No. 1 ESS Circuit Packs and Connectors

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The mechanical packaging design of any large electronic system can have a profound effect on the cost of the system and on its operating reliability. This article describes the No. 1 ESS packaging design and discusses the considerations which influenced it. Printed wiring packaging techniques are used for the individual circuit packs. A new connector and multiple board mounting, which allow considerable flexibility and a high degree of package density, were designed specifically for this application. A test program has established that the connector will perform reliably for a 40-year design life.

I. INTRODUCTION

The No. 1 ESS must compare favorably with existing switching systems in cost, reliability of operation, space requirements and ease of maintenance. The extent to which these basic objectives are achieved will depend to a considerable degree upon the mechanical packaging arrangement used for its electronic circuitry. The system must be packaged so that it can be mass produced economically and yet will operate with high reliability over a 40-year life.[1] Space requirements dictate compact packaging, although a high degree of miniaturization is not required. Once installed, any part of the system must be readily accessible for maintenance or replacement should the necessity arise.

At the present state of the packaging art, these objectives are best served with conventional printed circuit packaging techniques. The combination of a printed wiring board circuit pack and a molded wire spring connector is the basis of the packaging concept which was adopted for the No. 1 ESS.

II. CIRCUIT PACKS

Typical circuit packs are shown in Fig. 1. Each package measures approximately $3\frac{3}{4} \times 6\frac{7}{8}$ inches and can, where component sizes permit.

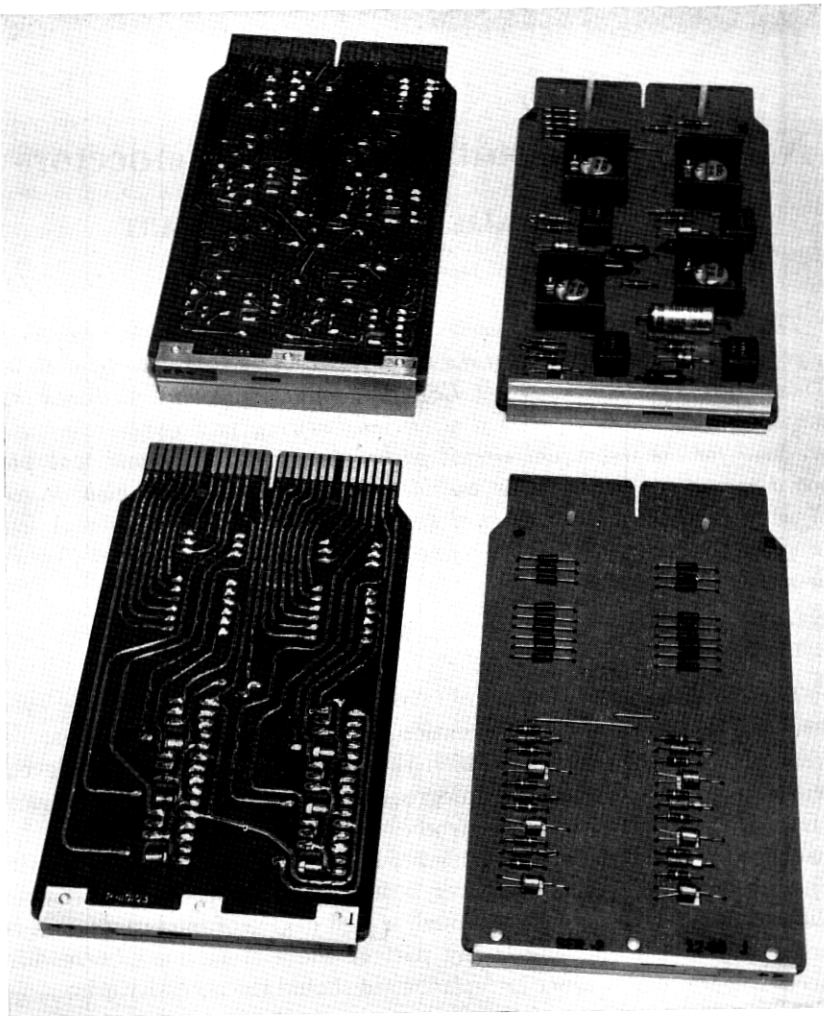

Fig. 1 — Typical No. 1 ESS circuit packs.

be mounted on 0.400-inch mounting centers. Twenty-eight contacts are provided on each circuit pack for supply voltages and interconnections with other circuit packs.

The printed wiring board is made from a fire-retardant grade of paper-based phenolic material. Its thickness is $\frac{3}{32}$ inch. In manufacture the board is blanked from sheet stock so that the grain of the laminate runs parallel to the $3\frac{3}{4}$-inch dimension of the board. Warp across the board contacts is minimized by this orientation. Most of the board warpage will occur in a direction perpendicular to the grain, and this is in the long direction of the board. Experience has shown that the $\frac{3}{32}$-inch boards have sufficient rigidity so that a stiffening frame is not required to control the warpage.

