THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 51, No. 8, October, 1972
Printed in U.S.A.

D2 Channel Bank:

Physical Design and Introductory Program

By D. J. VAN SLOOTEN and K. A. GLUCKOW

(Manuscript received June 22, 1972)

The D2 Channel Bank is designed to provide simplified engineering, installation, and maintenance. Integral voice-frequency alarm and access are provided in a packaged shop-wired frame with a centralized built-in test capability to facilitate initial line-up, testing, and trouble shooting.

Circuits are implemented with discrete components and with thin-film and silicon-integrated circuits. Low cost, reliable assembly and wiring techniques are employed. The frame organization and circuit partitioning provide a functional arrangement of circuits with good electrical isolation between critical multiplexing and coding functions.

An introductory program and an on-going reliability program have demonstrated the adequacy of both equipment and documentation. In the first 21 months of operation, approximately 3 percent of the circuit packs shipped have failed in initial line-up or in-service. This compares favorably with the performance of similar systems, and recent design modifications are expected to result in substantial improvements.

I. INTRODUCTION

The D2 Channel Bank multiplexes and codes the telephone traffic carried by 96 two-way toll-grade trunks into 4 two-way 1.544-megabit signals for transmission. Companion articles in this series discuss system aspects of the D2 Channel Bank, and the design of the circuits which embody it. This paper discusses the physical design of the D2 Channel Bank. This includes activities that have circuit information as input and, as output, the specification of a manufacturable design to Western Electric. The D2 introductory program and an on-going reliability program intended to ensure satisfactory service to the Operating Companies are also discussed.

II. PHYSICAL DESIGN OBJECTIVES

The primary goal of the physical design of the channel bank was a manufacturable design which would satisfy the performance and cost objectives for toll service. An analysis of the cost of the D1 Channel Bank equipment as installed for toll-connecting service indicated that a considerable portion of the installed cost was attributable to engineering, installation, and maintenance. Objectives for the D2 Channel Bank, therefore, included simplified engineering, installation, and maintenance, as well as low manufacturing cost.

Operating Company engineering and installation would both be simplified if the channel bank could be furnished in a "packaged" frame containing all of the voice-frequency equipment associated with the channel bank. This contributes to simplification of installation because the only wiring required would be that which brings the trunks to the channel bank and takes the digital signals to the transmission facility and back. Additional simplification of installation would result if the wiring could be identical from the Intermediate Distributing Frame to the channel bank for all types of trunks, and if the wiring could terminate in the same way regardless of the particular option used in the channel banks.

In order to simplify maintenance, a number of objectives were established. First, all apparatus was to be pluggable to minimize outage time and circuit packs were to be compatible on an individual basis, so that circuit packs need not be replaced in sets. Centralized controls and indicators were to be provided for simplified line-up and fault diagnosis. Further simplification was planned by eliminating the need for setting carrier-group alarm options and the need to store voice-frequency attenuator pads.

III. SYSTEM CONFIGURATION AND FEATURES

The physical design of the D2 Channel Bank was customized to satisfy the system and electrical requirements of a toll digital channel bank. An early decision to provide 96-channel coding (four digroups of 24 channels each) in a single coder required modular physical arrangements based on multiples of four digroups to be used in 7-foot, 9-foot, and 11-foot 6-inch (2.1, 2.7, and 3.5 meters) frame heights. Figure 1 shows the layout for the 11-foot 6-inch frame which houses four digroups and Fig. 2 shows the 7-foot version consisting of a triple bay frame housing eight digroups. An expandable 9-foot version houses 12 digroups in a four-bay arrangement. A D2 Channel Bank standby bay is also available in 11-foot 6-inch, 9-foot, and 7-foot frame heights. It is designed to provide protection switching for the D2 Channel Bank

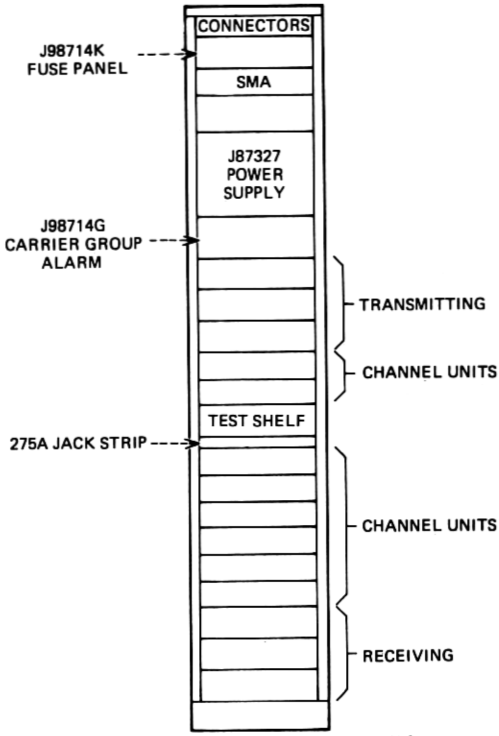

Fig. 1—D2 Channel Bank, 11′–6″ bay.

on a digroup basis. Forty digroups may be protected by one D2 standby bay.

