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SD 70-378

FLAT CONDUCTOR CABLE TERMINATION
DEVELOPMENT PROGRAM

FINAL REPORT

15 September 1970

Contract NAS9-10444

Approved by



E. E. Clements
Program Manager



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TECHNICAL REPORT INDEX ABSTRACT

FLAT CONDUCTOR CABLE TERMINATION DEVELOPMENT PROGRAM FINAL REPORT

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SPACE DIVISION OF NORTH AMERICAN ROCKWELL
CORPORATION, DOWNEY, CALIF.

SD 70-378

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NAS9-10444

A development program for methods of termination of
Flat Conductor Cable (FCC) to small electrical components.

ABSTRACT

This report summarizes the concept development, feasibility model fabrication, and development tests of method(s) for terminating FCC to small electrical components. Numerous concepts were evaluated with a design philosophy of "soft termination" or the ability to mate and unmate the FCC from the component. The method chosen for components with screw type terminals was to transition FCC to Etched Flexible Circuitry (EFC) which pick up the component header/terminal pattern and terminate through eyelets or plated through holes in the EFC. The prime concept chosen for use with components with solder terminals was to modify existing component header/terminals to utilize MIL-C-38999 type pin contacts which mate with FCC adapters using mating socket contacts. An alternate concept was used for components having flattened and pierced solder terminals. It consisted of an FCC adapter with spring clip contacts which mated to the existing component after slight terminal modification. Test models of each of the above termination concepts were fabricated utilizing typical existing small electrical components (relays, event indicators, toggle switches and circuit breakers). Development tests were conducted (vibration, salt fog, humidity, thermal cycling IR, DWV and voltage drop). Test results indicated that all three design concepts were suitable for termination of FCC to small electrical components.



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FOREWORD

The FCC Termination Development Program described in this report was performed by the Space Division of North American Rockwell for the NASA Manned Spacecraft Center under Contract NAS9-10444. The drawings defining the termination systems developed in this program are enclosed in this report. The test data contained herein summarizes the test results. Detailed test data (including test procedures) may be obtained by requesting NR Laboratory Memorandum LR-7614-3801.

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DEFINITIONS

DAP (Diallyl Phthalate) - A thermosetting plastic known for its excellent electrical and physical properties.

EFC (Etched Flexible Circuit) - A group of flat conductors chemically etched to a predetermined configuration and bonded on one or both sides to a flexible dielectric.

Etch Factor - The ratio of depth to side attack (undercut) of the etched circuit. A high etch factor is desirable.

Existing Components - Small electrical components as presently used on Apollo display and control panels with terminals and header patterns designed for use with round conductors.

FCC (Flat Conductor Cable) - Two or more flat conductors with controlled spacing laminated between flexible dielectrics (sometimes called tape cable).

Hard Termination - Termination of electrical conductors to mating interface by means of solder, weld, crimp, wrap, or other technique.

Header - The portion of the component containing the external electrical terminals such as hooks, eyelets, flattened and pierced contacts, screw type terminals, etc.

PCB (Printed Circuit Board) - A group of flat conductors chemically etched to a predetermined configuration and bonded to a rigid dielectric.

RC - Round conductor

RCC (Round Conductor Cable) - A group of individually insulated round conductors.

Ribbon Cable - A group of individually insulated round conductors bonded or braided together in a flat parallel configuration.

Soft Termination - Termination of electrical conductors to a mating interface by means of a connecting device which can be mated or unmated by use of a suitable coupling method without use of special tooling.



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INTRODUCTION

This report summarizes the results of a program for development of methods for terminating flat conductor cable (FCC) to small electrical components commonly used on electrical display and control panels, such as event indicators, switches, relays, and circuit breakers.

The program was accomplished in two phases—Phase I, Concept Development; and Phase II, Feasibility Model Fabrication and Development Tests. Phase I included a review of industry data, development and selection of termination concepts, material selections, and a study of concept producibility. Numerous concepts were evaluated and a method selected for each of four typical components: circuit breakers with screw-type terminals; switches; relays; and event indicators with solder-type terminals. In addition to basic requirements such as capability to meet present Apollo operational and environmental criteria, a basic design goal was established that no method would require "hard termination" (solder or weld) of the FCC conductors directly to the component terminal. This requirement (1) eliminated further consideration of current industry concepts that terminate the FCC to a flexible or rigid circuit which is then soldered or welded to the component terminals, and (2) established a philosophy of "soft termination" or the ability to mate and unmate the FCC from the component.

The concept chosen for termination of FCC to components with screw-type terminals, such as circuit breakers (Figure 1) was the transition of the FCC to etched flexible circuitry (EFC), with a circuit pattern matching that of single or multiple components. The circuits would terminate in screw-type terminals through eyelets or plated through holes in the EFC.

The prime concept chosen for use with the remaining type components was to adapt from existing headers with EFC to MIL-C-38999-type pin contacts which would mate to an FCC adapter containing mating socket contacts (Figures 2, 3, and 4). To gain the maximum data possible from the Phase II feasibility model fabrication and tests, an alternate concept was utilized for termination of the FCC to toggle switches. This method used flat, spring clip contacts, mated to modified flattened and pierced terminals on the toggle switches (Figures 5 and 6). Ten samples of each termination concept were fabricated (five each were shipped to NASA/MSD for evaluation and the remaining samples were mounted on an aluminum panel and tested by NR).



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(See Figure 7.) Development tests included vibration, salt fog/humidity, and thermal cycling in conjunction with electrical tests (i. e., insulation resistance, dielectric strength, and contact voltage drop).

The test results indicate that the concepts developed are feasible and could be utilized in production for terminating FCC to small electrical components.



TECHNICAL DISCUSSION

CONCEPT DEVELOPMENT

The basic design philosophy for concept development was to eliminate hard-termination of FCC conductors to component terminals. Since no suitable soft-termination methods were disclosed by an industry survey, consideration was given to several design approaches. A detailed analysis of termination concepts considered is contained in Phase I Report NR/SD 70-304, dated 15 April 1970.

CONCEPT SELECTION

The concept chosen for cable termination to components with screw-type terminals, such as circuit breakers, was the transition from the FCC to an EFC having a pattern matching that of single or multiple component screw-type terminals. This concept lends itself to the existing simple disconnect method and small number of terminals inherent in these components. The disadvantages of this type of termination is the same as that of terminating RCC to screw-type terminals (i.e., an encapsulation or coating is required to provide a moisture seal). (See Figure 1.)

The termination method selected for use with high-contact density component headers with solder terminals, such as relays, was to provide an FCC adapter with socket contacts; the contact to FCC transition being provided by EFC. The adapters mate to modified component headers containing pin contacts. The pin and socket contacts utilized are 20 gauge, MIL-C-38999 type reworked to remove the major portion of the crimp barrel. The pin contacts are terminated to the component header through use of EFC, which matches the existing header configuration and transitions to a pattern matching the socket contacts in the FCC adapter. Both header and adapter EFC are encapsulated to assure proper contact position, to provide for moisture sealing, and to provide structural rigidity required for mating/demating hardware. The EFC pin and socket termination and encapsulation are accomplished utilizing precision tooling. Environmental sealing at the component header/FCC adapter interface is provided through use of a molded silicone rubber gasket in the header (Figures 2 and 3). This termination concept is also utilized on the event indicators. (See Figure 4.)

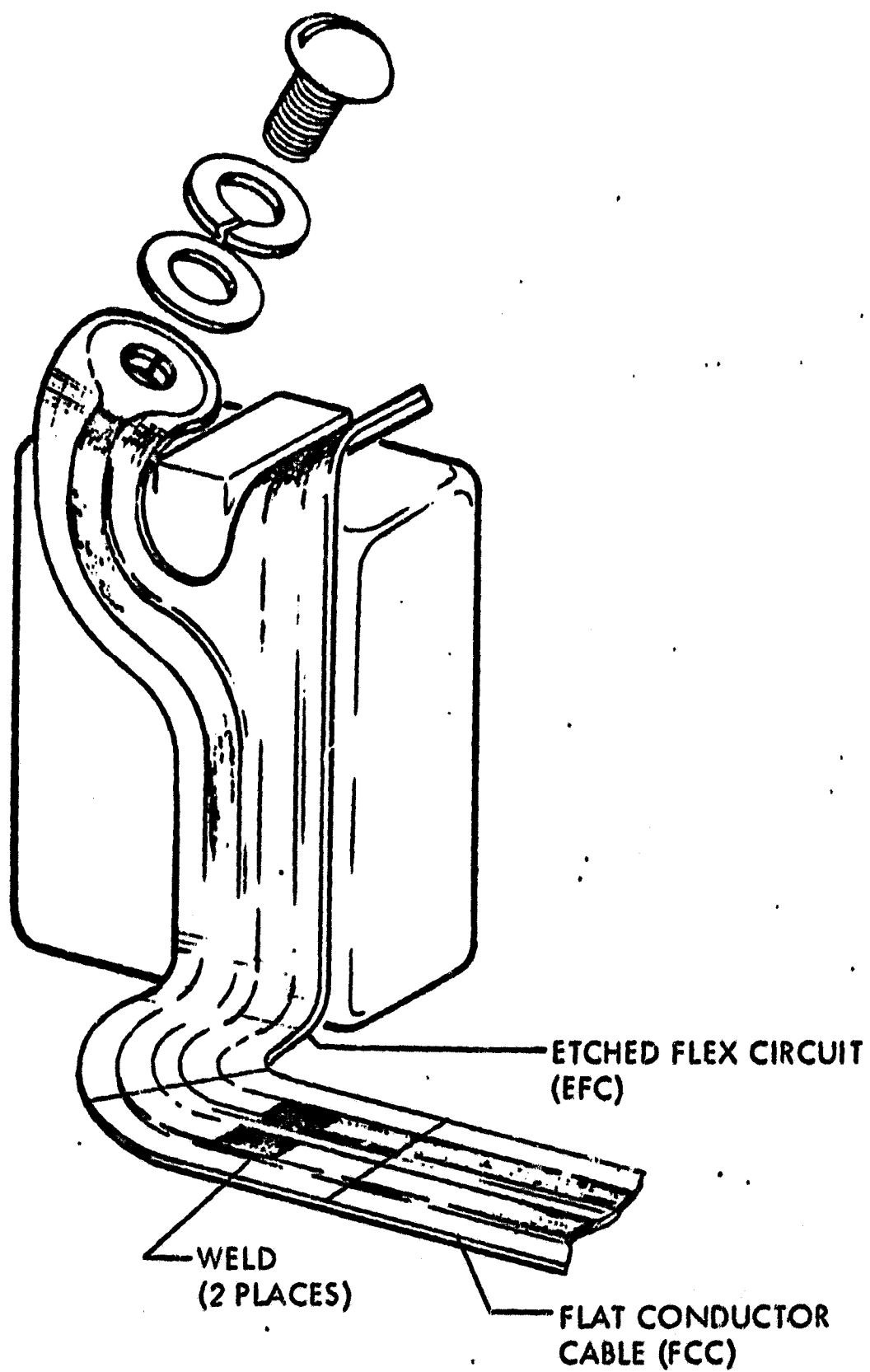


Figure 1. FCC Termination to Circuit Breaker
Through EFC Transition

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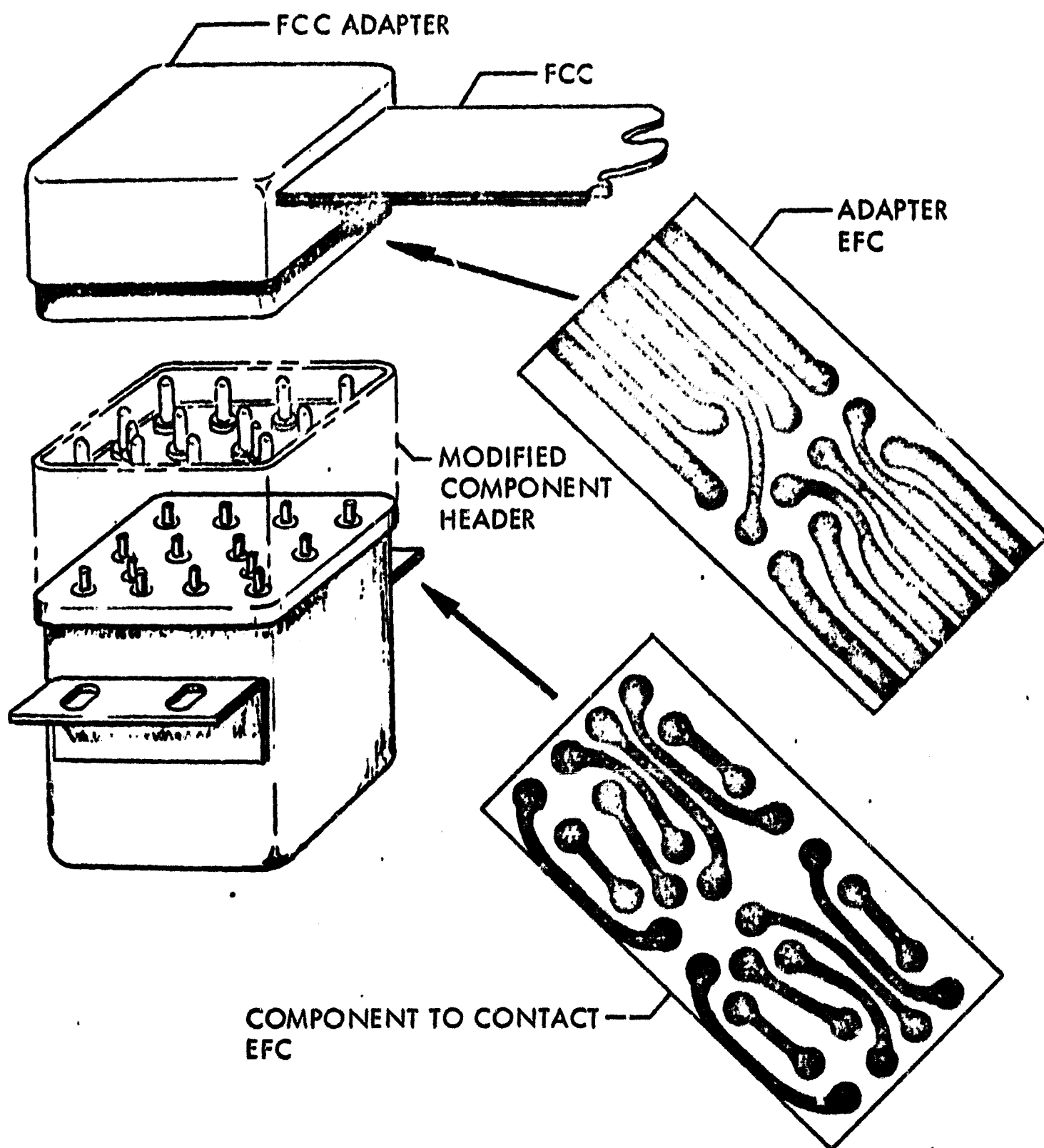


