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DESIGN AND ASSEMBLY OF PRECISION-TIERED FLAT, FLEXIBLE CABLES

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ABSTRACT

The cable assemblies described in this report are used in a weapon application and were constructed by joining several flat flexible branches at the terminations in a precision-tiered arrangement. The present discussion relates specifically to the problems encountered in the design and fabrication of development assemblies. The cable branches were produced from copper clad Kapton* laminate by the photo-etching process and were covercoated with Kapton insulation to protect and isolate the conductors. Subminiature rack and panel type connectors were used as the terminations. Polyurethane encapsulation provided both the required environmental backseal of the completed assembly and the needed mechanical support for the soldered connections.

Signal conductors on some of the cable branches could not exceed widths of 0.38 mm because of the very high conductor density. This constraint was imposed by the maximum widths and depths of routing channels that were allowed in the weapon case. Some branches varied from 100 to over 500 mm in length, and tolerances of ±0.25 mm were maintained on overall lengths between terminals of the completed cable assemblies.

Etched eyes in the periphery of the flex circuits were used to maintain precise positioning of branches relative to each other. Etched eyes also provided precise location of punched holes in lands.

A serious problem was encountered with lifting of narrow conductors during soldering. This condition was corrected by reshaping the ends of the conductors and covercoating them on either side of the soldered area. The confluence of the conductor and the land was made into a tear-drop shape to prevent lifting and rupture of the copper in the area.

The conductors were radiused and widened at the 90° transitions to eliminate local stresses and prevent tears during processing and during temperature excursions in use. Trim lines were employed on all branches to prevent damage to the outermost conductors. The narrow cross-talk circuits were widened at convenient locations and were interconnected to the ground plane with microsize eyelets. Support fixtures were used during assembly to relieve stresses on soldered joints and on the etched conductors. In process continuity checks and final dc resistance measurements were made on all circuits to insure the integrity of soldered connections and consistent electrical continuity.

Detailed process instructions were provided to the cable assemblers so that they would take the necessary precautions in handling the fragile cable assembly during fabrication.

INTRODUCTION

The precision arrangement of the tiered cable assembly was controlled by stacking the individual flexible harnesses to within ±0.25 mm of each other during fabrication. The separation between the tiers was maintained by using spacers when the harnesses were soldered to the connectors. This precise locating was necessary to insure proper connector

*Trademark-DuPont Inc., Wilmington, DE, 19898

mating within the case channels during installation.

Three principal objectives in designing and in fabricating the precision-tiered cable assembly were:

1. To provide harnesses that can be routed within very confined envelopes within the weapon case,

2. To construct a harness of sufficient mechanical strength to withstand the rigors of production handling and of installation and disassembly, and

3. To provide a cable assembly which can meet the electrical, mechanical, and environmental requirements of an operating weapon system.

Other specific design characteristics of the cable are as follows:

- Thin and flexible
- Light in weight
- Volume restrictions
- High conductor density
- Flat, flexible shielding
- Intricate interconnections of cross-talk circuits
- Precision-tiered concept
- Systemized design
- Precision mating of terminating connectors
- Sharp radius bends during installation
- Reliable adhesive bonding within the weapon system.

Early flight tests indicated that all cable design requirements were met successfully.

Other topics covered in this paper include the importance of design, fabrication of the flexible cable branches, procedures for production of the tiered cable assembly, a description of the encapsulation molds, and recommendations for product improvement.

The two precision-tiered cable assemblies designed, fabricated, and tested during this program are shown in Figures 1 and 2.

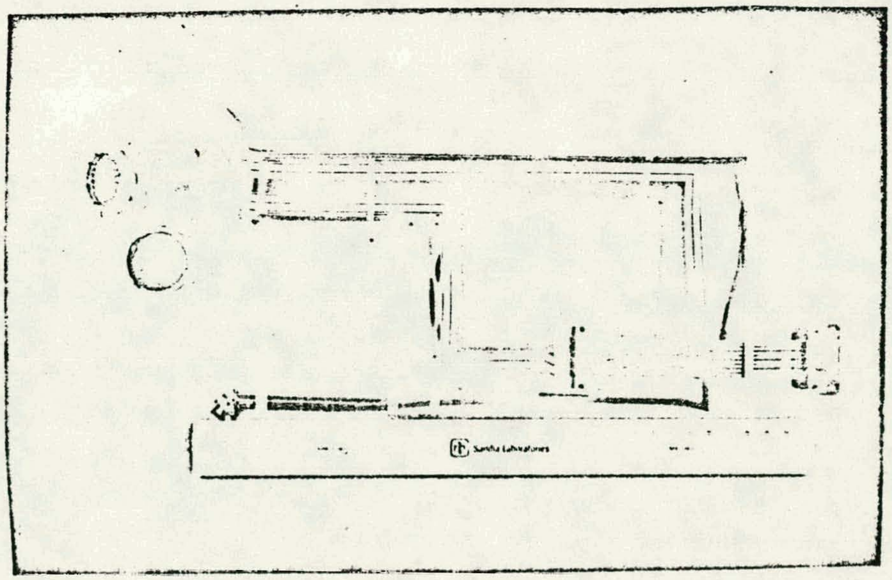


Figure 1. Precision-Tiered Cable Assembly Number 1.

