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D2 Channel Bank:

Manufacturing and Testing

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Previous articles in this issue have covered the design concepts of the D2 Channel Bank. This article is about the contribution by Western Electric, the manufacturing and supply organization for the Bell System. The discussions will focus on the effort at Western Electric, Merrimack Valley Works which includes bay and circuit pack manufacturing. Although certain portions of these topics are rather routine to those in manufacturing, they will be briefly mentioned in order to give completeness in explaining how a new product line is put into production. This article thus serves to give the reader a better understanding of how a product is introduced by telling, in narrative form, the D2 Channel Bank story.

I. INTRODUCTION

Manufacturing of the D2 Channel Bank takes place at Merrimack Valley and Kearny Works of the Western Electric Company. The introduction of any new system by Western Electric involves considerable effort by many locations within the system. This article will concentrate on those activities at Merrimack Valley which are directly associated with the manufacture of circuit packs and bays for the D2 Channel Bank.

Manufacturing development for the D2 Channel Bank began in 1965, and ended with the first shipments late in 1969. Major activities during this period were (*i*) early development (*ii*) construction of field trial units (*iii*) production planning (*iv*) test planning and (*v*) initial production. The project is presently on a continuing production basis.

1.1 *Early Development*

For those concerned with development to manufacture the D2 Channel Bank, the first stage was to become familiar with the details of the product and to make preliminary production plans. One of the first steps in this operation was to establish an estimated cost. This was a difficult task since the design work was not complete at the time. However, the known factors were calculated and the rest estimated using judgment gained from experience. Next, a schedule was established for completion of the design and development work in order to determine an availability date. This date and the pricing information were used with technical information from Bell Laboratories to transmit Engineering Letters to telephone companies that described the system. As development progressed, the data was updated to take into account new information.

Product engineers began studying the system for areas of new technology. One example was the precision thin-film resistors used in the coder and decoder. Steps were taken to ensure that these resistors could be manufactured in time for initial production. Models were made and submitted to the Laboratory for approval in this area of new technology.

At the same time, test engineers began studying D2 to learn how to test it efficiently and at a reasonable cost. One engineer from Merrimack Valley was assigned to Bell Laboratories, Holmdel to work directly with the design engineers during their final design stages. His specific duties were:

(*i*) Write preliminary test specifications.
(*ii*) Estimate test set requirements.
(*iii*) Coordinate test requirements with test set capabilities.
(*iv*) Learn the details of the D2 system.
(*v*) Establish personal contacts between the two engineering groups.

1.2 *Field Trial*

As the design of the D2 Channel Bank approached completion, a field trial was planned. Several bays and their circuit packs were constructed and installed in the Philadelphia area for evaluation. All equipment for the field trial was manufactured in the model shop at Merrimack Valley. This was the first direct contact with the actual product for most engineers in the group.

During field trial production, the product engineers had their first real opportunity to learn what kind of problems to expect in manufacturing this new channel bank. These problems were concerned with assembly techniques, module board handling, integrated circuit mounting and many others.

The magnitude of this project also became apparent during this period, as the nearly 160 different codes of circuit packs or module boards were assembled.

Test engineers used this time to good advantage by setting up "mucket" facilities and actually testing units. If available, preliminary test specifications were used to prove their adequacy. This procedure established a small group of test engineers who began to have a detailed understanding of the intricacies of the D2 Channel Bank's operation. Time spent during this period was repaid many times over during the difficult days of early production.

Another beneficial aspect of this period was the beginning of close relationships between individual Bell Laboratories and Western Electric engineers. The two parties discussed the problems as they came up, and arrived at solutions. This small operation repeated many times over a few months became a good foundation for mutual understanding. The authors feel strongly that these relationships were one prime factor in the successful introduction of this product.

II. PRODUCTION PLANNING

With the field trial complete, preparations were made to begin manufacturing the circuit packs and bays of the D2 Channel Bank. When a new product is introduced, many different organizations play an active role. In keeping with the scope of this article, only those engineering activities directly associated with the product will be discussed. The reader should be aware that this is the tip of the iceberg representing only a fraction of all the necessary activities.

2.1 *Drawings*

Before any product can be built, appropriate drawings must be made and distributed. This was one of the major tasks due to the many codes of module boards and circuit packs.

Initially, Laboratories' Design Information (LDI) is transmitted to Western Electric for a preliminary analysis of each code. Both Product and Test Engineers at Western Electric review the LDI, which usually consists of a schematic, stocklist, and a proposed layout, so that any particular assembly problem or test problem which might arise can be anticipated. Previous agreements between Bell Laboratories and Western engineers had established ground rules for the proposed layouts that included considerations for ease of manufacturing. This was done to reduce the huge load on the Western drafting organization.

Next, the Western drafting organization began preparation of the official manufacturing drawings. The draftsmen familiarized themselves with the schematic and proposed layout.

Variations from the proposed layout were initiated by the draftsman or engineer when alternates were seen that would substantially reduce the cost. An example of these changes was the elimination of a module board from certain codes of channel units when a method was found to incorporate the components on the main board. These proposed design variations were checked with Bell Laboratories, particularly when critical circuits such as the coder or decoder were involved.

The draftsman's layout was checked for accuracy by another member of the drafting organization, and the art master was made, usually by the original draftsman.

Prints of the formal drawings were sent to the product engineer for final analysis and approval. By working closely with the draftsman on the physical layout of the circuit, the product engineer's main task was to check the artwork against the schematic. With this accomplished, signatures were affixed making the drawings official.

