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D4 Digital Channel Bank Family:

Digital Terminal Physical Design

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This article describes the physical design of the D4 and related SLC™*-96 subscriber loop carrier system digital terminals. A detailed description of the bay, channel bank, and plug-in designs is also included, along with other very important considerations such as thermal design, manufacturability, and the effective use of hybrid integrated circuit technology. The D4 was designed as a system that was significantly smaller, used less power, and had a lower cost than previous digital terminals. These objectives were realized by using the latest technology and the optimal physical design format. Since these are relatively high-production terminals, the basic design has been aggressively reduced in cost and has proliferated with expanding D4 and* SLC*-96 subscriber loop carrier terminal capabilities, lightguide applications, and the use of the D4 hardware in other systems.*

I. INTRODUCTION

In 1962 the D1 channel bank, the voice-frequency (VF) pulse code modulation (PCM) terminal for the T1 carrier system, was first introduced into Commercial Exchange Office service. The 11-foot 6-inch central office bay framework contained equipment for 72 voice channels (three 24-channel banks). Discrete, solid-state technology was used and the typical power consumption was about 7.5 watts per channel.

In 1969 the D2 channel bank was introduced into service for Toll Office applications. Equipment for 96 voice channels (four 24-channel banks) was mounted in a bay. In addition to discrete solid-state technology, some thin film was used and a typical power consumption of about 6.2 watts per channel was dissipated.

In 1972 the D3 channel bank was first introduced into service. This bank served both Exchange and Toll applications and essentially replaced the D1 and D2 banks for new service. An 11-foot 6-inch bay contained 144 D3 voice channels (six 24-channel banks). Small-scale integrated (SSI) circuit and hybrid integrated circuit (HIC) technologies were employed and a typical power consumption of about 2.8 watts per channel was dissipated.

In early 1977 the first D4 channel bank was cut over to regular commercial service at the Crete Office in Chicago, Illinois. The physical and electrical D4 architecture departs significantly from previous bank designs.

The D4 is a self-contained, 48-channel bank that has optimized access to the T1C system but still retains the basic 24-channel format for efficient access to T1 systems. By using higher levels of integration and modular physical design approaches, the D4 bank achieves a 2:1 size and power reduction relative to the D3 channel bank. Six D4 banks (288 channels) are mounted in an 11-foot 6-inch frame and five D4 banks (240 channels) are mounted on a 9-foot 0-inch frame. Since many new telephone buildings are built with a lower ceiling height in accordance with New Equipment Building System (NEBS) standards, a 7-foot 0-inch frame with four D4 banks (192 channels) is a standard offering. Initial shipping data shows that the 11-foot 6-inch frame accounts for about 80 percent of the D4 production, with the remaining 20 percent divided between the 9-foot 0-inch and 7-foot 0-inch frames. The evolution of the D-type channel bank bay is summarized in Fig. 1.*

II. D4 CHANNEL BANK

The D4 bank is 19 inches high by 12 inches deep and is flush-mounted on a 23-inch wide, unequal flange, duct-type bay. There are four shelves in each bank. As shown in Fig. 2, each shelf contains up to 12 plug-in channel units plus common equipment located on the left side of each shelf in the bank. Each bank is completely shop assembled, wired, and tested and contains provisions for power conversion, fusing, equalization and connections to the office alarm system.

By using different Line Interface Units (LIU) and plug-in unit reconfigurations, the following five modes of operation can easily be established, as we see in Fig. 3.

Mode 1—Offers 48-channel service over a dedicated 3.152-Mb/s facility (T1C line) with another D4 bank at the other end. In this

* Acronyms and abbreviations used in the figures are defined in the section of the same title at the back of this issue.

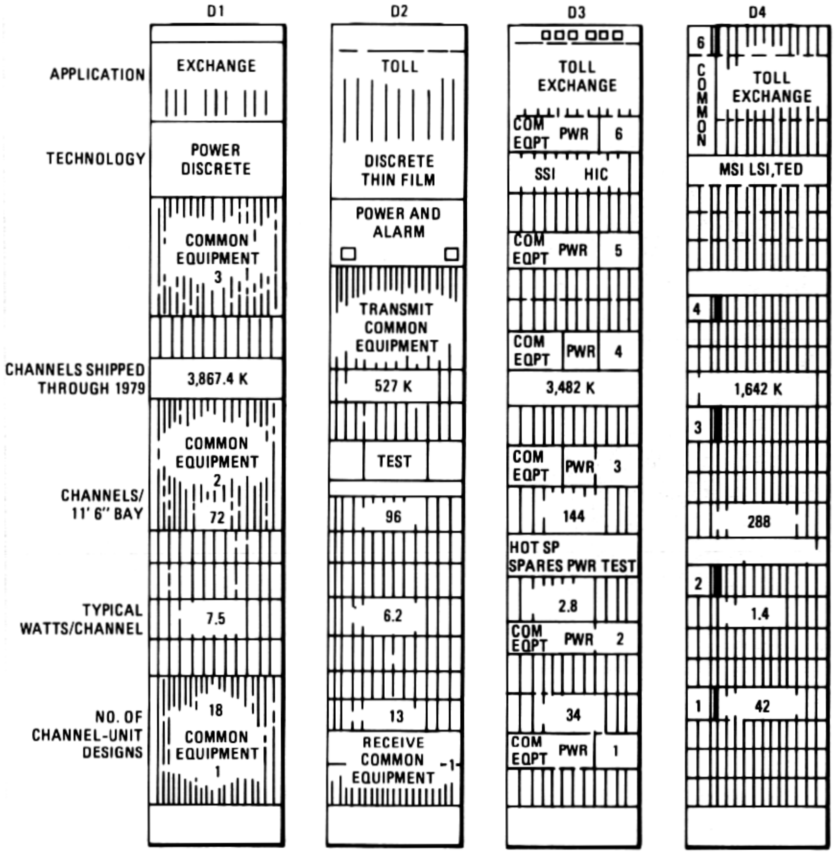

Fig. 1—D-type channel bank bay evolution.

mode, the synchronized digroups (24 channels) are interconnected to produce a unique, cost-effective, 48-channel bank with a special non-standard output signal. Alarming and trunk processing functions are administered on a 48-channel basis.

Mode 2—Provides 48-channel service over a 3.152-Mb/s facility (T1C line) with compatible digital terminals connected via an M1C multiplexer at the other end. (However, Mode 2 D4 banks could be used at both ends.) In this mode, the bank produces a signal identical to that of the M1C. Alarming and trunk processing are administered on a digroup basis. The multiplexer/demultiplexer stage of signal processing also has alarms.

Mode 3—Offers two digroups for connection to two 1.544-Mb/s facilities (T1 lines). In this mode the two separate digroups of the D4 are connected to compatible channel banks or applied to a multiplexer

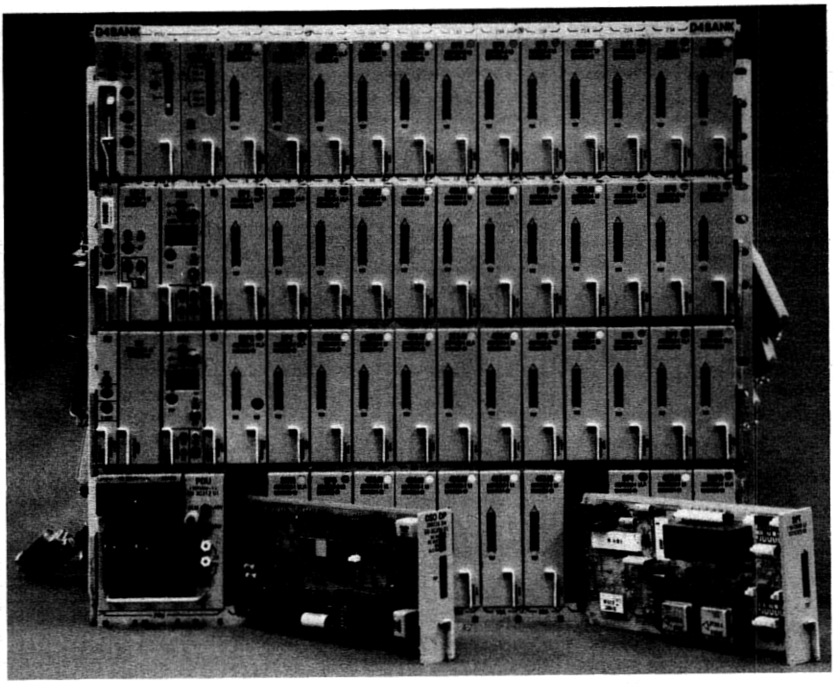

Fig. 2—D4 channel bank.

for a higher rate line. Alarming and trunk processing are administered on a digroup basis.

As shown in Fig. 3, conditioning of a D4 bank to Mode 1, 2, or 3 operation only requires inserting the correct plug-in modules. Modes 4 and 5, which essentially produce a 96-channel bank by combining the output of two banks, also require a modest amount of interbank wiring.

Mode 4—Supplies 96-channel service over a 6.312-Mb/s facility (T2 line) with digital terminals connected by means of a multiplexer at the other end (D4 Mode 4 banks could be used at both ends). In this mode, the interwired banks multiplex the four digroup outputs. Alarming and trunk processing are administered on a digroup basis.

Mode 5—Provides 96-channel service electrically similar to Mode 4 except that the 6.312-Mb/s signal interfaces directly to a lightguide line.

Clearing trouble in D4 is based on the quick replacement of plug-in units. To facilitate restoral, the D4 common units are equipped with built-in alarms. Light-emitting diodes (LEDs) are used for reliable alarm indications. A complete set of common units is shown in Fig. 4.

A common Power Distribution Unit (PDU) and Power Converter

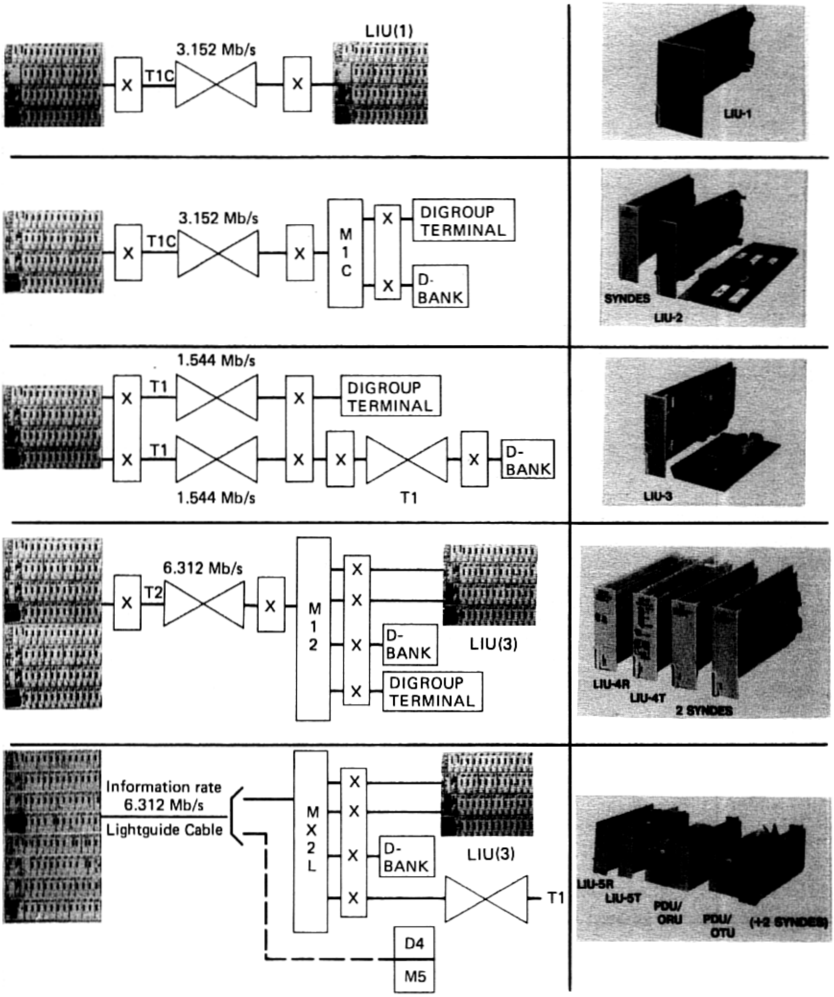

Fig. 3—D4 channel bank operating modes.