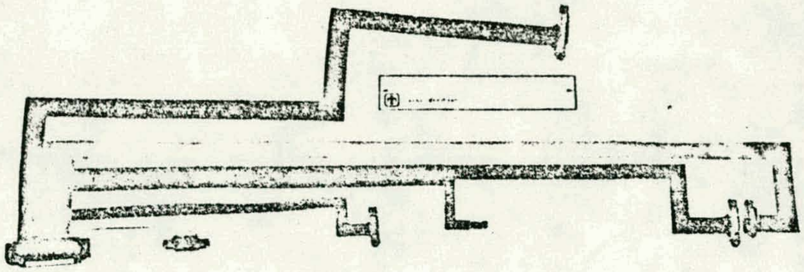


Figure 2. Precision-Tiered Cable Assembly Number 2.

The Importance of Design

If the optimized cable design is to evolve and if problem free processing is to be developed, all product features must be critically analyzed beforehand. At the earliest conceptual stages, it is not possible to anticipate all problems and their resulting effects. Therefore, only by actual assembly to prototypes will it be possible to resolve such problems. In these investigations, it was through such an approach that the design deficiencies were recognized and suitable corrective action taken to resolve them.

Target Eyes. In the first assemblies, the holes through the lands were drilled. The operation produced jagged edges of the copper and a fraying of the Kapton insulation. In addition to eliminating this condition, it was also important to provide a targeting mechanism for the precision location of the holes. The two problems were resolved by the following procedures: First, a targeting eye was placed in the center of the lands on the artwork. The etched target eye on the cable branches precisely located all holes as well as outlined their exact diameters. Second, a punching operation was developed which removed the Kapton in the hole cleanly and economically.

Signal Conductors. Most of the signal conductors on these cables were only 0.38 mm in width because of the space limitations mentioned previously. During soldering, these narrow conductors invariably were lifted from the Kapton base material. Three specific changes were made to eliminate the problem: (1) the power conductors were necked down at their terminations to allow at least doubling the width of the signal conductors, (2) the signal conductors were staggered to prevent solder bridging, and (3) the very ends of the conductors were also covercoated to provide added mechanical support against the possibility of lifting (see Figure 3).

Adhesive System. During chemical processing, the phenolic butyral adhesive initially used was severely degraded, and the copper bond was disrupted. All subsequent cable branches were constructed with a Kapton laminate which employed the nylon epoxy adhesive.

Cross-Talk Circuits. The 0.38 mm cross-talk circuits were widened to 0.76 mm at a convenient location so interconnections to the shield could be accomplished with miniature eyelets. The cross-over points were staggered to prevent solder bridging between the eyelets. The shield was then covercoated