2.2 *Production Facilities*

In planning for production facilities, the following phases of manufacturing were given attention: (*i*) initial low-volume production when the processes were unfamiliar to the shop personnel. (*ii*) intermediate volume production when the processes were familiar to some personnel and yet unfamiliar to the new personnel required for the increased volume, and (*iii*) normal expected future volume which will have a normal amount of experienced shop personnel with mechanized and automated production machinery to supplement the hand assembly requirements.

2.2.1 *Manufacturing Layouts*

Manufacturing layouts are the detailed instructions for the assembly of the various circuit packs. The initial set was written using the intermediate volume of production as a guide. This was done because a shop goes through the low-volume stage rather quickly. It would have been a waste of time to put too much effort on methods that would have only a short life.

Industrial engineers played an important role in writing layouts. They supplied base hour rate information for each assembly operation in the layout. Where possible, standard rates were used for normal operations such as inserting components, soldering, etc. Any new processes were estimated and later refined with actual time-motion studies. Accurate rate information is essential to a successful product. If the rates are too loose, the price of the product will be adversely affected; if too tight, the shop personnel will be frustrated in their efforts to meet these rates and could cause a severe morale problem. Industrial engineers also contribute by designing the individual work positions and visual aids.

2.2.2 *Manual Assembly*

Good manual assembly bench layouts are essential to efficient manufacturing in early low-volume production. They are equally valuable on larger volume production in the area of impractical automatic assembly and low-volume miscellaneous codes.

The typical D2 manual assembly position consists of a five-foot-wide standard bench position and chair. On this bench position is a semicircular rack which holds from 16 to 28 individual removable stacking bins (Fig. 1). Precut and formed components are held in these numbered bins and are available for insertion into a printed wiring board as called for on the associated visual aid. If more than 28 different components are required for this position, an additional rack can be used.

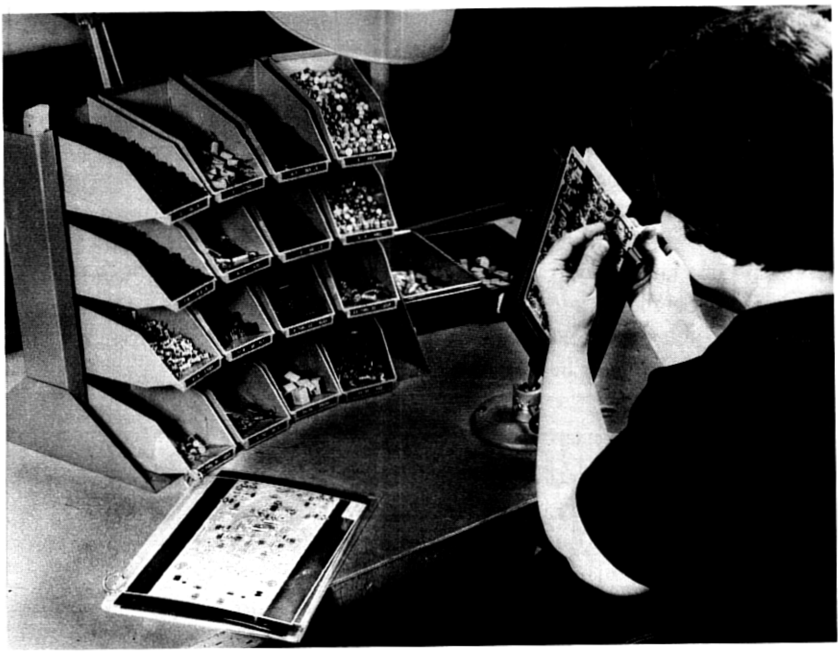

Fig. 1—Hand insertion position showing components in the rack and the board holder with PWB.

In the center of this semicircular arrangement is a spring-loaded device for holding the printed wiring board so that both hands of the operator are free for assembly work. The usual hand tools for this operation are also available. New and completed work is stored behind the operator on a hand truck.

2.2.3 *Visual Aids*

Visual aids are essential in any assembly shop if efficient use of time and a high degree of quality is to be expected. Two visual aids used in the D2 Channel Bank shop proved to be very helpful to the hand assembly personnel, semiautomatic machine insertion operators, and to the inspectors.

The inspection of interfacial "C" strap connections, which are the first items put on the printed wiring boards, is made faster and more accurate with the aid of a sheet of black phenolic cut to the same shape as the printed wiring board to be checked. Holes were drilled in the same location as each "C" strap connection with the remainder of the black phenolic being left blank. This configuration allows the inspector to see only the "C" strap connection area and makes it quite easy to determine if a connection has been omitted or not soldered. See Fig. 2.

The other type of visual aid is used where some complexity is involved in hand assembly of components. This visual aid consists of a color photograph of the printed wiring board with a series of numbers showing where components are to be inserted. These numbers indicate the correspondingly numbered bin where the operator will find the proper component. Those components actually inserted by the operator are shown on the visual aid. The industrial engineer specifies these components which will result in the most efficient learning pattern for the operator. See Fig. 3.

2.2.4 *Component Insertion Machines*

High-volume production requires the use of automatic machinery whenever possible. In manufacturing the D2 circuit packs, many of the components are inserted using automatic insertion equipment. Components with either axial or radial leads are inserted.