Unit (PCU) provides the filtered 48V talk battery power, the other signaling and alarm battery voltages, and ±12 and +5 volt converter power outputs. Converter input power for the common equipment and 48-channel units is about half of the D3 power requirements for 48 comparable channels. The lower D4 power needs are the result of circuit advances and use of low-power components. The channel-unit mix, activity factors, and loop lengths have a significant effect on the total power required. While digroups are largely independent, failures in those units that serve both digroups, such as the power units, are easily determined and quickly restored.

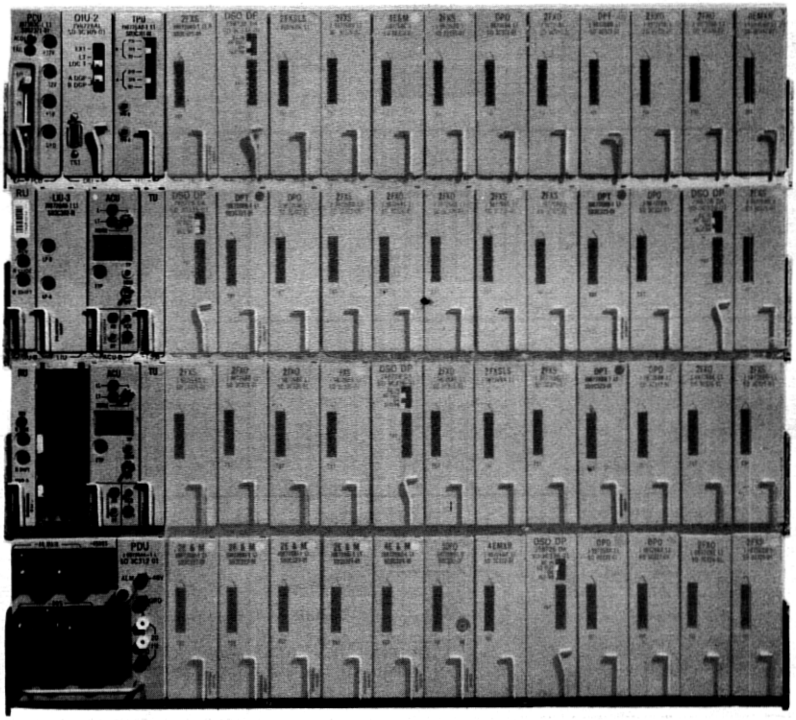

Fig. 4—D4 common units.

Transmit and receive units are provided separately for each digroup, resulting in digroup operational flexibility and independent digroup maintenance and restoral. Trunk processing control circuitry is included within the alarm unit, with trunk conditioning relays distributed in the trunk processing and channel units. Trunk conditioning is maintained during channel-unit removal.

For example, the Alarm Control Unit (ACU) shown in Fig. 5 contains lights and switches for indicating and isolating system troubles. As soon as the ACU recognizes an alarm it lights the appropriate LED, activates the office alarm, and initiates trunk processing. The alarm cutoff button silences the office alarms but maintains the alarm condition on the ACU.

A Carrier Group Alarm Counter that records the number of times the bank is out of service is visible through a window in the faceplate. The register reset switch is also accessible from the front of the ACU.

The dc-to-dc converter in the PCU (see Fig. 6) provides +5 and ±12 volts from the -48V input battery. In addition to the on/off switch,

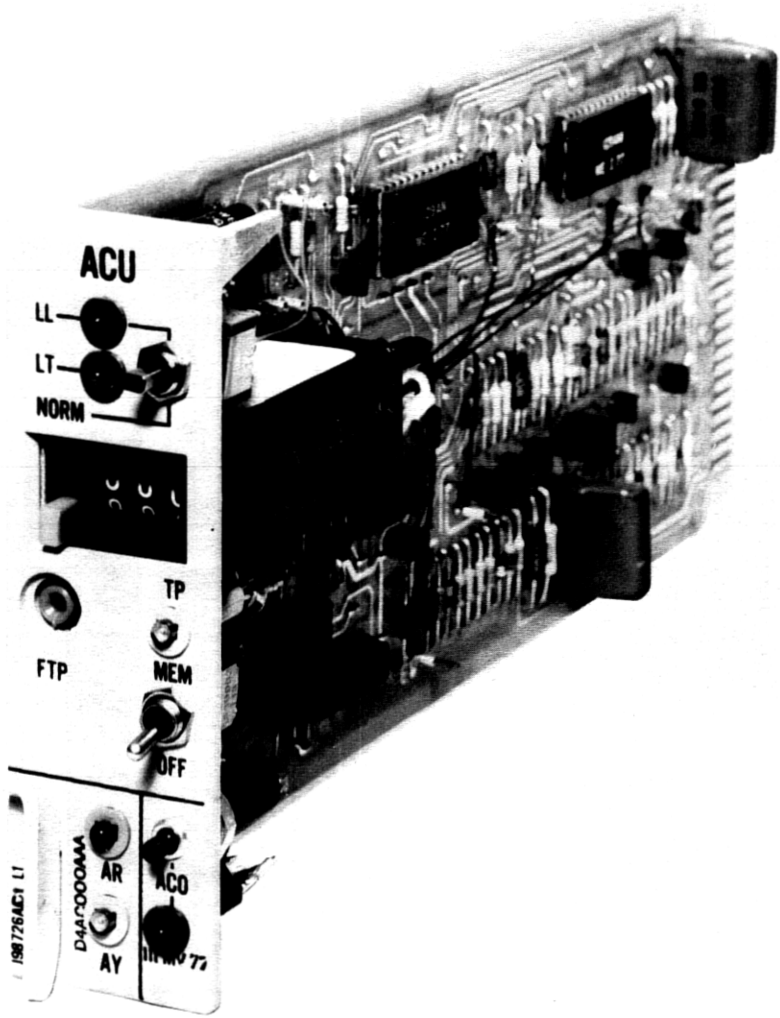

Fig. 5—Alarm control unit.

alarm lamps, and output test voltages, a mechanical interlock has been built into the latching mechanism to prevent the PCU from being plugged or unplugged with its power on. This limits the in-rush current and prevents damaging the plug-in unit or backplane connector contacts.

Over 40 different types of channel units are available to perform a wide variety of Plain Old Telephone Service (POTS) and special service

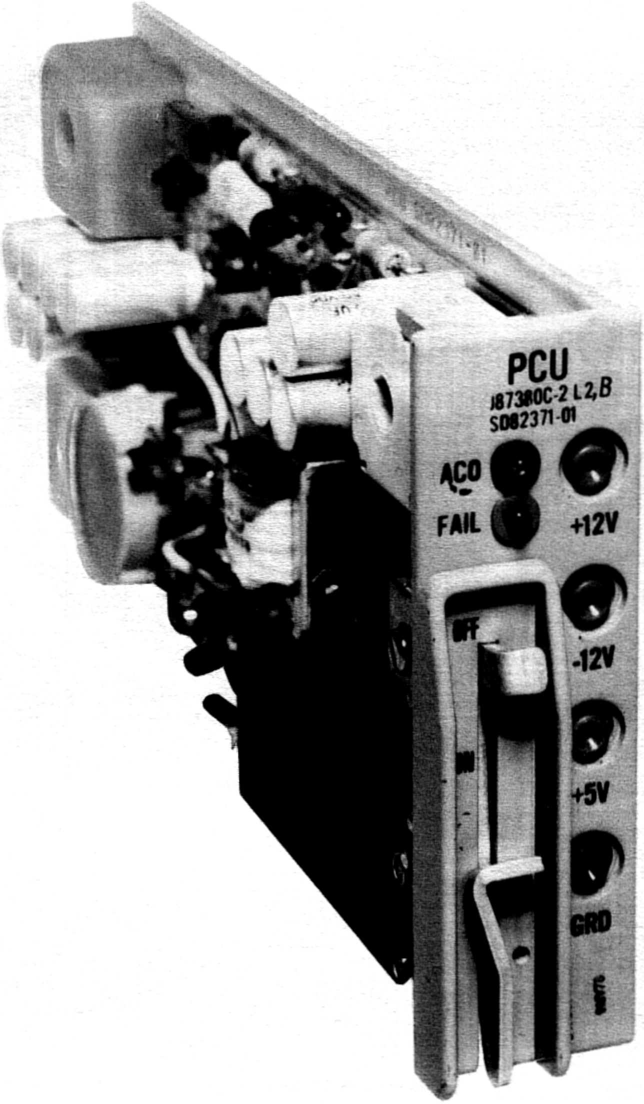

Fig. 6—Power converter unit.

signaling and transmission functions. A few of the features common to all channel units are:

(*i*) Reduction of false disconnects by storing and maintaining supervisory signaling states for up to 2 seconds during out-of-frame conditions before initiating trunk processing.

(*ii*) Card jack accessible through the faceplate that provides split-

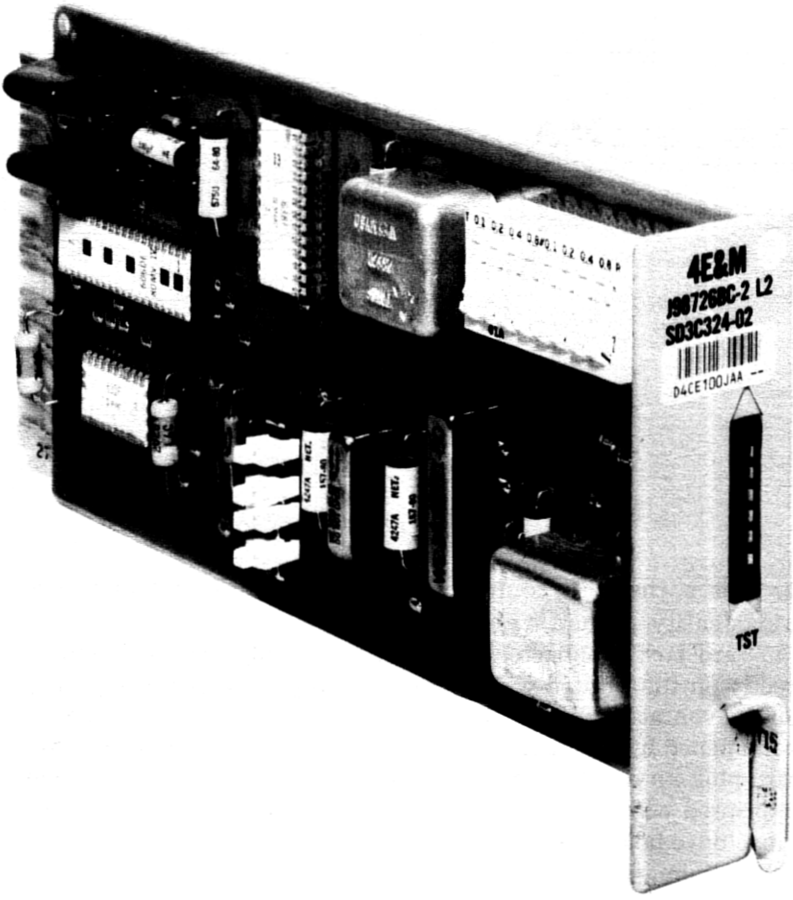

Fig. 7—Four-wire E and M channel unit.

ting access to equilevel test points in the four-wire transmit and receive paths and to the drop side signaling and supervision leads.