The interface between the voice-frequency plant and the common equipment of the channel bank is provided by the channel unit. The channel units mount in the center of the 11-foot 6-inch frame separating the transmitting and receiving common equipment. The 7-foot and 9-foot versions preserve the same arrangement of channel units and common equipment so that factory wiring is identical for all frame codes. Eight VF leads are brought to each channel unit from the intermediate distributing frame (IDF) which permits the various channel unit codes to be intermixed with identical wiring.

In addition to matching the particular types of trunk circuit to the channel bank, the channel unit provides standard signal level (transmission level of −16 dB, transmit, +7 dB, receive), and signaling jack access for maintenance as well as patching. Inter-bay patch jacks are also provided to facilitate restoration patching.

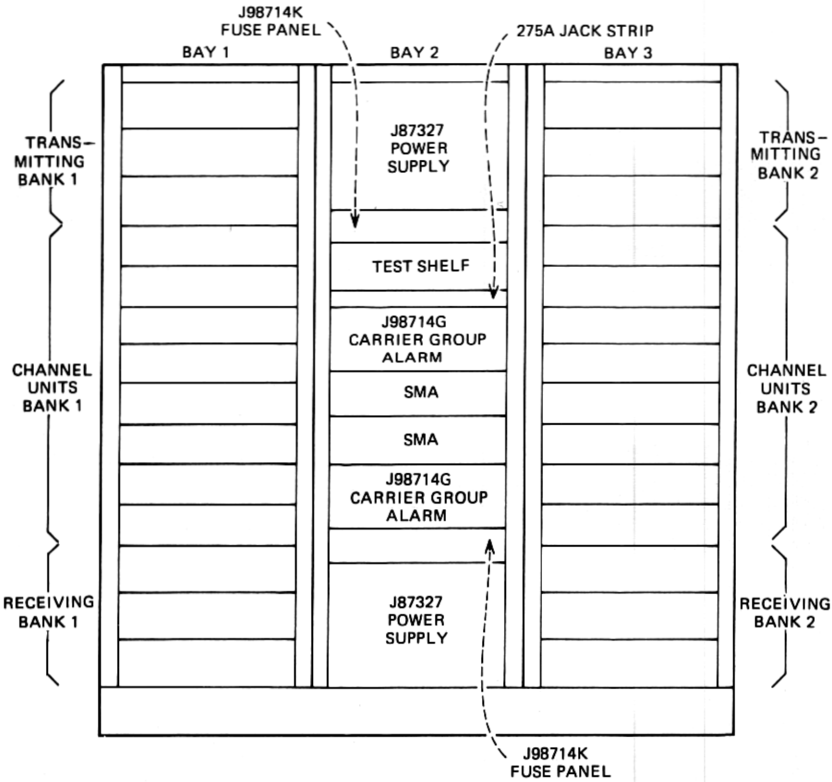

Fig. 2—D2 Channel Bank, 7′ triple bay.

On certain channel unit codes, additional access is provided to allow for connection to external trunk equipment such as echo suppressors or delay equalizers, and for additional access to remote maintenance or to automatic protection switching.

Additional voice-frequency equipment included in the factory wired frame, as shown in Figs. 1 and 2, consists of the carrier group alarm (CGA) and the switched-maintenance access system (SMAS) connector. In addition to standard office alarm interfaces, an E2 status and control interface* is provided at the test shelf. Energy for the dc-to-dc power converters in each frame are supplied from −48V office battery via a fuse panel.

* This allows remote monitoring and control of the channel bank at a distant centralized location.

The test shelf, mounted at a convenient height for craftsman operation, houses several circuit packs which form a built-in test facility. The test shelf is shown in Fig. 3. The facility includes a filter for measuring crosstalk resulting from a 1000-Hz test tone when applied at the 4-wire input of a channel bank. It is used in conjunction with access provided on the test shelf to the centralized transmission and noise-measuring system and to the milliwatt supply. A digital signal