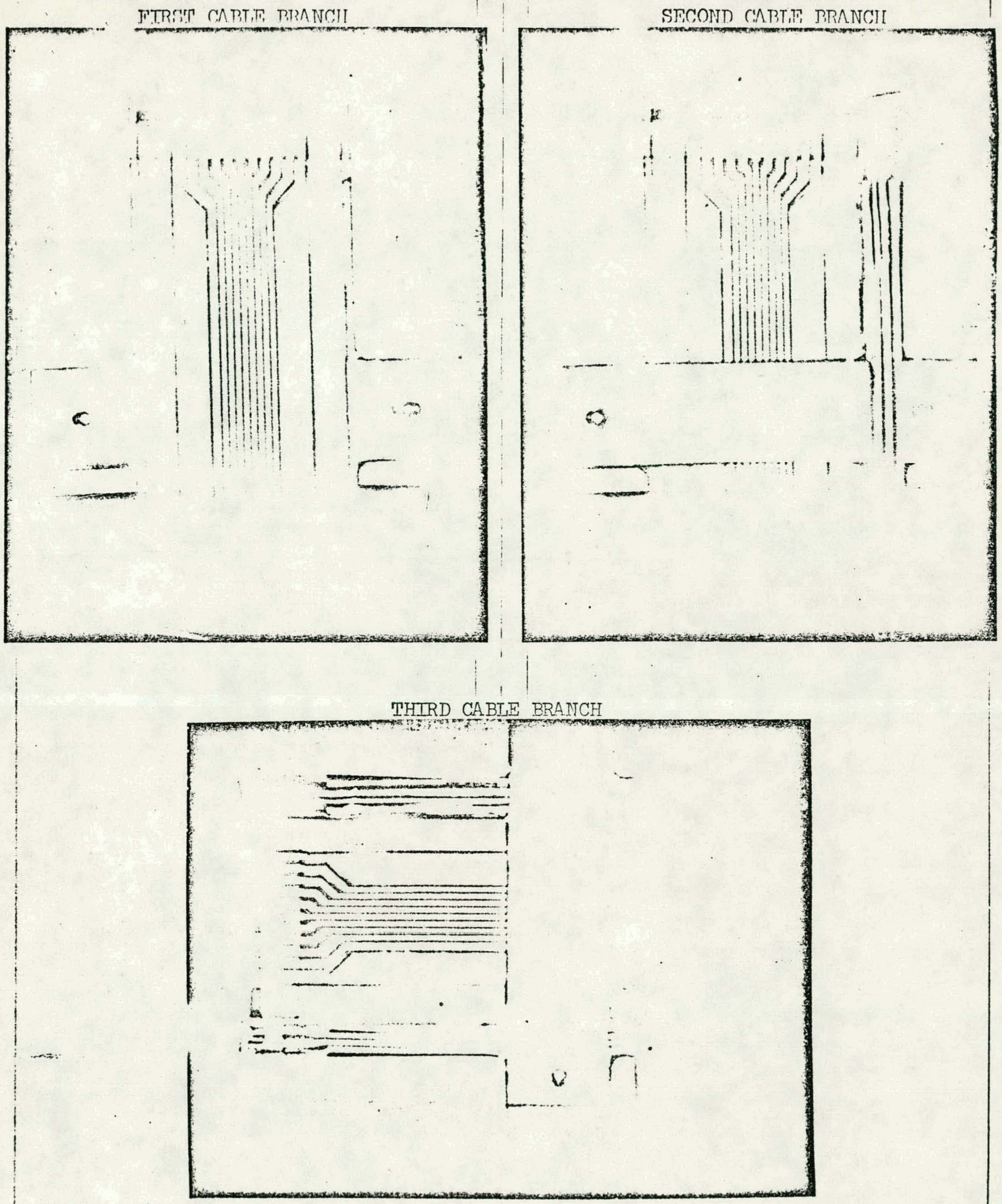


Figure 3. Precision Location of Flexcable Branches in Mold

with Kapton to prevent subsequent short-circuits with the weapon case.

Precision Alignment. Etched targets were used to provide holes through edge tabs of the cable branches for precision alignment of the branches relative to each other. The punched holes were mounted over alignment pins attached to the potting mold. Three flex cables mounted in such a manner are shown in Figure 3.

Radiused Conductors. The conductors were radiused at the 90° transition to provide additional mechanical strength to the cable.

Trim Lines. Trim lines were employed along all cable edges to prevent possible damage from tears.

Punched Corners. Cable corners were radiused by punching rounded transitions to prevent local tears.

"Krylon" Spray. It was possible to double the tear strength of the cover-coated branches by spraying the edges with "Krylon" particularly at corners.

Kapton Pre-Etch. The peel strength of the Kapton covercoat to the cable core can be increased by a factor of three or more if the Kapton surface is pretreated with N-Methyl-2-pyrrolidone.

The Flexible Cable Branches

The cable branches were produced with either 34µm-50µm-0µm or with 34µm-50µm-34µm copper clad Kapton laminate. The construction used was determined by whether the cable was shielded or unshielded. Printing of the conductors was accomplished by the photo-etching process. The cables were covercoated with 50 µm thick Kapton which was bonded to the core with nylon epoxy film adhesive of the same thickness. The exposed terminations were immersion plated for 20 to 30 seconds with bright tin approximately 0.12 µm thick from a Cuposit LT-26 bath maintained at a temperature of 65-82°C. The tin coating facilitated soldering and minimized the heating effects on the conductors and the lands. If the tin plate becomes tarnished after storage and atmospheric exposure, it is recommended that the conductors be replated in order to restore their initial solderability.

The Tiered Cable Assembly

In the assembly of the precision-tiered cable, it is necessary to stack the individual flexible branches within ±0.25 mm of each other and of the surface of the connector (Figure 4). These tolerances are important not only for maintaining the cable stack within the prescribed potting envelope, but also for controlling the overall cable length. If these dimensions are not controlled, the outermost branch will extend out through the encapsulation. Also, the individual branches may be either too short and not reach the mating connectors at their opposite ends or too long and result in wrinkling of the cable when it is installed in the case channels. Likewise, if the cable branch is misaligned longitudinally because of bent connector pins, it will not fit within the case grooves and will be damaged during installation. It is also apparent that the height of the solder meniscus and the length of the connector pins between the cable stacks must be carefully controlled. The overall dimensions of the connector encapsulation must likewise be maintained within the prescribed ±0.25 mm tolerances; otherwise upon mating the component will not fit within the allotted space within the weapon case.