Axial components such as diodes, resistors and capacitors are inserted using Dual Center Distance (DCD) and Variable Center Distance (VCD) insertion machines (Fig. 4). The VCD is capable of inserting components on centers varying from 1 to 3 cm. The variability feature permits a maximum number of components on a circuit pack to be inserted. The DCD machine is used primarily for inserting "bulk"

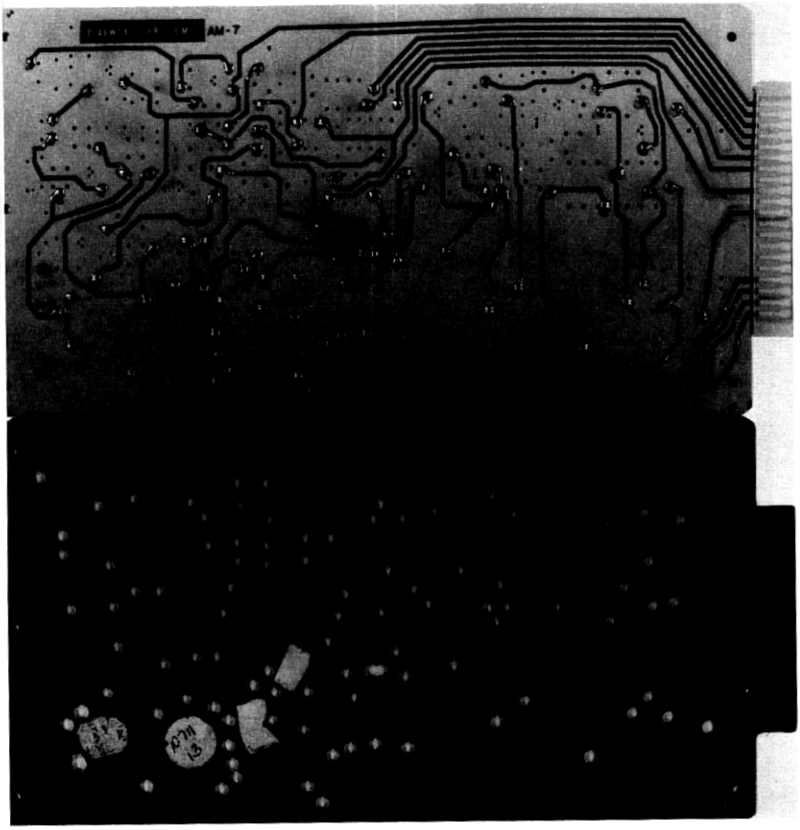

Fig. 2—C-strap inspection template.

components. The insertion machines are controlled by either a punched tape or by a small computer.

The normal work table has two positions: one rotated 180 degrees from the other. This permits polarized components such as diodes and tantalum capacitors to be inserted without stocking both polarities on the sequencer. A modified work table has recently been introduced with four positions at 90-degree intervals permitting even more components to be inserted. Radial leaded components are inserted using similar commercial equipment.

2.2.5 *Component Sequencing*

A normal part of any automatic component insertion operation is component sequencing. In this operation, the components are taken

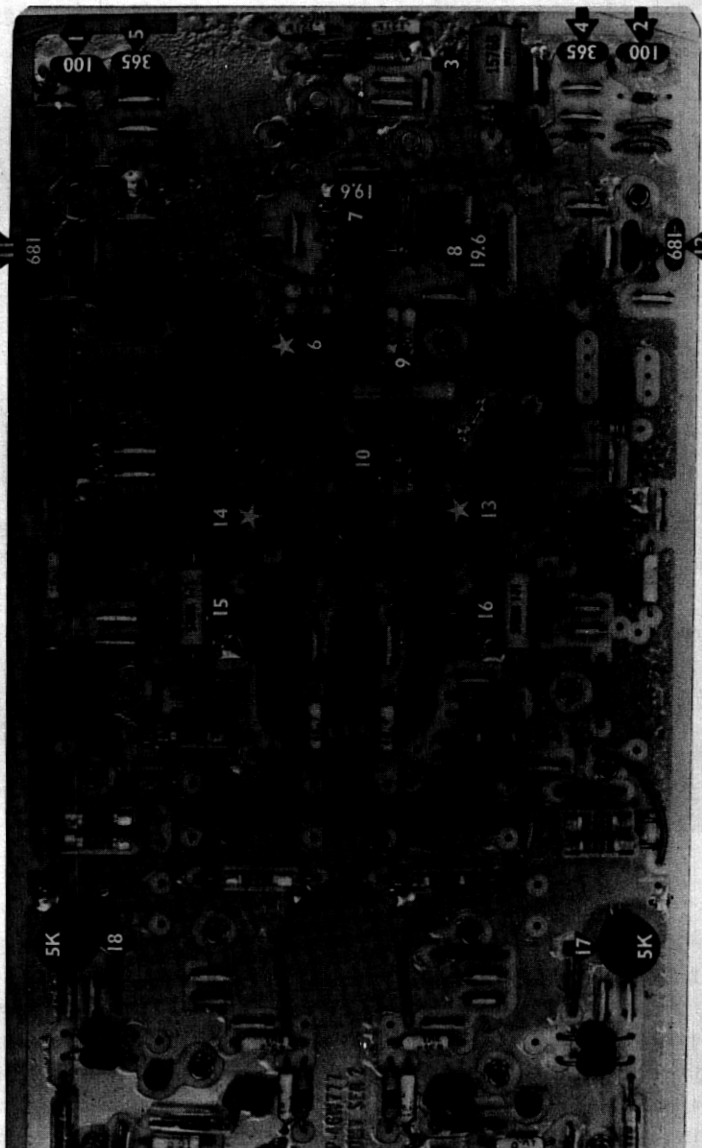

Fig. 3—Hand-assembly visual aid.

