SECTION II. FCC HARDWARE

2.1 Introduction

This section includes descriptive data on cable, plugs and receptacles, circuit change devices, fasteners, support brackets, and adhesives and tapes for use with FCC electrical interconnecting harnesses. MIL-C-55543, "Military Specification, Cable, Electrical, Flat Multiconductors, Flexible, Unshielded" and MIL-C-55544, "Military Specification, Connectors, Electrical, Environment Resistant, for use with Flexible Flat Conductor Cable, General Specification" may be used to complement this handbook.

Both nonshielded and shielded FCC are discussed. A military specification for shielded FCC will be available soon. The MIL-C-55544 NASA/MSFC conductor contact and the Picatinny Arsenal pin-and-socket contact connectors are included, as well as information on other existing, prototype, and proposed FCC connector systems.

Where applicable, part numbers and sources are given. In other instances, the information is general in nature to aid the designer in preparing drawings for the required hardware.

2.2 Cable

2.2.1 General Description. FCC is made up of solid, flat, rectangular conductors - usually bare or plated copper, but other conductor materials such as aluminum can be used - laminated between layers or sheets or high-performance insulating materials.

Figure 2-1 shows typical cross-sections of various nonshielded FCC constructions. The most widely used construction is the symmetrically laminated form (No. 1) with the individual conductors sandwiched between the plastic insulation sheets. An adhesive is used to keep the conductors properly spaced and to assure the integrity of the FCC when exposed to the various operating conditions. The extruded form (No. 2) is made with individual conductors similar to those used for the laminated construction. The insulation is applied by the extrusion process. This method would generally be applicable to ground application or for special electrical requirements where the weight of the added insulation thickness would be acceptable. Preinsulated and laminated (No. 3) is manufactured by the standard laminating process, except the conductors are first coated with an insulating varnish. This allows the conductors to be laminated in close proximity to each other while assuring maximum insulation integrity between adjacent conductors. FCC having etched conductors is shown in Nos. 4 and 5. Solid copper foil is bonded to the bottom insulation sheet, or the copper foil is spray or tower-coated with the insulation material. This assembly is then etched to provide the individual conductors. The top insulation layer is laminated (No. 4) or spray or tower-coated (No. 5) to complete the cable. Woven cable (No. 6) utilizes commercial weaving practices to apply the insulation thread, to space and securely hold the rectangular, solid conductors in place. The woven thread is later impregnated to provide a sealed and mechanically sound FCC.

Appendix III lists the various types of FCC cable described above, with names of vendors who have manufactured these types of cables (Appendix IV).

FCC can be further defined or categorized as standard-density and high-density low-power cables, power cables, and shielded cables. The power and shielded cables are covered in detail in subsequent paragraphs. The standard-density and high-density low-power cables are covered by the military specification sheets of MIL-C-55543. The standard-density FCC has a spacing between conductors of approximately 35 mils, while the high-density FCC has a spacing of approximately 10 mils.

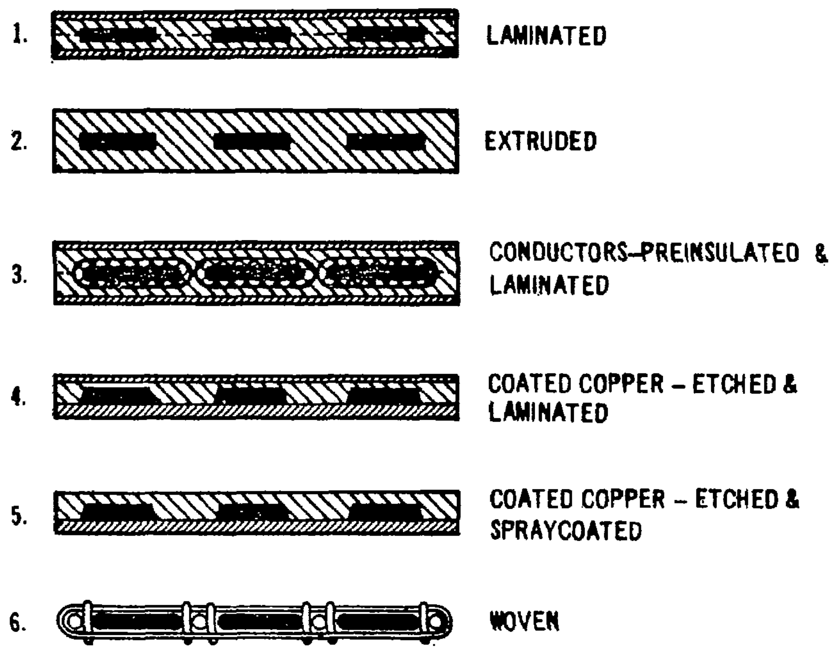

FIGURE 2-1. FCC cross-sections for various manufacturing methods.

2.2.2 Insulation Materials. The FCC system permits the use of many insulation materials in cable construction. Table 2-1 lists the detailed characteristics of many of the materials which have already been used or considered. An examination of Table 2-1 discloses the excellent comparative characteristic values of the polyester (Mylar[1]) and polyimide (Kapton[1]) which have been selected as the primary insulations for the MIL-C-55543 cable configurations.

Relatively low specific gravities of approximately 1.4 for weight reductions, high tensile strengths of approximately 20,000 psi, and high dielectric strengths of 7,000 volts per mil are among the more important characteristic advantages of these materials. The maximum service temperatures for polyimide (Kapton) and polyester (Mylar) are listed as 400°C and 150°C, respectively. When laminated into FCC with the required adhesives, the temperature rating of the finished cable is reduced to 200°C and 100°C, respectively.

Teflon[2], both TFE and FEP, has been used as the primary insulation on many FCC configurations. Specific electrical characteristics are achievable for special applications, and the improved flexing properties at extremely low temperatures are achievable. Both polyester (Mylar) and Teflon FEP can be used as heat-formable materials for making self-retractable corrugated and convoluted cable assemblies (Figures 3-77 and 3-78).

2.2.3 Conductors. Various types of conductor materials can be used successfully with FCC. Copper conductors, both bare and plated, have seen the most extensive use to date. For strip or laminated cable constructions, slit conductors in accordance with QQ-C576 and flattened round-wire conductors per QQ-W-343 or QQ-C-502 can be used. For etched conductor cable construction, soft or annealed, rolled copper foils or electrolytic deposited copper with a controlled minimum purity can be used. The copper conductors have been plated with nickel to improve resistance to oxidation at high temperatures, and to enhance subsequent termination processes.

The sealed construction of FCC makes the use of aluminum conductors feasible. Aluminum has a lower weight-per-conductivity ratio, is more economical, and is not affected by shortages or procurement priorities as copper often is. Aluminum conductors also have an improved resistance to nuclear radiation, which makes it a requirement on some programs.

Other conductor materials, such as iron and iron alloys for economy and special requirements, and special oxides for specific applications, are adaptable to the FCC constructions.

2.2.4 Nonshielded Cable.

2.2.4.1 General Description. The nonshielded FCC, as defined by MIL-C-55543, is suitable for aerospace, defense, and other government contracts requiring operation under various environmental conditions; minimum size with weight and space savings consistent with service requirements. Table 2-2 lists these various cable characteristics in comprehensive tabular form. It is anticipated that future revisions to MIL-C-55543 will add other insulation systems and conductor configurations; however, every attempt will be made to standardize a limited number of cable widths, insulation types, conductor spacings, and conductor sizes to eliminate an endless number of configurations and part numbers with their resultant problems in procurement and logistics. Similar cable with less stringent requirements have a very large application for commercial and less demanding programs.

The MIL-C-55543 specification has standardized on cable widths, conductor widths and thicknesses, number of conductors, and conductor centerline spacings. These data are tabulated in Table 2-3. Table 3-2 presents additional information on conductor cross-sections in square mils, nominal resistance, and resistance tolerances resulting from conductor cross-section tolerances. For resistance changes with conductor temperatures, use the correction factors from the curve of Figure 3-6.

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1. Trademark E. I. Dupont de Nemours and Co., Inc.
2. Ibid.

TABLE 2-1. DETAILED CHARACTERISTICS OF VARIOUS INSULATIONS

Characteristic	TFE Teflon[a]	FEP Teflon[a]	Kapton[a] Polyimide	CTFE[b]	PVF Tedlar[a]	Polypropylene	Mylar[a] Polyester	Polyvinyl-Chloride	Polyethylene
Specific Gravity	2.15	2.15	1.42	2.10	1.38	0.905	1.395	1.25	0.93
Flammable	No	No	Self-Ext	No	Yes	Slow Burning	Yes	Self-Ext	Yes
Appearance	Translucent	Clear Bluish	Amber	White & Opaque	Clear	Clear	Clear	Translucent	Clear
Bondability with Adhesives	Good[c]	Good[c]	Good	Good[c]	Good[c]	Poor	Good	Good	Poor
Bondability to Itself	Good	Good	Poor	Good	Good	Good	Poor	Good	Good
Chemical Resistance	Excellent	Excellent	Excellent	Excellent	Good	Good	Excellent	Good	Good
Sunlight Resistance	Excellent	Excellent	Excellent	Excellent	Excellent	Low	Fair	Fair	Low
Water Absorption (%)	<0.01/24 hr	<0.01/24 hr	3/24 hr	0	0.5/2 hr	0.01	0.8/24 hr	0.10	0.01/24 hr
Volume Resistivity ohm - cm	$>10^{18}$	$>2x10^{18}$	10^{16}	$3.1x10^{16}$	$3x10^{13}$	10^{16}	10^{18}	10^{10}	10^{16}
Dielectric Constant 10^2 - 10^8 Hz	2.2	2.1	3.5	2.5	7.0	2.0	2.8 - 3.7	3.6 - 4.0	2.2
Dissipation factor		$.4x10^{-4}$	$3x10^{-3}$		$9x10^{-3}$	$2x10^{-4}$	$2x10^{-3}$		
10^2 - 10^8 Hz	$2x10^{-4}$	$7.7x10^{-4}$	$14x10^{-3}$	$15x10^{-3}$	$41x10^{-3}$	$3x10^{-4}$	$16x10^{-3}$	$14x10^{-2}$	$6x10^{-4}$
Service Temperature									
Minimum (°C)	-60	-60	-60		-70	-55	-60	-40	-20
Maximum (°C)	250	200	400		105	125	150	85	80
Tensile Strength									
psi @ 25°C	3000	3000	25000	4500	13000	5700	20000	3000	2000
$N/m^2 x 10^8$ @ 25°C	0.2067	0.2067	1.697	0.31	0.8825	0.3927	1.378	0.2067	0.1378
Modulus of Elasticity									
psi	58000	50000	510000	190000	280000	170000	550000		50000
$N/m^2 x 10^8$	3.930	3.394	34.623	12.90	19.29	11.913	37.895		3.445
Thermal Expansion	(-30°C to 30°C)	(-30°C to 30°C)	(-14°C to 38°C)	(-195°C to 90°C)	(-30°C to 30°C)	(-30°C to 30°C)	(21°C to 50°C)		(-30°C to 30°C)
in./in./°F$x10^{-6}$	55	50	11	48	28	61	15	d	100
cm/cm/°C$x10^{-6}$	100	90	20	82	50	110	27		180
Dielectric Strength									
Volts/mil	800	3000	3600	2000	2000	750	3500	800[d]	1500
Sample Size (mils)	5	5	5	5	5	125	5	5	5

Notes: a. Trademark, E. I. Dupont de Nemours & Co., Inc.
b. Trademark, Minnesota Mining and Manufacturing Co., Inc.
c. Must be treated.
d. Depends on formulation (plasticizer)

The conductor temperature rise versus current for 1-, 3-, and 10-layer, 2-inch-wide cables with 4- by 40-mil conductors on 75-mil centers is shown in Figure 3-10 for operation in air, and Figure 3-11 for operation in vacuum. Table 3-3 gives correction factors for other conductor cross-sections and centerline spacing configurations.

2.2.4.2 Specification Requirements. Detailed specification performance requirements are given by MIL-C-55543. The military specification sheets define the various cable types or configurations as defined by Table 2-2.

In general, the specification dimensional tolerances are: ±5 mils for cable widths; ±5 mils for cable margin, the distance between the edge of the cable and outside edge of the outer conductor; ±5 mils noncumulative for conductor centerline spacing on standard density and ±2 mils for high density; ±1 mil for cable thickness; ±0.4 mil for conductor thickness; and ±2 mils for conductor width.

TABLE 2-2. MIL-C-55543 CABLE CONFIGURATION

Military Specification Sheet No.	Insulation	Conductor Plating	Cable Construction (Copper Conductor)	Voltage Rating (V)	Maximum Operating Temperature (°C)	Conductor Configuration (Density)
MIL-C-55543/1	Polyester	Nickel Plated	Strip	300	100	Standard
MIL-C-55543/2	Polyester	Nickel Plated	Strip	300	100	High
MIL-C-55543/3	Polyimide/FEP	Nickel Plated	Strip	300	200	Standard
MIL-C-55543/4	Polyimide/FEP	Nickel Plated	Strip	300	200	High
MIL-C-55543/5	Polyimide-Type Homopolymer/FEP	Bare	Etched	300	200	Standard
MIL-C-55543/6	Polyimide-Type Homopolymer/FEP	Bare	Etched	300	200	High
MIL-C-55543/7	Polyester	Bare	Strip	300	100	Standard
MIL-C-55543/8	Polyester	Bare	Strip	300	100	High
MIL-C-55543/9	Polyimide/FEP	Bare	Strip	300	200	Standard
MIL-C-55543/10	Polyimide/FEP	Bare	Strip	300	200	High
MIL-C-55543/11	FEP	Nickel Plated	Strip	300	175	Standard
MIL-C-55543/12	FEP	Nickel Plated	Strip	300	175	High
MIL-C-55543/13	TFE	Nickel Plated	Strip	300	200	Standard
MIL-C-55543/14	TFE	Nickel Plated	Strip	300	200	High

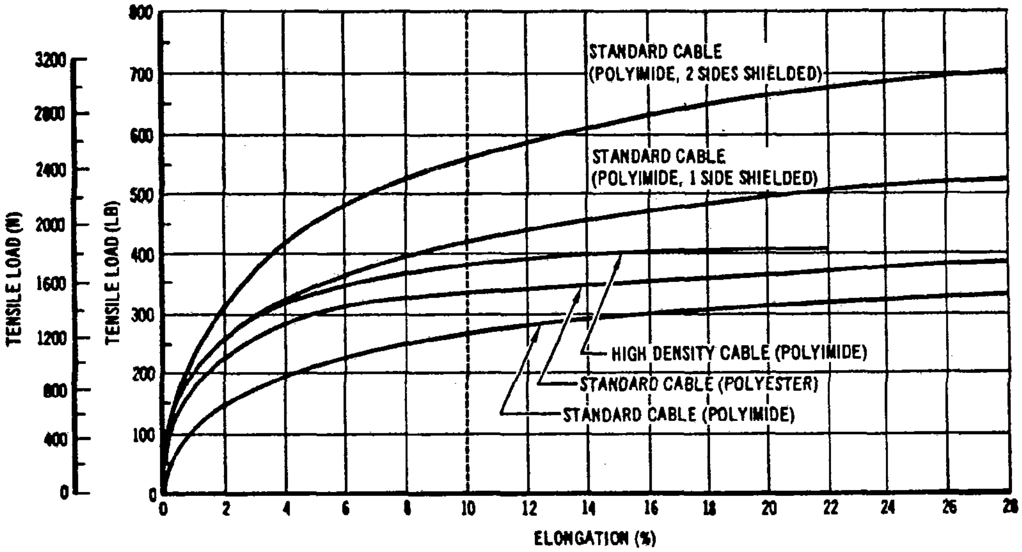
2.2.4.3 Tensile Strength. The tensile strength of FCC, with its insulation contributing to the cable collective strength, is exceptionally good (Section V). Figure 2-2 shows FCC elongation versus tensile load for various 1-inch-wide cables with copper conductors on 75-mil centers and 0.5-mil-thick solid copper foil for the shielded cables. The values shown will vary with other types of insulation and other conductor configurations.

2.2.4.4 Radiation Resistance. The polyimide and polyester insulations used for the MIL-C-55543 have very good resistance to nuclear radiation. Cables with these insulations were subjected to two phases of radiation exposure by NASA/MSFC. Phase I consisted of an average overall gamma dose of 7.03 by 10^5 roentgens (R) and an average flux of 7.7 by 10^{11} neutrons per square centimeter (N/cm^2) (# 0.5 MeV). The exposure time was approximately 1.25 hours. Phase II consisted of a total gamma exposure of 2.1 by 10^6 R and average neutron flux of 1.2 by 10^{14} N/cm^2. Exposure time was approximately 4 hours. There was no evidence of dielectric breakdown of insulation between conductors subjected to the above radiation and a potential of 2500 volts after radiation.