Fabrication of the tiered cable assembly presented a number of problems because of the fragility of the branches. There was risk of conductor and land separations during soldering, the possibility of cold solder joints because of poor wetting, rupture of soldered connections during improper handling, and tears of the Kapton at almost any stage of the processing. The problems were basically controlled by requiring the cable assemblers to comply with a set of written

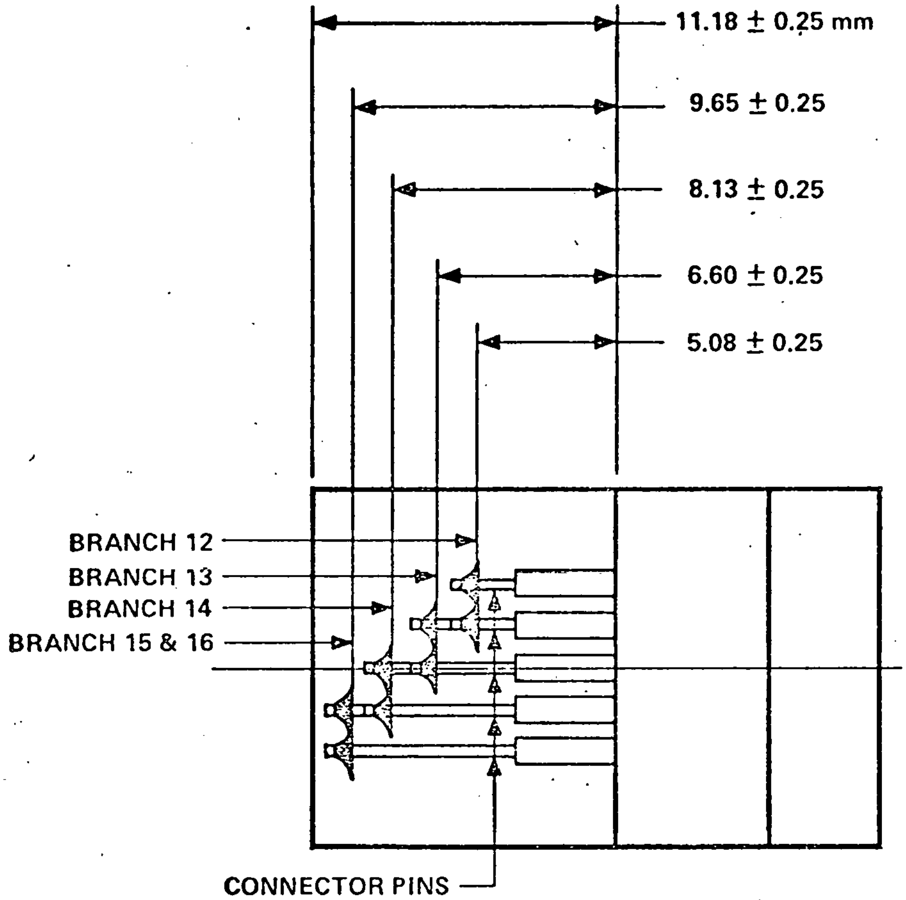


Figure 4. Precision Stack of Flexcables

instructions. Cautions were emphasized for each step in the process. Assemblers were made continually aware of the dollar loss consequences of mishandling of the components and the assembly. The step-by-step instructions listed below present a rather good insight to the processing used in the assembly operations.

1. Perform all assembly operations with great care.

2. If there is any confusion about the instructions or any details of the process, stop and get clarification before proceeding.

3. "Buzz out" each cable branch to ensure continuity of all circuits.

4. Examine branch terminations at 10 to 20X magnification to ensure there are no breaks or separation of lands or adjacent conductor segments.

5. Printed conductors and land areas must not be overheated during solder attachment because they will separate from the Kapton insulation.

6. If solder does not flow, re-tin the conductor and land areas before proceeding with soldering.

7. Avoid mechanical strain of any kind on the conductors and the lands during soldering.

8. Fill all solder cups of connectors with solder.

9. Attach solid wire leads in solder cups.

10. Insert cable branches over wire leads carefully so lands are not lifted from Kapton.

11. Connectors and cable branches shall be fixtured or taped to a support board during assembly to prevent movement of the solder joint.

12. Solid lead wires shall be clipped in a manner to prevent a strain on the solder joint during the process.

13. During spacing of cable layers over each other, spacers shall not be placed over the solder meniscus but will be in contact only with the cable surfaces.

14. Clean all solder joints with isopropyl alcohol to remove all traces of flux.

15. Examine at 10X to ensure cleanliness and to ensure integrity of solder joints.

16. Test circuits for continuity. Rework "open" or miswired circuits.

17. Mount assembly in mold with care so that soldered joints are not damaged in the process.

18. All branches and molds shall be secured to a support board to prevent strains on soldered joints during the encapsulation.

19. Preheat assembly (on support board) at 75°C for at least 2 hours prior to encapsulation.

20. Molds, while hot (75°C), shall be filled from one end only. In this manner the potting compound will fill the cavity by "sweeping" the air out and thus prevent air entrapment and voids in the casting.

21. Molds shall be filled level. Do not "mound" the potting compound alongside the cable. Excess compound causes wicking and prevents the finished casting from fitting into the connector cavity in the case.

22. Wicked EN-7 polyurethane resin between branches shall be softened by swabbing with toluene or xylene and then removed with tweezers.

23. Conduct dc resistance measurements on all circuits and record values. A permanent record shall be kept of these results.

24. Serialize and date code the cable assemblies of each set.

25. Tugging, pulling, twisting, and excess flexing of the cable branches shall be avoided. Do not apply excess tension at the 90° bends in order to prevent tears.