Figure 2. FCC Termination to Relay Through Use of Modified Component Header With Pin Contacts and FCC Adapter With Mating Socket Contacts

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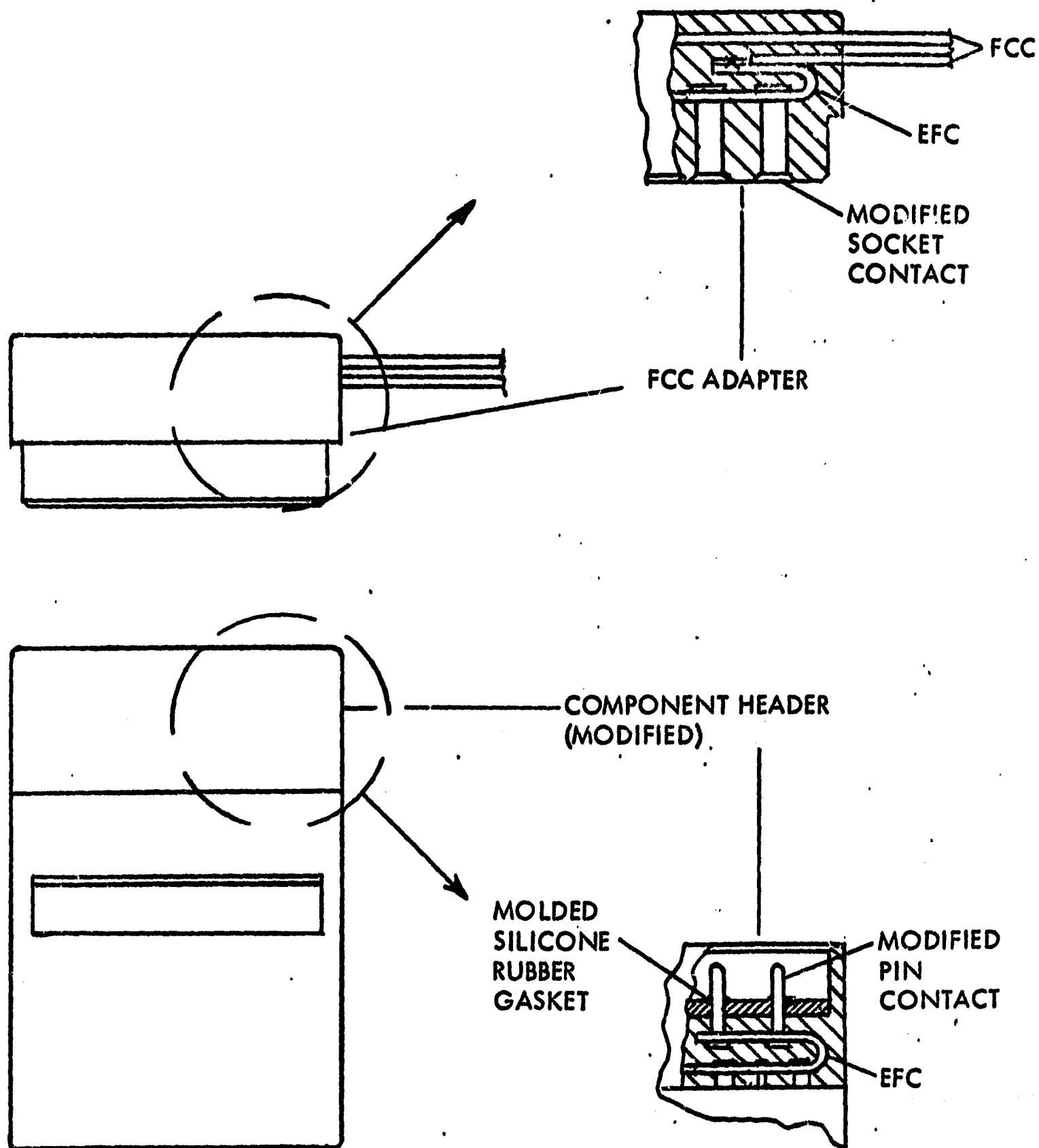


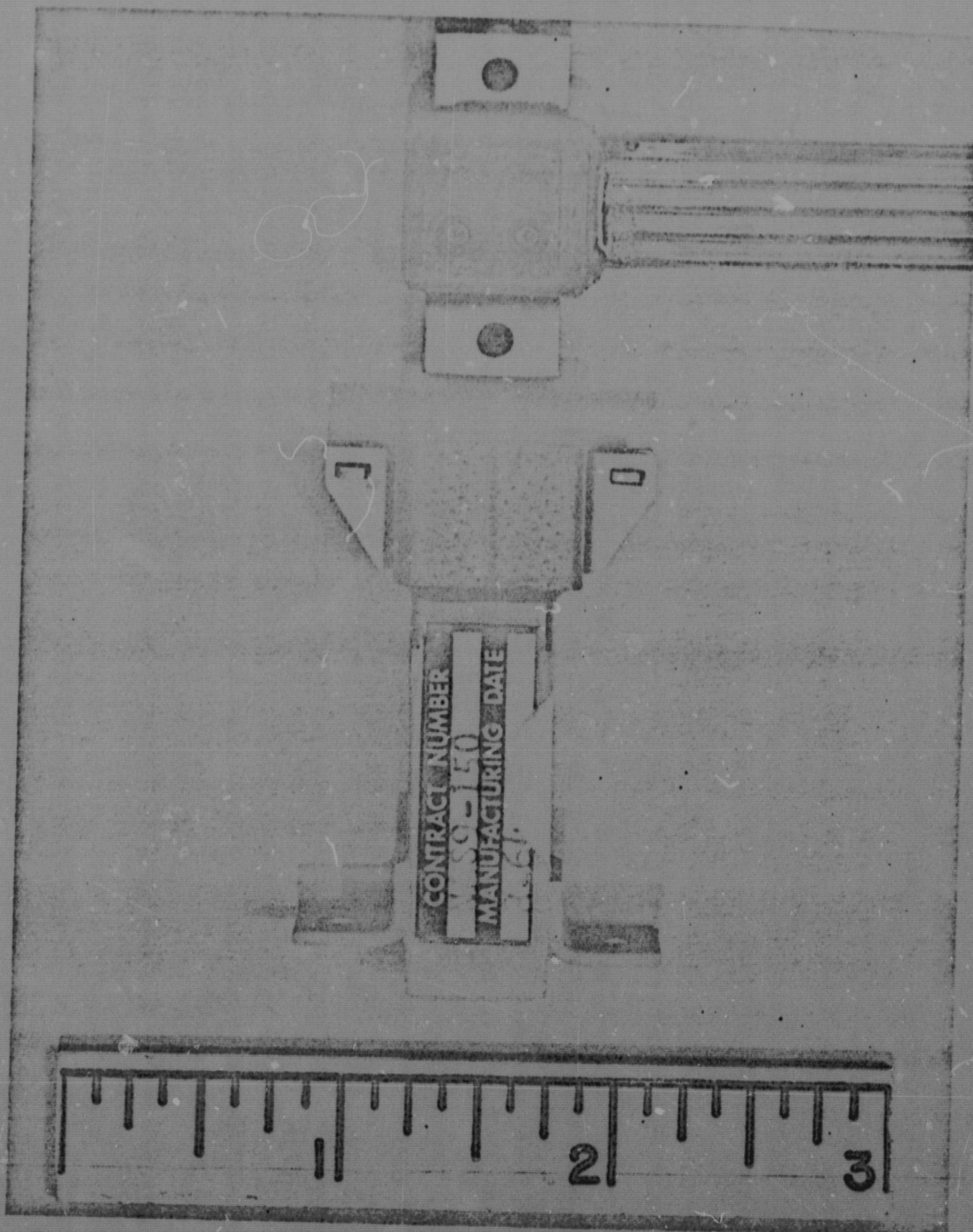
Figure 3. Details of Relay Header/Adapter Assembly

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Figure 4. FCC Termination to Event Indicator Through Use of Modified Header and Mating Adapter



Since the toggle switch offered greater center-to-center spacing of terminals, an alternate design concept was utilized for FCC termination. It involved the use of an FCC adapter with spring clip contacts that mate to slightly modified existing flattened and pierced terminals. The environmental seal at the FCC adapter/switch header interface was accomplished through use of rubber O-rings installed over the individual switch terminal stand-offs (Figure 5).

All components (circuit breakers, switches, indicators, and relays) used for fabrication of test models were either Apollo Block I qualification test specimens or miscellaneous non-flight hardware. The toggle switches used for feasibility model components had one terminal removed previously so only five terminals were available for FCC termination (Figures 6 and 7).

MATERIAL USAGE

Phase I

The Phase I concept evaluation models utilized FCC with unplated copper conductors insulated with polyester (Mylar) or polyimide (Kapton) film bonded with polyester adhesive. The models were encapsulated with clear epoxy resins that allowed visual evaluation of design concepts.

Phase II

Materials for feasibility models were selected to assure compatibility with conditions imposed by design and test criteria. The FCC and EFC constructions used unplated copper conductors insulated with Kapton film bonded with FEP Teflon. Component header and FCC adapter housings were fabricated using polyimide impregnated glass fabric laminates. Encapsulation of relay and indicator headers and adapters was accomplished with a mineral filled epoxy resin. The switch FCC adapters utilized acrylic plastic retainers and gold-plated beryllium copper contacts. Sealing gaskets were molded from silicone rubber. The switch seals were off-the-shelf neoprene O-rings. Bracketry was fabricated from nickel-plated beryllium copper and attached to the adapter housings with aluminum rivets.