TABLE 2-3. MIL-C-55543 FCC DIMENSIONAL DATA

Cable Widths (in.)	Spacing (in.)	No. of Conductors
0.50	0.050	7
	0.075	6
	0.100	4
	0.150	3
1.00	0.050	17
	0.075	12
	0.100	9
	0.150	6
1.50	0.050	27
	0.075	18
	0.100	14
	0.150	9
2.00	0.050	37
	0.075	25
	0.100	19
	0.150	12
2.50	0.050	47
	0.075	32
	0.100	24
	0.150	16
3.00	0.050	57
	0.075	38
	0.100	29
	0.150	19

Centerline Spacing (in.)	Conductor Configuration	Conductor Size (in.)		Nearest AWG Size
		Width	Thickness	
0.050	Standard	0.025	0.003	30
			0.004	29
			0.005	26
	High Density	0.040	0.003	28
			0.004	27
			0.005	26
0.075	Standard	0.040	0.003	28
			0.004	27
			0.005	26
	High Density	0.065	0.003	26
			0.004	25
			0.005	24
0.100	Standard	0.065	0.004	25
			0.005	24
			0.006	23
	High Density	0.090	0.004	24
			0.005	23
			0.006	22
0.150	Standard	0.115	0.004	22
			0.005	22
			0.006	21
	High Density	0.140	0.004	22
			0.005	21
			0.006	20



1. CABLE LENGTH 12.7 CM BETWEEN CLAMPS
2. PULL RATE 3 CM/MIN
3. TEMPERATURE: 23°C
4. ONE INCH CABLE, 4 X 40 MIL CONDUCTORS, 75 MIL CENTERS, 0.5 MIL SHIELD (IF SHIELDED)

FIGURE 2-2. FCC elongation versus tensile load.

2.2.4.5 Cable Selection. The FCC selected will be dependent on the program requirements. Most high-reliability government contracts will require the use of the MIL-C-55543 cable. On those programs, where special configurations not covered by the specification are required, it is recommended that detailed procurement specifications be prepared to meet the general requirements of MIL-C-55543, together with the specific special configuration and requirements.

On those programs not requiring cable to military specifications, special consideration should be given to procurement of cable with insulation systems, construction tolerances, performance requirements, and qualifications commensurate with the program requirements.

Special electrical characteristic requirements can often be met with nonstandard cable cross-sections. Over-and-under conductors, different cross-section conductors in the same cable, special spacings and special insulation material, and thickness configurations can often be made to replace much larger and more expensive coax type RWC. Layer termination techniques can be used to further reduce the overall cost of the special interconnecting harnesses. Extensive use of these special FCC configurations is currently being made in interconnecting computer module planes with high-speed electronic circuits.

Special mechanical characteristics are also possible. An example of a low torque application for a NASA/MSFC program (ATM) is given in Section III, Paragraph 3.2.8.4.

2.2.5 Shielded Cable. Various types of shield configurations have been used on FCC. Perforated-copper shielded cable, manufactured by Hughes Aircraft and W. L. Gore, was used by General Dynamics on the standard missile. A copper alloy screen shield was used by Methode Electronics for a shielded cable configuration developed for NASA/MSFC. The openings or windows in the shield material provided the required bond between the adjacent insulation layers. However, the openings greatly reduce the shielding effectiveness at critical frequencies. These shielded configurations also had offset edge conductors with each edge conductor in contact with one shield (Fig. 2-3). The offset edge conductors complicated the cable stripping and preparations for plug termination.

Improved cable-bonding techniques permit the use of solid metal foil shields. Electrical testing has disclosed that continuous contact between the shields and edge conductors is not required for electrostatic shielding effectiveness; in fact varying resistance with cable flexing could be a source of noise. The shielded cable configuration utilizing a solid foil shield and non-offset edge conductors is shown in Figure 2-3. This configuration with 0.5-mil copper foil shields and polyimide/FEP insulation has been successfully manufactured. NASA/MSFC has performed cable flexing tests on this cable, at both low and high temperatures essentially in accordance with the requirements of MIL-C-55543 to verify the electrical and mechanical integrity.

2.2.5.1 Shielding Materials. From the development and testing described above it has been concluded that a solid shield, without openings, should be used. If the shielded FCC is to be used for general routing and interconnection in conjunction with nonshielded FCC, the shield thickness should be limited to approximately 0.5 mil. By using polyimide (Kapton) or polyester (Mylar) as the primary insulations, a cable thickness of approximately 19 mils can be achieved which will provide the required flexibility.

For electrostatic shielding, 0.5-mil annealed copper provides the shielding attenuation as described in Section II, Paragraph 3.2.3.2.3. The ductility of the annealed copper provides the elongation and compression required when the cable is bent or flexed.

For electromagnetic shielding, effectiveness throughout the operational frequency range a ferromagnetic material is required. In addition, recent tests at MDC have indicated that this shielding must be ferromagnetically continuous around both edges of the cable. A study conducted by Picatinny Arsenal for NASA/MSFC has indicated the desirability of having the shield made up of multiple layers of very thin materials alternating between nonferrous and ferrous layers. The shielding nomographs and discussion in Section III verify the effectiveness of this design approach.

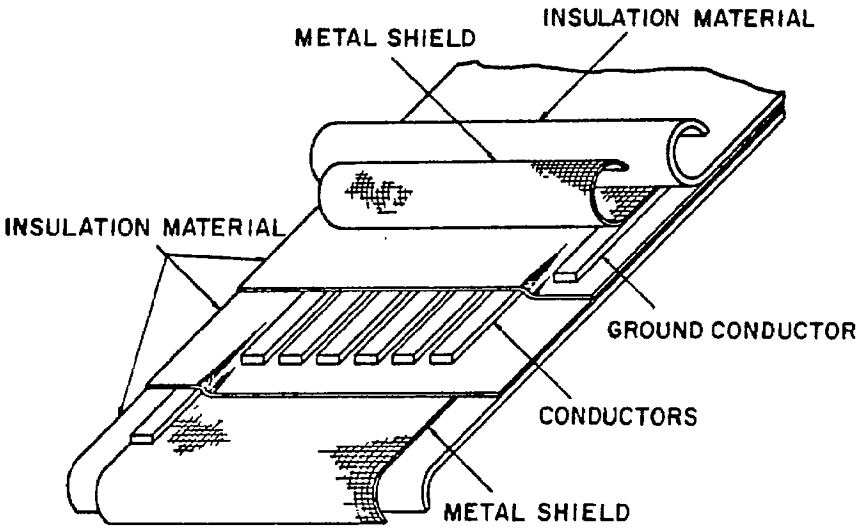


FIGURE 2-3. Shielded FCC with offset edge conductors.

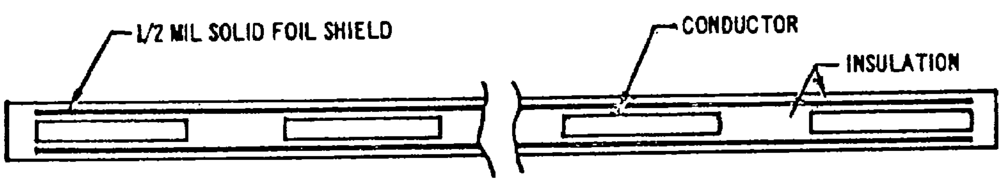


FIGURE 2-4. Shielded FCC with non-offset edge conductors.

A second approach investigated by MDC was to utilize a 0.5-mil fully annealed high permeability nickel-iron alloy shield plated with 50 microinches each of copper and nickel. Prototype samples of this material were made. Short samples were plated and longer nonplated samples were made into a 200-foot laminated shielded cable. However, the required continuous magnetic path around the edges of the cable was not provided, and the testing indicated inadequate magnetic shielding effectiveness.

The multilayer magnetic shield, continuous around the cable edges, could be achieved theoretically by several deposition methods.

A nonshielded FCC could have the shield applied directly to the outer insulation by vacuum deposition, electrolysis deposition, electrolytic deposition, or by gaseous deposition. An outer insulation layer could then be applied to complete the cable. The effectiveness of a prototype magnetic shield, continuous around the cable edges, should be verified before a development effort is expended on any of the above techniques. Then, the considerations for shield flexing, cable integrity under temperature cycling, and terminations must be made during the cable development.

An over-and-under conductor configuration can be used to reduce the effect of magnetic fields. There should be a minimum thickness of insulation between the conductor pairs. This method has been used successfully by Hughes Aircraft in a high-current shield application. If the high interconductor capacitance can be tolerated, this method provides a unique FCC application solution.

2.2.5.2 Stripping Considerations. Section VI describes various FCC stripping processes. The stripping of shielded FCC is generally much more difficult than the stripping of nonshielded FCC. This thickness of shield and the insulation between the shield and conductors, the greater bond strength required to the shield, and the insulation step between the edge of the shield and the conductors tend to complicate the stripping problems. For proper shield termination to a shielded FCC plug, it is necessary to prepare the cable end as shown in Figure 2-5.

After many cable constructions and many stripping methods were evaluated, the following cable construction is suggested. This applies to electrostatic shielded cable constructed as shown in Figure 2-4. The other insulation is tower-coated polyimide-amide or is polyester (Mylar). Both are chemically removable. The inner-cable construction is selected to meet the program requirements. The shield removal is accomplished in two separate chemical stripping operations. The first removes the outer insulations while the second removes the shield to provide the upper two steps shown in Figure 2-5. If subsequent stripping of the conductors is required, it can be accomplished by the technique established for nonshielded cable stripping. This simple approach assures the cable integrity after shielded cable stripping.

2.2.6 Power Cable. Power FCC configurations have been designed by NASA/MSFC and manufactured by Method Electronics. Various cable constructions with two and three conductors in 1-, 2-, and 3-inch cables are shown in Figure 2-6. Power cables, with equivalent conductor conductivities from 8 to 23 AWG, are designed for multiples of 75-mil centerline spacing. This permits them to be terminated in FCC connectors with 75-mil center contacts. By using special windows and shuttles for the NASA/MSFC molded-on plug, the stripped power-cable conductor can be formed to provide contact areas on both sides of the plug. This permits many parallel receptacle contacts to be used to complete each power circuit. Table 3-13 shows additional design data. Cables, copper and aluminum, have been made in sizes up to AWG 2/0 equivalent.

The advantages of the use of FCC power cables and other methods of application are discussed in Section III. Additional conductor cross-sectional requirements for various gages are given in Table 3-13, and Figure 3-60.

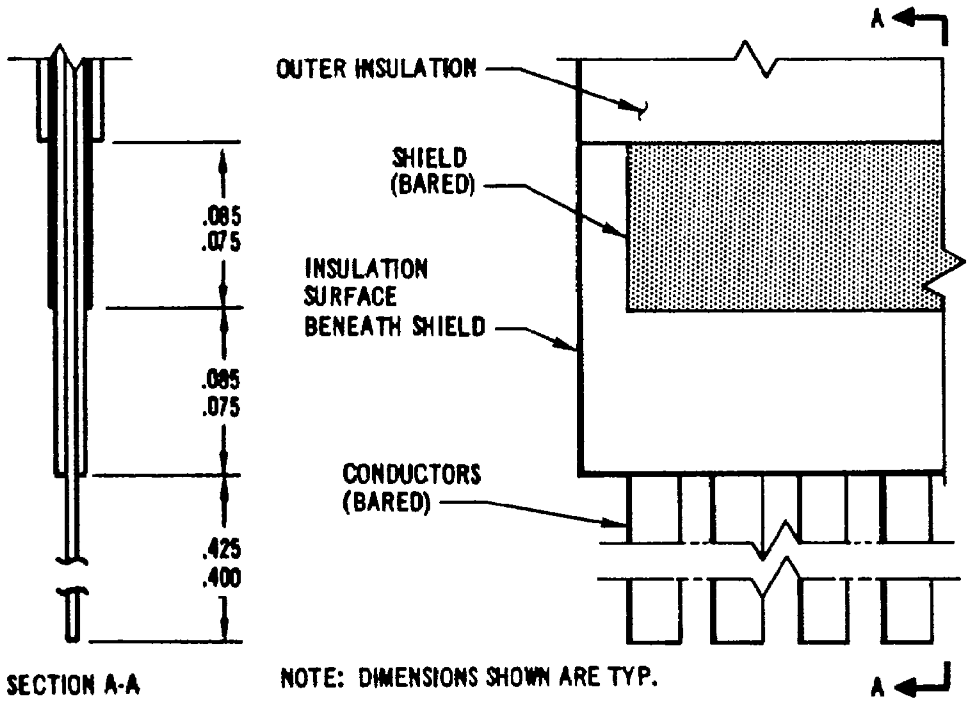
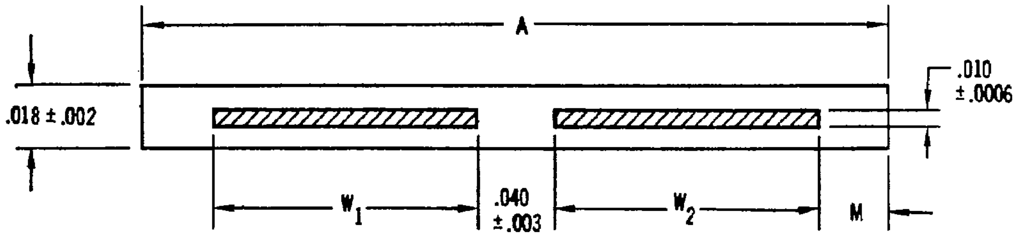
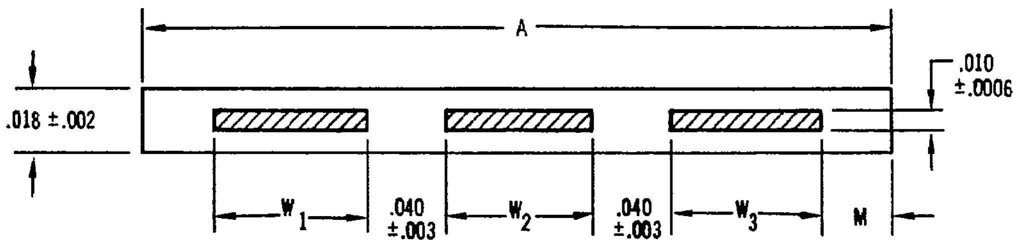


FIGURE 2-5. Shielded-cable preparation for plug termination.



A ±.010	W_1 ±.002			W_2 ±.002			M ±.008	WEIGHT lb/1000ft
	WIDTH	EQUIV. AWG	Ω PER 1000'	WIDTH	EQUIV. AWG	Ω PER 1000'		
1"	.410	13	2.0	.410	13	2.0	.070	38
2"	.860	10 +	.97	.935	9 -	.90	.082	81
3"	1.385	8 +	.61	1.385	8 +	.61	.095	125



A .010	W_1 ±.002			W_2 ±.002			W_3 ±.002			M ± .008	WEIGHT lb/1000ft
	WIDTH	EQUIV. AWG	Ω PER 1000'	WIDTH	EQUIV. AWG	Ω PER 1000'	WIDTH	EQUIV. AWG	Ω PER 1000'		
1"	.260	15	3.2	.260	15	3.2	.260	15	3.2	.070	37
2"	.560	12 +	1.5	.635	11 -	1.3	.560	12 +	1.5	.082	80
3"	.935	9 -	.90	.860	10 +	.97	.935	9 -	.90	.095	124

CONDUCTOR MATERIAL: HIGH CONDUCTIVITY COPPER, ANNEALED, NICKEL PLATED.
INSULATION MATERIAL: KAPTON 4 MIL, FEP BONDED.
APPLICABLE SPECIFICATION: MSFC-SPEC-220

FIGURE 2-6. FCC power cable configuration.

2.3 Connectors

2.3.1 Introduction. Numerous connector concepts have been developed for use with FCC. In other instances, existing RWC connectors have been adapted for FCC use. MIL-C-55544, "Connectors, Electrical, Environment Resistant, for use with Flat Conductor Cable, General Specification for," has been prepared to define the operational requirements of environmental connectors for use with FCC. This specification contains detail specification sheets for the NASA/MSFC conductor-contact connector and for the U. S. Army Picatinny Arsenal pin-and-socket contact connector. For purposes of this report, a connector is defined as a mated plug and receptacle. The receptacle contains the mounting provisions for attaching to a bracket or electronic unit.

To afford the users of this report a broader concept of connectors and termination systems which have been used, or are being prepared for use, the MIL-C-55544 connectors are discussed in detail in separate paragraphs, and general descriptions and illustrations are given for other connectors developed for and/or used with FCC.

2.3.2 Conductor-Contact Connectors (per MIL-C-55544). The conductor-contact FCC connector system was developed by NASA/MSFC. This system, which utilizes the cable conductor as the plug contact, eliminates at least one of the total connector junctions. In addition, it provides a light weight, simple, and economical FCC plug assembly. Production-type tooling has been developed by NASA/MSFC for a complete line of connectors, including five sizes for rectangular and two sizes for cylindrical configurations.