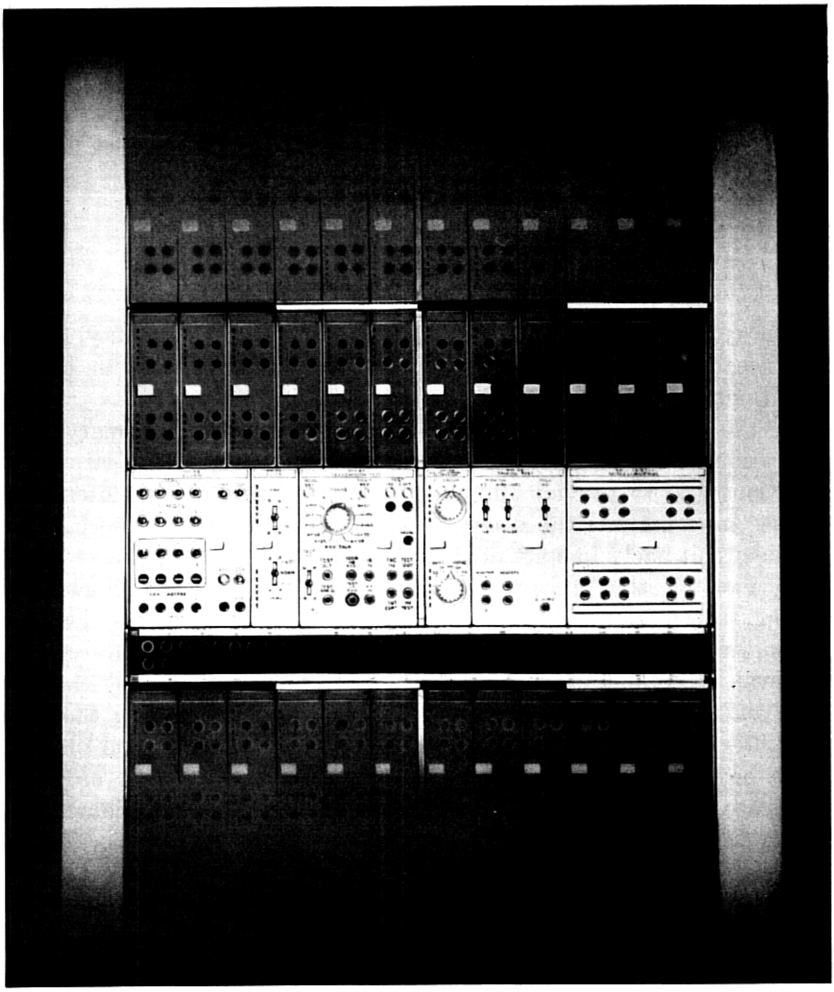

Fig. 3—Test shelf.

generator provides the digital equivalent of a 0-dBm0 level test tone as required for receiving gain adjustment of each voice channel. The talking test circuit is used to monitor transmission and noise on a high-impedance bridging basis and permits talking on the facility for maintenance and trouble shooting. In addition, alarm control circuitry on the shelf indicates various failure conditions, and provision is made for looping the digital signal for fault isolation. A miscellaneous jack unit is provided with jack, key, and lamp positions for order wires and jack-ended call numbers. The intent is that these features will be engineered by the operating companies to suit their individual needs.

In addition to the built-in test facility and the centralized transmission and noise measuring system (or their portable equivalent), a volt-ohm milliammeter and a portable trouble-locating test set are required for trouble-locating tests on the common equipment.

IV. PHYSICAL DESIGN CONSIDERATIONS

4.1 *Circuit Partitioning and Organization*

The constraints of circuit performance, operation, reliability, maintenance, and manufacturing cost are significant factors in circuit partitioning.

In the channel bank, functional partitioning was a primary consideration in order to provide adequate performance of critical circuit functions and to provide simplified factory testing and maintenance. A case in point was the decision to design the coder and decoder as single-circuit packs in spite of the large size of these functions.

In view of the multi-stage multiplexing scheme and 96-channel coding, considerable thought was given to minimizing the number of working trunks placed out of service by a circuit-pack maintenance removal. A notable exception was the packaging of eight per-channel gate and filters on a single circuit pack rather than placing the gate and filter on its channel unit. The need to place the gate and filter in close proximity to the multiplex and coding functions in order to minimize the length of the critical PAM bus was an overriding consideration.

An analysis of circuit function versus packaging volume indicated that a 5- by 10-inch (12.5 × 25 cm) printed wiring board was optimum for channel units and that a 6- by 10-inch (15 × 25 cm) printed wiring board was an appropriate choice for common units. This also provided a good pin match to the "908" series Western Electric 40-pin connector. Large functions could be accommodated within this scheme by the use of module boards and a second connector.

The arrangement of channel units and common-unit circuit packs is shown in Fig. 4. This arrangement was chosen to provide isolation of transmitting and receiving common equipment, and to provide for

