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FLAT CONDUCTOR CABLE CONNECTORS WITH INDIVIDUALLY SEALED CONTACTS

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16. ABSTRACT

The report contains information on the latest NASA/MSFC flat conductor cable connectors, a series with individually sealed contacts. Data and artwork are concerned with connector historical development, design requirements, design description, and test and cost data.

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INTRODUCTION

TECHNICAL MEMORANDUM X-64695

FLAT CONDUCTOR CABLE CONNECTORS WITH INDIVIDUALLY SEALED CONTACTS

SECTION I. INTRODUCTION

Purpose

This document presents data on a new series of NASA/MSFC flat conductor cable (FCC) connectors with individually sealed contacts, a family now entering the first stage of production. The series, designed to meet or exceed MIL-C-55544, will enable FCC to round wire, FCC to FCC, and FCC to PC board connections. A photo of the FCC to round wire connector is shown in Figure 1.

The development of connectors with individually sealed contacts is a continuation of NASA/MSFC's efforts to produce reliable FCC hardware capable of meeting any system requirement, using the method of cable termination in which conductors become contact surfaces. Increased attention in recent years by both the Government and industry may soon eliminate the problem of obtaining suitable hardware for a particular FCC system and, by so doing, result in more widespread application of FCC technology.

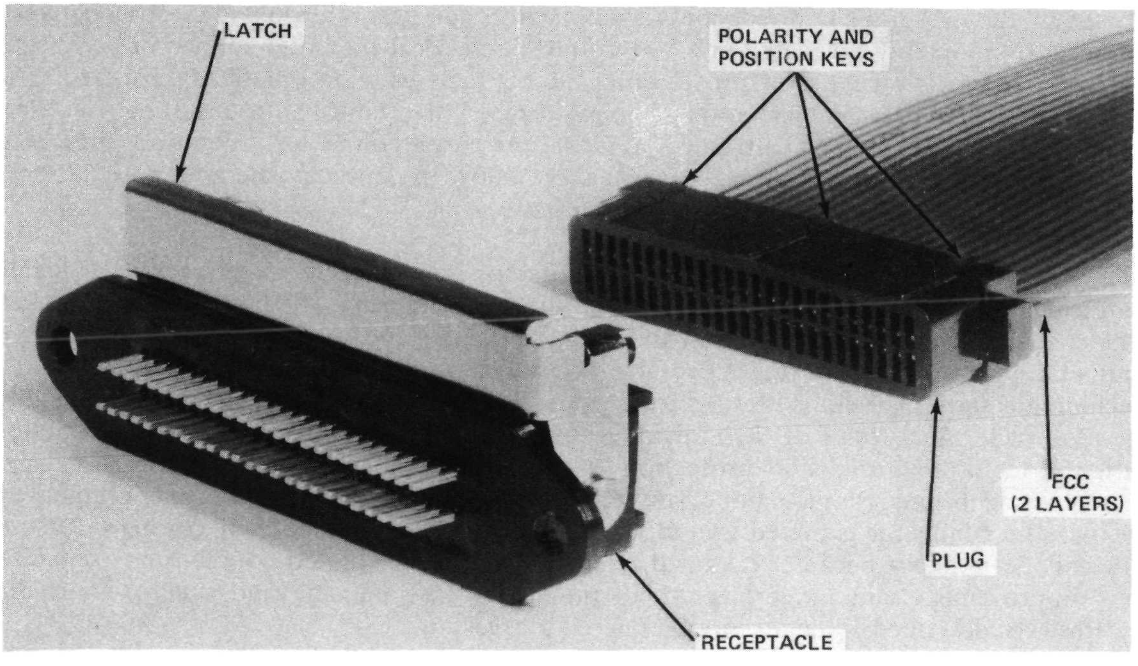

Figure 1. FCC to round wire cable connector with individually sealed contacts, unmated view (prototype).

NASA/MSFC's Connector Design Approach

While the connector industry, with few exceptions, has followed principles of round wire connector design, NASA/MSFC has been using an entirely different approach. Industry usually terminates a flat cable by adding contact pins or bushings to the flat conductors by soldering, crimping, or welding. NASA uses the cable conductor as a contact surface. Advantages have been noted for each method of conductor termination. For example, some companies claim to produce highly reliable connections without the need for cable stripping, and further claim that welded-through-plastic connections are sealed as a result of the displaced insulation, and thus have added insulation protection. On the other hand, although the NASA/MSFC FCC termination does require cable stripping, studies which have compared this type connector with others have repeatedly shown higher connector reliability, lower volume, lower weight, and lower costs. A typical figure is the 0.15 gram weight per contact of a completed FCC termination.

Main Features of the New Connector Series

Although the new series incorporates many proven features of earlier NASA/MSFC connectors, including use of cable conductors as contacts, extensive improvements have resulted in a drastically different and highly advanced design. Perhaps the single most significant feature is a system of individual contact seals designed to eliminate arcing over or electrical leakage between neighboring contacts under any environmental condition, including high altitudes (or low pressures).

In the earlier FCC direct-contact connectors, air was the only dielectric between contacts. Consequently, if mated in a moist atmosphere, or if the outer connector peripheral seal was broken allowing moisture to enter, all contacts were automatically affected. The voltage gradients between all contacts might exceed the limit, with resulting electrical leakage. In addition, high altitude (or low pressure) connector operation presented potentially severe problems of electrical leakage between contacts where air was the only separating dielectric (described by the Paschen Law).

In the latest NASA/MSFC FCC connector series, each plug-receptacle mated contact pair is completely enclosed in a solid dielectric housing which separates it from all other pairs. This sealing occurs when the plug, containing recessed and individually housed contacts, is pressed against the receptacle interfacial seal. It is maintained at all altitudes (including a state of vacuum) by a strong over-center safety latch which secures the plug to the receptacle. As a result of the individual solid dielectric contact housings, in conjunction with the latch, environmental protection is increased and arcing over or electrical leakage between neighboring contacts under any environmental condition is practically eliminated. Even if the connector is mated in a moist atmosphere, the possibility of corona occurring will still be unlikely because a solid dielectric always keeps mated contact pairs separate. This improvement and numerous others (including cost-reducing and quality-improving features) are described in detail in the following pages.

Report Format

Descriptive material is presented in the following manner. A brief history of the evolution of this newest family of NASA/MSFC connectors is given, including a description of "key" connector advancements. This is followed by a summary of requirements met by the new design, a detailed design description of each of the three connectors, cost comparisons, and information on connector testing. Detailed contact calculations and data on connector materials are contained in several appendices. For a comprehensive study of FCC technology, the reader is invited to obtain documents listed in the bibliography.

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SECTION II

HISTORY OF NASA/MSFC FCC CONNECTOR DEVELOPMENT

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SECTION II. HISTORY OF NASA/MSFC FCC CONNECTOR DEVELOPMENT

The new NASA/MSFC design for FCC connectors with individually sealed contacts can be viewed both as a logical extension of past achievements and as a totally new concept in FCC connectors. The following brief history of development portrays the evolution of this series.

Short Printed Cable with Eyelet Terminals

Development of continuous, flexible FCC was a natural outgrowth of printed circuit technology. While rigid printed circuits were being used to replace wiring of electronic components, short flexible printed circuits with eyelet terminals were being used for interconnective wiring within boxes. The concept of flat conductor "printed cable" primarily for exterior connections from or between component boxes was the next logical step. Actually, these first 1.2-m (4-ft), photoengraved cables (Fig. 2) of 1957, and their method of soldered eyelet termination, more closely resembled flexible printed circuits than the FCC systems of today.

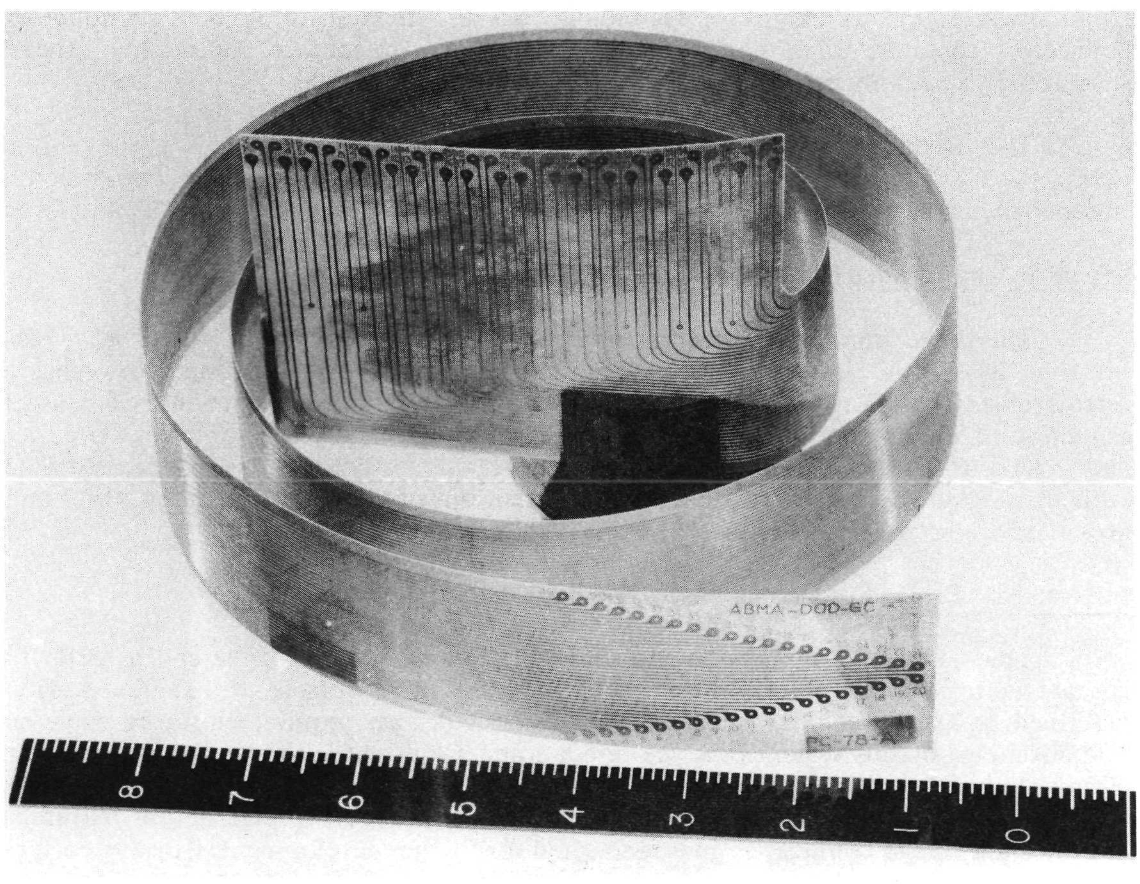


Figure 2. Printed cable 1.2 m (4 ft) long with 40 lines, 0.05-cm (0.020-in.) wide on 0.1-cm (0.040-in.) centers, and terminals at both ends.

Continuous Printed Cable for Use with Connectors

To obtain a product longer than 36 cm (14 in.), a limit imposed by the available camera equipment, a step by step process was used. A group of employees of the Guidance and Control Laboratory of the Army Ballistic Missile Agency at Redstone Arsenal, Alabama, now part of Marshall Space Flight Center, used a step and repeat method to produce the first flat conductor cables. This was rather tedious and new processes and equipment had to be developed. One way was continuous photoprinting of copper-clad phenolic strips with subsequent development and etching. Another method involved printing acid-resist wax lines on a copper-clad tape, removing unwanted copper by acid etching and then laminating a top film for insulation. Although both processes found limited application due to cost and, more especially, due to lack of a flat cable market at that time, they marked the beginning of continuous flat conductor cable production. With the elimination of eyelet terminals, the need for cable termination and connection hardware became readily apparent.

Early Connector Development

Principal features desired in the new connector included a low uniform contact resistance, low volume and weight, and, most important, a high degree of reliability. A major breakthrough in connector technology was the decision to use cable conductors as connector contacts, thus eliminating the conductor-to-contact joints and, thereby, substantially increasing reliability.

The original connector designs (all the "feed-through receptacle" type) initiated within the Guidance and Control Laboratory in 1957 can be grouped into two basic types of separable connectors.

Direct or Face-to-Face Contact

This type connector permits insertion of the cable without force, after which pressure is applied to provide electrical contact and cable retention. No cable end reinforcement (plug) is required. The greatest advantage for using face-to-face contact is reduction of the number of contacts from at least two to one. Connector types "H-2," "G," and "MA" in Figures 3, 4, and 5 employ the face-to-face contact design. Major problems with these connectors were the inability to obtain uniformly low contact resistance and to avoid leakage between the contacts in a moist atmosphere.

Intermediate Bridge Contact

This connector requires an insertion force applied to the cable end to deflect the contact springs during insertion of the cable into the receptacle. Unlike the previously described design, most intermediate bridge contact designs require reinforced cable ends. The advantage of this system over the direct contact method is the wiping action (contact cleaning) during cable insertion. Type "M" shown in Figure 6 is an intermediate bridge contact connector. Primarily because of the highly desirable wiping action feature, the intermediate bridge contact design was selected for further development. However, after the first handmade sample connectors were tested, development effort was discontinued because of the complexity of the principle and the lack of environmental protection. Conceptual work continued.

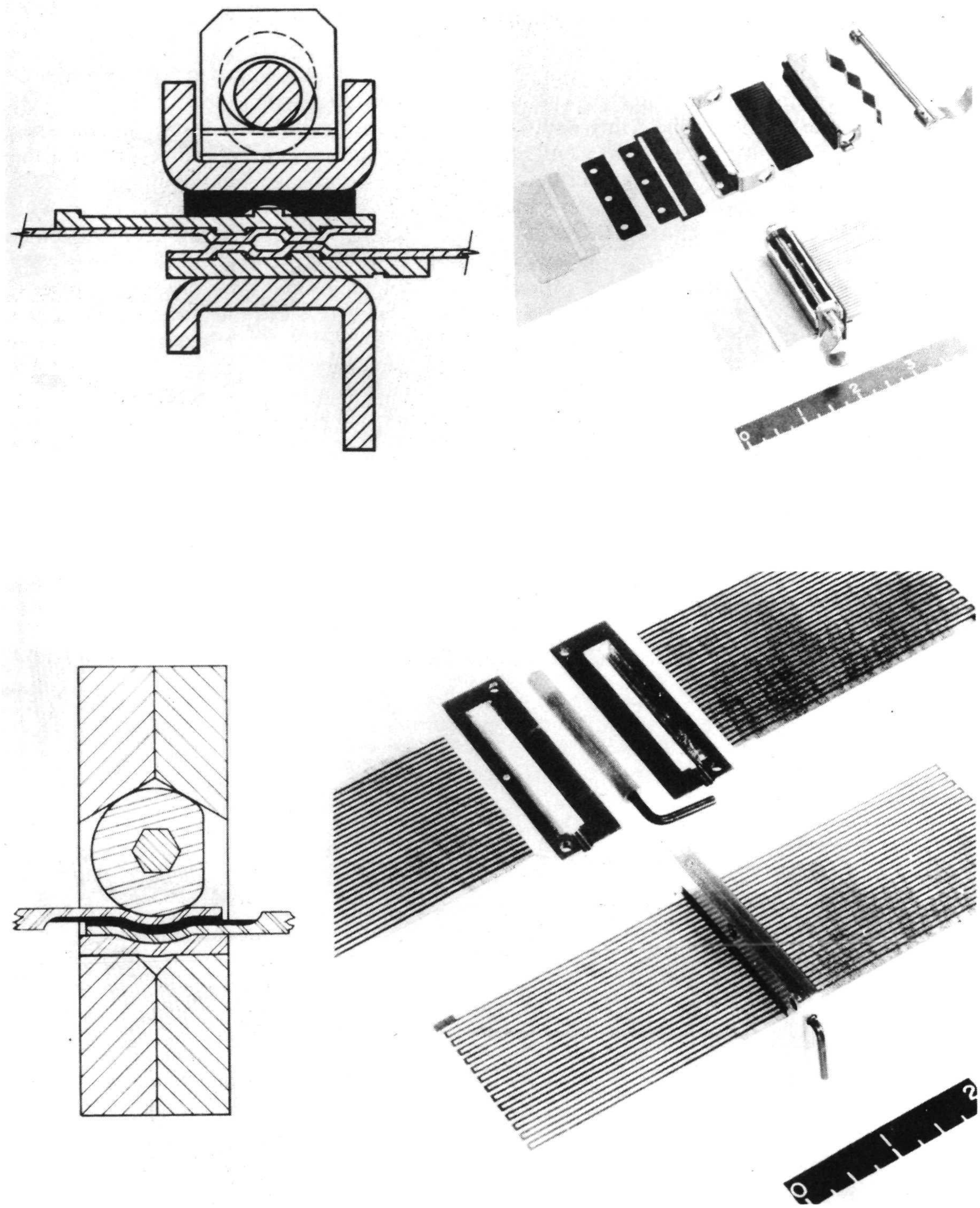


Figure 4. Direct contact connector, Type "G."

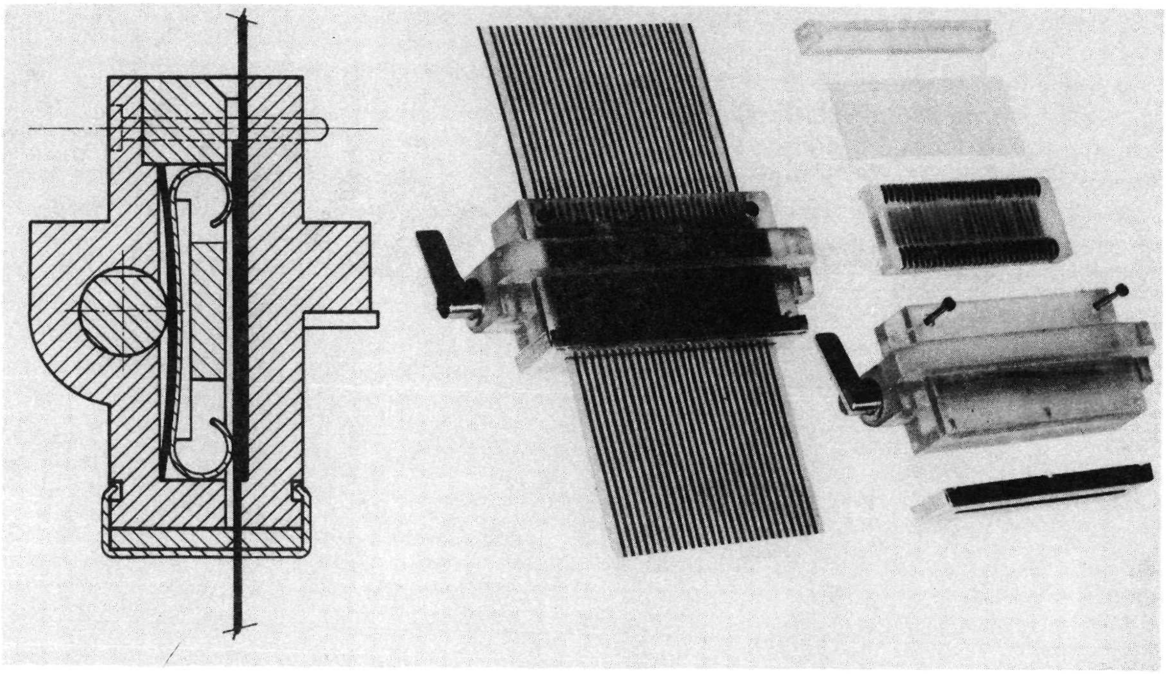


Figure 5. Direct contact connector, Type "MA."

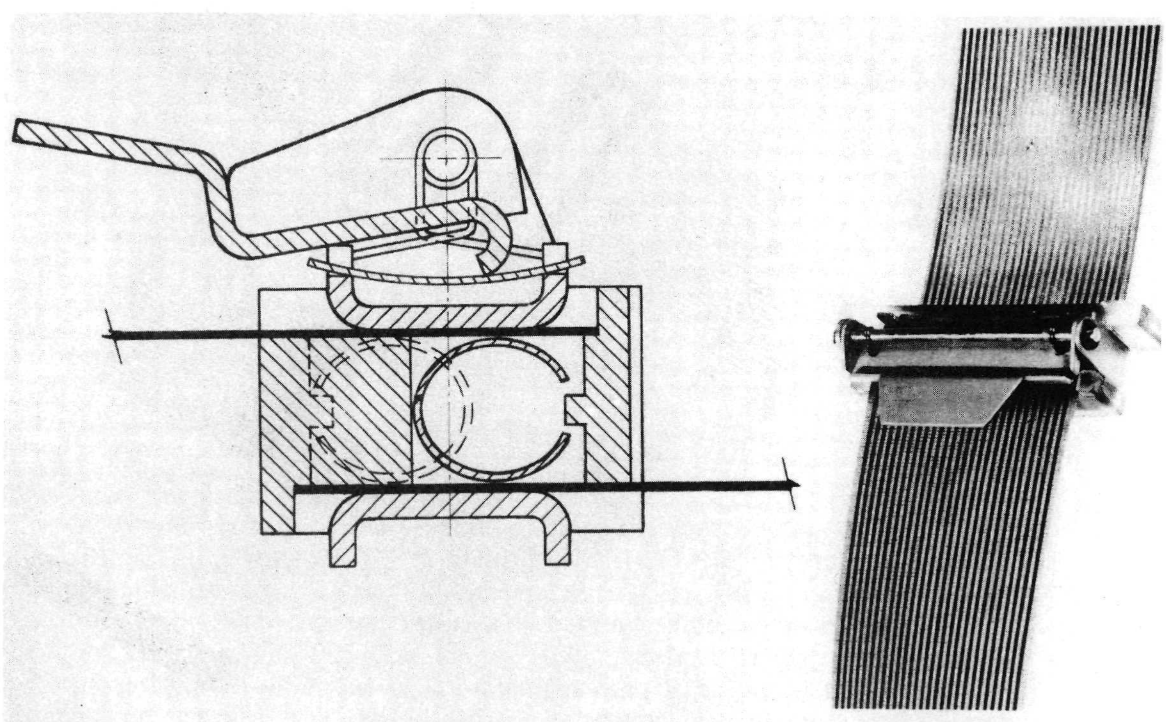


Figure 6. Intermediate bridge contact connector, Type "M."

Connector Standardization

Parallel to cable and connector development within MSFC, private industry was being encouraged to develop FCC systems. All of these combined efforts, with the resulting varieties in design, demonstrated that standardization must be established for optimum progress, economy, and usefulness of the new FCC technology. Therefore, specifications were drawn up in 1959 and 1960, with the first MSFC FCC connector specification approved in 1962, and designated as MSFC-SPEC-219, Connectors, Flat Conductor, Flexible Electrical Cable. In 1966, this was superceded by the current MSFC-SPEC-219A, and in 1968 a military specification was approved and designated as MIL-C-55544, Connectors, Electrical, Environmental Resistant, Flat Conductor Cable and Round Wire, General Specification for. In addition to connector specifications, cable specifications (MIL-C-55543) were also being designed and approved during this same time period.

First Qualified Series of NASA FCC Connectors

The first series of NASA FCC connectors, which is currently in use, was developed from those earlier described prototypes in which an intermediate spring contact served as a bridge between cable conductor-contacts. Three basic types of connections are possible with this series: (1) FCC to FCC, (2) FCC to printed circuit or flexible circuit, and (3) FCC to round wire cable. Widths of flat cable which can be used with these connectors are 0.6 cm (0.25 in.), and 1.3 cm to 7.6 cm (0.5 in. to 3 in.) in 1.3-cm (0.5-in.) increments. Cable can be used in either one or two layers. Connectors are designed to meet or exceed MIL-C-55544.

Plugs

Plugs molded onto the cable and others consisting totally of premolded components are available for cable ranging from 2.5 to 7.6 cm (1 to 3 in.) in width. The plug that is molded onto the FCC, as shown in Figures 7 and 8, consists of a window piece, conductor spacer, insulator, outer peripheral seal, potting and molded portion that integrates all components and adds such features as a conductor numbering flange and mating keys. Premolded plugs differ from the above primarily in that all parts are molded prior to assembly. Plugs for 0.6- and 1.3-cm (0.25- and 0.5-in.) FCC are similar to the plugs for the wider cable but have in addition an outer cylindrical metal shell and a coupling ring.

Receptacles

Two basic types of receptacles have been developed and manufactured (Figs. 9 and 10). The first type, plug-to-plug, is for connecting two flat conductor cables or an FCC with a printed circuit board. The second receptacle designed for FCC to round wire connections, has solder lugs for attaching round wires. Contact springs for these receptacles are contained in an insert made from high-grade dielectric material. Inserts are sealed around the contact springs to prevent moisture penetration and placed in an aluminum housing [cylindrical for 0.6- and 1.3-cm (0.25- and 0.5-in.) FCC, rectangular for 2.5- to 7.6-cm (1- to 3-in.) cable] for environmental protection. A gasket serves as a seal between the receptacle housing and the black box or bulkhead. Latching clips (four per FCC-to-FCC receptacles and two per FCC-to-round-wire receptacles) securely hold plugs and receptacles together.