It is envisioned that production models would be designed and fabricated to meet all physical and environmental criteria that are now required for the Apollo CSM Program, such as outgassing, toxicity, and flammability. The FCC would feature Kapton insulation bonded with FEP and nickel-plated copper conductors. The component adapter enclosing the FCC termination

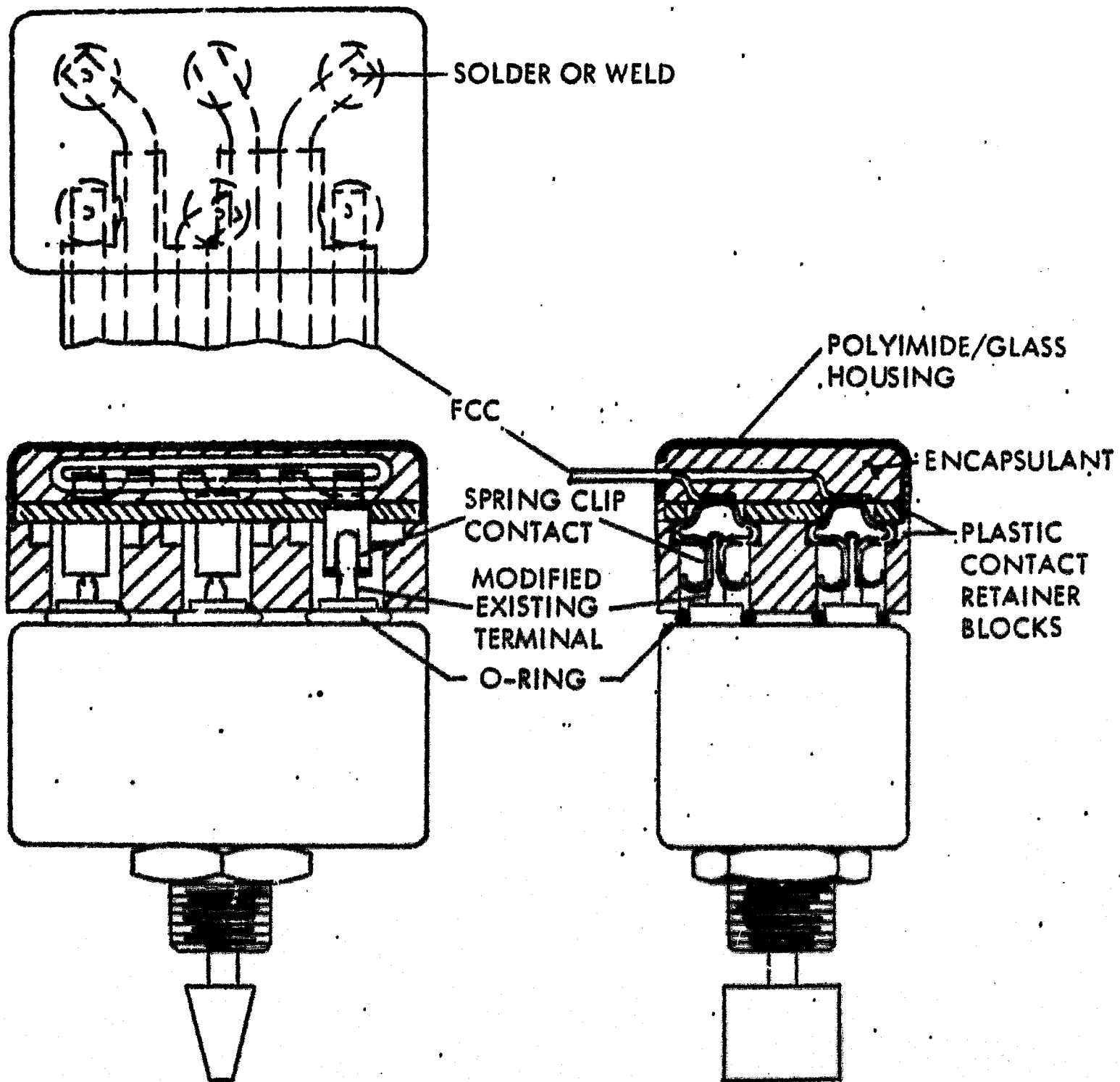
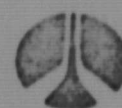


Figure 5. Details of FCC Adapter/Toggle Switch Assembly

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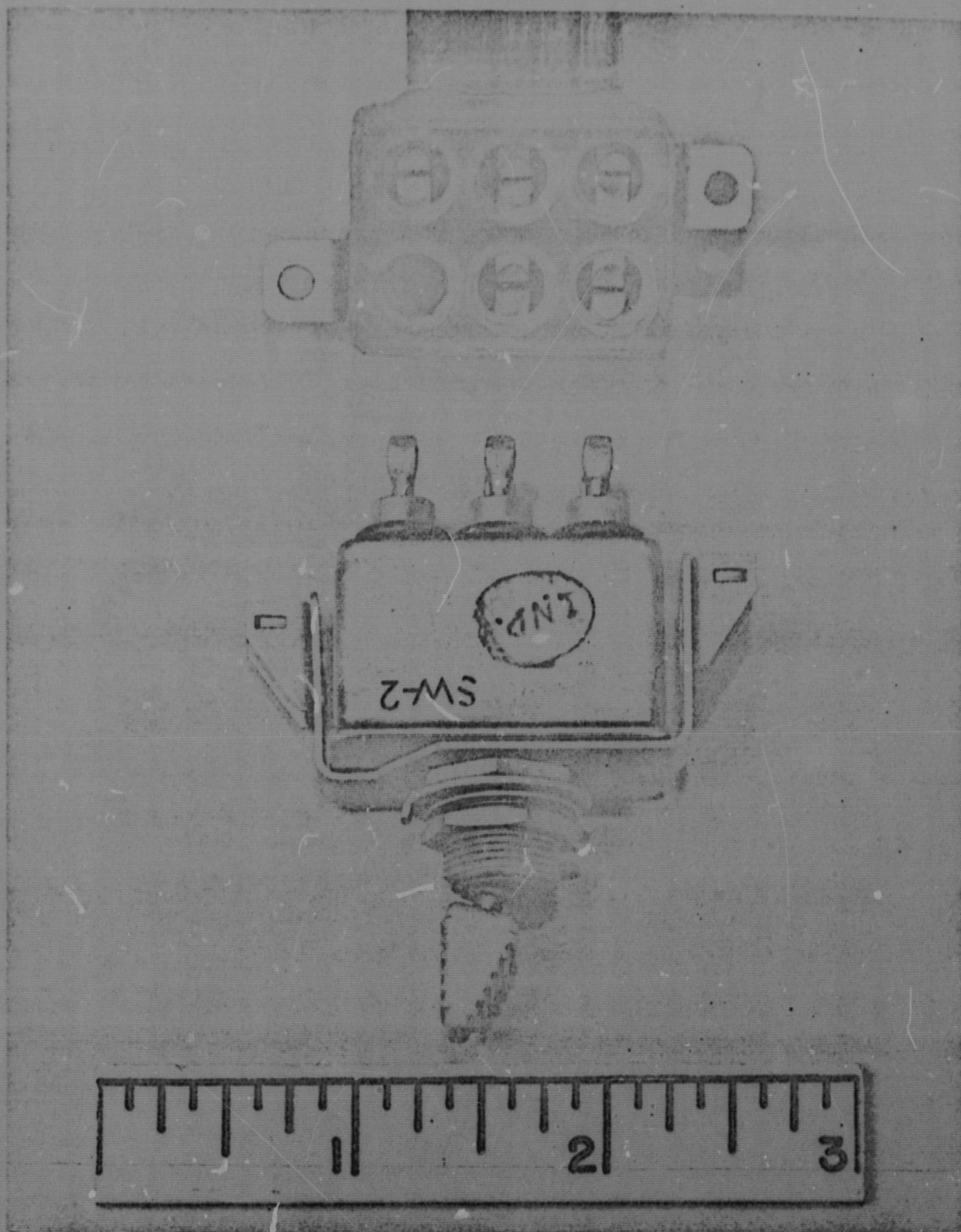


Figure 6. FCC Termination to Toggle Switch Through Use of
FCC Adapter Assembly With Spring Clip Contacts



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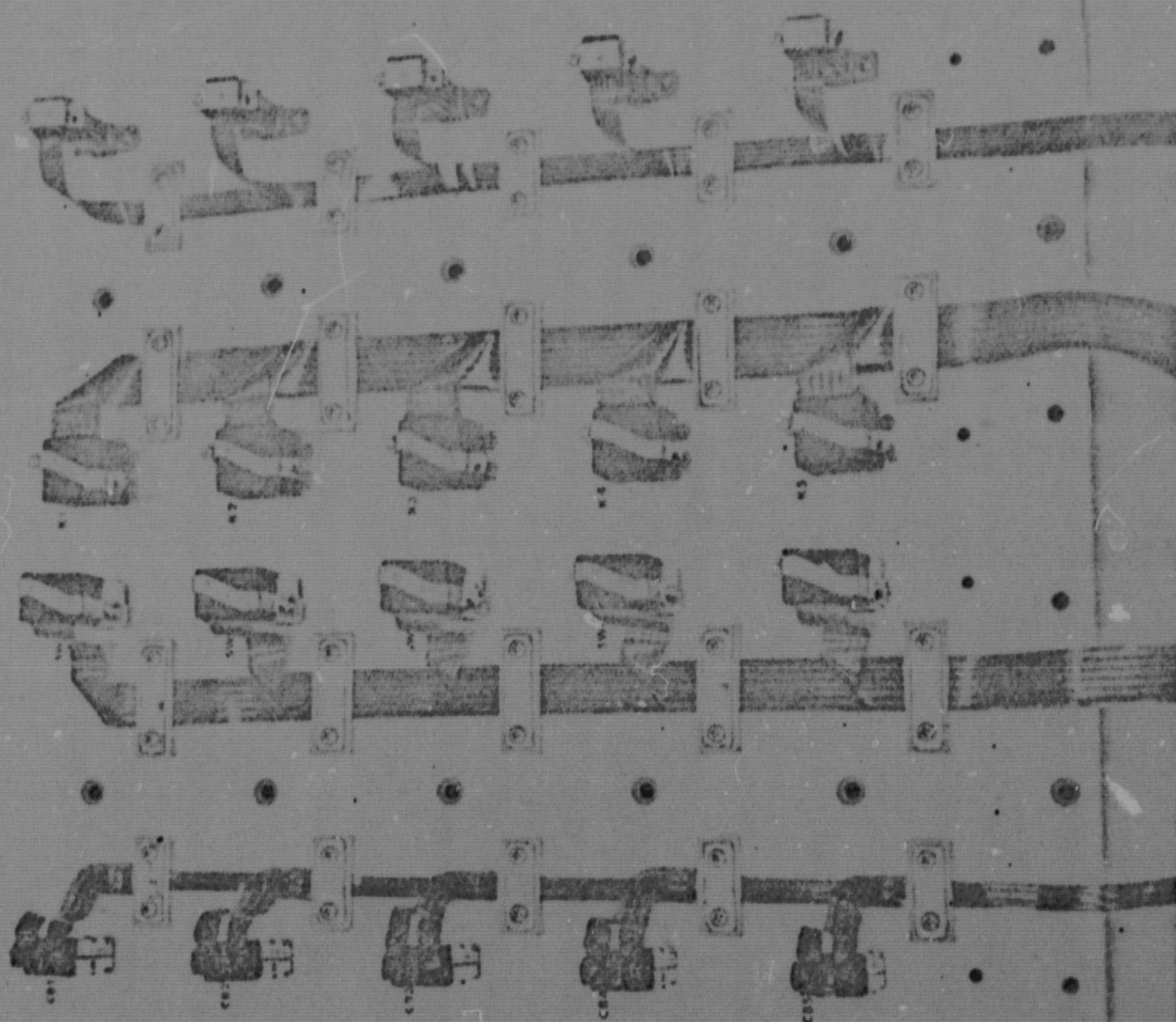


Figure 7. FCC/Component Termination Feasibility Models Mounted on Test Panel

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would be molded in epoxy resin. In addition, it may prove advantageous to mold silicone rubber sleeves around the contacts to aid in contact alignment. The molded assembly would subsequently be covered with a polyimide varnish or laminated polyimide glass fabric housing. Another design consideration would be multi-section molded parts using a DAP or silicone-filled molding compound. These parts would be designed to allow for installation of the termination devices and subsequent assembly by bonding with room or low-temperature curing adhesives. The seals would be molded of silicone rubber or standard O-rings. The mating/unmating bracketry would be of corrosion-resistant steel (CRES) and attached to the header/adapter assembly at the time of molding or fabrication.

Table 1 summarizes the material usage for both program phases and lists candidate production materials.



Table 1. Material Summary

Material Usage	Phase I Prototypes	Phase II Prototypes for Test	Production Recommended Materials
Flat conductor cable	Mylar or Kapton film polyester adhesive, unplated copper conductors	Kapton film FEP (Teflon) bonded, unplated copper conductors	Kapton film FEP bonded, nickel-plated copper conductors
Component header modifications and FCC adapters	Clear epoxy potting resin	Laminated polyimide im- pregnated glass fabric housings, filled epoxy resin encapsulants, acrylic plastic (spring clip) retain- ing blocks	Laminated polyimide impregnated glass fabric housings encapsulated with filled epoxy resins. DAP or molded silicone rubber sections assem- bled after termination operations with epoxy phenolic adhesives
Conformal coating	None	RTV silicone rubber	Same as Phase II
Gaskets or seals	Flat silicone rubber die-cut seals, neo- prene rubber O-rings	RTV silicone rubber sealing gaskets, neo- prene rubber O-rings	Molded silicone rubber seals, gaskets and O-rings
Spring clip contacts	Beryllium copper strip. (annealed)	Same as Phase I with the addition of gold plating	Same as Phase II
Locking devices	None	Corrosion-resistant steel (CRES) screws and cad- mium plated steel floating nut plates	CRES spring-type latch, threaded fastener or cam actuated design accept- able for flight operation including shock, vibra- tion, and environmental sealing
Brackets	CRES	Nickel-plated beryllium copper strip (annealed)	Same as Phase II or CRES



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FEASIBILITY MODEL DEVELOPMENT

ETCHED FLEXIBLE CIRCUITRY (EFC)

EFC was chosen for use in the pin and socket termination designs to minimize height and weight of the finished assembly. Its use in conjunction with modified MIL-C-38999 contacts afforded a lower profile than was possible utilizing RCC. A major problem in the use of EFC to replace RCC was in obtaining a conductor which would have a current-carrying capacity equivalent to that of the component being utilized (10 amps). Normally, EFC is fabricated using one, two, or three mils thick conductor material. Use of a three-mil material for 20 gauge RC equivalent would require a conductor width of 0.268 inches or greater. In the intended application, this would negate any advantage of EFC over RCC due to the increase in the overall width of the EFC. In order to minimize the width of the EFC and still maintain 20 gauge RC equivalent conductors, the EFC was fabricated with 16 ounce copper (0.0216 inches thick). The use of material this thick for EFC posed the fabrication problem of minimizing conductor undercut during etching to allow minimum spacing between circuits. Another related problem was identified during assembly of the component header and adapter terminations when the thickness of the EFC circuitry caused it to lift from the Kapton/FEP backing during the folding operation.

