the test trunk. The PGTC maintains control of the sleeve lead to the CO switch to prevent the connection from being dropped during the testing interval. The PGTC presents the results as a pattern of audible tones and as dc voltages applied to the test trunk, and these are summarized in Table II. The results indicate the class of service for which the tested channel unit is suitable. For example, if a multiparty channel unit is tested and only one tone is returned, it means that the channel unit is only good for single-party service. The results of the tests may

Table II—Test results

Channel Condition	Tone Output	Signal Output
Channel no good	None	T: Ground R: +48 Vdc
Channel good Single-party service	Single burst	T: Ground R: −48 Vdc
Channel good Multiparty service	Double burst	T: −48 Vdc R: Open
Channel good Coin service	Triple burst	T: +48 Vdc R: Open

be repeated if the sleeve is reopened; however, the PGTC does not perform new tests, it only repeats the results of the initial test.

3.2.4 Test disconnect

When the RSB test system has completed all tests of the customer's drop and has received the results of the PGTC tests, it must issue a disconnect signal to the PGTC. The test disconnect signal from the RSB is the negative high-current sleeve condition, which tells the PGTC to release the test connection. The PGTC, in turn, notifies the carrier system to restore all connections to normal by removal of the lock signal.

3.2.5 Maintenance features

The PGTC has built-in diagnostic and display features to aid in trouble analysis. The microcomputer card has a faceplate display capable of displaying 16 unique trouble codes. The microcomputer continuously scans its inputs for abnormal conditions, and if a trouble persists for more than four seconds, an office alarm is generated and the display indicates the repair procedure to be followed. The microcomputer firmware contains a sanity timer that must be reset at proper intervals or one of the display codes will be lighted indicating that the microcomputer must be reinitialized or replaced. When a tester unit is selected to test a channel and fails its verification test prior to assignment, the display codes indicate which unit has failed. The previously mentioned office alarm is displayed on the front face of the power card. An alarm cutoff is provided to retire office alarms while troubleshooting procedures are in progress.

IV. RELIABILITY AND FIELD PERFORMANCE

The *SLC* 96 carrier system has been designed to achieve a level of reliability that meets or exceeds that provided by conventional wire pair loops. The actual reliability of the system is commonly measured in the operating companies monitoring the customer trouble report rate. This rate is an indication of the failure levels perceived by the customer. Although the rate is composed of various failure rates due to the *SLC* 96 carrier equipment, station sets, metallic loops, and central office equipment, it is a good indicator of system performance when compared with a control group of comparable customers served over wire pair loops.

Such a comparative study has been performed for the *SLC* 96 carrier system, and it demonstrates that the trouble report rate is one-quarter to one-third less than that experienced by customers served on wire pair loops. These results conclusively show that the *SLC* 96 carrier system can be utilized in the telephone loop plant not only to provide a substitute for wire pair loops but to improve the telephone service provided to telephone customers.

V. ACKNOWLEDGMENTS

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The SLC *96 Subscriber Loop Carrier System:*

The Fiber *SLC* Carrier System

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(Manuscript received October 21, 1983)

The advantages of digital loop carrier systems operating on wire pairs can be enhanced by the use of lightguides in place of wire pairs. Lightwave systems can provide wide bandwidth capability, small cable size, long-range repeaterless operation, and immunity to electromagnetic interferences. This article describes the development of a 1.3-μm LED/PIN based system designed specifically for the loop environment.

I. INTRODUCTION

1.1 Rationale for lightwave systems in the loop plant

Until now, the loop plant has been defined as the pairs of metallic conductors that connect subscribers (customers) to a central office. The loop plant has been costly due to constant additions and rearrangements that result from rapid growth and movement of customers. Some of the costs of this changing plant (new cable installations) can be offset by substituting electronics for cable. In recent years, a family of digital loop carrier systems has evolved to meet this need. The latest of these offerings is the *SLC*® 96 carrier system, which links a remote terminal (with up to 96 subscriber lines) to a central office terminal

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by means of two or four T1 lines, which greatly reduces the number of wire pairs needed. Thus, the loop plant can be dissected into a loop feeder segment, the link between the central office and the carrier system remote terminal; and a loop distribution segment, the connections between the remote terminals and the subscribers.

When the growth rate of customers on a particular route exceeds a certain number, the provisioning of *SLC* 96 carrier systems with T1 lines becomes difficult. The difficulties arise from the congestion of manholes that have to house the repeaters, insufficient wire pairs to support the required number of T1 lines, and interference between T1 lines sharing the same cable. These problems can be alleviated by the addition of new cables and/or manholes. However, rather than the addition of metallic cable, it becomes economically advantageous to install lightguide cable and utilize each lightguide to support the transmission of several *SLC* 96 carrier systems. In addition, lightwave systems can inherently provide many advantages over metallic media, such as:

1. The wide bandwidth capability provides an extremely large feeder capacity for the future, thereby mitigating the effects of periodic cable relief and rearrangements.
2. The small size of the lightguide cable considerably lessens the problems of conduit and pole line congestion.
3. Low attenuation provides repeaterless operation for loop applications, which, in turn, favorably affects reliability, maintenance, and manhole congestion problems.
4. Compared to copper cables, crosstalk in fiber cables is insignificant. Thus, independent terminals can operate on the same route without level coordination or format compatibility considerations.
5. Immunity to inductive interference has significant benefits in providing service in electrically noisy environments.

1.2 Special considerations for the use of lightwave systems in the loop plant

The desire to achieve repeaterless operation leads to the choice of the 1.3-μm wavelength region. Lightguides have significantly lower attenuation in this region compared to the 0.8-μm region used in many earlier systems. At this wavelength, the material dispersion is a minimum, which combined with optimal fiber design for minimal modal dispersion, allows the use of Light-Emitting Diode (LED)* sources at high bit rates.

The choice of optical sources and detectors was greatly influenced by the design objective of high reliability when used in the loop plant,

* Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

where their use in non-environmentally controlled cabinets and huts subjects them to extreme temperature and humidity variations. Two types of optical sources are typically used in lightguide systems: Injection Laser Diodes (ILDs) and LEDs. The ILDs are capable of greater output power than LEDs; however, currently available ILDs are not temperature-stable devices and are less reliable than LEDs when operated at elevated temperatures. Thus, LEDs are chosen for transmitting sources, since they are environmentally stable and exhibit reliability consistent with loop applications.

Similarly, there are two types of optical detectors commonly used in lightguide systems: Avalanche Photodiodes (APDs) and Positive-Intrinsic-Negative (PIN) diodes. As with the ILDs, the APD is not presently a temperature-stable device. Therefore, PIN detectors were chosen for use in the present system. The LED/PIN combination, chosen here, allows nonrepeatered ranges of up to 20 kilometers when used with the lightguide cable described in this paper.

In the loop plant the distance between the central office and remote terminal is highly variable, and to keep administration and maintenance simple it is essential that the optical receiver has very large dynamic range to eliminate the need for optical attenuators, which would require administrative and maintenance complexities.

Unlike in the trunk plant, where the failure of a group of trunks merely increases the probability of blocking or requires alternate routing, a loop connection is unique, and its failure denies the customer all access to the telephone network. Therefore, protection switching that makes most failures nonservice affecting is needed. The maintenance philosophy is also different from that for the trunk plant since remote terminals are unattended, and all alarms have to be telemetered to the central office.

II. THE FIBER *SLC* CARRIER SYSTEM

The development philosophy used in the Fiber *SLC*® carrier system program was to gradually build into an existing loop carrier system product a lightguide transmission feature. In this way, the telephone company would not have to simultaneously train their personnel in the operation and use of both a new digital loop carrier and a new transmission medium. The *SLC* 96 digital loop carrier system was introduced in 1979 and within a year Bell operating companies throughout the country were knowledgeable of its operation. Conversion of this system from a metallic medium to a DS2 rate (6.312 Mb/s) lightguide transmission medium was the first phase of the lightguide development plan. It required the design of two new circuit packs (an optical line interface unit and a line switch unit), and a modified backplane on the channel bank. The result was a lightguide system that, from the customer's point of view, was very similar (in terms of turn-up procedures, maintenance procedures, etc.) to what they were already using.

The next phase of the development plan is the introduction of a DS3 rate (44.736 Mb/s) lightguide system that will multiplex up to 7 *SLC* 96 carrier systems (14 if they are used in Modes 2 or 3[1]) and will be able to operate on the same lightguide cables as the DS2 rate system. Upgrading from the DS2 rate to the DS3 rate will require the installation of a new shelf of equipment, replacing the DS2 rate optical line interface units with DSX-2 electrical line interface units in the *SLC* 96 carrier system and interconnecting the *SLC* 96 carrier systems with the new equipment shelf. Along with being compatible with the *SLC* 96 carrier system, the new DS3 rate lightguide system is also being designed to be compatible with the next generation of digital loop carrier systems. This again exemplifies the general development philosophy of introducing advanced technology to the field while, at the same time, minimizing the operational impact on the craft.

The third phase of the development will introduce equipment that will allow the placement of the remote terminals away from the DS3 rate lightguide terminals by means of T1 metallic carrier extensions or DS2 rate lightguide extensions. This same equipment will also provide DS1 port capability directly to the subscribing customer.

The Fiber *SLC* lightguide carrier system described above is thus being designed to allow the system user to economically expand the capabilities of the system. The system user may start out with the DS2 rate lightguide capability, expand to the DS3 rate when subscriber growth dictates, and provide new customer services (such as DS1 port capability) when demand appears. All of this can be done by adding electronics only, without cable plant rearrangements or additions.

III. OPTICAL DEVICES

3.1 1.3-μm light-emitting diode

At the heart of the transmitter of the Fiber *SLC* carrier system is a 601B 1.3-μm light-emitting diode manufactured by AT&T Technologies, Inc. This light source was chosen because of its outstanding ruggedness in the outdoor plant environment and because its output spectrum closely matches the optimum transmission characteristics of the lightguide medium. Figure 1 schematically illustrates the structure of the 1.3-μm LED that was developed for the Fiber *SLC* carrier system application. The inset is a scanning electron micrograph of a bonded LED chip. The LED chip is comprised of sequentially deposited epitaxial layers, each approximately 1 to 2 μm thick. Light is produced in the "active" layer, a quaternary InGaAsP alloy whose composition is chosen to provide a bandgap characteristic of the

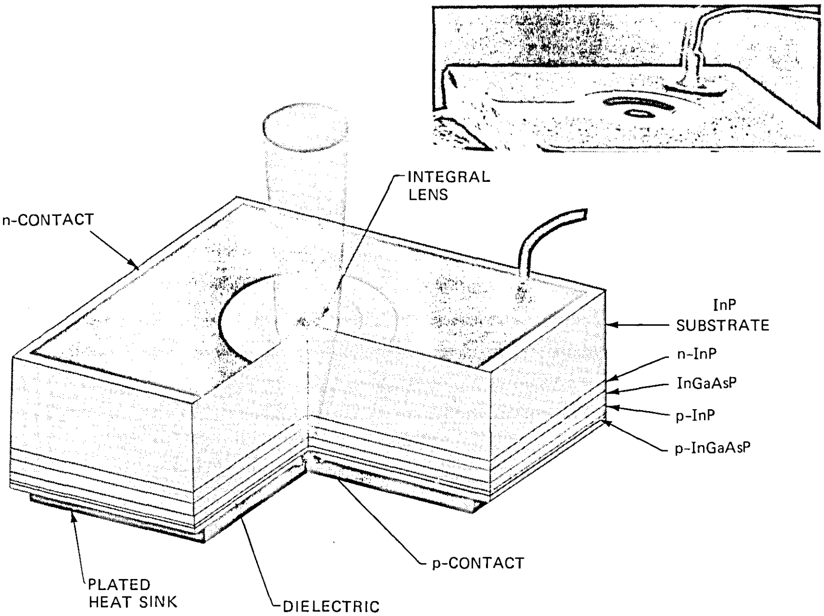

Fig. 1—Schematic illustration of surface-emitting 1.3-μm LED with an integral lens. Inset is a scanning electron micrograph of a bonded LED chip.

desired 1.3-μm emission. The active layer is clad by higher bandgap n- and p-type InP layers, forming a double heterostructure. These cladding layers serve three purposes: (1) to provide efficient minority carrier (hole) injection into the active layer; (2) to confine the injected carriers to the active region, enhancing the radiative recombination rate; and (3) to serve as a transparent window for efficient transmission of the light through the top surface of the device. Details of the epitaxy and fabrication techniques are given elsewhere.[2] The characteristics of the active layer principally determine switching characteristics and output power. For example, increasing doping (majority carrier concentration) and decreasing thickness of the active layer results in a faster transient response, permitting operation at higher data rates; the output power, however, is simultaneously reduced. These device parameters were optimized to provide the highest output power at the DS2 rate. Modulation at the DS3 rate is achieved with the same LED by using prebias and shaping of the current pulse to eliminate the slow components of the transient response, which are associated with the device capacitance.

Although the InGaAsP/InP LEDs can emit several milliwatts of output power, only a small fraction (0.02) is coupled into the fiber because of the wide angular emission pattern. However, making the light-emitting area smaller than the fiber core permits higher source radiance. Higher launched power can then be achieved using imaging optics to reduce the beam divergence. Maximum coupling is realized when the emerging light is collimated so that its image just fills the fiber core and the beam divergence is just within the acceptance angle of the fiber. Near-theoretical coupling has been achieved using lenses that are electrochemically etched into the top surface of the LED material. A novel projection-masking technique[3] has been developed to reproducibly control the shape of the integral lens. For an enhanced loop fiber (described in Section IV), coupling gains of 2.5 are typically realized, resulting in a *minimum* average end-of-life launched power of −16 dBm at a (worst case) 75°C ambient temperature.