2.3.2.1 Plugs. Two types of conductor-contact plugs have been developed; molded-on and premolded nonshielded plugs by NASA/MSFC. The nonshielded plugs, which have all-plastic bodies, are capable of accepting shielded FCC if there are no requirements for the shield path to be carried through the connector in a continuous peripheral manner. The shield can be "floated" or carried through one or two connector contacts. All plugs of the same size are interchangeable, and all have integral polarity keys to prevent reversed insertion. All plugs have the capability of accepting a number of cable segments per cable layer, as shown in Figure 2-7. All of the above plugs are currently designed and tooled for 75-mil and centerline contacts. The design concepts shown are applicable for 50- and 100-mil centerline contacts. Two or more contacts can be used in parallel, with the FCC, having centerline spacings a multiple of 75 mils, prepared as shown in Figure 3-59. Another method of terminating wider conductors or power FCC in a plug is to remove window spokes and ridges of the shuttle of the premolded plug parts to provide for wide power-cable conductors (Fig. 2-8).

2.3.2.1.1 Molded-On.

2.3.2.1.1.1 Rectangular. Figure 2-9 shows a typical cross-section of the rectangular molded-on plug assembly, together with details which define the parts required and the control and outline dimensions for all five plug sizes. Section VI of this report (and MS 75079, Proposed Method Drawing, included with the MIL-C-55544 specification) defines the steps required for plug assembly. If the polysulfone molding material is used as shown in Figure 2-9, the operating temperature is limited to a maximum of 100°C. If PPO molding material is used, the maximum operating temperature is increased to 150°C, and the resistance to chemical solvents is increased. NASA/MSFC has production-type molding dies for the five plug sizes shown. Tooling drawings for these dies are available to qualified organizations on request.

2.3.2.1.1.2 Cylindrical. Molded-on cylindrical plug assemblies for 0.25- and 0.5-inch-wide cable are shown in Figures 2-10 and 2-11. These plugs are similar to the rectangular plugs described above except for the circular geometry. The plug assembly steps are defined in MS 75080, Proposed Method Drawing, included with the MIL-C-55544 specification.

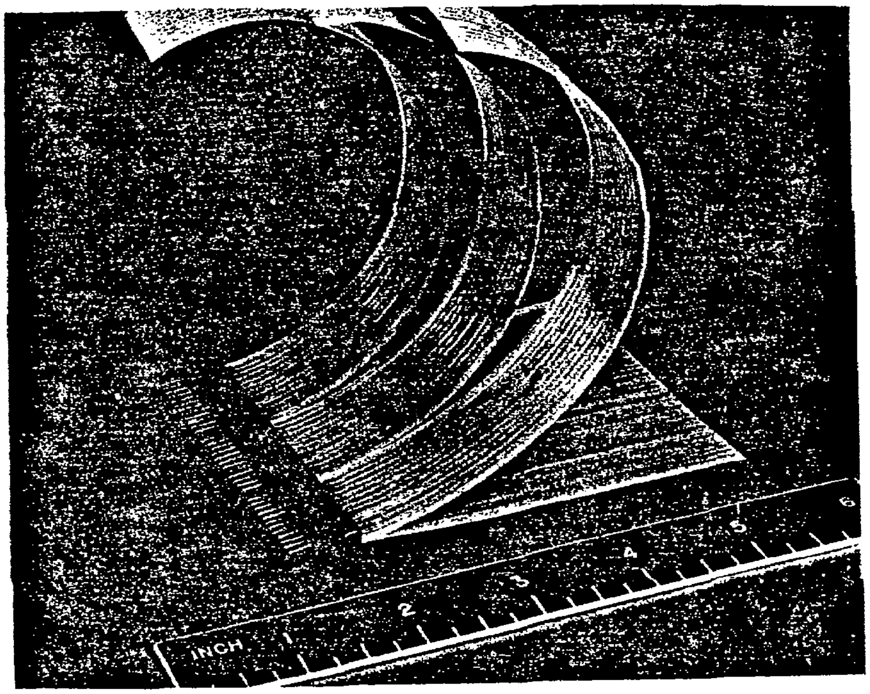


FIGURE 2-7. Multiple cable terminations in one layer.

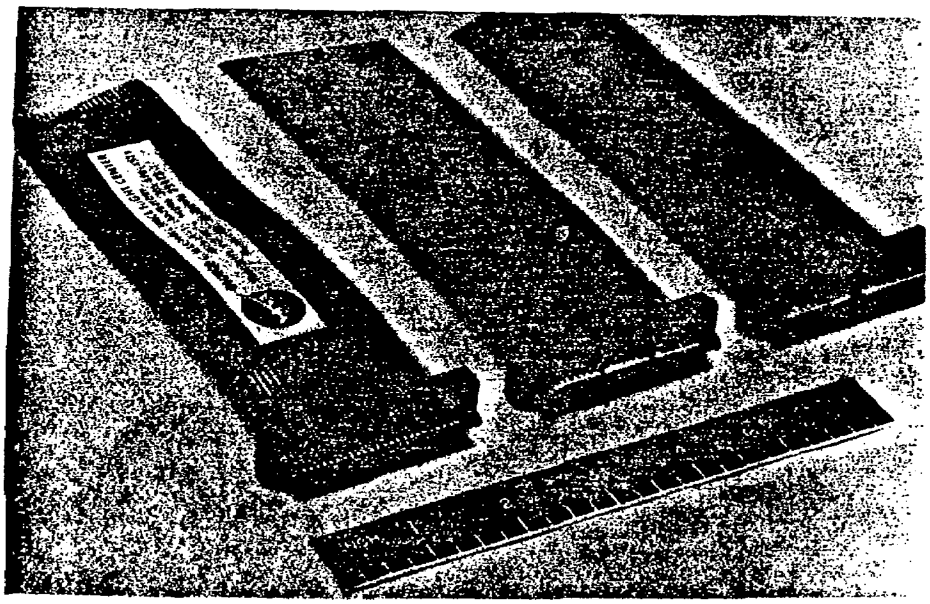
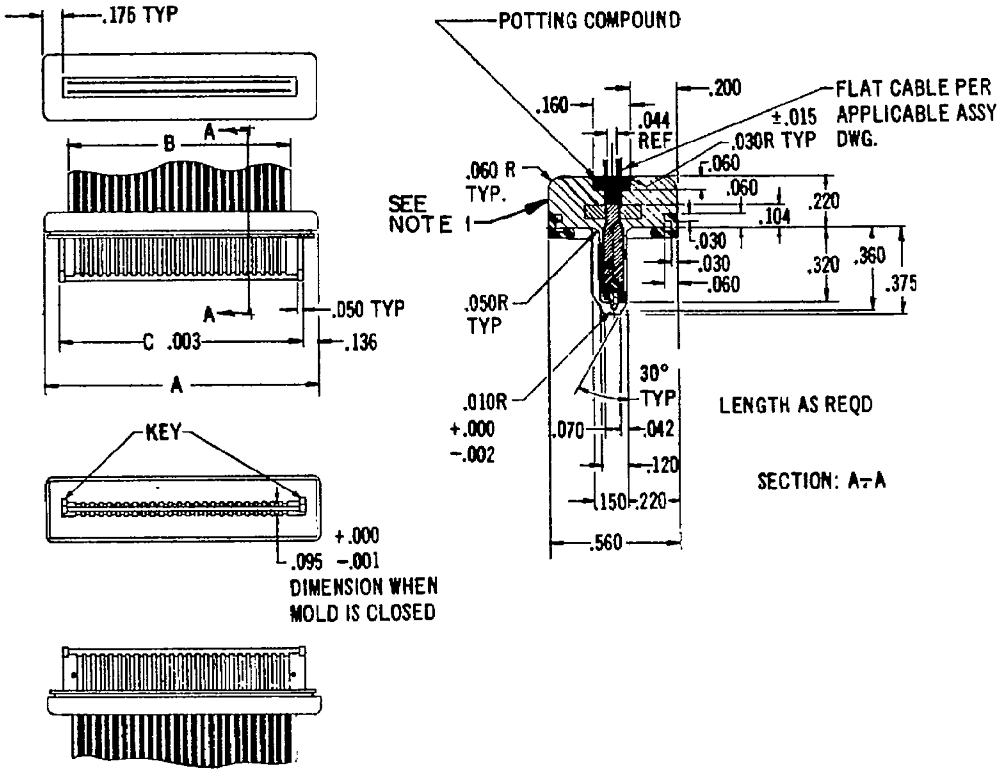


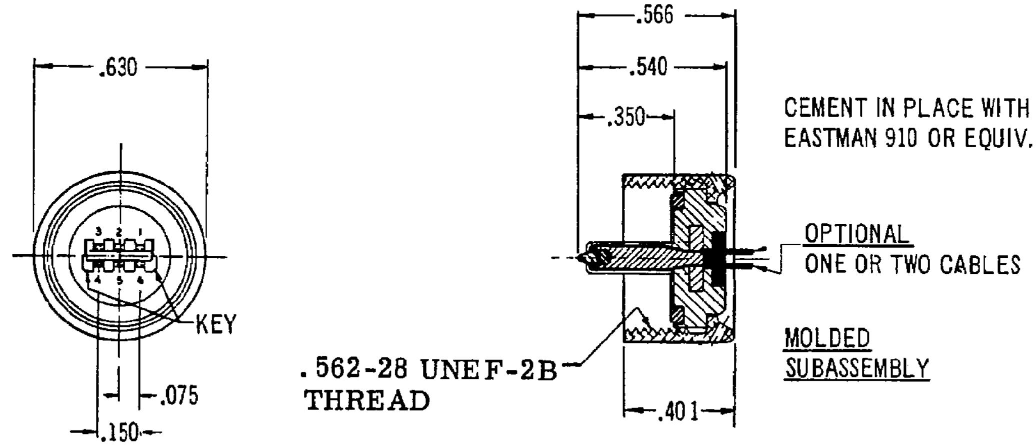
FIGURE 2-8. FCC power-cable termination.



A	B	C
1.409	1.000	1.137
1.859	1.500	1.587
2.384	2.000	2.112
2.909	2.500	2.637
3.359	3.000	3.087

NOTES:
1. Polyphenylene oxide.
2. Cable and conductors may be trimmed as required.
3. Temperature range: -65° C to 125° C.

FIGURE 2-9. MIL-C-55544/7 Molded-on rectangular plug.



VOLTAGE	300 Vrms
CURRENT PER CONTACT	3 A
TEMPERATURE RANGE PLUG MOLDED ON	-65° TO 125°C

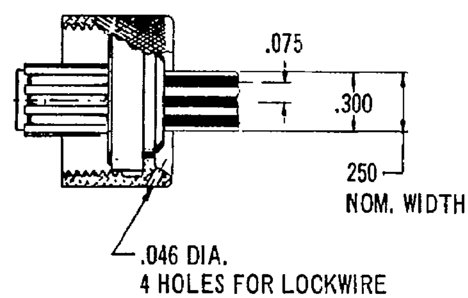
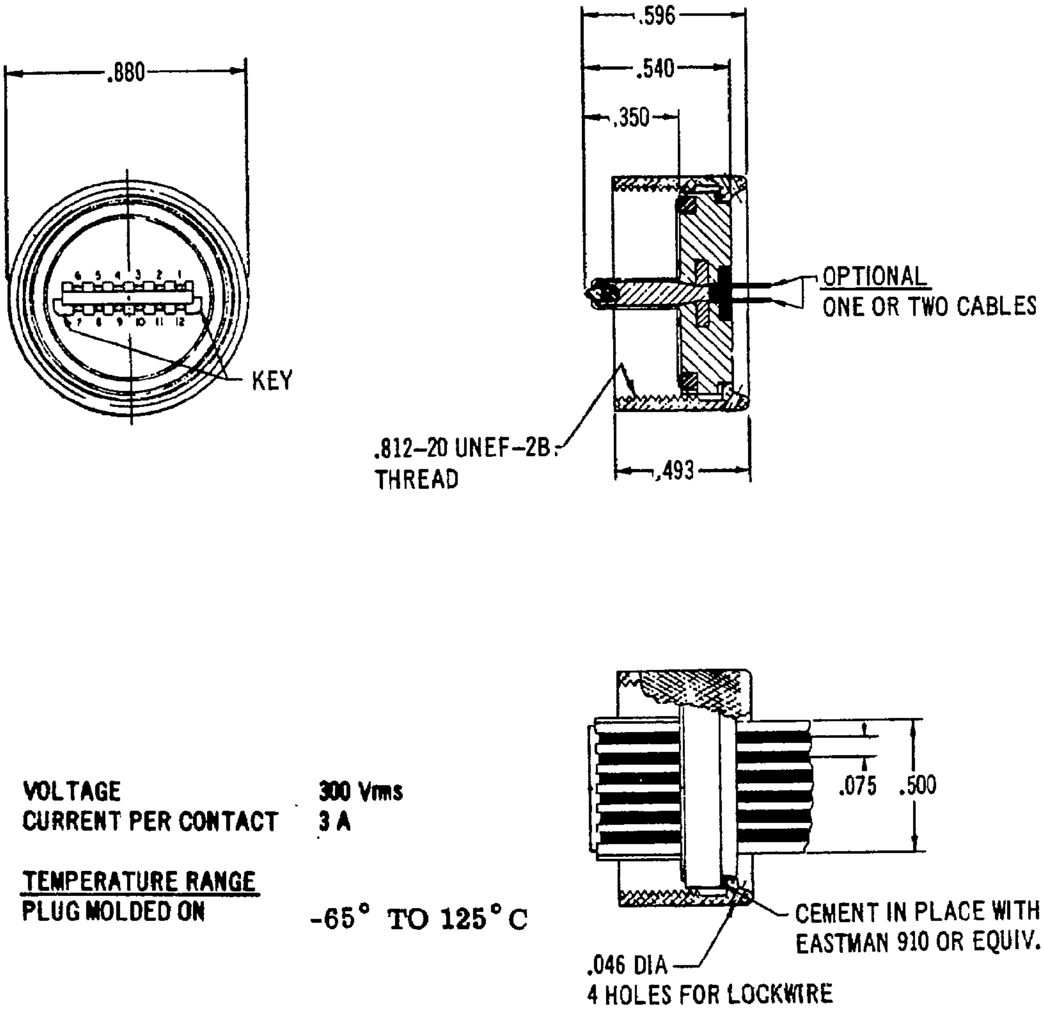


FIGURE 2-10. MIL-C-55544/9 Molded-on cylindrical plug assembly, .25-inch wide cable.



VOLTAGE	300 Vrms
CURRENT PER CONTACT	3 A
TEMPERATURE RANGE PLUG MOLDED ON	-65° TO 125° C

FIGURE 2-11. MIL-C-55544/9 Molded-on cylindrical plug assembly, 0.5-inch wide cable.

2.3.2.1.2 Premolded Plugs.

2.3.2.1.2.1 Nonshielded Rectangular. Figure 2-12 shows a typical cross section of the premolded plug assembly together with details which define the parts required and the control and outline dimensions for all five plug sizes. Section VI of this report and the MS 75078, Proposed Method Drawing (included with MIL-C-55544), define the steps required for plug assembly. The glass-filled epoxy molding material used for the premolded parts of this plug permits operating at a maximum of 200°C. Tooling has been developed for the five plug sizes shown, and parts are available from Methode Electronics.

2.3.2.2 Receptacles. Two types of receptacles have been developed for both the rectangular and cylindrical conductor-contact plugs described above; the "FCC to FCC" and the "FCC to RWC" (solder) types. The FCC to FCC mates with two identical FCC conductor-contact plugs. The solder type can be used for electronic units and feedthrough applications to effect a transition from an FCC plug to RWC. All receptacles have carefully designed contact springs with controlled radius, spring rate deflections, and contact force to achieve and maintain the required performance. Variations to the existing rectangular receptacles to provide conductive shell finish and conductive mounting gaskets would provide shielded receptacles.