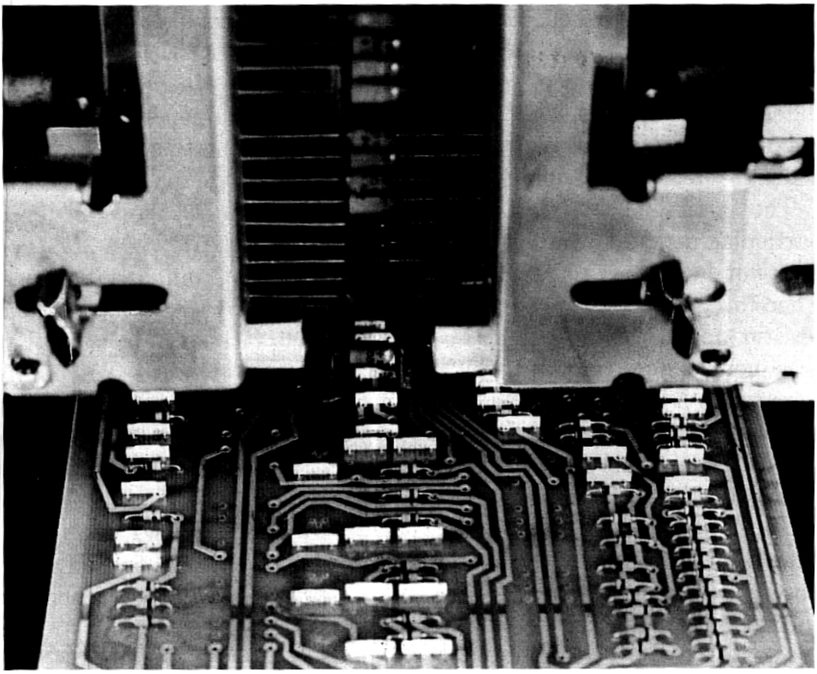

Fig. 4—Axial lead component insertion machine.

from reels of identical components and put onto reels of mixed components programmed for a specific circuit pack. The only exception to this general rule is in the insertion of diodes (458 series). Since they are used extensively throughout many of our circuit packs, we found it practical to use one machine to insert only these diodes. Proper polarity is achieved by stopping the machine after all diodes of one polarity are inserted, reversing the board and inserting the remainder.

An axial leaded sequencer was purchased from a commercial supplier. This machine has the capability of selecting from 39 types of components, sequencing in the reverse order to which they are to be used and then taping and winding the components on a reel. Only 39 types of components can be used on one code. A very thorough study was made to determine the maximum utilization of the machine and the maximum coverage of components and circuit packs.

The radial leaded 257-type resistors are used numerously throughout the D2 circuit packs. A commercial machine takes the container in which the resistors are shipped and vibrates the resistors down a track where they are sequenced automatically first onto a conveyor, and then to a taping station. This sequencing machine has positions available for 30 different values of resistors. These positions can be changed for different circuit packs. As in the axial leaded component sequencer, maximum utilization was determined for the machine to cover as many codes as much as possible with a minimum of change over. See Fig. 5.

The possibility of selecting the wrong value of 257 resistor for a particular machine head appeared to be quite high. Also, the 257 type does not lend itself to rapid visual identification of component values. Therefore, a test station was designed to measure the value of each resistor on its way to being taped. See Fig. 6. The only resistor that is sequenced here is a 257J which has a 3-percent tolerance. Test limits were set at 5 percent in order to detect gross errors but not to interfere with normal product variation. After introducing this operation, a further benefit was soon discovered. The sequencer would occasionally remove small chips from the resistors which changed their values slightly (5 to 10 percent). These chips were nearly invisible and might not have been detected by any other tests in our shop. This caused us to closely examine the various mechanical features of the sequencer to find and eliminate the source of the chipping.

Fig. 5—Resistor containers on radial sequencer machine.

Fig. 6—Resistor taping station on radial sequencer machine with test station in background.

2.2.6 *Mass Soldering*

Much material has been written about the benefits of mass soldering and its acceptance in the printed wiring board field. The major considerations of the mass soldering machine for the D2 shop were quality, reliability, and ease of maintenance. Several units were investigated before one commercial machine was accepted.

2.3 *Precision Thin Film Resistors*

The D2 film circuits include 19 resistor codes with two to six resistors per code. The resistors range in value from 150 to 77,000 ohms. Several codes have initial resistance tolerance requirements of 0.04 percent absolute, and 0.02 percent matching when specified at 38°C operating ambient temperature. These exceptionally tight tolerances were required for circuits in the coder and decoder in order to attain the high level of precision to ensure toll grade performance for the D2 Channel Bank.

The D2 Channel Bank precision resistor networks were the first film-integrated circuits processed in the Merrimack Valley Process Capability Laboratory (PCL). The reasons for the introduction of this project through the PCL were to evaluate lead frame bonding, precision anodizing to extremely tight tolerances and to prove in the PCL facilities.

The initial work in the PCL brought the following recommendations:

(*i*) Reduce the numbers of circuit sizes to aid future production inventory control of prescored substrates. This was before laser scribing was introduced as a production tool.

(*ii*) Change from the Ta-Ni-Cr-Cu-Pd metal system to Ta-Ti-Au, to allow the use of stable gold-gold thermo-compression bonds for the lead frames. Minor changes in contact pad locations permitted a common lead frame to be used on all circuit sizes. This lead frame allowed simultaneous bonding instead of the individually bonded nail-headed leads.

(*iii*) Reposition resistors to permit the use of a single substrate anodizing head for all codes to minimize the anodizing tool cost.[1]

These recommendations were carried out and reasonable yields were realized in production through the use of a computer-directed thin-film trim anodization processor and tester, which would optimize total adjustment time with respect to a minimum chance of overshoot.

The capability of trim anodization to precise resistor values depends not only on the basic absolute accuracy and repeatability of measurement, but also on the method of controlling the percent resistance change per anodization cycle. Using constant current as the anodization power sources, one method of controlling the percent resistance change is by reducing the current. Another method is to reduce the time per anodization cycle. These considerations led to a binary step approach which would allow for a total variation of 50 percent in the anodization constants and still not overshoot by more than one binary step. A moderately-fast precision-measuring system coupled with a small process control computer was used to obtain an efficient shop set up and use.[2]

III. TESTING AND SHIPMENT

Concurrent with the production planning, test planning took place. It included the development of an overall test philosophy and the design, prove-in, and introduction of 14 new test sets to the production floor.