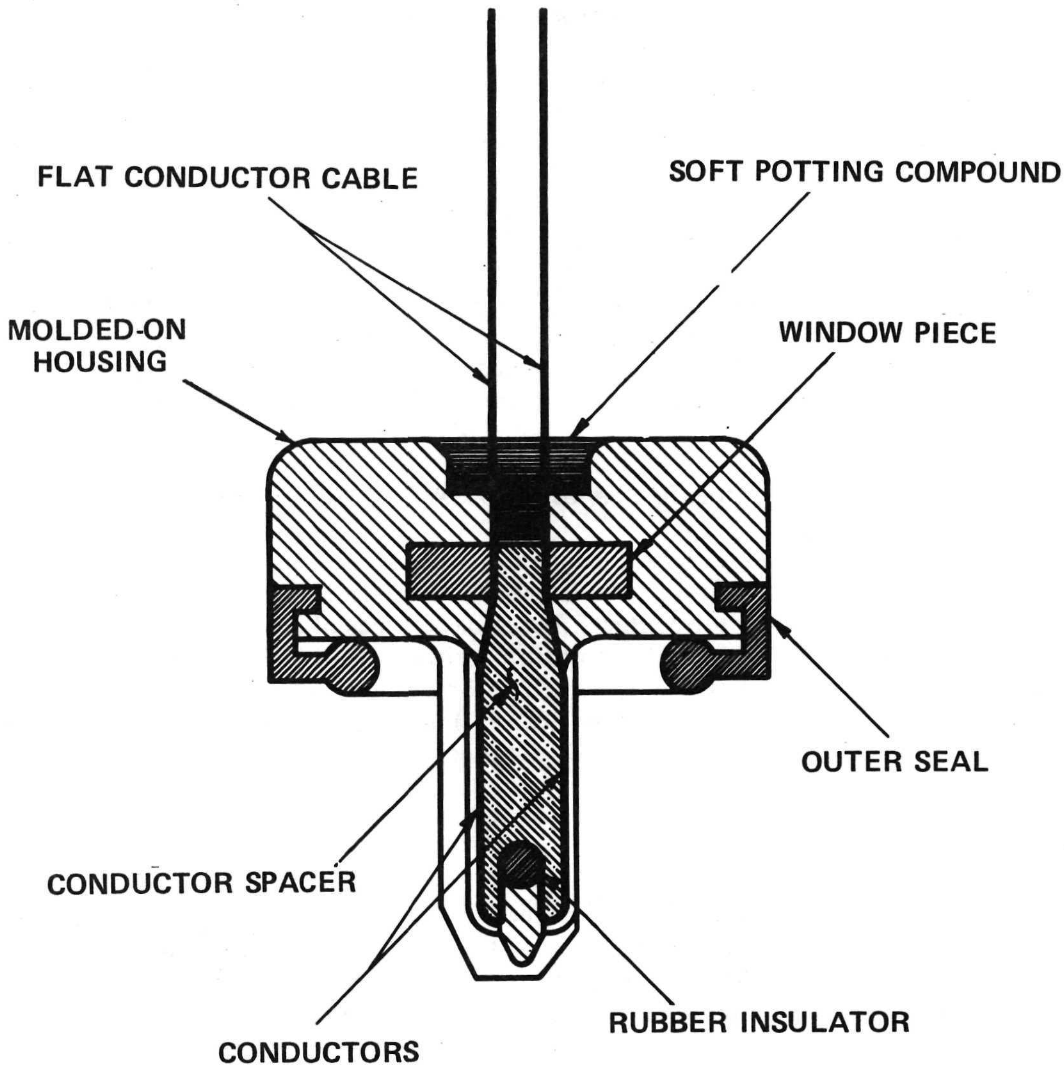


Figure 7. FCC molded-on plug.

New FCC Connectors with Individually Sealed Contacts

The new NASA/MSFC connectors with individually sealed contacts represent a major advancement in FCC technology. This latest effort can be viewed as a logical extension of earlier efforts, relying heavily on past development work, retaining many of the proven design features of other FCC connectors. However, because of extensive improvements which have been made to the total system, it cannot be considered as merely a slight modification of earlier efforts. With a solid development history as a foundation, a completely new FCC connector design has evolved, unlike any other existing models. One major design advancement is the provision for individual solid dielectric enclosures for each plug-receptacle mated contact pair. This feature is designed to eliminate electrical leakage between neighboring contacts under any environmental condition, including high altitudes (or low pressures). The individual contact seal and other major design advancements are shown in Table 1.

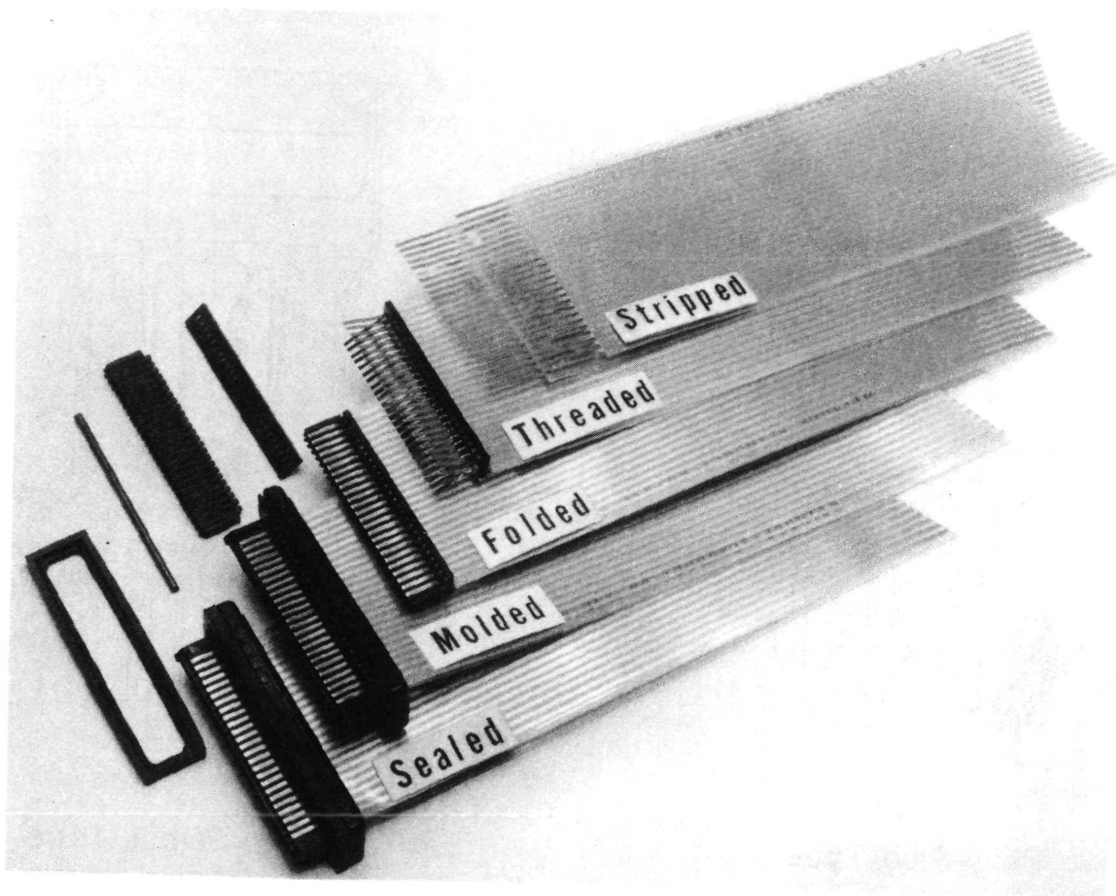
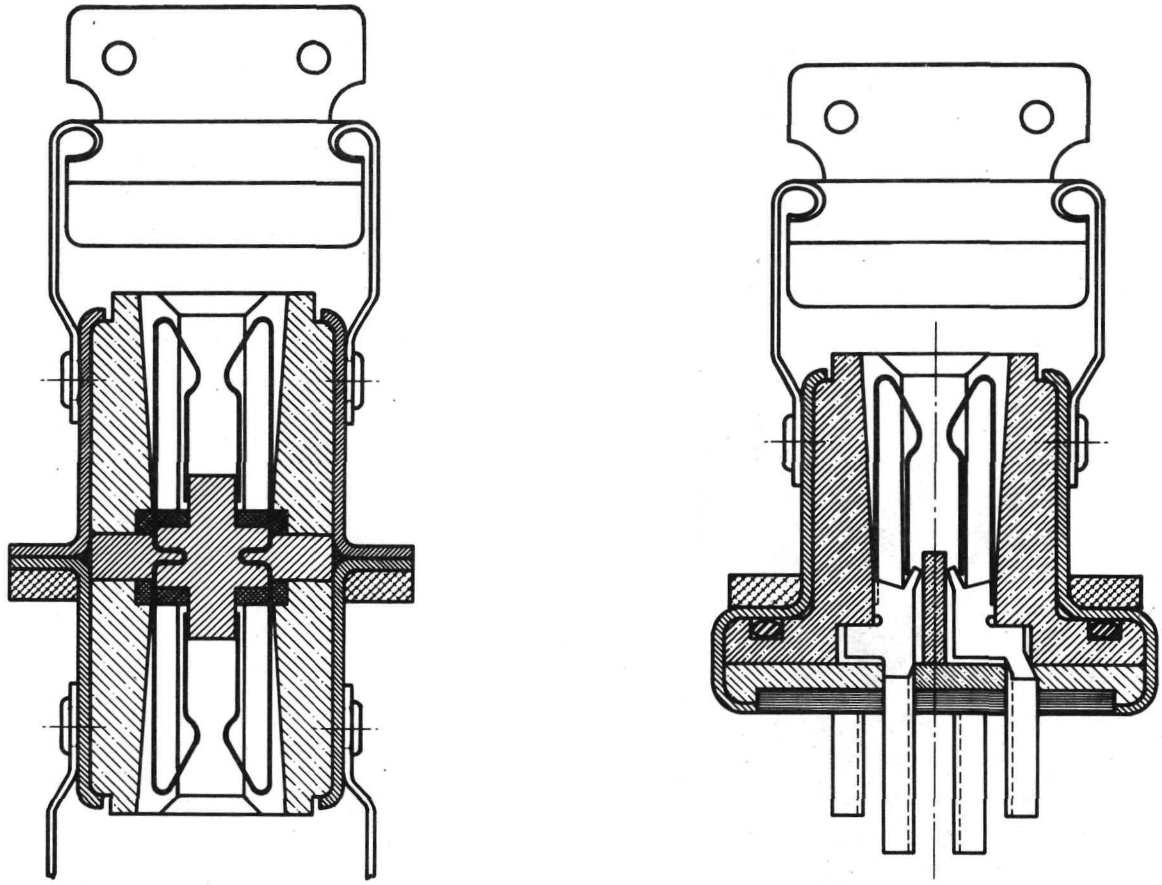


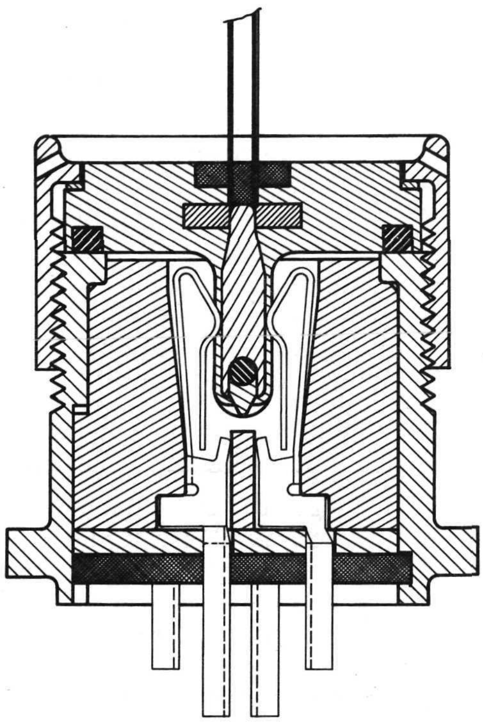
Figure 8. Assembly of FCC molded-on plug.



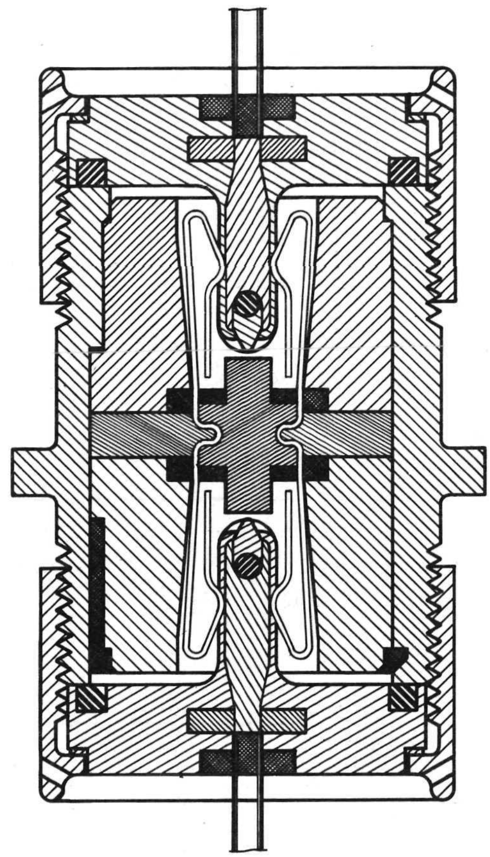
Plug-Plug Type

Plug-Solder Type

Figure 9. FCC receptacle for 2.5- to 7.6-cm (1- to 3-in.) wide cable.



Plug-Solder Type



Plug -Plug Type

Figure 10. FCC receptacle for 0.6- and 1.3-cm (0.25- and 0.5-in.) wide cable.

TABLE 1. EVOLUTION OF NEW NASA/MSFC CONNECTORS FROM EARLIER MODELS

Basic Item	Features of Earlier Connectors	Advancements
(1) Plug contact made from folded flat conductor	(1) Contacts are exposed, with no individual housing	(1) Each contact is recessed in the plug (preventing damage from handling) and individually housed in plastic (greatly reducing the possibility of low pressure corona)
(2) Receptacle spring contact	(2) Spring force results in good electrical contact with plug conductor-contact	(2) While the contact design is retained, mechanical protection is added
(3) Environmental seal for contact protection	(3) A peripheral seal is common to all contacts	(3) Each contact has its own peripheral seal; Result: electrical leakage between neighboring contacts is practically eliminated
(4) Safety latch to hold plug and receptacle together	(4) Two-clip mechanism	(4) The new one-piece latch provides greater ease in handling, greater vibration resistance, and is more rugged
(5) Keying system	(5) Polarity provision only	(5) The polarity key system can also provide correct pairing; A certain plug fits only to a certain receptacle
(6) Molded plug	(6) Four to five pieces	(6) The new plug body consists of one part only

SECTION III

GENERAL REQUIREMENTS

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SECTION III. GENERAL REQUIREMENTS

When MSFC first began developing separable connectors, certain basic design requirements were established for a practical connector. These same general requirements have been applied to the design of the newest family of individually sealed contact connectors. Requirements include:

1. Low and uniform contact.

2. Low weight.

3. Low volume.

4. Ability to withstand severe environmental conditions such as vibration, shock, humidity, corrosion, storage, temperature extremes.

5. Low cost.

6. Ability to be easily disconnected without the use of tools.

7. Excellent electrical insulation qualities.

8. High number of insertion cycles.

9. Durability.

10. Handling ease.

11. Highest possible reliability.

To meet requirements, many proven design features of the other MSFC series have been incorporated into this latest FCC connector family. One notable example is the use of flat cable conductors as contacts, thus eliminating needless joints, resulting in increased connector reliability. However, many new design features have been added, which provide advantages over earlier models. Specific requirements and connector features designed to meet them will not be further discussed at this time. Rather, connector design will first be described in detail in the next four sections, and then a requirement/design feature summary will follow.

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SECTION IV

CONNECTOR: FCC TO ROUND WIRE

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SECTION IV. CONNECTOR: FCC TO ROUND WIRE

General

The NASA/MSFC FCC individually sealed contact connector designed for FCC to round wire connections is shown unmated in Figures 11 and 12, and mated in Figures 13 and 14. Figure 15 is an exploded view. The connector is composed of two parts: (a) a plug using cable flat conductors as contacts and (b) a mating receptacle with spring contacts, which engage with the plug contacts at one end and are soldered to round wire conductors at the opposite end. Physical and mechanical data for each of the five connector sizes are contained in Table 2 and electrical data in Table 3. Figure 16 shows the dimensions of the receptacle contact and lead wires used for the MIL-C-55544 "total connector resistance" calculations in Table 3.

Distinctive design improvements which set this new connector apart from all earlier models include:

1. Mechanism for sealing and insulating each mated contact pair.

2. One-piece latch.

3. One main plug part.

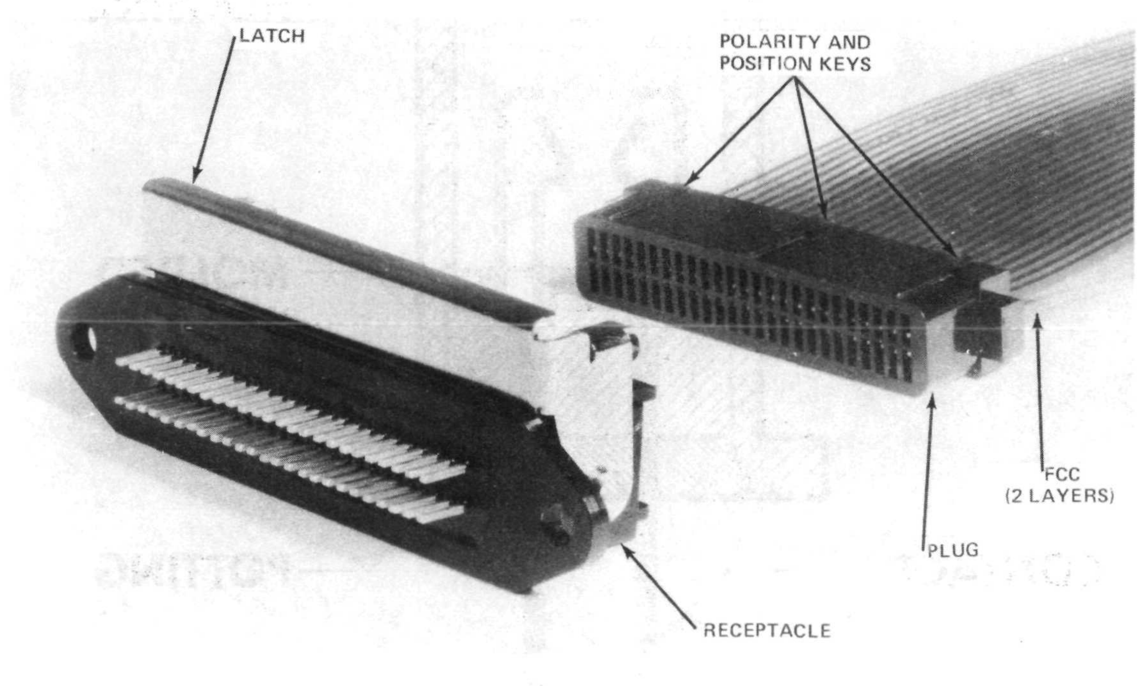


Figure 11. FCC to round wire cable connector with individually sealed contacts, unmated view (prototype).

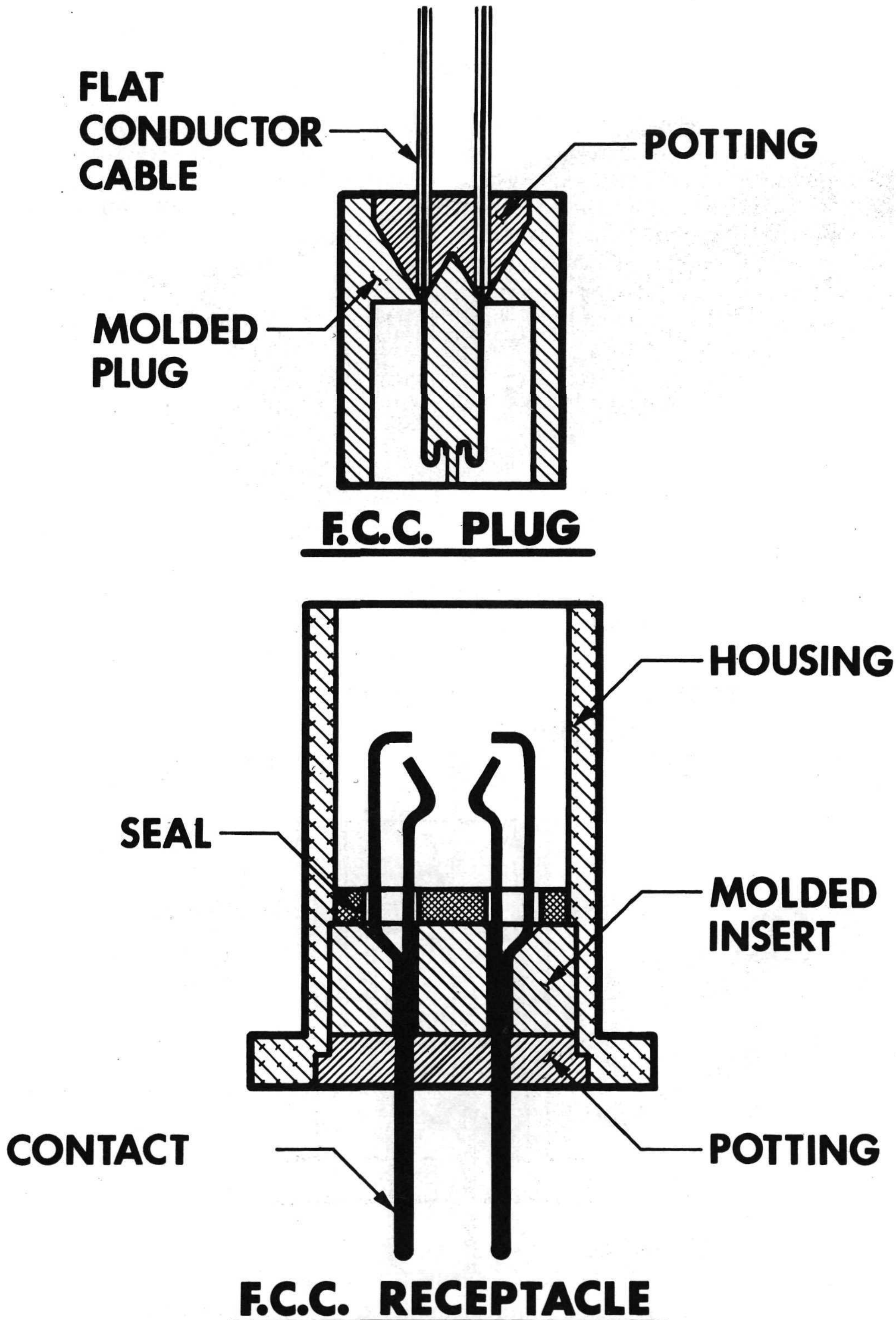


Figure 12. FCC to round wire cable connector with individually sealed contacts, unmated view.

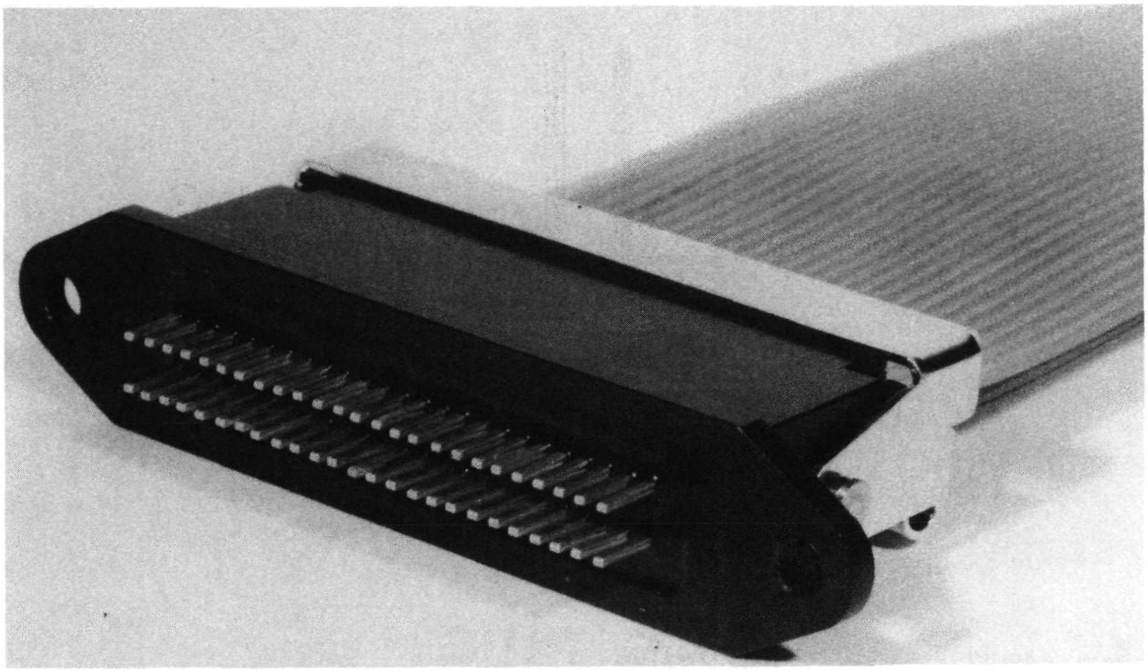


Figure 13. FCC to round wire cable connector with individually sealed contacts, mated view (prototype).

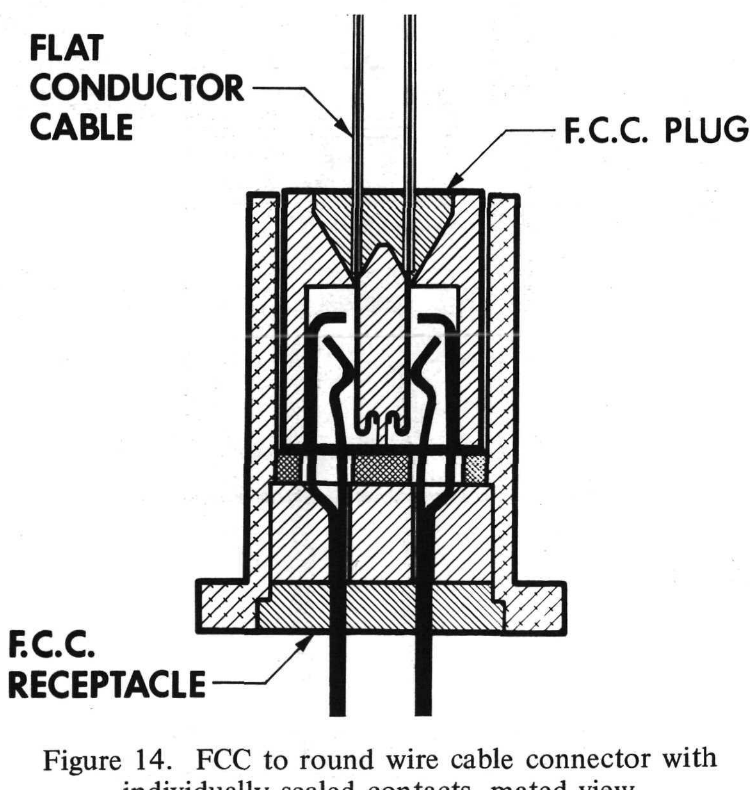


Figure 14. FCC to round wire cable connector with individually sealed contacts, mated view.