All the circuit packs use single-sided circuitry: i.e., the printed wiring is confined to one side of the board. This practice avoids the potential reliability hazards of through-connections and also simplifies the manufacturing processes. Special means are occasionally necessary to permit one printed conductor to cross another. Wire straps are used for this purpose. Nominally, the conductors are 0.050 inch wide with minimum spacings of 0.050 inch. In a few instances it is necessary to decrease one or both of these dimensions below the nominal value because of space limitations on the printed wiring board. The printed wiring is terminated in 28 contact fingers at one end of the board. These fingers are 0.070 inch wide by 0.380 inch long and are plated with a wear-resistant gold to serve as the circuit pack contacts. The conductors elsewhere are coated with a 0.001-inch thickness of 50/50 solder applied in a roller coating operation.

Most of the components are of the axially-leaded type. They are mounted on the blank side of the board with their leads brought through holes and soldered to the printed wiring on the opposite side of the board. The leads of the transistor used in the logic circuitry are specifically arranged to facilitate mounting on the printed wiring board. The base and emitter leads are brought through glass seals at the bottom of the case, while the collector lead projects from the top of the case. The transistor is then mounted so that its body is suspended over and projects down into a square cut-out in the board. This minimizes the projection of the transistor body above the board and decreases the width required by the circuit pack. For manufacturing purposes all component lead holes are located by the coordinates of a grid pattern with 0.150-inch spacings in the long direction of the board and 0.250-inch spacings in the short direction. The circuit pack provides space for about 70 typical components, although one circuit pack has as few as 6 components and another as many as 84.

After component assembly and electrical testing, an acrylic lacquer is spray applied to the wiring side of the board except in the area of the contact fingers. This coating prevents the printed wiring and the insulating surface from coming into contact with contaminants such as dust, condensed moisture or fingerprints. The coating is thermoplastic and can be removed in the area of soldered joints when repairs are necessary.

As shown in Fig. 1, a short length of aluminum extrusion is riveted to the front end of the board. Code information identifying the circuit pack is printed on this strip. On the other end of the board near the contact fingers two nylon pegs are forced into holes in the board. These nylon spacers together with the identifier strip serve to support the circuit pack when it is laid component-side-down, thus protecting the components from damage.

In a typical 10,000-line No. 1 ESS office approximately 12,600 circuit packs will be required.[2,3] Thirteen per cent of these circuit packs will be identical, i.e., of the same circuit or code. Sixty-five per cent of the circuit packs will use only 17 codes. The entire system will require about 150 different codes. Component sizes dictate that about half of the 12,600 circuit packs can be mounted on 0.4-inch centers, while the rest must be mounted on 0.8-inch and larger centers.

III. CONNECTOR

A new connector was designed specifically to accommodate the No. 1 ESS circuit packs. Two departures from convention were incorporated into the design. First, the circuit pack contacts are provided on the board as an integral part of the printed wiring. It is not necessary to add a contact-carrying applique or plug unit to the board. Second, the connector uses single contacts instead of bifurcated or twin contacts.

Bifurcation is undoubtedly worthwhile in relays where contact action is intermittent and the major cause of contact failure is dust or other foreign particles. But printed circuit contacts are essentially static contacts, and contact trouble is more likely to be due to corrosion films which interfere with metal-to-metal contact. In this case, the two requirements most essential to reliability are an inert, pore-free contact finish and a high contact force. If these requirements are met bifurcation is unnecessary. If they are not, neither single nor bifurcated contacts will provide the 40-year reliability needed for the No. 1 ESS.

The contact springs of the connector are made from spring-tempered, Grade A phosphor-bronze wire. The wire is 0.036 inch in diameter and is solder coated for corrosion resistance. Twenty-eight of these wires are molded into a common phenolic strip to form the wire spring assembly shown in Fig. 2. The springs are divided into four groups of 7 springs each. Within a group the springs are located on 0.110-inch centers. The spacing between groups is somewhat greater to allow clearance space for rivets which must pass through the phenolic strip. One end of each spring is flattened and serrated for wire wrap connections, with