Somewhat similar problems were encountered in fabrication of the EFC for use in termination to the circuit breakers, but were minimized by the use of 7-mil-thick copper. This conductor configuration (0.114-inch width) resulted in a more flexible EFC, but created a much greater cable width which was acceptable because of the circuit breaker header configuration. Details of how these problems were resolved are contained in the Manufacturing Processes Section of this report.

CONTACTS

A spring clip contact design was incorporated into the FCC adapters for toggle switches because of its ability to mate to the existing flattened and pierced header terminals. The only modifications made to the switch terminals were to align and chamfer the flattened portion and fill the pierced portion of the terminals to assure mateability with the clip contacts. In production, the switches could readily be obtained in the modified configuration from the supplier. Beryllium copper was selected for the contact material because of its combination of good workability in the fully annealed



condition, good physical characteristics after heat treatment, and electrical conductivity. Gold flash over a nickel underplate was used because of its demonstrated suitability as a contact plating system.

MIL-C-38999 pin and socket contacts (20 gauge) were selected for use in the relay and event indicator termination designs because of a shorter overall mated length as compared with that of other 20 gauge contacts with known history and proven reliability. Contact length was reduced by terminating the contact directly to EFC, thereby allowing removal of the major portion of the crimp barrels.

HOUSINGS

The use of polyimide-impregnated glass fabric for housings on component header and FCC adapters offered the combination of high strength and minimum weight in a material suitable for use in Apollo environments.

MOISTURE SEALS

The exposed terminal area of the EFC to circuit breaker attachment was conformally coated with an RTV silicone rubber using the same materials and processes currently used on Apollo.

The seals chosen for the relay and event indicator header/adaptor interfaces were molded RTV silicone rubber gaskets. The gaskets are installed in the component header half of the termination interface. Their design incorporates both the peripheral and individual contact seal features proven reliable in the NAS 1599 connector series used extensively on Apollo.

O-rings were used as seals on the spring clip FCC adapter to toggle switch interface. An O-ring was installed over each of the switch terminal standoffs. Neoprene rubber was used as the O-ring material because of availability, although a silicone or fluorosilicone rubber would be proposed for production use.

ATTACHMENT METHODS

A series of candidate attachment methods for mating FCC adapters to component headers are shown in Figure 8. For simplicity of fabrication, the feasibility test models utilized the jack screw-type of mechanism. It consisted of metal bracketry riveted to the FCC adapter polyimide/glass housings incorporating jack screws that mate to nut plates that were riveted to the polyimide/glass housings on the modified relay and indicator housings and to metal brackets on the switches.



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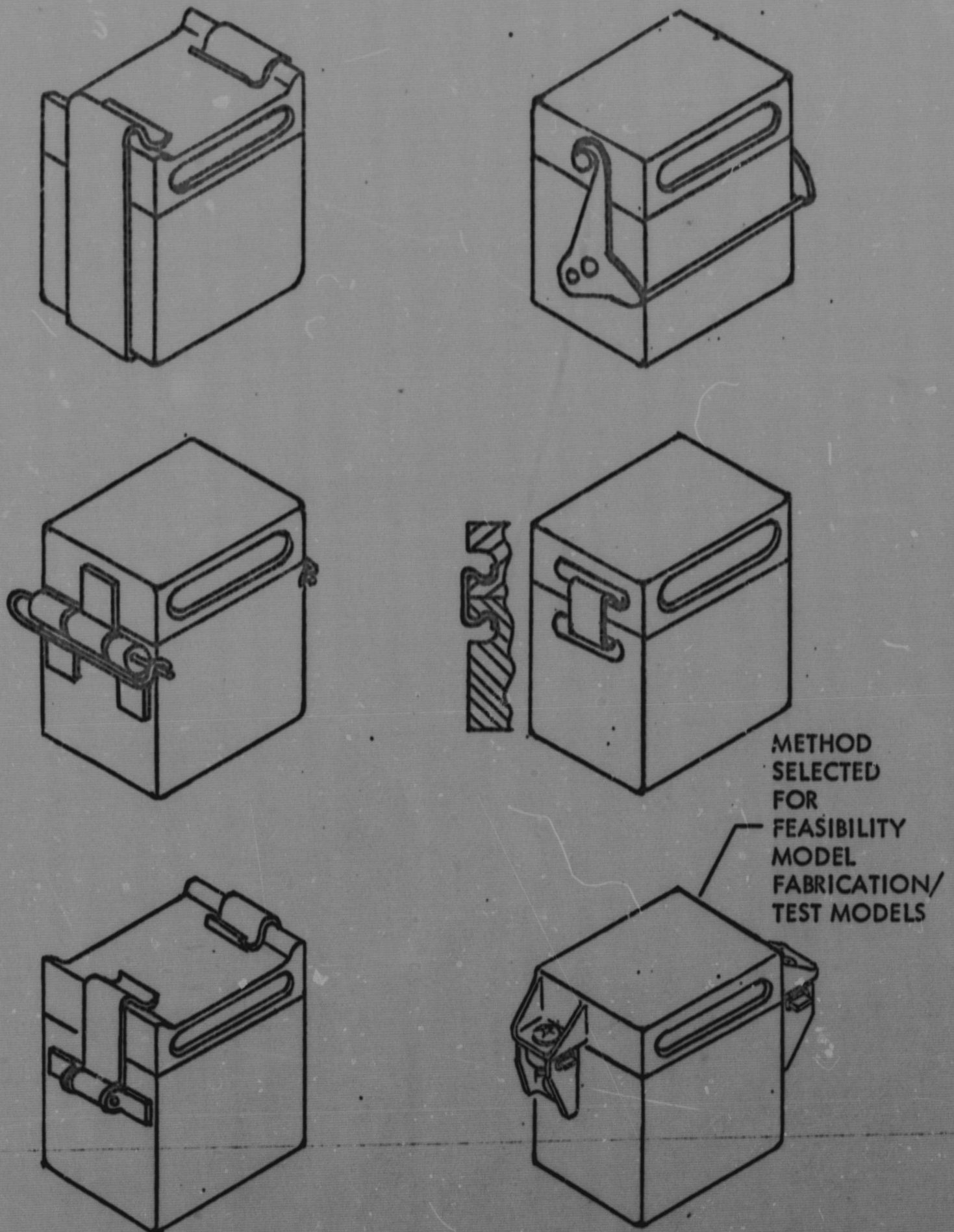


Figure 8. FCC Adapter Attachment Methods

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WEIGHT DATA

The use of the proposed method of terminating FCC/EFC to circuit breakers resulted in a small weight saving over the present RCC termination technique. The saving (approximately 4 grams per component) resulted primarily from deletion of two ring-tongue terminals and the use of FCC instead of RCC.

Weight of the soft-termination techniques that were developed for the other components are understandably somewhat higher than existing RCC hard-termination techniques. The FCC/event indicator feasibility model termination showed a weight increase of approximately 16 grams (30 percent) over the existing RCC method. The FCC/switch termination weight increase was approximately 26 grams (30 percent) over the existing method, and the FCC/relay termination was approximately 22 grams (10 percent) more in weight than the RCC hard-termination technique now used. Weight of the FCC soft-termination concepts utilized on the feasibility models compare favorably with known methods of soft-termination of RCC to similar components, such as use of sealed terminal junction feedthrough modules as component headers. These FCC soft-termination techniques would result in a nominal total vehicle weight increase (approximately 25 pounds on a vehicle such as Apollo). In addition, the inherent weight advantage of FCC as compared to RCC (the ability to use smaller gauge FCC) and special (shorter) pin and socket contacts would appreciably reduce the present FCC termination profiles and weights.

TRADEOFF STUDY

The fact that terminal spacing, height, and configuration of existing component headers do not lend themselves to FCC termination dictates that header modification or redesign be considered. Since the components currently in use on D&C panels involve numerous suppliers, header changes at the supplier level may be prohibitive from a procurement lead-time standpoint. The alternative then, was to develop methods of adapting existing component headers to make them compatible with hard or soft termination of FCC. The termination concepts chosen for the feasibility study (fabrication and test) can be utilized in conjunction with component redesign at the supplier level or by modification to existing component headers at the user level. Component header modification by the supplier would seem to offer the most practical approach to FCC/component termination on a production basis and would lower component cost, eliminate intermediate terminations, reduce handling and testing of components, and result in lighter weight.



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MANUFACTURING FABRICATION TECHNIQUES

The NR Advanced Manufacturing Development Department provided manufacturing support for the development of FCC terminations at electrical components.

During Phase I of the contract, numerous experiments were performed in order to establish suitable processing techniques.

In the Phase II effort the feasibility models were fabricated as proposed in the Phase I report with the exception of the use of an FCC/EFC transition for the circuit breaker wiring as opposed to a single length of EFC as proposed in SD 70-304.

TOOLING

The tooling concepts were selected based upon the limited number of hardware end items, tolerance requirements, and ease of processing. Engineering drawings and sketches were used to generate tool drawings and develop fabrication processes.

Male-type molds for polyimide housings (relay and indicator headers) were machined from aluminum and used as layup and curing tools. These were stick-type molds which permitted layup and cure of long pieces of polyimide which were subsequently cut to length and dressed. The relay and indicator adaptor polyimide housings were closed-end type and were fabricated individually.

Templates were made for use in sizing and forming of the beryllium copper sheet metal brackets.

Two-piece plexiglas dies were machined for molding of the silicone seals for the relays and indicators.

Close tolerance match-drilled, multi-purpose tools were made for relay and indicator buildup. The adapter encapsulation tools were made of teflon. The header encapsulation tools (two piece) consisted of a teflon body with an aluminum backing plate which contained steel pins for positioning the socket contacts.



A multi-pin removable forming die provided a step-by-step folding sequence of the beryllium copper spring clip contacts for the switch adapter. A heat treat fixture for the switch contacts secured the formed beryllium copper during the heat treat operation.

FABRICATION

EFC and FCC

The circuit breaker EFC was fabricated in short lengths, the ends were subsequently stripped of insulation, and a five-foot length of two conductor FCC (equivalent AWG 20) was resistance spot-welded to the EFC conductors. The EFC/FCC splice was then insulated with Kapton type F film consisting of 2-mil thick Kapton with a 2-mil FEP backing.

The experimental EFC for the relay posed a problem due to the thickness (0.0216 inch) of the 16-ounce sheet copper circuitry. Since insulation (Kapton/FEP) was required on only one side of the circuitry, the individual circuit conductors lifted off during folding of the EFC. This problem was resolved by treating the sheet copper with an oxide conversion coating to enhance the Kapton/FEP to copper bond. The use of immersion etch methods of the 16-ounce copper proved unsatisfactory, resulting in extreme undercut of the circuitry. A suitable etch factor was obtained through use of a special etchant in conjunction with a vertical spray etch technique.

Two types of FCC were procured and used to terminate to the Phase II feasibility models. The 20 gauge cables contained twelve unplated 0.007- by 0.114-inch copper conductors. The 25 gauge cables consisted of nine unplated 0.004- by 0.062-inch copper conductors. The required number of conductors for each component was slit out of the cable, and the insulation for each cable was stripped mechanically. The bare conductors of each cable were then tinned using an immersion tinning solution and then subjected to a physical examination and electrical test.

Polyimide Housing

The polyimide material was cut to proper size and formed over the tool allowing excess material on the "trim end" of the adapter housings. After curing, the housings were removed from the tooling and trimmed to length and slit where necessary for FCC ingress.

Sealing Gaskets

RTV silicone rubber was prepared for fabrication of sealing gaskets using mixing ratios recommended by the manufacturer. The mixture was



poured in the female portion of the seal mold and the top cover indexed and clamped into position and subjected to a two-hour precure. Subsequently, each seal was removed from the mold, placed on a clean aluminum tray, and given a 24-hour final cure cycle.

Component Brackets and Spring Clip Contacts

Beryllium copper sheet in the annealed condition was cut and formed to make brackets for the indicators, relays, and switches. The switch spring clip contacts were cut into strips and formed on the multi-pin forming die. Final length trimming was accomplished after forming. All the brackets and contacts were heat-treated at 600 F for 3 hours and, subsequently, nickel-plated (approximately 500 micro-inches). A gold flash of approximately 100 micro-inches was applied over the nickel plate on the spring clip contacts.

Component Test Panel

A piece of 2024-T3 aluminum alloy sheet was sized and cutouts made to accept the switch, relay, circuit breaker, and event indicator components. The bare panel was anodized after masking off specific areas for electrical grounding.

Switch Spring Clip Contact Retainer Assembly

The gold-plated beryllium copper switch spring clip contacts were placed in the contact retainer blocks and aligned. The mating surfaces of the blocks were then coated with a bonding agent and sealed together. A small amount of epoxy was used to effect a seal between the clip contacts and the retainer blocks. The assembly was checked for possible encapsulant leakage by placing distilled water in the recess around the clip contact.