One of the main attributes of the 601B 1.3-μm LED is the outstanding stability of the light output, even at elevated temperatures. The high reliability was realized by first choosing a device design that minimized stress and junction heating, factors known to be deleterious to long-term stability. Extensive testing at overstress conditions of current and temperature identified potential failure modes and assessed their impact on device reliability at nominal use conditions. To date, over one million device-hours have been accumulated in this test program. Test results were used to iterate both the design and fabrication techniques, and to develop a burn-in/screen procedure. The latter is intended to eliminate devices that are likely to fail early in

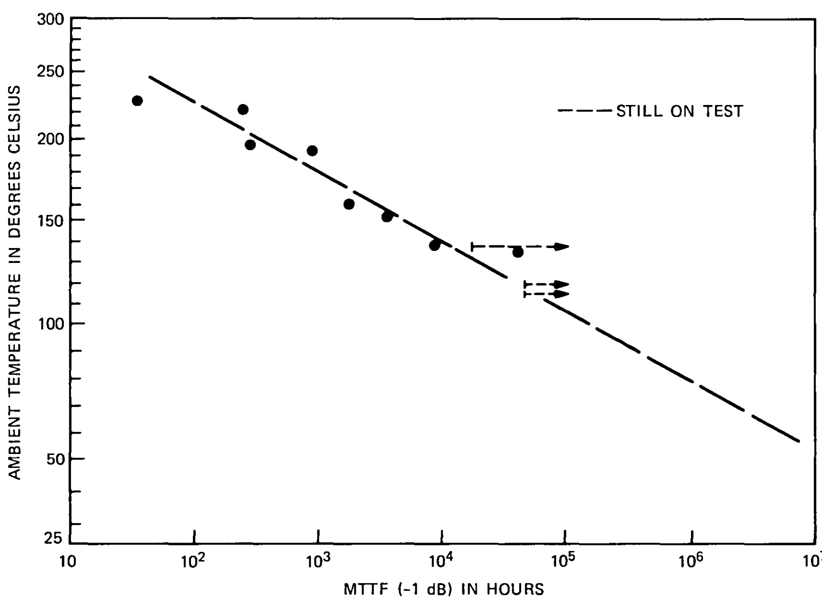

Fig. 2—Mean time to reach 1-dB degradation in output power as a function of ambient temperature. Junction temperature is 10 degrees higher than the ambient temperature.

the service life of the system. The remaining devices exhibit a slow, graceful decrease in output power under continuous operation. Degradation is accelerated at high temperatures, permitting estimates of useful life to be obtained in laboratory tests in a practical time period. Defining End Of Life (EOL) as a 1-dB decrease in output power, the mean time to failure can be estimated at various temperatures. (An LED "failure" is soft, i.e., it continues to operate, and in the worst case results in a slight increase in error rate.) Figure 2 summarizes such data for 55 LEDs.[4] An estimated mean time to failure of 10^6 hours is extrapolated for an ambient temperature of 75°C.

3.2 PIN/FET detector-amplifier

The first stage of the optical receiver is a PIN/FET detector-amplifier using an InGaAs PIN photodetector and a GaAs Field-Effect Transistor (FET). The particular design used here is similar to a design described by Ogawa,[5] and was chosen for its high sensitivity, reliability, and performance at extended temperatures.

A picture of the completed preamplifier detector package with its cover removed is shown in Fig. 3. The FET amplifier is fabricated on

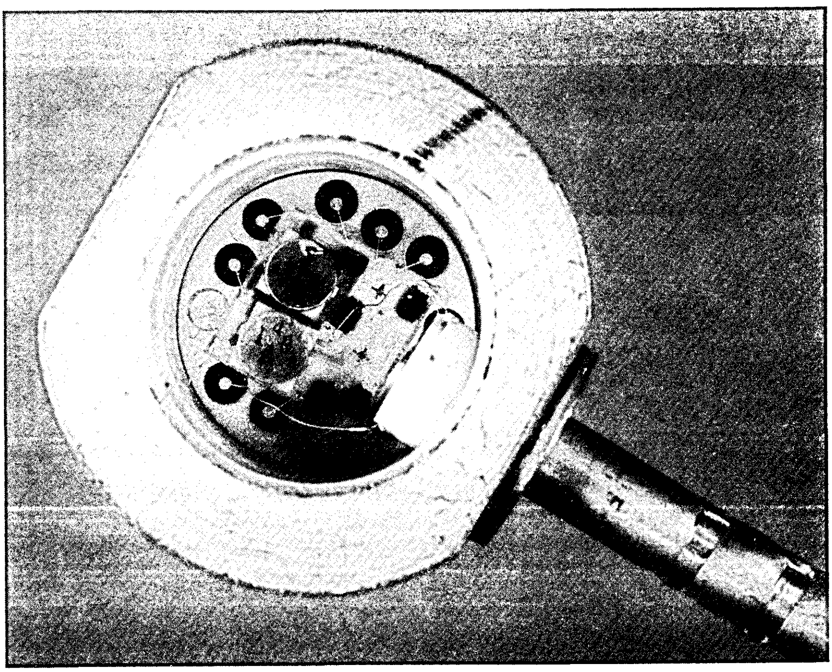

Fig. 3—PIN/FET receiver package showing the PIN diode package, and the two FET packages mounted on a thick-film ceramic circuit. The base for the overall package is a TO-8 header, and the package dimensions are 0.72 inch in diameter and 0.5 inch high.

a thick-film hybrid circuit 0.25 inch square and mounted on a standard 12-pin TO-8 header that forms the base of the package. The optical input is through a connectorized pigtail that mechanically terminates in a ferrule welded into the package wall. The fiber enters the package through a hermetic solder seal, with the fiber tip rigidly held within 3 mils of the backface of the photodiode. The axial alignment of the fiber with the photodiode is achieved by using an accurately cut fiber length and precise diode package dimensions. The transverse alignment is achieved actively by monitoring the diode photocurrent during assembly. Typical values of total receiver conversion efficiency range from 65 to 75 percent, including the diode quantum efficiency, the coupling loss at the diode-fiber interface, and the pigtail connector loss, which is nominally 0.5 dB.

The entire package is hermetically sealed, using welded joints and the fiber solder seal, in a dry helium ambient to provide the maximum reliability. In addition, both the PIN and the FETs are encapsulated in their own hermetic packages, primarily so they can be checked separately for reliability. The diode is connected to the amplifier circuit. There is no use of epoxy anywhere within the package.

The reliability of this design is based upon using a package and physical design that has been proven in several years of operating company service in the FT3 lightwave systems.

3.2.1 *Optical design*

The PIN photodetector has a nominal active area diameter of 75 μm, while the transmission fiber has a nominal core diameter of 62.5 μm. To minimize the coupling losses at both the connector and the diode interface, a pigtail having a graded index fiber similar to the transmission fiber but with a core diameter of 70 μm was used. The end of the fiber in proximity to the detector is flame polished to provide a smooth, regular surface, devoid of artifacts from the cutting process.

3.2.2 *PIN diode*

The photodetector is a back-illuminated, restricted contact, planar InGaAs PIN diode,[6] whose construction is shown schematically in Fig. 4. The double dielectric isolation layer is used first as a mask for selected area diffusion, and second to define the p-contact and act as an additional passivation layer. The entire junction is therefore protected from the environment, in contrast to diodes of mesa construction. The metal contact to the diode is restricted, so that the stress associated with the metal-semiconductor interface is removed from the junction perimeter. An Anti-Reflection (AR) coating is applied to the back face of the diode to maximize the quantum efficiency.

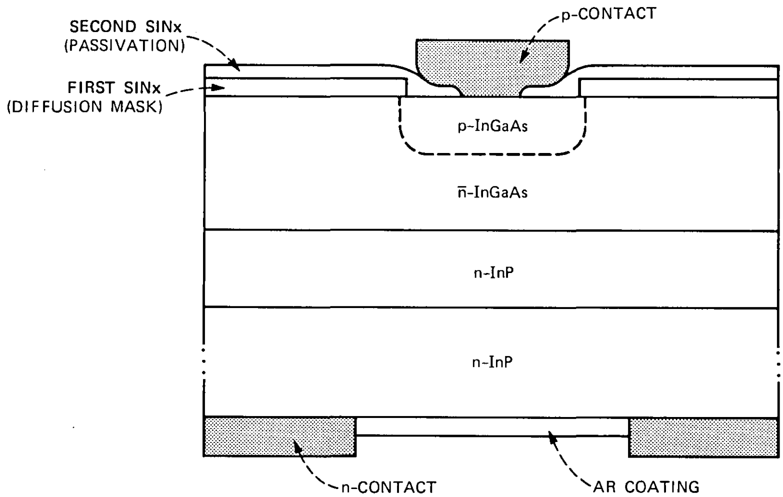

Fig. 4—Planar InGaAs PIN diode structure.

At a reverse bias of 10 volts, these diodes typically have a chip capacitance of 0.4 pF, room temperature (25°C) dark currents of 10 nA, and quantum efficiencies of 80 to 85 percent. The dark current increases with temperature to a typical value of 190 nA at 85°C. The rise and fall times of the diode are typically less than 250 picoseconds and 400 picoseconds, respectively.

3.2.3 GaAs FET amplifier

The transimpedance amplifier design is shown in Fig. 5. The input GaAs FET is cascode connected to a microwave PNP transistor to lower the Miller effect contribution to the front-end pole. The feedback resistance is 500 kΩ, the forward gain of the amplifier is approximately 30, and the resultant bandwidth is about 2 MHz. Thus, even though this is topologically a transimpedance design, there is significant integration of the baud rate signal and subsequent equalization is required.

Furthermore, the equalization is complicated by the output-limiting scheme used. The FET shunting the receiver input is operated at low drain-source voltage and is therefore nominally a resistor that can be varied by its gate voltage. Normal operation for the highest sensitivity requires the limiter-FET be shut off. At large signal levels, the gate voltage is raised and the limiter-FET shunts the input, reducing the dc gain. It also reduces the front-end time constant, changing the receiver bandwidth. The equalizer that follows must therefore track this variation, and its design is described in Section 5.5. The optical dynamic range of the receiver without the limiter-FET is about 25 dB, and with the limiter-FET it is about 45 dB.

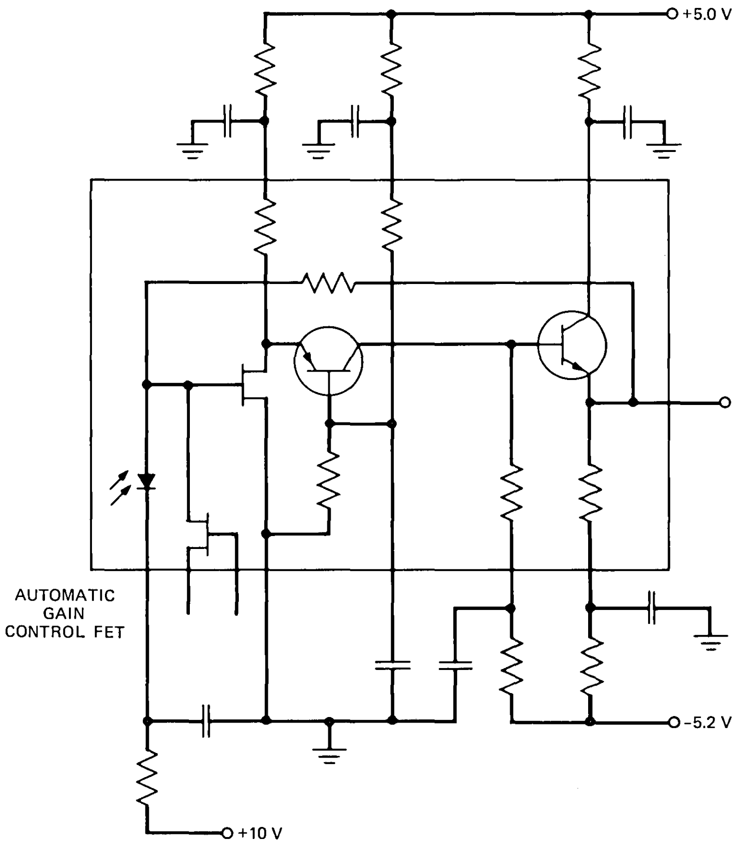

Fig. 5—1.3-μm InGaAs PIN-GaAsFET receiver preamplifier.

The GaAs FETs used in this receiver are microwave Metal Semiconductor Field-Effect Transistors (MESFETs) that have been modified to reduce their leakage currents. Typical gate-source capacitances (packaged) are about 0.6 pF, the minimum gm = 30 ms, and the gate leakage current is typically < 3 nA at 23°C.

The typical receiver sensitivity for a 10^{-9} Bit Error Rate (BER) is P = −52 dBm at a symbol rate of 12.6M baud at room temperature, and drops to approximately −51 dBm at the maximum system ambient temperature of 85°C.

IV. LIGHTGUIDE AND LIGHTGUIDE CABLES

4.1 Lightguide media

4.1.1 Optical fiber

To realize the desired system cost-effectiveness, the optical fiber had to be properly matched to the 1.3-μm LED/PIN. The basic fiber parameters, which can be varied to optimize the transmission characteristics, are defined in Fig. 6. These fiber parameters are core diameter (a), cladding diameter (b), and normalized refractive index difference (Δ). The refractive index shape is optimized for maximum transmission bandwidth (minimal modal dispersion). Moreover, a specially designed polymer coating is applied to the fiber cladding for protection from damage and to minimize transmission degradation due to mechanical (packaging, handling, installation) and environmental factors. For cost-effective embodiment of the loop feeder system, the optimal selection of fiber parameters, a, b, and Δ will provide the lowest loss, highest bandwidth transmission path when operated in the outside plant environment with the 1.3-μm LED/PIN modules.

4.1.1.1 Loss considerations. There are four loss mechanisms that are strongly dependent on the fiber design variables.

1. Source to fiber coupling loss (γ_c)—The power coupling efficiency between the microlensed LED chip and the fiber core area

$$\gamma_c(\mathrm{dB}) = 10 \log_{10} \left| \frac{K_c}{a^2\Delta} \right| . \tag{1}$$

2. Scattering loss (γ_s)—Basic or intrinsic glass fluctuations usually dominated by the Rayleigh scattering mechanism

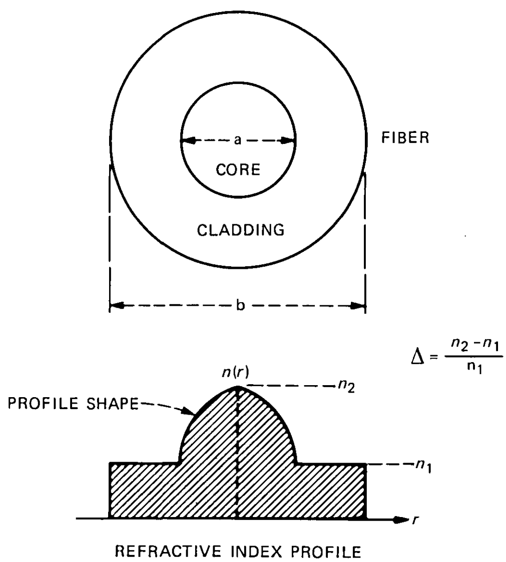

Fig. 6—Fiber parameters.

$$\gamma_s \left| \frac{\text{dB}}{\text{km}} \right| = \text{K}_s\, \Delta^{0.7} \text{ at } 1.3\ \mu\text{m}. \tag{2}$$

3. Microbending loss (γ_m)—Loss induced by random microdistortions or bends in the fiber axis; sensitive to packaging and the application environment. This is by far the most complex loss mechanism and is strongly influenced by the design and quality of the protective polymer coating:

$$\gamma_m \left| \frac{\text{dB}}{\text{km}} \right| = \frac{\text{K}_m a^4}{\Delta^3 b^6}. \tag{3}$$

4. Splicing loss (γ_{spl})—Extrinsic fiber misalignment at points of interconnection:

$$\gamma_{\text{spl}} \left| \frac{\text{dB}}{\text{splice}} \right| = \frac{\text{K}_{\text{spl}}}{a^{1.5}}. \tag{4}$$

To maximize system nonrepeatered distance, relative to loss considerations, it is necessary to minimize the total fiber parameter sensitive loss (γ_T), where

$$\gamma_T = \gamma_c + \gamma_s + \gamma_m + \gamma_{\text{spl}}. \tag{5}$$

Thus, for average cable reel lengths of 1 km (distance between splice points)

$$\gamma_T(\text{dB}) = \log_{10} \left| \frac{\text{K}_c}{a^2 \Delta} \right| + \left| \text{K}_s \Delta^{0.7} + \frac{\text{K}_m a^4}{\Delta^3 b^6} + \frac{\text{K}_{\text{spl}}}{a^{1.5}} \right| L, \tag{6}$$

where L is the distance in kilometers between the transmitter and receiver modules, and the K constants allow for parametric optimization of the link design. Two interesting points arise from eq. (6): first, the loss equation is only partially length-dependent (coupling is a one-shot function); and second, the optimal waveguide design is a function of desired (both present and ultimate) nonrepeatered system spacing.