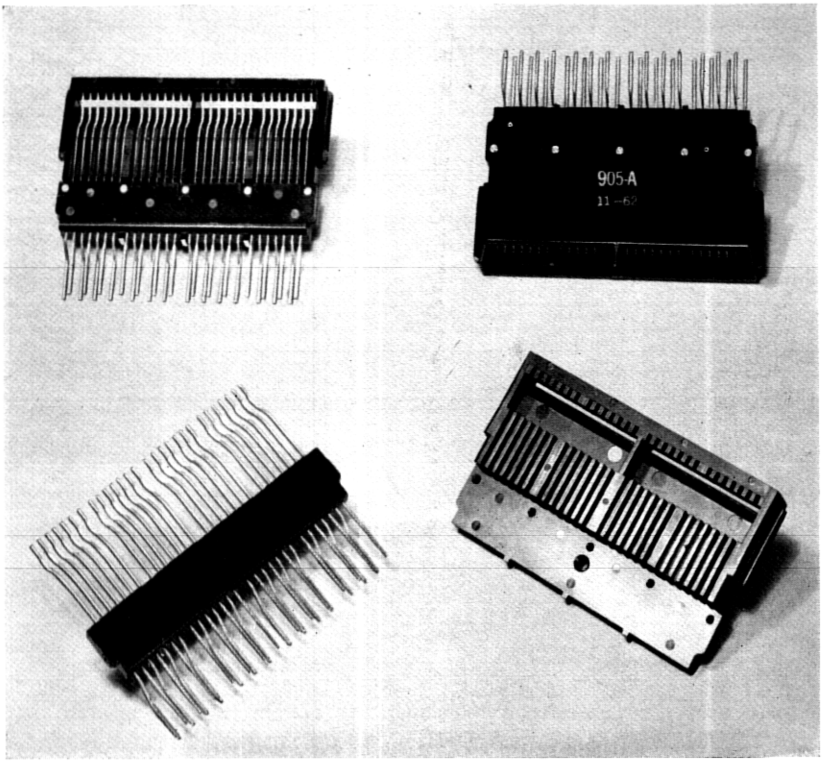

Fig. 2 — The connector assembly and the two main piece parts.

alternate terminals offset to allow access for the wire wrapping bit. The other end of each spring is formed to the correct configuration for the contact spring. A small contact button is welded to each spring at the point where contact will be established with the board.

The wire spring assembly is riveted to a second molded phenolic detail which is called the retainer. As the two parts are assembled the tips of the contact springs are forced against a surface of the retainer and are thus given an initial deflection or pretension. The retainer and the completed contact assembly are shown in Fig. 2. Fig. 3 shows in considerably more detail the pretensioning arrangement and the configuration of the springs. The tips of the springs are well protected from snagging. Even when the springs are fully deflected the tips will not project out of the contact assembly.

Fig. 3 also shows a magnified cross section of the teardrop-shaped contact button. The rolled overlay button consists of a 0.003-inch

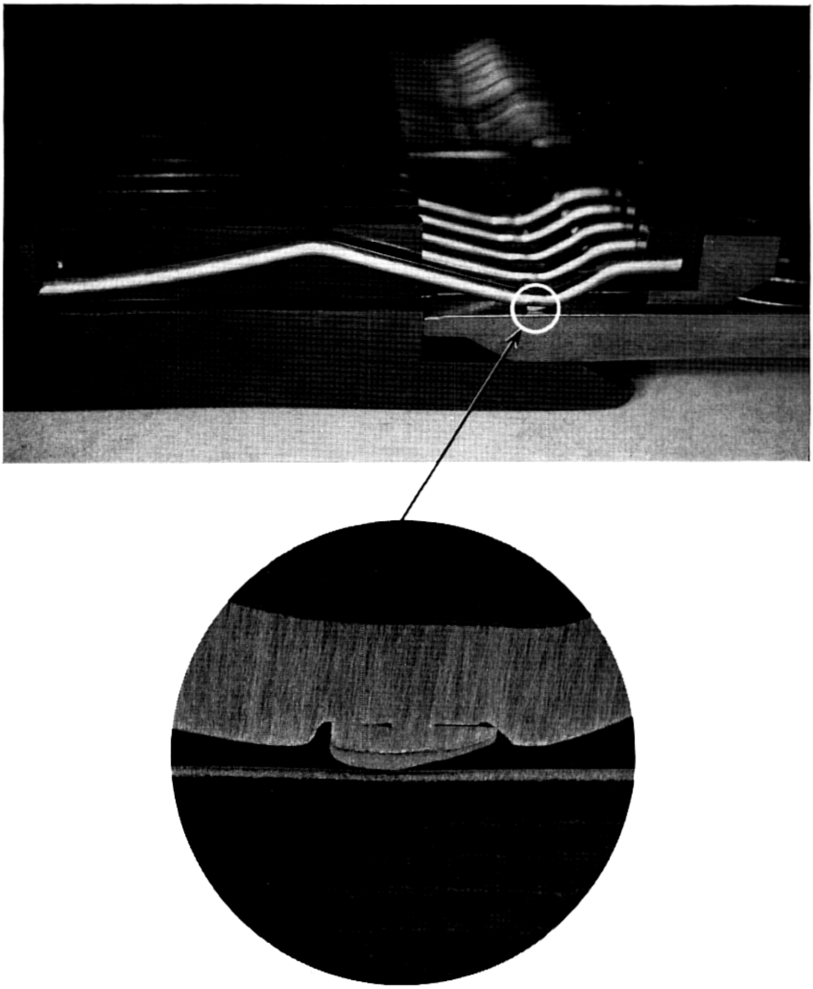

Fig. 3 — Connector spring and gold overlay contact cross section.