(*iii*) Precision-calibrated attenuators that permit prescription loss settings in 0.1-dB increments.

To ensure complete flexibility for service continuity and channel reassignments, circuitry for a single channel is provided on a single plug-in unit. These units are the interface between the central office trunk or other circuits and the bank common equipment. Different channel units match the two- or four-wire office circuits and also handle a variety of office signaling arrangements. For example, the four-wire E and M channel unit (shown in Fig. 7) interfaces with the four-wire E and M trunk circuits. It is also used to provide some special service arrangements, such as special access trunks and duplex signal-

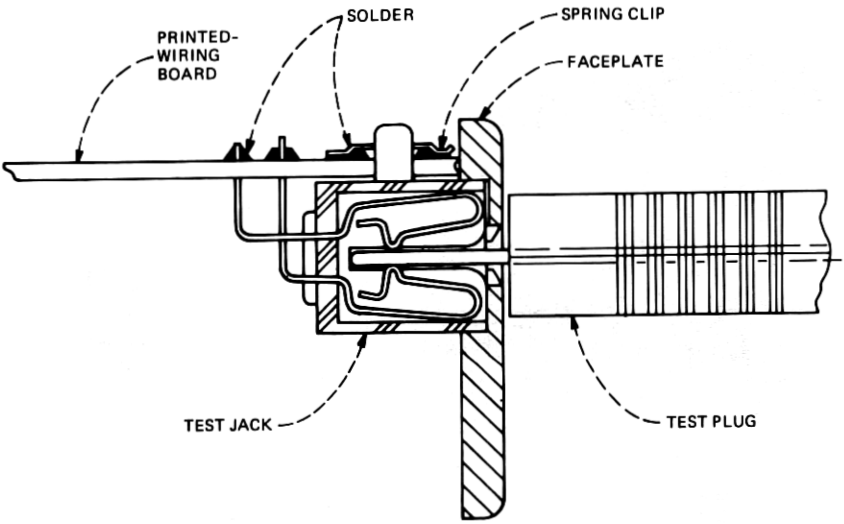

Fig. 8—D4 test access.

ing. This is the least complex, in terms of component and printed wiring density, of the D4 channel units.

A "card jack" connector, designed specifically for D4, is mounted directly on the printed wiring board. This connector has six pairs of shorting contacts that provide split-access for signaling and VF testing when opened by the insertion of an epoxy-coated metal printed wiring board plug. In addition to having the connector terminals soldered to the printed wiring board, a spring clip snaps into the bottom of the connector to hold it in position during mass soldering. It then becomes a solid retaining member when the clip is soldered to the board during the wave-soldering operation. This arrangement requires a minimum amount of board space. The connector is accessed through an opening in the channel-unit faceplate. This arrangement is illustrated in Fig. 8.

The rocker-type switch attenuator provides variable attenuation in the transmit and receive paths by setting a combination of mini-switches. This allows for prescriptively setting the attenuator in precise 0.1-dB increments of loss.

Options on D4 channel units are selected by using printed wiring board socket and plug combinations, as shown in Fig. 9. The plug and socket have been designed to provide a wiping action for high reliability when the plug is inserted. The plug snaps firmly into place, preventing disengagement during shock and vibration. The hybrid integrated circuits (HICS) are described in detail later in this article.

The two-wire Foreign Exchange Office End with Gain Transfer Unit (2FXO/GT) shown in Fig. 10 is one of the most complex channel units. This unit provides an interface to any two-wire foreign exchange

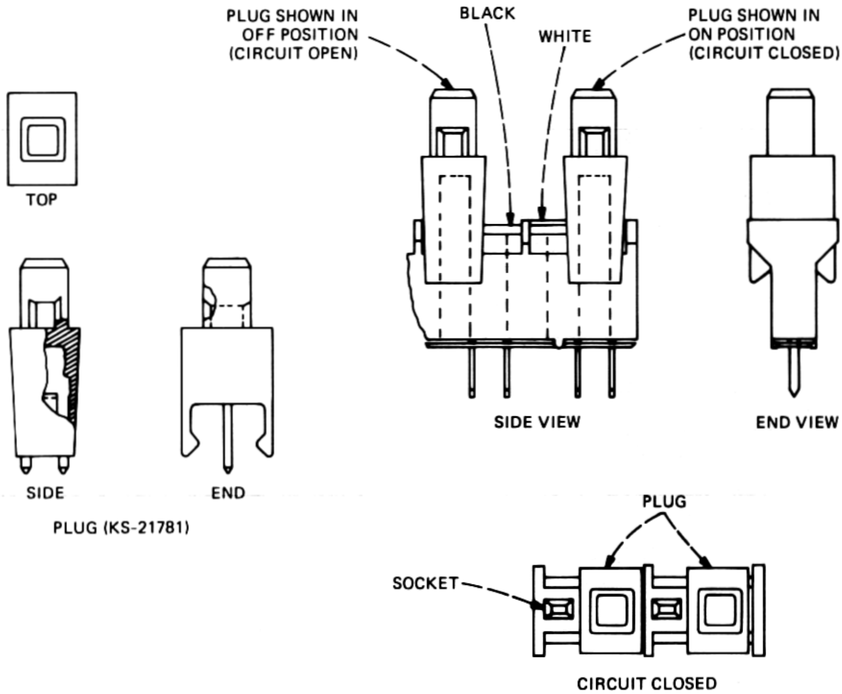

Fig. 9—D4 channel-unit option selector switch.

circuit at the office end of two-wire special service circuits (foreign exchange lines, off-premises station lines, foreign exchange trunks from a PBX, and other special access services). To accommodate the circuitry required for these functions, two printed wiring boards are required. The auxiliary printed wiring board is hinged to provide access for setting attenuator and option switches and is electrically interconnected to the main board through flexible printed wiring.

As the D4 channel bank production increased—it is currently running at about 50,000 banks and over 2-million channel units per year—it was apparent to designers of similar systems under development that a substantial reduction in cost and development effort could be realized by using the very versatile D4 hardware. Its most notable use is in the *SLC**-96 system.

III. THE SLC™-96 SYSTEM

The *SLC*-96 Subscriber Loop Carrier (*SLC*-96) system is a digital subscriber loop carrier system that can accommodate up to 96 subscriber channels between a central office terminal (COT) and a remote terminal (RT) using T1 digital lines. In addition to customer POT

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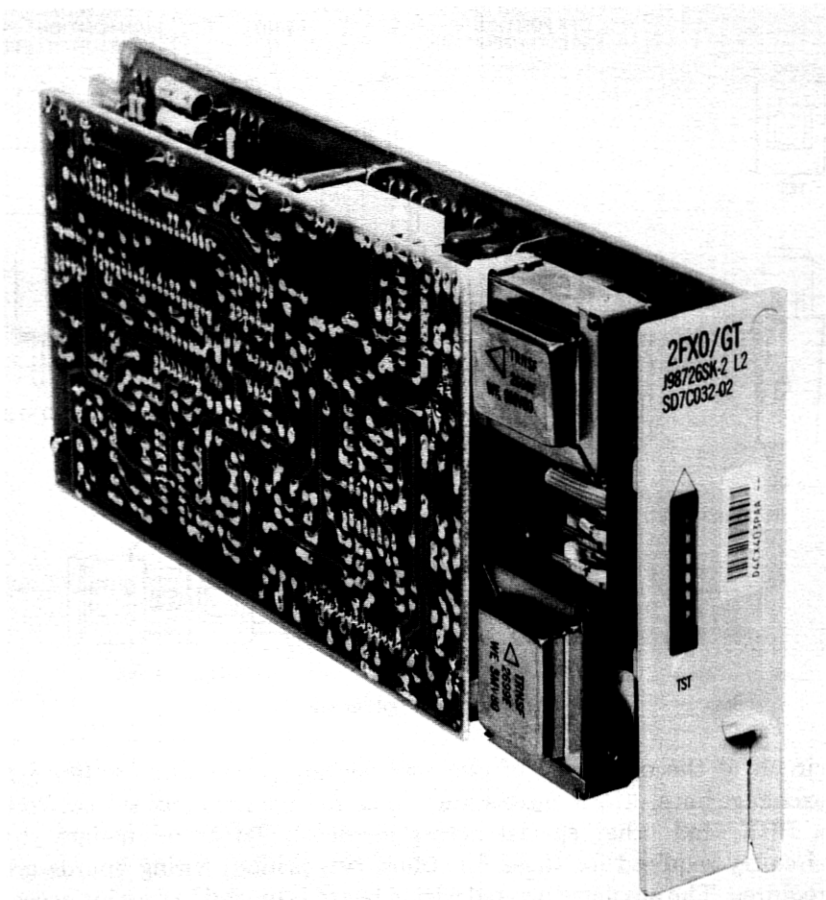

Fig. 10—Two-wire foreign exchange office end channel unit with gain transfer.

service, the system offers coin service, voice-frequency special services, and digital data services. The *SLC*-96 system is based on the transmission and physical design format of the D4 channel bank.

The *SLC*-96 system has two channel-unit designs for subscriber POT service: single-party service and multiparty service, combined with two-party automatic number identification (ANI). Coin service, including both dial-tone-first and coin-first modes, may be offered with a single pair of channel-unit codes. Most of the special service channel units developed for the D4 channel bank may be used in the *SLC*-96 channel bank.

The basic system components of the *SLC*-96 system are

(*i*) COT equipment and associated apparatus located in the serving central office

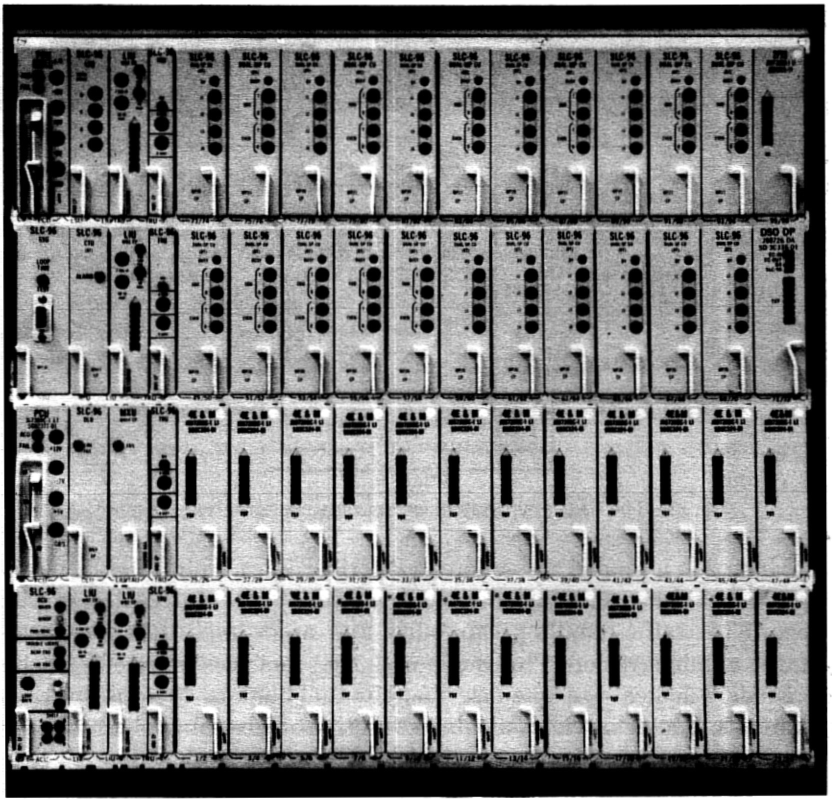

Fig. 11—*SLC*™-96 subscriber loop carrier channel bank.