4.1.1.2 Bandwidth considerations. In addition to dc attenuation, there is also signal distortion or pulse broadening (σ, RMS pulse width) along the fiber path, which is inversely proportional to the bandwidth (BW) or information-carrying capacity:

$$BW(\text{MHz}) = \frac{180}{\sigma(\text{ns})}. \tag{7}$$

Generally, fiber bandwidth is defined as the point in the baseband frequency response where the optical power is down 3 dB from its zero frequency value. Signal distortion is caused by chromatic (material) dispersion and modal delay differences. Material dispersion is a function of source spectrum and core materials, while modal effects depend on the fiber Δ and profile. Figure 7 shows the bandwidth spectrum for a narrow source (modal effects). In general the fiber modal bandwidth is inversely proportional to the varying power of Δ,

$$BW \alpha \frac{1}{\Delta^{y}}. \tag{8}$$

It is obviously advantageous to properly align the fiber spectral bandwidth with the system operating wavelength (λp).

The path bandwidth at the output end of a section of n concatenated (spliced) cable segments is given by

$$BW(L) = BW(1)L^{-x}, \tag{9}$$

where $BW(L)$ is the required output end (exit point) bandwidth after L kilometers of spliced-together cable (n segments), $BW(1)$ is the normalized 1-km bandwidth of a cable segment in MHz-km (quite often used as a means of supplier classification), and x is the length dependence exponent (sometimes referred to as "gamma"). The length dependence exponent can generally vary between 0.5 and 1.0, depending on the amount of intermodal power exchange, fiber design, buffer materials, core dopant materials, and λp relative to the system source

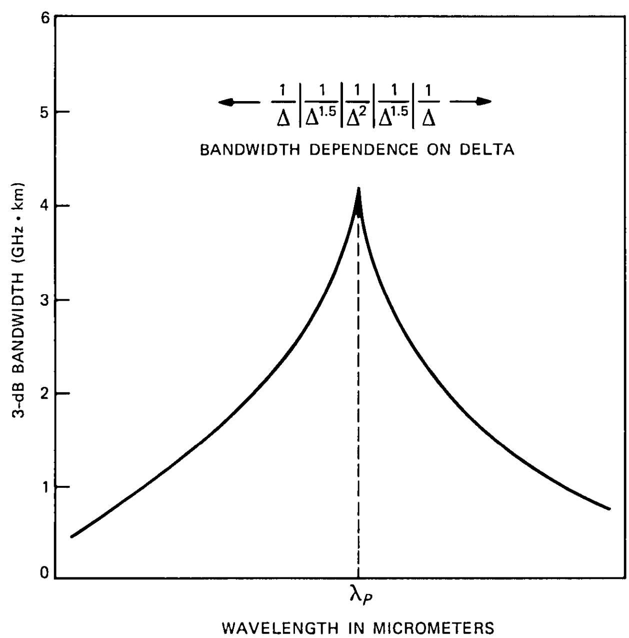

Fig. 7—Fiber spectral bandwidth for a narrow source.

wavelength. $BW(L)$, the required bandwidth at the cable exit point, or receiver input point, strongly depends on the transmitter/receiver used.

4.1.1.3 Fiber choice. The loss and bandwidth design eqs. (6), (8), and (9) can be combined to obtain design curves versus system spacing. These expressions were computerized along with cost sensitivity functions to facilitate the optimal design choice. In general terms, the loss design equation (6) drives a, b, and Δ to large values. Bandwidth constraints limit Δ to less than 2.2 percent. Cost and yield limitations require a, Δ, and especially b to be limited in magnitude. Also, as b increases the fiber becomes stiffer and thus affects cable handling. In order to take advantage of splicing apparatus commonality with other systems, b was chosen to be 125 μm. Δ was chosen to be as large as possible, 2.0 percent (numerical aperture 0.29), with allowed manufacturing tolerances. With these selections of b and Δ, the optimal clad-to-core ratio is approximately 2:1, so a was chosen to be 62.5 μm. Again it should be strongly emphasized that this selection of fiber parameters is optimal for a 1.3-μm LED/PIN based system. In fact, this design is 3.8 dB more efficient in LED power coupling than a $\Delta =$ 1.3 percent, a = 50-μm fiber, and 5.0 dB more efficient than a $\Delta = 1.0$ percent, a = 50-μm fiber. With installed cable losses less than 1 dB/km, this results in significant spacing improvements.

The AT&T Technologies, Inc. fiber production is subdivided into three categories for ease of planning and engineering. These cable grades are listed in Table I.

V. The DS2 PHASE OF THE FIBER *SLC* CARRIER SYSTEM

5.1 General description

As mentioned earlier, the DS2 optical transmission capability of the *SLC* 96 carrier system is built into the basic bank.[1] In the nonconcentrated mode the four DS1 signals originating in the four shelves are fed into two Optical Line Interface Units (OLIUs). The two OLIUs are identical and one is used for normal service and the other is used

Table I—Standard AT&T Technologies, Inc. fiber grades ($\lambda = 1.3$ μm, a = 62.5 μm, b = 125 μm, $\Delta = 2.0$ percent)

Grade	Loss (dB/km)	Bandwidth (MHz⊕km)
N	0.70	600
M	1.06	450
L	1.80	300

as a protection unit. Each OLIU multiplexes the four DS1 streams into a DS2 stream and then converts the electrical DS2 stream into an optical pulse stream for transmission on a lightguide. The light pulses from each OLIU are transmitted over separate fibers. In the receive direction the optical receiver provides the optical-to-electrical conversion and the electrical signals are demultiplexed into four DS1 streams. The two sets of DS1 streams from the two OLIUs are fed into a Line Switch Unit (LSU) that selects one of the sets and feeds it to the four TRUs.[1] Thus all multiplexing, demultiplexing, optical-to-electrical translations, and the lightguide medium are fully duplicated. This duplication protects against service interruptions due to any single failure. The functional block diagram of the OLIU is shown in Fig. 8. It physically consists of two printed circuit boards, one of which has all the opto-electronic components and the associated circuitry, and the other of which has the multiplexer circuitry. Optical and electrical connections are made to the backplane through built-in biconic optical connectors and gold fingers at the card edge. This

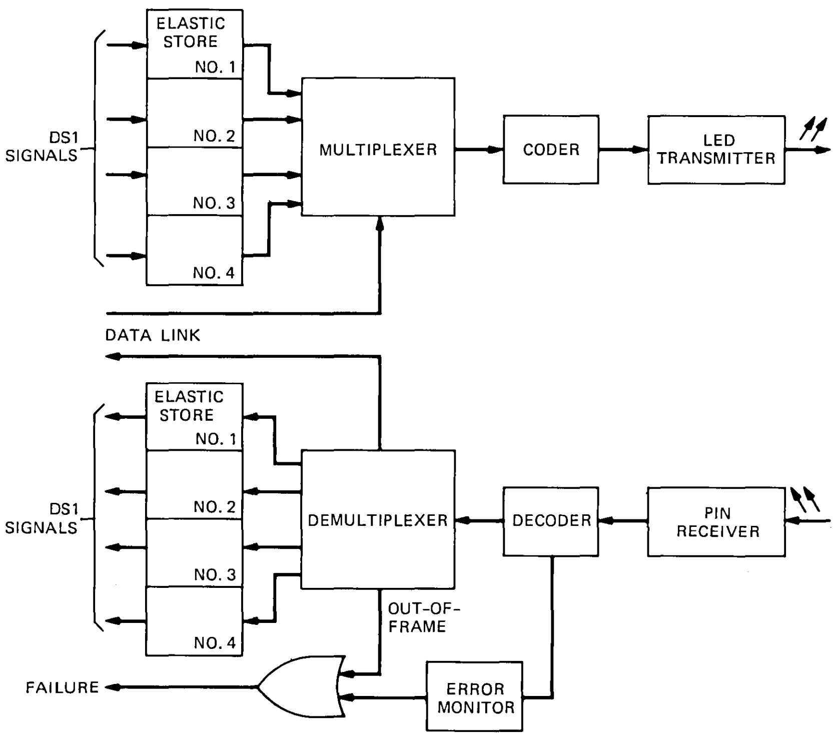

Fig. 8—Functional block diagram of the optical line interface unit.

connecting arrangement allows the craft to treat and handle the OLIU as any other circuit pack.

5.2 Multiplexer

The four DS1 signals that are multiplexed can be asynchronous and they are multiplexed into a DS2 stream by using standard bit-stuffing techniques.[7] The transmit and receive elastic stores are implemented by two custom gate arrays. Each gate array contains two transmit and two receive elastic stores, allowing the two gate arrays to be identical. The multiplex and demultiplex operations are done by two custom Complementary Metal-Oxide Semiconductor (CMOS) integrated circuits.

In transmission systems operating on wire pairs at the DS2 rate, the signals are coded to be bipolar with the B6ZS format to minimize crosstalk and ensure a minimum one's density for the recovery of clock signal at the far end. For optical transmission at the DS2 rate a two-level Nonreturn to Zero (NRZ) signal was chosen and, for ease of clock recovery, alternate dipulse coding was used. As illustrated in Fig. 9, zeros in the data stream are transmitted as a 10 pair while alternate ones are transmitted as 11 or 00. This code obviously doubled the line rate but this was not of practical importance since all fibers used with this system are capable of being used at 90 Mb/s. All DS2 installations should have the capability to be upgraded to the DS3 rate by the addition of DS3 multiplexers at the central office and remote terminal, and hence the spacing between terminals is determined by the distance limitations at the DS3 rate, and the extra range possible at the DS2 rate is not utilized. The advantages of using the alternate dipulse code are that it allows for simple clock recovery and error detection. The dipulse decoder in the receive direction has an error output lead that

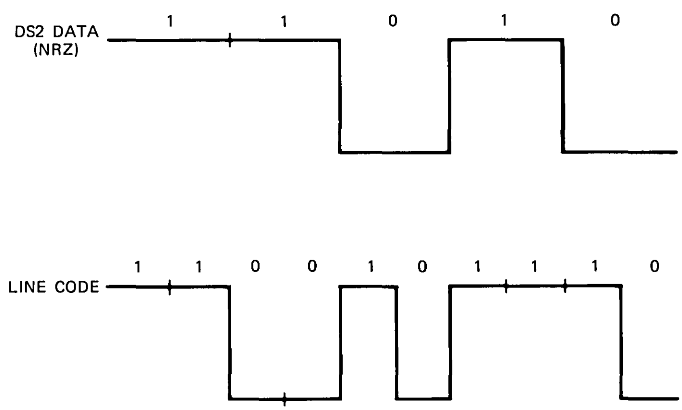

Fig. 9—Alternate dipulse coding.

indicates every error in the pulse stream. The error monitor processes these errors and puts out an error signal whenever the errors in a predetermined time interval exceed the set limit. The error rate at which error signal is activated is switch selectable for one error in 10^4, 10^5, or 10^6 bits. DS2 transmission is declared to have failed if either the bit error rate exceeds the set threshold or if the incoming bit stream cannot be framed.

5.3 Protection switching

The LSU implements the protection switching feature. In the transmit direction, both OLIUs multiplex the four DS1 signals originating in the four shelves and transmit them at all times. No switching is involved in the transmit direction. However, in the receive direction, the LSU has the capability to select one of the OLIUs and transmit the DS1 signals from it to the TRUs, as shown in Fig. 10. Control logic on the board determines which OLIU is chosen. The determination is made on the basis of DS2 failure indications from the OLIUs. Switching is also controlled by analogous information received from the far end over a data link. The data link is formed out of the M4 bit in the DS2 format that is normally used for terminal alarms. The M4 bit is available 5367 times per second and data are transmitted asyn-

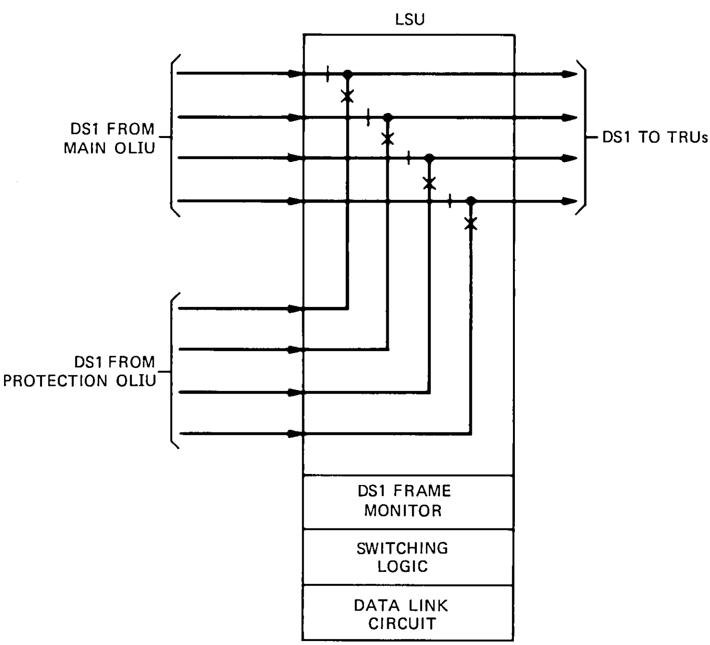

Fig. 10—Functional diagram of the line switch unit.

chronously at 300 bits per second. This one-bit-wide channel is expanded to eight bits by the use of a Universal Asynchronous Receiver/Transmitter (UART), and twenty words can be sent per second. Various failures detected by the LSU are used to control the minor and major alarm buses of the system to generate the appropriate system alarms.