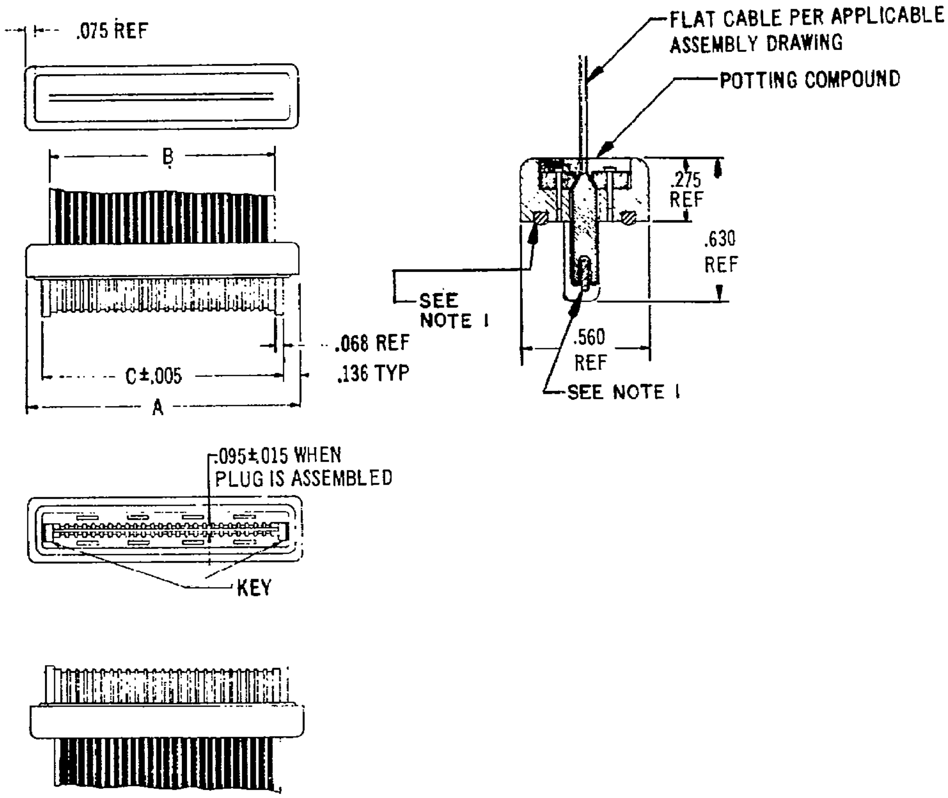
2.3.2.2.1 FCC to FCC, Rectangular. Figure 2-13 shows the five sizes of actual receptacles, a chart with tabulation data, a receptacle cross-section, and an enlarged contact-area view with a spring-force chart. Additional outline and control dimensions, performance, and marking information are given in the M55544/8 specification sheet included with MIL-C-55544. These production-type receptacles are manufactured by Amphenol, and are patterned after the original NASA/MSFC machined-shell receptacle. Qualification-type testing has been accomplished by two agencies to verify performance with the specification.

2.3.2.2.2 FCC to RWC, Rectangular. Figure 2-14 shows five sizes of receptacles, a data chart, and contact information. Additional outline and control dimensions, performance, and marking information are given in M55544/6 specification sheet included with MIL-C-55544. These production-type receptacles are: manufactured by Amphenol; patterned after the NASA/MSFC machined-shell design; and have passed specification qualification-type tests by two independent agencies.

2.3.2.2.3 FCC to FCC, Cylindrical. Figure 2-15 shows the cylindrical flat-cable to flat-cable receptacle for one-hole mounting with tabulation for 0.25- and 0.5-inch-wide cables. The cross section shows the mated plug and receptacle with contact details. Prototype receptacles of both sizes have been made and evaluated by NASA/MSFC. Similar receptacles with square flange mounting have also been made.

2.3.2.2.4 FCC to RWC, Cylindrical. Figure 2-16 shows the cylindrical flat-cable to round-wire receptacle for one-hole mounting, with tabulation for 0.25- and 0.5-inch-wide cables. The cross-section shows the mated plug and receptacle with contact details. Prototype receptacles of both sizes have been made and evaluated by NASA/MSFC. Similar receptacles with square flange mounting have also been made.

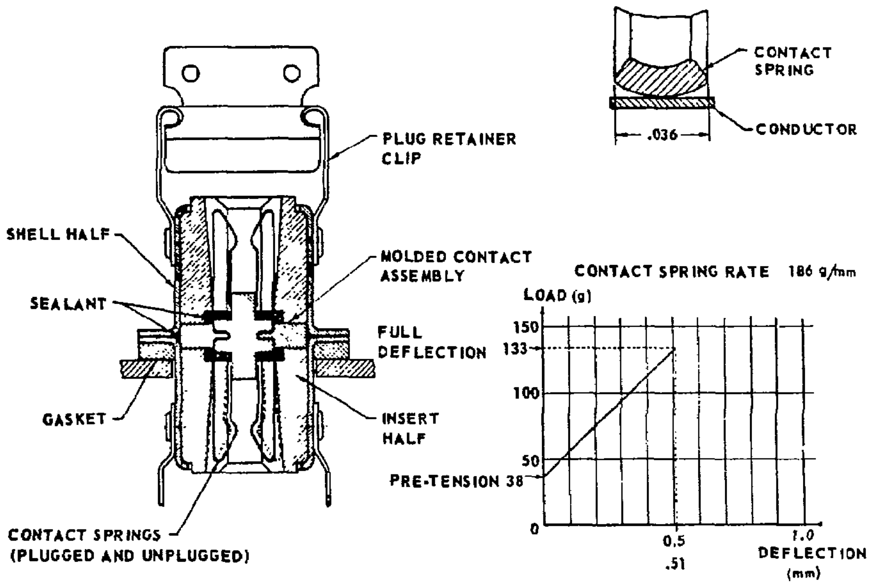
2.3.3 Pin-and-Socket (per MIL-C-55544). A pin-and-socket FCC connector system has been designed by the U.S. Army at Picatinny Arsenal, and a 2-inch cable size, single-layer, shielded version has been tooled, manufactured, and is undergoing evaluation testing. MIL-C-55544 contains two versions of this connector: shielded and nonshielded. The basic bulkhead-type receptacle and mating plug are capable of accepting either FCC or RWC, with different interchangeable back hardware. The specification requires crimp-removable contacts for the round-wire termination. The FCC terminations can be made by crimping to the stripped, preformed conductors by welding or by lap soldering. Termination by layer is possible in all termination systems. Peripheral-shield continuity is achieved in the cable-shield area by a compressed, silver-filled conductive gasket and at the plug interface by fingered conductive springs. Figure 2-17 shows this connector configuration.

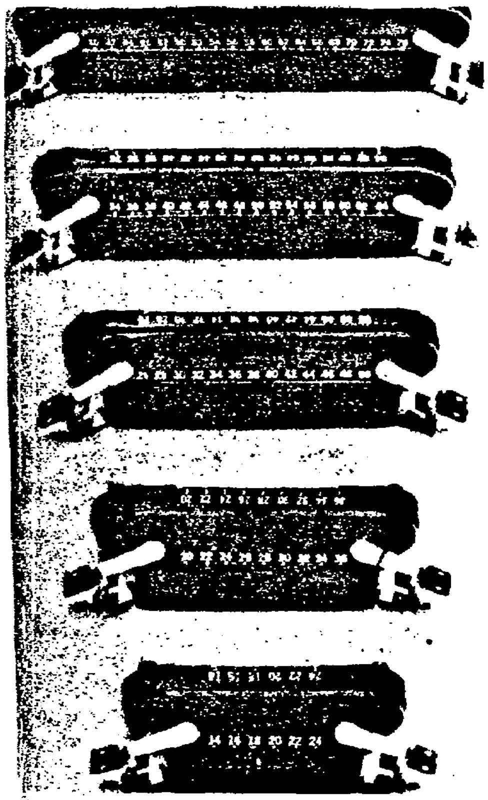


A REF	B REF	C REF
1.409	1.000	1.137
1.859	1.500	1.587
2.384	2.000	2.112
2.909	2.500	2.637
3.359	3.000	3.087

NOTES:
1. Cement wedge and seal in place with Dow Corning 140 or equivalent.
2. Temperature range: -65° C to 125° C.

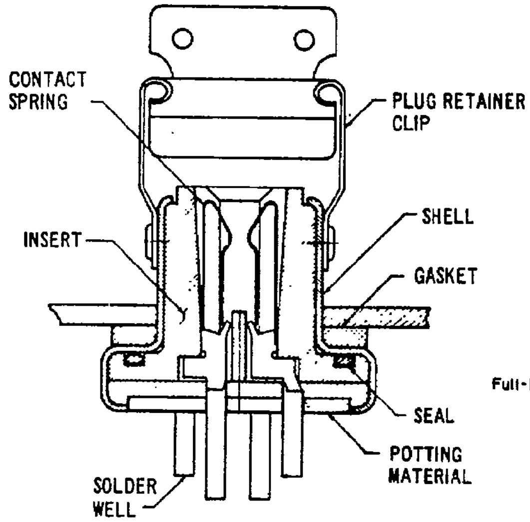
FIGURE 2-12. MIL-C-55544/5 Premolded rectangular plug.



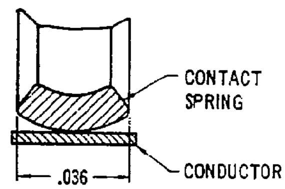


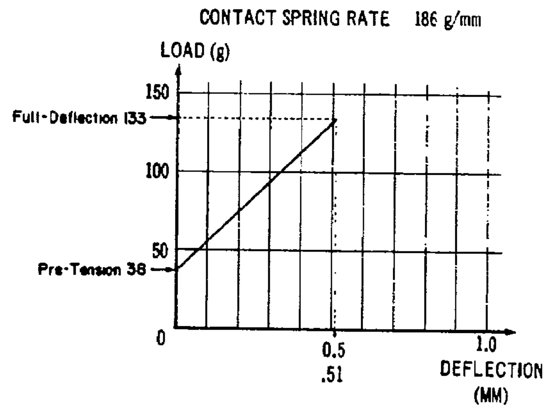
CABLE WIDTH INCHES	NUMBER OF CONTACTS	MOUNTING AREA INCHES	WEIGHT IN GRAMS	
			RECPT	PLUG EA
3	76	.9 X 4.2	67	17
2.5	64	.9 X 3.8	60	15
2	50	.9 X 3.3	50	12
1.5	36	.9 X 2.7	39	9
1	24	.9 X 2.3	32	7

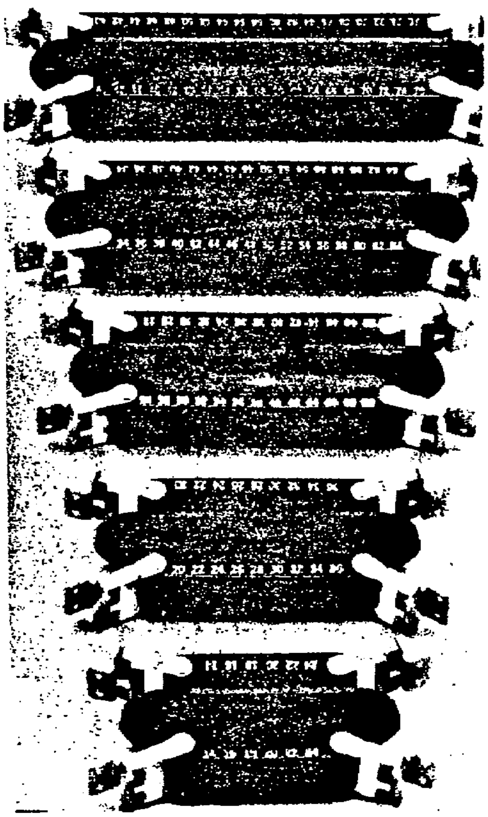
FIGURE 2-13. FCC to FCC receptacle, rectangular.



ENLARGED SECTION

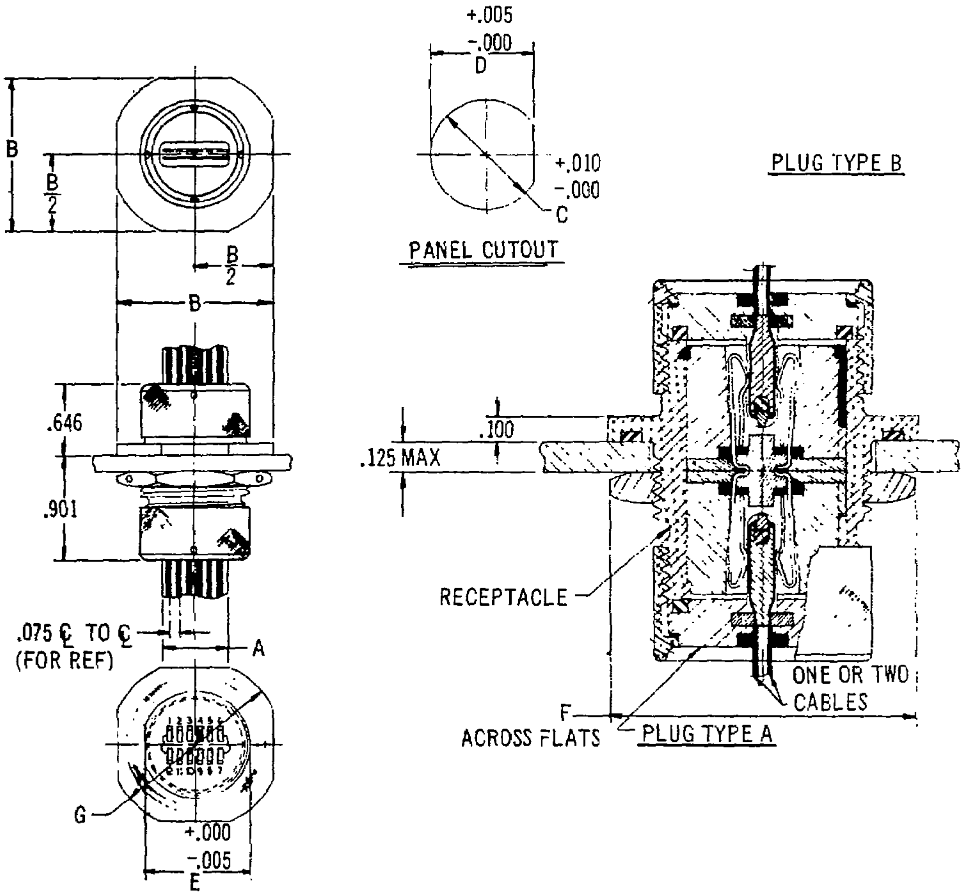






CABLE WIDTH INCHES	NUMBER OF CONTACTS	MOUNTING AREA INCHES	WEIGHT IN GRAMS	
			RECPT	PLUG EA
3	76	.9 X 4.2	57	17
2.5	64	.9 X 3.8	50	15
2	50	.9 X 3.3	40	12
1.5	36	.9 X 2.7	33	9
1	24	.9 X 2.3	28	7

FIGURE 2-14. FCC to RWC receptacle, rectangular.

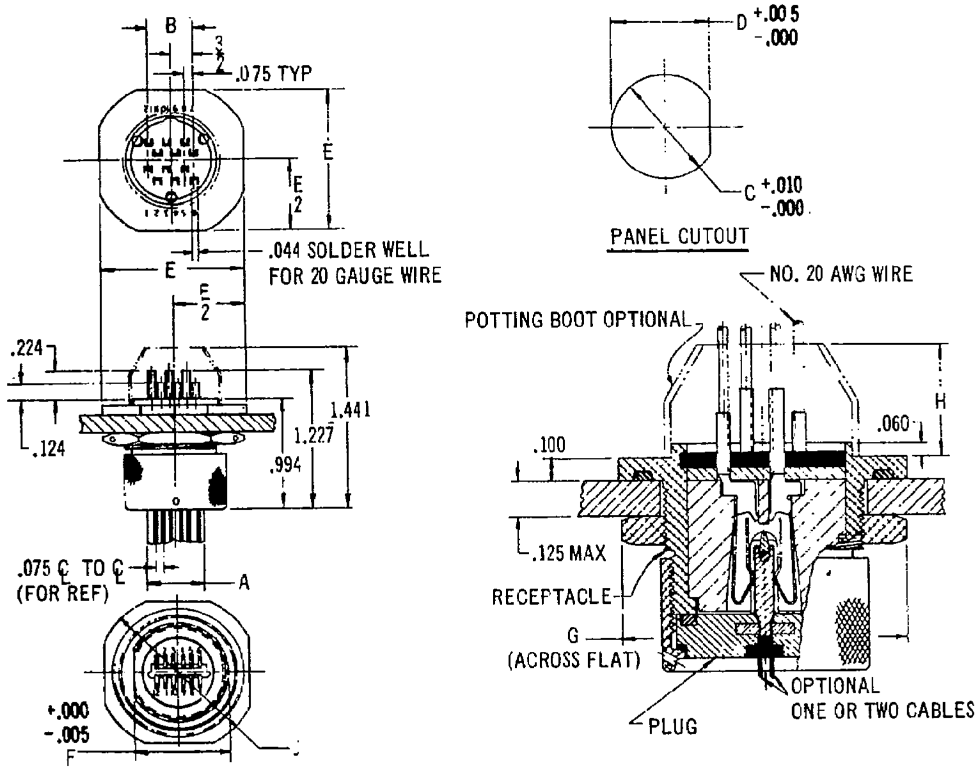


DIMENSION						
A	B	C	D	E	F	G
.300	.938	.572	.542	.540	.750	1.00
.500	1.250	.884	.830	.818	1.062	1.38

VOLTAGE -------------300V.RMS
CURRENT PER CONTACT----- 3A.
CONTACT RESISTANCE------ .006 OHMS MAX.
TEMPERATURE RANGE
RECEPTACLE ---------- -65° TO 125°C

PLUG MOLDED ON -------- -65° TO 125°C.
AIR LEAKAGE
RECEPTACLE ---------- LESS THAN 1 CU CM/HR
AT 2 ATM. DIFF.
HUMIDITY -------------- MIL-STD-202 METHOD 106

FIGURE 2-15. MIL-C-55544/16 FCC to FCC receptacle, cylindrical.