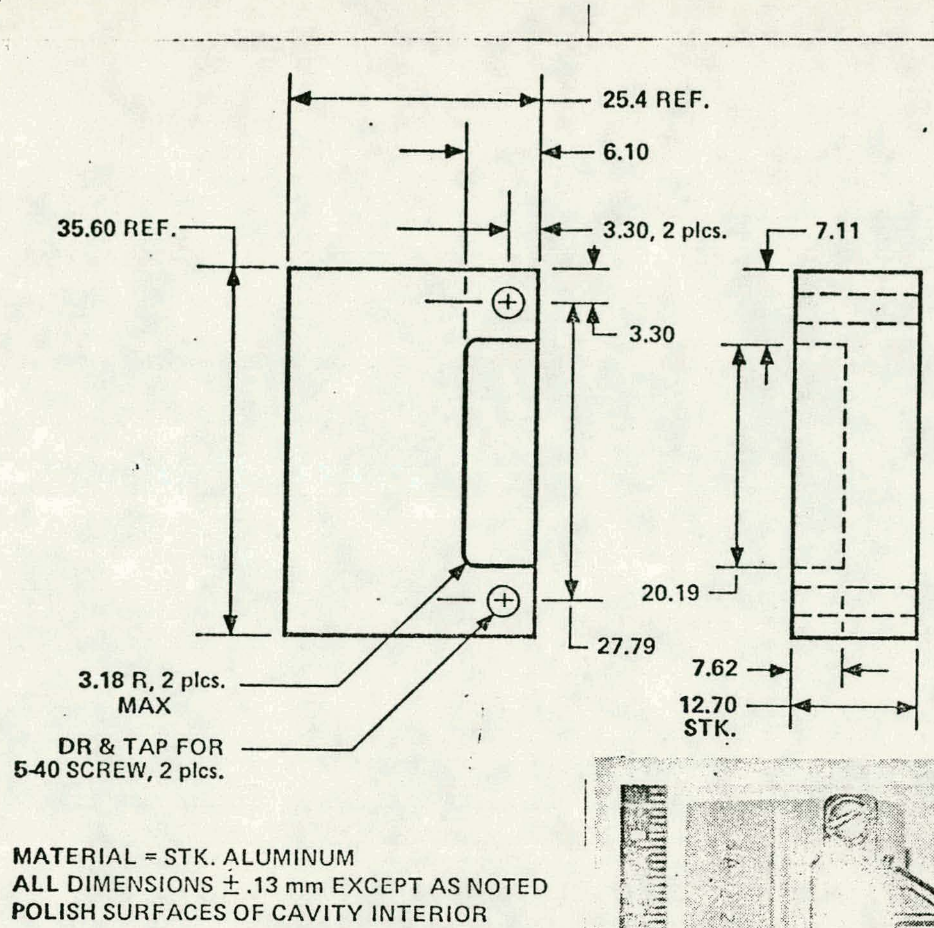
26. Finished cables shall be mounted and transported on support boards.

The purpose of the meticulous visual, mechanical, and electrical inspection both during and after fabrication was to ensure the required physical integrity and functional characteristics of the cable assembly.

The Encapsulating Molds

Back potting of the connectors provided the required environmental seal of the cable terminations and the necessary mechanical support for the soldered connections and the individual branches.

The typical mold used (Figure 5) for encapsulation was machined from solid 6061 aluminum stock. Internal dimensions were controlled to tolerances of ±0.13 mm, and the cavity surfaces were polished to facilitate removal of the casting. Since the cable branches in the present design were required to exit at



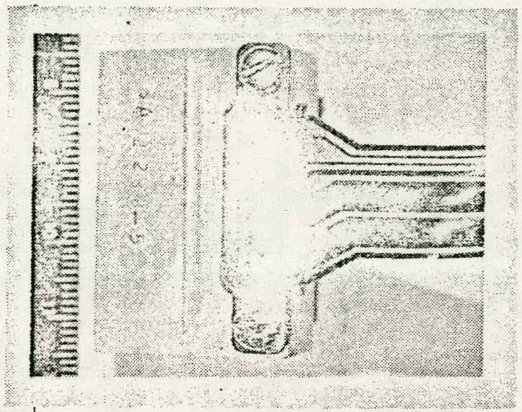


Figure 5. Single Exit Potting Mold

a 90° angle from the back of the connector, the connector body provided a resin-tight closure against the mold. These molds were designed to accommodate the subminiature rack and panel type connectors shown in Figure 6. This particular mold provided emergence of the cable branches in one direction only.

A more complicated mold is shown in Figure 7. In this design the cable branches exit in both directions. On the left side of the mold, the 2 mm high shelf positions the cable branches vertically with respect to the back of the connector. Along the shelf surface, a resin seal was developed by placing suitable Teflon shims on either side of the emerging cable branches. The stack of flex cables and shims was then securely clamped between the mold and the hat-shaped plug shown in the figure. The attached connector forms the closure along the open face of the mold, as described above. The mold cavity is then filled from the remaining open face of the mold.