(*ii*) RT equipment and apparatus located in the area to be served
(*iii*) DS1 facilities between the two terminals
(*iv*) The normal VF distribution facility extending from the RT to the subscribers.

Physically, the *SLC*-96 channel bank consists of four shelves, as shown in Fig. 11. Each shelf contains 12 slots for channel plug-ins and four additional slots for common equipment. Subscriber POTS channel units contain two channels per plug-in, while coin, special service, and dataport channel units contain one channel each. Therefore, each non-POTS channel displaces two subscriber channels.

The *SLC*-96 channel bank may be configured in a carrier-only mode, a carrier-concentrator mode, and a special services mode. Typical configurations illustrating these modes of operation are shown in Figs. 12, 13, and 14.

Mode 1 is primarily intended for subscriber lines with very high traffic. Since all channels are available on a full-time basis, non-POTS channel units may be mixed, as desired, with POTS channel units. Of course, each non-POTS channel unit displaces two POTS channels.

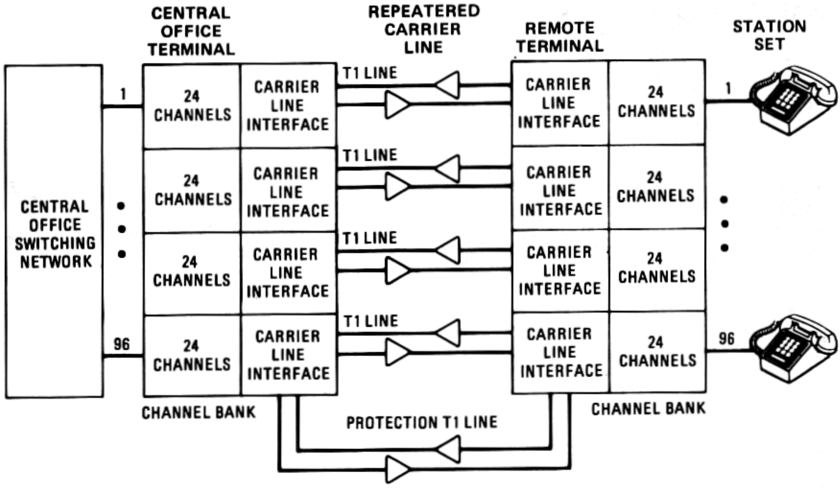

Fig. 12—The *SLC*™-96 system carrier-only configuration—Mode 1.

Mode 2 is intended for general subscriber lines. Full-access 48 to 24 digital switching (2:1 concentration) is a very conservative design with regard to traffic-handling capability and accordingly has no special traffic administration. This mode uses DS1 facilities more efficiently.

Mode 3 dedicates a 96-subscriber channel bank to 48 nonsubscriber channels. Each channel is available full time. Subscriber channel units are excluded from a bank operating in this mode. Mode 3 uses T1 lines more efficiently than Mode 1, for applications requiring large quantities of nonsubscriber channels.

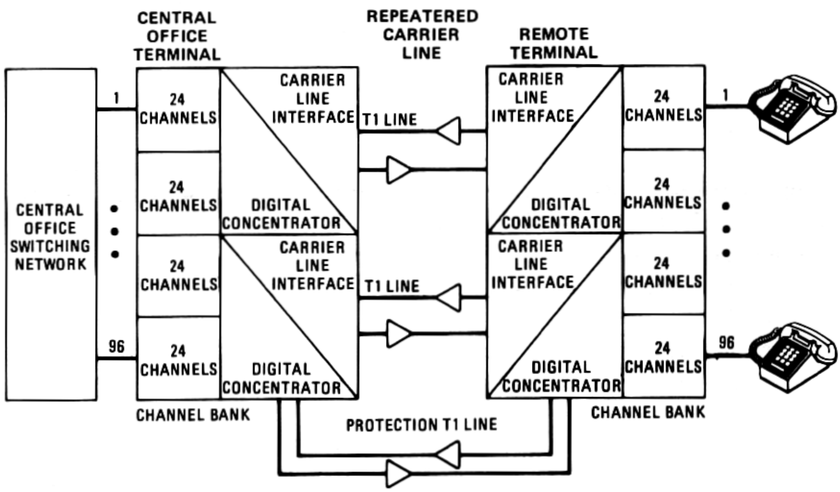

Fig. 13—The *SLC*™-96 system carrier-concentrator configuration—Mode 2.

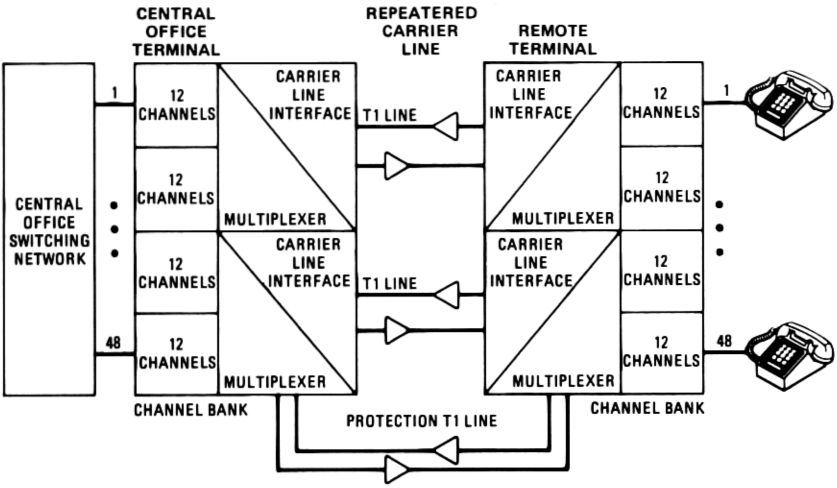

Fig. 14—The *SLC*™-96 system special services configuration—Mode 3.

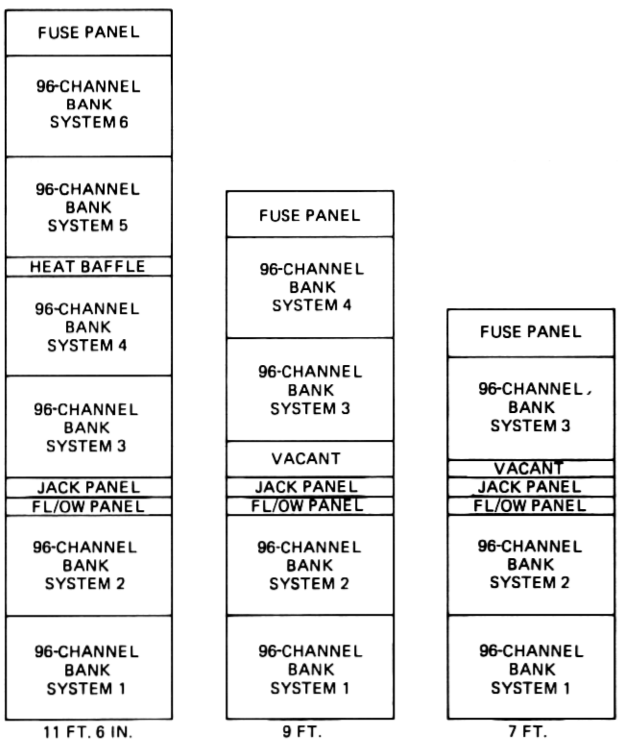

Fig. 15—Typical COT full-bay configuration for 7-foot, 9-foot, and 11-foot 6-inch frames.

COT equipment consists of a channel bank assembly, fuse and alarm panel, jack panel, and an optional T1 fault-locate and order-wire panel. (This section covers only central office channel banks and bays. Discussion of the *SLC*-96 remote terminal includes hut and cabinet considerations and is covered in this issue's article on the *SLC*-96 system.)

The fuse and alarm panel is mounted at the top of the central office bay, and can accommodate up to six *SLC*-96 systems. The panel provides fused -48V circuits to each power converter unit and distributes ±130 and -48V circuits to the LIUs for powering the digital lines. Each system in a bay has major, minor, and power/miscellaneous summary alarm arrangements, including local visual alarm and connections to office and remote alarm systems. One fuse and alarm panel requires five inches of vertical bay-mounting space.

The COT jack panel provides access to the digital lines and associated fault-locate lines for maintenance. The jack panel gains access to the digital line to be tested by means of a cord and card plug, which is inserted into a connector on the faceplate of the LIU serving the digital line. One jack panel is required for each bay and can accommodate up to six channel bank assemblies. One jack panel requires two inches of vertical bay-mounting space and is typically located at a convenient working height from the floor. A fault-locate and order-wire panel may be optionally provided at a COT bay for system maintenance. Figure 15 illustrates typical full-bay configurations possible for 7-foot, 9-foot, and 11-foot 6-inch bays.

IV. BANK HARDWARE

The size of the D4 channel bank was optimized to allow four 4-shelf channel banks to fit in a 7-foot unequal flange duct-type bay framework. The original banks were constructed with die-cast aluminum shelves that had plug-in unit guides cast on the top and bottom. The four connectorized backplanes were attached to the rear of the shelves. The shelves were fastened together with side brackets that were also used to mount the bank to the bay. Additional holes were drilled in the side plates so that the same part could be used for banks that are mounted in bays with a 5-inch front extension. Oversized screw holes were used in the brackets with factory assembly gauges to fix the spacing between shelves before the screws were set. Banks were coupled together in the bay with the top shelf of one serving as the bottom for the one above and with gauges again used to set the proper spacing. The top bank contained a top cover, with plug-in guides on the bottom side only.