3.1 *Test Philosophy*

The development of a test philosophy involved considerations of the product to be tested (both physical and electrical), and the methods to use for both an inexpensive and thorough test. The philosophy evolved gradually with inputs from the test engineers, Bell Laboratories engineers, and shop supervisors. The following test philosophy was adopted for the circuit packs:

(*i*) Component verification and circuit pack integrity test,
(*ii*) Module test,
(*iii*) Circuit pack test,
(*iv*) Common equipment terminal test.

For the bays, a two-step procedure was adopted:

(*i*) Back plane wire test,
(*ii*) Bay wire test.

These elements will be discussed in greater detail. Supporting the test philosophy are the test specifications (called X-Specs). These are Bell Laboratories controlled documents. For the D2 project, however, most X-Specs were initiated by the Western Electric test engineer who had the responsibility for designing the test facility for the code. Many discussions concerning testing techniques and parameters to be tested were held as the X-Specs began to take form. These discussions had the dual purpose of educating the Western engineer to design considerations in the product and the Bell Laboratories engineer to testing methods in the manufacturing environment. The net result was a set of test specifications that both parties were happy with and that formed a well planned foundation for the design of test facilities. We feel, particularly as products become more complex, that test considerations must be included during the design of the product. Based on our experience in D2, the test and design engineers should begin discussions very early in the design of the product.

3.2 *Component Verification and Circuit Pack Integrity Test*

The circuit packs in the D2 Channel Bank are characterized by discrete components attached to double-sided printed wiring boards. Some of these boards are very densely packed as shown in Fig. 7. Testing such a circuit pack would be easier if there were a way to check the overall integrity of the board and to measure the components to specified tolerances. To accomplish these ends, a commercial test set was purchased. The test set uses punched tape control to set the

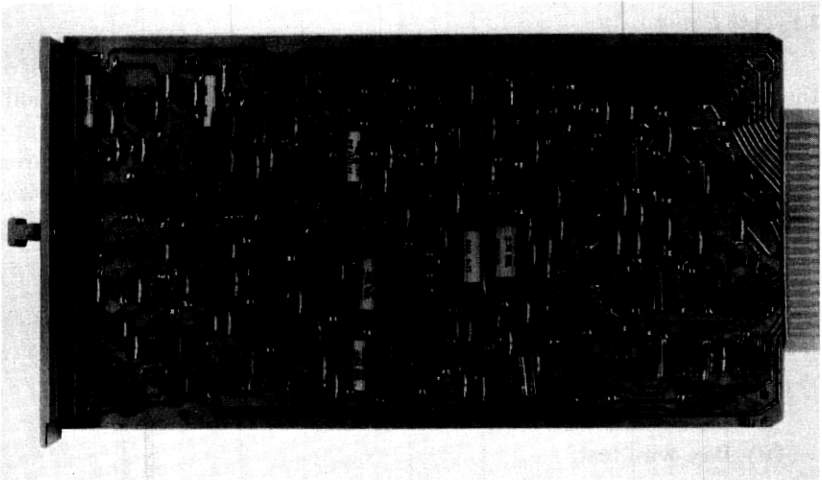

Fig. 7—DM2 Circuit pack.

input parameters for each test. A vacuum fixture and spring loaded plungers give random access to the circuit pack under test. See Fig. 8. The tests are made automatically (about 1000 per minute) with any defects being printed on paper tape for analysis.

The effect of parallel components is removed by using the guarding technique. In Fig. 9, let R_x be the unknown resistor with R_o and R_i as parallel components. A specified voltage is supplied at point A by the input amplifier. A ground is put at point Z by the test set. The other side of R_x (point B) is connected to the input of an operational amplifier. Since this point is a virtual ground, no current flows through R_i. The current through R_o does not affect the measurement. The current through R_x is sent into the op amp and is easily measured.

Each circuit pack is tested twice; the first pass is for overall card integrity; the second pass is an actual component check. Some of the typical tests used on the first pass are as follows:

(*i*) Continuities—most "long" paths on the card are checked for continuity, especially those paths that have C-straps or plated-through holes.

(*ii*) Shorts—tests for solder crosses on both sides of the circuit pack are made.

(*iii*) Diodes—forward voltage drop is measured. For example, the 458 series is measured to 0.7V ±10 percent. This has proven sufficient to detect most diode failures.

(*iv*) Zener diodes—measured to specified voltage ±10 percent.
(*v*) Transistors—junctions CB and BE are tested to 0.7V ±20 percent.
(*vi*) Transformers and Relays—resistance of windings measured to ±20 percent.
(*vii*) Jacks—continuity through jack contacts.

After the first pass, the defects are removed and the unit is given a second test. Resistors are measured to slightly more than their rated tolerance. For example, a 257J-type resistor with a 3-percent rating is tested to 3-1/2 percent. Capacitors could be measured but are not in our application. Most have small values and would be very difficult to check. Capacitors are given an implied test during the functional test of the circuit pack.