The most complex mold (Figure 8) was constructed of four separate sections

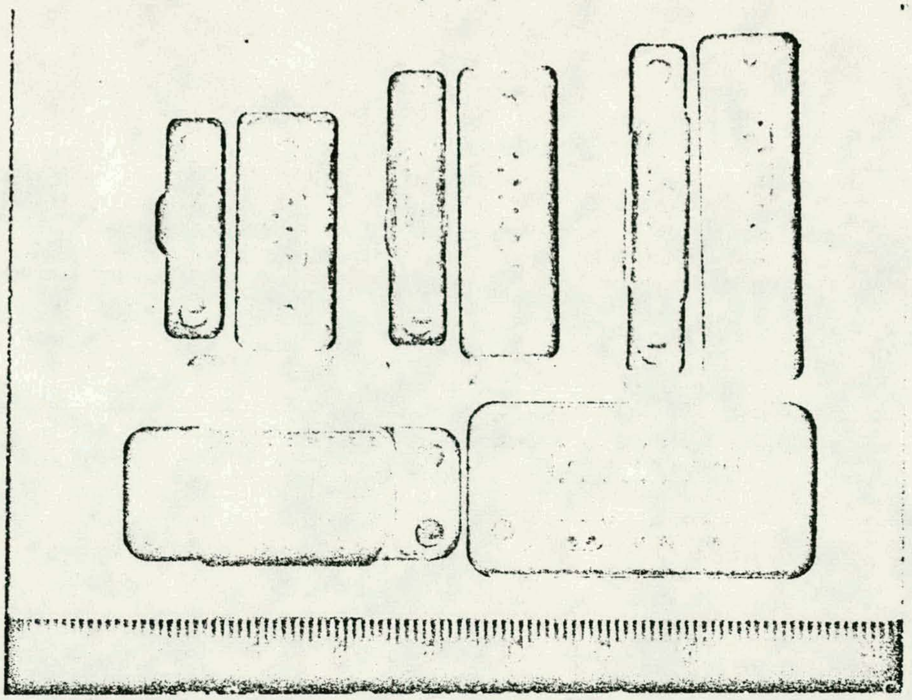


Figure 6. Subminiature Rack and Panel Connectors

which were bolted together during the potting operation. The mold cavity was completely enclosed except for the fill hole and the connector port. A slot was machined along the arc of the back section to provide a resin-tight seal at the surfaces of the flex cables emerging from the mold at that area. The front circular opening was sealed by bolting the connector against the mold. The mold and cable assembly before and after encapsulation are shown in Figures 9 and 10.

The finished casting from the latter mold was in the shape of a quarter moon (See Figure 11) in order to provide a perfect fit in the cavity of the weapon. The casting also provides the necessary mechanical support for the flex cables and their terminations. The casting resin in all moldings was clear so visual inspection could be conducted of the soldered connections and of the workmanship quality.

When the casting is clear, it is possible to locate faulty soldered joints, to penetrate to them by removing the compound, to repair them, and then to re-seal them. This rework option is very important since, otherwise, a very expensive assembly might be a reject. Emphasis throughout the assembly operations, however, should be placed on quality workmanship so there is no necessity for repair.

Product Improvement

Because of the complexity of the tiered-cable assemblies, specific controls shall be maintained over all manufacturing phases of the products. Additional controls not previously mentioned in the sections on design and assembly are high-lighted here to reemphasize their importance in achieving the expected quality.

- Materials control (clad laminates, film adhesives, covercoats)
- Eyelets or plated through holes for all interconnections
- Support and alignment fixtures during fabrication