5.4 Optical transmitter

The optical transmitter circuit essentially consists of a constant current source feeding the LED and a high-speed shunt switch that diverts the current from the LED. Implementation of a circuit that does the above would normally be straightforward except for other restrictions on the circuit imposed by the system in general. In addition to the generation of light pulses with the appropriate rise and fall times, the circuit has to satisfy several other requirements. The LED power output variations due to variations in ambient temperature, power supply voltages, and ohmic resistance of the LEDs from one device to another should be kept to a minimum. A decrease in the effects of these variations on the optical power output has a direct effect on the range of the system, since the range has to be based on the minimum output power. The power supply voltages available for the operation of the circuit are +5, +12 and −12. To minimize the power dissipation it was desired to draw all the required power from the +5V supply. This supply is regulated to within ten percent of its nominal value and variations in it should not affect the current source. The circuit shown in Fig. 11 satisfies these requirements. The collector current of the transistor Q1, which is essentially the same as its emitter current, is regulated to a constant value by the combination of the operational amplifiers OA1, OA2, the associated resistors, and the +5V reference. The regulated current normally flows through the LED. The four nand gates, with small series resistors in their output leads to minimize current hogging, are connected in parallel and act as the shunt switch to divert the current away from the LED and thus to turn it off. The capacitor C1 gets charged when the LED is turned on, and this voltage is used to offset the voltage across the shunt switch during its "on" state. This tends to decrease the fall time of the light output. The circuit can provide up to 200 mA of current to the LED, as determined by R2. Once set, the current varies no more than a couple of percent over the temperature range of −40 to +85°C, ±10 percent variations in the supply voltages, and a relatively wide variation in the ohmic resistance of the LED. One disadvantage of the circuit is that the current drawn by the circuit is independent of the one's density in the data stream; thus on random data, the total current drawn is twice what is absolutely needed from the +5V supply.

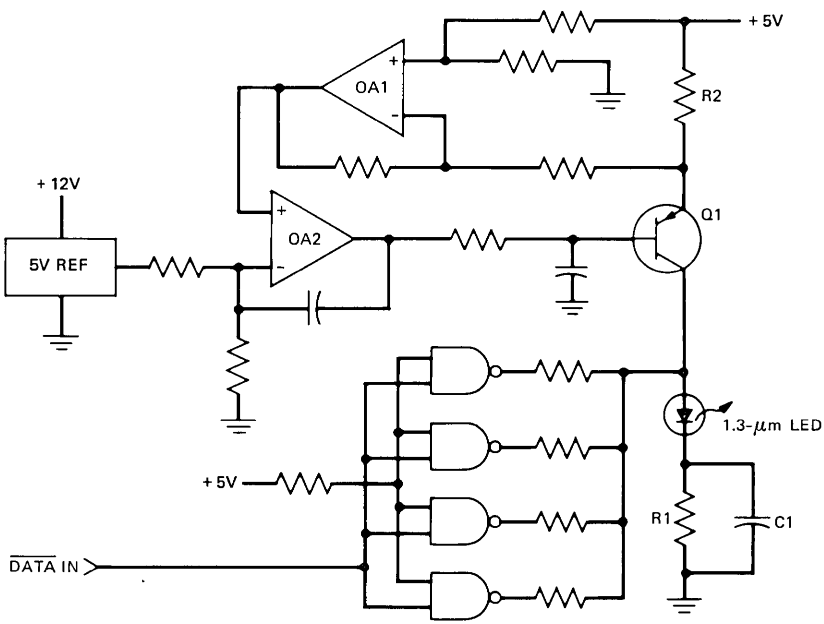

Fig. 11—Simplified circuit diagram of the LED transmitter.

This disadvantage is more than compensated for by the fact that the ground and power supply noises on the board that also accommodates the optical receiver are kept to a minimum.

5.5 Optical receiver

Figure 12 shows the receiver section of the optical line interface unit, which comprises the photodetector/transimpedance preamplifier assembly, preamplifier output limiter, linear channel/AGC/equalizer section, and clock recovery. The receiver was designed to operate over a local component temperature of −40 to +85°C and have a worst case sensitivity of −50 dBm. A design feature of this receiver is its ability to operate over an optical input power dynamic range of 45 dB.

5.5.1 Limiter circuit

Optical receivers generally have a limited dynamic range over which they can satisfactorily process incoming optical signals. The typical optical power dynamic range of an LED-based system is 40 dB, which represents an 80-dB voltage range over which the receiver must operate. Most fiber optical communication systems are limited to a 20- to 25-dB optical dynamic range (or 40- to 50-dB voltage range). This limitation is due to the onset of overloading at the output of the preamplifier shown in Fig. 12. In such a system, if the transmitter and

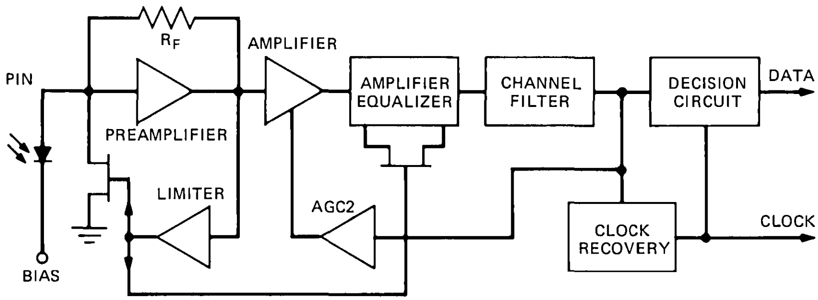

Fig. 12—Block diagram of an optical receiver.

receiver are located in proximity, optical attenuators must be inserted into the lightguide path to reduce the incoming optical signal strength to within the dynamic range of the receiver. These optical attenuators represent additional component, engineering, and administrative costs to the system user and therefore are undesirable.

There are several ways of increasing the dynamic range of optical receivers, including varying the impedance of the feedback resistance, R_F, of the transimpedance preamplifier, varying the gain of the transimpedance preamplifier and shunting photocurrent away from the preamplifier at high optical input levels. The method chosen for the present receiver was the shunting method. The reasons for this choice are beyond the scope of this paper, but include factors related to the effect of each method on receiver sensitivity, accuracy of control, and ease of implementation. A simplified circuit diagram of the implementation of the photocurrent shunting is shown in Fig. 13. The circuit shown separately controls the dc and ac portions of the photocurrent with FET_1 used as the shunting element at the input of the transimpedance preamplifier.

The circuit operates as follows. The dc component of the photocurrent generated in the photodiode flows through the Q_2 branch of the current mirror pair Q_1–Q_2 and is reflected through Q_1. This current is then inverted in the Q_4 leg of current mirror Q_4–Q_5 and reflected by Q_5, which is connected to the input of the transimpedance amplifier through the FET. Through the operation of the sense and sink current mirrors, the dc component of the photocurrent is effectively diverted through the FET, away from the input of the transimpedance preamplifier.

The remaining ac component of the photocurrent is amplified by the transimpedance preamplifier and sensed by the peak detector comprised of D2–D4, Q_6–Q_8, and the passive components associated with these devices. When the peak ac voltage at the peak detector exceeds a certain value, Q_8 begins to conduct and turns on FET_1,

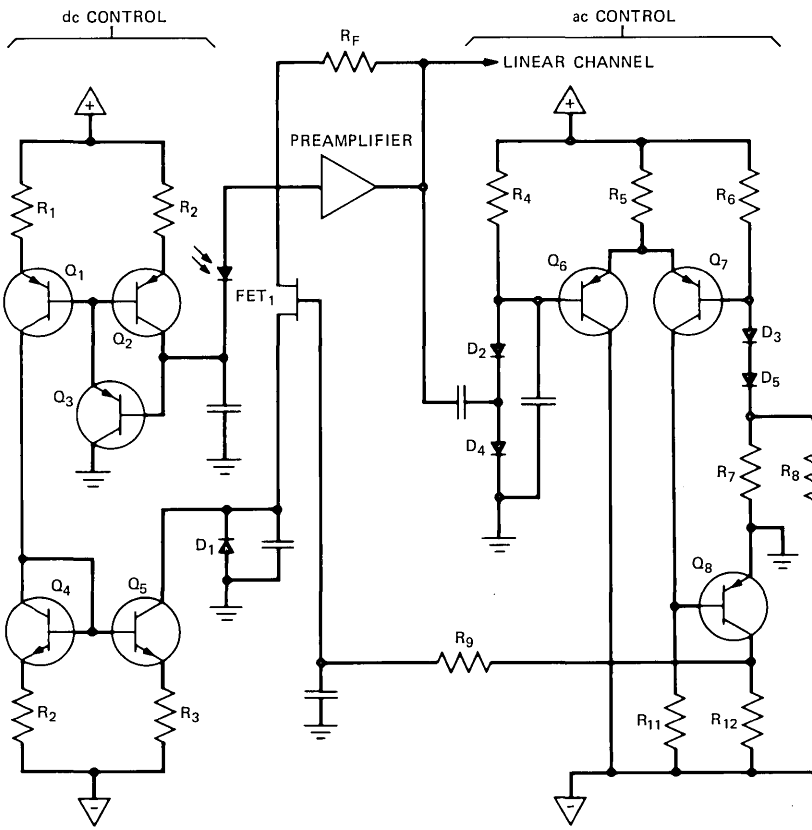

Fig. 13—Simplified circuit diagram of output limiter circuit used to increase the optical receiver dynamic range.

providing an ac impedance shunting the input of the transimpedance amplifier. Thus, the output voltage swing of the preamplifier is limited.

In this implementation, Q_1 through Q_8 are all on one integrated circuit and D2 through D5 are specially matched diodes for improved temperature and voltage tracking. The shunt FET is incorporated on the same thick-film hybrid integrated circuit as the preamplifier in order to reduce stray and packaging capacitances associated with it.

Since the shunt FET is off during low input signal operation, the only effect of the FET on the sensitivity of the preamplifier is due to leakage currents through the drain and capacitive effects on the channel noise and 1/f noise of the preamplifier input FET. These effects result in less than 0.5-dB degradation of the receiver sensitivity. The FET limiter action begins at an input power level of approximately −30 dBm. The maximum allowable input power of the receiver is essentially limited by the minimum "ON" resistance of FET_1 and is approximately −10 dBm.

5.5.2 *Linear channel and equalizer*

The linear channel and equalizer is comprised of the amplifier, equalizer, channel filter, and AGC blocks of Fig. 12. The amplifier section is realized with two IC amplifiers: a wideband AGC amplifier, and a wideband, fixed-gain amplifier whose response is tailored to generate a pole-zero pair needed for the equalization of the limited frequency response of the transimpedance preamplifier.

The AGC amplifier is capable of 40-dB gain, and an AGC range of 60 dB. The control for the AGC amplifier is generated by the monitoring of the output signal of the channel filter by a peak detector. The low-pass filtered output of the peak detector is compared against a reference voltage and the resultant signal is used to control the gain of the AGC amplifier. As can be seen from Fig. 12, the AGC control loop and the limiter control loop are completely separate and therefore coupled oscillation between the two loops is impossible. In addition, interaction between the two loops is minimized by the widely separated time constants of the two control loops. Since the limiter circuit is meant to absorb long-term variations (such as cable temperature and equipment temperature variations), its time constant is made much longer than that of the AGC circuit time constant, which absorbs shorter-term variations.

A simplified circuit diagram of part of the fixed-gain, equalizing amplifier is shown in Fig. 14. The need for equalization, and, in particular, adjustable equalization, can best be shown by means of Fig. 15. This figure shows a small signal representation of the transimpedance preamplifier, including the effect of the limiter FET. Here i_s is the ac photocurrent, C_F is the stray capacitance associated with the thick-film feedback resistor, C_{IN} is the capacitance associated with the preamplifier input and the shunt FET, and R_{FET} is the variable ac resistance of the shunt FET. It is easily shown that v_{out} is given by

$$v_{\mathrm{out}} = \frac{-\left|\dfrac{R_{\mathrm{FET}}\cdot R_F/(1+A)}{R_{\mathrm{FET}} + R_F/(1+A)}\right| A i_s}{1 + j\omega \left|\left|\dfrac{R_{\mathrm{FET}}\cdot R_F/(1+A)}{R_{\mathrm{FET}} + R_F/(1+A)}\right| [(1+A)C_F + C_{\mathrm{IN}}]\right|}. \tag{10}$$

At low signal levels, where the shunt FET is off, this reduces to

$$v_{\mathrm{out}} = \frac{-\dfrac{A}{1+A} R_F i_s}{1 + j\omega \left|R_F \left|C_F + \dfrac{C_{\mathrm{IN}}}{1+A}\right|\right|}. \tag{11}$$

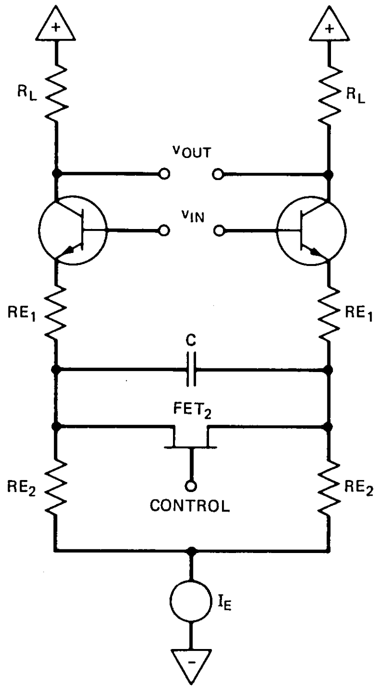

Fig. 14—Simplified circuit diagram of fixed-gain equalizing amplifier.

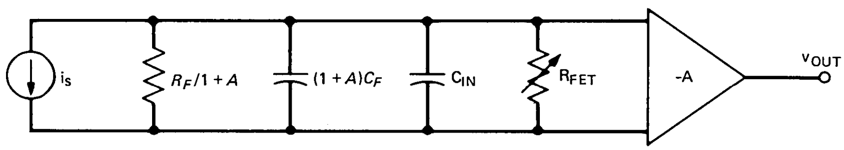

Fig. 15—Small signal representation of transimpedance preamplifier.

The low signal pole shown in the above equation is on the order of 2 MHz and therefore must be equalized. This equalization is accomplished by means of the pole-zero pair formed by R_{E1}, R_{E2} and C, shown in Fig. 14, the zero canceling the transimpedance preamplifier pole. However, it is clear that as the shunt FET turns on, the preamplifier pole shifts to higher frequencies, and therefore the equalizer must be made to track this change. This is accomplished by simultaneously turning on FET_2 in Fig. 14, which moves the equalizer pole-zero pair to higher frequencies. Since the shunt FET does not turn on until the input optical power is well above the noise floor of the receiver, some misequalization can be tolerated and the tracking between the limiter FET and equalizer FET need not be perfect.

The remaining portion of the linear channel is the channel filter, which is a five-pole filter with complex poles at $6.42 \pm j\ 8.06$ MHz, $18.9 \pm j\ 9.88$ MHz, and a real pole at 12.4 MHz. The low-frequency response of the linear channel is limited by interstage coupling capacitors and is made to be approximately 7 kHz. This low-frequency cutoff is somewhat higher than what one normally considers appropriate in digital communications systems at the present baud rate; however, because of the alternate dipulse coding used here, the usual baseline wander problems associated with low-frequency rolloff are minimized. This is because the longest string of continuous "1's" or "0's" is this coding scheme is three. This then allowed the use of physically smaller interstage coupling capacitors, which simplified printed wiring board layout problems.

5.5.3 Clock recovery

The dipulse-coded data at the output of the linear channel contain a component of the clock needed to receive and decode the alternate dipulse signal. This clock information is contained in the positive-going transitions of the data, which occur at the 6.312 MHz rate.