thickness of 24-karat gold and a base section of 80/20 copper-nickel alloy. The overlay material is supplied in tape form. It is cut to size and resistance welded to the contact springs in a continuous manufacturing process.

As a board is inserted into the connector, the board tongue enters a molded pocket in the retainer. Mating surfaces on the tongue and retainer pocket align the board so that the printed contact fingers engage and wipe against the spring contact buttons. Eventually the spring

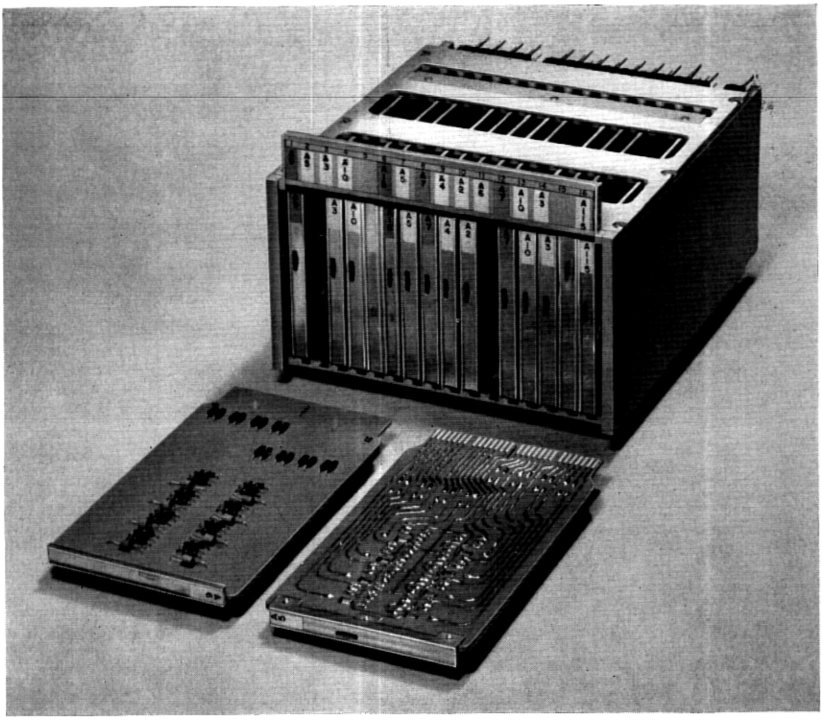

Fig. 4 — Circuit pack and connector mounting.

tips are lifted off the pretensioning surface, and the full contact force is applied to the board, forcing the tongue against the back of the retainer. The back surface of the board is specially contoured, as shown in Fig. 3, so that the contact force builds up gradually as the board is inserted. This minimizes the force required to insert the board.

IV. CIRCUIT PACK AND CONNECTOR MOUNTING

The mounting for the circuit packs and connectors is shown in Fig. 4. It is composed of upper and lower guide walls and two end plates which are assembled into an open box structure. All parts are aluminum die castings. Both of the guide walls and both end plates are identical parts, so that only one die is required for each. Two rectangular cutouts are provided in each of the guide walls to allow for the circulation of air between the circuit packs. The interior surfaces of the guide walls are lined with slots which are located on 0.400-inch centers. These slots locate the connectors and the circuit packs in the mounting. Molded