A new, inexpensive method of keying plug-in units in the common equipment area was used by providing extra slots in the designation

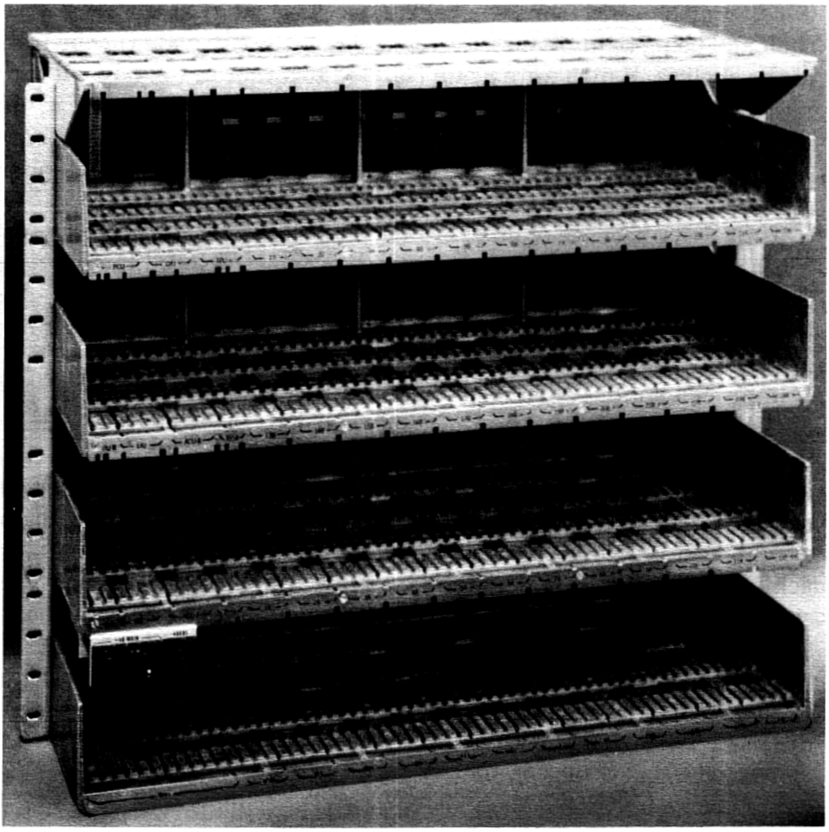

Fig. 16—Aluminum die-casting channel bank assembly.

strips that run along the front edge of the shelves. Distances between these extra slots and the plug-in printed wiring board slots were varied and matching bosses were cast into the rear of the faceplates to align with the slots in the proper plug-in positions. This bank assembly is illustrated in Fig. 16.

A second bank shelf assembly was subsequently designed to reduce cost. Shelf castings were simplified by removing the sides and the rear backplane support framework from the shelf casting. This allows the shelves to be stacked in various heights, making the bank assembly attractive to other systems looking for a low-cost, high-volume production shelf.

Overall bank weight was reduced by 25 percent. Shelves were coupled together with full-width sideplates, and bay-mounting adapters were, in turn, applied against the sideplates. Backplanes were fastened along the bottom edge of the shelf above and the top edge of the shelf below. Gauging of shelf-to-shelf spacing was minimized on all but the top shelf by using the backplanes as a gauge at the rear of the shelf and using tight diameter screw holes in the sideplates at the front of the shelves. Banks were again coupled together in the bay with the top of one serving as the bottom of the one above. Openings in the shelf were increased from a previous level of 29 percent to 45 percent, resulting in improved cooling with an average decrease in bank operating temperature of 6 degrees Fahrenheit.

At present, because of an ever-increasing demand and cost sensitivity, a new third-generation channel bank shelf assembly has been developed. While the assembly shown in Fig. 17 will initially be used for the *SLC*-96 system, it has been designed to accommodate D4 and other related projects.

Improvement has been made in three areas: a cost reduction of shelf die castings; a simplification of bank and bay assembly; and finally, the incorporation of other desirable features such as independent bank mounting, smaller stand-alone bank size, and increased structural stability. The new shelf die castings have been optimized for strength, weight, and castability while maintaining the improved bank cooling achieved with the second-generation shelf, which has 45-percent open shelf area. The basic structure that led to the optimization is a Z beam that is perpetuated through a lattice, as conceptualized in Fig. 18.

The Z beam is similar in principle to an I beam, minimizing weight while maximizing strength, and in addition allowing easy coring of the die part. To design a shelf of the right strength, the design criterion chosen was that a plug-in unit in the center of a shelf should not fall out of the groove in the shelf above when the bank is subjected to a 3-gram load. While in practice, the backplane connector would likely prevent actual fallout, this degree of conservatism was preferred. Through a tolerance study of the bank assembly and plug-in unit designs, it was determined that the shelf could have a maximum deflection of 0.017 inch under worst-case static loading, or 0.051 inch with a 3g dynamic load. The shelf was then designed to be slightly stronger, with a 0.012-inch (0.036 inch at 3g's) deflection under worst-case loading. Since the shelf is supported on both sides and at the back, the beams were spaced progressively closer from back to front to concentrate the strength where it was most required. The weight of the shelf is just over 3 pounds, and the worst-case load on the shelf was assumed to be 20 pounds.

The structure chosen enhances the die-casting process by virtue of its uniform and thin-cross sections. Metal flow is unrestricted and even, which ensures good fill and minimizes erosive die wear, thus prolonging die life. Also, the die can be efficiently designed with minimum gate sizes and the trim die can be correspondingly simple. Since all cross sections are relatively uniform, all material will solidify

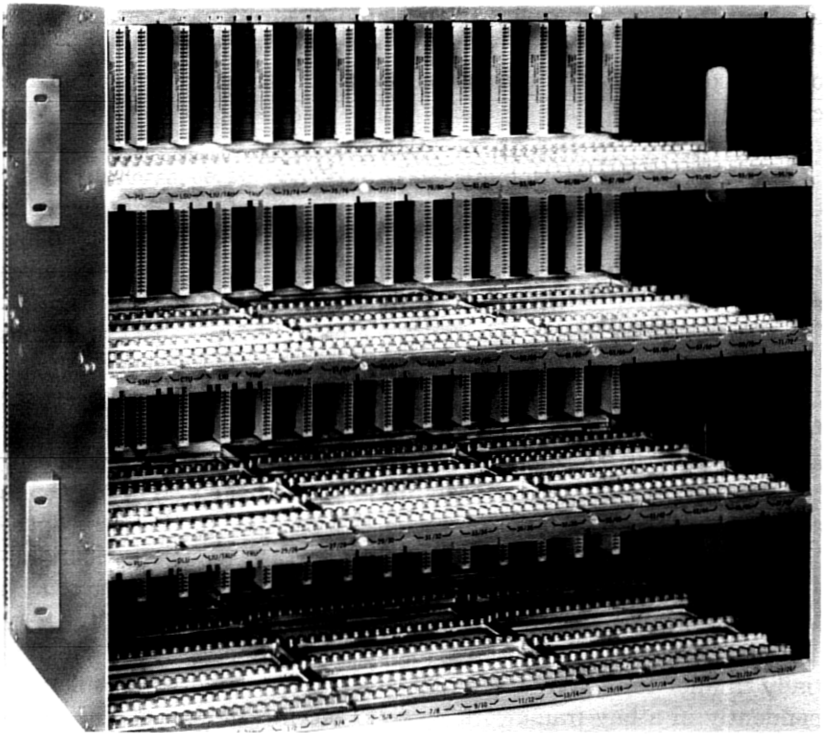

Fig. 17—Third-generation shelf assembly.

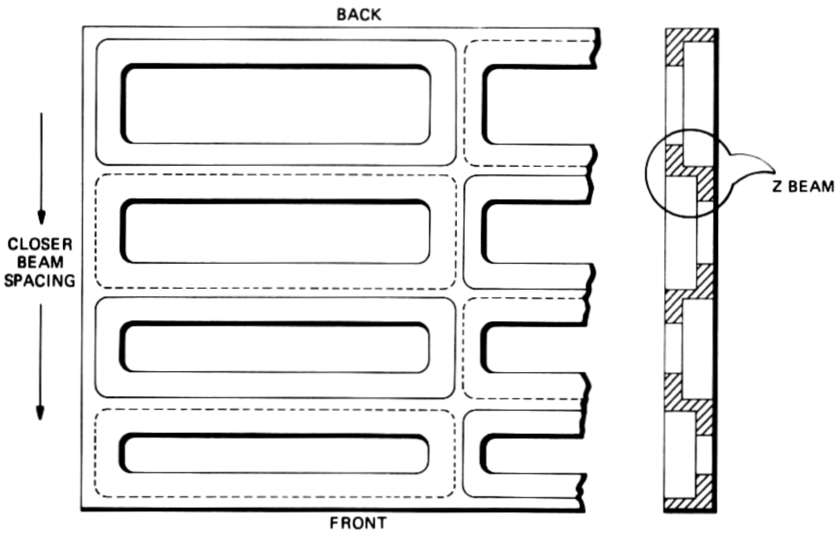

Fig. 18—Z-beam lattice die-cast shelf.

at about the same time, which will minimize shrink areas, microporosity, and residual stresses. Since all sections are relatively thin, the overall cooling time is minimized with a resultant decrease in die casting cycle time. This produces a higher casting rate, which in turn reduces the cost per casting.

Assembly of the new banks and bays has been streamlined by eliminating the need for any type of accurate fixturing and reducing the number of parts and screws. Bank fixturing is eliminated by using round mounting bosses, which are cast into the ends of the shelves and which match up with three slots in the side plates (see Fig. 19). Two slots are used to fix the shelf height, while the third establishes uniform depth. Since the mounting bosses make only tangential contact with the slots, the parts easily mate with even a slight interference fit. The slot width has, therefore, been nominally dimensioned only slightly larger (0.003 inch) than the boss diameter, thus promoting tight registration of the shelf. Mounting bosses have also been used to accurately locate the backplanes on the shelves. In this case space limitations and backplane variations led to the use of one diamond-shaped boss in a round backplane hole and one round boss in a backplane slot.

By using slightly thinner bottom and middle shelves and a substantially thinner top cover, the banks are now designed to mount independently in a bay framework with no sacrifice in space. This eliminates the need for any alignment when the shelf is mounted in a bay. Assembly and piece part costs have been further reduced by combining side plates and bay-mounting adapters into one piece. Also, fewer screws have been used to assemble the side plates to the shelves since the mounting details are also weight-bearing members.

In addition to the shelf and assembly cost reductions, there are several other desirable features incorporated in the new design. The shelves are less susceptible to movement caused by shock and vibration since all shelves are securely positioned via the mounting bosses.

Since banks are independently mounted, removal for repair and replacement of a bank in a bay, especially in the field, is greatly simplified. Independent banks also allow for shipment of partially filled, low first-cost bays for slow growth offices with additions conveniently made in the field as required.

Other applications have arisen where a channel bank may stand alone or be used in a bay with other types of equipment. While the existing design can be used in this single bank mode, the interlocking features on the top and bottom shelves add to its overall height. The new design has been trimmed to 19 inches as opposed to about 20 inches for the existing design. The new one-shelf units, such as the subscriber loop interface module (SLIM), will be five inches high instead

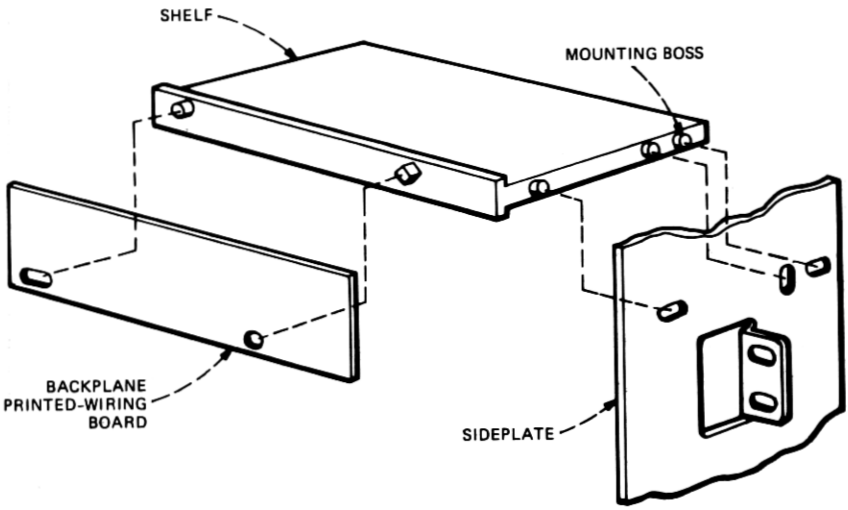

Fig. 19—Bank assembly alignment.

of about 6 inches and new two-shelf units will be 10 inches high instead of about 11 inches.