FCC to Switch Adapter Contact Termination

The exposed surfaces of the assembled clip contacts were tinned and the FCC conductor ends positioned vertically above the contacts and soldered to the tinned contact surfaces. Some folding of FCC conductors was required to assure proper alignment and to permit the cable to protrude through the adapter housing when installed prior to encapsulation. All operations occurring after the contact retainer blocks were sealed were accomplished with the retainer assembly mated to the switch terminals.



Component Header, EFC/Pin Contact Assembly

The relay and event indicator header EFC was positioned on the shortened component terminals and soldered in place. The EFC was then folded up 90 degrees on either side and the modified pin contacts placed in a teflon tool, positioned with respect to the EFC and then butt-soldered in place. After all contacts were terminated to the EFC, the folding was completed and contacts checked for alignment.

FCC Adapter, EFC/Socket Contact Assembly

The relay and event indicator backing plate tools containing steel pins and the teflon encapsulation tool were indexed together and the socket contacts engaged to the steel pins. The adapter EFC was positioned relative to the contacts and butt soldered in place. The EFC was then aligned to the FCC and soldered. The FCC was then threaded through the polyimide housing and retained for subsequent encapsulation.

Relay Solder Temperature Test

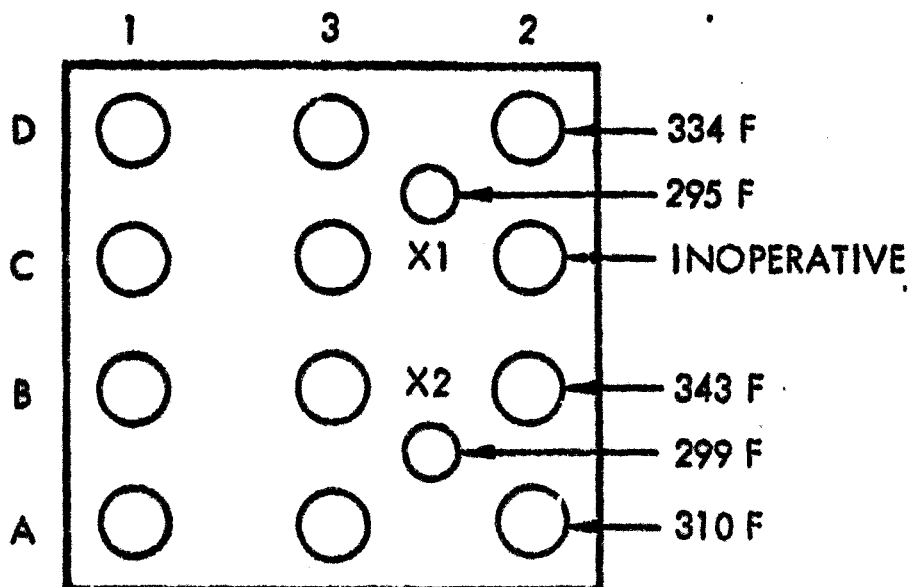
In order to maintain a low profile on the modified relay headers, the hook-type terminals were cut down to a height of 0.050 inches. This process, however resulted in removal of most of the heat dissipating surface of the terminal. Since some of the relay terminals are terminated internally with a solder that exhibits a melt temperature of 430 F, a solder temperature rise test was performed on a representative relay to assess the effects of soldering the EFC to the shortened terminals. The relay was disassembled, and thermocouples were installed at relay internal solder joints corresponding to terminals X1, X2, A2, B2, C2, and D2. (See Figure 9.) The relay was then reassembled and the thermocouple wires brought out through a small hole in the case.

The first test of the relay configuration was to tin the individual terminals using 60/40 alloy solder. The sequence used was to tin the internally riveted terminals and then the internally soldered terminals to allow maximum heat buildup (worst-case condition). During the tinning operation, the dwell time on each terminal was 2 to 3 seconds with minimum delay from one terminal to the next. (See Figure 9.) Subsequently, a relay header EFC was positioned and soldered to the instrumented relay terminals in the same sequence that the terminal tinning was accomplished.

Dwell times during the EFC to relay terminal solder operation varied (the soldering iron was removed when it was evident that an electrical connection had been made). It appears that the EFC conductors provided some additional area for heat dissipation during soldering. (See Figure 10.)

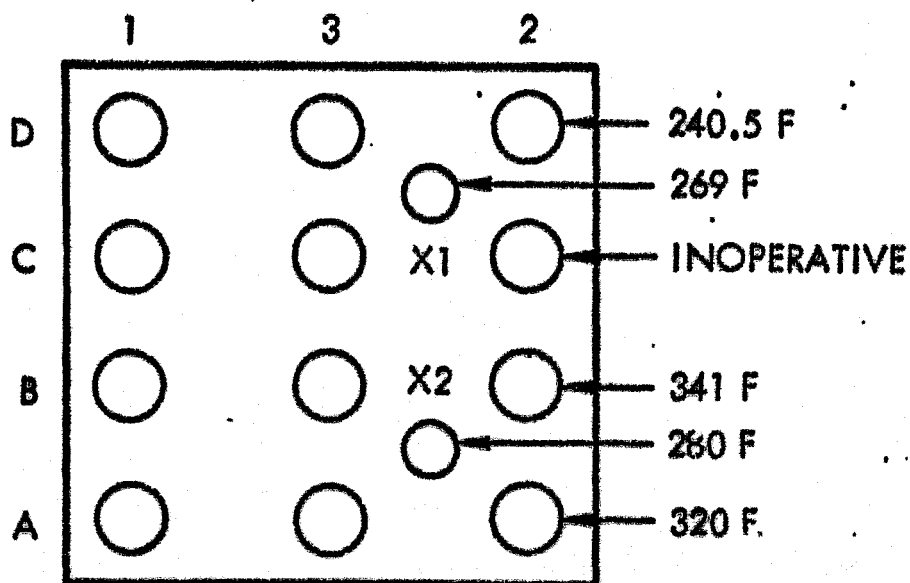


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VIEW, TERMINAL
SIDE OF RELAY

Figure 9. Relay Terminal Tinning Instrumented Relay



VIEW, TERMINAL
SIDE OF RELAY

NOTES - IN FIGURES 9 AND 10 THE FOLLOWING SOLDERING
SEQUENCE WAS OBSERVED:

A1, B1, C1, D1, A3, B3, C3, D3, X2, X1, A2, B2,
C2 AND D2

Figure 10. EFC Soldering Operation Instrumented Relay



After each test, a continuity check was made on the test relay, and the internal solder joints were visually inspected after EFC soldering. No defects were encountered.

It was determined that strict procedures for soldering the EFC to the shortened relay terminals would reduce the temperatures at the internal relay connections. Dwell time at each terminal was minimized, and a 15-second delay between terminations was effected. This approach was used successfully on assembly of feasibility test components.

ASSOCIATED ACTIVITY

The Advanced Manufacturing Development Department (AMDD) had been conducting internal research and development effort in the area of FCC preparation and termination. Data obtained from this parallel activity were quite valuable in resolving some of the problems encountered. For example, the splice welding of the circuit breaker EFC to FCC and its reinsulation process was based upon recent research into maintenance and repair of FCC.

The AMDD supplied sophisticated equipment items to accomplish the FCC stripping, slitting, soldering, and welding. Research is currently in progress on a limited basis utilizing this and other equipment to further the state of the art on such FCC fabrication processes; e. g., stripping Kapton insulations utilizing laser techniques. This effort will include "spot stripping" for individual FCC conductor repair or splicing.



FEASIBILITY MODEL TEST PROGRAM

The test program was divided into two sections—acceptance tests and development tests. The acceptance tests were performed upon all (40) feasibility models during, or at completion of, model fabrication. Development tests were then conducted upon 20 of the models to verify the feasibility of the termination concepts selected.

ACCEPTANCE TESTS

Test Objective

The acceptance tests were performed on all feasibility models to verify electrical integrity.

Test Procedures

The acceptance tests included the following:

1. Component Examination and Identification. Laboratories and Test personnel visually examined each component, header, FCC adapter (switches, indicators, and relays, and circuit breakers, for evidence of contamination or damage. Each component was identified numerically to aid in recording of test data.
2. Dielectric Withstanding Voltage (DWV). A DWV test was run on each component (except event indicators), header assembly, and FCC adapter assembly with a test voltage of 375 vdc.
3. Insulation Resistance (IR). IR tests were run on each component, header assembly, and FCC adapter assembly. Test voltages were as follows:

Relays	500 vdc (component and component/header assembly)
Switches	100 vdc
Circuit breakers	500 vdc
Indicators	50 vdc (component and component/header assembly)
Adapter assemblies	500 vdc



4. Contact Voltage Drop (CVD). A contact voltage drop test was run on each component, except the indicators, (after terminal modification on relays and switches) with a voltage of 28 vdc and a current load of 3 amperes.
5. Special Operational Test. A special test was performed on the event indicators only, since the internal circuitry would be damaged by standard test voltages and currents. The test consisted of insulation resistance tests at 50 vdc between all contacts and the case and a functional test to verify that the indicator operated in accordance with design requirements.

DEVELOPMENT TESTS

The primary test objective was to demonstrate that the structural and functional integrity of the test specimen terminations would not be degraded by exposure to specified dynamic, thermal, and climatic environments. The main criteria used to evaluate the electrical characteristics of the specimen terminations included dielectric withstanding voltage, insulation resistance, contact voltage drop, and discontinuity monitoring tests.

Twenty feasibility models (five each of the relays, toggle switches, circuit breakers, and event indicators) were mounted on an aluminum panel (approximately 22 inches by 23 inches by 1/8 inch) to facilitate environmental testing. The component panel-mounting hardware was torqued per applicable specifications prior to environmental exposure. The FCC was supported and clamped to the panel surface during component installation. Round wire was soldered to the FCC harness to provide a simplified interface with the test control panel. (Refer to Figure 7 for physical configuration of the test panel.)

Test Procedure

A detailed test procedure was prepared by Laboratories and Test personnel in accordance with Engineering requirements. An electrical test control panel was fabricated and wired to facilitate performance testing during development tests. The development tests were performed in the following sequence:

1. Initial specimen examination. Before development testing began, the test specimens and panel were visually examined to detect and correct any detrimental defects or discrepancies.



2. Performance test. A complete performance test was performed on the test panel.
 - a. Dielectric withstanding voltage test, with a voltage of 375 vdc on all relays, switches, and circuit breakers.
 - b. Insulation resistance, with test voltages of 500 vdc for relays and circuit breakers and 100 vdc for switches.
 - c. Contact voltage drop, with a test voltage of 28 vdc and a current load of 3 amperes on relays, switches, and circuit breakers.
 - d. A special operational test conducted on all indicators and consisted of insulation resistance test at a voltage of 50 vdc and a functional test to verify that the indicator operated satisfactorily.
3. Thermal (high/low temperature) test. Thermal (high/low temperature) test was performed on the test panel at 40 F for 48 hours and 150 F for 48 hours.
4. Random vibration. Random vibration test was performed on the test panel in each of the three orthogonal axes at the following levels:

Level 1: Acceleration spectral density increasing at a rate of 3 db/octave from 20 to 200 Hz; constant at $0.06 \text{ g}^2/\text{Hz}$ from 200 to 1200 Hz; decreasing at a rate of 3 db/octave from 1200 to 2000 Hz; 5.0 (+0.25, -0) minutes per axis.

Level 2: Acceleration spectral density increasing at a rate of 3 db/octave from 20 to 200 Hz; constant at $0.06 \text{ g}^2/\text{Hz}$ from 200 to 2000 Hz; 10.0 (+5, -0) seconds per axis.
5. Salt fog/humidity test. The test panel was subjected to a one-hour salt fog test at 95 F in a 5-percent salt solution and to a humidity test for 72 hours with the temperature cycling between 60 and 125 F in a relative humidity of 95 percent.
6. Final complete performance test. Final complete performance test was performed to the same requirements as the initial complete performance test.



7. Final specimen examination. Final specimen examination was performed to note and analyze the effects of the development test on the specimen.
8. Data review. The test data were reviewed in order to arrive at conclusions and to make recommendations.

DEVELOPMENT TEST DETAILS

The feasibility model development tests were conducted by Laboratories and Test and monitored throughout by Design Engineering. The test panel with 20 feasibility models installed was turned over to L&T by Manufacturing and the following tests were conducted.

Initial Specimen Examination

A preliminary visual examination of the test specimen panel was conducted by Laboratories and Test and Engineering personnel to determine the functional/physical configuration and condition of the assembly before the start of environmental testing. All defects or discrepancies that were considered detrimental to the performance of the assembly during environmental exposure were corrected.

Initial Complete Performance Tests

A complete performance (electrical) test consisting of dielectric withstanding voltage, insulation resistance, contact voltage drop, and special operational checks for indicators was conducted on the 20 panel-mounted specimens with FCC adapters mated before any environmental exposure and after the completion of all environmental testing. IR and CVD tests were conducted after vibration testing, and IR tests were performed during humidity testing. A total of two DWV, seven IR, three CVD, and two special operational tests for indicators were performed during development testing.