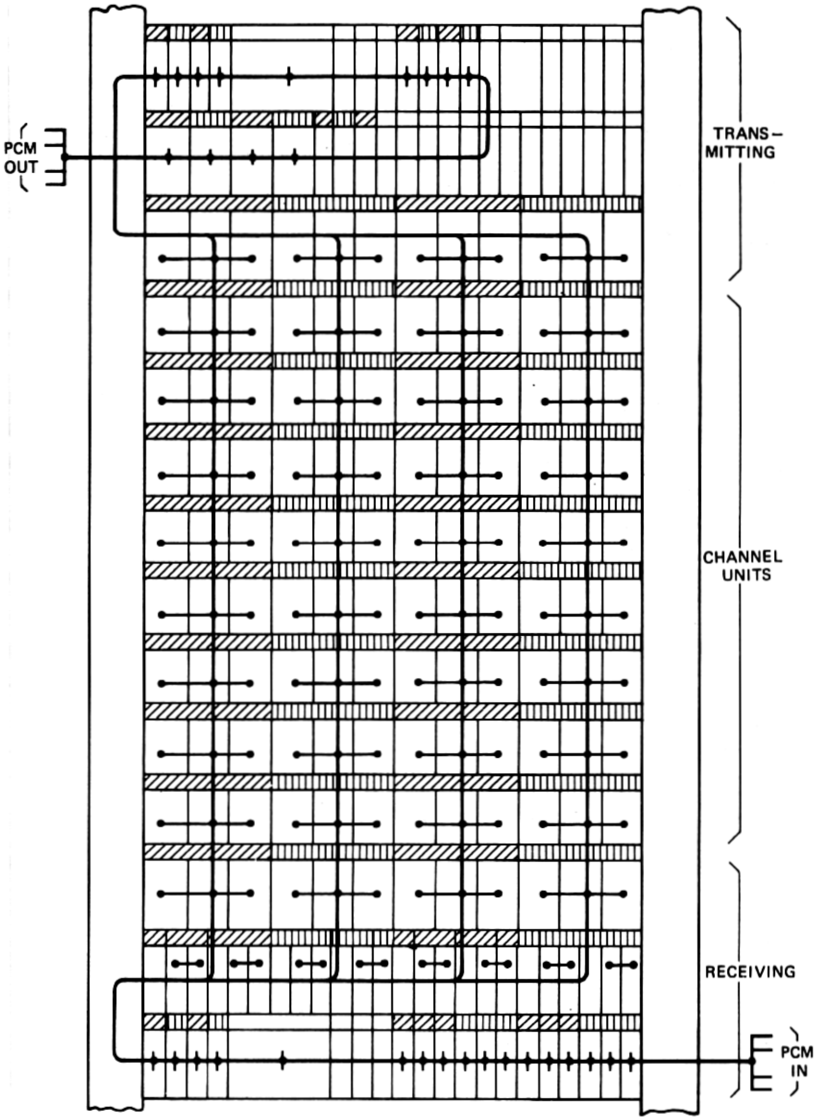

Fig. 4—Signal flow.

an orderly signal flow from the PCM input through the decoding and demultiplexing common functions to the channel units. The opposite direction of transmission is similar in physical arrangement. This gives good isolation of low-level analog signals and high-level digital signals and minimizes critical lead lengths.

The channel units for each of the four digroups are arranged in three adjacent vertical columns of eight units each. Each column of channel units is associated with the transmitting gate and filter circuit pack directly above it and the receiving gate and filter circuit pack directly below it. This facilitates level adjustment in the gate and filter circuit packs.

4.2 *Framework and Circuit Pack Mounting*

The D2 Channel Bank employs the transmission standard 23-inch (58 cm) unequal-flange cable-duct frame. The circuit packs are flush mounted with the wide flange of the frame for good appearance and to provide a full duct for cabling.

A flexible multiheight circuit pack mounting or shelf assembly was designed to accept the diversity of channel bank functions. The shelf is shown in Fig. 5 which is made from three identical die-cast aluminum parts that form the top, bottom, and rear of the assembly. The casting provides circuit pack guides and mounting slots for connectors with a 50 percent open area for ventilation. The use of a single part guarantees accurate alignment of card guides to connectors. The rear piece is trimmed to provide a shelf height from 5 to 10 inches in 1-inch increments. The side plates are fabricated with an integral

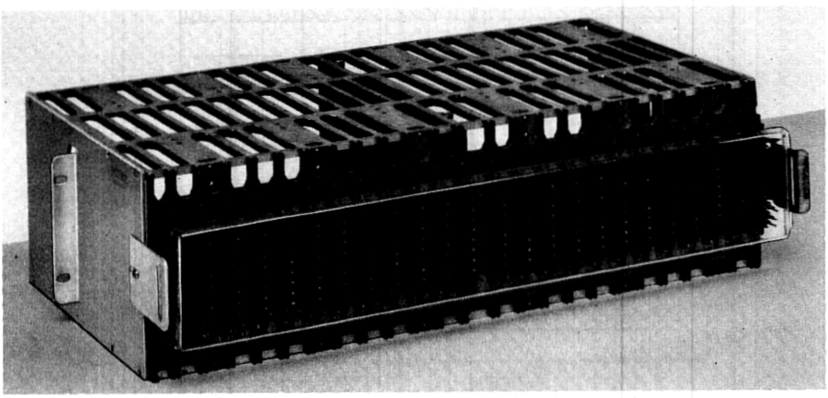

Fig. 5—Flexible multiheight circuit pack mounting or shelf assembly.

mounting bracket for assembly to the frame. The design provides a minimum circuit pack module width of seven-eighths of an inch with a maximum capacity of 24 circuit packs per shelf. Circuit packs of up to five module widths are used. Additional features include a notched locking bar for retaining circuit packs and for digroup designation. A rear plastic cover provides protection to the terminals.