Holes used to mount the bank to the bay have been positioned at a conventional incremental distance from the bottom of the equipment since they do not have to be placed to accommodate odd-size banks being tied together. This allows for mounting with other equipment above or below, not wasting some portion of an inch.

V. BACKPLANE

In the early D4 channel bank production, rigid aluminum backplanes with press-fit edgeboard connectors were used. There are four backplanes in each bank and sixteen 54-pin connectors on each backplane. The bottom shelf backplane is smaller than the other three to facilitate mounting the Power Distribution Unit (PDU), which is the only unit in the bank that is not a plug-in unit. Insulated 26-gauge wires were wrapped manually to make the intra- and inter-backplane circuit connections. After a sufficient amount of operational experience was gained, a printed-wiring backplane was introduced into production.

The backplane edgeboard connectors are manufactured to Bell System requirements by commercial connector manufacturers. The connector pins are inserted into plated-through-holes in the backplane. The pin-to-board connection is made through a compliant section of the pin, which eliminates the need for soldering. This was especially important, since to efficiently use a printed-wiring board backplane it was necessary to use circuit paths nominally 0.010-inch wide separated by 0.010-inch spaces. The solderless compliant section was approved for Bell System use after a very extensive qualification program was completed.

The connector housing was designed to support alternate rows of early- and late-make contacts. This arrangement is important to avoid circuit "hits" and also to reduce the force required to insert or remove a plug-in unit. Two sets of "normal through" or "shorting" contacts are provided for each channel-unit position to facilitate trunk processing. Selective plating and other techniques are being used to supply gold in the contact area only.

At present, about 70 percent of the backplane wiring is printed. A three- to four-layer backplane would be required to print the remaining 30 percent of the wires, which at this time would be prohibitively expensive.

VI. PLUG-IN UNITS

There is one basic printed-wiring board size for all plug-in units in the D4 channel bank except for the PDU, which is covered later. The basic plug-in unit design employs an epoxy glass, double-sided rigid printed-wiring board about 9.9 inches long and 4.3 inches high. Each board has 54 gold fingers, 27 on each side, for interconnection to the edgeboard connector in the backplane.

Each plug-in unit contains a faceplate with a simple latching mechanism that aids in extracting the unit and also serves as an automatic lock that prevents the unit from becoming unseated by shock or vibration such as might occur during earthquakes.

The plug-in unit and shelf have been designed to ensure proper insertion and connector mating over a relatively wide tolerance range. When the plug-in unit is inserted in the shelf, the faceplate always comes in contact with the shelf, preventing the printed-wiring board from bottoming in the backplane connector. Since the backplane connector is rigidly mounted, float is provided in the shelf track.

VII. HYBRID INTEGRATED CIRCUITS

Hybrid integrated circuits (HICs) were used extensively to achieve a compact and cost-effective channel bank. A typical channel unit contains two resistor-capacitor (RC) low-pass filter HICs, two planar thin-film integrated circuits as part of the attenuators, and one custom resistor-crossunder HIC for the rest of the integratable electronics.

The principal reason for the extensive use of HIC technology is the small size that is achievable at a cost comparable to, or less than, the cost of a discrete equivalent. The small size allows fewer and smaller printed-circuit boards. The use of hybrids also tends to allow a simpler class of printed board since much of the interconnection is accomplished in the HIC.

The transmit and receive units of D4 were initially designed using predominantly small-scale integration "catalog" silicon devices. The longer term expectation was that larger scales of integration could be used, as cost reductions, when such devices became available. With this in mind, it was desirable to package the existing small-scale devices as compactly as possible to allow for a graceful evolution to larger scales of integration. Initially, the transmit and receive units contained 52 and 51 silicon integrated circuits, respectively. The present transmit and receive units contain only six and five devices, respectively. This evolution of large-scale integration into the receive unit is illustrated in Fig. 20.

In predominantly digital circuits like the transmit and receive units, the hybrids have been replaced by LSI silicon, but in most cases the hybrid remains the optimum packaging technique for providing functional modules of precision passive components and a mix of silicon device technologies.

Two different film-circuit process classes were used for the D4 HICs. The resistor-crossunder class was used for most of the hybrids in the channel bank. The fabrication sequence for this class of circuits is described in the next paragraph. The resistor-capacitor process class was used for the active filter realizations in the channel units and a

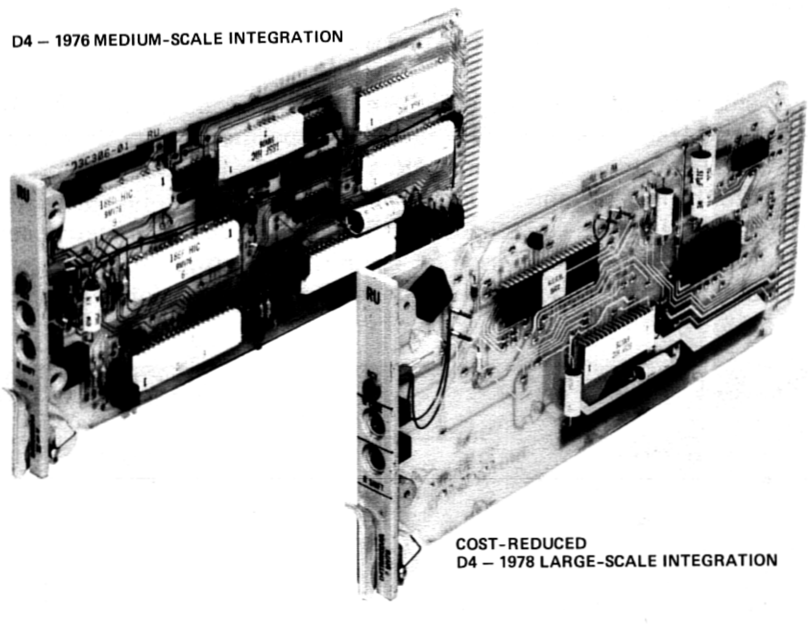

Fig. 20—Evolution of large-scale integration (LSI) into the receive channel unit.

description of this process class follows the resistor-crossunder description. Typical circuits are shown in Figs. 21 and 22.

A combination of thick-film and thin-film technology is used on the resistor-crossunder hybrids. The thick film is used for a rugged crossover structure, and the thin film for resistor fabrication and fine-line conductor metallization. All of the film-circuit processing is done on a major substrate, 3-3/4 inches by 4-1/2 inches. Eighteen of the 24-pin DIP-size circuits are processed at the same time. Briefly, the process sequence is as follows: Starting with a fine-grain, 99-percent alumina substrate, a thick-film gold conductor pattern is screen printed and then fired. Two layers of dielectric glaze are then screen printed and fired on top of the gold conductor, leaving short lengths of gold extending beyond the glaze. This will eventually form part of the crossover structure. Next, the thin-film resistor and conductor films are deposited over the entire substrate. The resistor film of either 100 or 300 ohms per square tantalum nitride is deposited by sputtering. The conductor film consists of thin layers of sputtered titanium and palladium, followed by about 1.5 μm of plated gold. Two pattern-generation sequences are then performed to selectively remove the conductor and resistor metallization. The resistors are then stabilized at 300 degrees Centigrade for four hours and laser trimmed to value. Next, the beam-lead silicon integrated circuits are bonded by thermocompression and the substrate is snapped into individual circuits. Soldered leads are then attached, the room temperature vulcanization (RTV) encapsulant is flow coated, and the circuits are tested and burned in.

A small set of standard sizes had been chosen for all HICs for telephone transmission applications. The specific circuits developed for the D4 system conformed to this standardization. The standard sizes are the 24-, 32-, and 40-pin, 0.600-inch wide, dual in-line packages (DIPs). This external size standardization enables common high-speed handling equipment to be used for burn in and testing.

Standard metallization features have also been incorporated on the

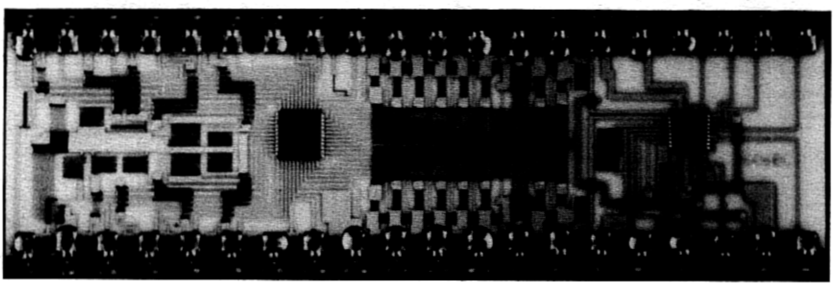

Fig. 21—Typical resistor-crossunder HIC.

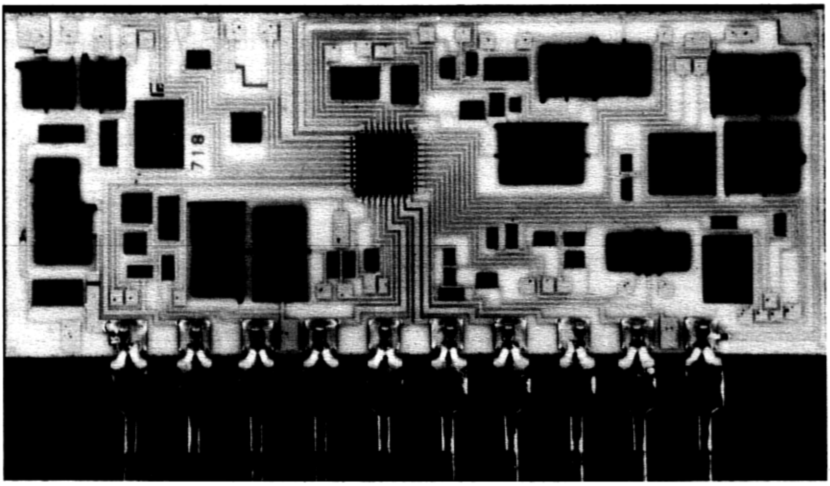

Fig. 22—Typical resistor-capacitor HIC.

ceramic to allow for common probing fixtures for resistor trimming and testing, isolation testing, and fault diagnostics. These features are located along the edge of the ceramic, allowing for maximum layout flexibility on the interior of the circuit.

The resistor-capacitor (RC) circuits used for the active filter functions in the channel units have many similarities to the resistor-crossunder circuits previously described. They use the same substrate material and size standardization, the same laser-trimmed resistor geometries, the same bonding and lead attach techniques, and the same encapsulation procedure. The differences are in the film-circuit process sequence that creates the capacitors and in the functional adjustment of the resistors to provide the required filter characteristics.