CVD measurements made during the development testing included the total voltage drop in all of the related test specimen circuitry (FCC/EFC, component, test connections, etc.) in addition to the test setup wiring and control devices (switches, etc.). carrying the 3-ampere test load at 28 vdc. During acceptance testing, CVD included only the component contacts (3-ampere load). Thus, to maintain a continuity for correlation purposes, the same terminology (CVD) was used in both acceptance and development tests.



All performance test data and related information were recorded in the Laboratory Notebook, NR Laboratory Memorandum LR-7614-3801, and any test measurements greater or less than specified values were identified and tabulated to facilitate further analysis by Engineering.

Table 2 contains a summary of all test anomalies (vibration discontinuity in excess of 70 microseconds, IR readings below 10 megohms, DWV readings in excess of 2 milliamperes) occurring during development testing.

Table 2. Test Anomalies

Description	Rationale
All circuit breakers, CB1 through CB5, exhibited insulation resistance readings below 10 megohms during the 72-hour humidity test. The lowest reading was 4 megohms.	The readings are typical of values that have been experienced in previous tests on other programs with round conductors on similar circuit breakers and using identical materials and processes for conformal coating.
Relays K1, K3, and K5 exhibited insulation resistance readings below 10 megohms during the 72-hour humidity test. The lowest reading was 3 megohms at 200 vdc.	These relatively low values may be attributed to bonding techniques used for installation of sealing gaskets or possible quality deficiencies in the sealing gaskets. The gaskets use the same seal concept as commonly used throughout the connector industry and have been proven in previous tests on other programs. The more sophisticated tooling and improved bonding techniques that would be used on a production basis would eliminate these deficiencies.
Circuit breakers CB3 and CB4 and all relays, K1 through K5, exhibited discontinuities in excess of 70 microsecs during various phases of vibration tests. The discontinuities were randomly monitored with a storage oscilloscope and revealed a time duration ranging from 80 to 150 microsecs.	Since the examination of the test panel, hookup and test specimens, including the EFC/FCC weld joints and the connection of the EFC to the circuit breaker terminals, revealed no defects, it is surmised that the components were the contributing factor to the discontinuity. As previously noted, test model components used were non-flight (red painted) hardware, to minimize program hardware costs.



Table 2. Test Anomalies (Cont)

Description	Rationale
Relay K2 had a "short" condition between two adapter contacts, as described in the final specimen examination and data review section.	Electrical short between two adapter contacts resulted from inadequate space between EFC and contacts. Improved tooling and fabrication techniques would eliminate this condition.
Relay K4 indicated low IR readings (short condition) and excessive leakage current during final DWV test across contacts that should be open when coil is energized.	Blown (open) fuse in coil circuit on test setup panel. The fuse was replaced and the relay operated normally.
Relay K5 (same as K4 above).	Coil circuit determined to be open. The cause was suspected to be an overcurrent condition that occurred during the initial performance (electrical) test.
Chamber temperature controller stuck during humidity test, maintaining chamber temperature at 117 F for approximately 9 hours in lieu of decreasing to 60 F over a 10-hour period.	This out-of-profile condition is not considered significant to the overall humidity test, since the specimens did receive proper temperature cycling during the first and final 24-hour periods of test, and moisture was visible on the specimens throughout the test.

Thermal (Low/High Temperature) Test

After the completion of the initial complete performance test, the specimen panel assembly was transferred to the dynamics laboratory for random vibration exposure. However, because of schedule conflicts the test sequence was changed to authorize the performance of the thermal test prior to vibration exposure. The panel assembly was mounted in a horizontal position (with component wiring facing up) in the temperature chamber and subjected to the thermal test. The chamber temperature was decreased from room ambient to 40 ± 5 F at a rate no greater than 5 degrees per minute, and the chamber was maintained at this temperature for a minimum of 48 hours. The chamber temperature was increased to 150 ± 10 F at a rate no greater than 5 degrees per minute, and this temperature was maintained for a minimum of 48 hours. Subsequently, the chamber temperature



was decreased to room ambient conditions at a rate no greater than 5 degrees per minute. The post-thermal performance test was waived to expedite the starting of vibration testing. The panel was removed from the temperature chamber and transferred to the dynamics laboratory for vibration testing.

Random Vibration

A special dynamic test fixture was designed and fabricated to facilitate vibration testing. Special 1- by 3-inch spacer bars were used to suspend the test panel (FCC side facing up) three inches above the vibration fixture surface. All mounting bolts were properly torqued before each axis of vibration testing. One control and ten response accelerometers were used during vibration testing. The Apollo CSM Dynamics Group examined and approved the entire vibration test setup (including accelerometer types and locations). The overall vibration test setup included all of the necessary power, control, instrumentation, recording, and analyzing components.

After completion of the bare fixture equalization (Test Run 1) in the X (vertical) axis, the panel assembly was mounted on the vibration fixture for exposure to random vibration. The specimen assembly was subjected sequentially to the following levels of vibration in each of the three orthogonal axes:

Level 1. Acceleration spectral density increasing at a rate of 3 db/octave from 20 to 200 Hz; constant at $0.06 \text{ g}^2/\text{Hz}$ from 200 to 1200 Hz; decreasing at a rate of 3 db/octave from 1200 to 2000 Hz; 5.0 (+0.25, -0) minutes per axis.

Level 2. Acceleration spectral density increasing at a rate of 3 db/octave from 20 to 200 Hz; constant at $0.06 \text{ g}^2/\text{Hz}$ from 200 to 2000 Hz; 10.0 (+5, -0) seconds per axis.

Selected specimen circuitry was monitored for discontinuity in excess of 70 microseconds during all vibration tests. (See Table 2 for a summary of vibration test anomalies.) A total of 14 vibration test runs was required to complete vibration testing in three axes. The test panel was then transferred to the electrical laboratory to conduct the post-vibration performance tests (IR and CVD).

Salt Fog/Humidity Test

After the completion of the postvibration performance tests, the panel assembly was suspended in a horizontal position (with the FCC wiring facing up) inside the salt fog chamber to perform the one-hour salt fog test. A five-percent (by weight) salt solution was added, the chamber was closed, and the chamber temperature was increased to $95 \pm 5 \text{ F}$. To expedite starting the humidity test, the performance of the postsalt fog IR test in the salt fog chamber was waived, since the humidity test required an initial IR test.



The panel was installed in the temperature/humidity chamber in a horizontal position (with component wiring facing up) and exposed to a 72-hour humidity test. A deviation from the prescribed temperature profile occurred during the test when the temperature controller pointer "stuck" during temperature decrease and maintained the chamber temperature at approximately 117 F for about 9 hours, instead of decreasing to 60 F.

Four IR tests were performed during the humidity test. (See Table 2 for a summary of humidity test anomalies.)

Final Complete Performance Tests

A final complete performance test, defined by the initial complete performance test, was performed after completion of the environmental testing.

Final Specimen Examination

The panel was removed from the humidity chamber and transported to the electrical laboratory for the final examination and data review.

Since the circuit breakers exhibited IR readings below 10 megohms and CB3 and CB4 had discontinuities in excess of 70 microseconds during vibration, the conformal coating was visually examined and no defects were observed. The conformal coating on CB3 and CB4 was carefully removed from the terminal connections, which were found to be tight (lockwashers fully locked). CB3 EFC/FCC welded splice insulation was peeled back to expose the weld joints, which were found to be intact. All other circuit breaker EFC/FCC welded splices were examined. CB2 and CB4 exhibited slight delamination of Kapton insulation over the weld joints; however, this did not extend to the copper conductors. There was no evidence of corrosion or faulty weld joints on any of the EFC/FCC welded splices.

All component adapters were unmated and visually examined, and no defects were observed, with the exception of minor discoloration on some contacts, which was considered insignificant. (See Table 2 for a summary of all test anomalies.)

Data Review

A review of the data for the three CVD tests did not indicate any definite trend or effect that could be interpreted as a permanent degradation of component circuitry due to environmental exposure. The CVD values for the initial and final performance tests did not vary appreciably for any of the components (considering the usual test variables that normally affect such measurements). Since the CVD readings obtained during environmental



testing also represent the summation of the voltage drops of the test setup and the specimen circuitry elements as previously identified, it is logical to conclude that the actual CVD across the header/adaptor assembly is within a value range compatible with existing electrical design requirements.

The test data indicate that the current leakage values obtained during the initial and the final DWV tests were less than two milliamperes for all components tested, except the circuitry for relays K2 and K5. Subsequently, it was determined that the continuity between relay K2, terminals B2 and C2, was caused by D2 and D3 (unwired) contacts in the adapter shorting to the EFC for adapter contacts C2 and B2, respectively. Continuity between B2 and C2 was completed through the normally closed contacts D2 and D3 and inside the relay when the coil was deenergized. The same electrical test had been performed separately on the K2 adapter and header/relay units during the acceptance testing, but the "short" condition (as explained above) will not appear unless the FCC/adaptor is mated to the header/relay unit. It was also determined that the coil circuitry inside the K5 relay/header assembly was open. After vibration exposure, relay K5 could not be energized because of this open-circuit condition. The defects in K2 and K5 affected both IR and DWV testing.



PAGE 34 MISSING

CONCLUSIONS AND RECOMMENDATIONS

EXISTING COMPONENT HEADER DESIGNS

As previously documented in the Phase I, concept development report (NR SD 70-304, dated 15 April 1970), most existing small electrical components are designed for termination with round conductor cable (RCC). The header configurations utilize terminal designs, such as hook, eyelet, flattened and pierced, turret, bifurcated, wire well, etc., suitable for use with RC solder techniques, or screw-type terminations for use with RC crimp or solder type terminal lugs. In many instances, the heights of the terminals are staggered to assist in RC termination, and odd center-to-center spacings are employed since multi-conductor RCC usually has any common insulation removed and the individual conductors routed to the termination points. One of the prime features of FCC is the added strength offered in small-gauge configurations in which the conductors are retained within a common insulation, and component headers should be designed to allow FCC conductors to be terminated while maintaining their common insulation. For example, the header on the existing toggle switches could be redesigned to incorporate butt-type solder terminals which would be staggered in a pattern to allow six conductor FCC to be terminated by spot removal of insulation on each conductor. This header redesign could be accomplished within the existing header envelope dimensions, although other components might require a complete header redesign. However, in most instances this would not mean increasing overall size or weight. Component header redesign to utilize "soft termination" techniques, however, would result in increased envelope and weight, although this same increase would be involved whether FCC or RCC were soft-terminated.

As discussed in the tradeoff study section of this report, it appears more practical to redesign component headers at the supplier level rather than modify components at the user level on a production program, unless the usage is too small to warrant the supplier change.

This program has verified that both "hard" and "soft" termination of FCC to existing small electrical components can be accomplished reliably, but that large scale usage of FCC would probably merit component header redesign.



ADDITIONAL TERMINATION CONCEPTS

As previously noted in the Phase I report, other termination concepts were evaluated in addition to those selected for test. Two of these concepts warrant further consideration but were not pursued in this program because of a lack of a suitable connector (receptacle) for mating to existing, or proposed, FCC-type (plug) connecting devices.

One method of termination is the modular concept, wherein groups of components would be terminated to a rigid PCB. The board would have circuit patterns to allow the existing component headers (with modified terminals) to terminate directly to the PCB. The board would also contain a circuit pattern for termination to an FCC receptacle. The module would have each component partially encapsulated to offer environmental integrity and component support. The FCC cables would be soft-terminated to the module through use of a mating connector (plug) similar to MIL-C-55544/5 or /7 (see Figure 11). This concept would eliminate the need for individual soft-termination devices at each component. The modular concept also lends itself to use of RC ribbon cable, which could be terminated to a number of existing RCC receptacles suitable for use with PCB's; then the ribbon cable could be converted to FCC through the use of MIL-C-55544 type connectors.

The second termination concept is the one in which each component would be redesigned by the supplier or modified by the user to accommodate a light-weight receptacle/adaptor which would mate with a standard-type FCC plug similar to MIL-C-55544/5 or /7 (see Figure 12). The receptacle/adaptor assembly would be an integral part of the component, and the contact members would be formed from the FCC conductors, thus eliminating additional solder or weld joints. It is envisioned that this concept could be developed to reduce the overall height increase on the component to 1/2-inch or less, with weight factors approaching closer to the present RCC/solder/conformal coat system than the systems tested in this program.

Both of these concepts offer promise for termination of FCC to small electrical components but require development or availability of a suitable series of FCC connecting devices not known to exist at this time.

Some preliminary design effort has been completed toward development of FCC connecting devices that would utilize the FCC conductor as the contact member in one or both halves of the connector (see Figures 13, 14, and 15) and be suitable for use with the above termination concepts. Further development effort in this area would enhance the use of FCC and minimize the problems presently associated with its termination and interconnection, where modification of existing components is dictated by their termination to FCC.