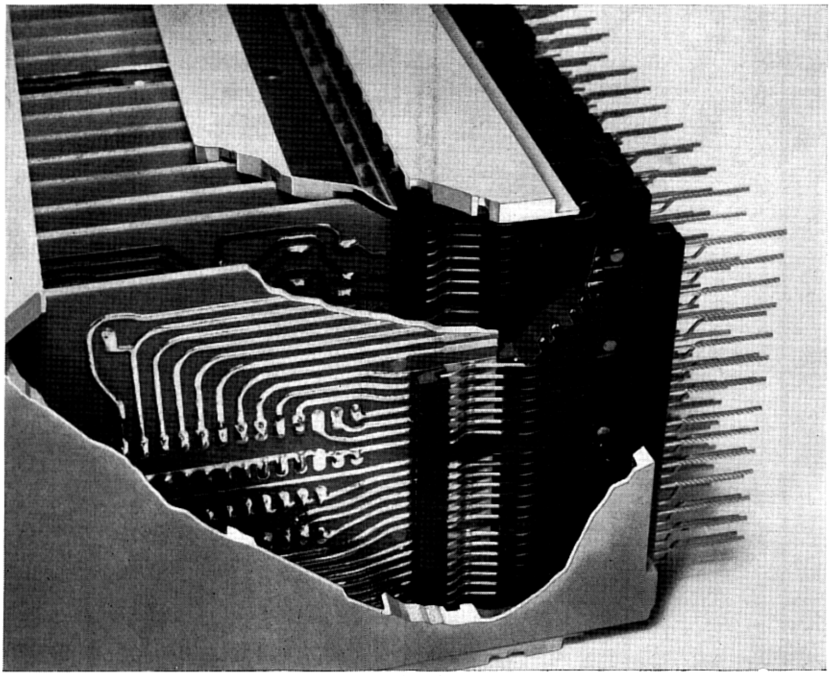

Fig. 5 — Cutaway mounting showing connector retaining latch.

keys at each end of the connector fit closely in the slots, which also align and guide the circuit pack into engagement with the contact springs. The slot entrances are funneled to facilitate entrance of the board. The connectors are retained in the mounting by stops in the slots and by spring latches which are riveted to each of the guide walls. As shown in Fig. 5, the latches are formed so that they project into the slot area. As the connectors are assembled in the mounting, the spring latches are deflected outward by the molded keys on the retainer. When the connector is completely inserted, the spring latches will snap back over the keys, thus locking the connector in place. A connector can be easily removed by deflecting the upper and lower latch springs past the point where they restrain the molded keys.

A designation strip is provided on the front of the mounting so that the circuit packs can be readily identified. The strip is rotated 180° to remove or insert packages. Package designations in the form of a letter-number combination and a color coding system are included on the designation strip and also on the circuit pack identifier. Correct location of a circuit pack is assured by matching the code number and

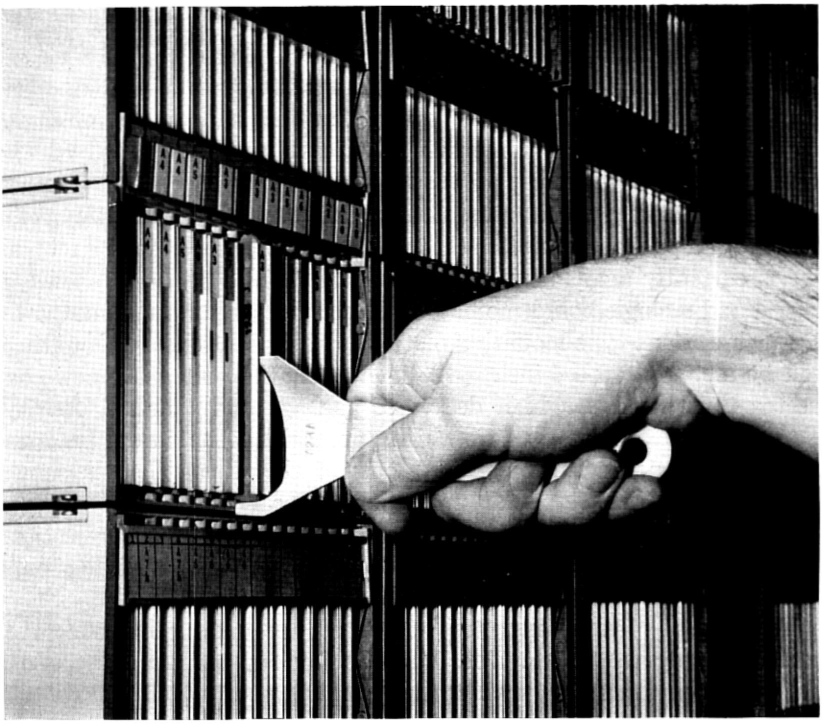

Fig. 6 — Circuit pack extractor tool.

color on both the designation strip and the package identifier. This method should provide adequate and reasonable safeguards against incorrect package insertion. The ultimate would of course be a mechanical coding scheme which would accept the correct code of circuit pack at a given location and make it physically impossible to insert any of the other 150 existing codes. This method was rejected as being prohibitive from the standpoints of cost, mechanical complexity and space consumption.

V. EXTRACTOR TOOL

Because of the close spacing of most circuit packs, a special tool is generally necessary to remove them. The extractor tool is shown in Fig. 6. The top prong of the tool is hooked into a slot in the circuit pack identifier and the bottom prong is rested against the lower guide wall. The board can be removed easily and in a controlled fashion by rotating the tool about the bottom pivot point.