The film-circuit fabrication starts with screen printing and firing of a thick-film dielectric glaze to prepare a smooth surface at the future capacitor sites. Then tantalum is sputtered over the complete circuit and thermally oxidized to create a chemically inert surface. Next, the capacitor film (αTa) is sputtered. The capacitor base electrodes are then delineated by pattern generation (photoresist and etching). The capacitor dielectric is generated by anodizing the capacitor film through a photoresist mask. The anodization voltage determines the capacitor dielectric thickness. Next, the resistor and conductor films are deposited over the entire substrate. The resistor film is 300 ohms per square tantalum nitride, and the conductor film is sputtered titalum and palladium followed by plated gold. The conductor and resistor geometries are next pattern generated using standard photolithographic techniques. The capacitors are then tested for leakage current at 55 volts. Circuits passing this test proceed to have their resistors trimmed to achieve a precise RC product. This is the frequency-determining parameter in the filter. The silicon operational amplifiers are then bonded and the substrates are laser scribed and snapped into individual circuits. The external leads are then attached and the circuits are electrically tested. A small percentage of the circuits require additional functional trimming to achieve a precise gain at 1kHz. The circuits are then encapsulated and retested.

VIII. HEAT TRANSFER

It is generally true that components used in the D4 and *SLC*-96 systems can operate reliably in a 185-degree Fahrenheit ambient temperature. D4 and *SLC*-96 banks have, therefore, been designed to operate with internal ambient temperatures of 185 degrees Fahrenheit or less even during emergency periods and while dissipating typical worst-case power. Emergency periods, as defined in the New Equipment Building System General Equipment Requirements, BSP Section 800-610-164, permit the office ambient to be 120 degrees Fahrenheit for a maximum of three days in a row, not to exceed fifteen days per year. The ambient temperature of an office is measured five feet up from the floor and 15 inches in front of the bay. Typical worst-case power is not an absolute maximum but is a level which few banks are expected to exceed. For D4 tests an assortment of channel units were chosen that were somewhat weighted towards high-dissipating units; a busy level of 75 percent was used. For *SLC*-96 tests a traffic level of 7 hundred call seconds (ccs) or 19 percent was used. Also, *SLC*-96 Line Interface Units (LIUs), which can vary considerably in dissipation level because of the inclusion of T1 office repeaters, were simulated at the high end of their dissipation range.

During the initial stages of D4 development a prototype bay was assembled and tested to determine expected operating temperatures. The bay consisted of six simulated D4 banks mounted in an 11-foot 6-inch bay. The top two banks were equipped with simulated D4 plug-in units. These units consisted of resistors, to dissipate anticipated power levels, and wooden blocks, to simulate air flow restrictions, mounted on printed-wiring boards. In addition, a working prototype of the power converter unit, which is the highest dissipating unit, was mounted in one of the top two banks. The four bottom banks were metal boxes equipped with light bulbs that dissipated equivalent bank power. Testing established that the design should perform adequately without any special measures being taken to cool the equipment. As D4 production bays and plug-ins became available, a production bay was tested as a check on the temperature performance and the validity of the early testing. The configuration tested dissipated 81 watts per bank. Again, when projected to a 120-degree Fahrenheit office, the equipment did not exceed the 185-degree Fahrenheit limit (shown in Fig. 23). There were, however, some differences between the production and simulation bay results. While the average common-unit temperatures were approximately the same, the hottest production channel unit was 15 degrees Fahrenheit above the same in the simulated bay and the production power converter unit was 9 degrees Fahrenheit higher.

When the *SLC*-96 COT development was initiated, an improved prototype bay was constructed based on the experience gained from the D4 prototype bay. The top four banks were equipped with simulated plug-in units and light bulbs in metal boxes used for only the bottom two banks. Backplane printed-wiring boards and connectors were used. Also, the power dissipated in simulated channel units was asymmetrically distributed as the busy channels were randomly distributed throughout the banks. The power level tested in the bank was 134 watts. This power level was not only higher than D4, it was not as evenly distributed. With the inclusion of a second PCU and T1 office repeaters in each of the five LIUs, 63 percent of the *SLC*-96 dissipation is in the common-unit section, which occupies the left quarter of the bank. As a result, the maximum temperature levels were exceeded with a local ambient temperature in the power converter units of up to 212 degrees Fahrenheit and up to 196 degrees Fahrenheit in the interface units.

To improve the temperature levels several steps were taken. The power converter unit was redesigned with particular attention paid to distributing dissipating components throughout the unit. Heat dissi-

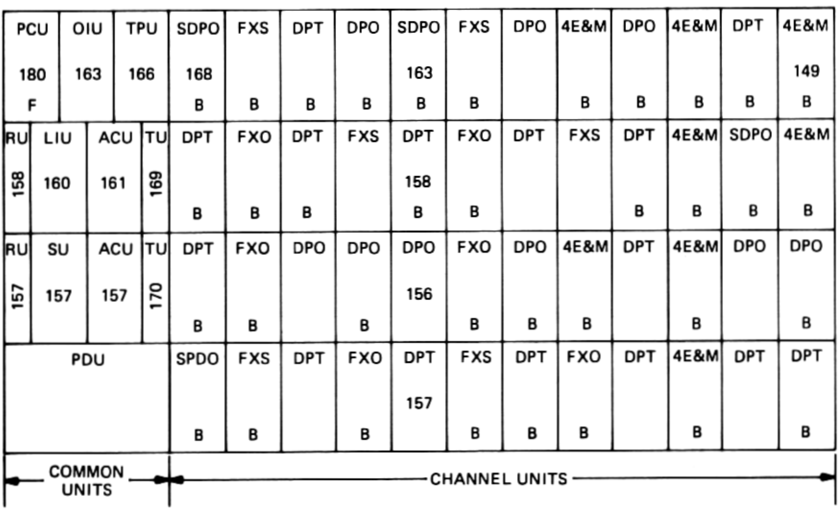

Fig. 23—D4 temperature profile.

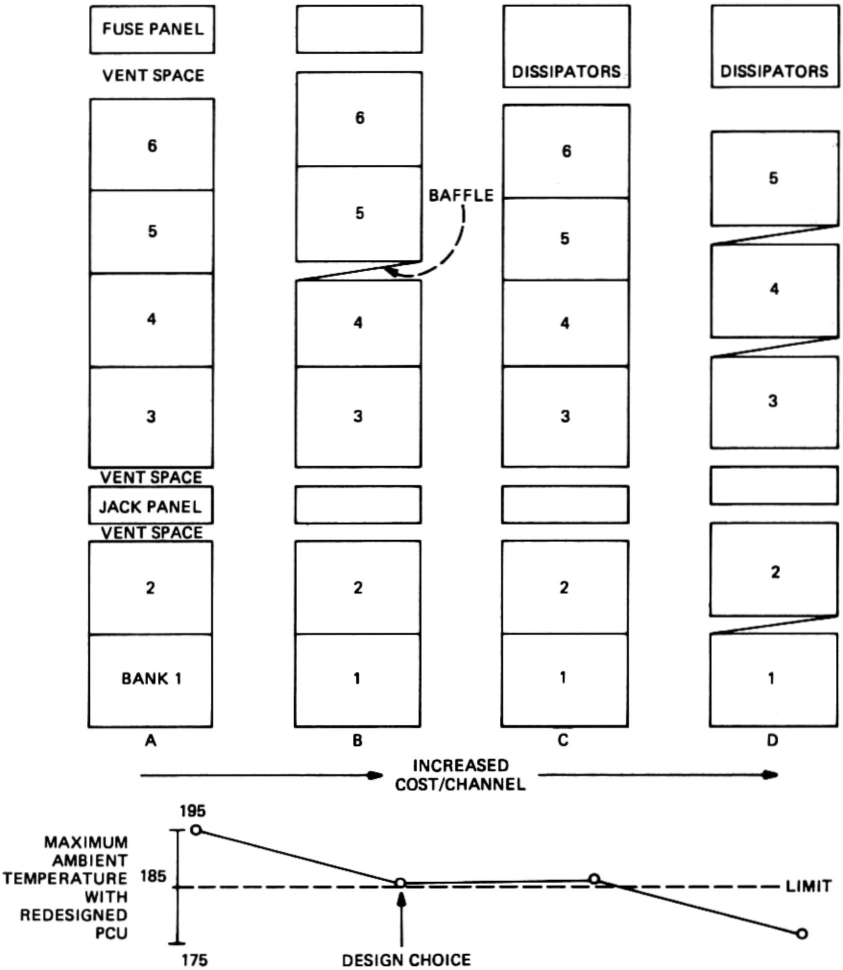

Fig. 24—Effect of bay baffles on bank temperatures.

pation was also improved by using an epoxy-clad metal printed wiring board rather than an epoxy-glass board. The redesign accounted for a 16-degree Fahrenheit reduction in unit temperature. Several approaches were considered to reduce overall bank temperatures, including a reduction to five banks per bay with heat baffles between each bank and external dissipation at the top of the bay of some of the line interface power. However, the most economical alternative that still met the requirements was the use of one baffle between the fourth and fifth banks and ventilation spaces above the second bank, below the third, and above the sixth, as shown in Fig. 24.

After D4 production was well established, a cost-reduced shelf and

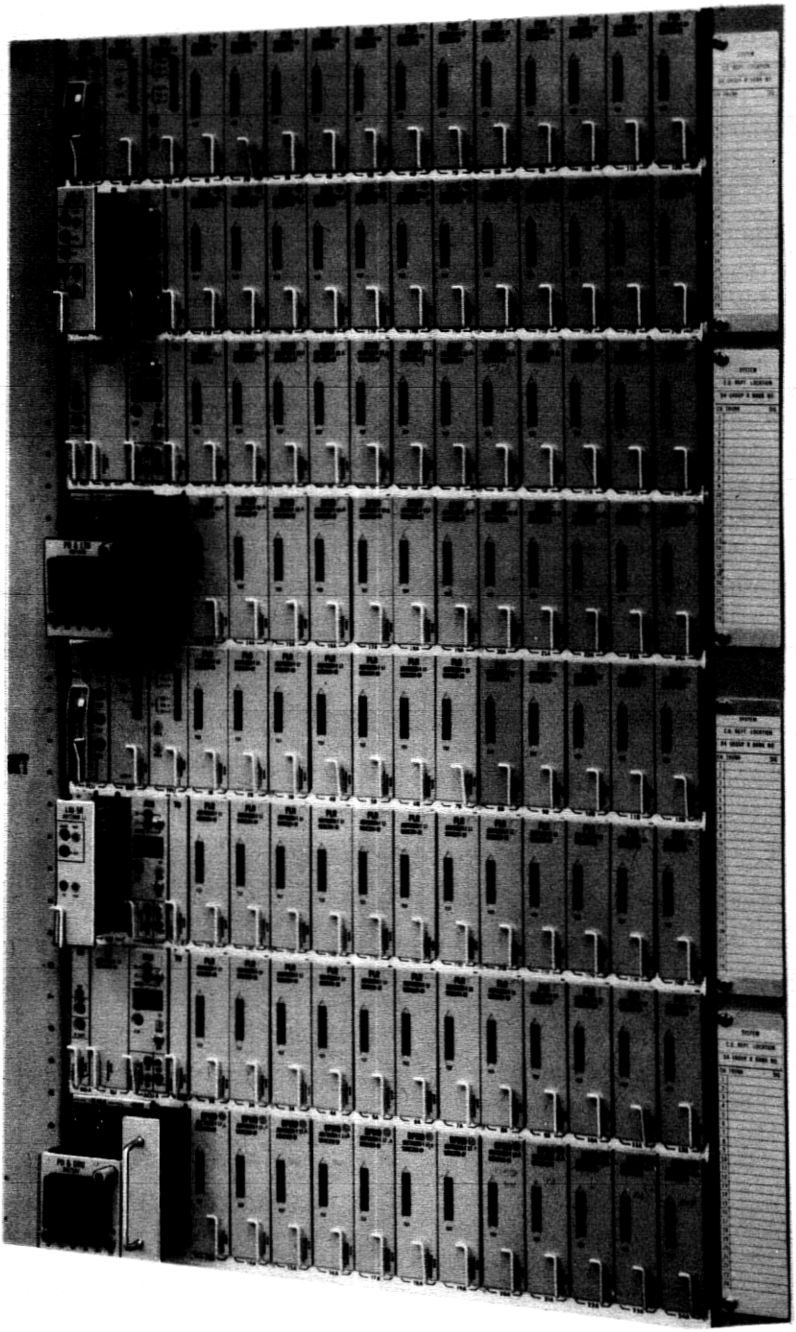

Fig. 25—D4 channel bank—Mode 5.

bank assembly was designed. As part of the redesign, the open area in the shelf was increased from 29 percent to 45 percent. As a result, the average temperature reading in the bank dropped 6 degrees Fahrenheit. This shelf is now being used in production on both D4 and *SLC*-96 systems, thus giving an added margin for temperature performance.