DIMENSION								
A	B	C	D	E	F	G	H	J
.300	.150	.572	.542	.938	.540	.750	.500	1.00
.500	.375	.884	.830	1.250	.818	1.062	.750	1.38

VOLTAGE -----------300 V.RMS
CURRENT PER CONTACT -- 3 A
CONTACT RESISTANCE ---.006 OHMS MAX.
TEMPERATURE RANGE
RECEPTACLE ---------65 TO 125°C

PLUG MOLDED ON---65 TO 125°C
AIR LEAKAGE
RECEPTACLE------LESS THAN 1 CU CM/HR AT 2 ATM. DIFF
HUMIDITY--------MIL-STD-202 METHOD 106

FIGURE 2-16. MIL-C-55544/14 FCC to RWC receptacle, cylindrical

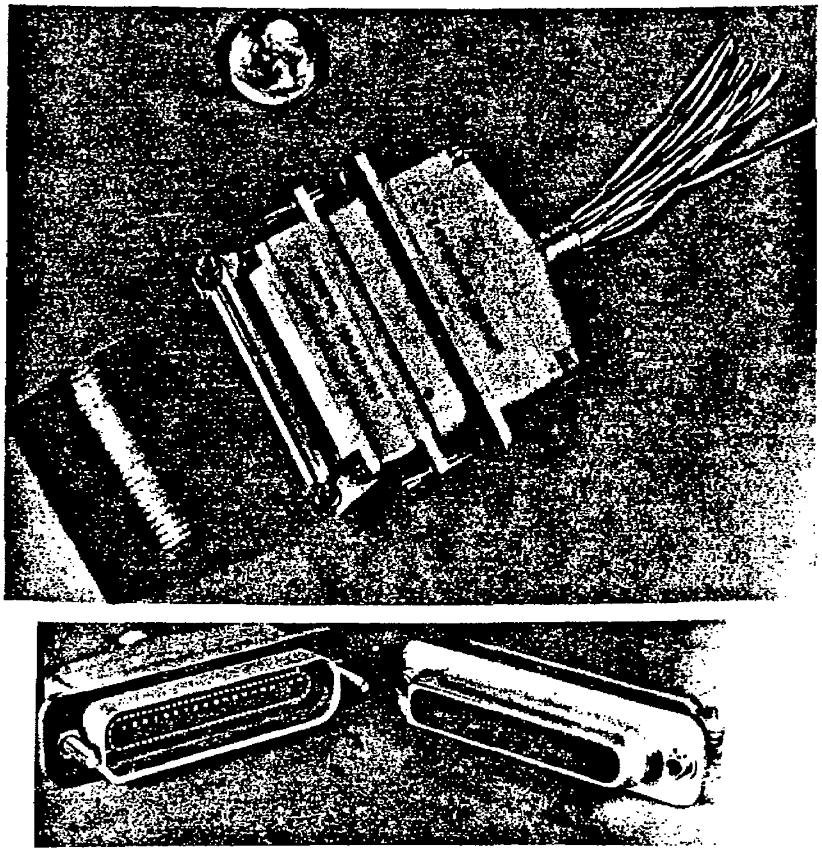


FIGURE 2-17. Pin-and-socket connectors (Picatinny Arsenal)

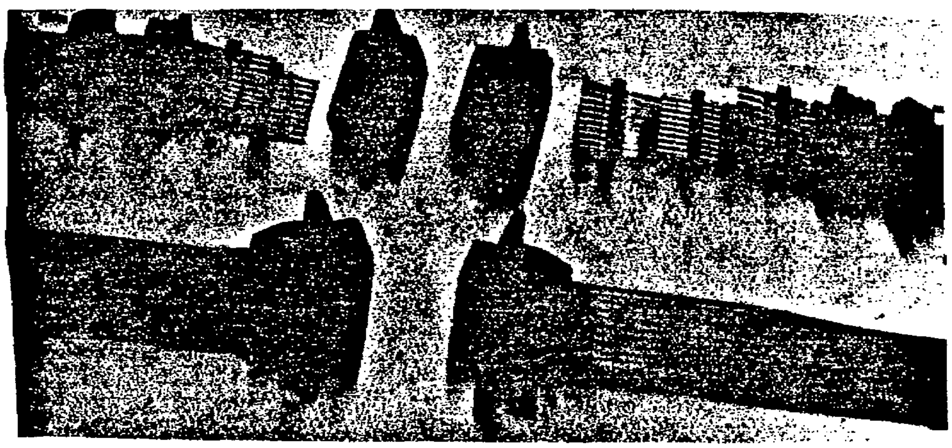


FIGURE 2-18. Multilayer connector, 16-gage contacts (ELCO).

The MIL-C-55544/1 and /3 specification sheets define the nonshielded and shielded plugs, and the /2 and /4 sheets define the nonshielded and shielded receptacles. All sheets are tabulated for 1-, 2-, and 3-inch cable widths, for 1, 2, and 3 layers of contacts, and for 50-, 75-, and 100-mil contact centerlines. This represents a total of 27 each different plug and receptacle configurations. If shielded and nonshielded versions are considered, then there are 54 different configurations for plugs and 54 for receptacles. So it can be seen that considerable more design, tooling, and qualification testing is required before this connector design approaches the availability status of the NASA/MSFC conductor systems.

2.3.4 Other FCC Connectors. To present a broader concept of connectors and termination systems that have been used, or being proposed, general descriptions and illustrations are given for other connectors developed for and/or used with FCC.

2.3.4.1 For Severe Environmental Conditions. Numerous connectors have been designed and developed for severe environmental conditions. Although the following connectors are not included in the existing draft of the MIL-C-55544 connector specifications, they meet many of the specification requirements.

2.3.4.1.1 Initial Development. Figure 2-18 shows a multilayer FCC connector developed by ELCO Corporation for Picatinny Arsenal. This was one of the first pin-and-socket type connectors designed for the termination of the FCC on a by-layer concept. Although the 16-gage pin-and-socket contacts and the 0.16 contact centerline spacing resulted in a contact density and connector weight generally not acceptable for flight-type connectors, many of the principles incorporated in this design were included in the high-density connectors which were to follow.

2.3.4.1.2 Prototype Connectors for the Poseidon Program. The Lockheed Aircraft Company Missile Division at Sunnyvale, California, had flat-cable prototype connectors developed for possible use in the Poseidon Missile tunnel. All connectors were for 2-inch-wide FCC with contacts on 100- and 150-mil centers. The connector system provided a production break and a transition from FCC tunnel wiring to RWC equipment area wiring. Electrical shielding provisions were included for both the FCC and RWC connector parts. Sealed contact wafers for each FCC cable layer were used for connector assembly. Each wafer could be replaced for repair or rework, as required.

Figure 2-19 shows the prototype built by Cannon IT&T. Figure 2-20 shows a cross section of the design submitted by Bendix. A prototype version was also manufactured by ELCO Corporation. All designs utilized terminations in the flat-cable portion of the connector, made by welding through the insulation.

2.3.4.1.3 High-Density FCC Connectors. Figure 2-21 shows a Mark II Micro Dot connector manufactured by Cannon IT&T. This connector has FCC contact centerline spacing of 50 mils with a contact-layer spacing of 44 mils to provide a contact density of over 400 per square inch. It has metal backshells plus interfacial and intercontact seals. Recommended termination is welding through the FCC insulation, followed by encapsulation. This connector is available in 9-, 15-, 21-, 25-, 37-, and 51-contact layouts.

Figure 2-22 shows a Micro Dot type MMD, high-density flat-cable connector. This prototype connector accommodates three 1-inch-wide standard FCC's on 50-mil centerline. Contact termination is made by welding through the insulation to contact wafers which are subsequently assembled into the connector backshell. Interfacial and intercontact sealing as well as provisions for keying and electrostatic shielding are provided.

Figure 2-23 shows a 50-mil center multilayer-prototype connector made by Cannon IT&T. It incorporates metal shells, separately sealed, removable wafers for each cable layer, interfacial and intercontact seals, and electrostatic shielding provisions. This connector was designed specifically to meet the requirements of MIL-C-55544.

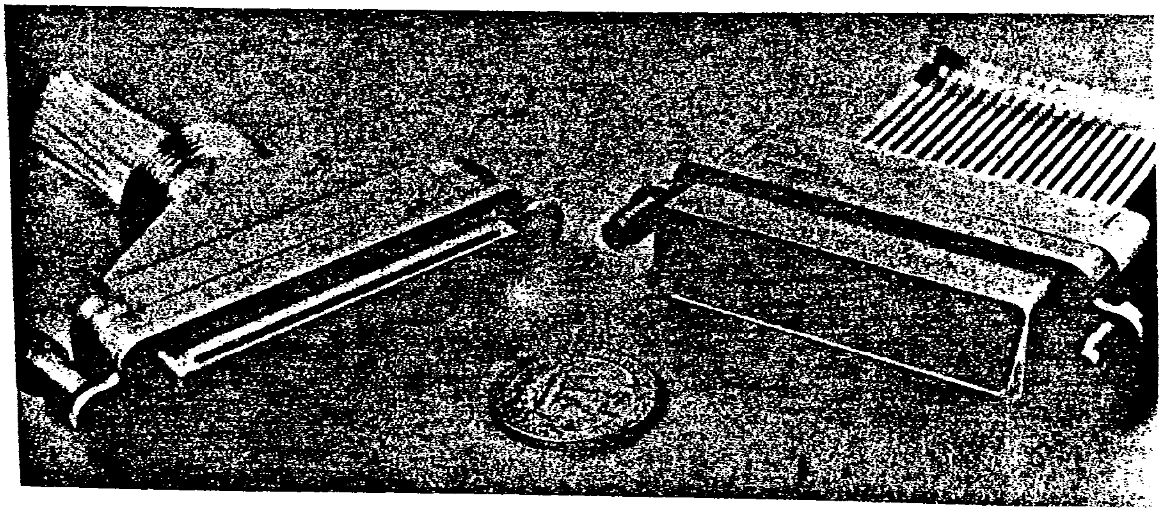


FIGURE 2-19. Multilayer connector prototype for Poseidon (Cannon IT&T).

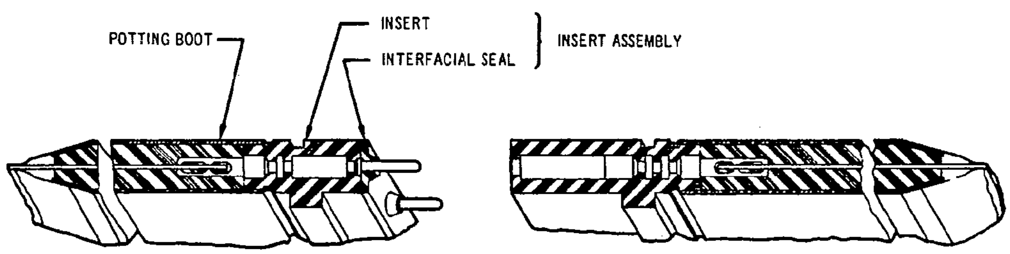


FIGURE 2-20. Multilayer connector cross-section for Poseidon (Bendix).

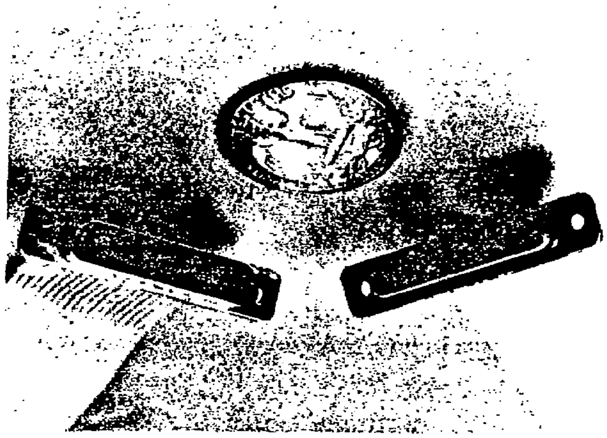


FIGURE 2-21. MARK II Micro Dot high-density connector (Cannon IT&T).

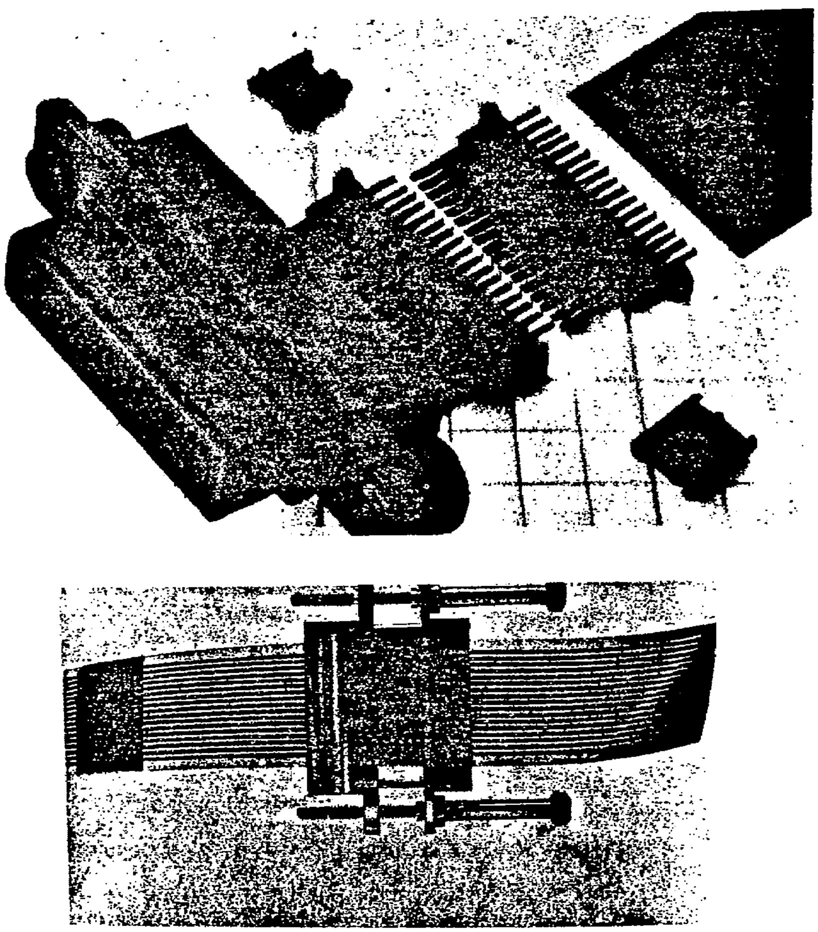


FIGURE 2-22. MMD high-density connector (Micro Dot).

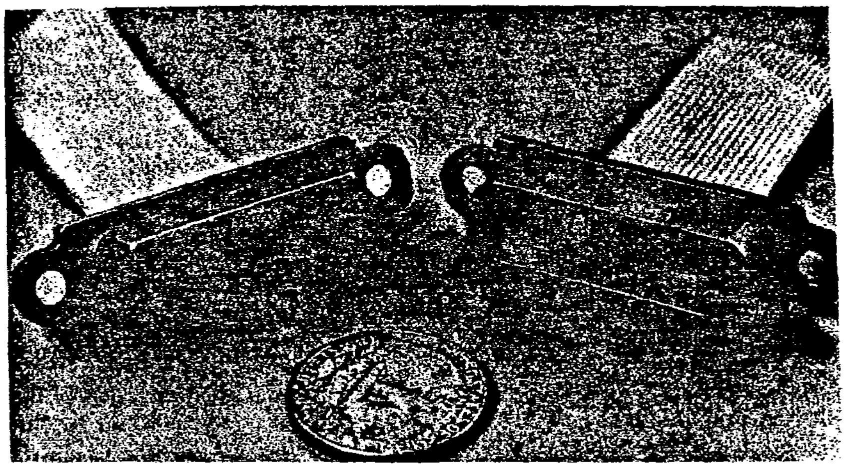


FIGURE 2-23. 50-Mil center multilayer prototype (Cannon IT&T).