A block diagram of the clock recovery circuit is shown in Fig. 16. The 12.624-Mb/s output of the channel filter is input to a comparator, which acts as a zero crossing detector. The comparator output is used to trigger a precision one-shot multivibrator; the one-shot is used to provide one pulse for each zero to one transition. The width of the one-shot pulse is factory selected and ultimately determines the clock–data phase relationship. The output of the one-shot multivibrator is fed into a monolithic crystal filter, which extracts the 6.312-MHz component. The phase delay of the crystal filter is modulated by the pulse width of the one-shot output and is used to adjust the clock–data phase relationship. The balanced sinusoidal output of the crystal filter is then amplified and squared-up by the output comparator, resulting in a phase-adjusted, 6.312-MHz square wave clock.

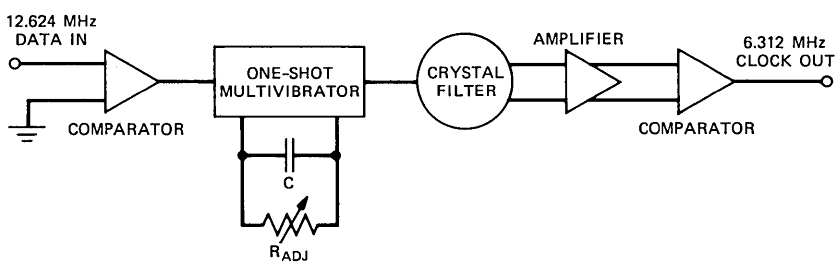

Fig. 16—Block diagram of clock recovery circuit.

VI. OUTLINE OF THE DS3 PHASE

The DS3 phase of the Fiber *SLC* carrier system is an important enhancement to the DS2 phase, since the capacity of the installed lightguides can be increased seven-fold by the addition of DS2/DS3 multiplexers at the CO and RT. The attractiveness of this is further enhanced by the fact that the system uses no repeaters that might have to be upgraded to the higher rate. All additions and modifications to the DS2 rate system are done at the terminals only and the cable plant is untouched.

The DS3 phase is currently under development and the design details will be the subject of a future paper. The DS2/DS3 multiplexer will consist of one shelf of equipment at the CO and one at the RT. The shelf at the RT is augmented by a battery charger and batteries for protection against ac power failures. A simplified block diagram of the multiplexer is shown in Fig. 17. Each shelf essentially consists of two DS2/DS3 multiplexers. Like the DS2 system, it uses four lightguides, two for normal operation and two for protection. Each low-speed interface card receives electrical DS2 signals from a DSX-2 cross-connect. The OLIUs in a *SLC* 96 carrier system are replaced by

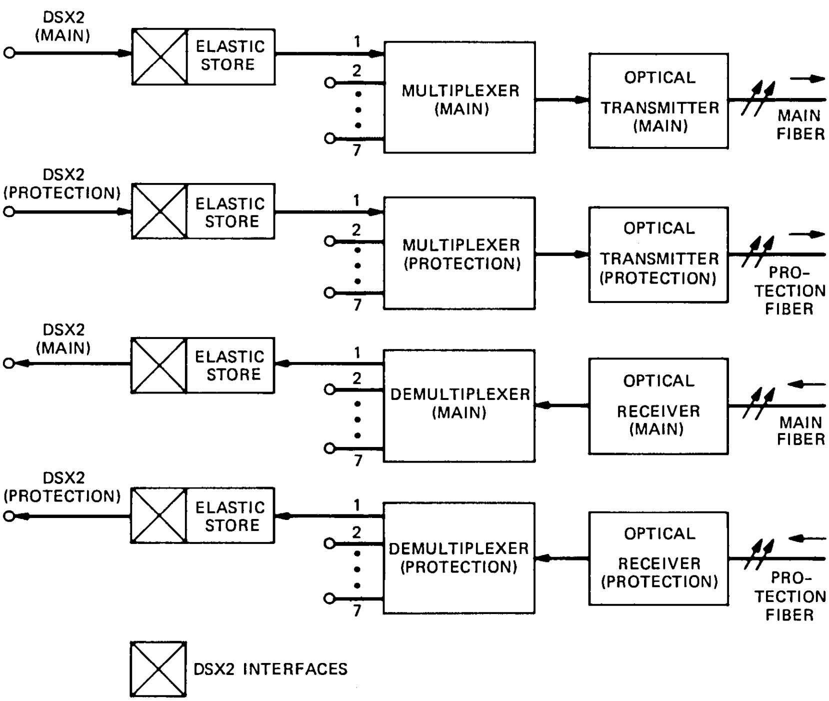

Fig. 17—Block diagram of DS2/DS3 multiplexer.

electrical DS2 circuit packs called ELIUs, which receive and transmit electrical signals from a DSX-2 cross-connect. The main and protection DS2 electrical signals are connected to the main and protection side of the DS3 multiplexer. A major advantage of preserving the main and protection sides of the *SLC* 96 carrier system is that DS2 to DS3 upgrading can be done without service interruptions. This is easily accomplished by first locking the system in the main operation mode on lightguides and transferring the protection side to operate through the DS3 multiplexer. Once the protection side is operating through the DS3 multiplexer, the main side is transferred similarly. The operation does cause two clicks to be heard on a voice line but does not drop any calls that are in progress. The optical part of the system uses the same 1.3-μm LEDs and PINs as in the DS2 system, but the transmitter and receiver circuits associated with them are very different due to the difference in bit rates.

VII. THE FUTURE FOR THE FIBER *SLC* CARRIER SYSTEM

Improvements in opto-electronic devices, like increased power outputs from the sources and increased sensitivities in the detectors, are bound to occur. These improvements will certainly allow an increase in the nonrepeatered range of operation. The extra optical losses that can be tolerated between the source and the detector will be useful in other important ways also. Wavelength division multiplexers that allow the operation of several systems on the same lightguides introduce additional optical losses and these losses can be overcome with improved devices without a decrease in nonrepeatered range. Also, multilevel coding techniques will become feasible without a decrease in the range. Both of the above techniques can increase the transmission capacity of the lightguides significantly.

The availability of high-bit-rate transmission capability in the feeder plant provided by lightguides is expected to hasten the introduction and application of many wideband services like customer DS1 and picture services.

VIII. ACKNOWLEDGMENTS

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The SLC *96 Subscriber Loop Carrier System:*

Integration With the *5ESS* Switching System

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(Manuscript received August 1, 1983)

A new *5ESS*™ switching system peripheral unit provides an efficient integrated interface to Remote Terminals (RTs) of the *SLC*® 96 digital subscriber loop carrier system. This unit has been named the Digital Carrier Line Unit (DCLU). Each DCLU serves up to six remote terminals [576 Plain Old Telephone Service (POTS) lines]. Each T1 line from an RT terminates on a Digital Facility Interface (DFI) circuit pack, which is the microcomputer-controlled circuit pack used in the *5ESS* switching system to interface to T1 lines. The DCLU consists of up to thirty of these DFIs. For purposes of control, the DFIs are separated into two service groups of fifteen DFIs each. There is one control multiplexer circuit pack for each service group. Also there are two data multiplexer circuit packs that are shared by all thirty DFIs. The design of the DFI is described in this paper. The software structure of the *5ESS* switching system is explained in general terms and then the software that had to be expanded to support integrated *SLC* 96 carrier systems is outlined. The paper concludes by describing the topology and traffic-handling capability of the two-stage switching network formed by the DCLU and the remote terminals that are connected to it. The first *SLC* 96 carrier system integrated into a *5ESS* switch went into service on April 14, 1984, in Spotsylvania, Virginia.

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I. INTRODUCTION

A new *5ESS* switching system peripheral unit provides an efficient integrated interface to Remote Terminals (RTs)* of the *SLC* 96 digital subscriber loop carrier system. This unit has been named the Digital Carrier Line Unit (DCLU). The remote terminal of each *SLC* 96 carrier system time-multiplexes 96 lines onto two (if concentrated) or four (if nonconcentrated) primary T1 digital lines. The concentrated systems are designated Mode 2 systems, and the nonconcentrated systems are designated Mode 1 systems. Each RT also has a protection T1 digital line that is switched into service automatically if one of the primary T1 lines should fail. The economic advantages of integrating digital subscriber carrier and digital switching systems have been addressed in a number of earlier papers.[1–3] This paper addresses the design rather than the economics of such an integrated interface.

Primary design objectives for the integration of the *SLC* 96 carrier system with the *5ESS* switch include:

- The total concentration ratio (at both the RT and the Central Office [CO]) for lines served by either a concentrated or a nonconcentrated integrated *SLC* 96 carrier system should be equivalent to the CO concentration ratio for lines served directly over copper pairs from the central office.
- The software must be designed so that it is transparent to the *5ESS* switch components that do not terminate integrated *SLC* 96 carrier systems.
- The software required to support the integrated *SLC* 96 carrier system should meet the modular design criteria for the *5ESS* switch software.

The design described here meets all three of these objectives.

In the remaining sections of this paper we describe the overall architecture, the hardware design, and the software structure for the integration of the *SLC* 96 carrier system with the *5ESS* switch. Then, we discuss the traffic capacity and present our conclusions.

II. ARCHITECTURE

Figure 1 is an overall block diagram of a *5ESS* switch office equipped with a DCLU. As described in Ref. 4, the office consists of an Administration Module (AM) and a number of Switching Modules (SMs) interconnected by a Communication Module (CM). Each switching module consists of common equipment, a Switching Module Processor Unit (SMPU) and a Time Slot Interchange Unit (TSIU), plus a number of Interface Units (IUs). The function of these IUs, of

* Acronyms and abbreviations used in the text are defined at the back of the *Journal.*

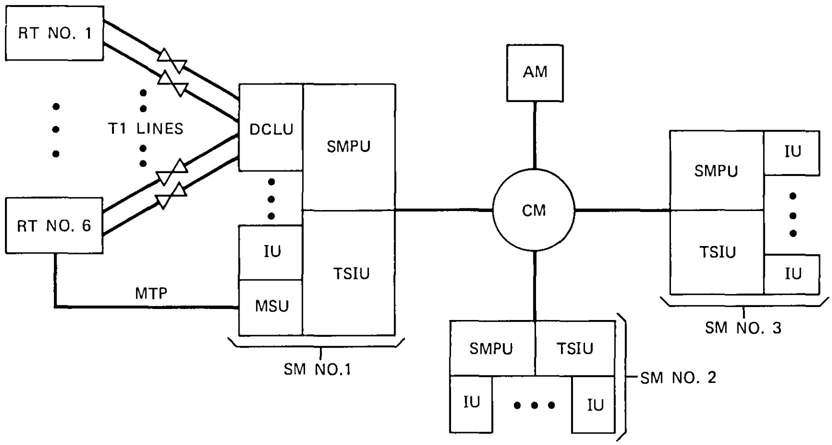

Fig. 1—*5ESS* switch equipped with digital carrier line unit.

which the DCLU is one, is to terminate lines, trunks, or service circuits on the *5ESS* switch. An IU exchanges control messages with the SMPU using 2.048-Mb/s Peripheral Interface Control Buses (PICBs) and sends pulse code modulation (or other) data to the TSIU over 4.096-Mb/s Peripheral Interface Data Buses (PIDBs).

Figure 2 is a block diagram of the DCLU. Each DCLU serves up to six remote terminals [576 Plain Old Telephone Service (POTS) lines]. The RTs are connected to the DCLU by up to 30 T1 lines.* The DS1 signal from each T1 line terminates on the DCLU on the facility side of a Digital Facility Interface (DFI) circuit pack.† The DFI performs various functions, such as framing, associated with the termination of a DS1 digital bit stream.‡ As shown in Fig. 2, each DFI is connected to both data multiplexers and both control multiplexers using dual data and control buses.

The function of the data and control multiplexers is to concentrate the DFI data and control buses onto a smaller number of PIDBs and PICBs. The topology of the concentrator in the data path is discussed in Section V.

Under nonfailure conditions, the data multiplexers operate in a load-sharing mode, with each taking part of the traffic load from all thirty DFIs; whereas, each control multiplexer is dedicated to a service group of fifteen DFIs. Hence, the RTs terminating on a DCLU are divided into two service groups, A and B. The DFIs associated with

* The number of T1 lines connected to a given DCLU depends both on the fill of that DCLU and the mode of operation (concentrated or nonconcentrated) of its RTs.

† An office repeater bay and a DSX-1 cross-connect are used between the outside plant T1 facilities and the DFIs.

‡ The operation of the DFI is described in more detail in Section III.

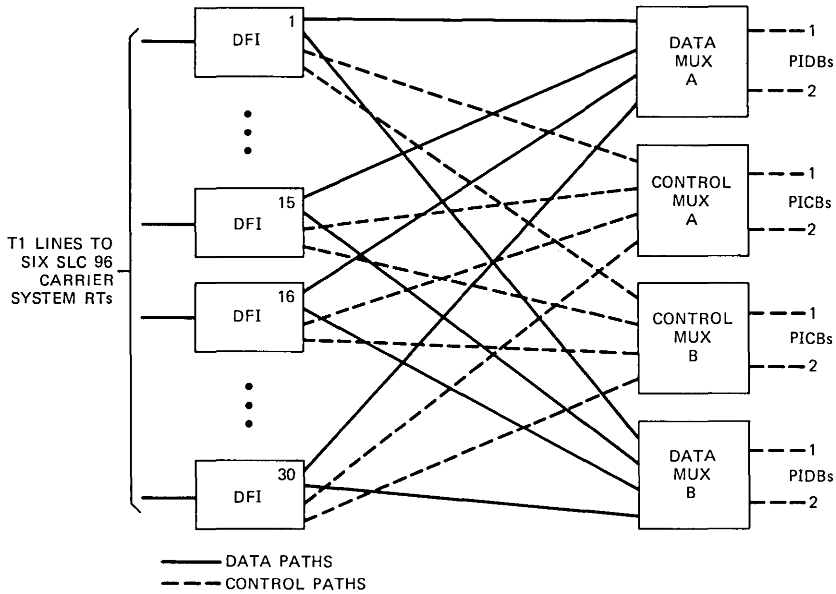

Fig. 2—*5ESS* switch digital carrier line unit.

the three RTs in service group A normally use the control multiplexers labeled "A" in Fig. 2, while the DFIs from service group B normally use the "B" control multiplexers. However, if a DCLU data or control multiplexer fails, all traffic is handled by the working data and control multiplexers. Of course, the traffic capacity is diminished if a data multiplexer fails, but no customer is permanently deprived of service. Protection line switching is done by the appropriate data multiplexer upon receipt of a command from the SMPU.

The two PICBs connected to each control multiplexer are used for different purposes. The first PICB is used to send messages to the service group common circuitry *or* to designate the address of a particular DFI circuit pack. Once a DFI has been addressed over this first PICB, the second PICB is used to send subsequent communications to the designated DFI. Control of the DCLU is implemented by a combination of firmware stored in the microprocessor that is on each DFI circuit pack and software stored in the SMPU.