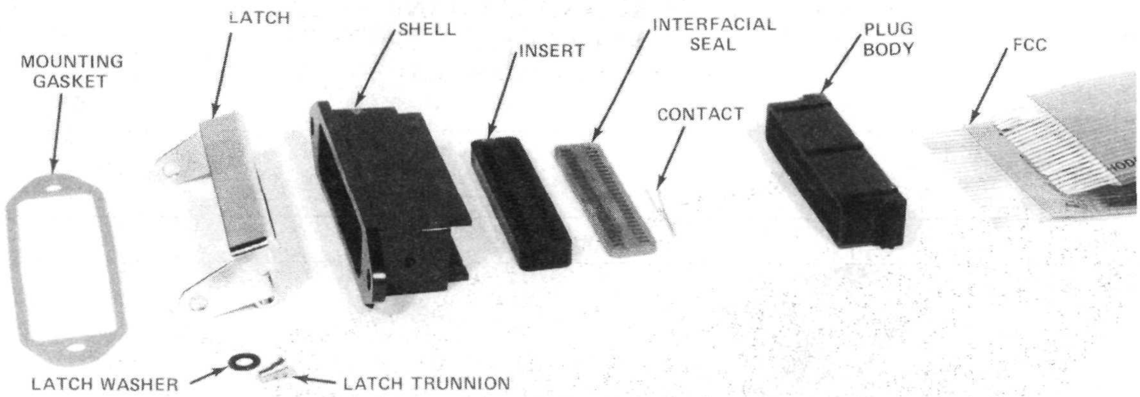


Figure 15. Exploded view of FCC to round wire cable connector with individually sealed contacts (prototype).

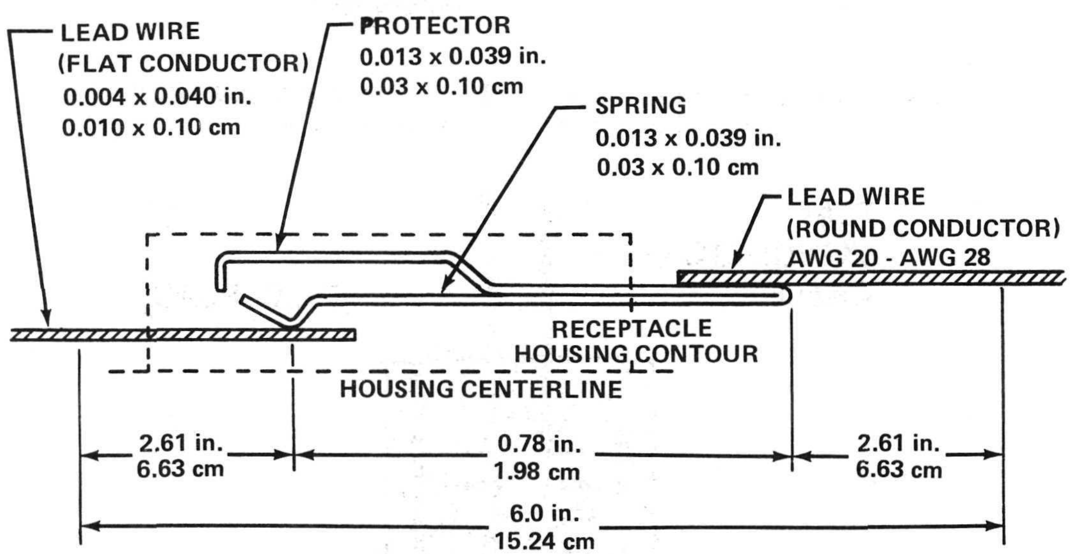


Figure 16. Contact and lead wires, with dimensions, used in calculating "total connector resistance" values, as defined by MIL-C-55544.

TABLE 2. PHYSICAL AND MECHANICAL DATA FOR FCC TO ROUND WIRE CONNECTORS
(According to Cable Width)

Cable Width	cm (in.)	2.54 (1.0)	3.81 (1.5)	5.08 (2.0)	6.35 (2.5)	7.62 (3.0)
Layers of FCC		2	2	2	2	2
Number of Contacts		24	36	50	64	76
Flat Conductor Width	cm (in.)	0.1 (0.04)	0.1 (0.04)	0.1 (0.04)	0.1 (0.04)	0.1 (0.04)
Round Wire Size, Maximum[a]		AWG 20	AWG 20	AWG 20	AWG 20	AWG 20
Center-to-Center Contact Spacing	cm (in.)	0.19 (0.075)	0.19 (0.075)	0.19 (0.075)	0.19 (0.075)	0.19 (0.075)
Mounting Area[b]	cm (in.)	1.91 X 5.59 (0.75 X 2.2)	1.91 X 6.73 (0.75 X 2.65)	1.91 X 8.08 (0.75 X 3.18)	1.91 X 9.4 (0.75 X 3.70)	1.91 X 10.54 (0.75 X 4.15)
Mated Connector Length	cm (in.)	3.6 (1.4)	3.6 (1.4)	3.6 (1.4)	3.6 (1.4)	3.6 (1.4)
Contact Density[c]	cm^2 ($in.^2$)	0.45 (0.07)	0.39 (0.06)	0.32 (0.05)	0.26 (0.04)	0.26 (0.04)
Plug Weight[d]	g	4	6	8	10	12
Receptacle Weight[d]	g	25	32	42	51	59
Connector Total Weight[d]	g	29	38	50	61	71
Weight per Contact[e]	g	1.2	1.05	1.0	0.95	0.93
Mating Force, Maximum	kgf (lb)	0.9 (2)	1.35 (3)	1.8 (4)	2.25 (5)	2.7 (6)
Unmating Force, Maximum	kgf (lb)	0.68 (1.5)	1.04 (2.3)	1.35 (3.0)	1.67 (3.7)	2.03 (4.5)
Temperature Range	°C	-65 to +200	-65 to +200	-65 to +200	-65 to +200	-65 to +200
Wear Life, Minimum	Insertions	500	500	500	500	500

a. For receptacle only.

b. Add 1.3 cm (0.5 in.) to height when allowing for latch movement.

c. Mounting area divided by number of contacts.

d. With potting.

e. Connector weight divided by number of contacts.

4. Unique receptacle spring contact.

5. Revised connector keying mechanism.

6. Aluminum die-cast receptacle shell.

7. Receptacle molded insert with low-tolerance contact spaces.

These design features, and their resulting advantages, are included in the following detailed description of the individual parts making up the connector plug and receptacle.

TABLE 3. ELECTRICAL DATA FOR FCC TO ROUND WIRE CONNECTORS

Voltage Rating	300 volts rms
Current Rating	3 amps
Insulation Resistance, Minimum	5000 megohms
Contact Point Constriction Resistance, Min[a]	0.5 milliohm
Contact Point Surface Resistance[b]	0.2 milliohm
Contact Spring Resistance, Max[c]	2.76 milliohms
Total Connector Resistance Using AWG 27 or 4 × 40 mil Lead Wire[d]	25.86 milliohms (22.4 milliohms for wire)
Total Connector Resistance Using AWG 20 Lead Wire[d]	7.86 milliohms (4.4 milliohms for wire)

a. For calculations and explanation, refer to Appendix E.

b. Resistance due to surface contaminants and oxides.

c. A calculated figure for resistance from contact point to solder joint of the receptacle spring contact. For calculations and explanation, refer to Appendix D.

d. Measured per MIL-C-55544A (25 June 1971), paragraph 4.6.12. Observe how the "total connector resistance" varies depending on which size lead wire is used. Using AWG 27 lead wire the "total connector resistance" exceeds the MIL-SPEC maximum, while when using AWG 20 lead wire the MIL-SPEC is met. The same connector is used in both examples, and therefore all internal resistance values are the same. If the total connector resistance measurement as defined by the MIL-SPEC is to be meaningful, the designer must know the size of the lead wire which was used.

Plug (MR&Tsk-1556)

Molded Plug Body

The molded plug body consists of only one part, replacing the four to five pieces of earlier NASA series. This reduction in number of parts will result in a considerable reduction in materials as well as labor required for assembly. Glass fiber filled epoxy has been selected as the construction material for the plug body; however, other thermosetting plastics can also be used with the design. Figure 17 is a photo of a plug prototype. In Figure 18, design details are shown and, in Table 4, plug dimensions are given.

Termination of Unshielded FCC to Plug

The two layers of FCC are attached to the plug body by a few simple operations, which are depicted in Figure 19 and briefly described below.

1. Measure and cut two lengths of cable for each cable-to-plug termination.

2. Strip about 1 cm (0.4 in.) of insulation from ends of cable. Use NASA's standard cold blade stripper (Figs. 20 and 21) if the insulation/adhesive system is polyimide/FEP. Use chemical means if the system is polyester/polyester. (For details, refer to NASA TMX-53975, Flat Conductor Cable Design, Manufacture, and Installation. A TMX report concerned solely with FCC stripping is in preparation and will be available the latter part of 1972).

3. Clean and, if desired, plate the bared conductors with 0.0025 mm (0.0001 in.) of nickel and then with 0.0025 mm (0.0001 in.) of gold. (For details, refer to the above-referenced TMX-53975).

4. Thread the stripped cable ends through the back of the plug body. A tapered channel for each conductor is designed for ease of cable insertion.

5. Align the two sets of cable conductors with respect to each other.

6. Fold conductor ends in place as shown in Figure 19 to make the plug contacts. Use a contact forming tool, a multifinger fixture for simultaneously bending all conductors of one cable.

7. Pot the back of the assembled plug.

Termination of Shielded FCC to Plug

FCC with bonded-on shields is terminated in much the same way as the unshielded cable. In this type construction, two copper-foil shields are attached to the two outer conductors for the full length of the cable. After cable stripping, these outer ground conductors are included with other conductors in each cable termination operation performed. At MSFC, two types of cable with bonded shields are used, one with a polyester/polyester insulation system and one with polyimide/polyester. Both are chemically stripped. The configuration of a stripped cable with bonded-on shields is shown in Figure 22.

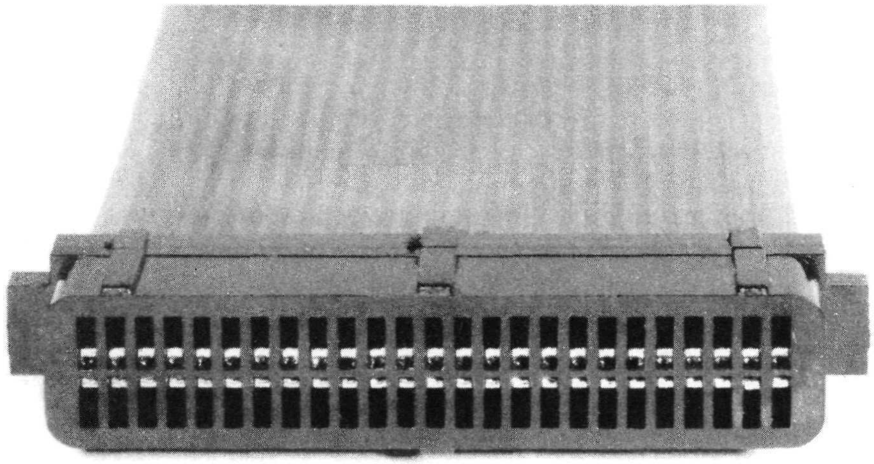
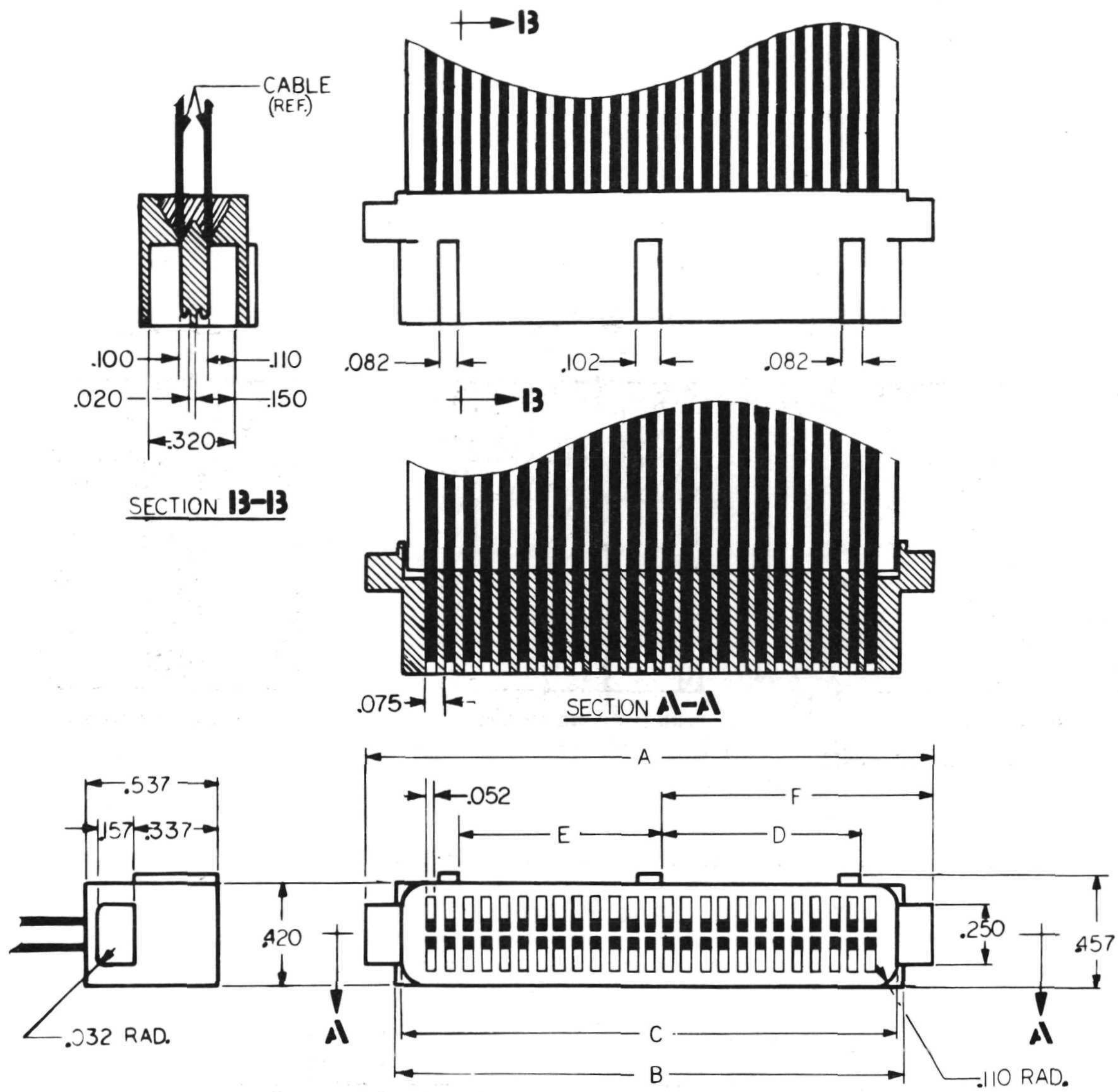


Figure 17. Plug, part of FCC to round wire cable connector (prototype).

TABLE 4. PLUG SPECIFICATION DIMENSIONS
(Size by Cable Width and Number of Conductors.
Refer to Figure 18, Specification Drawing)

Cable Width	No. of Contacts	A	B	C	D	E	F
cm (in.)	(2 cables)	cm (in.)	cm (in.)	cm (in.)	cm (in.)	cm (in.)	cm (in.)
2.54 (1)	24	3.401 (1.339)	2.796 (1.099)	2.642 (1.049)	0.818 (0.322)	0.869 (0.342)	1.572 (0.619)
3.81 (1.5)	36	4.544 (1.789)	3.934 (1.549)	3.807 (1.499)	1.389 (0.547)	1.450 (0.567)	2.147 (0.844)
5.08 (2)	50	5.876 (2.314)	5.268 (2.074)	5.141 (2.024)	1.634 (0.810)	1.685 (0.830)	2.812 (1.107)
6.35 (2.5)	64	7.211 (2.839)	6.601 (2.599)	6.474 (2.549)	2.723 (1.072)	2.744 (1.092)	3.503 (1.369)
7.62 (3)	76	8.549 (3.289)	7.744 (3.049)	7.602 (2.999)	3.294 (1.297)	3.345 (1.317)	4.049 (1.594)



NOTES

1. THE BODY OF THE PLUG IS PRESSURE MOLDED FROM A GLASS FILLED EPOXY COMPOUND (FIBERITE–E–2748).
2. THE CABLES ARE POTTED INTO THE PLUG WITH A COMPOUND CURED AT AN ELEVATED TEMPERATURE.
3. THE TEMPERATURE RANGE IS –65° C(–85° F) TO +200° C (392° F).

Figure 18. Specification drawing of plug.

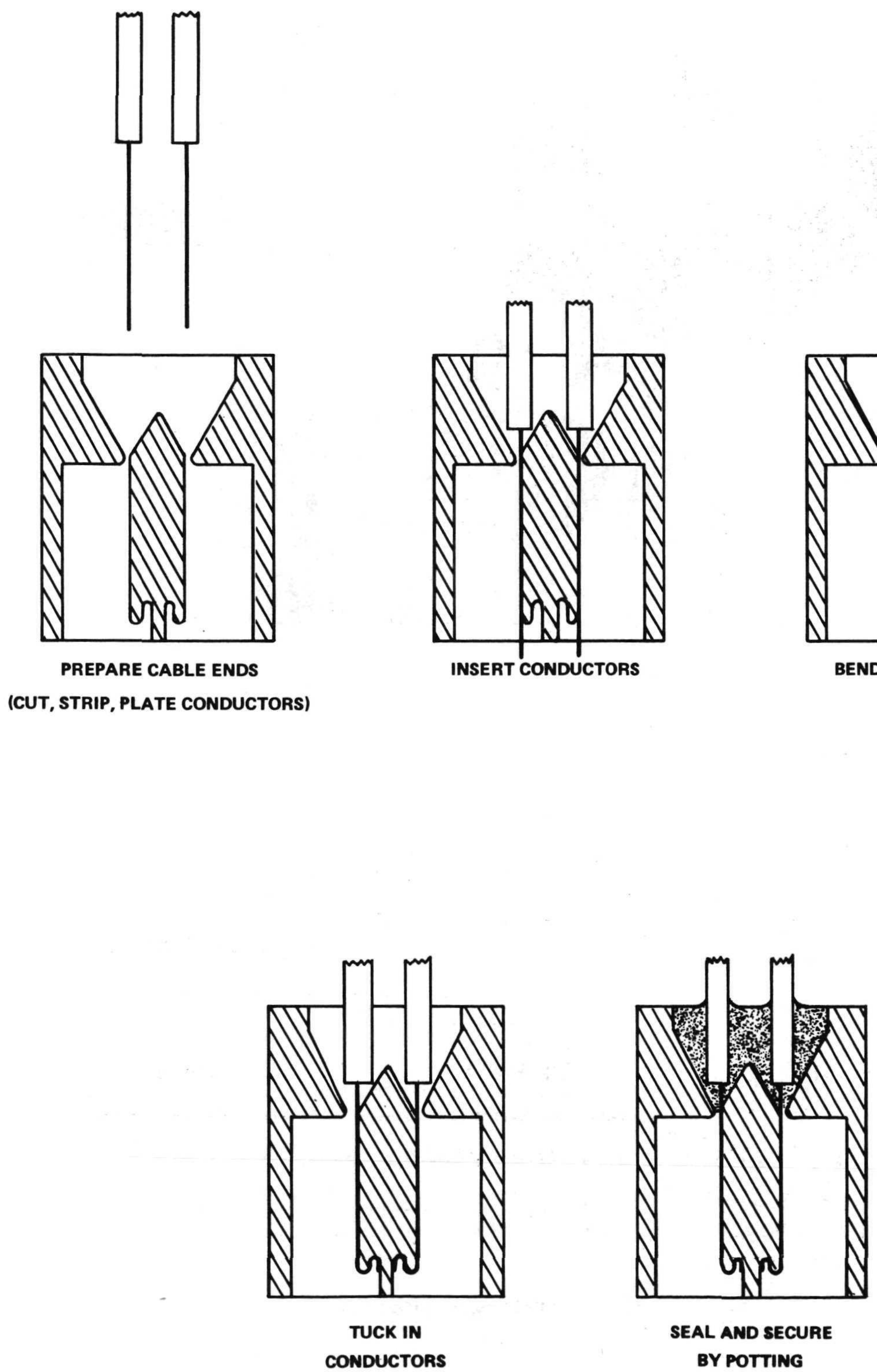


Figure 19. Termination of FCC to a plug.

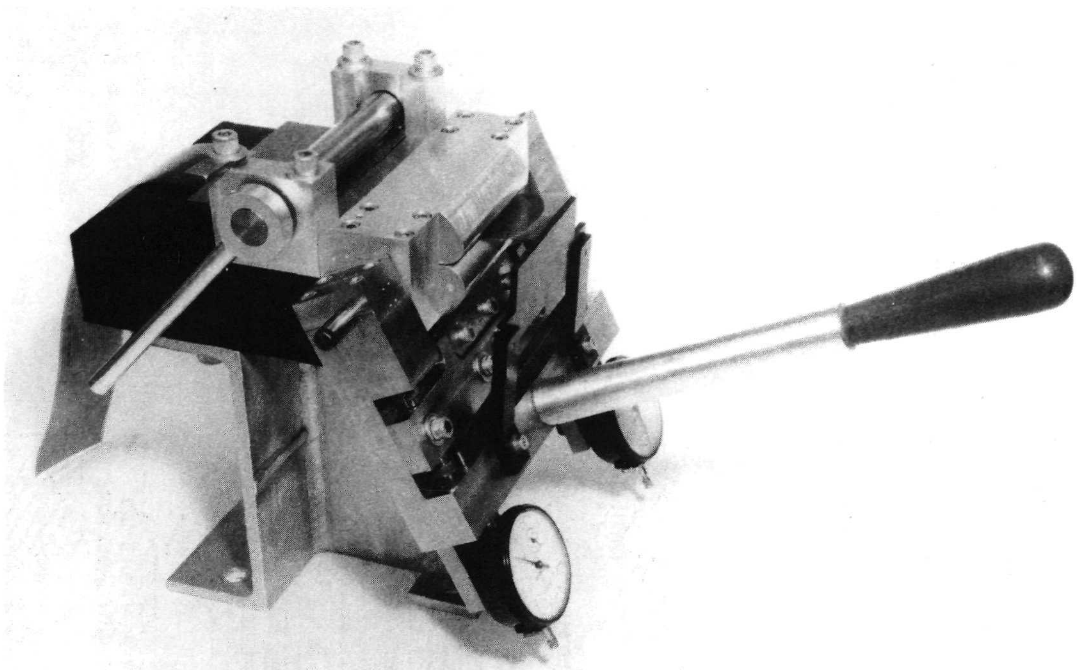


Figure 20. NASA cold blade stripper.

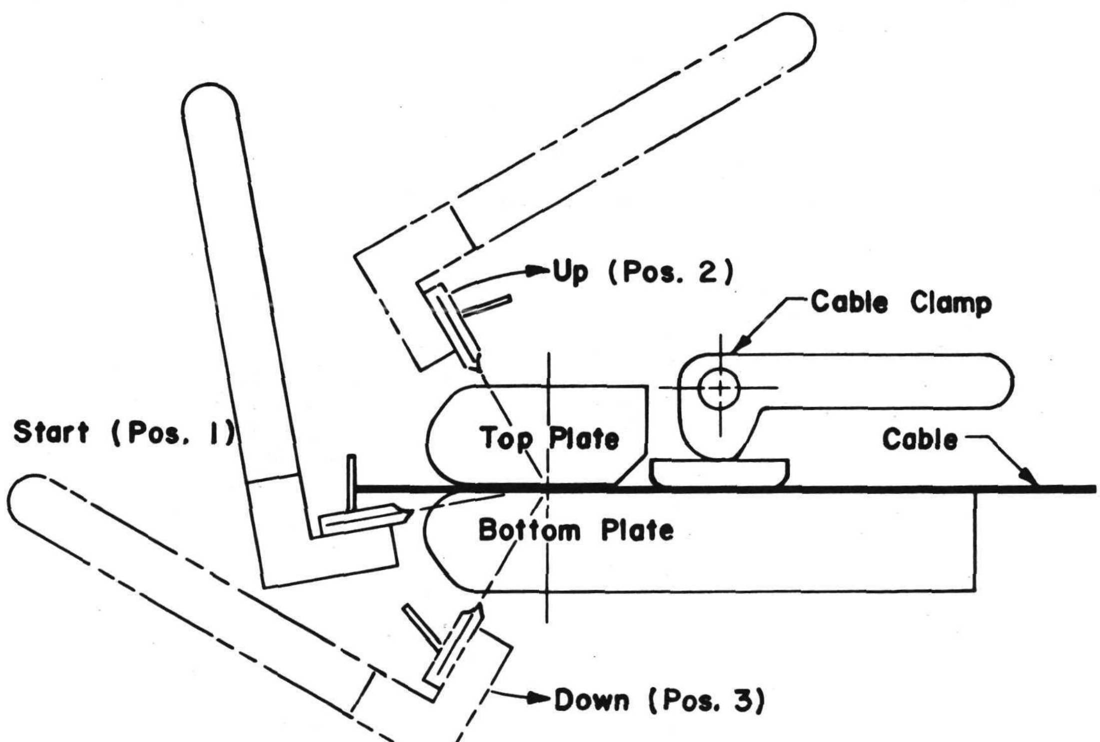


Figure 21. Operation of NASA cold blade stripper.