3.3 *Module Test*

Some of the circuit packs contain modules which are attached to the master board. The modules are given a functional test prior to

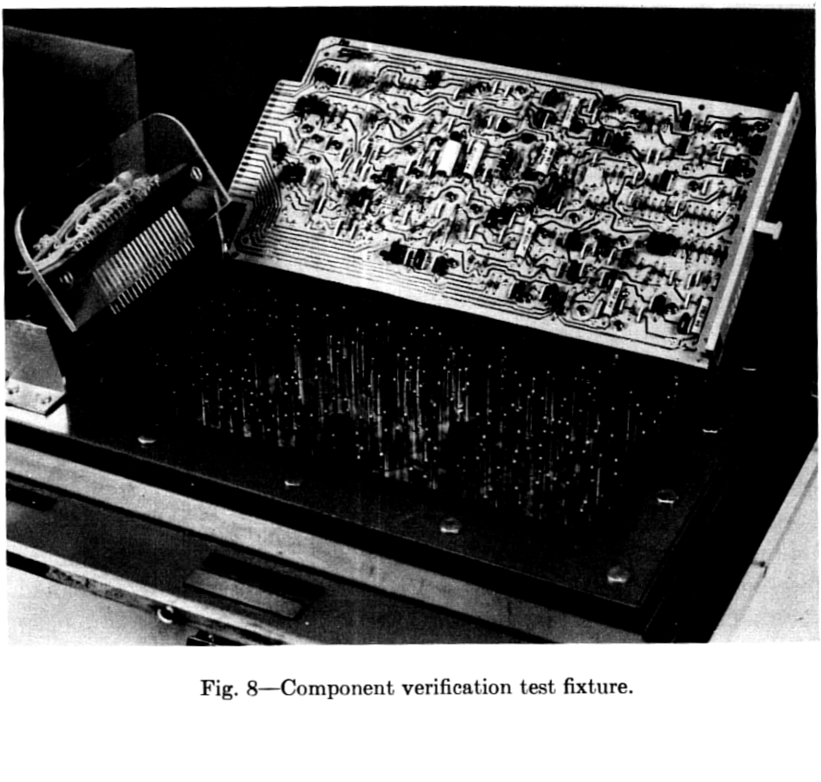

Fig. 8—Component verification test fixture.

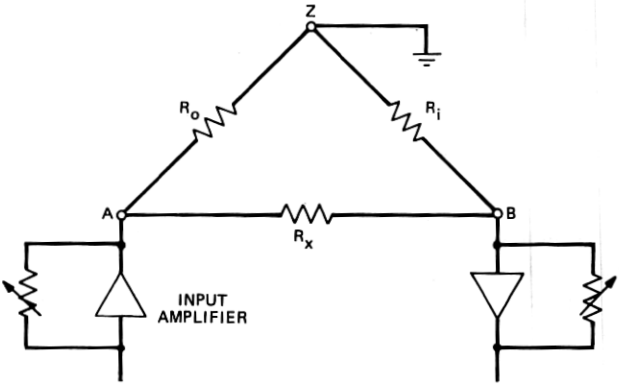

Fig. 9—Circuit diagram of "guarding" technique.

mounting on the master board. This test simulates the actual operating conditions of the module in the circuit pack. Input and output impedances are carefully matched. Driving voltages and currents are chosen to duplicate actual conditions. The purpose of this test is to eliminate the work of removing a module if it causes a test failure and in some cases to test a specific function that would be difficult to test in the complete assembly. For example, the zero code suppression of the coder is checked during a module test.

3.4 *Circuit Pack Test*

Each circuit pack is given a complete functional test during the testing procedure. In general, the unit-under-test is placed in a circuit that simulates conditions in the bay. Actual D2 circuit packs are used to provide the input signals and output loads. This technique provides the same operating conditions found in the bay. Test measurements are divided into two categories: digital and analog.

The digital measurements are made with an oscilloscope. Factors such as pulse height, width, rise time and phase relationship are measured for all pulses as they leave the circuit pack and for specific internal wave forms. The present test sets are manual or semiautomatic in operation.

However, increased volume permits the introduction of automatic pulse-measurement techniques. When the automatic sets are completed, the original manual sets will be used for analysis and repair of defects. This is the normal evolution of test sets.

Analog circuit packs are tested in a different manner. Basically, they are tested within a complete operating system.

A test set (Coder-Decoder Test Set) has been designed which is a two-digroup system with the transmitter looped into the receiver. The unit-under-test is plugged in as a replacement for one of the units in the test set. The unit then is tested using transmission measurements such as noise and signal-to-distortion. On some units, internal wave forms are examined for specific attributes.

All circuit packs are "margin" tested to reduce the chances of incompatibility. In margin test, the power voltages to the unit-under-test are raised or lowered by 10 percent, while the voltages to the load circuits are held fixed. This is an attempt to find the marginal failure that will cause trouble later in the field. The 10-percent figure is based on twice the allowable deviation of the bay power supplies in order to allow for differences in bays and other circuit packs. In most cases, the same performance limits apply to a unit under margin test as to a unit powered with the normal voltages.

The testing method described is referred to as "testing product with product". It is not a perfect test method since the selection of "standard" units within the test set is not well defined. An alternative method would be to actually measure the output of individual circuit packs after stimulating them with artificial circuits. This method has its hazards also. All inputs must be well defined and exactly simulated. The detectors must be sensitive enough to detect small traces of noise and other imperfections on waveforms such as a PAM sample. We must also be able to define exactly how much signal degradation is permissible in each unit of the entire channel bank. Not that the alternative technique is impossible, the authors merely feel that this is impractical to implement for a new system that is still going through its growing pains.

3.5 *Terminal Test*

All of the common equipment circuit packs are given a terminal test. In this test, groups of units are plugged into an actual D2 bay. Measurement of idle circuit noise, signal-to-distortion, gain tracking and crosstalk are made. Additional tests of signaling and alarm circuits are made. Most of these tests are duplicates of tests that will be made by the operating companies. The rationale for making these tests is to provide the customer with an assurance that his product is free from incompatibilities. Many design improvements have been initiated as a result of difficulties in this test area. This is expected when the complexity of the completed system is considered. The terminal test also gives engineers the opportunity to continuously monitor system performance and to detect unfavorable trends.