Remote terminal lines on an integrated carrier system are maintained and tested via a Metallic Test Pair (MTP). The MTP provides craft with a metallic test connection to the line at the RT from the Metallic Service Unit (MSU) of the *5ESS* switching system as shown in Fig. 1. This connection allows testing via the Local Test Desk (LTD), the Mechanized Loop Testing (MLT) system, or the Trunk and Line Work Station (TLWS). The MTP can be shared by both universal *SLC* 96 and integrated *SLC* 96 carrier systems. Accurate measurements will result if the customer equipment is within an ohmic range of 3000 ohms (10.9 miles using 24-gauge wire) of the testing equipment.

III. HARDWARE DESIGN

The hardware structure of the DCLU consists of up to thirty DFI circuit packs separated into two service groups of up to fifteen DFIs each. Also, there is one control multiplexer circuit pack for each service group and two data multiplexer circuit packs. (See Fig. 2.) Each DFI has control and data access to both data multiplexers and both control multiplexers.

3.1 DFI description

The DFI is a microcomputer-controlled circuit pack that is used in *5ESS* switching equipment to interface to the DS1 signals from T1 lines and trunks. Different versions of this basic circuit pack are used for terminating remote terminals of the *SLC* 96 carrier system and for terminating digital trunks from channel banks or other electronic switching machines. Figure 3 is a block diagram of the DFI circuit pack. The DFI used in a DCLU must have the capability of processing the data link that is used for transferring control information to and from the remote terminal of the SLC 96 carrier system. This Facility Data Link (FDL) is obtained by robbing some of the framing bits used on the digital line and using them for a data link. The FDL carries alarm, maintenance, and protection-switching control messages. In addition, for a concentrated *SLC* 96 carrier system, the FDL also carries the call-origination information that is used by the SMPU to control the Time Assignment Unit (TAU)[5] in the RT.

Signaling and PCM data flow through the DFI is managed primarily by three multimode custom LSI devices, the Framer (FR), the Receive Synchronizer (RS), and the Transmit Formatter (TF). The framer is responsible for maintaining proper frame alignment on the digital line in both directions and for extracting and inserting the FDL. It also checks for facility fault conditions and alarms. The incoming FDL is sent to a Universal Synchronous/Asynchronous Receiver/Transmitter (USART) that handles the message formatting, while the incoming PCM data goes to the RS. The RS converts the data from line timing to system timing by providing an elastic storage buffer for the data. Once the data have been retimed, they are ready to be sent to the TSIU via the data multiplexer. Signaling and data from the TSIU and data multiplexer are reformatted by the TF and sent to the FR. The FR also receives the outgoing FDL from the USART. The framer

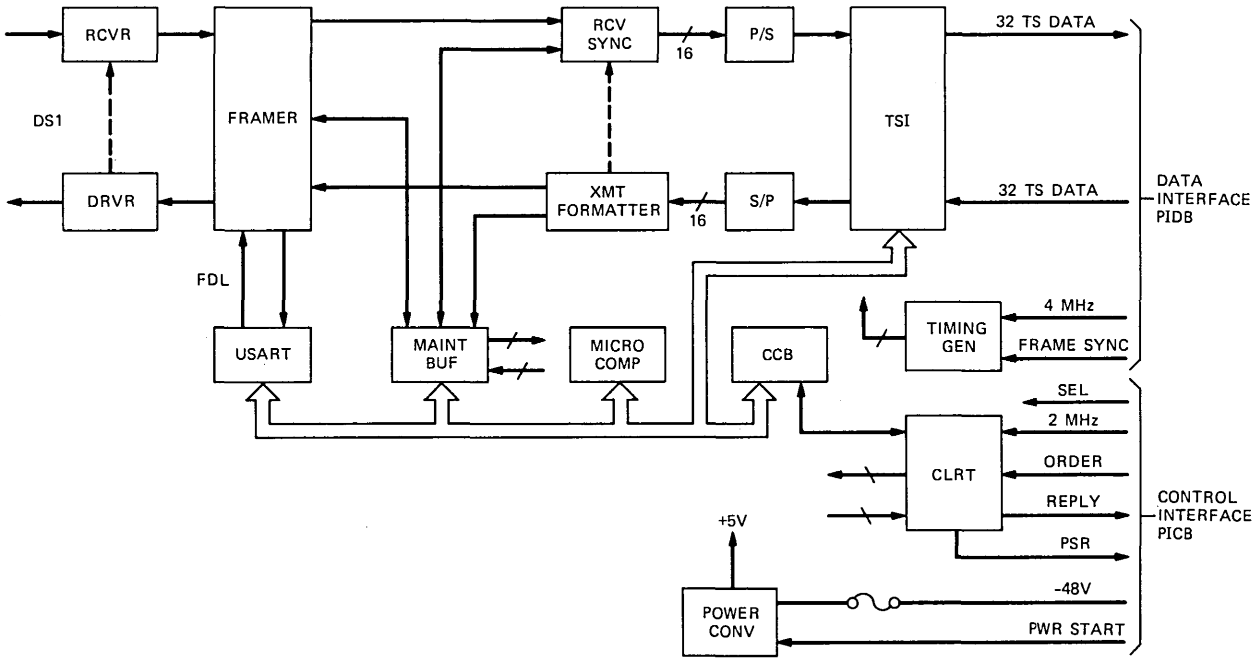

Fig. 3—Digital facility interface.

reinserts the FDL into the framing pattern, reformats the data from the TF, and sends them out over the T1 line.

Timing for the data flow through the DFI is accomplished by processing a 4-MHz clock and 8-kHz synchronization pulse received from the *5ESS* switch TSIU. Two custom gate arrays and a phase locked loop generate most of the timing signals needed on the circuit pack.

Another feature incorporated into the DFI for the DCLU is a 32 by 64 Time Slot Interchanger (TSI) LSI device that provides the switching capability needed to terminate nonconcentrated remote terminals (see Section V).* This device also does A and B signaling bit scanning to allow the DFI to detect off-hook and is capable of sending idle code (that is programmable on a per-time-slot basis) towards the RT. The device interfaces to the hardware on the switch side of the RS and TF and is controlled by the DFI microcomputer.

3.2 DFI control

Control and maintenance of the DFI is accomplished by an on-board microcomputer with 4K bytes of ROM and 256 bytes of RAM. The microcomputer has access to the maintenance information generated by the FR, RS, and TF. This information includes out-of-frame, remote alarm, clock slips, etc., as well as internal device alarms. Each of these devices receives a serial control stream from the microcomputer, which serves to configure and exercise the devices. The microcomputer also has access to the USART for sending and receiving messages over the FDL from the RT.

Communications between the DFI microcomputer and the SMPU takes place through the control multiplexer over the PICBs. Each PICB includes serial control data in both directions, clock and select signals from the SMPU, and provision for service requests from the DFI. Since the SMPU is duplicated, the select signal is needed to indicate to the DFI which SMPU side is active. The service request lead tells the SMPU that a message from the DFI is pending. Two custom LSI devices are used on the DFI to handle messages in each direction. One device handles the PICB protocol, while the other is a dual-port RAM that can be accessed directly by the microcomputer. This device, called the Control Communications Buffer (CCB), has 62 registers in each direction for messages and an activity flag associated with each register.

The microcomputer firmware uses data it collects from the FR, RS, and TF, and receives control information from the SMPU through

* For concentrated RTs, the time slot interchanging function in this device (but not its other functions) is bypassed.

the CCB in order to process various alarm and status conditions associated with both the T1 lines and the DFI hardware. This processed information is then made available to the SMPU, again through the CCB. Some of the facility alarms processed and reported by the firmware include incoming signal failure (red alarm), remote alarm messages, error rates high enough so that a major or minor alarm should be raised, out-of-frame counts, and clock-slip counts. Hardware maintenance alarms include several exercise alarms and a ROM checksum alarm. The SMPU can perform many on-demand operations on the microcomputer such as exercising any LSI device, presetting facility counters, and sending remote alarm messages.

The firmware also has responsibility for encoding and decoding messages sent over the FDL through the USART. Depending on whether the RT is concentrated or nonconcentrated, the firmware processes three or four data-link fields: a concentrator field, a maintenance field, an alarm field, and a switch field, each with its own set of messages.

IV. SMPU SOFTWARE

4.1 Summary of 5ESS *switch software structure*

The Operating System for Distributed Switching (OSDS) is the operating system that executes in a *5ESS* switch module.[6] It supports multiple processes and interprocess communications. In *5ESS* switch terminology, lines and trunks are referred to as ports. A terminal process is created to control each active port and is killed when the port returns to the idle state. The processes associated with the originating and terminating port communicate via the OSDS communication package.

The software that executes in the switching module is functionally divided into several subsystems. The subsystems that are relevant to the integrated *SLC* 96 carrier system are:

1. Feature Control contains the software that sequences call processing actions. Its design is feature driven and is independent of the hardware characteristics of the interface to the port.
2. Switch Maintenance maintains the circuits within the switching module. It performs error analyses and is capable of removing circuits from and restoring circuits to service.
3. Terminal Maintenance maintains and tests the facilities that are connected to the switching module.
4. Peripheral Control serves two primary functions:
   a. Isolating the hardware characteristics of the switching module circuitry from the feature control and maintenance subsystems;

b. Performing real-time operations such as scanning of peripherals, per-call testing, and the control of tone cadencing.

4.2 *Impact on* 5ESS *switch software*

The following subsections describe the software that was expanded to support the integrated *SLC* 96 carrier system.

4.2.1 *New database translations*

The static and dynamic parameters relating to the architecture of the integrated *SLC* 96 carrier system are contained within the *5ESS* switch database. These data describe the configuration of the DCLUs and their associated RTs. They also act as the interface between peripheral control and switch and terminal maintenance.

4.2.2 *Peripheral fault recovery*

The two DCLU service groups and their associated DFIs are considered to be *5ESS* switch circuitry and as such are maintained by the switch maintenance subsystem. Peripheral fault recovery is the portion of switch maintenance that maintains peripheral circuits. It has been expanded to include the maintenance of the DCLU service groups and the DCLU DFIs.

4.2.3 SLC *96 carrier system maintenance process*

An OSDS system process is a process that cycles continuously and performs system-related operations. The *SLC* 96 carrier system maintenance process is the system process that is responsible for the maintenance of the remote terminals and their T1 facilities. This process receives OSDS messages from peripheral control scanning software (see Section 4.2.6.) and initiates switching to the spare line, removal or restoral of T1 facilities, and craft message generation.

4.2.4 *Logical-port primitives*

The Logical-Port (LP) primitives are a set of peripheral control functions that are invoked by feature control software. Each LP primitive performs an abstract switching operation. For example, the primitive called LP-actring sets up a path to a port and begins the ringing cadence. The feature control software invokes the LP primitives regardless of the hardware characteristics of the interface to the port. Each LP primitive determines these characteristics and performs the appropriate hardware operations. A subset of the LP primitives was expanded to support the integrated *SLC* 96 carrier system.

4.2.5 *Origination processing*

The peripheral control origination processing software has been expanded to process line activity that is reported by the DFIs. This function will either cause a new terminal process to be created or an OSDS message to be sent to an existing terminal process.

4.2.6 Scanning

Each PICB is scanned for a service request on a periodic basis by software. Two PICBs are connected to each DCLU service group. A request on PICB 1 (see Fig. 2) indicates a failure in the data or control multiplexers, while a request on PICB 2 indicates that one or more DFIs require service. A DFI request may result from a DFI circuit failure, T1 line faults, or a message from the remote terminal. When the scanning software detects a request from PICB 1, it will send a report to peripheral fault recovery. A request from PICB 2 is processed by a peripheral control function that determines which DFI is requesting service and the nature of the request. This function may send a report to peripheral fault recovery, send a report to the maintenance process, or invoke origination processing software.

4.2.7 Metallic line testing

Terminal maintenance and peripheral control software has been enhanced to provide the ability to test ports on a RT of a *SLC* 96 carrier system via a metallic path. These ports consist of standard channel circuits of the *SLC* 96 carrier system and the metallic loops extending beyond the RT to customer locations. Terminal maintenance is responsible for the establishment of the test configuration. Peripheral control is invoked by terminal maintenance and controls the hardware that actually establishes the metallic connection.

V. TRAFFIC

This section considers the traffic capacity of the DCLU switching network. In this paper, peak capacities are calculated for the Extreme Value Engineering (EVE) criterion[7] of 3-percent blocking occurring no more often than Once A Month (OAM) that was used in the design of the DCLU.* The effective access method[8] is used to compute these OAM traffic capacities. It is also shown how the OAM capacities can be converted to "equivalent" Average Busy Season Busy Hour (ABSBH) capacities by dividing them by an appropriate peak factor.

It is assumed that each of the RTs connected to the DCLU is fully filled with 96 single-party POTS lines. It is further assumed, for simplicity, that a given DCLU has either all nonconcentrated (Mode 1) or all concentrated (Mode 2) RTs on it. Traffic capacities are given

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* For operational reasons, the criterion used for the traffic engineering of *5ESS* offices is slightly different from this one.

for the allowable range of one to six 96-line RTs that may be served by a DCLU.

The amount of concentration done in the DCLU depends on whether one or two PIDBs are used to connect each DCLU data multiplexer to the TSIU. Figure 4 illustrates six remote terminals connected to a DCLU. The DCLU in turn is connected to the TSIU by two PIDBs, one from each DCLU data multiplexer. If the six RTs are fully filled, they serve 576 POTS lines. Since each PIDB contains 32 time slots, the 576 customers are competing for 64 time slots to the TSIU; hence, we have 9.0:1 concentration for these customers. This total concentration is of the same order of magnitude as the maximum 8.0:1 concentration available for lines served directly over copper pairs and terminated on a standard *5ESS* switch line unit. Note that this 9.0:1 concentration ratio is available whether the RTs are operating in Mode 1 or in Mode 2. If the RTs are operating in Mode 1, then all of the 9.0:1 concentration takes place in the DCLU. If the RTs are operating in Mode 2, then 2.0:1 concentration is done in each RT, and an additional 4.5:1 concentration is performed in the DCLU.

Figure 5 is the same as Fig. 4 except that four PIDBs (two from each data multiplexer) are used to interconnect the DCLU and the TSIU. The 576 customers are now competing for 128 TSIU time slots, thus yielding a 4.5:1 concentration ratio. Again this 4.5:1 concentration ratio can be achieved with either Mode 1 or Mode 2 RTs.

5.1 Switching network topologies

The DCLU switching network consists of two stages. The first stage is time division; the second stage is space division. These two stages concentrate the up to 576 POTS lines that can be served by a DCLU onto either 64 or 128 PIDB time slots. As explained earlier, both the physical realization and the topology of the DCLU two-stage switching network depend on whether the remote terminals of the *SLC* 96 carrier system are operating as concentrated (Mode 2) or as nonconcentrated (Mode 1) systems. The second stage of switching (space division) always takes place in the DCLU data multiplexers; the implementation of the first stage of switching (time division) depends on the mode of operation of the RTs.