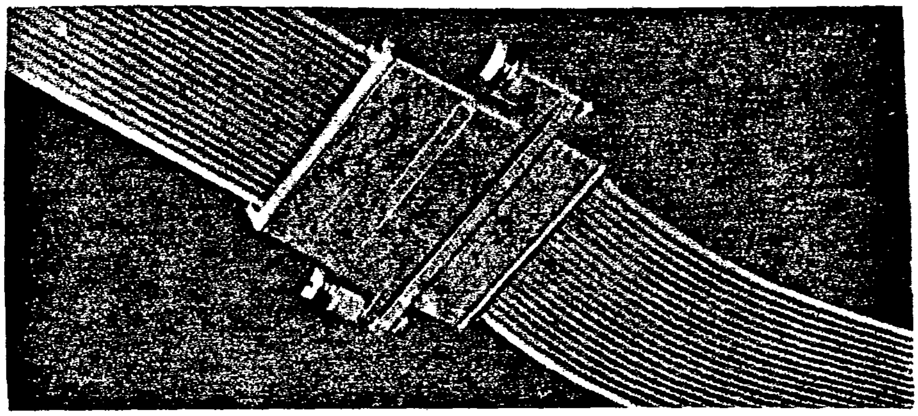


FIGURE 2-24. 218 Flex-1 series connector (Amphenol).

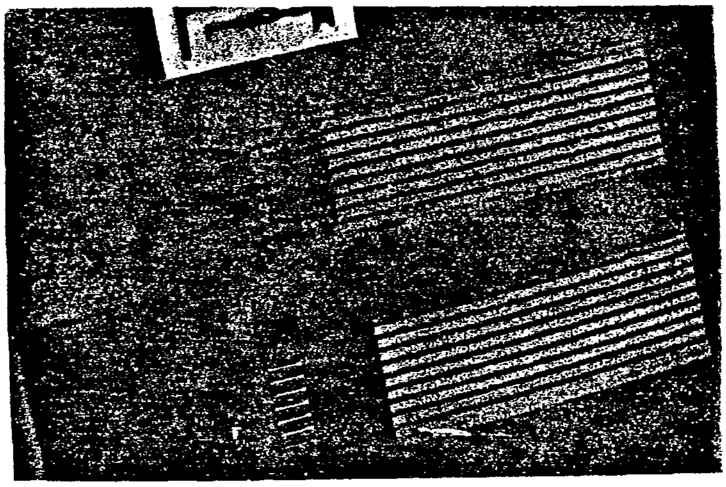


FIGURE 2-25. Crimp contact connector (Amp).

2.3.4.2 Nonenvironmental Connectors. Many different types of FCC connectors have been developed and manufactured for applications not requiring the MIL-C-55544 performance requirements. These can generally be broken down into pin-and-socket and conductor-contact systems.

2.3.4.2.1 Pin-and-Socket Contacts. Figure 2-24 shows a 218 Flex-1 series connector made by Amphenol. This connector was designed to meet the operational requirements of the IPC-FC-218 FCC commercial specification. The 218 Flex-1 connectors are available in 2- and 3-inch widths with 75-, 100-, and 150-mil contact spacing. In addition to the weldable contacts for FCC, solder eyelet contacts are available for RWC, to permit easy transition from FCC to RWC. Contact is made to the FCC by a simple welding process that melts the insulation at the junction point and welds the conductor directly to the contact.

Figure 2-25 shows a crimp-contact connector manufactured by Amp, Incorporated. This production, commercial-type FCC connector utilizes reel-fed contacts for high production termination. The stamped and formed (0.025 square) gold-plated contact can be incorporated into numerous existing Amp miniature connector designs. No cable preparation, soldering, or welding are required for this termination system.

Figure 2-26 shows a multilayer connector with Varicon[3] contacts manufactured by ELCO Corporation. Many existing, similar connector configurations can be adapted to FCC use for nonsealed, low-environment applications.

Figures 2-27 and 2-28 show completed cable assemblies manufactured by ACI, Inc. which specializes in furnishing completed FCC harness assemblies to meet the customer requirements. These are called Signalflo systems, and they are furnished for special transmission lines, memory devices, etc., with specific requirements for impedance, propagation velocity, crosstalk, capacitance, and other physical and electrical parameters. The combinations of characteristics available are limitless.

Figure 2-29 shows completed, typical FCC harness assemblies manufactured by Methode Electronics which supplies completed harness assemblies in addition to several types of rectangular connectors suitable for use with FCC. The Plyo-Duct harnesses can be furnished in many configurations of nonshielded, shielded, continuous, and PC-type circuits. In addition, Methode Electronics has a complete line of Reli-Acon PC-type connectors which can be applied to low-environmental FCC interconnecting systems.

Figures 2-30 and 2-31 show completed FCC harness assemblies manufactured by Ansley West. This company designs and manufactures many special FCC harness configurations for military high-performance systems. Figure 2-30 shows flexible, continuous shielded cable terminated to rectangular and round connectors. This is one of a large series of SINS cables made for Autonetics. Figure 2-31 shows a special gyro cable with very low torque requirements, which is used by Autonetics on the Minuteman II. Ansley West uses, almost exclusively, their Flex-Weld termination method to terminate the FCC. Welding is accomplished through the insulation to the connector contact or to an intermediate pin or wire.

2.3.4.2.2 Conductor Contacts. Figure 2-32 shows a completed harness assembly manufactured by Rogers, Inc. This company has available a line of receptacles and molded-on plug assemblies for various FCC widths. This company has developed two high-performance FCC connector lines; the nonmetal backshell connector shown, and a metal backshell version for extreme environmental conditions. The Positerm[4] system shown in Figure 2-32 is available in four sizes for 0.100-inch conductor centerline cables of approximately 0.90 through 3.30-inch widths. Two mating receptacle configurations for wire soldering and PC-board application are available. The metal backshell connector has only been developed for a 3.20-inch-wide, 100-mil center FCC. All plugs are limited to terminating one FCC.

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3. Trademark of Elco Corporation.
4. Trade name of Rogers Corp.

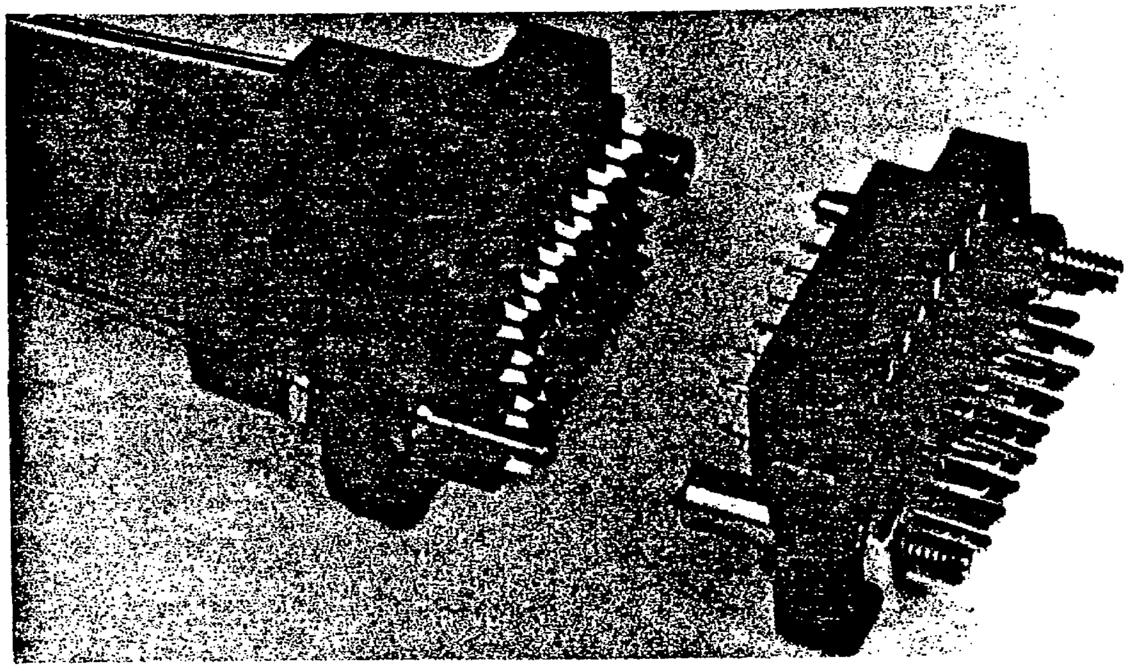

FIGURE 2-26. Multilayer connector (ELCO).

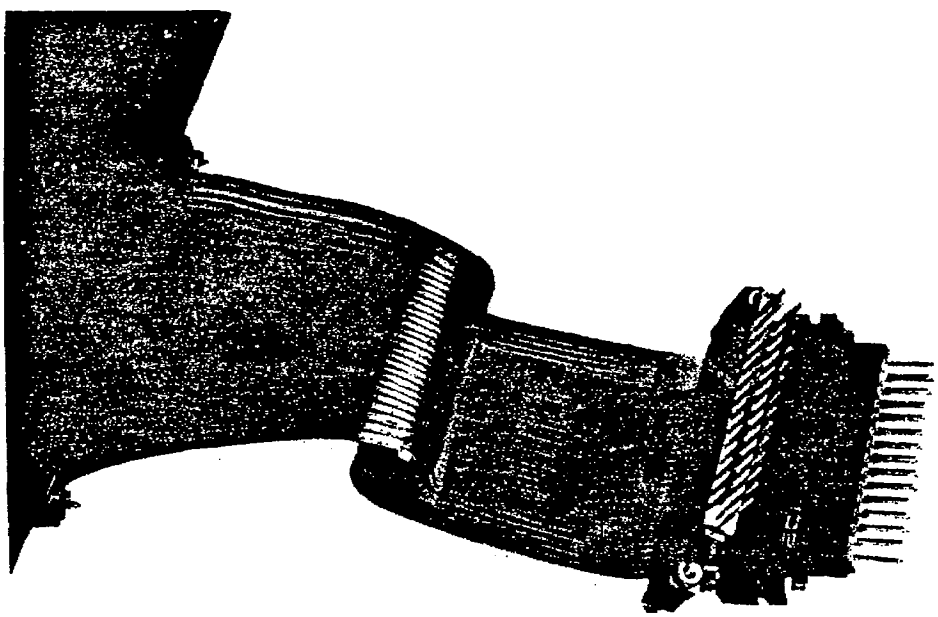

FIGURE 2-27. Retractable cable assembly (ACI).

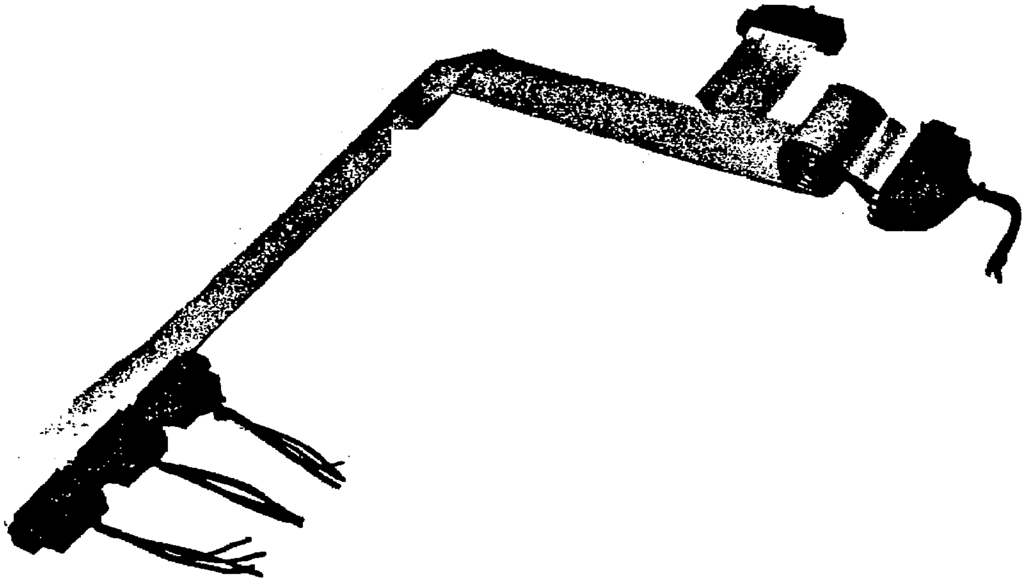

FIGURE 2-28. Harness Assembly (ACI).

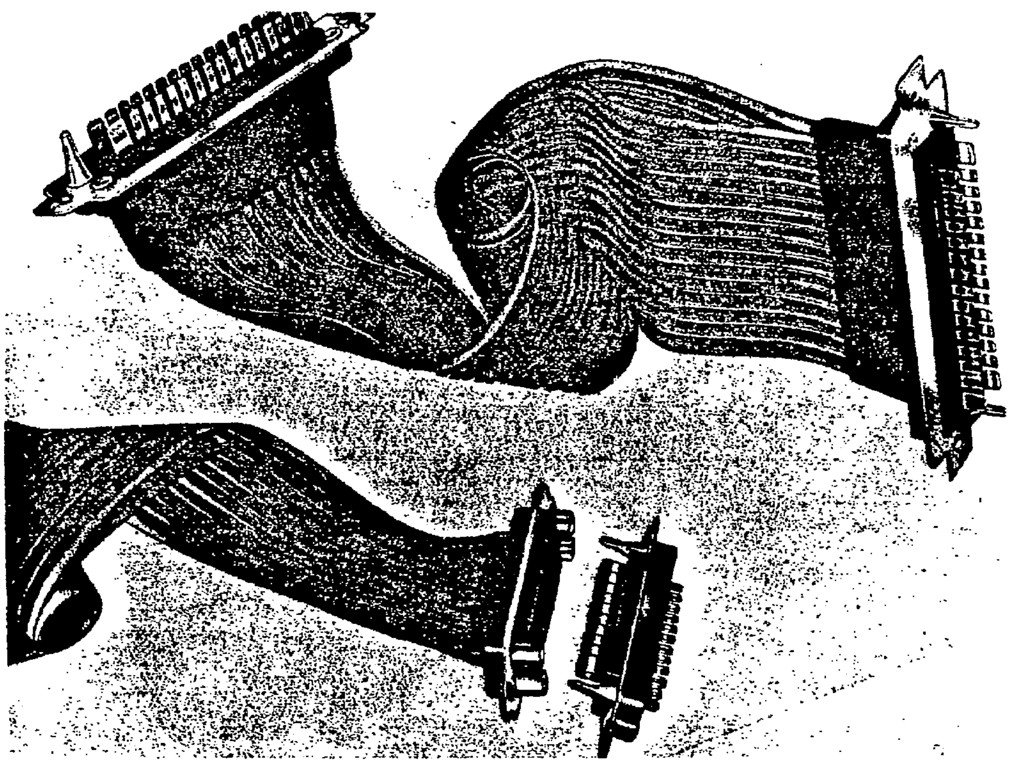

FIGURE 2-29. Harness assembly (Methode Electronics).

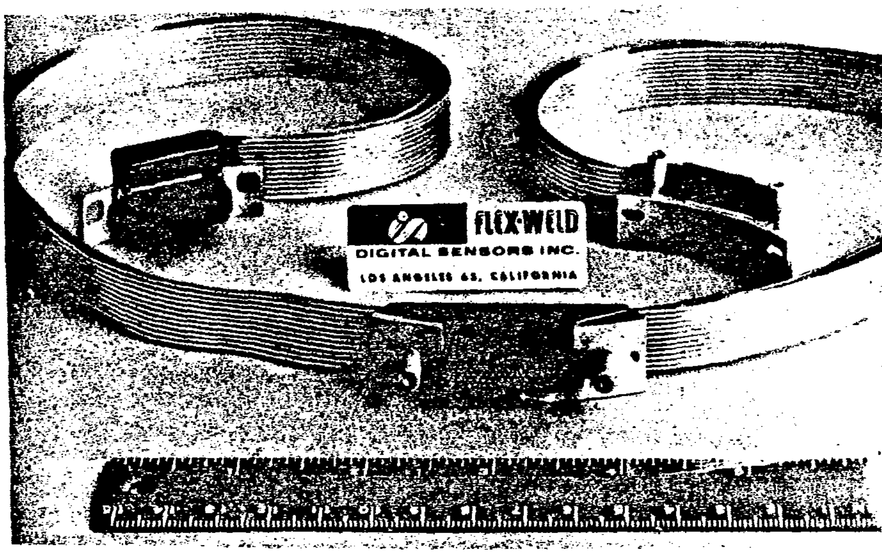

FIGURE 2-30. Shielded assembly (Ansley West).

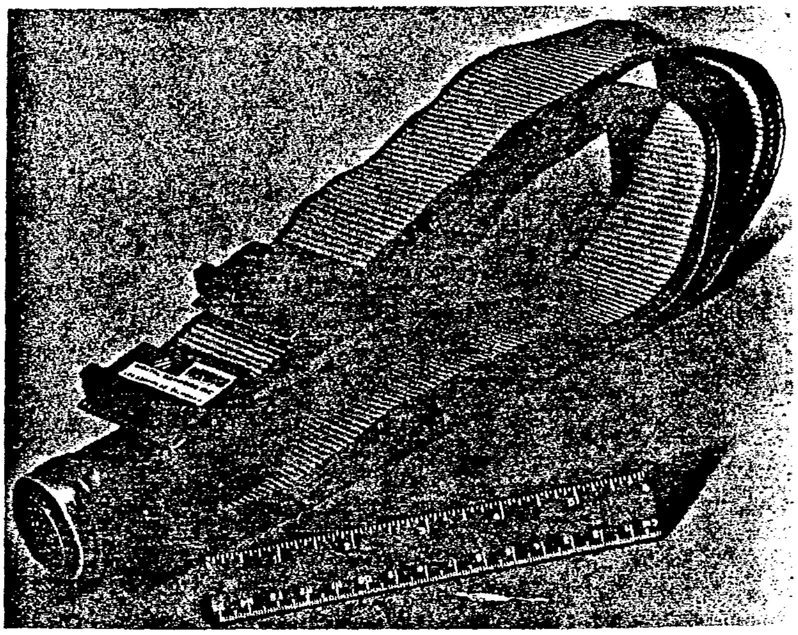

FIGURE 2-31. Gyro harness assembly (Ansley West).