The Terminal Test Set was designed to provide random access to each of the 96 channels in the D2 bay. To accomplish this, two Western Electric crossbar switches were mounted to each bay. See Fig. 10. These switches (each a 10 by 10 matrix) can be individually controlled to allow for random access to one channel in the transmitting and receiving sections. The test set itself contains a minicomputer which controls the crossbars and the measuring instruments. Operation is automatic after an initial alignment of the system. This set could be used (with minor modifications) to test any voice frequency channel bank. All that would be necessary to adapt to another system is a different program for the computer and a scheme to attach the crossbar switches to the bay.

3.6 *Data Collection*

A data collection and reduction scheme is needed for any complex test system. To be reliable, the data should be collected automatically.

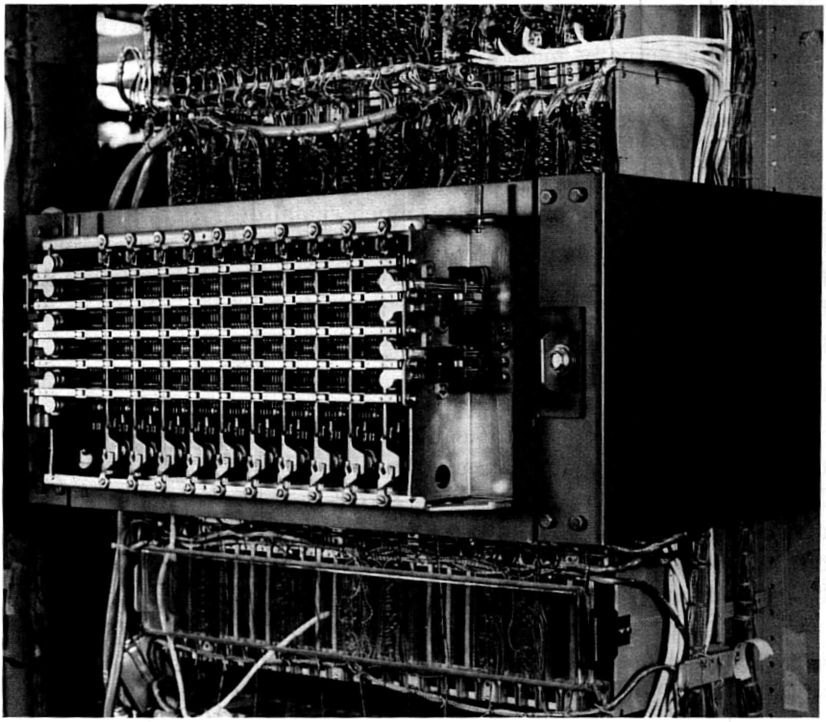

Fig. 10—Crossbar switch attached to D2 bay.

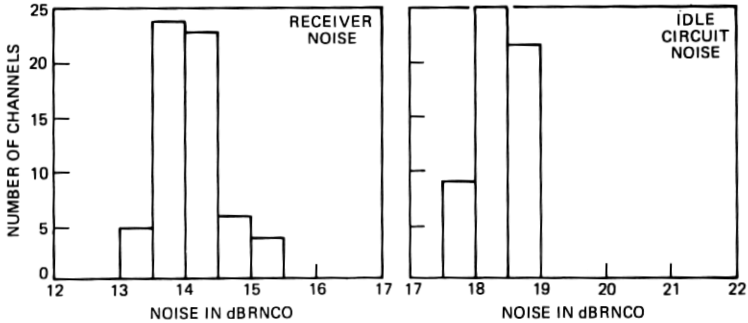

Fig. 11—Histogram plot of typical data.

Such an automatic system was designed into an early version of the Terminal Test Set.[3] Each test reading was sent via a Data-Phone link to a process control computer. The computer stored the readings of a complete system test (304 readings) and at the end of the test gave the following outputs:

(*i*) A UNIT SUMMARY of averages by test number.
(*ii*) A set of punched cards with all 304 readings.
(*iii*) Update of a history file of readings.

Each week or on demand the history file was printed out. The cards were available for off-line analysis such as histogram plots, trend studies and others. See Fig. 11. Although the data collection feature was not included in the newest Terminal Test Set, these data have given us a very complete picture of how the D2 Channel Bank met its requirements and which tests should be worked on to improve the performance. It also gave a data base to evaluate the effects of any major change to the system.

3.7 *Bay Test*

The D2 bays are given a wire verification test and shipped directly to the customer. Two steps of testing are used: a process test and a final bay test.

In the process test, each shelf backplane is given a wire verification. A tape-controlled test set checks for continuity (<5 ohms) and insulation (>1 megohm at 500 volts) for all wires.

For final test, a larger tape-controlled test set is used to test all wires for opens and shorts as in the process stage. Additional tests are made on the Carrier Group Alarm by operating the various relays in these circuits. Another test is made to see if all the empty terminals in the bay are really empty.

The test sets used for bay test are generally purchased from outside suppliers. They are functionally similar, and use a punched tape to supply the input parameters. In the D2 bays, the test program has about 8000 tests and takes about ten minutes to run. Defects are printed for analysis and repair.

Programming these test sets requires supplying a list of wires to be tested and specifying the type of test to be made. Creating a test program by manual methods would be very laborious. Therefore, a computer program that generates the test tape has been developed.[4] The program, which runs on a general purpose computer, is general in nature and is not restricted to any specific type of bay. Test tapes for other product lines have been produced using this program.

There are two inputs to the program:

(*i*) A Fixture List telling how the test set is connected to the product.
(*ii*) A Wire List telling how the product is wired and the type of test desired.