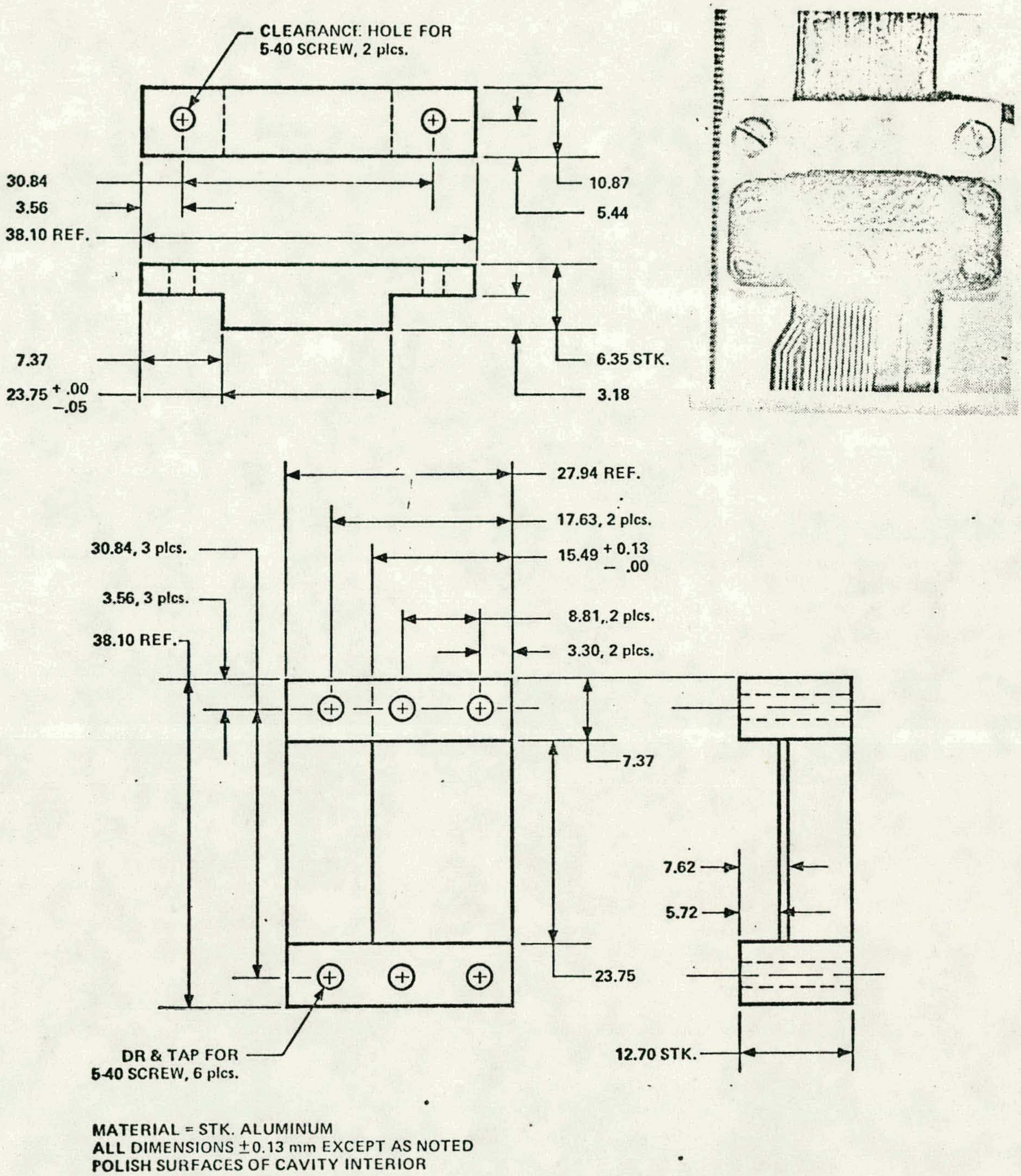


Figure 7. Double Exit Potting Mold

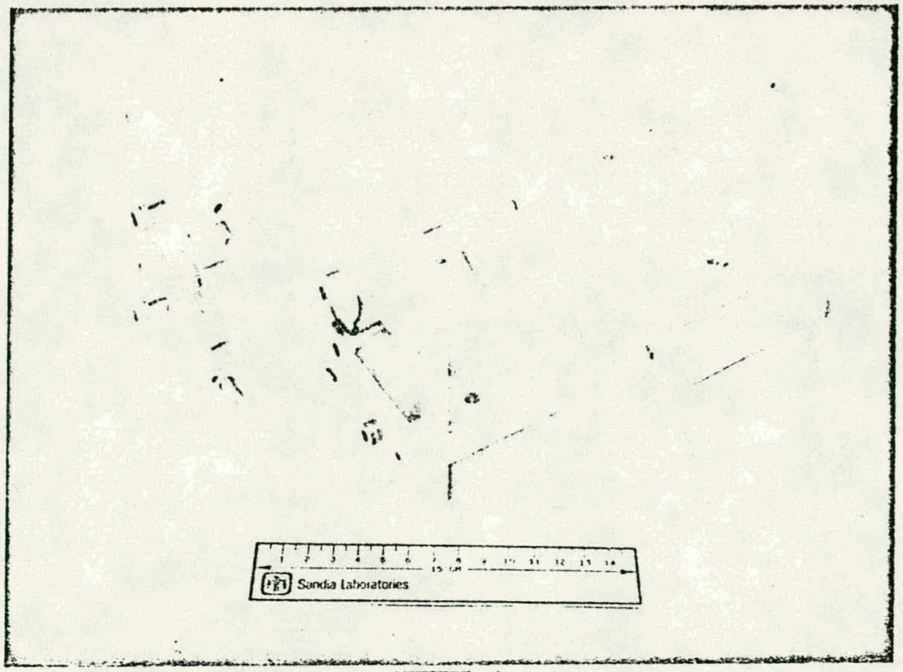


Figure 8. Four-Part Potting Mold

- Temperature controlled soldering irons
- Support attachments on molds
- In-process monitoring and inspection
- Manufacturing procedures
- Final product testing
- Product quality history
- Training program for assemblers

Two important objectives shall be achieved by instituting these controls: (1) the evolving systemized process shall be problem-free and (2) a high quality product shall be produced at a lower cost because the reject rate shall be virtually nil.

CONCLUSIONS

The precision-tiered flat, flexible cable assembly was successfully designed and fabricated to meet the exacting physical constraints of a weapon system. Early flight tests indicate that the cable assembly successfully passed the electrical, mechanical and environmental requirements of an operating weapon system.