VI. DESIGN ADVANTAGES

The new connector is quite flexible in that it permits the circuit pack spacings in the mounting to be varied as required by component sizes or other considerations. Four-tenths of an inch is the minimum spacing, but any integral multiple of this value is also possible. The maximum circuit pack capacity of the mounting can also be changed simply by varying the lengths of the guide walls. The basic connector and the end plates need not be changed. Actually, the No. 1 ESS mounting is currently available in two forms, the 16-board version shown in Fig. 4 and a single-board mounting. Either version can be mounted on a 4-inch channel-type mounting plate. Three of the 16-board mountings can be mounted on a 4-inch by 25-inch mounting plate. The new connector thus permits a high degree of package and terminal density. Terminal spacings are realized which approach the minimum practical for wire-wrapped terminations. A view of the wiring field is shown in Fig. 7. Three rectangular projections appear on the base of the retainer where the terminals are separated for rivets. These projections are painted white to accentuate the division of the terminals into groups of 7 and aid the craftsman in identifying terminals.

The design of the connector minimizes the undesirable effects of manufacturing tolerances. The pretensioning feature permits the use of a relatively compliant spring, thus reducing the variation in contact forces due to board thickness and other manufacturing tolerances. The alignment keys and the reference surfaces which locate the contact spring and the printed wiring board are all on one molded part, the retainer. The relative locations of these surfaces is thus tool controlled. In addition, the contact assemblies are located in the mounting in the same slots that are used to guide the printed wiring boards.

A significant advantage is achieved by the fact that the springs are molded in phenolic for a length of approximately $\frac{5}{8}$ inch. This feature provides a high degree of mechanical independence between the contact and terminal ends of the spring. Terminal or wiring disturbances are not expected to affect contact stability.

The welded gold button has several important advantages over the alternative possibility of an electroplated gold contact spring. The button provides a relatively thick layer of gold at the exact spot where it is needed at a cost which is less than that of electroplated gold. The wear resistance is thus optimized. Also, the possibility of a porous, corrosion-prone contact surface is eliminated, at least insofar as the contact spring is concerned.

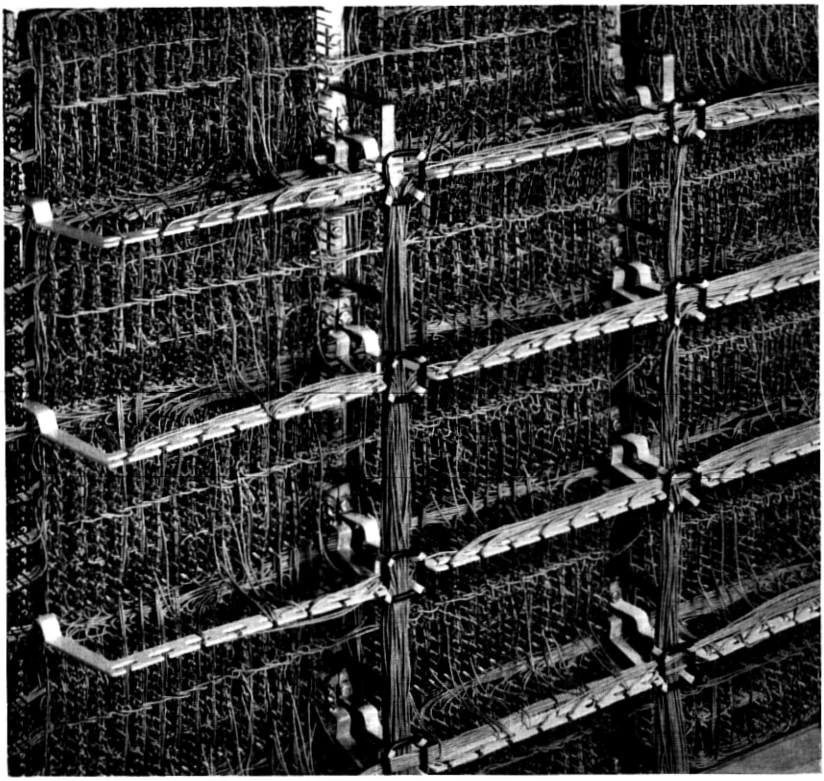

Fig. 7 — Connector wiring field.

The stepped contour which is machined on the back edge of the board facilitates board insertion. The contour delays the application of full contact force until the board fingers are well underneath the contact buttons. The buttons cannot wipe with appreciable force against the board insulation at the leading edge of the board fingers. There is thus no possibility of contaminating the contacts with wiped-on insulating material. This is a frequently overlooked source of contact contamination.