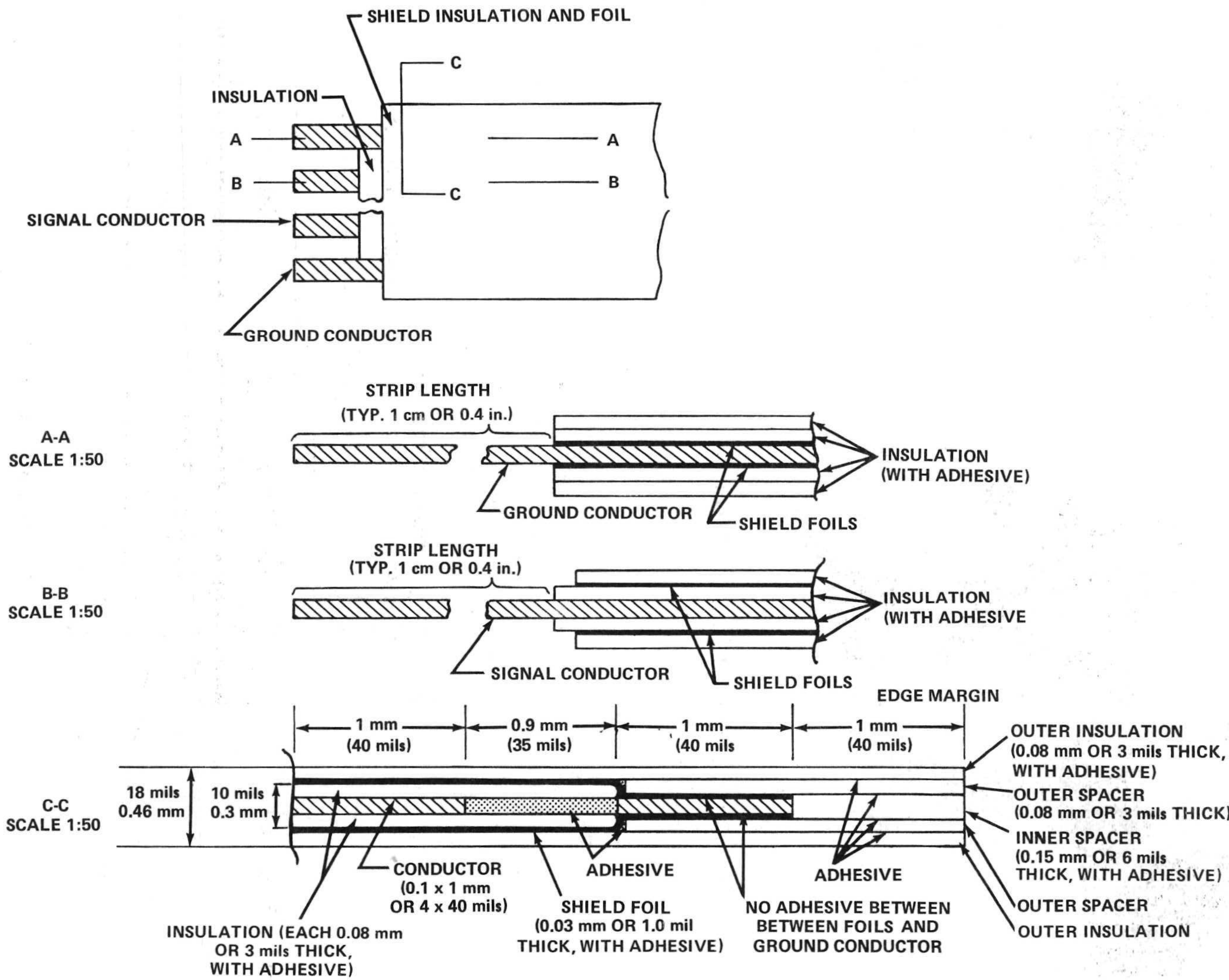


Figure 22. Cable with bonded-on shields, prepared for termination to plug.

FCC with loose shields is also terminated in much the same way as the unshielded cable. In this case, cable and shields are prepared separately, using a combination of methods previously discussed, and are then joined at the ends. The shield consists of a thin copper foil insulated with polyimide (Kapton)/high temperature polyester adhesive. After one side of the shield end is chemically stripped, a copper solder tab is applied to it, providing reinforcement, and thus preventing tearing of the thin 0.013-mm (0.5-mil) foil. The cable can be either of the three standard types discussed earlier: polyester (Mylar)/polyester, polyimide (Kapton)/high temperature polyester, or polyimide (Kapton)/FEP. The first two are chemically stripped, and the third is mechanically stripped using NASA's cold blade stripper. After stripping the shield and cable ends and attaching them together with the shield tabs, the completed assembly (Fig. 23) is subjected to the remainder of the termination operations described for the unshielded FCC.

A word of caution is in order about FCC shielding even though this document is not a report on shielding. Every possible effort should be made to establish the amount of protection a circuit needs before a shield foil or screen is applied. It is the experience of the author that in most cases less costly methods can be used. These include mounting the FCC to a grounded metal surface, removing the sensitive conductors from the disturbing conductors, surrounding the sensitive conductors right and left by grounded conductors of the same FCC, and in very critical cases placing ground conductors above and below the sensitive conductors.

Recessed and Individually Sealed Contacts

Contact housing design is unique for two main reasons. Because contacts are recessed in the plug, they are protected against inadvertent damage resulting from rough handling. In addition, a solid dielectric housing for each contact is part of a contact sealing system which provides greater environmental protection and practically eliminates electrical leakage between neighboring contacts. Each plug contact is recessed and surrounded (except at plug face) by a solid dielectric. An interfacial seal fits over the receptacle contacts; therefore, a solid dielectric also surrounds each receptacle contact at its base. When plug and receptacle are mated, every mated contact pair is completely enclosed in a solid dielectric housing, and is separate from other pairs. A connector latch provides sufficient pressure to maintain this system at all altitudes, including a state of vacuum. High altitude connector operation no longer poses special electrical problems, as low pressure corona (described by the Paschen Law) is practically eliminated.

Protective Cover

A protective cover with seal, constructed of Lexan and polyurethane, respectively, is available for covering the plug face when the plug is not mated. This protects the contacts and seals out contaminants. Two snapping ears hold the plug face pressed firmly against the cover's interfacial seal. The cover is shown in Figure 24.

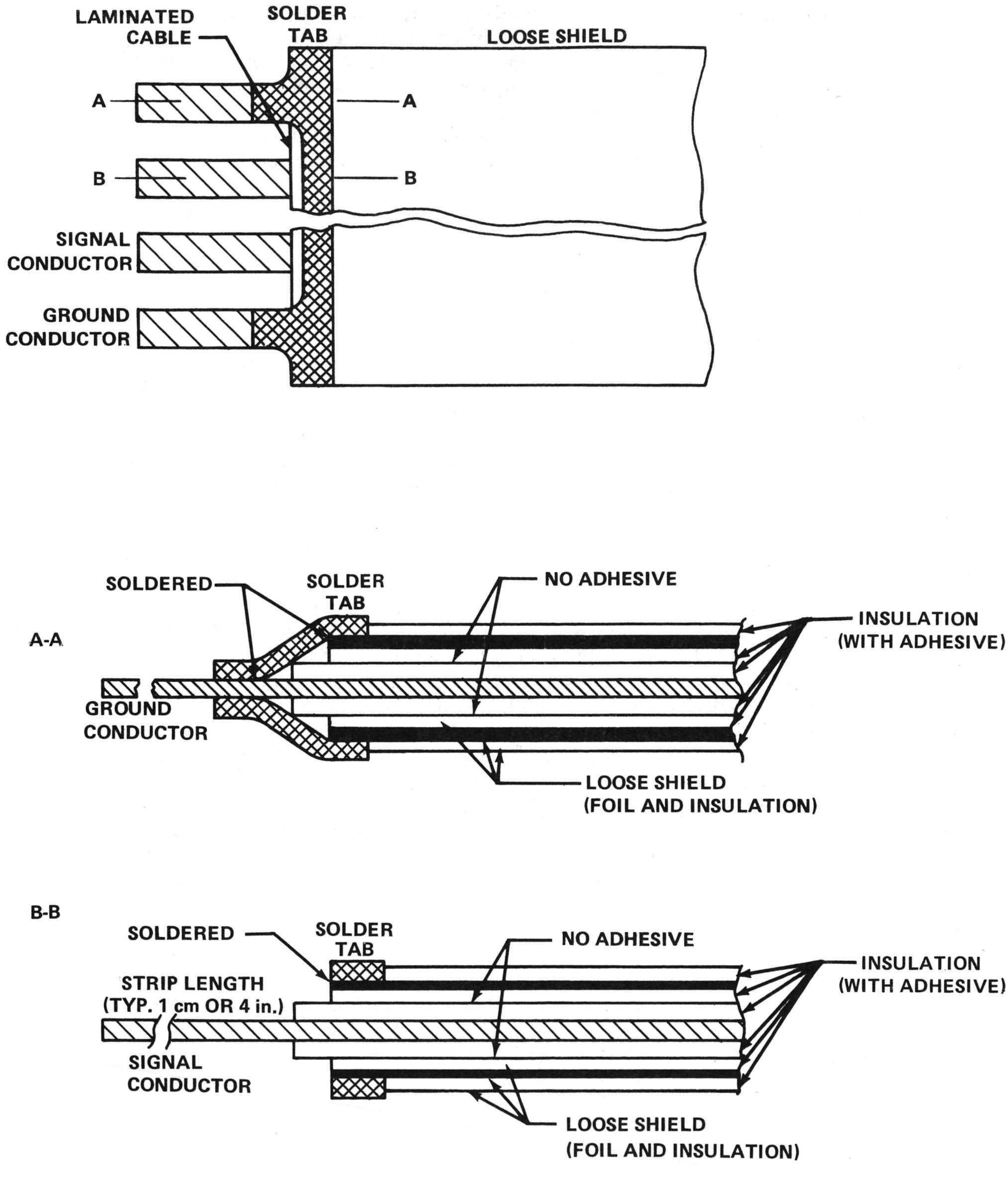


Figure 23. Cable with loose shields, prepared for termination to plug.

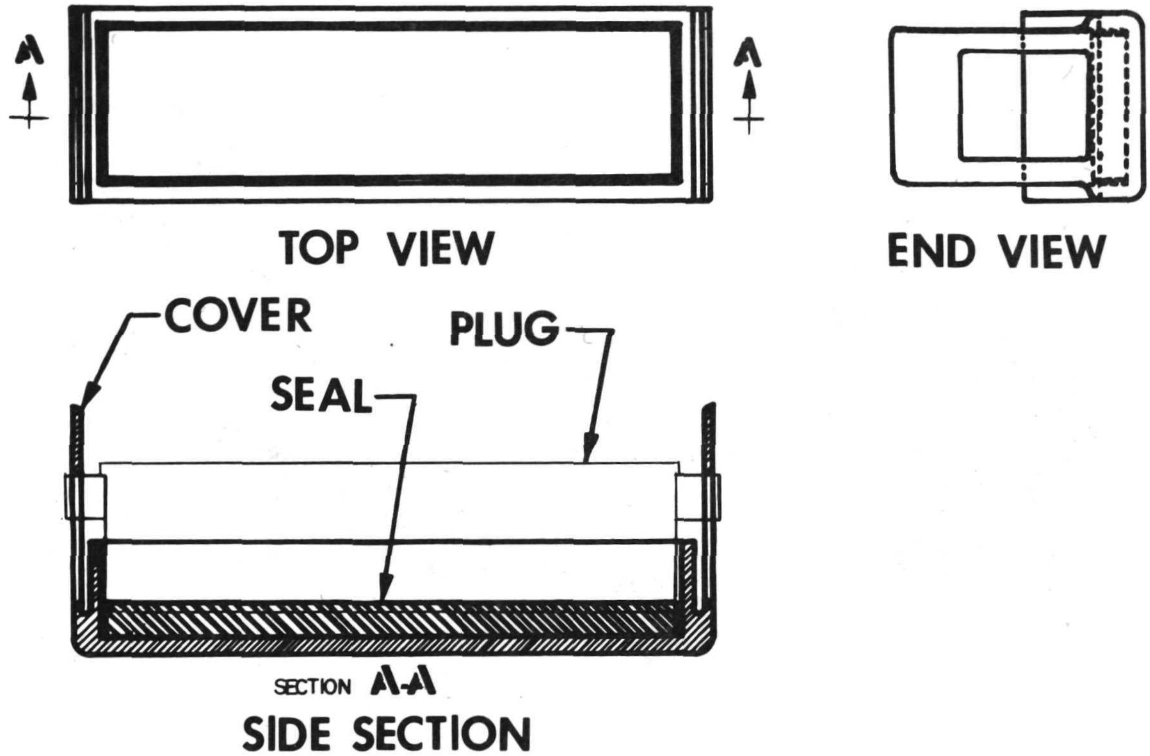


Figure 24. Plug protective cover.

Receptacle (MR&Tsk-15395)

The FCC to round wire receptacle consists of the following parts: (1) shell, (2) one-piece molded insert, (3) interfacial seal, (4) spring contacts, (5) latch, (6) gasket for mounting, and (7) protective cover. Figure 25 is a photo of a receptacle prototype. In Figure 26, design details are shown and, in Table 5, receptacle dimensions are given. Receptacle parts are described in the following paragraphs.

Shell With Mounting Feature

The shell (Fig. 27) consists of only one piece, with a flange for gasket placement and for screw-mounting of the completed receptacle assembly. This outer housing is constructed of an aluminum alloy, then is anodized. The resulting material has the features of low weight, high mechanical strength, and a strong, corrosion-resistant surface.

A contact protection feature, keying mechanism, and feature for cost reduction have all been incorporated in the shell design. The contact protection feature of earlier FCC receptacles is retained in this shell, and is the natural result of the shell's extending out past the contact-containing molded insert. In Figure 27, note the three grooves in the shell wall. Together with three ribs on the mating plug, these constitute the connector's keying system for polarity and position. (See Figure 1 for plug ribs.) This shell is designed to be aluminum die-cast. Thus, after initial tooling costs, production run expenditures will be considerably less than would be possible with machined items.

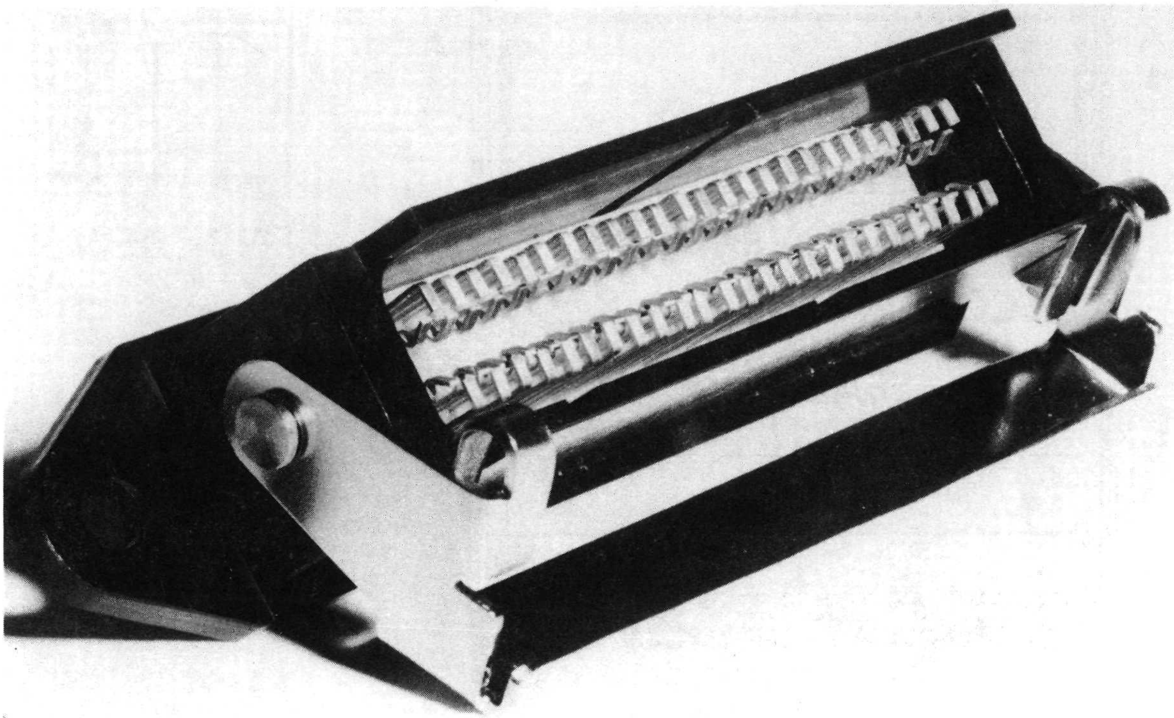


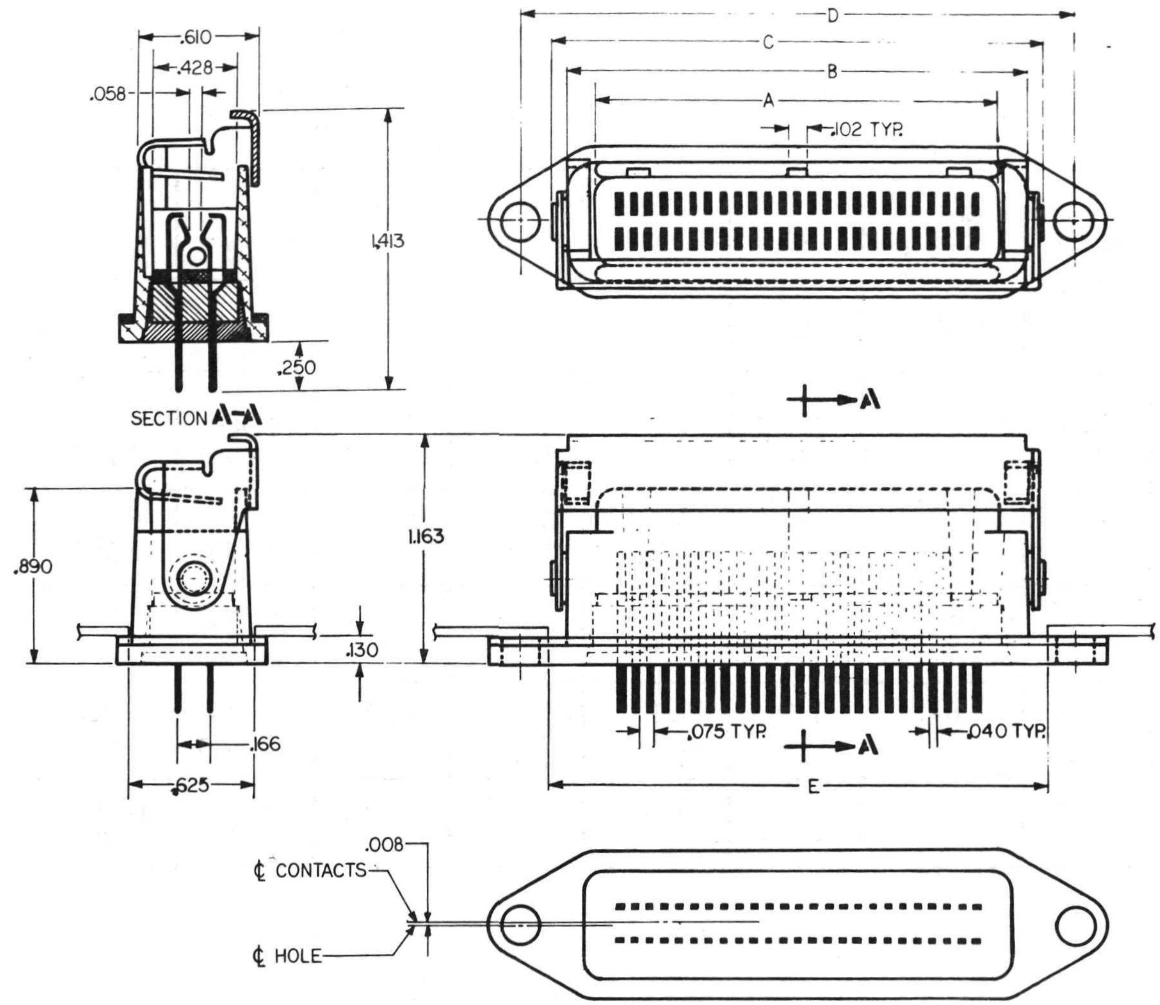
Figure 25. FCC to round wire cable receptacle (prototype).

Latch

A one-piece, over-center latch (Fig. 28) is designed to secure the plug to the receptacle and to provide sufficient pressure between the front surface of the plug and the receptacle rubber seal to eliminate any air path between contacts. This latch is permanently attached to the receptacle by two trunnions, one at each receptacle end, about which the latch pivots for opening and closing. The latch is constructed of heat-treated beryllium copper and, thus, is a mechanically strong spring. Nickel plating provides the desirable properties of wear and corrosion resistance.

The pressure is produced by two integral leaf springs of the latch. During manual actuation of the latch, the springs ride over the edges of two ears on the plug and snap into the closed position, preventing self-opening either by vibration or shock. The total force of the springs is designed for 9.2 kgf at 0.60 mm (20 lb at 0.024 in. deflection). Calculations for these figures can be found in Appendix A.

The latch pressure, in conjunction with the individual solid dielectric enclosure for each plug-receptacle mated contact pair, practically eliminates the possibility of low pressure corona (described by the Paschen Law). To demonstrate this point, consider the following. The largest connector, for a 7.6-cm (3-in.) wide cable, has a sealing area of 5 cm^2 (0.83 $in.^2$) which results in a sealing pressure of $9.2/5 = 1.8$ kgf/cm^2 ($20/0.83 = 24$ $lb/in.^2$). The total interior front area of the contact chambers of this plug size is 2.8 cm^2 (0.43 $in.^2$).



NOTES:

1. MATERIAL:

   SHELL – ALUMINUM ALLOY 380-T6 (QQ-A-591).

   INSERT – GLASS FILLED EPOXY (FIBERITE-E-2748).

   CONTACT PINS & LATCH - BERYLLIUM COPPER ALLOY.

2. THE MOUNTING HOLE DIMENSIONS ARE .625 INCHES WIDE AND "E" INCHES LONG.
3. TEMPERATURE RANGE –65° C (–85° F) TO +200° C (392° F).

Figure 26. Specification drawing of FCC to round wire receptacle.

TABLE 5. SPECIFICATION DIMENSIONS OF FCC TO ROUND WIRE RECEPTACLE (Size by Cable Width and Number of Conductors. Refer to Figure 26, Specification Drawing)

Cable Width	No. of Contacts	A	B	C	D	E	F
cm (in.)	(2 cables)	cm (in.)	cm (in.)	cm (in.)	cm (in.)	cm (in.)	cm (in.)
2.54 (1)	24	2.700 (1.063)	3.448 (1.358)	3.907 (1.538)	4.635 (1.825)	4.064 (1.600)	5.428 (2.137)
3.81 (1.5)	36	3.839 (1.513)	4.590 (1.807)	5.047 (1.987)	5.778 (2.275)	5.270 (2.050)	6.558 (2.582)
5.08 (2)	50	5.102 (2.038)	5.914 (2.332)	6.378 (2.512)	7.112 (2.800)	6.390 (2.575)	7.904 (3.112)
6.35 (2.5)	64	6.510 (2.563)	7.257 (2.857)	7.485 (2.947)	8.255 (3.325)	7.214 (2.840)	9.228 (3.637)
7.62 (3)	76	7.654 (3.013)	8.403 (3.307)	8.857 (3.487)	9.589 (3.775)	9.017 (3.550)	10.381 (4.087)

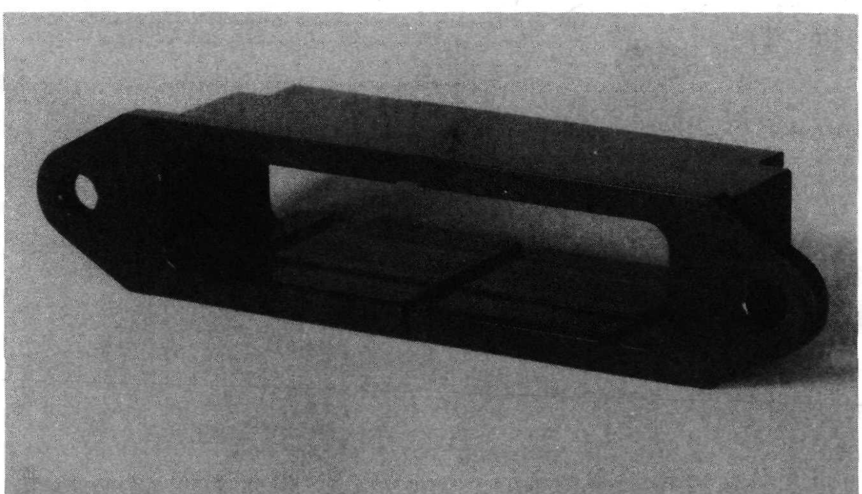


Figure 27. Shell for FCC to round wire receptacle.