To achieve an almost optimized cable design, a number of unique design features were incorporated in the product, and a systemized process for fabrication of the tiered cable assembly was developed. Visual and electrical inspection during processing was used to monitor product quality. Variables electrical data were used to determine process consistency and final product quality.

ACKNOWLEDGEMENTS

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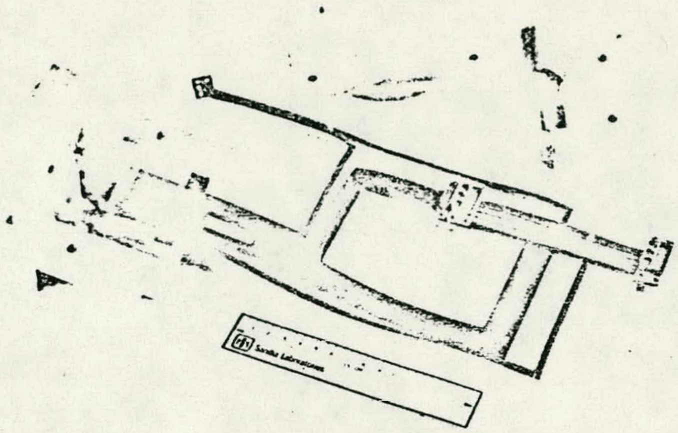

Figure 9. Cable Assembly Number 1 Before Encapsulation

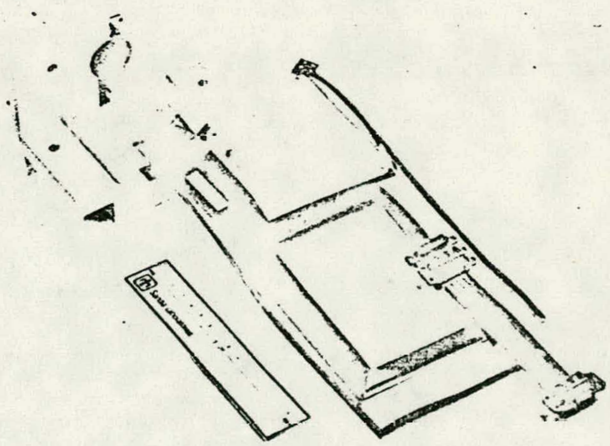

Figure 10. Cable Assembly Number 1 After Encapsulation

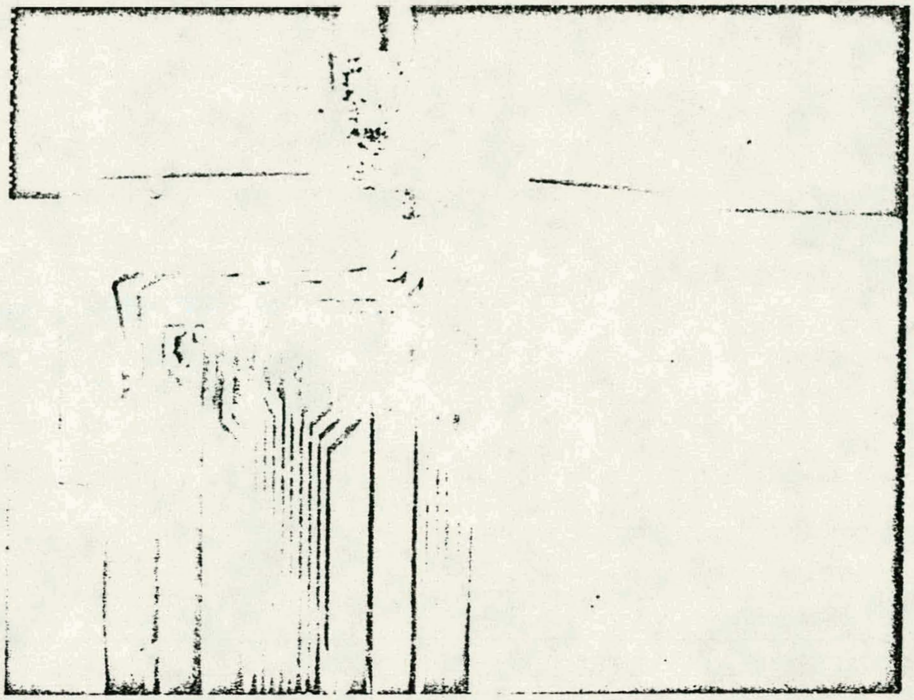

Figure 11. Close-Up of Form Fit Potting on Cable Number 1

BIOGRAPHY

George Voida is a Staff Member of the Interconnections Division at Sandia Laboratories. In this position, he is responsible for design, development, and evaluation of cable assemblies for weapon applications.

Mr. Voida also has a specialty assignment for evaluating new flat, flexible cables with specific emphasis on miniaturization.

During his twenty-two years at Sandia, Mr. Voida has been engaged in research and development of printed circuits, electronic packaging, molecular sieve dessicants, and organic materials.

Mr. Voida has recently written and has had published journal articles and conference papers on solder fused interconnections in flexible circuits, micro-size plated through connections in flexible cables, silicone elastomers for cable jackets, and non-destructive evaluation of interconnections in printed wiring boards.