The heat dissipation for the 11-foot 6-inch version of the channel bank is 720 watts. Thermal analysis and temperature measurement indicated satisfactory operation and reliability in the required range of office ambients from 2°C to 49°C. In some cases, relocation of components was necessary to eliminate hot spots in order to achieve the desired thin-film resistor aging characteristics.

The frame features a low-impedance power feed and ground system. The power supply voltages are distributed to the circuit packs by means of laminated distribution bars which have up to seven layers. The shelf assemblies for the transmitting and receiving sections of the frame contain an insulated ground plane at the rear within the connector field. Insulated ground straps separately connect the ground planes to the power supply to provide a radial single-point ground system within the frame.

Wiring volume within the frame is considerable as a result of the voice frequency interface requirements. For example, connections to the SMAS connector, to the carrier group alarm, to external trunk equipment require twelve, eleven, and eight leads per channel, respectively. The provision of protection switching necessitates an additional eight leads per channel. The voice-frequency input requires 768 (96 by 8) 24-gauge wires which are cabled from the IDF directly to the channel units. In retrospect, the elimination of a terminal strip at the top of the frame proved to be a poor choice since damage has occurred during installer wiring at the channel units. Future bays will have all voice frequency leads connectorized, which will correct the problem and further simplify installation.

4.3 *Circuit Pack Design*

The D2 circuit packs consist of an epoxy-glass printed wiring board, and a plastic faceplate and handle. Discrete components, thin-film and silicon integrated circuits mount through holes in the boards for connection by mass soldering. Printed wiring board modules mount on the master printed wiring board to realize large functions that could not be otherwise accommodated by a single planar board.

Epoxy glass was chosen as a board material because of its mechanical strength and stability. Heavy apparatus could be accommodated without requiring the use of metal supporting frames. Epoxy glass permitted the use of plated-through via holes for codes where minimum circuit area and path length was desirable. Gold fingers are provided for contact to the "908"-type connector. The faceplates are constructed of fire-retardant PVC, and provide cavities for test points and a handle to facilitate removal. The circuit-pack code and title are placed on the faceplate for easy identification. In addition, color-coded handle labels are provided for identification of special service trunks.

Figure 6 illustrates a typical channel unit. All channel units are two modules (1-3/4 inches) wide. Jacks mounted on the faceplates provide standard level (−16 dB, +7 dB) access for maintenance and patching. Dark grey faceplates are used on channel units to distinguish them from common circuit packs. Thin-film loss-adjusting pads are provided for adjusting office losses over a range of 0 to 16.5 dB in 0.1 dB steps. Options on certain types of channel units are controlled by screws which are screwed down to insert the option and unscrewed to remove the option. The options provide for loop resistance compensation, network built out capacitance, and for matching trunk characteristics to the carrier group alarm. On certain codes of channel units, a second connector is provided to allow for access to external trunk equipment such as echo suppressors or delay equalizers, and for additional access to remote maintenance or to automatic protection switching.

Figure 7 shows a typical common-unit circuit pack. In Fig. 7, note

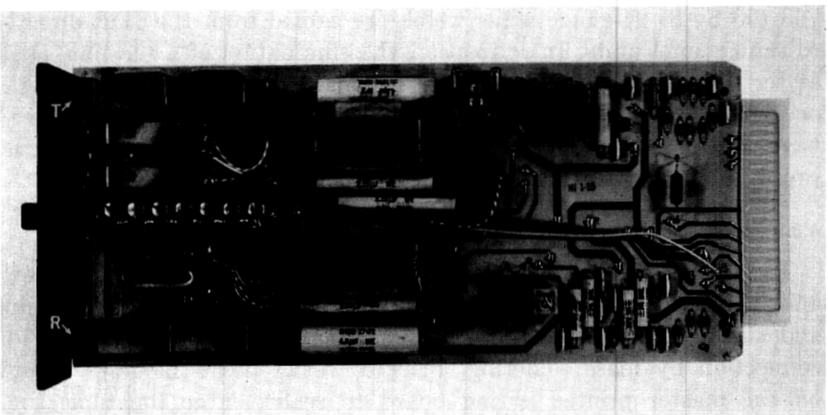

Fig. 6—Typical channel unit.