If the remote terminals are operating in Mode 2, the first stage of switching is a 48 by 24 TSI, two of which are located in each RT. Figures 6 and 7 give the topologies of the two-stage switching networks that result when S fully filled Mode 2 RTs are connected to DCLUs that are in turn interconnected to the TSIU by $j = 1$ and $j = 2$ PIDBs from each data multiplexer, respectively.

If, however, the RTs on a DCLU are operating in Mode 1, there are no TSIs in the remote terminals; instead the 32 by 64 TSI on each

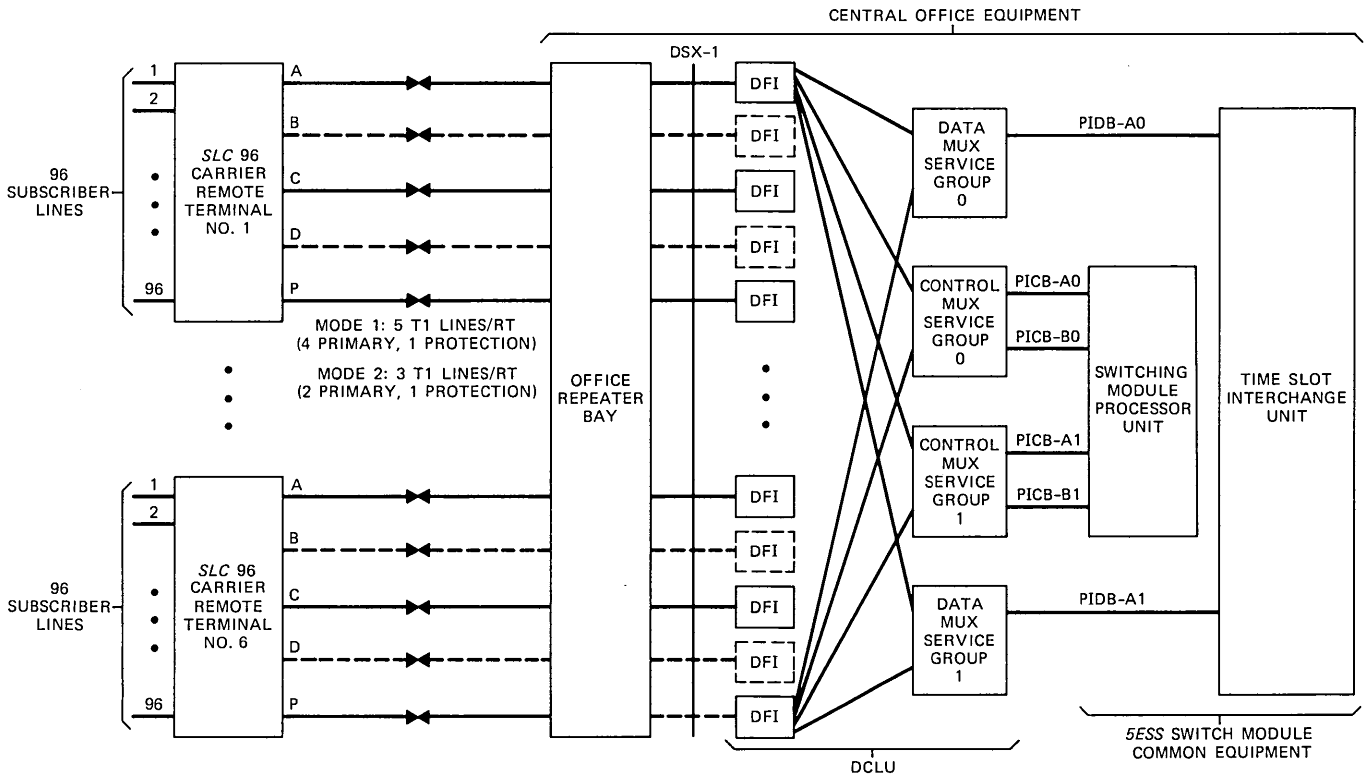

Fig. 4—*5ESS* switch digital carrier line unit with two PIDBs to TSIU.

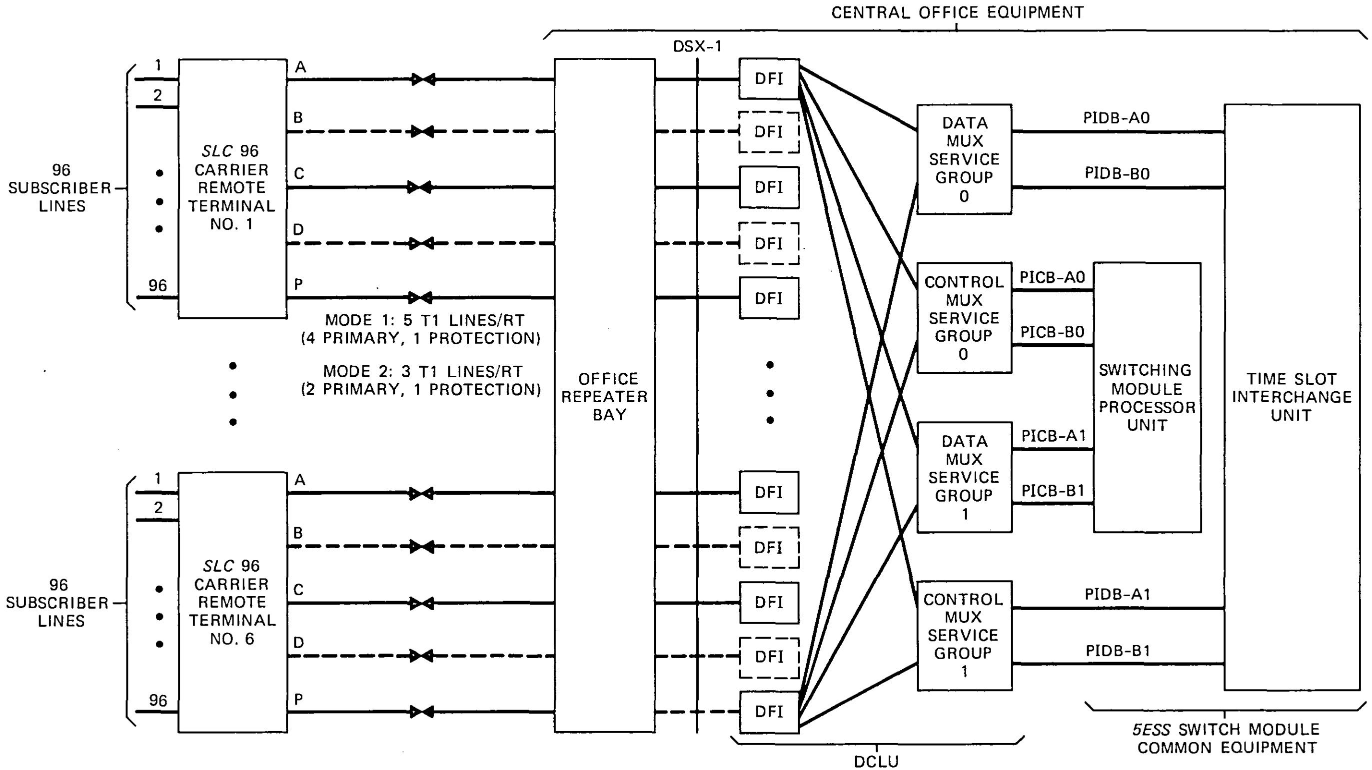

Fig. 5—*5ESS* switch digital carrier line unit with four PIDBs to TSIU.

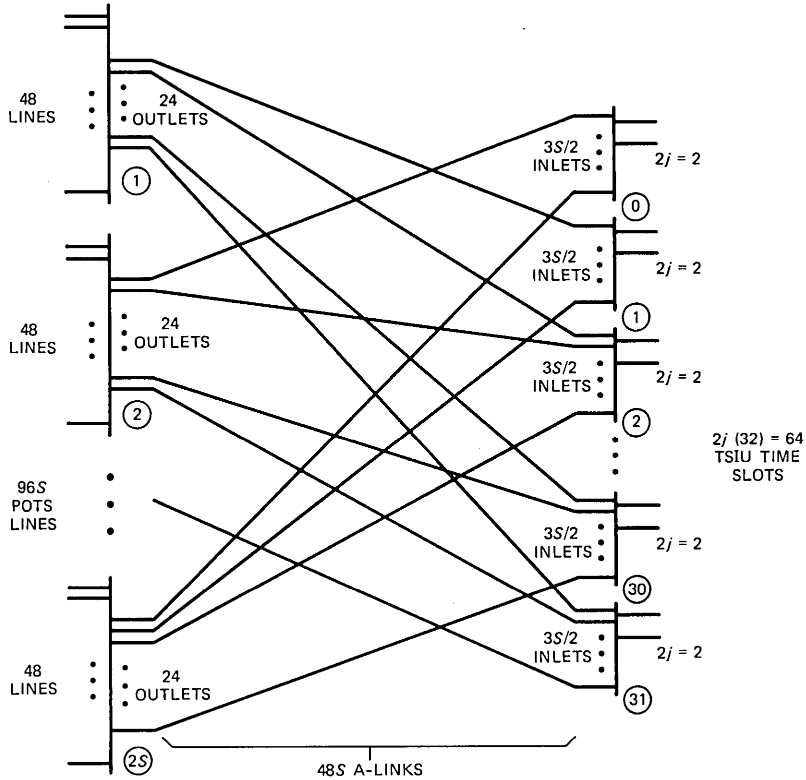

Fig. 6—RT and DCLU switching network topology with $S (1 \leq S \leq 6)$ Mode 2 RTs and $j = 1$ PIDB to TSIU from each data multiplexer.

DFI circuit pack (see Section III) is activated and is used to map the 24 T1 line time slots into 32 DCLU internal data bus time slots. The combination of the DFI TSIs associated with the primary T1 lines on a DCLU and the DCLU data multiplexer results in the two-stage switching network topologies illustrated in Figs. 8 and 9, respectively, for DCLUs that are connected to the TSIU by $j = 1$ and $j = 2$ PIDBs from each data multiplexer.

5.2 Effective access

Under high-traffic conditions in a multistage switching network, the effective access, k_{eff}, of inlets to outlets is reduced from its no-traffic value to some lower number because of internal network congestion.[8] By using k_{eff} as the availability in an appropriate traffic capacity formula, one can approximate the traffic capacity of the multistage network at any desired blocking probability.

For example, in the networks of Figs. 6 and 7 under high-traffic

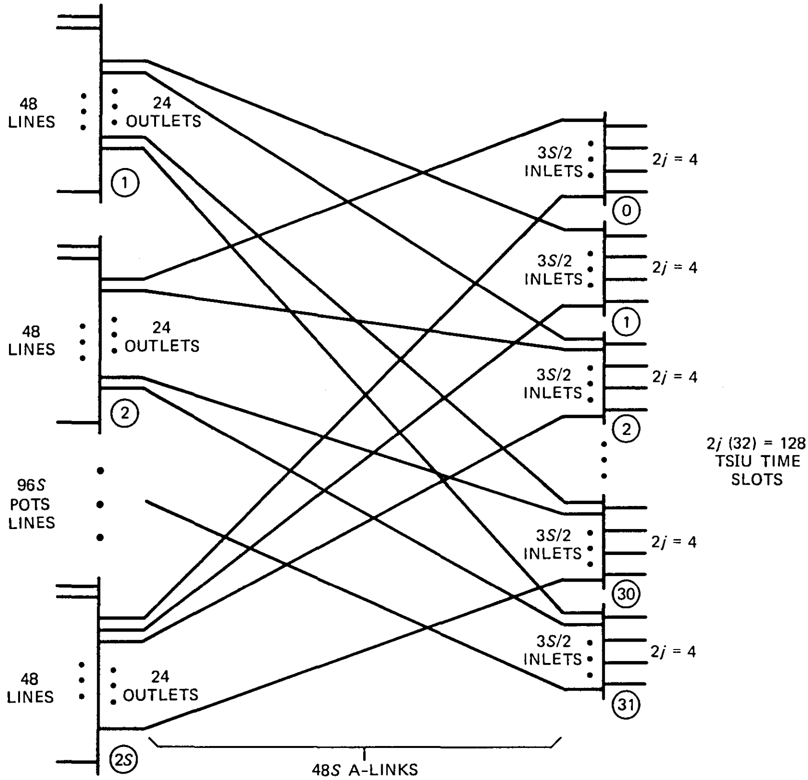

Fig. 7—RT and DCLU switching network topology with $S(1 \le S \le 6)$ Mode 2 RTs and $j = 2$ PIDBs to TSIU from each data multiplexer.

conditions, the access, k, of a line to the $64j$ possible servers is reduced from its no-traffic value of

$$k = k_1k_2 = 24 \cdot 2j = 48j, \tag{1}$$

where k_i is the number of outlets from each ith-stage switch, to the lower effective value of

$$k_{\text{eff}} = k_1k_2\text{Pr(idle A-link)}, \tag{2}$$

where Pr(idle A-link) is the probability that the A-link between a given pair of first- and second-stage switches is idle.

The following three assumptions were made:

- The choice of an idle A-link is independent of the state of the network;*
- The network is carrying A erlangs of traffic;

* Note that we assume no optimization of the path search algorithm.

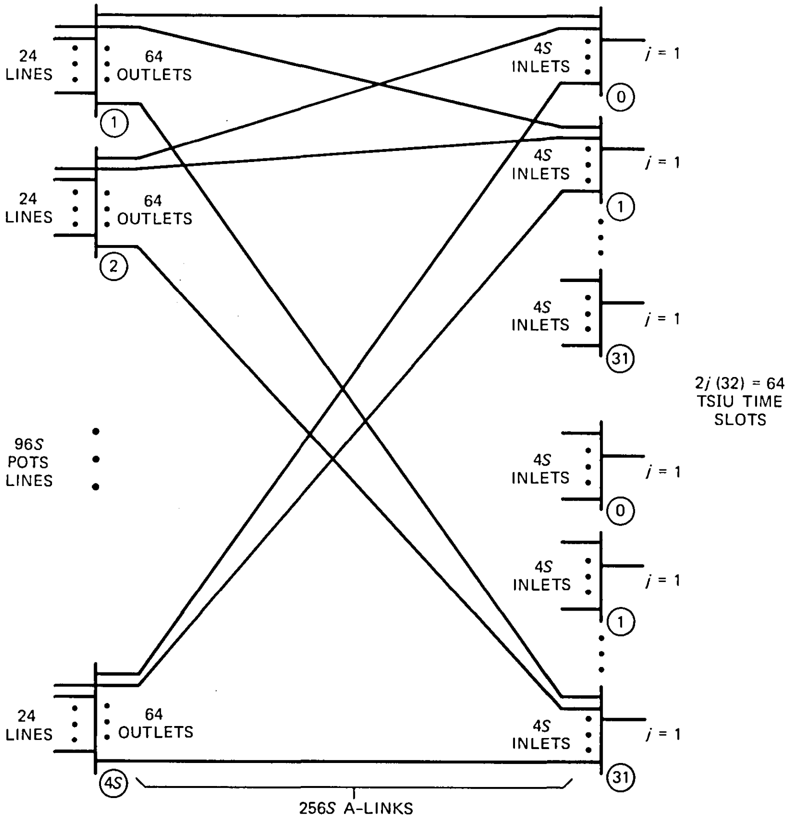

Fig. 8—DCLU switching network topology with $S(1 \leq S \leq 6)$ Mode 1 RTs and $j = 1$ PIDB to TSIU from each data multiplexer.