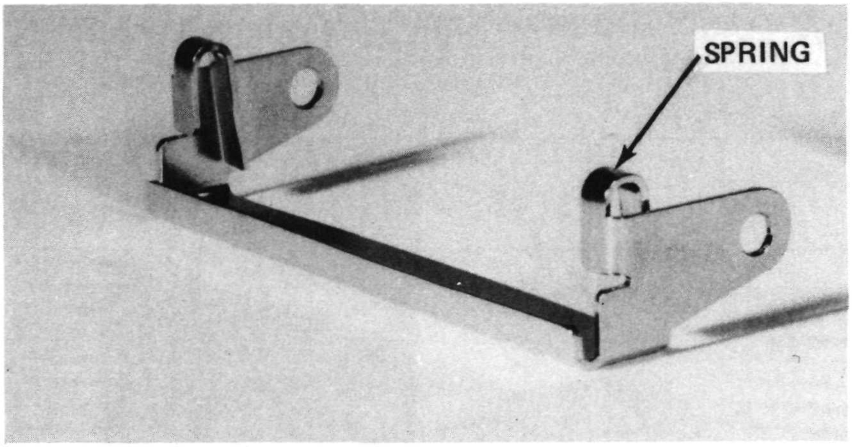


Figure 28. Latch for FCC to round wire receptacle.

When the connector is secured and then subjected to a vacuum, a total force of $1.03 \times 2.8 = 2.9$ kgf ($14.7 \times 0.43 = 6.4$ lb) pushes against the rubber seal from within the contact chambers. The counter latch spring force of 9.2 kgf (20 lb) will be sufficient to prevent air leakage, and thus prevent low pressure corona.

In addition to fulfilling main requirements of (1) securing the plug in the receptacle and (2) providing adequate pressure for sealing, the latch design incorporates two major improvements over earlier models. First, a one-piece latch obviously allows a connector to be more easily connected and disconnected. Second, this latch is more rugged, not readily disturbed by vibration. Therefore, accidental unlatching is extremely unlikely. However, if additional protection is desired, a simple aluminum safety lock is available which can readily be attached to the mated connector. In Figure 29, the safety lock has been placed on the connector and is ready for insertion. In Figure 30, it has been inserted and locked in place.

Interfacial Seal

An interfacial seal made of silicone rubber (Fig. 31) is fitted down over the exposed receptacle contacts. Silicone rubber has a shore hardness of 50 to 55, good high and low temperature properties, good sealing and resiliency properties, excellent electrical properties, is highly resistant to many degrading materials, and has very little tendency to set. All of these properties make silicone rubber an excellent compound for use as a seal.

When the receptacle is mated with a plug, the interfacial seal combines with the plug's individual contact housings, enclosures of high dielectric strength around the mated pairs of contacts. This individual sealing feature practically eliminates the possibility of electric corona and prevents the automatic spread of damaging elements from an initially affected contact pair. Refer to "plug, recessed and individually sealed contacts" in this section for a more detailed description of the individual contact sealing mechanism.

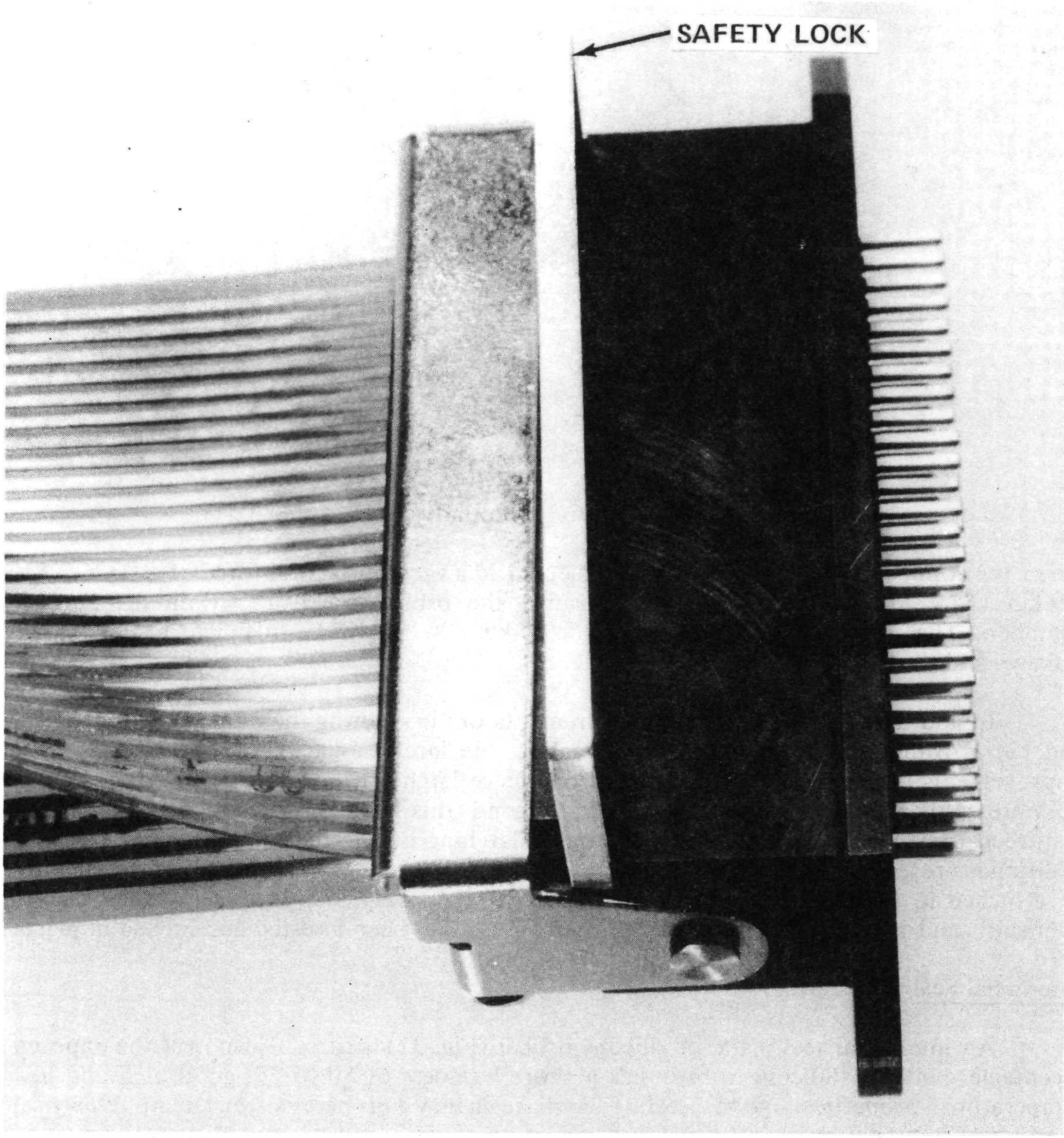


Figure 29. Safety lock ready for insertion.

One-Piece Molded Insert

The body of the receptacle is a contact-containing one-piece insert (Fig. 32), molded of glass fiber filled epoxy, and designed so as to allow use of two significant labor-saving production procedures. Because the insert is a premolded item, contact placement can be performed at room temperature, with none of the handling problems associated with hot

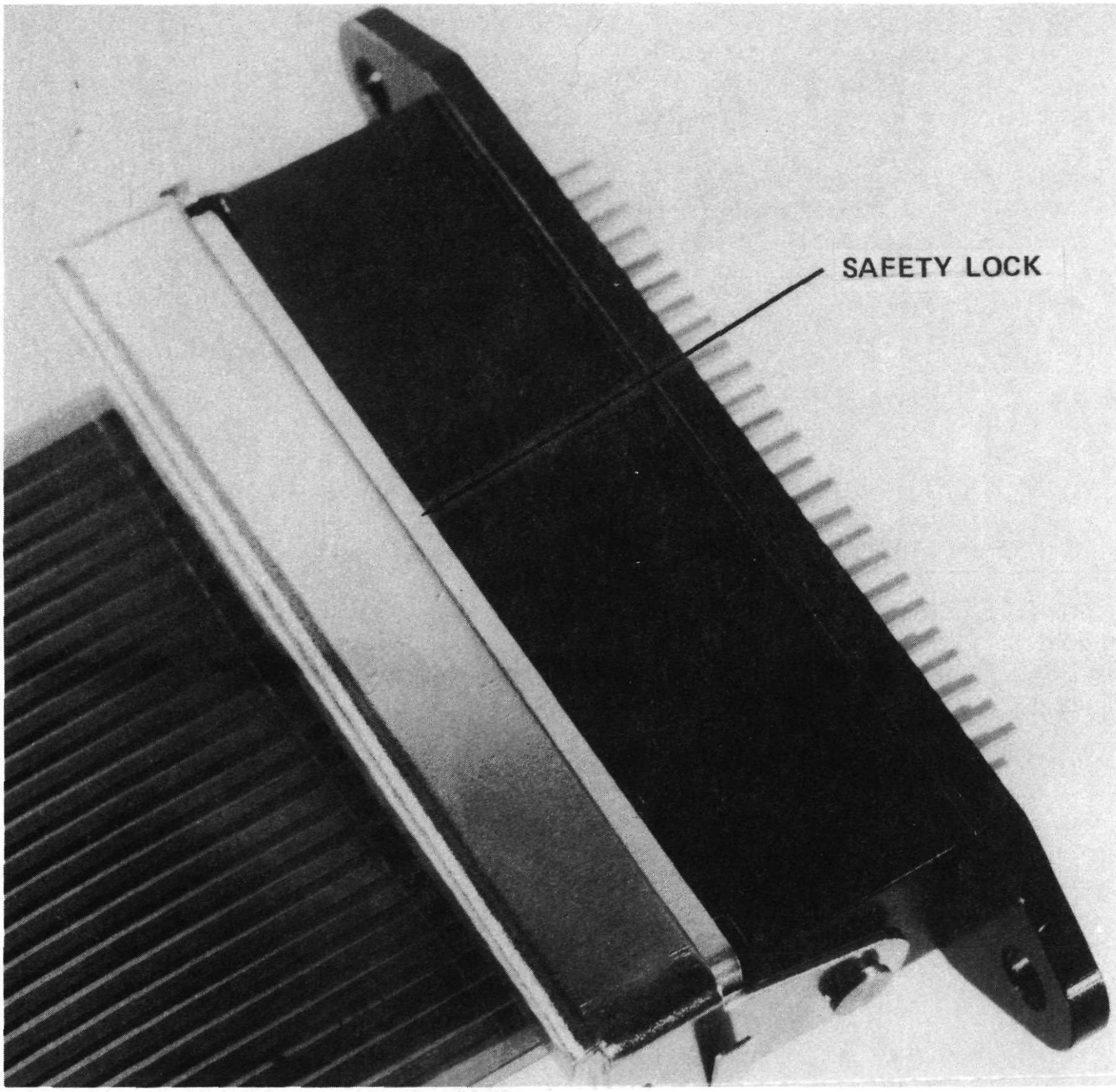


Figure 30. Safety lock inserted and bent in place.

molds. Additional production savings accrue through use of the following technique for fitting the insert into the outer housing. After placement of spring contacts, the insert is positioned in the outer shell, then held in place temporarily by four shell swages and by a specially prepared "dummy plug." As a final step, epoxy potting is applied to the back of the shell and acts as contact fastener and seal. Through use of a "dummy plug," loosely-fitted contacts are held in precise position for the above-mentioned potting. Thus, production of inserts with costly high-tolerance insert contact spaces is not required.

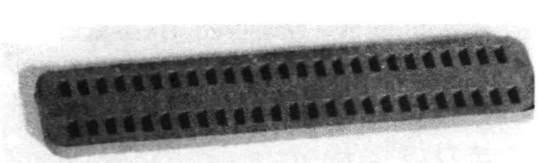


Figure 31. Interfacial seal for FCC to round wire connection.

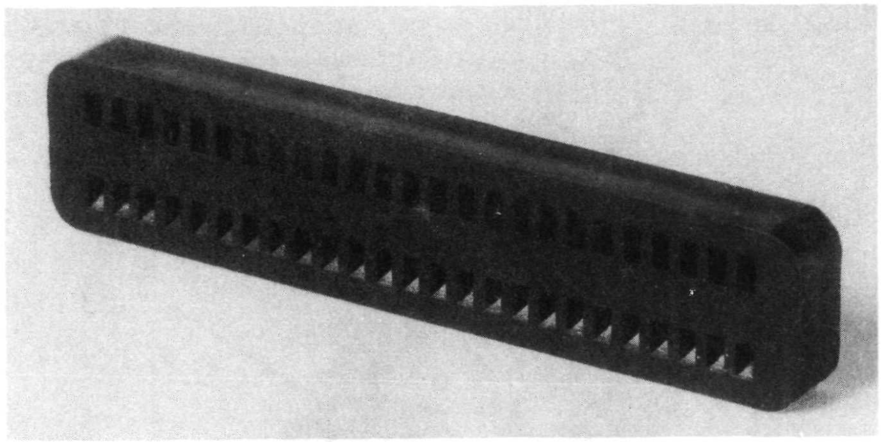


Figure 32. Molded insert for FCC to round wire receptacle.

Contact Spring With Protector

Each receptacle contact is formed from a single, flattened round wire, with no internal weld or braze joints which could lower system reliability. It is bent in such a way that contact spring, contact protector, and round wire solder lug are all formed, as shown in Figure 33.

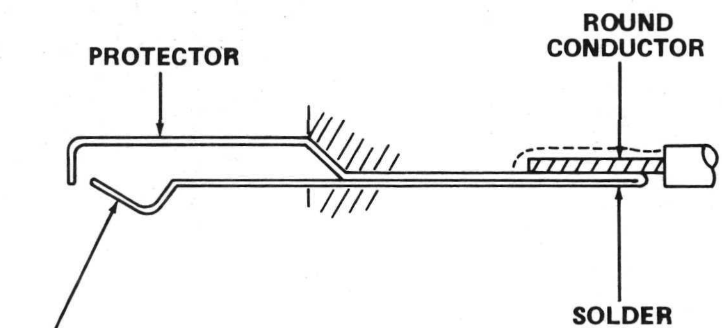


Figure 33. Receptacle contact.

See Figure 16 for all contact dimensions. This unique contact was designed with two main goals in mind: (1) maintain low contact point and contact spring resistance, thus eliminating destructive heat buildup, and (2) provide a protective cover for the contact spring, thereby preventing handling damage. The contact point resistance and contact spring resistance are extremely low, 0.7 milliohms and 2.76 milliohms (measured from contact point to solder joint). The connector resistance meets the MIL-C-55544 10 milliohms maximum requirement. To obtain and maintain low electrical resistance, the following features were incorporated into the contact design:

1. Base material – Beryllium copper alloy 172, per FED-SPEC-QQ-C-533, Temper AT, was selected as the base material, primarily for its excellent spring properties after heat treatment. Properties after age hardening are:

Tensile Strength	11 600 - 13 357 kgf/cm^2 (165 - 190 $\times$ 10^3 psi)
Yield Strength	9842 - 11 900 kgf/cm^2 (140 - 170 $\times$ 10^3 psi)
Proportional Limit	7030 - 8788 kgf/cm^2 (100 - 125 $\times$ 10^3 psi)
Modulus of Elasticity "E"	13.0 $\times$ 10^5 kgf/cm^2 (18.5 $\times$ 10^6 psi)
Electrical Conductivity (min)	13.2/microhm-cm (22 percent IACS)

With this material, a contact spring has been designed which provides the necessary pressure for good electrical contact, and which continues to do so over a long period of connector use.

2. Plating – 0.0025 mm (0.0001 in.) of hard gold per MIL-G-45204, Type II, Class 2 over 0.0025 mm (0.0001 in.) of low stress nickel per QQ-N-290, Type VII is plated on the beryllium copper contact. The 23+ carat gold plate (99.0 percent gold) has a Knoop hardness of 130-250. This gold-over-nickel plating results in (a) good surface conductance, (b) prevention of copper corrosion, and (c) long wear. The nickel plating serves as a corrosion barrier and as a receiving surface for the gold plating, which provides excellent surface conductivity, resistance to corrosion, and resistance to contact wear.

3. Contact spring curvature – The contact area is coined to a spherical shape with a 1-mm (0.040-in.) radius. Coupled with the designed spring pressure, this allows for optimum elastic contact area, and therefore optimum area of conductivity.

4. Spring pressure – The spring deflection during plug insertion is 0.6 mm (0.025 in.) which causes about 0.177 kgf (0.39 lb) contact force. The resulting average contact pressure of 340 kgf/cm^2 (4835 psi) is sufficient for penetrating oxides and other surface contaminants, while low enough to prevent galling and severe plastic deformation. The sliding contact action results in maintenance of good conductivity between the two contact surfaces. Prevention of galling and excessive plastic deformation assures a long connector wearlife, far exceeding the MIL-SPEC requirements.

5. Spring cross section and length – Contact design provides for the shortest electrical path and greatest cross-sectional area for high conductivity, while maintaining the necessary spring force.

6. Wiping mechanism – When plug and receptacle are connected or disconnected, a wiping action occurs between mating contacts, thus maintaining clean surfaces for good electrical contact.

A summary of contact data can be found in Table 6. Detailed contact calculations and test data are located in Appendices B, C, D, and E.

TABLE 6. CONTACT DATA SUMMARY
FOR FCC TO ROUND WIRE CONNECTOR

Physical and Mechanical Data for Receptacle Spring Contact (Contact Spring Material: Copper Beryllium Alloy 172, FED-SPEC-QQ-C-533, Temper AT)	
Spring width and thickness	1 X 0.34 mm (0.04 X 0.013 in.)
Free bending length	7.6 mm (0.300 in.)
Deflection for mating	0.64 mm (0.025 in.)
Contact force	0.177 kgf (0.39 lb)
Spring rate	0.277 kgf/mm (15.6 lb/in.)
Hardness, after heat treatment	Knoop 360-414
Modulus of elasticity, E	13.0 X 10^5 kgf/cm^2 (18.5 X 10^6 psi)
Moment of inertia, I	32.0 X 10^{-8} cm^4 (0.77 X 10^{-8} in.^{4})
Section modulus, I/c	18.7 X 10^{-6} cm^3 (1.14 X 10^{-6} in.^{3})
Yield strength	9.8 - 11.9 X 10^3 kgf/cm^2 (140 - 170 X 10^3 psi)
Stress at max deflection	7.2 X 10^3 kgf/cm^2 (102 X 10^3 psi)
Contact form: spheric, radius	1.0 mm (0.040 in.)
Spring plating: nickel gold, hard	0.00250 mm (0.000100 in.) 0.00250 mm (0.000100 in.)
Physical and Mechanical Data for Plug Contact (FCC Termination) (Contact Material: Copper, soft, FED-SPEC-QQ-C-576)	
Flat conductor width X thickness	1 X 0.1 mm (0.040 X 0.004 in.)
Hardness	Knoop 74
Modulus of elasticity, E	11.0 X 10^5 kgf/cm^2 (16 X 10^6 psi)
Yield strength	703 kgf/cm^2 (10 X 10^3 psi)
Plating: Same as for contact spring	
Electrical Data	
Contact point resistance	0.7 mΩ
Contact spring resistance	2.76 mΩ

Round Wire Cable Termination

Round wire can be hand solder terminated to protruding ends of the spring contacts at the back of the receptacle. After soldering, each solder-joint is encased in a sleeve, and the entire junction area conformally coated, or potted with a resilient material. As an aid to hand soldering, a special fixture (Figs. 34 and 35) has been designed to accomplish two goals: (1) properly align round wires and solder lugs and (2) firmly hold wires and receptacle

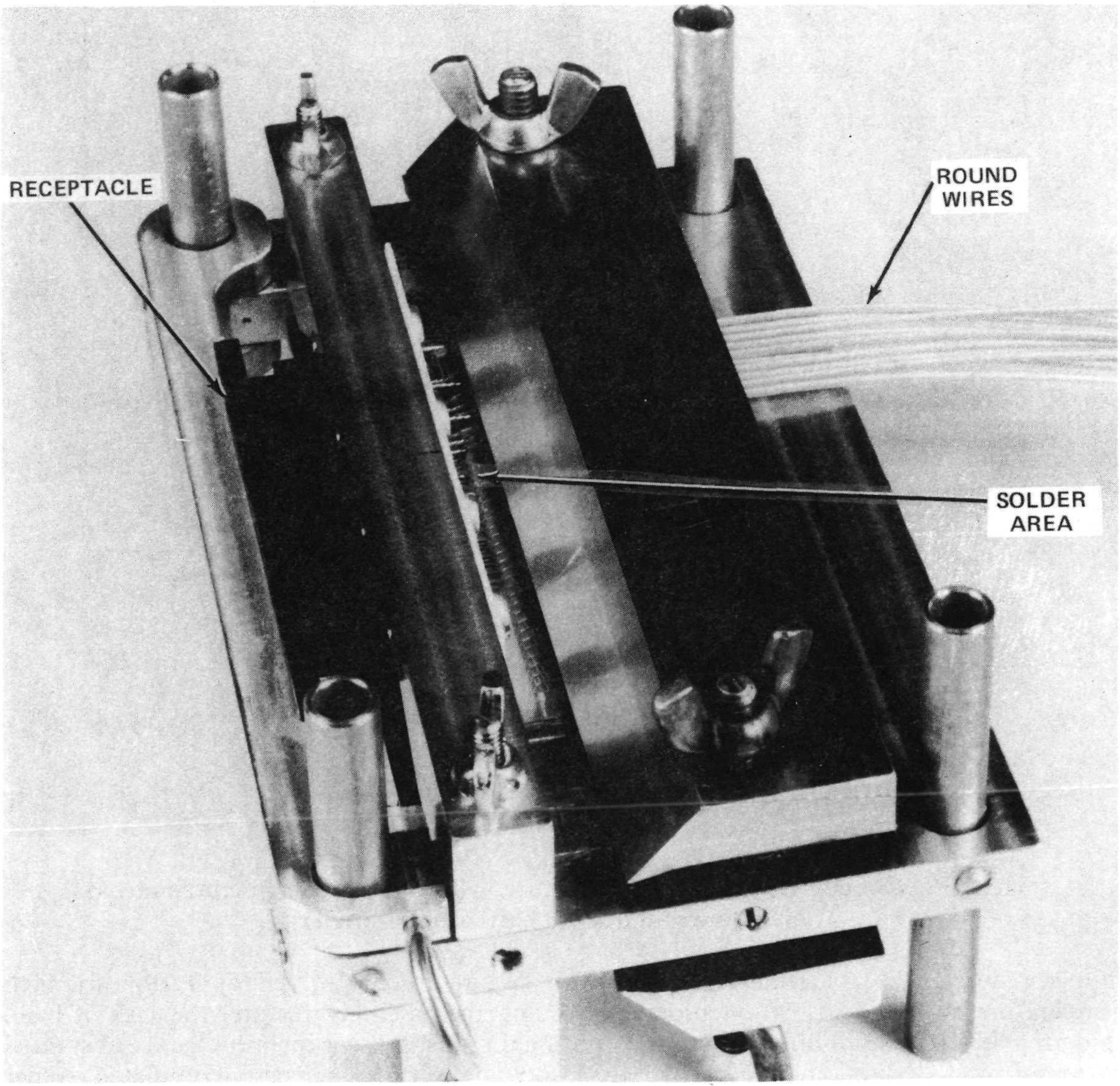


Figure 34. Fixture used in hand-soldering round wires to receptacle solder lugs (overall view).

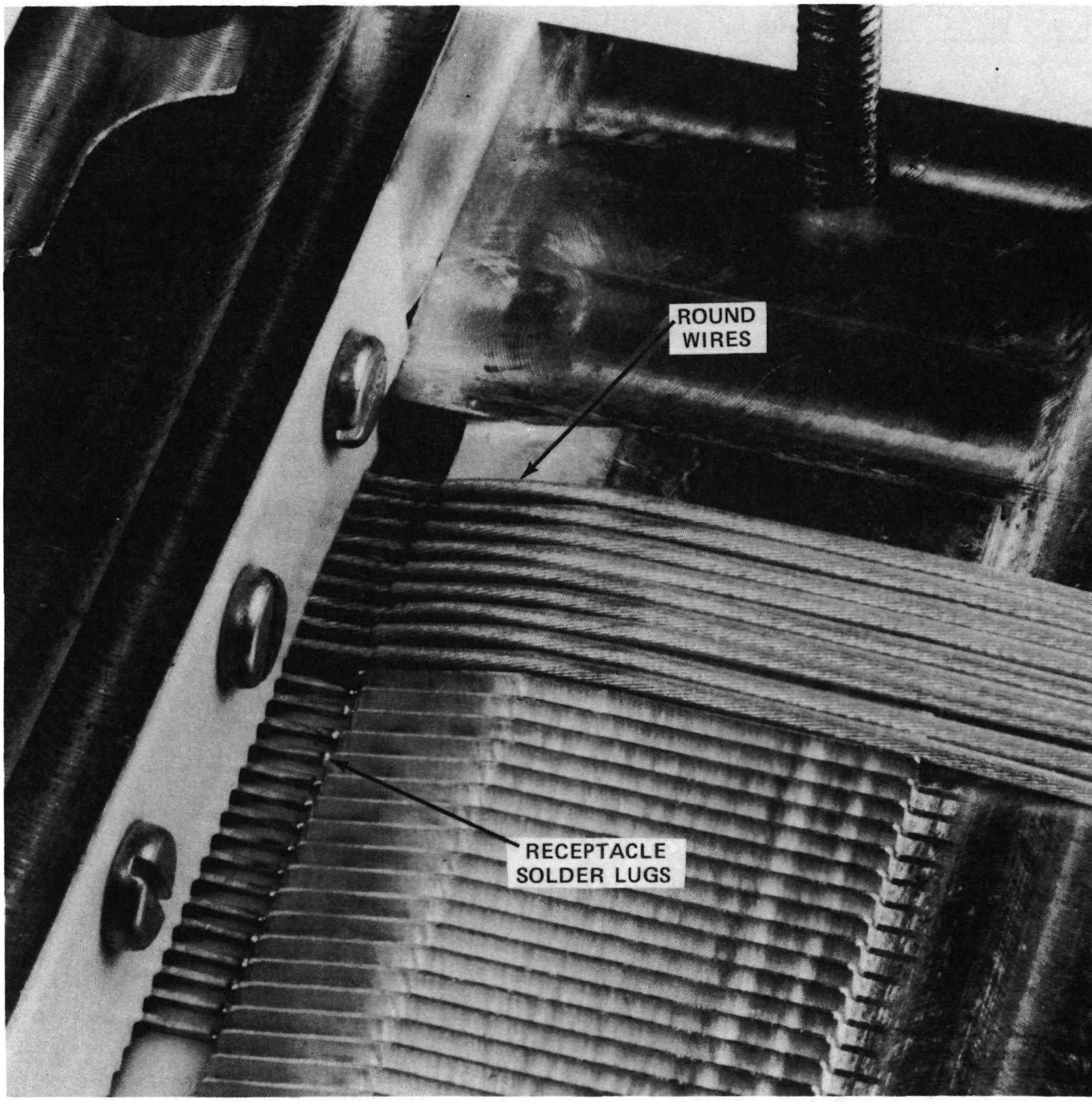


Figure 35. Closeup view of soldering fixture, with one clamping plate removed (only a few round wires have been inserted).

in place during the soldering operation. The fixture is constructed of Teflon for high temperature and heat insulation properties. Using the assembly fixture, the task of hand soldering is vastly simplified, thereby resulting in quality workmanship and substantial assembly cost reduction. Figure 36 is an example of a partially completed solder termination.