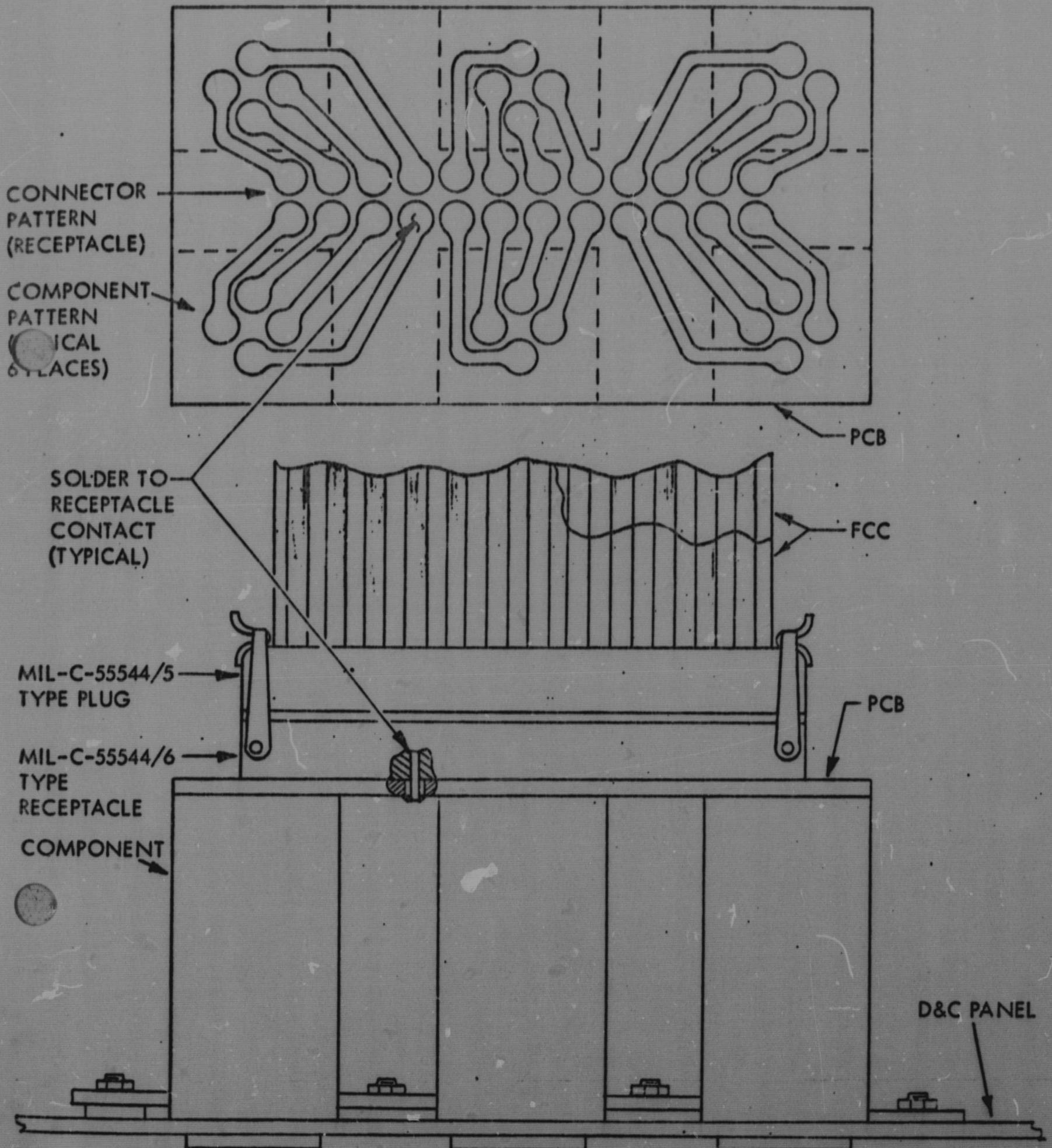


Figure 11. Modular Concept; FCC Terminated to MIL-C-55544 Type Connector; Connector and Components Terminated to PCB

NOT TO SCALE



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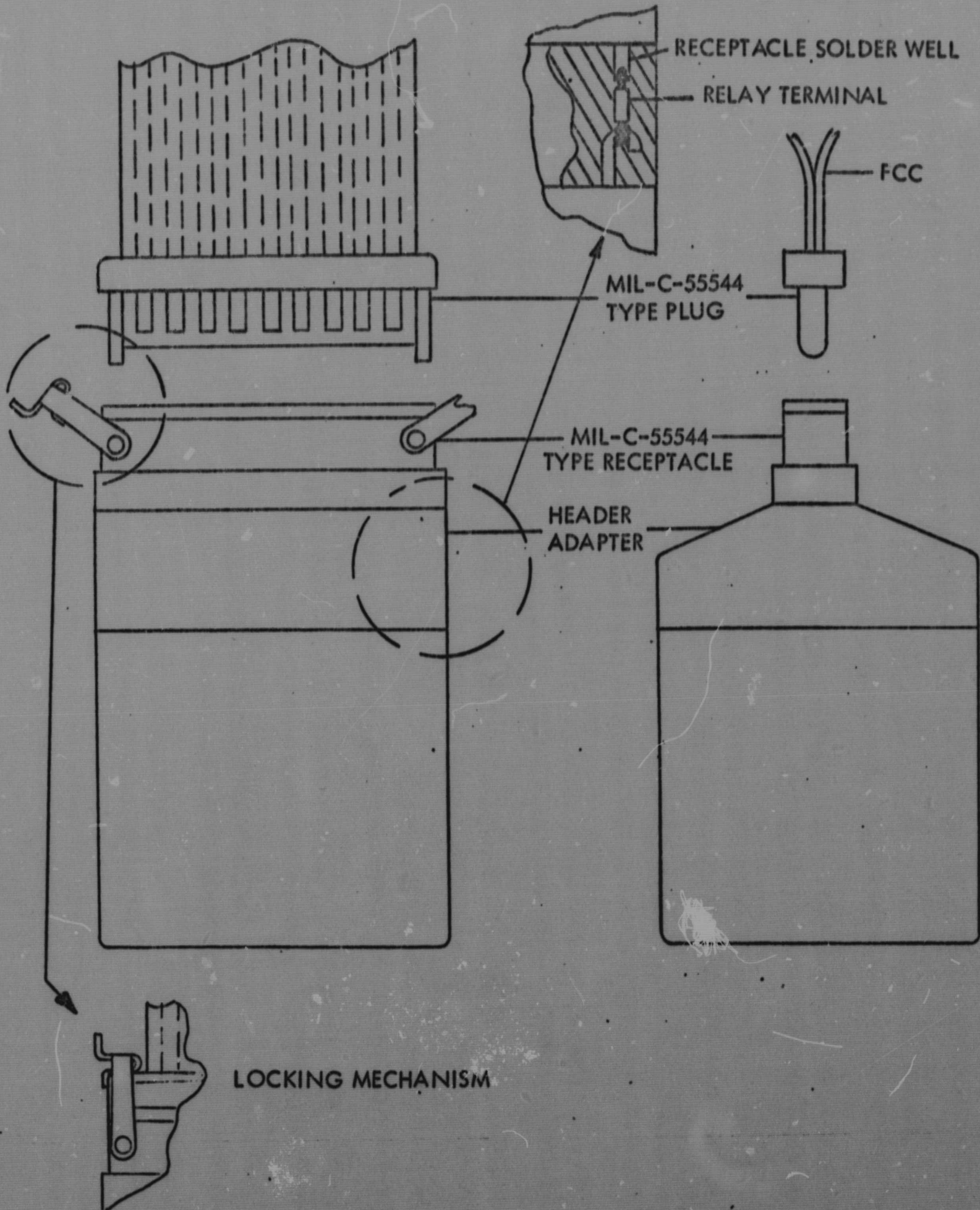


Figure 12. FCC Termination to Component Through Use of MIL-C-55544 Type Connector Assembly

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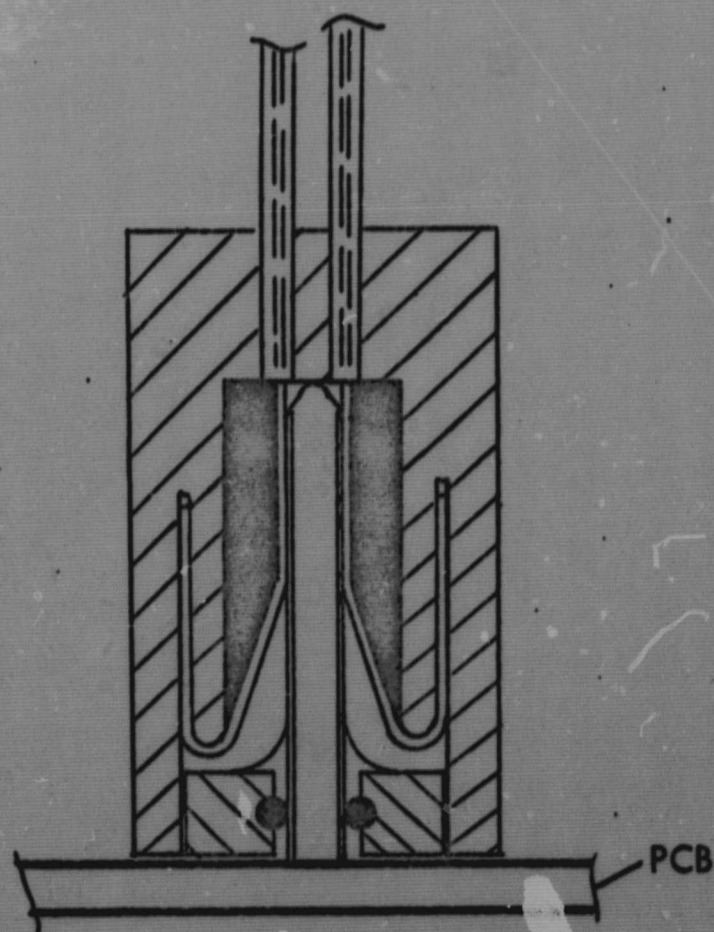
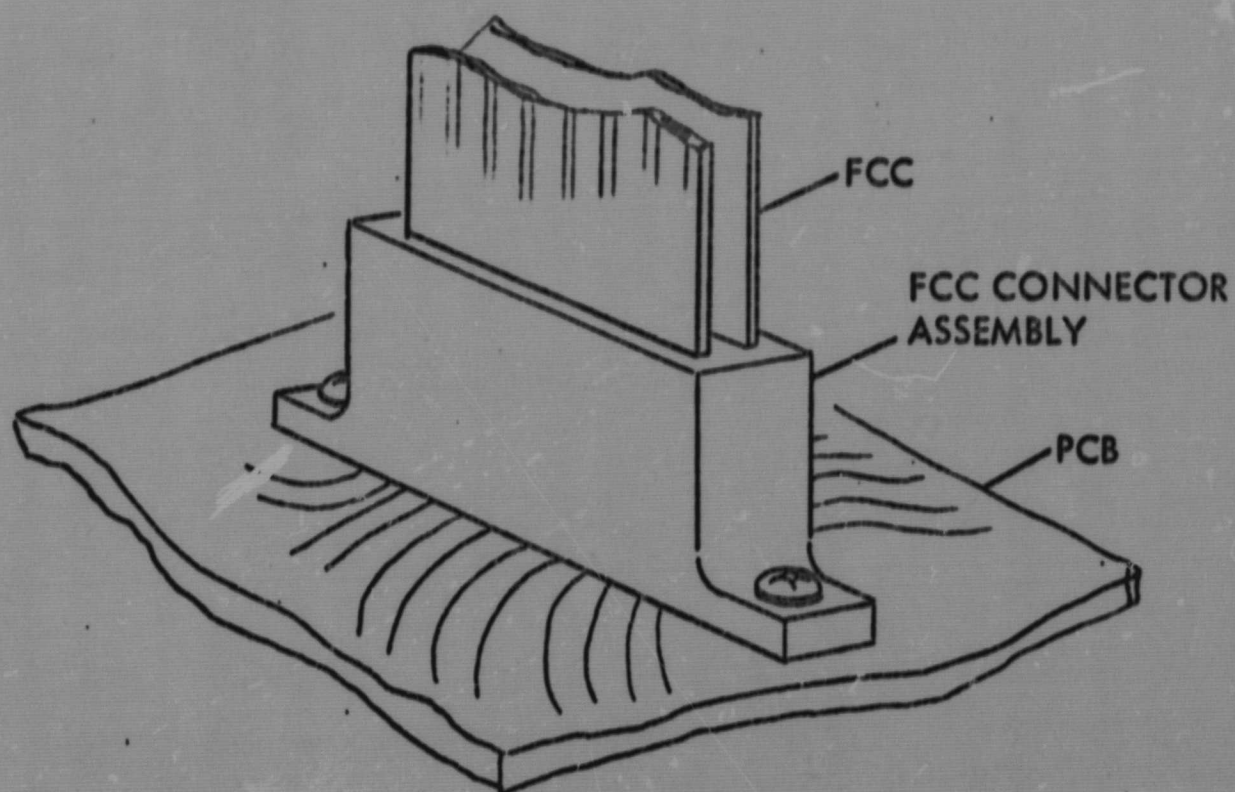