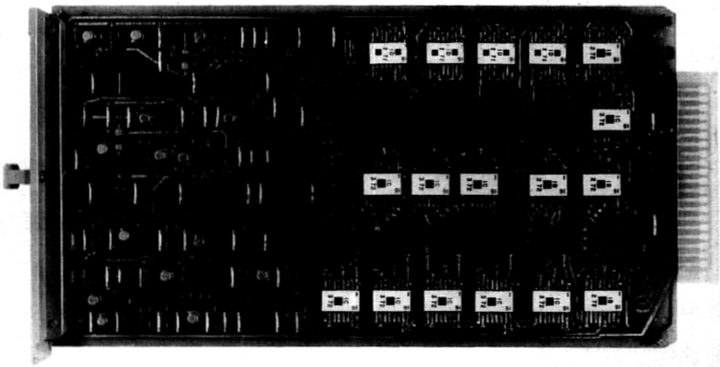

Fig. 7—Typical common-unit circuit pack.

the alignment of components on a single axis to facilitate machine insertion. Figure 8 shows the most complex circuit pack in the terminal, namely, the coder, which contains over 840 components. The module boards employ connectors to provide interconnection between boards which facilitate assembly and repair.

Table I summarizes the type and number of printed wiring boards used in the channel bank. Note that the packaging density is 5.5 com-

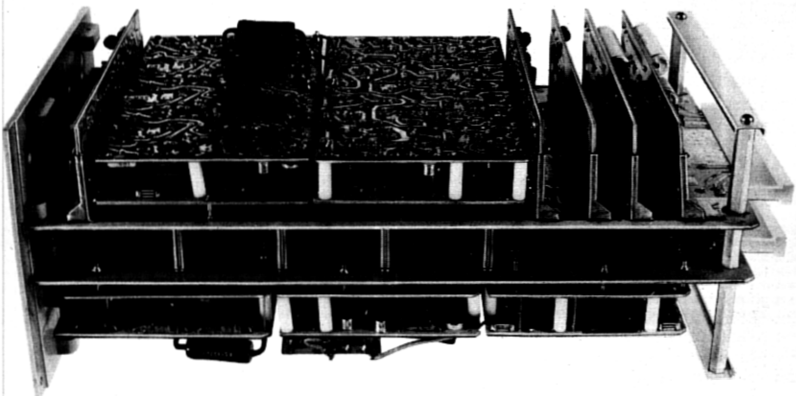

Fig. 8—Coder—the most complex circuit pack in the terminal.

Table I—Printed Circuit Boards

Master boards	207
Module boards	496
	703
Number of different boards	90
Maximum components on single-space circuit pack with modules	388
Maximum components on single-space circuit pack without modules	292
Maximum components on any circuit pack	890 (coder)
53 square inches usable board area	
5.5 components per square inch	

ponents per square inch (one component per square centimeter).

Table II summarizes the type of circuit components used in the channel bank. The terminal is realized primarily with discrete components, although 19 codes of thin-film precision networks are used for multiplexing and coding, and one family of silicon-integrated logic circuit is used for digital processing. Figure 9 shows an assembly containing thin-film resistor networks. The resistor end-of-life tolerance is 0.04 percent absolute, and 0.02 percent in resistance ratio.

Selection criteria for components included minimization of code

Table II—Components

Quantities shown are for fully-equipped bay with 96 dial-pulse-orig channel units, but does not include power supply components

Resistors	9380
Diodes	5739
Capacitors	4833
Transistors	2006
Varistors	735
Transformers	574
Attenuators	384
Jacks	309
Potentiometers	213
Connectors	207
Filters	193
Relays	106
Inductors	130
Integrated circuits	68
Networks	51
Special thin-film resistors	23
Miscellaneous switches, keys, etc.	55
Total	25,946

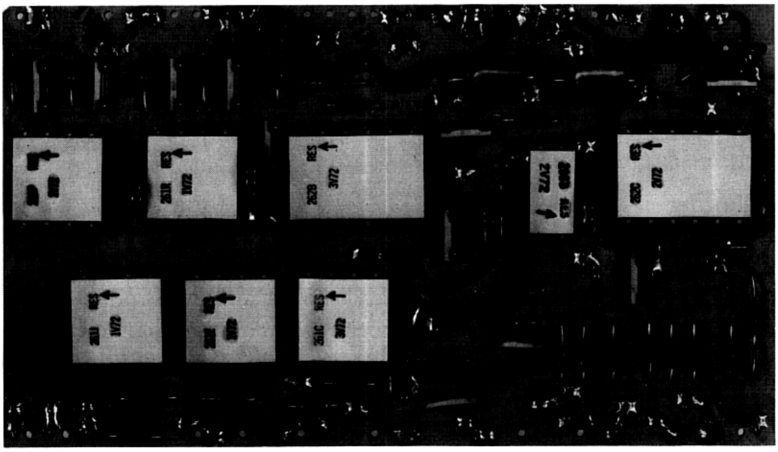

Fig. 9—An assembly containing thin-film resistor networks.

types consistent with performance and cost objectives. Good reliability was a key concern, and components were derated to assure satisfactory life. The predicted total channel-bank failure rate is 114,000 FU (Failure Units) corresponding to a mean time to failure of 8760 hours. This compares favorably with similar equipment. (The actual failure rate during the life of the D2 Performance Study was 6300 hours mean time, or 1.4 the predicted rate. This represents the first two years of service.)