Another method of terminating round wires to the lugs, which is currently being evaluated for use in large scale connector production, is Raychem's Thermofit Solder Pak®

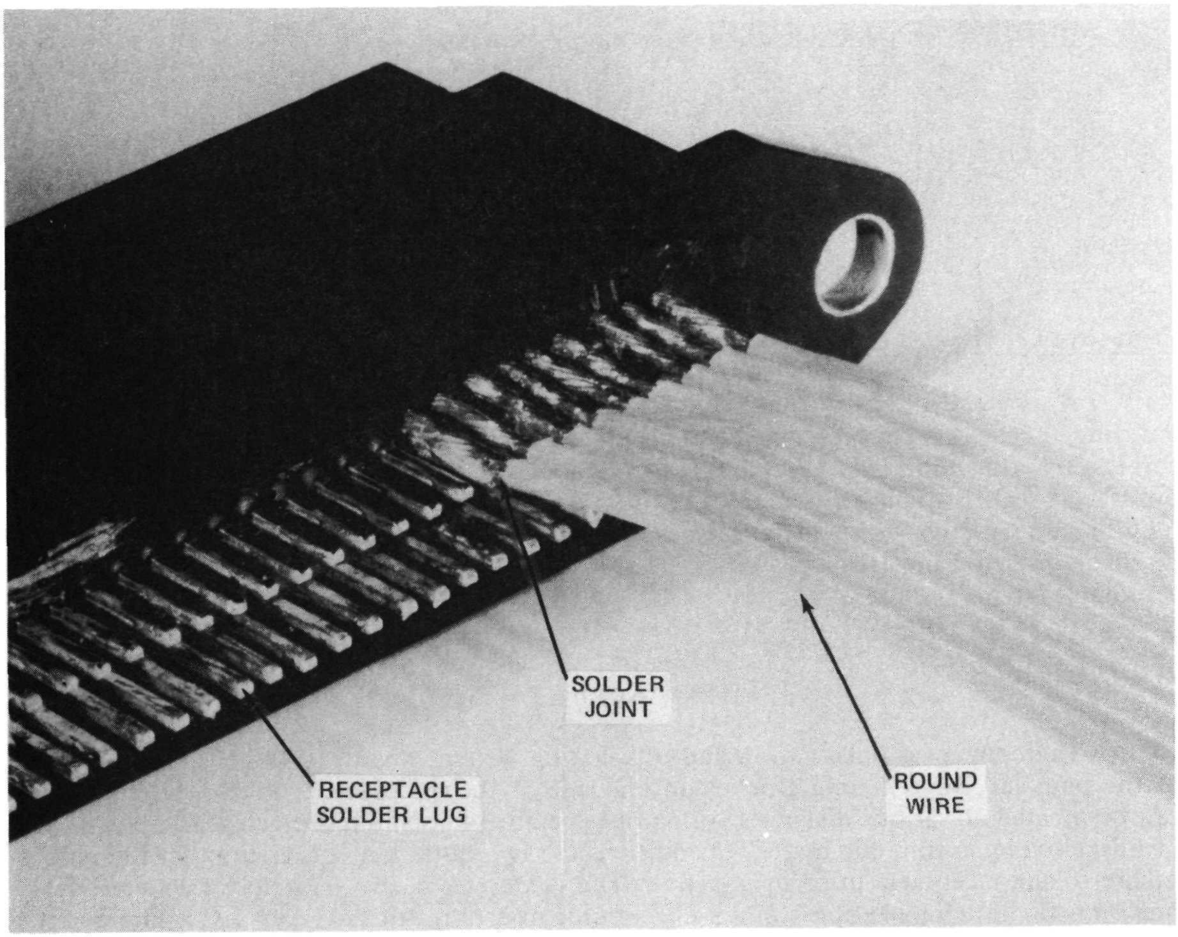


Figure 36. Partially completed solder termination.

System. The Thermofit Solder Pak is a continuous strip of multiply-packaged solder sleeves. These radiation cross-linked, heat-shrinkable sleeves contain a preform of solder and flux. The required length for one row is cut from the strip, sleeves slipped over solder lugs, and round wires inserted in place. Measured infrared heat shrinks the sleeves, melts the solder, and provides strain relief for the entire row of contacts all in one burst.

Mounting Gasket

The gasket (Fig. 37), constructed of durable silicone rubber with a shore hardness of 50 to 55, is used when the receptacle is to be mounted to an instrumentation box. It seals off the opening formed in the box for receptacle placement, preventing pressure losses as well as entry of degrading matter such as moisture. For inside or outside box mounting, the gasket can be placed on either side of the shell flange. When absolute pressure tightness is required, an additional seal must be placed under the heads of the mounting bolts.

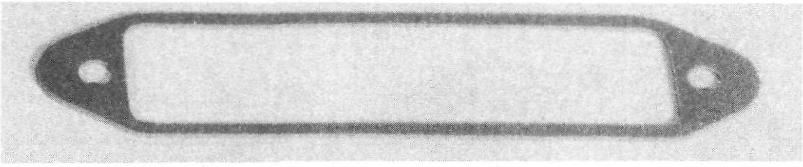


Figure 37. Mounting gasket for receptacle.

Protective Cover

A protective cover constructed of Lexan, shown in Figure 38, is available for covering the receptacle face when the receptacle is not mated. This protects the contact springs from handling damage and, when the cover is pressed against the receptacle interfacial seal, contaminants are sealed out. The cover is similar in design to that of the plug, including keys for guidance. However, an overhang has been added to each side as aids in cover insertion and removal. After insertion, the cover can be locked in place with the receptacle latch.

Keying

The connector polarization and positioning system consists of three ribs on one side of the plug and three mating grooves on one side of the receptacle. The two outer key sets can be located at various distances for pairing specific plugs and receptacles. The possibility of mismatching is thus eliminated. In addition, the two outer key sets assure that the plug is square to the receptacle prior to insertion. The center keys have very close tolerances for a precision fit, thus preventing binding during plug insertion. All three key sets assure correct plug-receptacle polarity. Ribs and mating grooves can be seen in Figure 1 and 27.

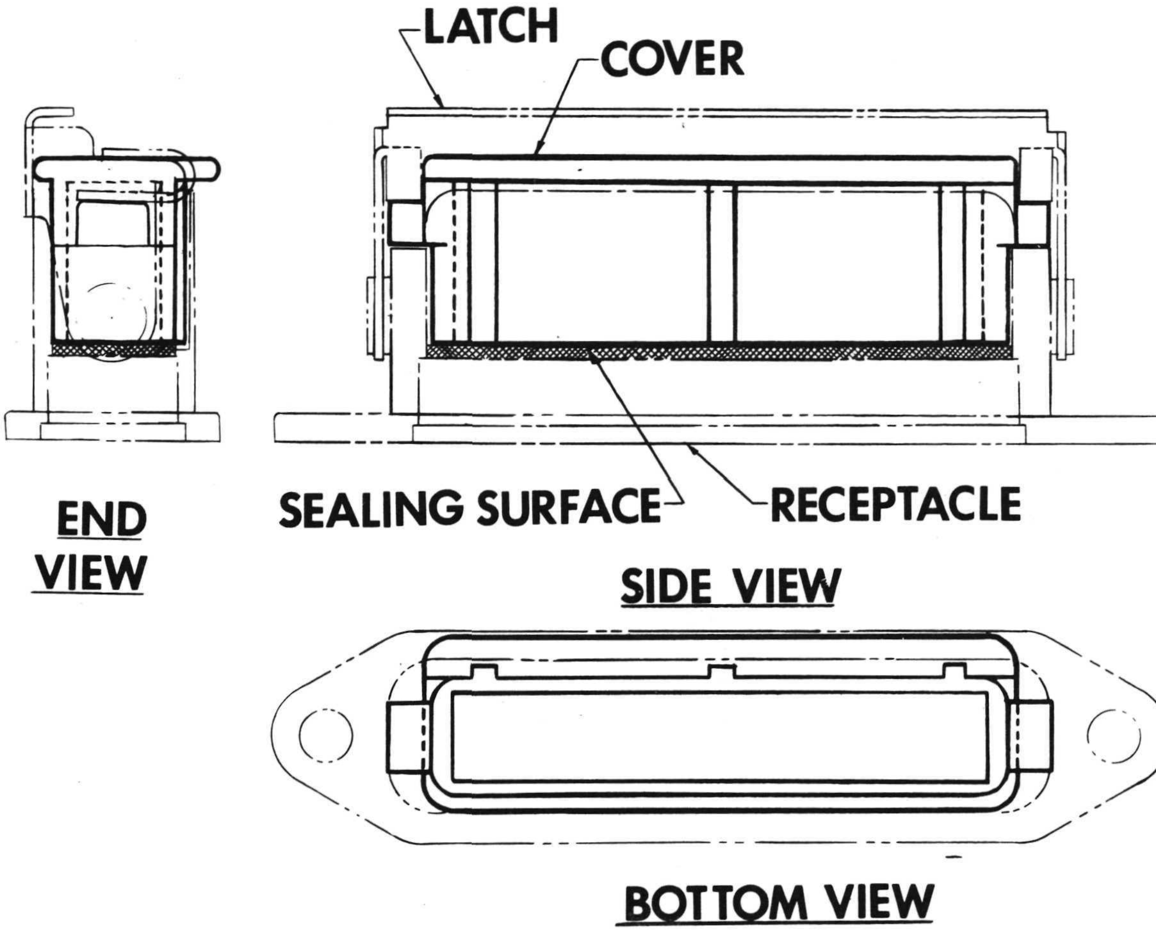


Figure 38. Receptacle protective cover.

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SECTION V

CONNECTOR: FCC TO FCC

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SECTION V. CONNECTOR: FCC TO FCC

General

Designed for FCC to FCC connections, this connector, shown in Figure 39, consists of a feed-through receptacle and two of the previously described plugs. Receptacle design incorporates many of the FCC to round wire receptacle features, and the connector keying mechanism is the same as that of the FCC to round wire connector. Table 7 contains physical and mechanical data for each of the five connector sizes, and Table 8 contains electrical data. Figure 40 shows the dimensions of the receptacle contact and lead wires used for the MIL-SPEC-55544 "total connector resistance" calculations in Table 8.

Receptacle (MR&Tsk-15375)

The FCC to FCC receptacle is shown in Figures 41 and 42, and receptacle dimensions are given in Table 9. All of the basic flat to round receptacle parts (and their materials) are used here, with the exception of the round wire terminal provision which has been eliminated. Some are precisely the same and, therefore, will not be mentioned in detail at this time. Two of the flat to round shells are joined at the base flange through the mounting holes to form a flat to flat shell, as shown in Figure 39. The same mounting gasket is also used, as well as two of the earlier noted interfacial seals, two latches, and two protective covers. However, some modifications have been made to the contact and molded insert design, as noted in the following paragraphs.

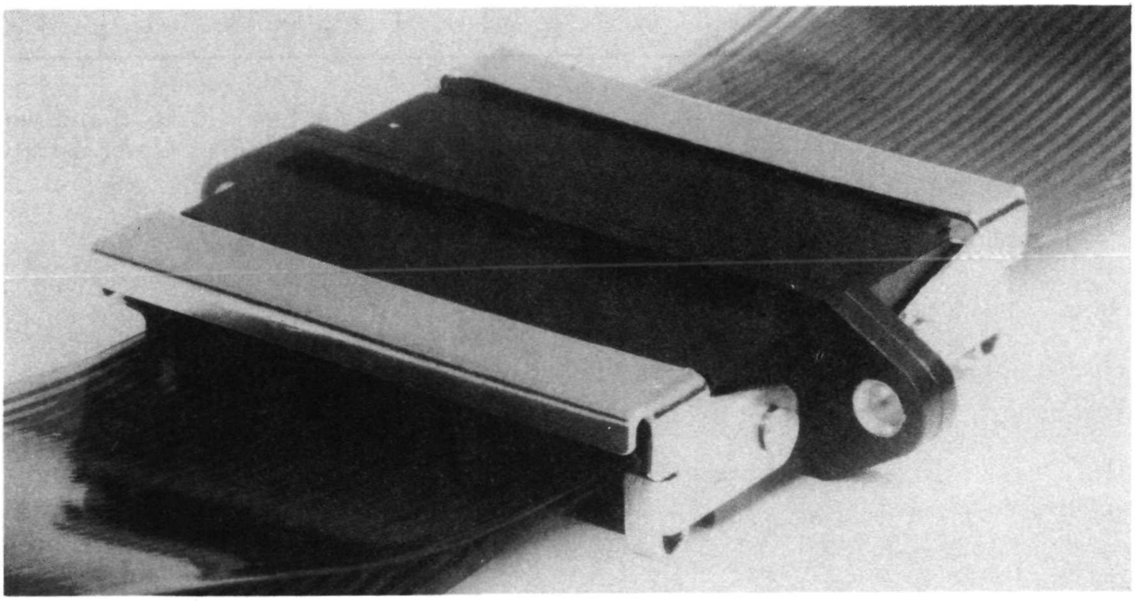


Figure 39. FCC to FCC connector.

TABLE 7. PHYSICAL AND MECHANICAL DATA FOR FCC TO FCC CONNECTORS (According to Cable Width)[a]

Cable Width	cm (in.)	2.54 (1.0)	3.81 (1.5)	5.08 (2.0)	6:35 (2.5)	7.62 (3.0)
Mated Connector Length	cm (in.)	5.92 (2.33)	5.92 (2.33)	5.92 (2.33)	5.92 (2.33)	5.92 (2.33)
Receptacle Weight[b]	g	50	60	70	80	90
Weight of Two Plugs[b]	g	8	12	16	20	24
Connector Total Weight[c]	g	58	72	86	100	114
Weight per Contact[d]	g	2.4	2.0	1.7	1.6	1.5
Mating Force, Maximum	kgf (lb)	0.9 (2)	1.35 (3)	1.8 (4)	2.25 (5)	2.7 (6)
Unmating Force, Maximum	kgf (lb)	0.68 (1.5)	1.04 (2.3)	1.35 (3.0)	1.67 (3.7)	2.03 (4.5)

a. Data for the following items are the same as noted for FCC to round wire connectors: (1) FCC data, (2) connector mounting area, (3) contact density, (4) temperature range and (5) wear-life. See Table 2.

b. With potting.

c. Includes two plugs with potting.

d. Connector weight divided by number of contacts.

TABLE 8. ELECTRICAL DATA FOR FCC TO FCC CONNECTORS[a]

	Resistance (mΩ)	
	Using AWG 27 or 4 X 40 mil Lead Wire	Using AWG 20 Lead Wire
Contact Point Constriction Resistance, for Two Contacts, Min	1.0	1.0
Contact Point Surface Resistance, for Two Contacts[b]	0.4	0.4
Contact Spring Resistance, Max[c]	4.4	4.4
Lead Wire Resistance[d]	21.4	4.2
Total Connector Resistance[d]	27.2	10.0

a. Data for the following items are the same as noted for FCC to round wire connectors: (1) voltage rating, (2) current rating, and (3) minimum insulation resistance. See Table 3.

b. Resistance due to surface contaminants and oxides.

c. Resistance from contact point to contact point.

d. Measured per MIL-C-55544A (25 June 1971), paragraph 4.6.12. Observe how the "total connector resistance" varies depending on which size lead wire is used. Using AWG 27 lead wire, the "total connector resistance" exceeds the MIL-SPEC maximum, while when using AWG 20 lead wire, the MIL-SPEC is met. The same connector is used in both examples, and therefore all internal resistance values are the same. If the "total connector resistance" measurement as defined by the MIL-SPEC is to be meaningful, the designer must know the size of the lead wire which was used.

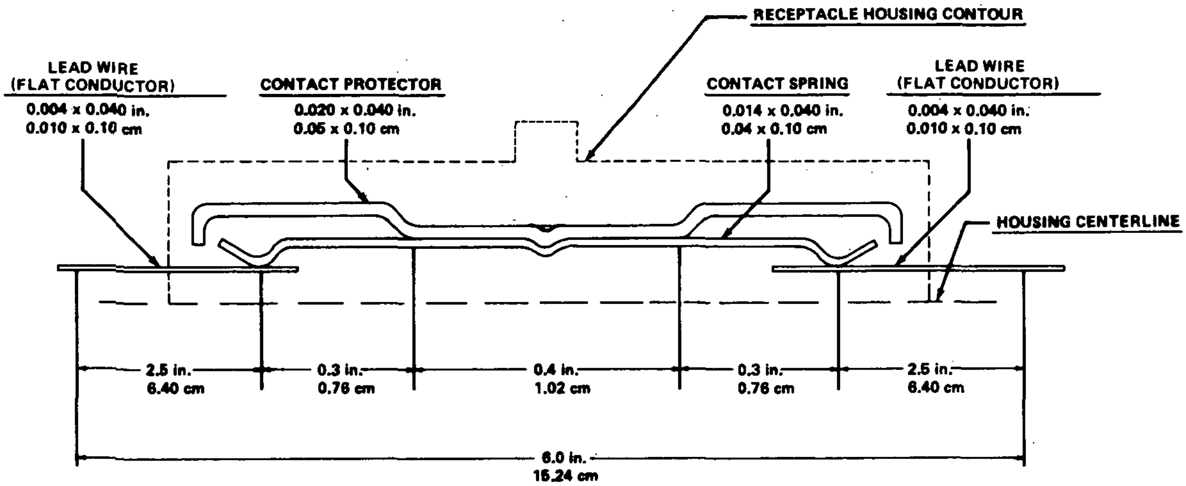


Figure 40. Contact and lead wires, with dimensions, used in calculating "total connector resistance" values, as defined by MIL-C-55544A.

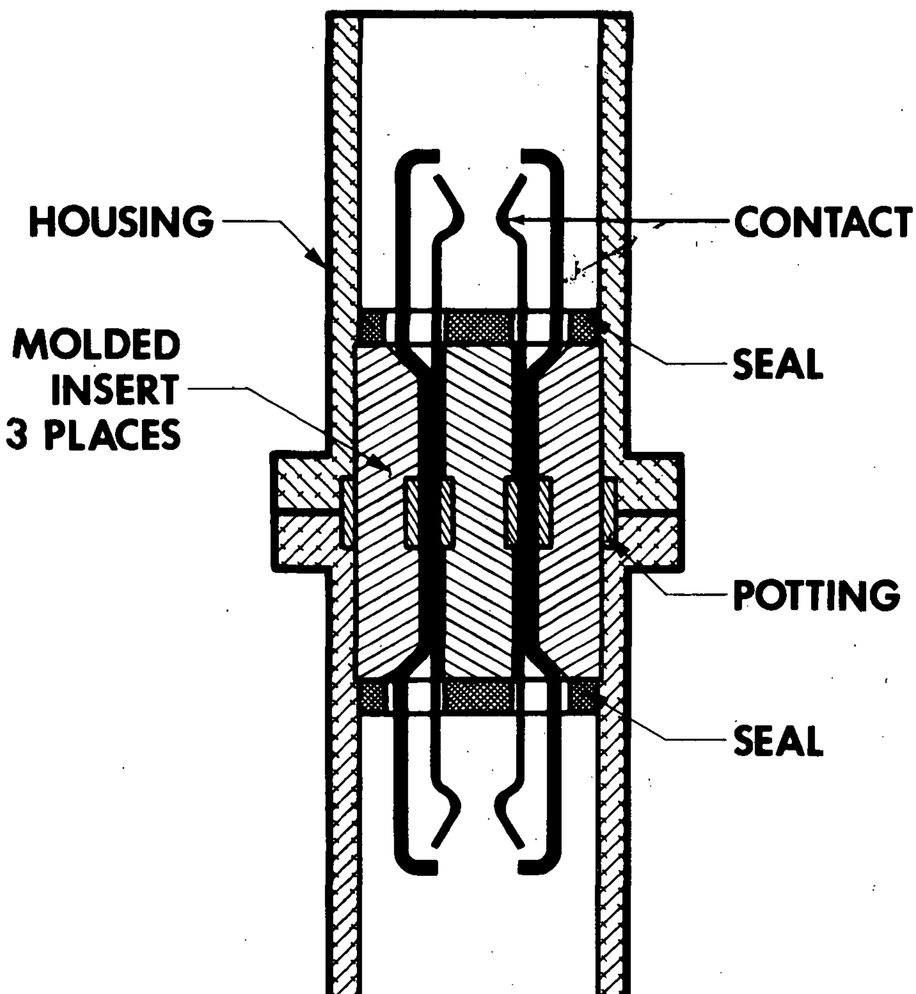


Figure 41. FCC to FCC receptacle.

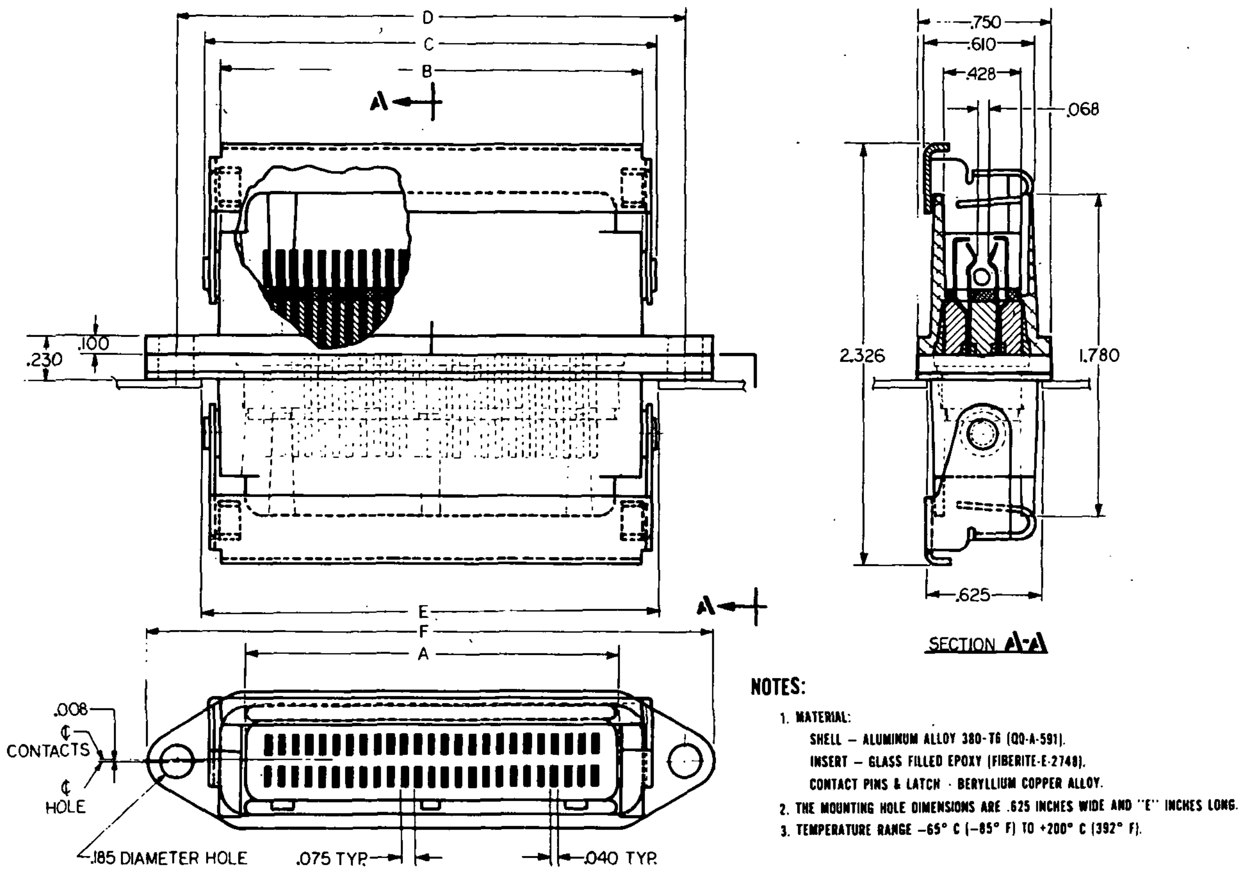


Figure 42. Specification drawing of FCC to FCC receptacle.

Contact

The dual-function contact design used in the flat to round receptacle is essentially the same used here, with these differences: (1) the contact spring and contact protector are two separate parts, (2) a slight bend is made in the center of each contact part as an aid for internal seal formation, and (3) no provision is made for round wire termination.

Three-Piece Molded Insert

A three-piece molded insert is used, containing special potting channels which fit around the contact centers. Potting injected into these channels through holes in the shell sides locks the contacts and insertion parts firmly in place and acts as a through-receptacle seal. As with the flat to round receptacle, "dummy plugs" are used to position the contacts prior to potting.