Figure 13. Design Concept for Termination of FCC to PCB



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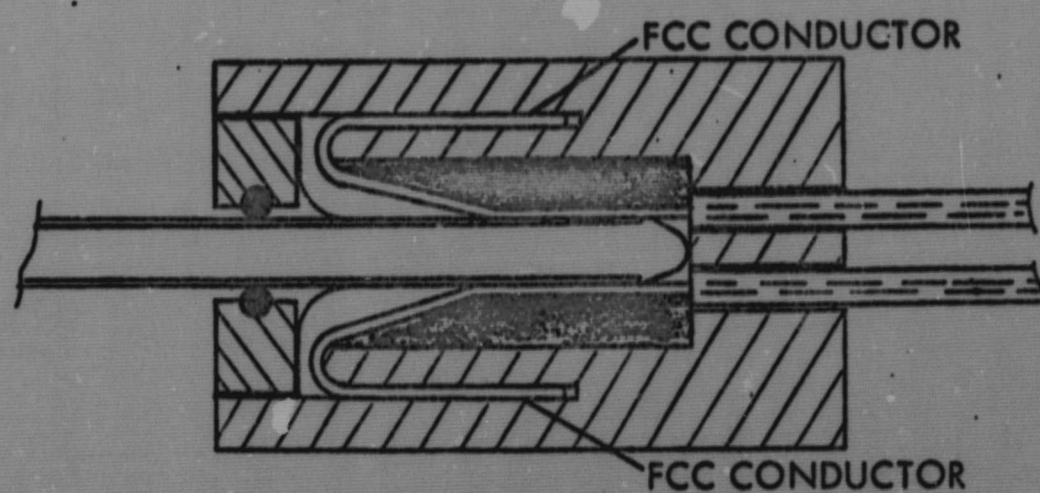
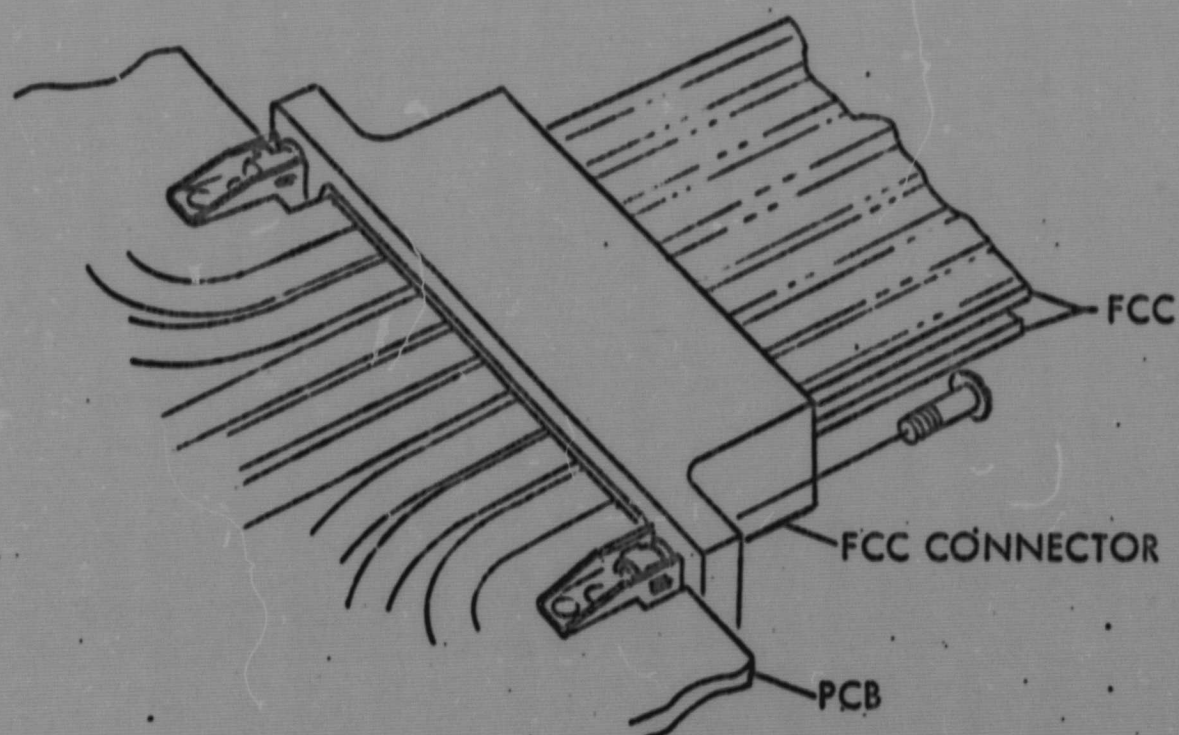


Figure 14. Design Concept for Termination of FCC to PCB

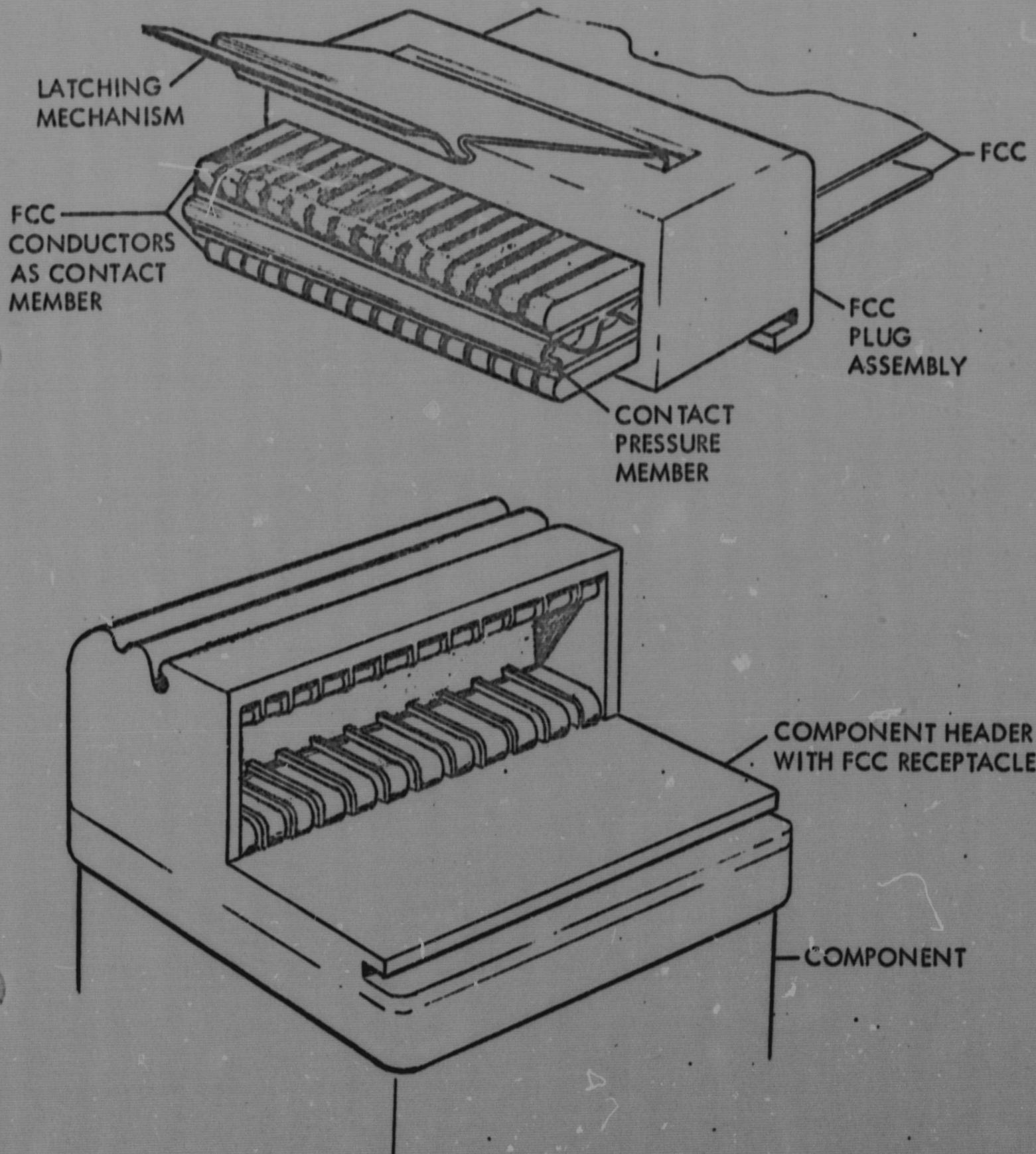


Figure 15. Design Concept for Termination of FCC to Electrical Component



RELATED RESEARCH AND DEVELOPMENT

As more consideration is given to the use of FCC as replacement for RCC in space vehicle applications, it becomes necessary to analyze the impact to both Engineering and Manufacturing that may occur through the use of FCC. Research of existing application data for FCC indicates a need for an accelerated development program aimed at eliminating apparent gaps in FCC process and application technology.

Work conducted by NR Space Division in the development of termination techniques for FCC to small electrical components has generated a concurrent effort in acquiring knowledge in the areas of FCC preparation, i. e., cutting, stripping, slotting, etc. Technology in these aspects of FCC applications have received more attention from industry, since all usage of FCC requires cable preparation prior to termination.

The lack of adequate FCC assembly and installation technology and the limited number of FCC connecting devices available was again made apparent when NR Space Division submitted a proposal on the use of FCC in large solar cell arrays. The scarcity of suitable connecting devices and of assembly and installation technology for space vehicle applications led NR Space Division to determine the items requiring further development before it is deemed feasible to phase FCC into space vehicle harness applications. These items are listed as follows, not necessarily in any order of priority.

1. Establish meaningful data on relating the current/temperature characteristics of RCC to FCC in space environments. A prime advantage of FCC to replace RCC in space vehicle applications is in the use of FCC constructions with smaller gauges where the RCC gauges are being dictated by strength rather than current-carrying requirements. This requires the development of FCC current/temperature data that can be correlated to the existing RCC data available such as that used on the Apollo Program. Since this is one of the early decisions that must be made by Engineering, this type of data must be established at the beginning of a program.
2. Develop a wire data system adaptable to both RCC and FCC. An automated data system compatible to both RCC and FCC would be preferable and must be instituted early in the program at the engineering level.



3. Develop FCC preparation, assembly and installation processes, and associated specifications. This would include processes for stripping of insulation; slitting of conductors from basic cable; termination, assembly, and installation, including such items as foldover of multi-layered cables, breakouts, clamping and/or other retention techniques, etc. Associated specifications would include such items as FCC identification techniques, acceptance test methods, harness fabrication and installation, and electrical test methods.
4. Compare cost of FCC versus RCC as related to low-volume production programs, such as space station or shuttle, where a limited number of vehicles will be fabricated. The study would include cost comparison of the following:
 - a. RCC/FCC wire data systems
 - b. Additional training of personnel
 - c. Special tooling requirements
 - d. Material (cable, termination devices, clamps, junctions, etc.)
 - e. Development of fabrication and installation processes.
 - f. Special test equipment.
5. Develop a series of FCC-to-FCC/RCC connecting devices with environmental capabilities including moisture and humidity. The problem of a lack of suitable FCC connecting devices with environmental capability is one which is cited in many articles on use of FCC. It is likely that the lack of a firm market for this hardware has caused a wait-and-see attitude on the part of connector suppliers. It is felt that development of suitable hardware is dependent on furnishing the supplier with either some firm requirements or designs which have been proven suitable for future applications. It is safe to predict a favorable reaction from the connector industry to any new developments that offer FCC connecting devices with proven environmental capability.
6. Develop processes and techniques for repair and rework of FCC using materials compatible with spacecraft environments. As FCC is integrated into spacecraft usage, it will be necessary to learn more about the techniques for rework and repair, since the existing RCC methods will no longer be applicable.



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7. Establish the EMI capabilities of, and requirements for, the use of FCC and evaluate the capability of existing configurations. The problems of EMI protection for FCC is an important one, although most of the footage of wire and cable used on Apollo consists of nonshielded constructions. Existing data on the EMI characteristics of FCC indicate it to be superior to the corresponding RCC configurations, but the extent of EMI protection necessary will be dependent upon system requirements and vehicle configuration.



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ENCLOSURES

E2C-954170	Modification Requirements for FCC Adaptation, Components
E2C-954180	Modification Requirements for FCC Adaptation, Pin and Socket
E2C-954152	Etched Flexible Circuit, Component Side, FCC Adapter
E2C-954151	Etched Flexible Circuit, Harness Side, FCC Adapter
E2C-954160	Gasket Seal, Electrical Components, FCC Adapter
E2C-954210	Assembly, Relay/FCC Adapter
E2C-954211	Connector Assembly, Relay FCC Adapter
E2C-954212	Header Assembly, Relay, FCC Adapter
E2C-954200	Assembly, Indicator/FCC Adapter
E2C-954201	Connector Assembly, Indicator FCC Adapter
E2C-954202	Header Assembly, Indicator FCC Adapter
E2C-954150	Etched Flexible Circuit, Circuit Breaker
E2C-954100	Assembly, Switch/FCC Adapter
E2C-954101	FCC Adapter Assembly, Switch
E2C-954103	Modification Requirements for FCC Adaptation of Switch
E2C-954104	Electrical Contact, FCC Adapter, Switch
E2C-954300	FCC Termination Test Panel