The output is a punched tape which is capable of controlling the test set. The program has the following features:

(*i*) Validation of fixture and wire listings.
(*ii*) Addition of empty terminal tests.
(*iii*) Automatic sorting and printing of multiple wire runs.
(*iv*) Listing of Machine to Product Points.
(*v*) Punching of cards of the test program.

3.8 *Shipment*

D2 circuit packs are packed for shipment in two ways: in systems according to various list structures and singly for channel units and spares.

In systems packaging, the circuit packs are packaged by list number. Each circuit pack is fitted into a corrugated shipping container with grooved polystyrene inner details that guide and hold the printed wiring board.

The spare circuit packs and channel units are packaged in individual containers made of two pieces of expanded polystyrene to support the circuit pack properly. The packaged unit is then inserted into a form-fitting corrugated sleeve and secured at the ends with gummed tape.

Similar-shaped circuit packs use similar containers to keep the number of different containers to a minimum.

The advantages of using individual containers are (*i*) the existence of suitable reusable containers in which to return defective units from the operating companies to the repair centers and (*ii*) the freedom in stocking circuit packs by the Merchandising organization.[5]

IV. INITIAL PRODUCTION

The initial production phase began in the summer of 1969 and continued for approximately six months until the first systems were shipped in December 1969. This was an exciting time as all the planning and organizing began to show results. It was also a period characterized by close cooperation between Bell Laboratories and Western Electric as all the final details were examined and reconciled.

As finished drawings of each code and its detailed piece-parts became available from drafting, models were constructed in the shop. Both the supervisory and assembly personnel became familiar with the details of each code. They also contributed valuable advice on potential trouble areas. When the shop and engineering found trouble areas, solutions to correct them were proposed to Bell Laboratories. By this time, close personal relationships between the individuals had formed. Thus, both sides respected the advice and judgment of the other. Problems were discussed; solutions were synthesized; and final corrective action was formulated in a highly efficient manner.

After models were built, they were turned over to a Western Electric test planning engineer. He examined the electrical performance of the unit, using the experience he gained during the field trial evaluation period. Again, problem areas were discussed with his Bell Laboratories counterpart and solutions were formulated. Once the test engineer was satisfied with a unit, he shipped it to the Bell Laboratories engineer for final evaluation.

By October of 1969, most of the circuit packs had had their initial evaluation. An actual production bay was erected in our shop and the final evaluation phase, prove-in of the system, began. This was one of the busiest periods of the entire project. As the system gradually took shape in the bay, each circuit was closely examined for proper operation. The results of this examination were fed back to the individual circuit pack test in an effort to duplicate actual operating conditions. The entire group, Bell Laboratories and Western, equipment and circuit engineers, were collectively working on the single project of final prove-in of the

D2 Channel Bank. Traditional lines between designer and manufacturer were set aside as each individual contributed according to his ability. It was a proud moment when the first system was packed and sent to a customer.

V. CONTINUING PRODUCTION

With the first systems shipped to the customer, Western is now in a continuing production phase. Some aspects of this phase are customer support, cost reduction, and design improvement.

5.1 *Customer Support*

Western Electric takes the position that a customer should be satisfied with a system he purchases. A new system is likely to cause some difficulties in the earliest installations. Therefore, we have traveled to a few field installations in order to offer assistance. The primary purpose of these trips is to get the equipment on-line and make money for the telephone company.

We at Western benefit from these trips by finding inadequacies in our own production methods. In the first year, Western Electric engineers made four trips to field sites due to requests from the telephone companies. In each case, the engineers (including the authors) returned with a greater appreciation of how the units arrive and how they are used in the field. This valuable information was fed back to our associates for corrective action. In addition to field trips, we consulted with operating company personnel by telephone to offer assistance in solving installation and line-up problems. The customer support effort has provided the required installation assistance and also brought information back to Western to improve the product.

5.2 *Cost Reduction*

Cost reduction is a very important part of all Western Electric product lines. The Bell System strives to continue to offer service at low prices in spite of rising costs of labor and materials. Cost reduction is one tool used to achieve this end.

In the case of a project such as the D2 Channel Bank, cost reduction can come from sources such as circuit redesign, physical redesign, component substitution, and automation. One particular case, which included these elements, is discussed to show the technique of cost reduction.

The case involved the filter and gates in the transmitting section.

This unit had a large number of module boards and LC filters mounted in metal cans. It had some redundant circuitry and it was produced in high volume.

One aspect of the case was to reduce the number of module boards from 19 to 1. This involved a relayout of the circuit and repositioning circuit elements from the many small module boards to one larger module board.

The reason for a savings at this point may not be obvious and so will be expanded. Previously, the unit had 19 modules of six different codes. Each one was a different size and shape. Some were used once; others were used eight times per circuit pack.

All these odd sizes and shapes discouraged the use of automatic component insertion, mass soldering, etc. In addition, each individual PWB had a cost that was significant. The use of only two PWB's, one main and one module board, saves in material costs and also allows the use of automatic equipment.

Another portion of the case was to remove the metal cans from the filters. This may seem elemental and even a reflection on the designer's ability when he specified the cans. Actually, this is far from obvious. Removal of the cans included a detailed study of the effects of cross-modulation and other circuit effects. This investigation showed improvement in crosstalk performance and no degradation in any other parameters. Removal of the cans would have been extremely risky if attempted before the system was well characterized and being routinely produced.

Another part of the project is to utilize Cap-Pak in place of discrete capacitors. Cap-Pak is an assembly of groups of capacitors mounted in a common case similar in shape to a transformer. Savings result from reduced labor effort in the manufacture of the capacitors and reduced labor effort in inserting the capacitors.

The example above is a typical large cost reduction case. Numerous small cases are constantly in progress as the manufacturing engineer constantly searches for ways to improve his product.

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