TABLE 9. SPECIFICATION DIMENSIONS OF FCC TO FCC RECEPTACLE (Size by Cable Width and Number of Conductors. Refer to Figure 41, Specification Drawing)

Cable Width	No. of Contacts	A	B	C	D	E	F
cm (in.)	(2 cables)	cm (in.)	cm (in.)	cm (in.)	cm (in.)	cm (in.)	cm (in.)
2.54 (1)	24	2.700 (1.063)	3.448 (1.358)	3.907 (1.538)	4.635 (1.825)	4.064 (1.600)	5.428 (2.137)
3.81 (1.5)	36	3.839 (1.513)	4.590 (1.807)	5.047 (1.987)	5.778 (2.275)	5.270 (2.050)	6.558 (2.582)
5.08 (2)	50	5.102 (2.038)	5.914 (2.332)	6.378 (2.512)	7.112 (2.800)	6.390 (2.575)	7.904 (3.112)
6.35 (2.5)	64	6.510 (2.563)	7.257 (2.857)	7.485 (2.947)	8.255 (3.325)	7.214 (2.840)	9.228 (3.637)
7.62 (3)	76	7.654 (3.013)	8.403 (3.307)	8.857 (3.487)	9.589 (3.775)	9.017 (3.550)	10.381 (4.087)

SECTION VI

CONNECTOR: FCC TO PC BOARD

SECTION VI. CONNECTOR: FCC TO PC BOARD

General Physical and Mechanical Data

This connector consists of plug MR&Tsk-1556 (described earlier), receptacle MR&Tsk-15424, and a 0.24-cm (0.093-in.) thick PC board. Table 10 contains physical and mechanical data for this connector. The receptacle is shown in Figures 43 and 44, and receptacle dimensions are given in Table 11.

TABLE 10. PHYSICAL AND MECHANICAL DATA FOR FCC TO PC BOARD CONNECTORS (According to Cable Width)[a]

Cable Width	cm (in.)	2.54 (1.0)	3.81 (1.5)	5.08 (2.0)	6.35 (2.5)	7.62 (3.0)
Mated Connector Length[b]	cm (in.)	1.8 (0.71)	1.8 (0.71)	1.8 (0.71)	1.8 (0.71)	1.8 (0.71)
Receptacle Weight[c]	g	44	53	62	71	80
Plug Weight[c]	g	4	6	8	10	12
Connector Total Weight[b,d]	g	48	59	70	81	92
Weight per Contact[e]	g	2.0	1.6	1.4	1.3	1.2

a. Data for the following items are the same as noted for FCC to FCC connectors: (1) FCC data, (2) connector mounting area, (3) contact density, (4) temperature range, (5) wear-life, and (6) maximum mating and unmating forces for plug to receptacle. See Table 7.

b. Excluding PC board.

c. With potting.

d. Includes one plug with potting.

e. Connector weight (excluding PC board) divided by number of contacts.

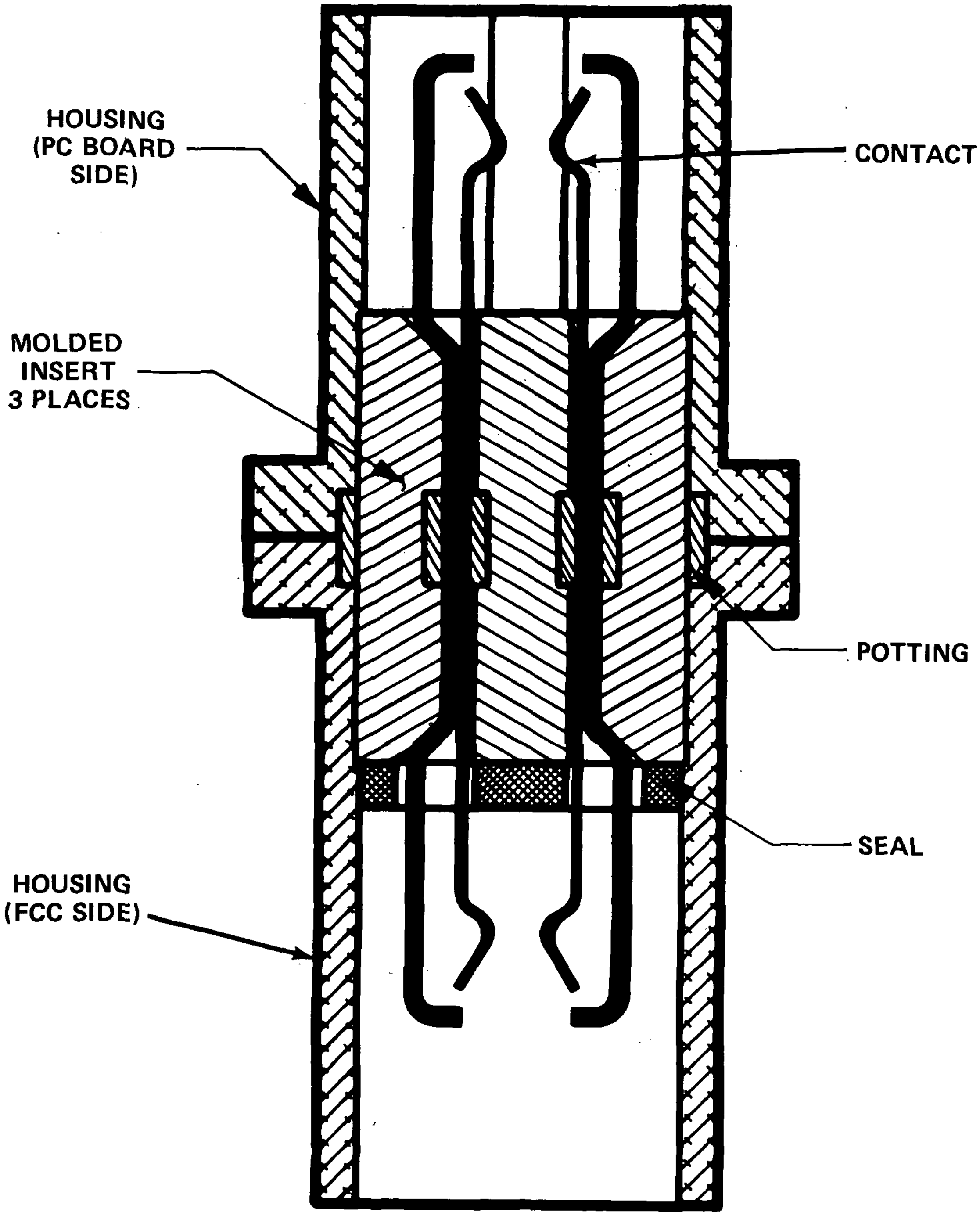


Figure 43. FCC to PC board receptacle.

Electrical Data

Voltage and current ratings, minimum insulation resistance, maximum connector resistance and maximum contact spring resistance are the same as for the FCC to FCC connector. However, the contact point resistance will be slightly higher. The PC board's thickness of 0.24 cm (0.093 in.) is less than the plug's thickness of 0.27 cm (0.108 in.) between receptacle contacts when plug and receptacle are mated. As a result, the receptacle contact pressure is decreased and, consequently, contact resistance is slightly increased.

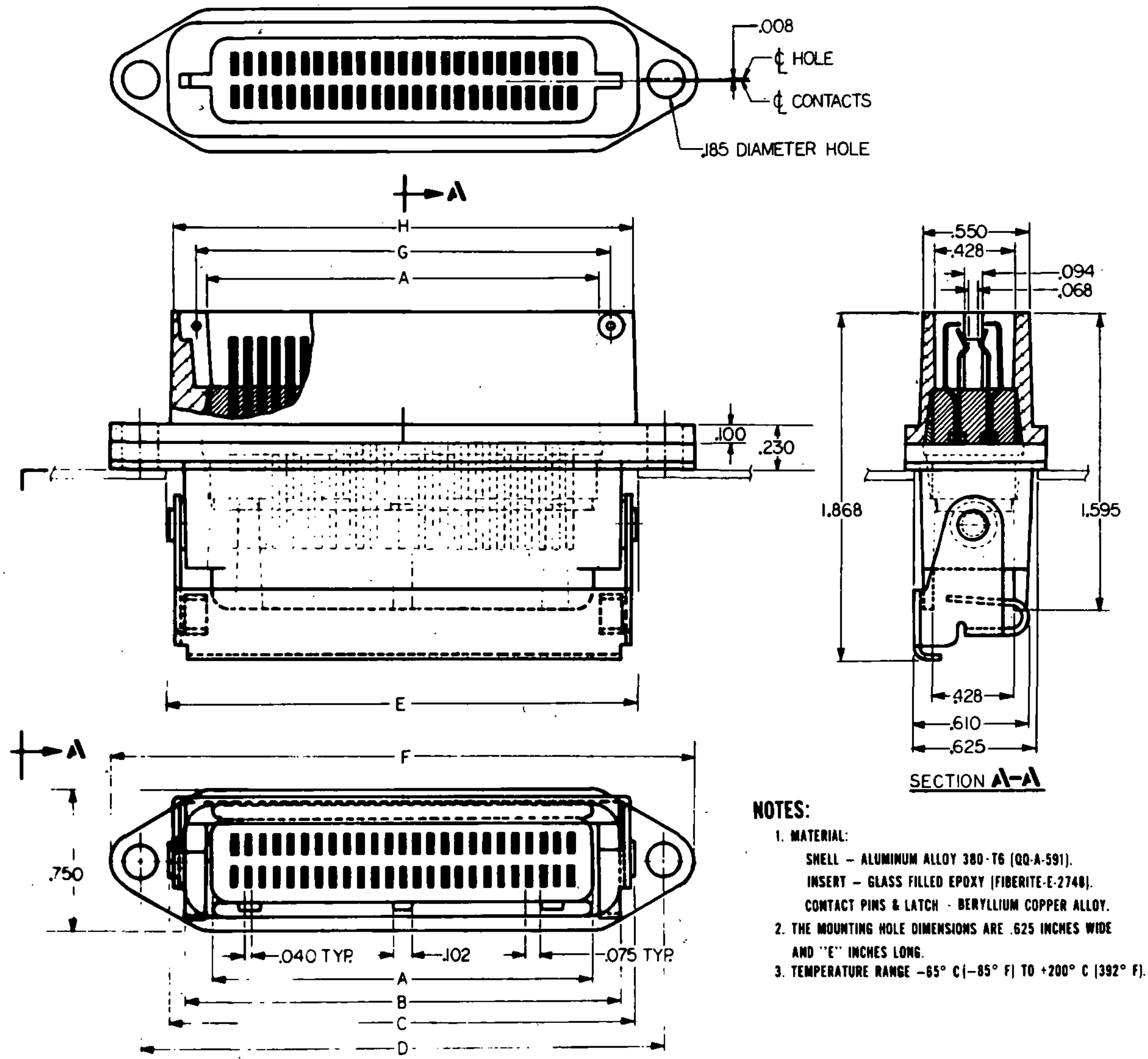


Figure 44. Specification drawing of FCC to PC board receptacle.

Design

The design of the receptacle for FCC to FCC connectors has been modified to enable FCC to PC board connections. The half for accepting an FCC plug is the same; however, the opposite half has been shortened and changed to accept and support a PC board. Locking of board and receptacle is accomplished by inserting two pins through shell and board. A keying system, consisting of a slight off-set in one board side and its mating receptacle groove, assures correct polarity of the inserted PC board.

TABLE 11. SPECIFICATION DIMENSIONS OF FCC TO PC BOARD RECEPTACLE (Size by Cable Width and Number of Conductors. Refer to Figure 43, Specification Drawing)

Cable Width	No. of Contacts	A	B	C	D	E	F	G	H
cm (in.)	(2 cables)	cm (in.)	cm (in.)	cm (in.)	cm (in.)	cm (in.)	cm (in.)	cm (in.)	cm (in.)
2.54 (1)	24	2.700 (1.063)	3.448 (1.358)	3.907 (1.538)	4.635 (1.825)	4.064 (1.600)	5.428 (2.137)	3.147 (1.239)	3.832 (1.509)
3.81 (1.5)	36	3.839 (1.513)	4.590 (1.807)	5.047 (1.987)	5.778 (2.275)	5.270 (2.050)	6.558 (2.582)	4.265 (1.689)	4.976 (1.959)
5.08 (2)	50	5.102 (2.038)	5.914 (2.332)	6.378 (2.512)	7.112 (2.800)	6.390 (2.575)	7.904 (3.112)	5.622 (2.214)	6.309 (2.484)
6.35 (2.5)	64	6.510 (2.563)	7.257 (2.857)	7.485 (2.947)	8.255 (3.325)	7.214 (2.840)	9.228 (3.637)	6.955 (2.739)	7.643 (3.009)
7.62 (3)	76	7.654 (3.013)	8.403 (3.307)	8.857 (3.487)	9.589 (3.775)	9.017 (3.550)	10.381 (4.087)	8.100 (3.189)	8.786 (3.459)

SECTION VII

SUMMARY OF REQUIREMENTS AND DESIGN FEATURES

SECTION VII. SUMMARY OF REQUIREMENTS AND RESPONSIVE DESIGN FEATURES

General requirements set up by NASA/MSFC when FCC connector design was initiated have been outlined in an earlier section. Design details for each connector have also been related as well as the specific requirements and needs which these designs meet. The following is a summation of requirements and design information.

Requirement	Design Feature
1. Low and uniform contact resistance	1. Contact springs are designed for high quality and repeatable characteristics.
2. Better electrical insulation between contacts at any barometric pressure and humidity	2. An individual housing of high dielectric-strength material encloses each mated contact pair.
3. Greater ease in handling	3. One-piece latch replaces earlier two-clip system.
4. Improved locking system to prevent accidental plug-receptacle separation	4. One-piece over-center latch is much more substantial than earlier two-clip systems. A metal strip provides safety locking.
5. Improved environmental sealing	5. Each mated plug-receptacle contact pair is individually sealed.
6. Protection for exposed plug and receptacle contacts	6. A receptacle protective cover and a plug protective cover provide contact protection from handling damage when connector is disconnected, and act as environmental seals.
7. Protection for spring part of receptacle contact	7. Contact design includes a protector which prevents damage from handling.
8. Improved connector keying system	8. Three sets of keys provide polarity and guidance for plug insertion, and prevent mismatching of plugs and receptacles.
9. Increased reliability	9. This is the net result of all of the preceding design features. Some are specifically directed to improving electrical operation. These include contact design for lower total connector resistance, individual contact seals for less electrical leakage, and a solder-aid assembly for obtaining better solder joints. Several other features (receptacle contact protector, improving keying, plug and receptacle protective covers) prevent handling damage, while still additional features (improved sealing, more rugged latch) prevent damage from contaminants such as moisture. The overall simplicity of design also contributes to reliability.

Requirement (Continued)	Design Feature (Continued)
10. Lower costs	10. (a) A one-piece plug has replaced the previous four to five piece assemblies. (b) The receptacle shell is designed to be die-cast aluminum. (c) Use of a simple contact positioning tool for potting eliminates the necessity for high-tolerance contact spacings within the receptacle insert. (d) Use of a special assembly fixture simplifies the task of hand-soldering round wires to receptacle lugs for FCC to round wire connections. Use of Raychem's Thermofit Solder Pak® method of automatically forming solder terminations will also reduce manhours.

SECTION VIII

COST COMPARISONS

SECTION VIII. COST COMPARISONS

Low Manufacturing Costs

After initial tooling expenditures, production costs for this connector should be considerably less than those of comparable round wire cable connectors, for the following reasons.

Low Number of Parts

The FCC connector has an exceedingly low number of pieces, accounted for in large part by the one-piece plug and the use of cable conductors as plug contacts, thus eliminating the need for additional contact pins. When this connector is compared with the standard round wire cable connector in Table 12, a large disparity in number of parts is evident.

The number of parts required for the MS 24-contact round wire connector is almost 2 1/2 times that required for the comparable FCC to FCC connector. Figures are even more startling when larger connectors of the same two series are compared. The NASA FCC to FCC connector with 50 contacts has a total of 121 parts. Compare this with a total of 325 parts for a comparable MS connector – an increase of 270 percent!

Inexpensive Production Techniques

Part design is compatible with the most inexpensive production techniques. None of the parts are machined. They are either punched and formed (latch, contacts), stamped (gasket), injection molded (plug, seal, insert), or die-cast (shell).

Few Surface Treatment Requirements

Surface treatment (plating, anodizing) requirements are low. Many parts (plug, seal, insert, gasket) are constructed of rubber or plastic and, thus, do not need a corrosion-resistant finish.

Low Material Cost

Material costs are negligible because of (a) extensive use of inexpensive materials, (b) small parts, and (c) the low requirements for plating with costly metals.

Low Cable Termination and Connector Assembly Costs

Undoubtedly the greatest potential cost savings in FCC connector systems arises through ease of connector assembly and cable termination. The low number of parts to fit and the ability to treat all flat cable conductors as a single unit inevitably results in low costs, relative to round wire cable systems.

TABLE 12. COMPARISON IN TOTAL NUMBER OF PARTS OF A STANDARD ROUND WIRE CABLE CONNECTOR AND OF FCC CONNECTORS

24-Contact/Pin Connector for Round Wire to Round Wire

Straight plug MS24266R

Single hole mounting receptacle MS24265R

No. of Parts	Part Type
72	Contact-containing locks (24 locks, each with 3 pieces)
72	Contact parts (pin contacts, socket contacts, contact springs)
25	Additional parts (including potting, excluding mounting screws)
TOTAL 169	

(1) 24-Contact NASA/MSFC Connector for FCC to FCC

Two plugs MR&Tsk-1556
Receptacle MR&Tsk-15375

No. of Parts	Part Type
48	Contact parts
21	Additional parts (including potting, excluding mounting screws)
TOTAL 69	

(2) 24-Contact NASA/MSFC Connector for FCC to Round Wire

Plug MR&Tsk-1556
Receptacle MR&Tsk-15395

No. of Parts	Part Type
24	Contact parts
11	Additional parts (including potting, excluding mounting screws)
TOTAL 35	

Few Parts

NASA/MSFC has always placed emphasis on elimination of unnecessary parts, thereby cutting both manufacturing and assembly costs. Further reduction has been made in this latest FCC connector design. All functions of earlier four- to five-part plugs have been replaced by a single part. The previous two-part latching system has been replaced by one piece. These innovations, coupled with the historical elimination of needless contact pieces by use of cable conductors as plug contacts, have resulted in a connector with a minimum of parts – and with a high level of reliability.

Ease With Which FCC Can Be Terminated

Because of the planar design of FCC, all conductors of a cable can be treated as one unit, an impossibility with round wire bundles. FCC thus lends itself well to labor-saving automation techniques.

The conductors of FCC are always maintained in a set sequence. Therefore, electrical ringout of individual wires is unnecessary, making wiring mistakes by shop personnel virtually impossible. This is not the case for termination of round wire bundles to connectors. Each round wire must be electrically selected to be placed in the proper pin location, a time-consuming procedure with attendant high costs as well as likelihood of wiring mistakes.

Soldering Aids for Round Wire Termination

Total connector assembly time has been further reduced for this newest FCC series, through use of a simple device which aids hand-soldering round wires to terminals. This assembly, described earlier, properly aligns round wires with solder lugs and firmly holds wires and receptacles in place during the soldering operation. The end result: task simplification and quality workmanship.

Use of Raychem's Thermofit Solder Pak® method of automatically forming solder terminations will also reduce manhours.

Stop-watch Assembly Study

As proof of the low assembly time required for this connector, a stop-watch laboratory study was conducted to determine average time for plug assembly on a small production level. Only 7 1/2 man-minutes were required to completely assemble a plug, including termination of two cables, gold plating conductor ends, and potting the plug back. Without plating, only 4 1/2 minutes were required. A time savings of over 2 minutes per plug assembly is noted when comparison is made with NASA's earlier FCC molded-on plug. This savings results from elimination of the molding, trimming, and gasket-fitting operations. On a mass production level, assembly time would be considerably improved. Details of the study are found in Table 13.

TABLE 13. ASSEMBLY TIME FOR 3.8-cm (1.5-in.) PLUG[a]

Operation	Average Time per Operation (sec)
Cut two cables	9
Strip two cable ends	28
Plate two cable ends	188
Fold two cable ends	106
Pot plug back	120
TOTAL (including plating)	451 (or 7 1/2 man-minutes)
TOTAL (not including plating)	263 (or 4 1/2 man-minutes)

a. Assembly time for other plug sizes would be the same except for potting time, which would be slightly less for the 2.5-cm (1-in.) size and slightly greater for the 5.1-cm (2-in.) and above.

SECTION IX

TESTING

SECTION IX. TESTING

This connector series has been designed to meet or exceed MIL-C-55544, Connectors, Electrical, Environmental Resistant, For Use With Flexible Flat Conductor Cable, General Specification For; and MSFC-SPEC-219A, Connectors, Flat Conductor, Flexible Electrical Cable.

Because the new FCC connector has evolved from earlier NASA models, much of past testing is applicable. All materials used are well known and properties are established. A complete listing of construction materials and applicable military specifications and standards is contained in Appendix F. Many connector design features have been retained from the past and, therefore, all tests related to these aspects apply as well to MSFC's newest series. In Tables 14 and 15, each part of the FCC to round wire connector design is noted, compared, and contrasted with earlier models. One clearly sees that many features are exactly the same or quite similar and, thus, do not require extensive additional testing. The major new areas are the capabilities of the individual contact sealing system and of the retainer. Handmade sample connectors have been tested with satisfactory results. When production samples become available, extensive qualification testing will be conducted.[1]

1. A NASA report on items of equipment used to test FCC and connectors is currently in preparation.

TABLE 14. DESIGN FEATURES OF THE NEW PLUG AS COMPARED WITH THE EARLIER MODEL[a]

Part	Retained Features	New Features
Contacts	Flat cable conductors are used as contacts.	None
Rear Sealing	Potting	None
Plug Body	Plug is basically rectangular, contains the contacts, and when mated fits in the receptacle shell.	(a) One piece replaces four to five. (b) Individual housings are provided for contacts. (c) When plug face is pressed against receptacle interfacial seal, each mated contact pair is sealed off (old: peripheral seal only) (d) Keying ribs assure correct polarity when inserting plug, and prevent mismatching plugs and receptacles (old: polarity provision only)

a. 2.5- to 7.6-cm (1- to 3-in.) sizes only.

TABLE 15. DESIGN OF NEW FCC TO ROUND WIRE RECEPTACLE AS COMPARED WITH EARLIER RECTANGULAR MODELS[a]

Part	Retained Features	New Features
Shell	(a) Mounting area size and basic configuration (b) Shell extension for contact protection (c) Holes for screw mounting of connector (d) Holes for latch attachment	(a) Key slots are present for plug ribs (b) Gasket can be mounted on either side of flange (old: only one side)
Locking Mechanism	(a) Over-center latch design (b) Latch pivots about trunnions which are attached to the shell (c) Latch spring action holds plug and receptacle together (d) Latch extension for ease in locking and unlocking (e) Safety wire	(a) One latch replaces two (b) Heavier, more rugged construction (c) More uniform latching force
Rear Sealing	Potting	None
Mounting Gasket	Basic configuration	None
Insert	Molded parts locate contacts	Simpler design, fewer parts
Interfacial Seal	None	Part designed for sealing individual contacts
Contacts	(a) A solder lug for round wire termination is part of the contact (b) A spring provides pressure for junction with plug contact	Part of the contact acts as a protector for the spring portion

a. See Figures 9, 12, and 39.

SECTION X

CONCLUSION

SECTION X. CONCLUSION

NASA's new FCC connector with individually sealed contacts, designed to operate effectively at all altitudes, is the result of a long history of development. Proven features of earlier models have been retained, such as the use of conductor as plug contact for increased reliability. Many improvements have also been incorporated. The single most significant new feature is the sealing system for each plug-receptacle mated contact pair, a system occurring when the plug, containing recessed and individually housed contacts, is pressed against the receptacle interfacial seal. The resulting solid dielectric enclosures provide complete corona safety at critically low gas pressures, as well as improved environmental protection. Other design advancements include one-piece latch design, and several modifications for lower production costs and improved quality.

Although developed to meet stringent aerospace requirements, this connector will be equally suitable for many commercial uses and should be considered whenever specifications include low weight, low volume, low cost, high reliability under severe operating conditions, and long wear-life.

It has often been said that the one greatest impediment to widespread application of FCC is the lack of suitable termination hardware. Thus, this latest family of NASA FCC connectors is of great importance to the field, and combined with recent commercial efforts will markedly help to alleviate the hardware problem.

APPENDIX A

LATCH SPRING CALCULATIONS

APPENDIX A

LATCH SPRING CALCULATIONS

The latch used on the receptacles for locking plug to receptacle is shown in Figure A-1. Figure A-2 is a drawing (with data) of a latch spring. In the following paragraphs, force and deflection calculations for this spring are provided.

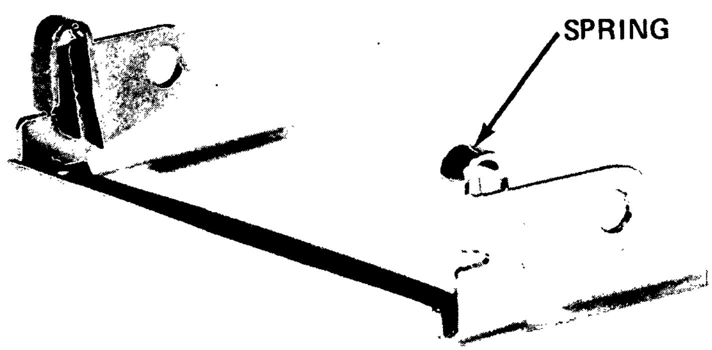
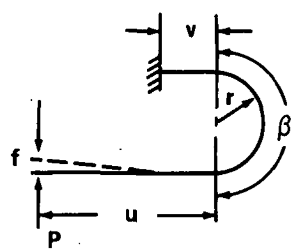


Figure A-1. Receptacle latch.