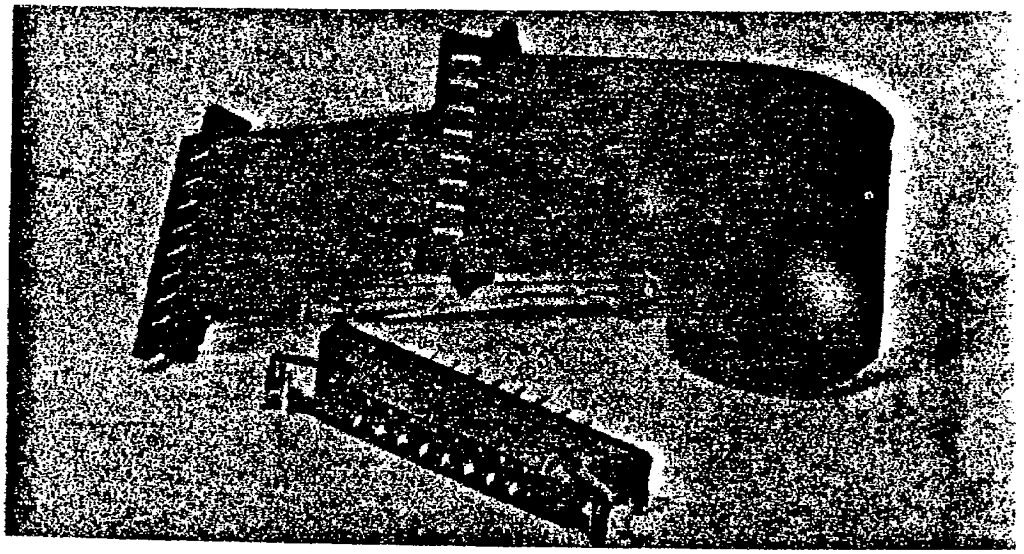

FIGURE 2-32. Harness assembly (Rogers Corp.).

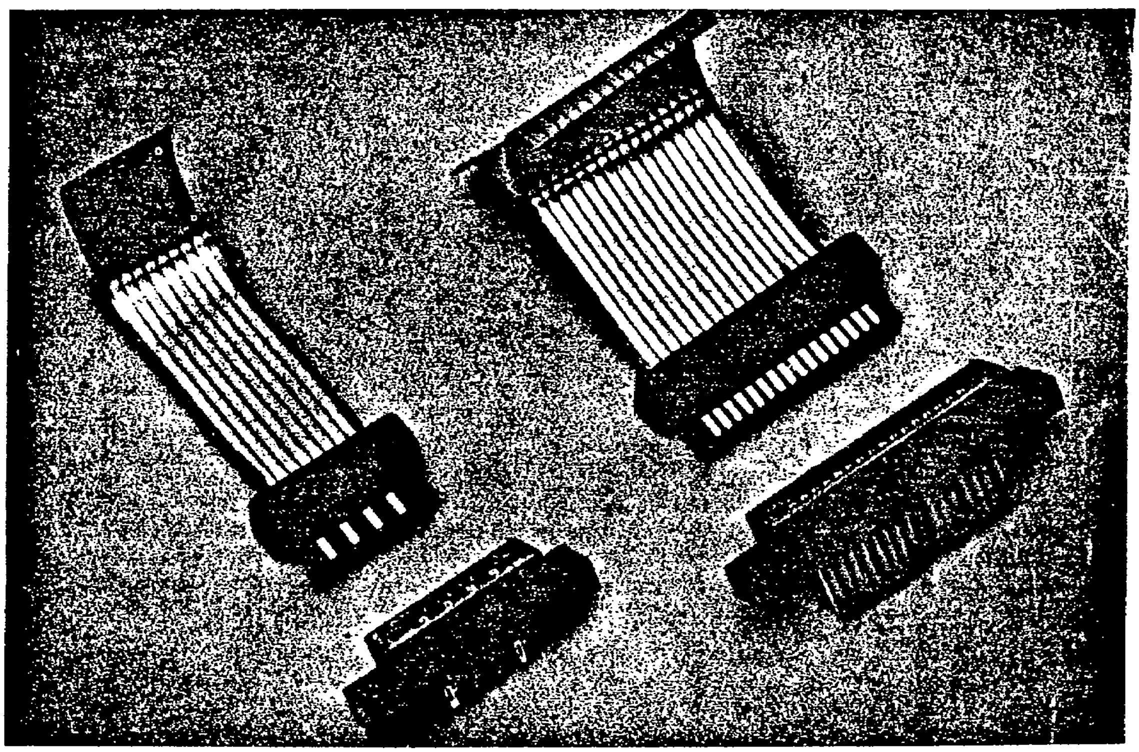

FIGURE 2-33. Harness assembly (ECS).

Figure 2-33 shows the Electronic Connective Systems (ECS) SIM/PLUG[5] FCC system. Complete harness assemblies with molded-on plugs are furnished by EGS. The 100-mil centerline connectors are presently tooled, and the design has been completed for 50-mil centerline. Both opposed and alternating contact configurations are available. The opposed arrangement permits redundant contacting for each conductor when used with a single cable. For maximum density with the opposed arrangement, two separate cables can be terminated in the single plug. The copper conductors can continue through a plug to provide parallel connections to a mating receptacle without interrupting the basic cable circuitry. The receptacle contacts are available with various detailed configurations for soldering, wire wrapping, and PC-board tab soldering.

2.4 Wire Change Devices

2.4.1 Introduction. Various wiring-change devices have been proposed and developed for FCC interconnecting systems. The philosophy, application, and hardware descriptions are given in Section IV for many different schemes. The following paragraphs define existing and prototyped hardware for accomplishing wiring changes.

2.4.2 FCC to RWC Transition. Figure 2-34 shows both a straight-and right-angle version of a round-wire plug with an adapter-bracket-supported FCC to RWC transition. As detailed in Section IV, Paragraph 4.2.1.2, NASA/MSFC has completely developed, tooled, and tested this wire-change transition device. The use of removable crimp pins in the RWC connector permits simple rework for maximum pin-assignment changes. Section VI, Paragraph 6.3.7, describes the manufacturing techniques for accomplishing the required transition.

2.4.3 PC-Board Distribution Box. Figures 2-35 and 4-11 show a PC-board distribution box developed by NASA/MSFC. Circuit changes are accomplished by introducing a short removable length of parallel-conductor PC-board on which the necessary alterations or connections are made. This unit is installed between two NASA/MSFC conductor-contact plug assemblies. Nonsymmetrical mounting holes assure proper installation registration of the distribution box.

2.4.4 Jumper-Wire Distribution Box. Figures 2-36 and 4-10 show a typical jumper-wire distribution box using NASA/MSFC FCC to RWC receptacles. The required interconnections are made by soldering insulated RWC between solder pots of the two receptacles. More than two receptacles can be used as required, and the box can be pressurized. Simple field rework can be easily accomplished.

2.4.5 Termi-Point[6] Distribution. Figure 2-37 illustrates a multiple-receptacle distribution unit mockup made by MDC under contract to NASA/MSFC. A receptacle similar to the conductor-contact FCC receptacle, except for Termi-Point posts, would be required. This unit would be capable of automatic interconnection, but could also be wired and/or reworked with simple hand tools.

2.5 Clamps

2.5.1 Introduction. The rectangular cross section of FCC precludes the use of conventional cushioned clamps used with RWC bundles. During the Saturn IV-B FCC Development Program, goals were established for clamp designs, and various type clamps were developed and installed on the mockup fixture.

2.5.2 Design Goals. Design goals for clamps to be used with FCC interconnecting harnesses are listed as follows:

a. Simple and lightweight

b. Utilize captivated hardware (no loose parts)

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5. Trade name of ECS.
6. Trade name of AMP Incorporated.

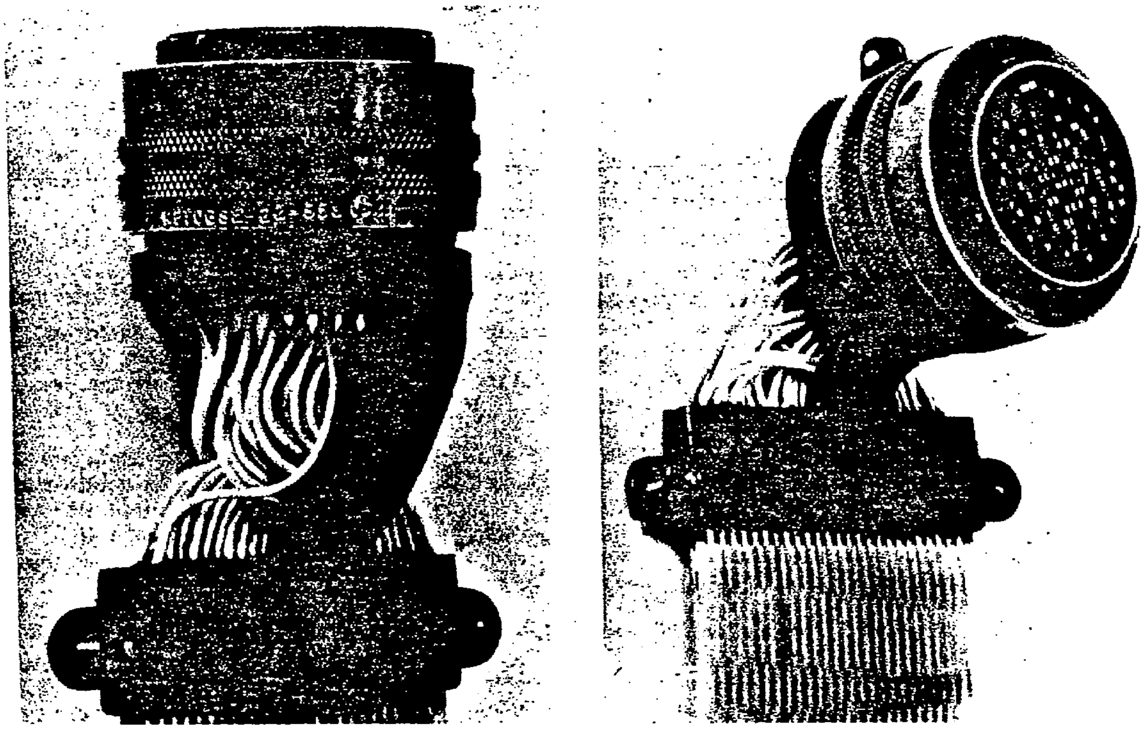


FIGURE 2-34. FCC to RWC transition.

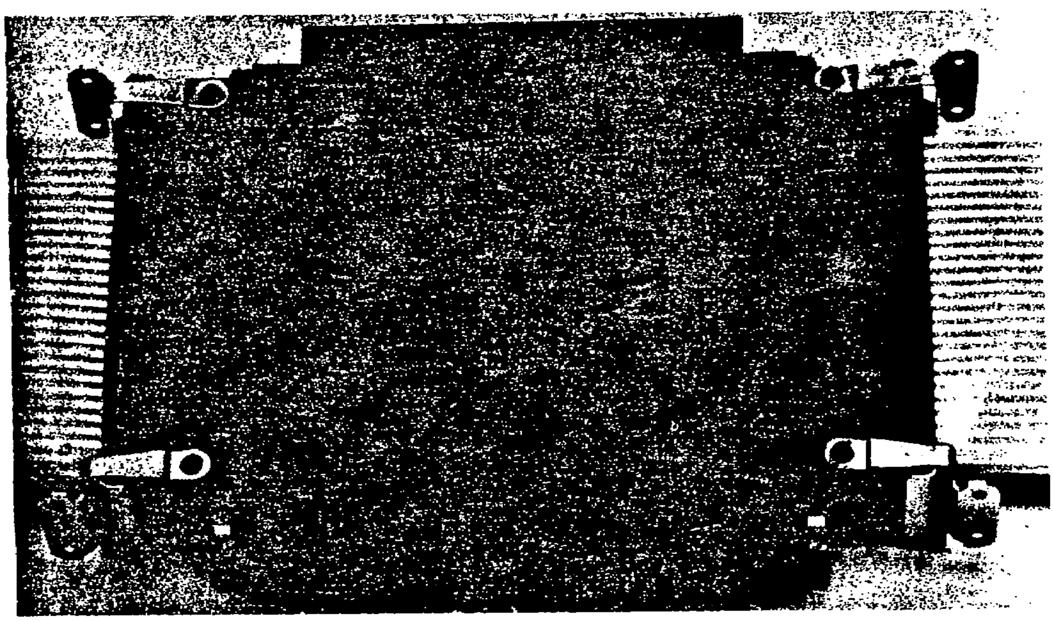


FIGURE 2-35. PC-board distribution box.

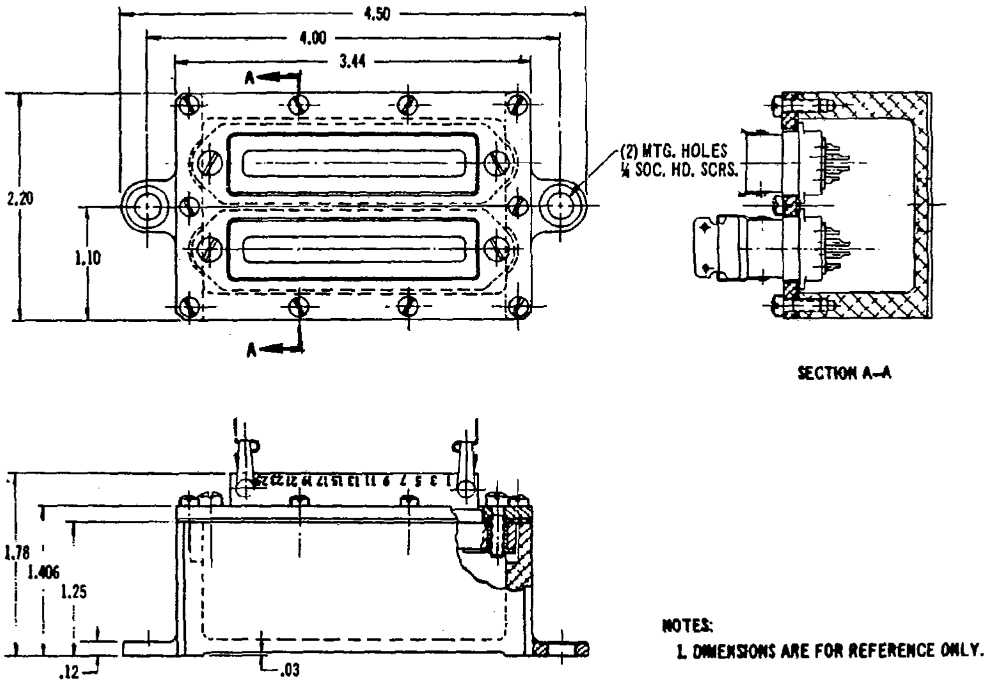


FIGURE 2-36. Jumper wire distribution box.