VII. TESTING PROGRAM

An extensive mechanical and electrical testing program was conducted to completely evaluate the performance of the connector.

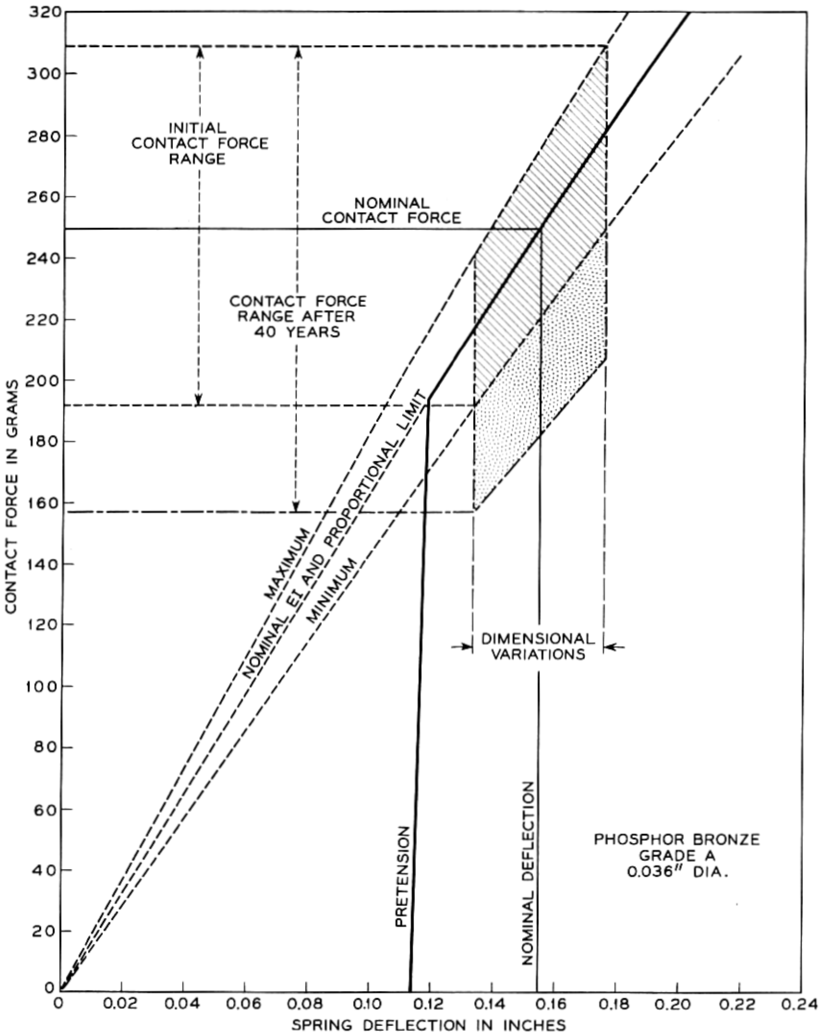

Fig. 8 — Connector spring characteristics.

7.1 *Mechanical Tests*

The force-deflection curve for the contact springs as obtained on the Instron Tester is shown in Fig. 8. Nominally, the springs are pretensioned with a force of 195 grams and will apply a contact force of 250 grams when an 0.093-inch thick board in inserted. There are many factors which can cause the contact force to assume a different value.

Variations in the spring properties of the wire or its size can, for a given deflection, appreciably affect the contact force. The extent of this effect is indicated by the maximum and minimum EI and proportional limit curves. The contact force will also be affected by dimensional variations in the molded connectors and the printed wiring boards. When all possible variations are considered and their effects accumulated arithmetically, the contact force is found to vary between 190 and 308 grams. These are initial values. There will be some degradation of the contact force with time, due principally to stress relaxation of the phosphor bronze wire. Stress relaxation studies conducted on the contact springs have indicated that over a 40-year period the contact force may diminish by about 15 per cent. Thus the minimum contact force could diminish to 157 grams in the unlikely event that all of the possible variations assumed the maximum unfavorable values.

7.2 *Contact Finish Tests — Corrosion Resistance*

A considerable part of the testing activity was pointed toward establishing the preferred contact finish for the printed wiring boards and connector springs. Good corrosion resistance is essential. The connector will be expected to provide a high degree of electrical contact stability in all of the wide variety of environments in which it might be located. The contact finishes must also have sufficient wear resistance to withstand the number of contact wipes which could occur over a 40-year life. A wear life of 200 insertions and withdrawals was adopted as the design requirement for the board contact finish and 500 insertions and withdrawals for the contact finish of the connector.

The corrosion resistance of a number of contact finishes was evaluated in laboratory tests and in outdoor exposures at Columbus, Ohio, New York City, and Kure Beach, North Carolina. Tin, solder and 24-karat gold were the contact finishes investigated.