$v = 0.76$ mm
$u = 4.59$ mm
$r = 1.58$ mm
b = SPRING WIDTH = 3.05 mm
h = SPRING THICKNESS = 0.81 mm

MATERIAL: BERYLLIUM COPPER 172
σ: MAXIMUM BENDING STRESS: 8.4 8.4×10^3 kgf/cm^2
E: MODULUS OF ELASTICITY: 1.3×10^6 kgf/cm^2

Figure A-2. Latch spring.[2]

2. Product Engineering, Sept. 1960.

Spring Force

The expression for spring force P is given by the equation

$$P = \frac{S\sigma}{u + r} , \tag{A-1}$$

where σ is the maximum bending stress ($\sigma = 8.4 \times 10^3$ kgf/cm²), u and v are given in Figure A-2, and S is the section modulus and is given by

$$S = \frac{bh^2}{6} , \tag{A-2}$$

where b and h are given in Figure A-2. Substituting the values given in the figure in equations (A-2) and (A-1), respectively, the following values have been calculated:

$$S = 3.356 \times 10^{-4} \text{ cm}^3 ,$$

$$P = 4.6 \text{ kgf per spring} .$$

Spring Deflection

The spring deflection f is given by the empirical equation

$$f = \frac{P}{3EI} [1.82r^3 (m + 1.57)^3 + (u - v)^3] , \tag{A-3}$$

where P is given in equation (A-1); E is the modulus of elasticity ($E = 1.3 \times 10^6$ kgf/cm²); u, v, and r are given in Figure A-2; I is the moment of inertia and is given by

$$I = \frac{bh^3}{12} , \tag{A-4}$$

where b and h are given in Figure A-2; and m = u/r. Substitution of numerical values in equations (A-4) and (A-3) gives

$$I = 1.37 \times 10^{-5} \text{ cm}^4 ,$$

$$m = 2.88 ,$$

$$f = 0.6 \text{ mm} .$$

APPENDIX B

SPRING CONTACT FORCE CALCULATIONS FOR THE FCC TO ROUND WIRE RECEPTACLE

APPENDIX B

SPRING CONTACT FORCE CALCULATIONS FOR THE FCC TO ROUND WIRE RECEPTACLE

Maximum Stress

The maximum stress σ is given by the equation

$$\sigma = \frac{3Ehf}{2\ell_1^2} \quad , \qquad \text{(B-1)}$$

where E is the modulus of elasticity ($E = 1.3 \times 10^6$ kgf/cm^2), f is the maximum deflection ($f = 0.635$ mm), and h and ℓ_1 are shown in Figure B-1. Substitution of these numbers in equation (B-1) gives

$$\sigma = 7.206 \times 10^3 \text{ kgf/cm}^2$$

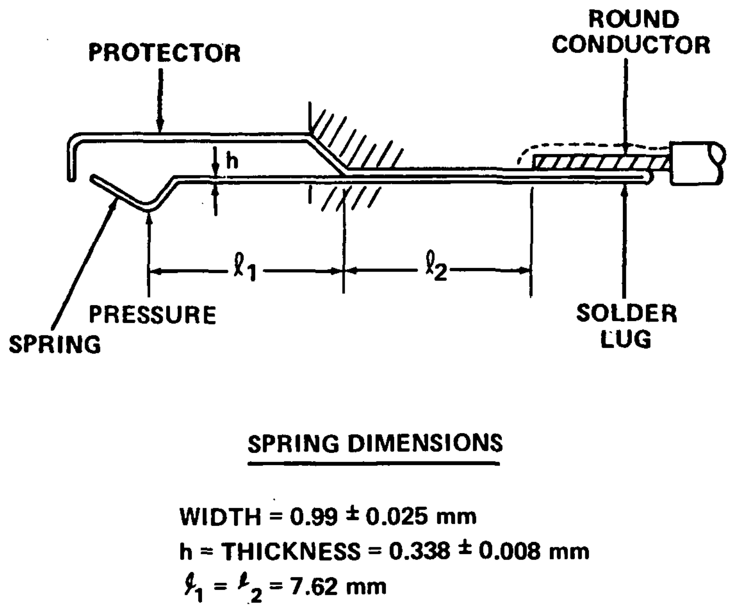


Figure B-1. Receptacle spring contact.

Contact Force at 0.635 mm Deflection

Contact pressure P is given by the equation

$$P = \frac{\sigma\left(\frac{I}{c}\right)}{\ell_1} \quad , \tag{B-2}$$

where σ is given in equation (B-2), ℓ_1 is shown in Figure B-1, and I/c is the section modulus and is given by

$$\frac{I}{c} = \frac{bh^2}{6} \quad , \tag{B-3}$$

where b is the width and h is the thickness (shown in Figure B-1). Substitution of values in equations (B-2) and (B-3) yields

$$I/c = 1.87 \times 10^{-5} \text{ cm}^3 \quad ,$$

$$P = 0.177 \text{ kgf} \quad .$$

APPENDIX C

CONTACT PRESSURE CALCULATIONS FOR THE FCC TO ROUND WIRE CONNECTOR

APPENDIX C

CONTACT PRESSURE CALCULATIONS FOR THE FCC TO ROUND WIRE CONNECTOR

If the maximum pressure which exists in the middle of the compressed surface between a sphere and a plane does not exceed the elastic limit of the materials, the following Hertz Equation can be applied:

$$S_{max} = \left(\frac{0.0584\,PE^2}{r^2}\right)^{1/3} , \tag{C-1}$$

where S is the maximum pressure; P is force, 0.177 kgf; E is the modulus of elasticity; and r is the radius of the spherical surface, 1.0 mm.

Calculations show that the maximum pressure of the involved contact materials does exceed their elastic limits because of the small radius of 1.0 mm of the spherical contact surface at the applied compression force of 0.177 kgf. Therefore a plastic deformation will occur, so that the maximum contact pressure cannot be calculated using the above equation. The compression strength of the beryllium copper spring is four to five times greater than that of the copper conductor, therefore the plastic deformation will occur mainly on the soft conductor. Assuming that the 0.0025 mm thick gold plating over 0.0025 mm nickel plating and the beryllium copper spring will have a negligible effect on the deformation, the required contact surface area "A" is

$$A = \frac{P}{\sigma_y} = 2.5 \times 10^{-4}\ \text{cm}^2 , \tag{C-2}$$

where σ_y is the yield strength of the conductor ($\sigma = 7.03 \times 10^2$ kgf/cm^2).

The contact area of the engaged connector will be approximately semicircular, having a diameter D:

$$D = \left(\frac{8A}{\pi}\right)^{1/2} = 0.253\ \text{mm} , \tag{C-3}$$

and depth h:

$$h = r - 0.5\,(4r^2 - D^2)^{1/2}$$

$$= 0.008\ \text{mm} . \tag{C-4}$$

Tests with similar contacts showed that the actual diameter of the contact area is approximately 25 percent less than calculated using the above formula. The plating of the surfaces with hard gold over nickel, work-hardening of the materials caused by repeated connector mating, and elastic deformation of the materials contribute to this reduction. Therefore the actual diameter of the contact area of this contact is approximately $D = 0.19$ mm and the depth change σ is

$$\sigma = h - h'$$

$$= 0.0035 \text{ mm} \quad . \tag{C-5}$$

APPENDIX D

ELECTRICAL RESISTANCE OF THE FCC TO ROUND WIRE RECEPTACLE CONTACT SPRING

APPENDIX D

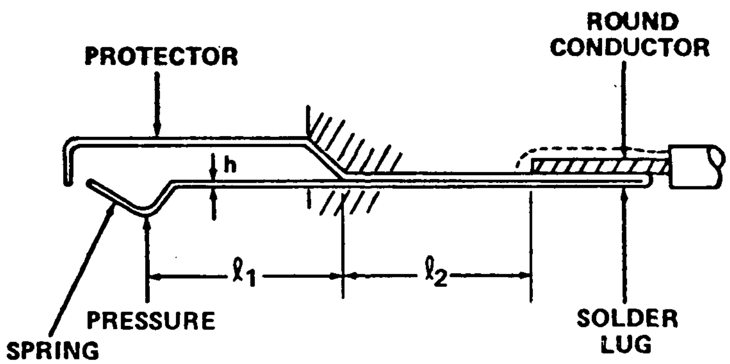
ELECTRICAL RESISTANCE OF THE FCC TO ROUND WIRE RECEPTACLE CONTACT SPRING

Flat copper conductors 1 × 0.1 mm are generally used with this connector. They have a cross-sectional area of 0.1 mm², which is equivalent to wire size AWG 27. For equal resistance at the same length, a beryllium copper alloy 25 conductor must have a cross section of 0.455 mm² because its conductivity is only 22 percent that of copper. The cross-sectional area of part ℓ_1 of the contact spring (Fig. D-1) is 0.33 mm² and that of part ℓ_2 is 0.66 mm². The resistance of ℓ_1 is, therefore, 42 percent higher than that of an AWG 27 copper conductor and that of ℓ_2 is 29 percent lower. A copper conductor AWG 27 has a resistance of 0.172 ohm/m. The resistance of ℓ_1 and ℓ_2 of the contact spring is, thus,

$$R_{\ell_1} = 1.84 \times 10^{-3} \text{ ohm}$$

$$R_{\ell_2} = 0.92 \times 10^{-3} \text{ ohm} \quad . \qquad \text{(D-1)}$$

The total resistance of the contact spring from the contact point to the solder joint is 2.76×10^{-3} ohm, while an equally long piece of AWG 27 copper would have 2.6 mΩ, which is about the same as the spring net resistance.



SPRING DIMENSIONS

WIDTH = 0.99 ± 0.025 mm
h = THICKNESS = 0.338 ± 0.008 mm
$\ell_1 = \ell_2 = 7.62$ mm

Figure D-1. Receptacle contact.

Calculations included in Appendix E show the contact point constriction resistance to be 0.5×10^{-3} ohm. The total resistance introduced by the contact spring and the contact point is

$$R = (\underbrace{1.84 + 0.92}_{\substack{\text{contact spring} \\ \text{resistance}}} + \underbrace{0.5}_{\substack{\text{contact} \\ \text{constriction} \\ \text{resistance}}} + \underbrace{0.2}_{\substack{\text{contact} \\ \text{surface} \\ \text{resistance}}}) \times 10^{-3} = 3.46 \times 10^{-3} \text{ ohm} \qquad \text{(D-2)}$$

A continuous copper conductor AWG 27 in place of the contact spring has a resistance of

$$R_{Cu} = 2.6 \times 10^{-3} \text{ ohm} \qquad \text{(D-3)}$$

This shows that the connector increased the line resistance of an AWG 27 copper conductor by 0.86×10^{-3} ohm only.

APPENDIX E

A CALCULATION OF THE CONSTRICTION RESISTANCE OF THE FCC INDIVIDUALLY SEALED CONTACT CONNECTOR CONTACTS

APPENDIX E

A CALCULATION OF THE CONSTRICTION RESISTANCE OF THE FCC INDIVIDUALLY SEALED CONTACT CONNECTOR CONTACTS[3]

Introduction

The new FCC individually sealed contact connector has as contacts a beryllium copper spring with spherical contact surface and a soft copper flat piece. The copper piece is actually the FCC conductor. Each is plated with a 0.0025-mm layer of nickel, then a 0.0025-mm coating of gold. The spring piece is held against the copper surface by spring force, thus indenting the copper surface a certain amount. This report calculates the area of actual contact between the two pieces and thus the contact resistance.

When the term "contact resistance" is used it must be noted that this term applies to several phenomena collectively. The major phenomena contributing to contact resistance are surface contamination, tunnel effect through insulating oxide layers, and constriction resistance. Of these three, only the last, constriction resistance, can be calculated with some accuracy.

The constriction resistance arises from the reduced conductor cross-sectional area of the contact point. Even in the case of large, apparently flat contacts, the actual contact area is a small portion of the apparent contact area. In the case of interest here, the contacts have the form of a hard ball indenting into the soft FCC copper conductor. Their contact area is much smaller than the dimensions of the contacts themselves. So the contact point appears as a constriction.

To calculate the constriction resistance, first the contact area must be determined, then the actual resistance. This is the procedure followed below. Later in this appendix, some experimental values of surface resistance will be mentioned.

Theory

All the equations in this appendix are from the Electric Contacts Handbook[4].

When a hard ball is pressed into a softer surface, the average pressure $\bar{p}$ on the surface under the ball satisfies the equation

$$P = A_m \bar{p} = \pi a^2 \bar{p} \quad , \qquad \text{(E-1)}$$

where P is the load and A_m is the mouth area of the indentation (Fig. E-1).

3. From Technical Report ED-515 by T. D. Barber, Contract NAS8-21809, PT Lab Operations. Report is concerned with the FCC to round wire connector.

4. Ragnar Holm, Electric Contacts Handbook, Springer-Verlag, Germany, 1958.

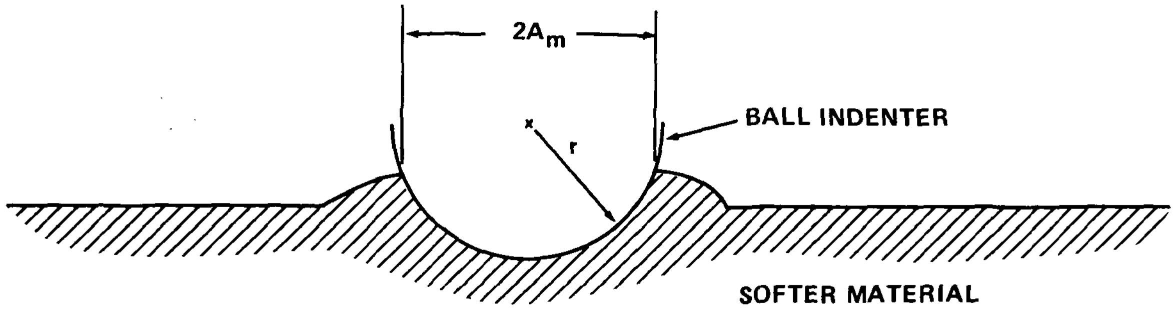


Figure E-1. Cross section of ball indentation (A_m is radius of mouth).

Holm defines the contact hardness H as

$$H = \bar{p} \tag{E-2}$$

for rather large indentations, i.e., $d/r > 0.02$, where d is the depth of the indentation and r is the radius of the indenter. The hardness H is related to the yield strength Y by the relation

$$H = 3Y \text{ to } 4Y \quad . \tag{E-3}$$

From the above relations, one may derive the radius of the mouth of the indentation

$$a = \left(\frac{P}{3\pi Y}\right)^{1/2} \quad . \tag{E-4}$$

The justification for this equation is the assumption that the material will yield plastically until the area of contact is large enough such that the contact pressure is equal to the contact hardness. This is implicit in equation (E-2).

If the surface is deformed from a true flat surface (by the indentation resulting from sliding the contacting sphere over the flat surface), the result should be the same; the softer material will flow until the pressure is equal to the contact hardness. The contact area should be the same in each case.

Since the pressure varies over the actual contact surface, the above radius is the effective radius to be used in the resistance calculations.

The contact constriction resistance for each member is given by

$$R = \frac{\rho}{4a} \quad , \tag{E-5}$$

where ρ is the resistivity of the contact and a is the radius from equation (E-4). The total constriction resistance is thus given by

$$R = \frac{\rho_1 + \rho_2}{4a} \tag{E-6}$$

where ρ_1 and ρ_2 are the resistivities of each contact.

Conclusions

Using the accepted physical constants for beryllium copper alloy 172 and annealed copper given in Table E-1, the following numbers have been calculated:

$$H = 2460 \text{ kgf/cm}^2$$

$$a = 5.17 \times 10^{-3} \text{ cm}$$

$$R = 4.61 \times 10^{-4}\ \Omega$$

The constriction resistance of the contacts is then about 0.5 milliohm, as calculated by the techniques given by Holm.

TABLE E-1. PHYSICAL PROPERTIES

	Beryllium Copper Alloy 172	Annealed Copper
Contact Force	0.177 kgf	
Yield Strength	$9.8 - 11.9 \times 10^3$ kgf/cm^2	7.03×10^2 kgf/cm^2
Resistivity, ρ	$7.8 \times 10^{-6}\ \Omega$-cm	$1.724 \times 10^{-6}\ \Omega$-cm

The surface resistance may be derived from experimental data given by Holm. The contact resistance of crossed copper rods is independent of apparent cross section, depending only on contact pressure. From a graph in Holm which plots contact resistance versus contact pressure, the figure 0.7 mΩ is obtained as total contact resistance. Since the constriction resistance is 0.5 mΩ (as discussed earlier), one may say that the surface resistance is, on the average, 0.2 mΩ.

APPENDIX F

CONNECTOR MATERIALS

APPENDIX F

CONNECTOR MATERIALS

Summaries of all connector materials and finishes, and their applicable specifications, are found in Tables F-1 and F-2. Table F-3 contains information on particularly relevant physical and electrical properties.

TABLE F-1. MATERIALS FOR THE NEW FCC PLUG

Part	Materials
Plug Body	Glass fiber filled epoxy, Fiberite-E-2748 or equivalent; or other thermosetting plastics
Conductor Contact	Soft copper per FED-SPEC-QQ-C-576
Conductor-Contact Plating	2.5×10^{-3} mm of hard gold per MIL-G-45204, Type II, Class 2, over 2.5×10^{-3} mm of low stress nickel per FED-SPEC-QQ-W-290, Type VII, Class 2
Potting	Epoxy compound, Emerson and Cummings Stylecast 2651 or equivalent

TABLE F-2. MATERIALS FOR THE NEW FCC RECEPTACLES

Part	Materials
Shell (Die Cast)	Aluminum alloy 380-T6, per FED-SPEC-QQ-A-591, anodized per MIL-A-8625, Type II, Class 2
Latch	Beryllium copper alloy 172, per FED-SPEC-QQ-C-533, Temper AT
Latch Plating	Low stress nickel plate per FED-SPEC-QQ-N-290, Type VII, Class 2
Latch Trunnions and Washers	Corrosion resistant steel, type 303, per AMS5738. Passivated per FED-SPEC-QQ-P-35.
Interfacial Seal	Silicone rubber per FED-SPEC-ZZR-765A, Class 2A, Grade 50 to 55
Insert	Glass fiber filled epoxy, Fiberite-E-2748 or equivalent
Contact	Beryllium copper, alloy 172, per FED-SPEC-QQ-C-533, Temper AT
Contact Plating	2.5×10^{-3} mm of gold plate per MIL-G-45204, Type II, Class 2, over 2.5×10^{-3} mm of low stress nickel per FED-SPEC-QQ-N-290, Type VII, Class II
External Gasket	Silicone rubber, per FED-SPEC-ZZR-765A, Class 2A, Grade 50 to 55
Potting	Epoxy compound, Emerson and Cummings Stylecast 2651 or equivalent

TABLE F-3. PROPERTIES OF CONNECTOR MATERIALS

1	Material: Epoxy Resin Compound (Emerson and Cummings Stylecast 2651) Used in Part: Potting for Plug and Receptacles	
Physical Properties	Tensile Strength	633 kgf/cm^2 (9000 psi)
	Compressive Strength	1125 kgf/cm^2 (16 000 psi)
	Water Absorption	0.310 24 hr %
	Temperature Range	-73°C to +204°C (-100°F to +400°F)
	Shrinkage	0.003%
	Linear Coefficient of Thermal Expansion	43×10^{-6}/°C (23.9×10^{-6}/°F)
Electrical Properties	Surface Resistivity (42% RH)	1.5×10^{14} ohms
	Volume Resistivity (51% RH)	10.66×10^{14} ohm-cm
	Dielectric Strength (short time)	158 000 to 254 000 volts/cm (403 to 645 volts/mil)
	Dielectric Constant, 60 cy	5.08
	Dielectric Constant, 1 meg	3.97
	Dissipation Factor, 60 cy	0.053
	Dissipation Factor, 1 meg	0.0274
	Insulation Resistance (40% RH)	2×10^{12} ohms

TABLE F-3. (Continued)

2	Material: Glass Fiber Filled Epoxy Compound (Fiberite E-2748) For Parts: Receptacle Inserts and Plug Body	
Physical Properties	Tensile Strength	773 kgf/cm^2 (11 000 psi)
	Compressive Strength	1968 kgf/cm^2 (28 000 psi)
	Rockwell Hardness, M scale	115
	Water Absorption, 24 hr at 23°C 48 hr at 50°C	0.1% 0.3%
	Deflection Temperature, Post Cured 2 hr at 160°C (320°F)	300°C + (572°F +)
	Thermal Coefficient of Linear Expansion, -30°C to +30°C	3.1×10^{-5}/°C
Electrical Properties	Dielectric Constant, 1 MC dry	4.5
	Dissipation Factor, 1 MC dry	0.01
	Dielectric Strength, S/T dry	157 480 volts/cm (400 volts/mil)
	S/S dry	141 732 volts/cm (360 volts/mil)
	S/T wet	149 606 volts/cm (380 volts/mil)
	S/S wet	133 858 volts/cm (340 volts/mil)
	Volume Resistivity	9×10^{15} ohm-cm

TABLE F-3. (Continued)

3	Material: Silicone Rubber (per FED-SPEC ZZ-R-765A, Class 2A, Grade 50 to 55) For Parts: Receptacle Interfacial Seal, Gasket		
Physical Properties		Grade 50	Grade 60
	Hardness, Shore-A Durometer	50±5	60±5
	Tensile Strength Min	49 kgf/cm^2 (700 psi)	46 kgf/cm^2 (650 psi)
	Elongation, Min	200%	150%
	Temperature Range	-62°C to +218°C (-80°F to +425°F)	-62°C to +218°C (-80°F to +425°F)
4	Material: Corrosion Resistant Steel, Type 303, per AMS5738 For Parts: Latch Trunnions and Washers		
Physical Properties	Tensile Strength, Min		8788 kgf/cm^2 (125 000 psi)
	Yield Strength at 0.2% Offset, Min		7030 kgf/cm^2 (100 000 psi)
	Elongation in 2 inches		12%
5	Material: Aluminum Alloy 380-T6, per FED-SPEC-QQ-A-591 For Part: Shell		
Physical Properties	Tensile Strength		3234 kgf/cm^2 (46 000 psi)
	Yield Strength at 0.2% Offset		1617 kgf/cm^2 (23 000 psi)
	Elongation in 2 inches		2.5%

TABLE F-3. (Concluded)

6	Material: Soft Copper per FED-SPEC-QQ-C-576 For Part: Plug Conductor-Contact	
Physical Properties	Tensile Strength	2250 - 2461 kgf/cm^2 (32 000 - 35 000 psi)
	Yield Strength (0.5% ext.)	703 - 773 kgf/cm^2 (10 000 - 11 000 psi)
	Hardness	Knoop 74
	Shear Strength	1547 - 1687 kgf/cm^2 (22 000 - 24 000 psi)
Electrical Properties	Electrical Conductivity (68 F, Ann)	101% IACS or 58.5/microhm-cm
	Electrical Resistivity (68 F, Ann)	1.71 microhm-cm
7	Material: Beryllium Copper Alloy 172, per FED-SPEC-QQ-C-533, Temper AT For Parts: Latch, Receptacle Contact	
Physical Properties	(After Heat Treatment)	
	Tensile Strength	11 600 - 13 357 kgf/cm^2 (165 000 - 190 000 psi)
	Yield Strength at 0.2% Offset	9842 - 11 900 kgf/cm^2 (140 000 - 170 000 psi)
	Proportional Limit	7030 - 8788 kgf/cm^2 (100 000 - 125 000 psi)
	Modulus of Elasticity, E	13.0×10^5 kgf/cm^2 (18.5×10^6 psi)
Electrical Properties	Electrical Conductivity, Min	22% IACS or 13.2/microhm-cm
	Electrical Resistivity, ρ	7.8×10^{-6} Ω-cm

BIBLIOGRAPHY OF SELECTED GOVERNMENT AND INDUSTRY DOCUMENTS

BIBLIOGRAPHY OF SELECTED GOVERNMENT AND INDUSTRY DOCUMENTS

A. SPECIFICATIONS AND STANDARDS

IPC-FC-218A, General Specification for Connectors, Electrical, Flexible FC Type. September 1968.

IPC-FC-220, Specification for FCC, Unshielded, May 1970.

IPC-FC-230, Handbook for FCC and Flexible Printed Wiring. April 1969.

MIL-C-55543, Cable, Electrical, Flat Multiconductor, Flexible, Unshielded. November 15, 1968.

MIL-C-55544, Connectors, Electrical, Environment Resistant, For Use With Flexible Flat Conductor Cable, General Specification for. December 26, 1968.

MSFC-SPEC-220B, Cable, Flat Conductor, Flexible, Electrical Copper. January 28, 1966.

MSFC-SPEC-219A, Connectors, Flat Conductor, Flexible Electrical Cable. May 5, 1966.

B. REPORTS

Angele, W.: Flat Conductor Cable Manufacture and Installation Techniques. NASA TM X-53586, March 1967.

Angele, W.: Measuring the Conductor Spacing in Flat Conductor Cables. NASA TM Report No. 53843, June 13, 1969.

Angele, W. and Hankins, J.D.: Flat Conductor Cable Design, Manufacture, and Installation. NASA TM X-53975, January 9, 1970.

Angele, W.; Martineck, Hans G.; Bennight, J D; and Hankins, J.D.: Flat Conductor Cable Connector Survey of 1970. NASA TM X-64613, July 1971.

Astrionics Laboratory: Flat Conductor Technology Exemplified. NASA TM X-53584, March 1967.

Carden, James R.: Flat Conductor Cable for Limited Rotary or Linear Motion. NASA TM X-53960, October 1970.

Institute of Printed Circuits: IPC FCC Handbook. 1965.

Kennedy, B. W.: Evaluation of Adhesives for Installing Flat Conductor Cables. NASA TM X-53080, October 8, 1964.

Marshall Space Flight Center: Flat Conductor Cable Technology. Office of Technology Utilization, NASA. NASA SP-5043, 1968.

Tools, Fixtures, and Test Equipment for Flat Conductor Cables. Office of Technology Utilization, NASA. NASA SP-5924 (01), November 1968.

Wilkinson, T. H.: Contact Resistance of Electroplated Flat Conductor Cable Conductors. NASA TM X-64542, July 15, 1970.

APPROVAL NASA TM X-64695

FLAT CONDUCTOR CABLE CONNECTORS WITH INDIVIDUALLY SEALED CONTACTS

By W. Angele

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

9/26/72

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