IX. LIGHTWAVE APPLICATION

The D5 Channel Bank Mode 5 (Fig. 25) was introduced to meet the emerging needs of the telephone companies for small cross-section, low-bit rate, lightwave transmission systems. Mode 5 is a 96-voice grade channel facility that can be connected directly to to a maximum of 4.5 miles of lightguide cable. This arrangement is targeted primarily for the short-haul point-to-point routes where the lightwave transmission attributes are required but the cross sections are too small to justify the installation of higher capacity lightwave systems.

D4 Mode 5 expands the versatility of the D4 channel bank family by offering a "built-in" capability for connecting to lightwave systems. D4 Mode 5 is electrically similar to D4 Mode 4, a 96-channel mode of operation that interfaces with DS2 rate-transmission facilities. In the Mode 5 operation, however, the multiplexed DS2 rate signal is dipulse coded and transmitted directly over an optical fiber using either a laser

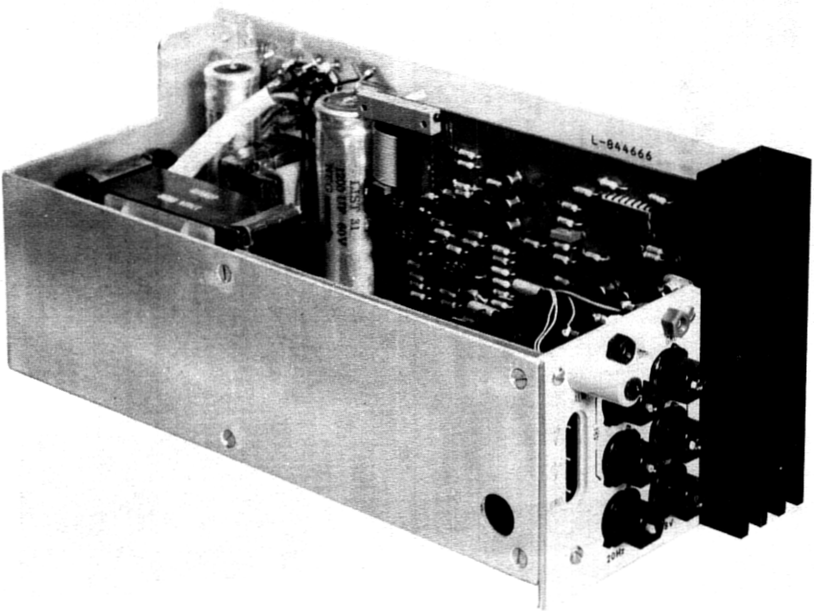

Fig. 26—Power distribution unit equipped with optical transmitter.

diode or an LED transmitter. The transmitter is housed in one of the two Power Distribution Units (PDUs), as shown in Fig. 26. The receive-path optical transducer is located in the second PDU (see Fig. 27), along with a silicon avalanche photo diode (APD) used to convert and amplify the light energy from the optical fiber.

Converting from Mode 4 to Mode 5 only requires changing the PDUs and the transmitting and receiving LIUs and adding a few wires at the rear of the bank. An extensive field trial evaluation was conducted in Sacramento, California. The route used was 2.7 miles long, connecting the Gladstone and Main offices. The lightguide cable contained 36 fibers. In addition to D4 Mode 5, the MX2-L Lightwave Digital Multiplexer-Demultiplexer (Muldem) and DLC-2 Direct Lightwave Connectors were also tested at Sacramento. These designs also use the D4 hardware.

The first commercial service over D4 Mode 5, manufactured by Western Electric, was installed at the 1980 Winter Olympic Games in Lake Placid, New York. The D4 Mode 5 provided flawless voice transmission between the Lake Placid central office and the broadcast center throughout the entire period. A map illustrating the communications route and equipment is shown in Fig. 28.

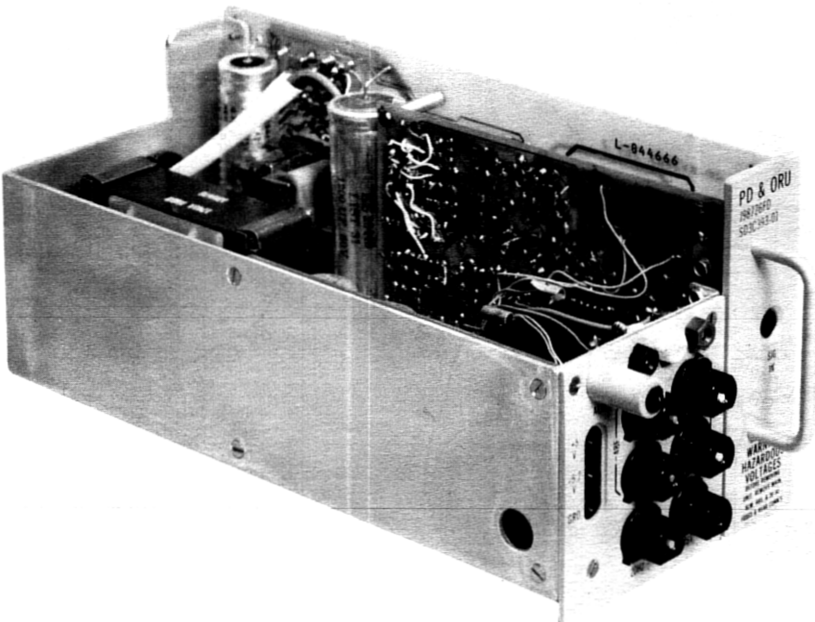

Fig. 27—Power distribution unit equipped with optical receiver.

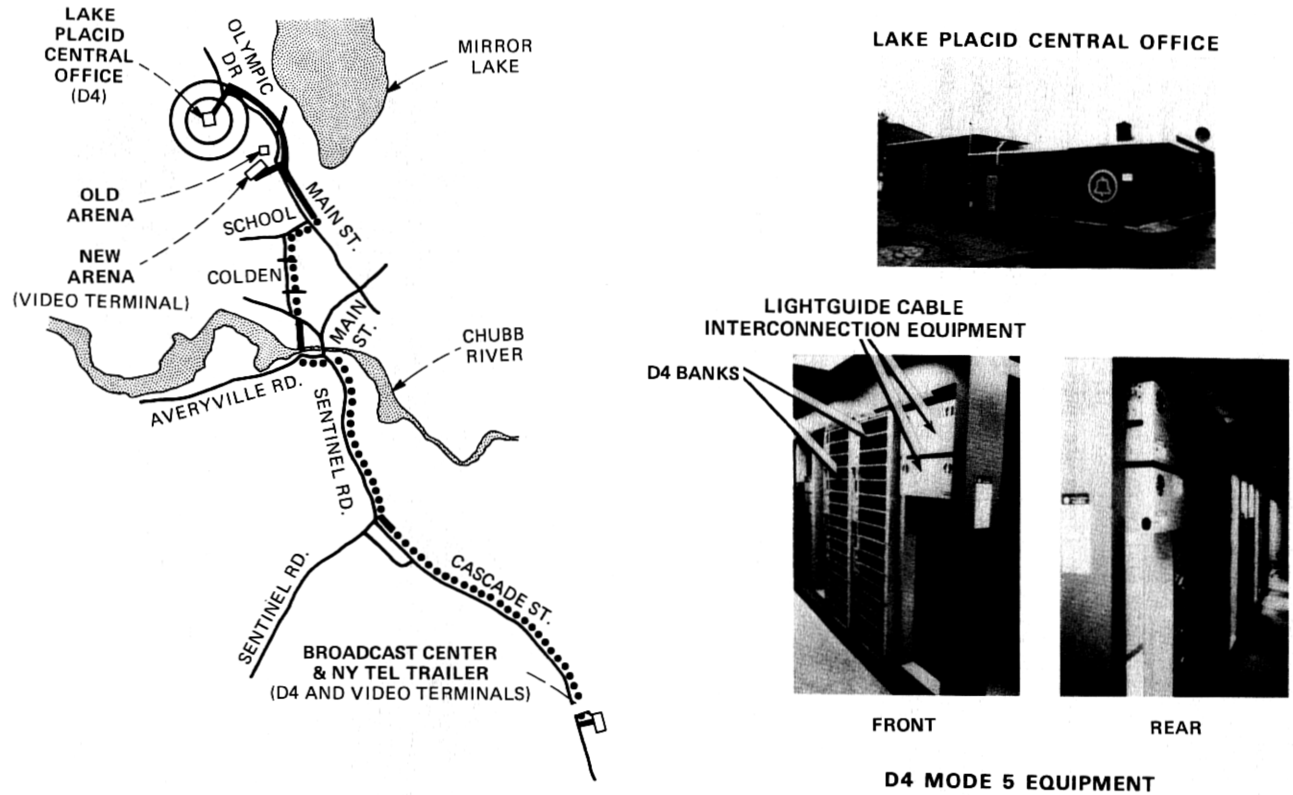

Fig. 28—D4 Mode 5 at Lake Placid, New York during the 1980 Winter Olympic Games.

Fig. 29—Display of different systems using D4 technology.

X. PROLIFERATION OF D4 HARDWARE

In addition to the systems discussed, a number of other systems have been designed using the D4 format. To illustrate the successful utilization of packaging commonality, a display, as shown in Fig. 29, was constructed and placed on exhibit by Western Electric at the International Telecommunication Conference in the fall of 1979 at Geneva, Switzerland. The individual systems comprising the display are:

(*i*) MX2-L Digital Lightwave Multiplexer Terminal, which interfaces T1 or T1C digital lines to FT2 lightwave facilities

(*ii*) DCT Digital Carrier Trunk Terminal, which provides a direct interface between No. 1 ESS and T1, T1C, or T2 digital facilities

(*iii*) LT-L Connector Double Digroup, which offers an economical means of terminating analog on the No. 4 ESS

(*iv*) The D4 Channel Bank, D4 Mode 5 Channel Bank, and *SLC*-96 Systems, which have been described earlier.

XI. SUMMARY

The D4 digital terminal is an integrated composite of efficient and economical bank assembly hardware, plug-in unit, component, and integrated circuit physical designs. High production levels have encouraged continual improvement and cost reduction since its inception, while its attractive features have resulted in a proliferation of the design through a number of systems.

XII. ACKNOWLEDGMENTS

The authors would like to acknowledge the contributions of the many people who made the success of these systems possible.