Tin and solder were included in the hope that one or both of them might prove to be a low-cost contact finish which would be suitable for use with the No. 1 ESS connector. Both are soft metals which form hard and brittle tarnish films. Generally such films are easily fractured by the application of a force sufficient to cause deformation of the underlying metal. It was felt that the relatively high forces of the ESS connector and the plowing action of wiping contacts would be sufficient to disrupt all tarnish films, so that clean metal-to-metal contact could be established. While this condition was essentially realized, there was one important side effect. The residue of disrupted tarnish films proved to be a source of contact contamination. This residue, composed of minute fragments of broken films, is created with each contact wipe in which a tarnish film is ruptured. With successive insertions in certain environments the debris can accumulate on the contact surfaces to the point where it interferes with metallic contact, thus causing high and unstable contact resistance. In environments of high humidity this point is reached in just a few insertions. On the basis of this behavior tin and solder were judged unacceptable for the ESS application. Gold, on the other hand, performed well in the environmental tests and satisfied the contact stability requirement in every respect.

The environmental tests established the advisability of restricting the circulation of air past the contacts. Contacts so protected were consistently less affected by corrosive atmospheres than unprotected contacts. When the circuit packs are spaced on 0.400-inch centers, the close spacing of the connectors affords sufficient protection against air circulation. For larger spacings, a cover is available which covers the open side of the connector and effectively restricts air flow past the contacts.

7.3 *Contact Finish Tests — Wear Resistance*

Although the corrosion resistance of 24-karat gold is excellent, its wear resistance was found to be quite poor. A 0.0001-inch thickness on the printed wiring board contacts would frequently be worn through in less than 10 insertions into the connector. Alloy golds with much better wear resistance are commercially available. These finishes are electrodeposited as alloys which generally contain less than 1 per cent of either cobalt or nickel. Their corrosion resistance is comparable to that of pure gold. A cobalt-gold alloy with a Knoop hardness of 160 proved to be the most suitable for the contact finish of the ESS circuit packs. A minimum thickness of 0.0001 inch is specified. The contact finish of the spring is provided by the pure gold overlay of the welded button.

With this finish combination the following type of contact wear occurs. As the soft gold button comes into contact with the hard gold board finish, cold welds will be established between the two surfaces at some of the several points of contact. These welded junctions will be broken and others established and subsequently broken as the two surfaces are wiped together. Some of the welds will be weak at the interface of the two contact metals and failure will occur there. Other welds will be strong at the interface and failure will occur sometimes within the bulk of the soft gold button and sometimes within the bulk of the board conductor copper. In the first case, where failure occurs within the gold, a fragment of the pure gold will be left welded to the hard gold finish on the board. When failure occurs within the copper conductor, a small fragment of the hard gold finish will be plucked out of the board and left welded to the button. In either case both contact surfaces are roughened and surface damage will progress rapidly with successive insertions. This welding and plucking type of surface damage is typical of that which generally occurs when soft metal is slid on a hard metal.

The amount of surface damage depends to a remarkable degree upon the type and thickness of the contaminant films which are on the contact surfaces. Certain films which form naturally, such as water vapor or adsorbed gas films, are inevitable on normal contact surfaces and can provide a surprising amount of lubrication. The degree of lubrication, however, is generally inadequate for the wear requirements of 200 cycles on the board and 500 cycles on the connector. Additional contact lubrication is necessary if these requirements are to be met consistently.

A contact lubricant, in addition to minimizing surface damage to the contact finishes, must not degrade the contact resistance. The lubricated surfaces must not be sticky or they will become contaminated with dust and other particulate matter. The lubricant must also stay on the contact surface where it is applied. It should not creep or migrate even in warm environments. Tests have established that these requirements are best satisfied for No. 1 ESS purposes with a thin film of one of the microcrystalline waxes. The lubricant is applied from a dilute trichloroethylene solution (0.5 per cent of wax by weight) to the contact surface of the board. It can be applied either by dipping or spraying.

VIII. CONCLUSIONS

It is concluded from the results of the testing program that the ESS connector in its present form will perform reliably for the 40-year design life. There were no indications that its performance would be improved by adding a contact-carrying plug unit to the board instead of using the board conductors as contact fingers. There was similarly no indication that the design should be modified to include contact bifurcation.

IX. ACKNOWLEDGMENTS

The developments described here represent the combined efforts of many people in Bell Telephone Laboratories and the Columbus Works of the Western Electric Company. The authors wish to express their appreciation for all these contributions. The outstanding work of a few should be given special recognition. The late J. H. Mogler made substantial contributions to the initial connector design, while J. A. Bachman and M. T. Skubiak have contributed significantly to the present design.

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