- The offered traffic is evenly distributed over the $2S$ first-stage switches.*

Under these assumptions, the probability of finding an idle link between a given pair of first- and second-stage switches is

$$\Pr(\text{idle A-link}) = 1 - \left(\frac{A}{2Sk_1}\right). \tag{3}$$

We can place an upper bound on the quantity A [and hence a lower bound on Pr(idle A-link)] by assuming that all 32 $k_2 = 64j$ servers are

* This assumption will not be true in practice. However, a conservative assumption for the network traffic load A is made (at the end of this section) in order to compensate for the traffic imbalance on the first-stage switches that is to be expected in practice.

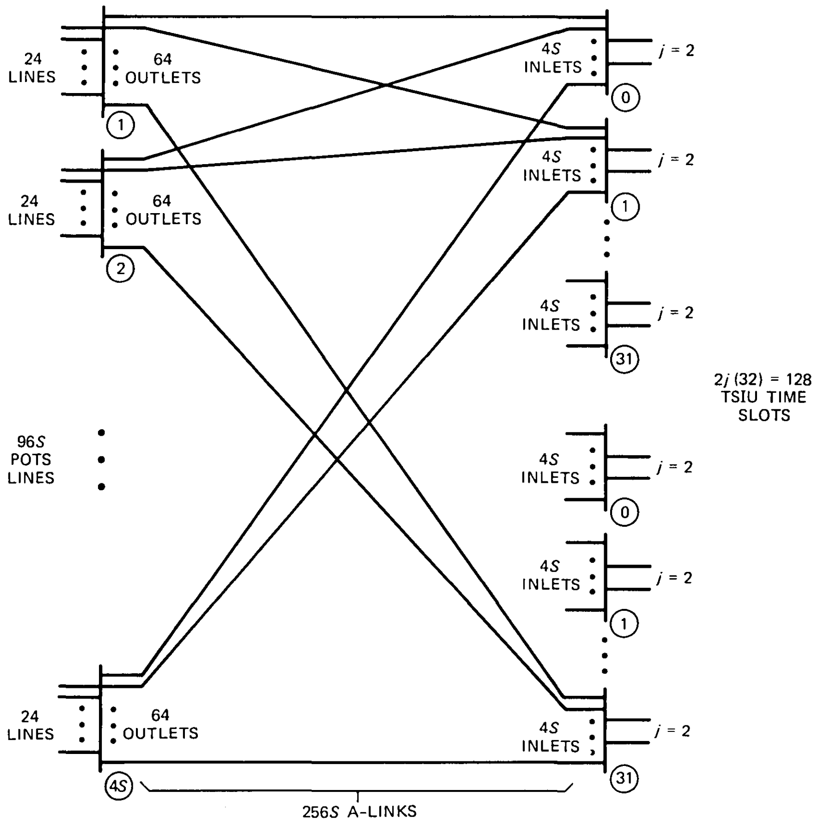

Fig. 9—DCLU switching network topology with $S(1 \le S \le 6)$ Mode 1 RTs and $j = 2$ PIDBs to TSIU from each data multiplexer.

busy so that $A = 64j$. Substitution of $64j$ for A and 24 for k_1 in eq. (3) and then using eqs. (1) and (2) yields the following lower bound on the effective access $k_{\text{eff}}^{(\text{Mode } 2)}$ for S Mode 2 RTs on a DCLU that is connected to the TSIU by j PIDBs from each data multiplexer:

$$k_{\text{eff}}^{(\text{Mode } 2)} \ge 43j \left(1 - \frac{4j}{3S}\right). \tag{4}$$

Similarly, the following formula gives a lower bound on the effective access $k_{\text{eff}}^{(\text{Mode } 1)}$ for S Mode 1 RTs on a DCLU that is connected to the TSIU by j PIDBs from each data multiplexer:

$$k_{\text{eff}}^{(\text{Mode } 1)} \ge 64j \left(1 - \frac{j}{4S}\right). \tag{5}$$

Table I—OAM traffic capacities for DCLUs with Mode 2 RTs and one PIDB from each data multiplexer to the TSIU

Number of RTs S	Eff. Access	Number of Servers	OAM Capacity (Erl.)	Number of Lines	OAM Capacity (CCS/Line)	Peak Factor	Equiv. ABSBH Cap. (CCS/line)
1	na	2 × 24	2 × 17.072	96	12.804	1.187	10.79
2	16	64	46.177	192	8.658	1.168	7.41
3	26	64	49.516	288	6.190	1.164	5.32
4	32	64	50.646	384	4.748	1.163	4.08
5	35	64	51.098	480	3.832	1.163	3.29
6	37	64	51.369	576	3.211	1.162	2.76

Table II—OAM traffic capacities for DCLUs with Mode 2 RTs and two PIDBs from each data multiplexer to the TSIU

Number of RTs S	Eff. Access	Number of Servers	OAM Capacity (Erl.)	Number of Lines	OAM Capacity (CCS/line)	Peak Factor	Equiv. ABSBH Cap. (CCS/line)
1	na	2 × 24	2 × 17.072	96	12.804	1.187	10.79
2	na	4 × 24	4 × 17.072	192	12.804	1.149	11.14
3	10	128	86.090	288	10.761	1.141	9.43
4	32	128	105.117	384	9.855	1.135	8.68
5	44	128	107.998	480	8.100	1.135	7.14
6	53	128	109.436	576	6.840	1.134	6.03

5.3 Traffic capacities

The effective access formulas derived in the preceding subsection will now be used to calculate the OAM traffic capacities of the DCLU for both concentrated and nonconcentrated remote terminals. One can use the bound of eq. (4) as the availability in the adapted modified Palm-Jacobaeus (AMPJ) formula[9] in order to derive the Mode 2 OAM traffic capacities* shown in Table I for DCLUs with one PIDB from each data multiplexer and in Table II for DCLUs with two PIDBs from each data multiplexer. Similarly, one can use the bound of eq. (5) in the AMPJ formula to derive the Mode 1 OAM traffic capacities that appear in Table III for DCLUs with one PIDB from each data multiplexer and in Table IV for DCLUs with two PIDBs from each data multiplexer. The peak factor and the equivalent ABSBH capacities shown in the two rightmost columns of Tables I to IV will be discussed in the next subsection.

5.4 Relating OAM to ABSBH traffic capacity

Most available traffic data are ABSBH rather than OAM. Hence, it

* The OAM capacity is defined as the load that can be carried at 3-percent blocking. To meet a once-a-month EVE performance criterion, the office should be engineered so that this level of traffic loading will be exceeded no more often than once each month.

Table III—OAM traffic capacities for DCLUs with Mode 1 RTs and one PIDB from each data multiplexer to the TSIU

Number of RTs S	Eff. Access	Number of Servers	OAM Capacity (Erl.)	Number of Lines	OAM Capacity (CCS/line)	Peak Factor	Equiv. ABSBH Cap. (CCS/line)
1	48	64	52.568	96	19.713	1.161	16.98
2	56	64	53.232	192	9.981	1.160	8.60
3	58	64	53.379	288	6.672	1.160	5.75
4	60	64	53.520	384	5.018	1.160	4.33
5	60	64	53.520	480	4.014	1.160	3.46
6	61	64	53.588	576	3.347	1.160	2.89

Table IV—OAM traffic capacities for DCLUs with Mode 1 RTs and two PIDBs from each data multiplexer to the TSIU

Number of RTs S	Eff. Access	Number of Servers	OAM Capacity (Erl.)	Number of Lines	OAM Capacity (CCS/line)	Peak Factor	Equiv. ABSBH Cap. (CCS/line)
1	na	96	96.000	96	36.000	1.000	36.00
2	96	128	113.363	192	21.256	1.133	18.76
3	106	128	113.960	288	14.245	1.133	12.57
4	112	128	114.285	384	10.714	1.133	9.46
5	115	128	114.440	480	8.583	1.133	7.58
6	117	128	114.541	576	7.159	1.133	6.32

would be useful if one could convert OAM capacities to "equivalent" ABSBH capacities.* The following formula for the peak factor (*pf*) for any given traffic-handling unit in a central office was derived from empirical data made available to AT&T Bell Laboratories:

$$pf = \frac{\mathrm{OAM_{unit}}}{\mathrm{ABS_{unit}}} \tag{6}$$

$$= 1 + \left(1.80 + \frac{138}{\mathrm{ABS_{unit}}}\right)\left[(0.06)^2 + \frac{6}{\mathrm{ABS_{unit}}} + \frac{6}{\mathrm{ABS_{office}}}\right]^{1/2},$$

where $\mathrm{OAM_{unit}}$ is the *total* once a month peak traffic and $\mathrm{ABS_{unit}}$ is the *total* ABSBH traffic, both measured in CCS, being carried by *that particular unit.* Also, $\mathrm{ABS_{office}}$ is the ABSBH traffic in CCS being carried by the *entire central office* in which the unit is located. The formula is valid provided that $\mathrm{ABS_{unit}} \geq 200$ CCS. Note that the last term in the square-bracketed expression is negligibly small for most medium- to large-sized offices.

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* It is important to realize that the OAM and ABSBH capacities presented here will be equivalent *only* if the assumptions used to derive the peak factor are valid for the central office in question.

From Tables I and III, we can see that the total OAM traffic capacity of DCLUs connected to the TSIU by two PIDBs (one from each data multiplexer) ranges from about 1662 to 1930 CCS, if we neglect the degenerate case of one RT on a DCLU where the DCLU does no concentration. The exact value depends on the mode of operation (1 or 2) and the number of RTs terminated. Using eq. (6), we can show that the corresponding range of total equivalent ABSBH capacities is 1423 to 1665 CCS (for medium- to large-sized central offices), thus yielding a peak factor of about 1.165 for DCLUs utilizing two PIDBs to the TSIU. In a similar fashion, we can show that the peak factor will be about 1.135 for DCLUs utilizing four PIDBs to the TSIU (and located in medium- to large-sized central offices). The calculated peak factors and equivalent ABSBH traffic capacities are given in the two rightmost columns of Tables I to IV.

VI. CONCLUSIONS

The digital carrier line unit described in this paper provides a flexible and economic integrated interface between the *5ESS* switching equipment and remote terminals of the *SLC* 96 carrier system. It handles concentrated and nonconcentrated RTs equally well. The DCLU architecture assures reliable operation in the event of single failures.* The hardware was designed with modularity and flexibility in mind, and the abundance of custom LSI devices provides for low overall costs. The structured design of the *5ESS* software made it possible to integrate *SLC* 96 carrier system remote terminals without affecting the majority of the existing switching software. The first *SLC* 96 carrier system integrated into a *5ESS* switch went into service on April 14, 1984, in Spotsylvania, Virginia.

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* This is at an increased concentration ratio, however, in the case of DCLU data multiplexer failures.

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ACRONYMS AND ABBREVIATIONS

ABSBH	average busy season busy hour
ACO	alarm cutoff
ACU	alarm control unit
AGC	automatic gain control
AH	ampere hour
ALIT	automatic line insulation test
AM	administration module
AMPJ	adapted modified Palm-Jacobaeus
ANI	automatic number identification
APD	avalanche photodiodes
AR	anti-reflection
ARSB	automated repair service bureau
BER	bit error rate
BERT	below-ground remote terminal
BPV	bypolar violations
BW	bandwidth
CAF	cable failure
CCB	control communications buffer
CEV	controlled environment vault
CL	carrier line
CM	communication module
CO	central office
COT	central office terminal
CRSAB	centralized repair service answering bureau
CSC	community service cabinet
CTR	customer trouble report
CTU	channel test unit
DACS	Digital Access and Cross-connect System
DCLU	digital carrier line unit
DDS	digital data service
DFI	digital facility interface
DIP	dual in-line package
DLC	digital loop carrier
DLR	display line record
DLU	data link unit
EEE	electronic equipment enclosure
ELIU	electrical line interface unit
EOL	end of life
ETO	equalized transmission only
EVE	extreme value engineering
FDL	facility data link
FET	field-effect transistor

FMTR	formatter
FR	framer
HIC	hybrid integrated circuit
IC	integrated circuit
ICOT	inter-city and outstate trunk
ILD	injection laser diode
ISDN	Integrated Services Digital Network
IU	interface unit
LED	light-emitting diode
LIU	line interface unit
LMOS	Loop Maintenance Operations System
LP	logical port
LSU	line switch unit
LTD	local test desk
MAT	metropolitan area trunk
MC	maintenance center
MCU	module control unit
MESFET	metal semiconductor field-effect transistor
MLT	mechanized line testing
MLT	mechanized loop testing
MSU	metallic service unit
MTP	metallic test pair
MTS	message telephone service
MUX	multiplexer
MXU	multiplex unit
NEBS	new equipment building standards
NRZ	nonreturn to zero
NTEC	network terminal equipment center
NTPI	negative tip party identification
OAM	once a month
OH	on-hook
OLIU	optical line interface unit
OSDS	operating system for distributed switching
OSHA	Occupational Safety and Health Administration
OSS	Operations Support System
P/S	parallel/serial converter
PAM	pulse amplitude modulation
PCB	printed circuit board
PCM	pulse code modulation
PGCU	program channel unit
PGTC	pair gain test controller
PIC	polyethylene insulated cable
PICB	peripheral interface control bus
PIDB	peripheral interface data bus

PIN	positive-intrinsic-negative diodes
POTS	plain old telephone service
PSR	peripheral service request
PTPI	positive tip party identification
RNDIS	receive disable
RPAM	receive pulse amplitude modulation
RS	receive synchronizer
RSA	repair service attendant
RSB	repair service bureau
RSS	remote switching system
RT	remote terminal
SCC	switching control center
SLC®	Subscriber Loop Carrier system
SLIM	subscriber loop interface module
SLM™	Subscriber Loop Multiplexer system
SM	switching module
SMPU	switching module processor unit
SSU	special services unit
TASC	Telecommunication Alarm Surveillance and Control system
TAU	time assignment unit
TCAS	T-Carrier Administration System
TF	transmit formatter
TLWS	trunk and line work station
TNOP	Total Network Operations Plan
TO	transmission only
TPAM	transmit pulse amplitude modulation
TPI	tip party identification
TRAF	traffic overload alarm
TRU	transmit/receive unit
TS	time slots
TSI	time slot interchanger
TSIU	time slot interchange unit
UART	universal asynchronous receiver/transmitter
USART	universal synchronous/asynchronous receiver/transmitter
VCXO	voltage-controlled crystal oscillator

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