V. INTRODUCTORY PROGRAM

5.1 *AT&T Introductory Program Planning*

As enunciated by the American Company, the Introductory Planning Program for New Transmission Systems involves four activities:

(*i*) Organization of AT&T, Bell Laboratories, and Western Electric managing teams to coordinate the introduction of each new product.

(*ii*) Development and continuous monitoring of schedules for all necessary activities needed to assure smooth introduction of the new product.

(*iii*) Establishment of a close working relationship with the Operating Companies in the early stages of development to assure that field needs are met.

(*iv*) Organization of follow-up programs for initial production to verify proposed operation of field conditions and adequacies of written Bell System Practices (BSP's).

The fourth point applied to the activity of the Laboratories performed during the initial manufacture and during the initial installation.

5.2 *Initial Installation*

Following a number of AT&T, Bell Laboratories, and Western Electric tri-company meetings, the Western Electric Quality Service Management (QSM) Organization chose a Los Angeles central office of the Pacific Telephone and Telegraph Co. for the New Product Survey of the D2 Channel Bank. As the survey is organized, participation of personnel from all three companies is required as a means of implementing and evaluating the New Product Survey.

The QSM Organization provided observers at the chosen site to monitor the adequacy of packaging, bay and circuit pack installation, including related documentation (Western Electric drawings, installation handbooks, and Bell Laboratories BSP's).

An expedited repair procedure to enable Bell Laboratories and Western Electric personnel to quickly repair and evaluate circuit pack failures was implemented with the cooperation of the Western Electric Merrimack Valley Works merchandising organization.

A summary of problems found during the New Product Survey was submitted to members of the team within four months after the survey began. The group reviewed these problems, and referred them to the responsible organizations for corrective action. The New Product Survey served its purpose most effectively in the identification of problems in the areas of packaging and bay wiring.

VI. RELIABILITY PROGRAM

6.1 *Objectives*

In the early part of 1964, it became increasingly clear to the Bell Laboratories and Western Electric personnel involved in the repair of D1-T1 circuit packs that a thorough study was required to examine the reliability of these plug-ins. Thus began the first effort within the transmission area to record a history of failures for circuit packs of a given transmission system.

Beginning in 1964, the D1-T1 Repair Study was able to clearly identify problem areas associated with individual circuit pack codes, and served as a means of providing the development organization with clearly defined current engineering experiences through these reports.

In 1967 it became evident that a more detailed accountability of D1-T1 failures was necessary to evaluate improvements made in the various circuit packs, design changes incorporated into the D1 bays, as well as trouble-shooting procedures used by Operating Company craftsmen. A further problem uncovered was the excessively large number of plug-ins returned for repair with no-trouble-found (NTF). As a means of providing more valid data concerning the overall reliability of D1-T1, a study was begun in the Operating Company central office to evaluate initial lineup and in-service performance of this system.

These two studies were the forerunners for the D2 Repair Study and the D2 Performance Study. The objective of these studies is to determine:

(*i*) the nature and scope of D2 circuit packs troubles
(*ii*) the adequacy of BSP's and craftsmen usage
(*iii*) the nature of channel bank outages
(*iv*) the cause of no-trouble-found returns
(*v*) the results of circuit pack improvements
(*vi*) the requirements for telephone company circuit pack spare inventory.

6.2 *D2 Repair Study*

The Repair Study is intended to continue throughout the manufacturing interval. Data for this program are collected by Western Electric personnel at the repair locations which are presently the Merrimack Valley Works and the Los Angeles Service Center. The Repair Study examines and analyzes information on all D2 apparatus returned for repair.

During the first year and a half of repair, the information received from Western Electric repair locations was manually analyzed by physical design personnel. Quarterly summaries of the results were provided for general information to outside organizations, while constant feedback was provided to development organization personnel for action as required.

During the second quarter of 1972, the outputs of the incoming data were summarized and analyzed through a computer program written and maintained by a programming support group.

6.3 *Performance Study*

The purpose of the D2 Performance Study, as stated earlier, is to provide a means of evaluating the nature and scope of D2 troubles beyond the simple analysis of individual circuit pack failures. Data for this program are provided by central office craftsmen at three locations. These are the Los Angeles and San Diego regions of Pacific Telephone, the Chicago area of Illinois Bell Telephone, and the Dallas area of Southwestern Bell. The basic objective is to obtain information on craftsmen-BSP-equipment interactions and thus determine where there are defects or weaknesses in the BSP or the equipment. When difficulties are experienced by craftsmen in either equipment, line-up routines, or in connection with in-service failures, they fill out a form reporting the nature of the failure. If the trouble is one involving the return of apparatus for repair, the craftsman identifies the circuit pack with a sticker serialized to agree with the number on the form he is returning. In this way, it is possible to correlate the craftsman's report with repair information received from the repair center. In this connection, the incidence of no-trouble-found is of particular interest. The Performance Study, as originally planned, was completed in December, 1971, after a life of 1-3/4 years.

6.4 *The Results of the D2 Repair and Performance Studies*

The D2 Performance Study and its interaction with the D2 Repair Study has provided a means of analyzing D2 outages much more rapidly than for other transmission systems in the past.

Approximately 1000 digroups of D2 apparatus were installed in the three performance-study locations during the life of the study. This quantity of installed digroups represents a significant percentage of D2 digroups installed through the entire country during this period.

During the life of the study, 782 circuit packs were replaced during initial line-up representing a 2.8-percent replacement of all circuit packs shipped. One hundred seventy-five circuit packs were replaced on an in-service basis, and reflected an actual replacement rate of 1.4 times that which was predicted on the basis of component FU rates for a fully equipped N2 Channel Bank. The actual equipage of D2 Channel Banks during the life of this study was 2.8 digroups per bank. Although some individual circuit pack codes reflect high replacement rates, the overall replacement rate was shown to be far better than previous transmission systems had experienced during such early stages of production. The actual initial lineup replacement rates of common plug-ins have shown significant reductions which reflect craftsmen experience and product improvement. This drop-off with time is shown in Fig. 10.

A further area of concern has been the high initial-lineup replace-

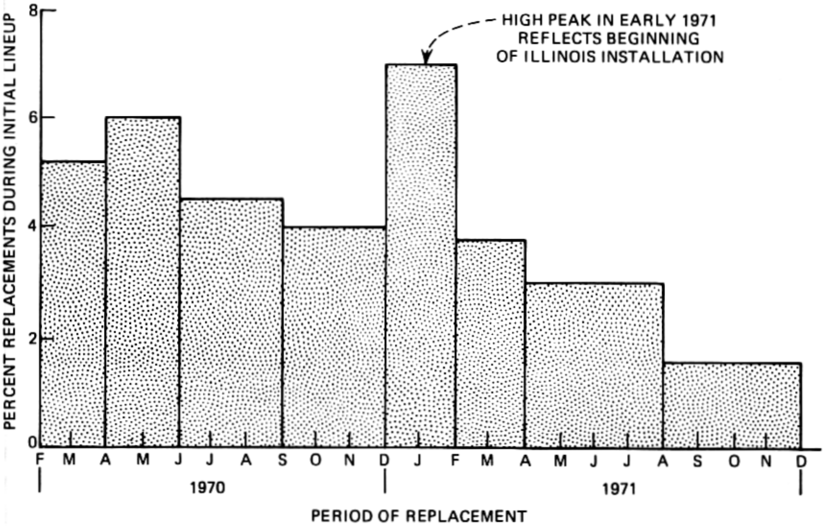

Fig. 10—Replacement rates for D2 circuit packs.

ment rate of D2 power supplies, and this continues to present a problem at the close of the Performance Study. In-service replacement rates for the power supply plug-ins appear reasonable at 1.5 the predicted rate.

The Performance Study is the quickest means of uncovering the broad patterns of failure which develop during initial production. The information received through the D2 Repair Study is, however, significant in that it reflects all plug-ins returned for repair from the Operating Companies. It further provides us with a means of examining changes incorporated into existing products by relating failure to dates of manufacture and series numbers appearing on the faceplate of each plug-in.

One means of evaluating craftsmen's performance is to examine the relationship between plug-ins removed and no-trouble-found with the equipment when it is repaired at the Service Center. In the case of D2, the no-trouble-found (NTF) rate for repaired plug-ins is approximately one-half that of its predecessor. A further examination of NTF removals shows that, in the case of 86 multiple plug-ins removed (that is, for a single failure, more than one plug-in is removed), only four cases were reported of no-trouble-found in any of the removals. This supports other evidence of the adequacies of the D2 BSP routines and of the ease in which craftsmen were able to go through line-up and trouble-shooting procedures with the equipment.

The overall replacement rate of D2 plug-ins received from all Operating Companies is 2.8 percent. When no-trouble-found rates are subtracted from replacements or all plug-ins returned for repair, the failure rate for returned plug-ins drops to 2.4 percent.

As noted, the failure rate of D2 common circuit pack in-service failures is presently 1.4 times higher than predicted. With the improvements being incorporated into the various plug-ins which have shown excessive replacement and failure rates, it is expected that this ratio will drop to approximately 1.1 by the end of 1972.

Further work is presently under way to establish relationships between failure rates and circuit outages. A standard spare ratio based on reliability considerations is being compiled which will permit the Operating Company to reduce their present inventory of D2 spares which currently amounts to approximately 10 percent of the total installed circuit packs. It is expected that this number will drop to between 4 and 6 percent and will reflect a substantial cost reduction to the Operating Companies.