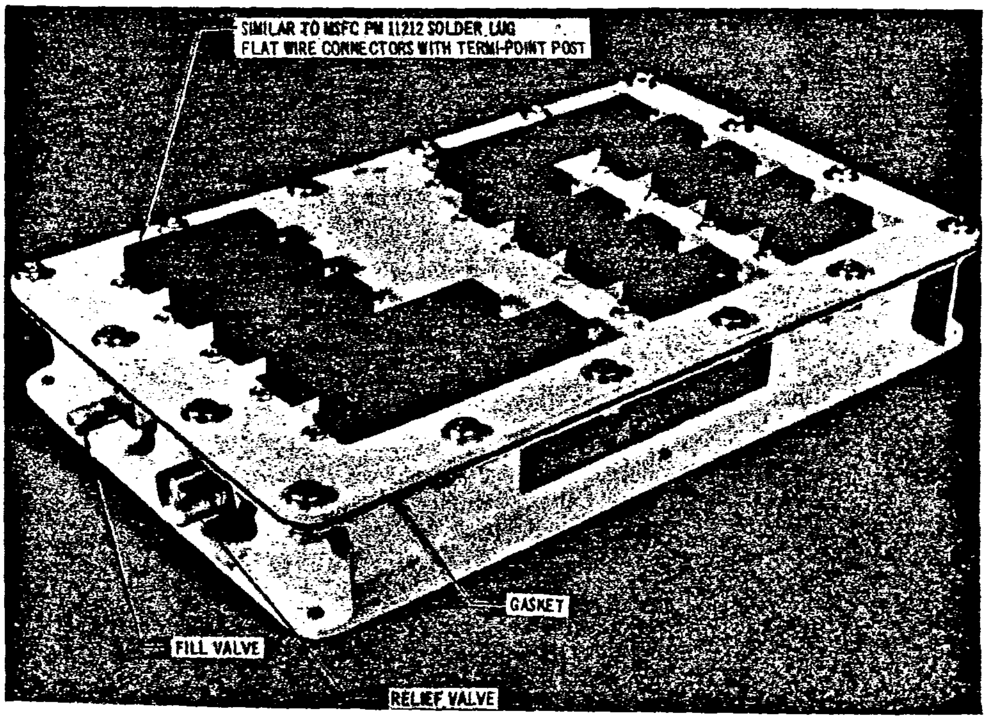


FIGURE 2-37. Termi-point distributor.

c. Require minimum mounting cutouts and hardware in supports or structure.

d. Modular in construction to accommodate the different FCC widths with the same clamp design.

e. Contain no sharp protrusions.

f. Be capable of installing in blind or poor-access areas.

2.5.3 Clamps for Severe Environmental Conditions. Several clamp types have been developed which are suitable for the handling, temperatures, and vibrations normally encountered in airborne applications. These are described in the following paragraphs.

2.5.3.1 Nonmetal Clamps for 100°C. Figures 2-38, 2-39, and 2-40 show lap clamps. These clamps utilize a Velero hook-and-pile material to securely hold the FCC bundles. The multiple clamps permit the minimum centerline spacing between adjacent bundles. The grommet prevents the tearout of the nylon material when exposed to loads over an extended time period. The Velero material and the nylon plunger fasteners are available from the Hartwell Corporation.

Figure 2-41 shows a lap-type clamp and support suitable for installation on curved surfaces.

Figure 2-42 shows a tubular cushioned clamp developed by NASA/MSFC which utilizes nylon fasteners. Figure 2-45 shows a similar clamp which uses conventional attaching screws in lieu of the nylon fasteners.

2.5.3.2 Metal Noncushioned Clamps for 200°C. Figure 2-43 shows a simple C-section aluminum clamp with captivated attaching screws. Tests conducted by NASA/MSFC on this type clamp indicate that maximum screw torque can be applied to a polyimide (Kapton) FCC over an extended time period without mechanical or electrical degradation of the FCC.

Figure 2-44 shows a tubular metal clamp for FCC right-angle routing and support. Sheet-metal spacers, similar to the one shown on Figure 2-45, are installed under the tubes for properly securing the FCC metal bracket.

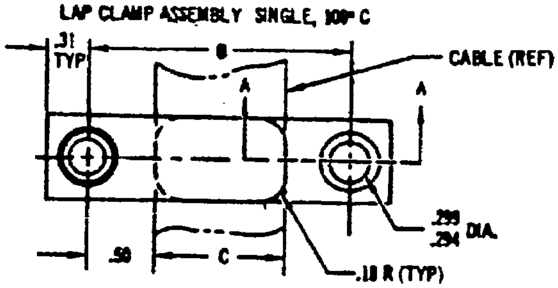
2.5.3.3 Metal-Cushioned Clamps for 200°C. Figure 2-47 shows a metal-cushioned clamp with Expando grip fasteners. This clamp requires only a round mounting hole in the support brackets, and is installed and removed by rotating the fastener a quarter turn. The fasteners are available from the Adjustable Bushing Company, North Hollywood, California.

Figure 2-48 shows a double-grip cushioned clamp which provides added resistance to cable slippage. Figure 2-49 shows two simple-cushioned C-channel clamps used to accomodate two adjacent right-angle folds for nonshielded FCC.

2.5.4 Clamps for Noncritical Application. Figure 2-50 shows two plastic clamps and fasteners utilizing existing, commercially available hardware. These are the simplest and lowest cost of all clamps presented.

2.5.5 Shop-Aid Clamp Support. Figure 2-51 shows a shop-aid cable support. It permits all FCC harnesses to be temporarily routed and assembled on the deliverable end item. These clamps are then replaced by flight-type clamps prior to the final installation.

LAP CLAMP ASSEMBLY SINGLE, 100° C



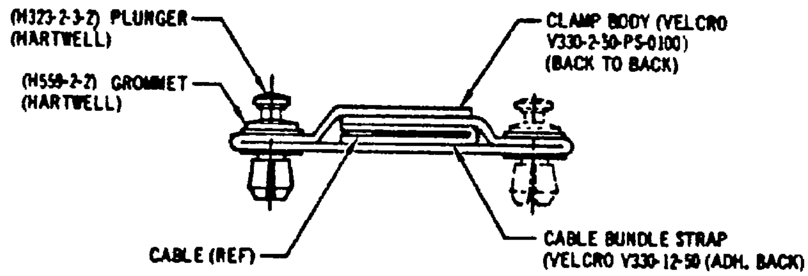
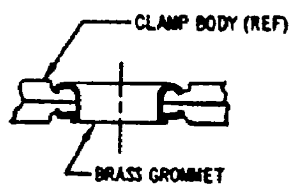


TABLE I			
CLAMP ASSY TYPE	CABLE WIDTH IN INCHES	B DIM.	LAP DIM. C
I	½" - 1"	2"	1"
II	1¼" - 2"	3"	2"
III	2½" - 3"	4"	3"



VIEW A-A

GENERAL NOTES:

1. PROVIDE $^{.314}_{.312}$ DIA. MOUNTING HOLE FOR INSTALLATION OF CLAMP ASSEMBLY.

2. CLAMP ASSEMBLY CONSISTS OF CLAMP BODY, CABLE BUNDLE STRAP, TWO (2) BRASS GROMMETS, TWO (2) PLUNGERS, AND TWO (2) GROMMETS.

FIGURE 2-38. Lap clamp assembly, single, 100° C.

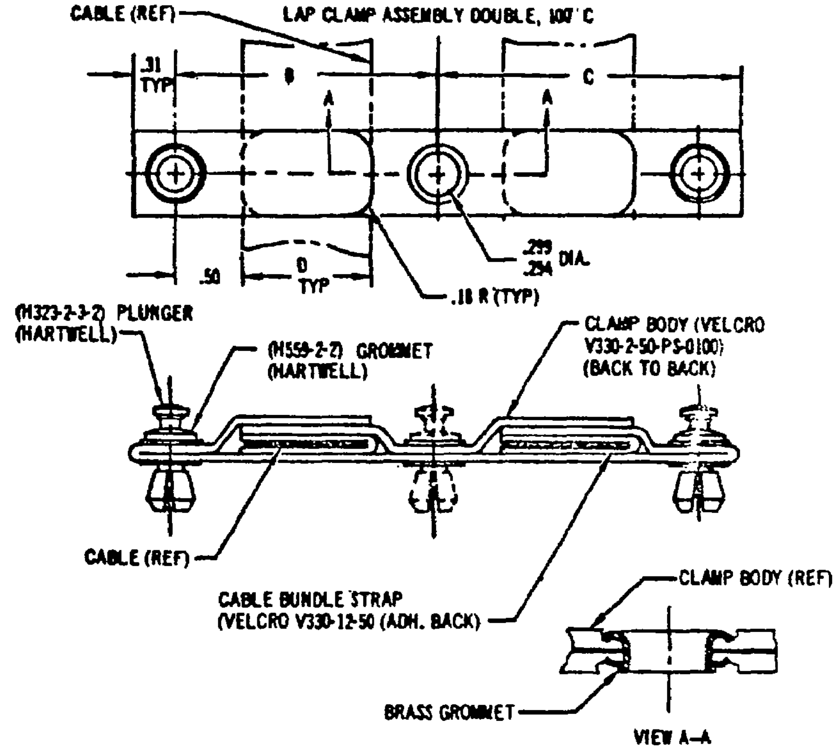


TABLE I				
CLAMP ASSY TYPE	CABLE WIDTH IN INCHES	B DIM.	C DIM.	LAP DIM. C
I	½" - 1"	2"	2"	1"
II	1½" - 2"	3"	3"	2"
III	2½" - 3"	4"	4"	3"

GENERAL NOTES:

1. PROVIDE $^{.314}_{.312}$ DIA. MOUNTING HOLE FOR INSTALLATION OF CLAMP ASSEMBLY.
2. CLAMP ASSEMBLY CONSISTS OF CLAMP BODY, TWO (2) CABLE BUNDLE STRAPS, THREE (3) BRASS GROMMETS, THREE (3) PLUNGERS, AND THREE (3) GROMMETS.

FIGURE 2-39. Lap clamp assembly, double, 100° C.

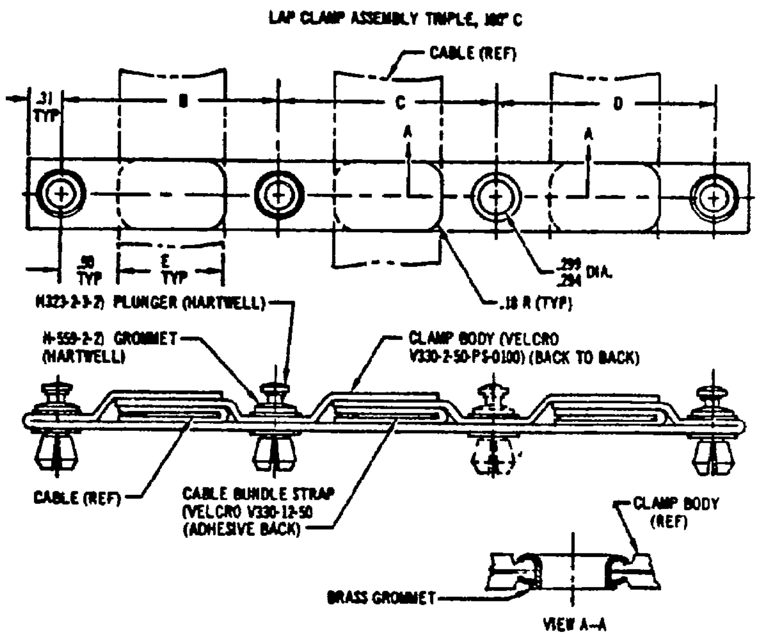


TABLE I					
CLAMP ASSY TYPE	CABLE WIDTH IN INCHES	B DIM.	C DIM.	D DIM.	LAP DIM. E
I	¼" – 1"	2"	2"	2"	1"
II	1¼" – 2"	3"	3"	3"	2"
III	2¼" – 3"	4"	4"	4"	3"

GENERAL NOTES:

1. PROVIDE $^{.314}_{.312}$ DIA. MOUNTING HOLE FOR INSTALLATION FOR CLAMP ASSEMBLY.
2. CLAMP ASSEMBLY CONSISTS OF CLAMP BODY, THREE (3) CABLE BUNDLE STRAPS, FOUR (4) BRASS GROMMETS, FOUR (4) PLUNGERS, AND FOUR (4) GROMMETS.

FIGURE 2-40. Lap clamp assembly, triple, 100° C.

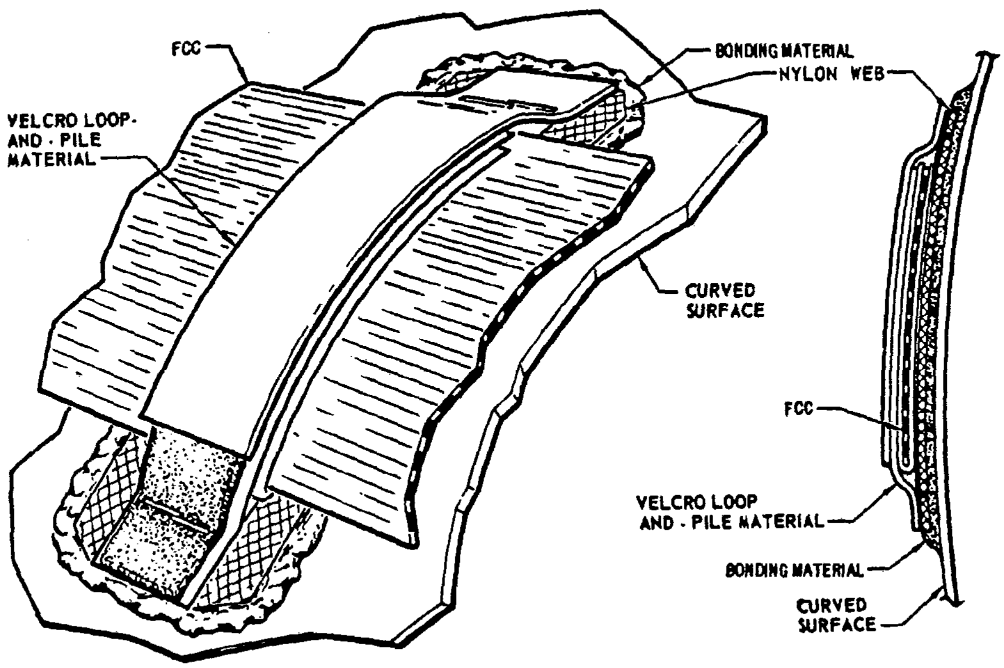


FIGURE 2-41. Lap clamps and support, curved surface, 100° C.

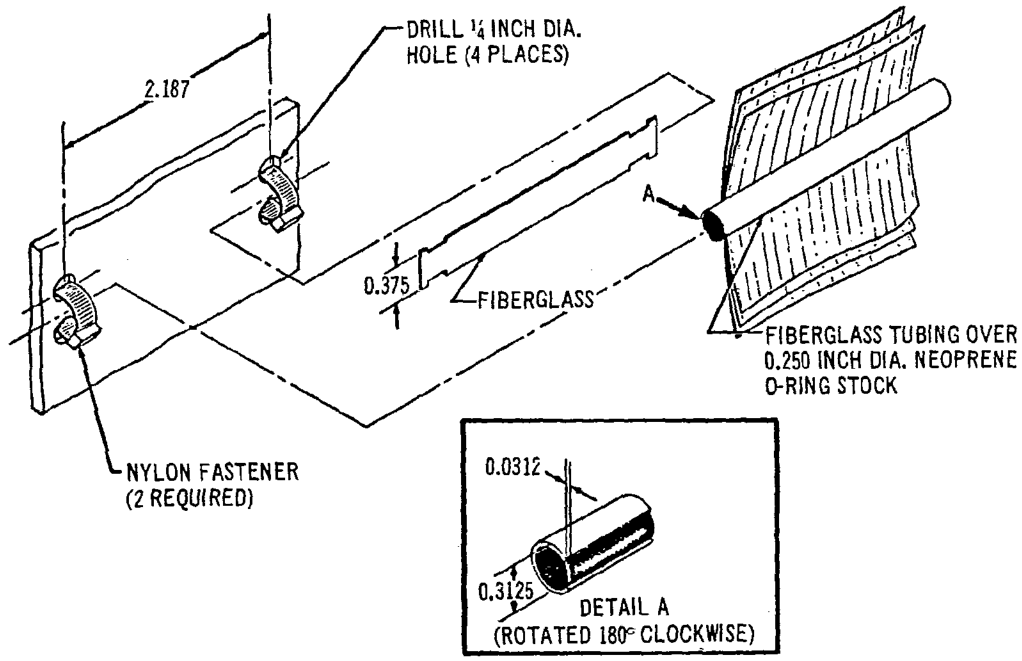


FIGURE 2-42. Tubular clamps with nylon fasteners, 100° C.

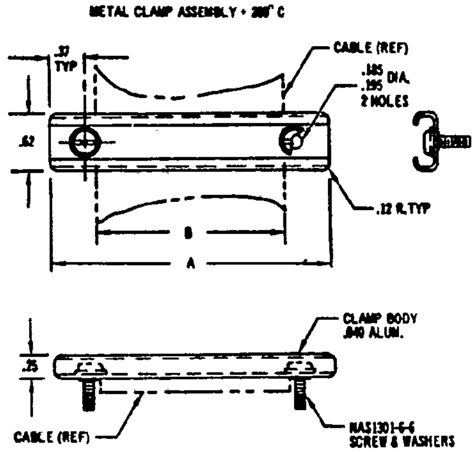


TABLE I			
CLAMP ASSY TYPE	CABLE WIDTH IN INCHES	A DIM.	B DIM.
I	½" - 1"	2"	1"
II	1½" - 2"	3"	2"
III	2½" - 3"	4"	3"

GENERAL NOTES
1. CLAMP ASSEMBLY CONSISTS OF CLAMP BODY, TWO (2) SCREWS, TWO (2) WASHERS. TWO (2) RETAINERS.

FIGURE 2-43. Metal noncushioned clamps, 200° C.

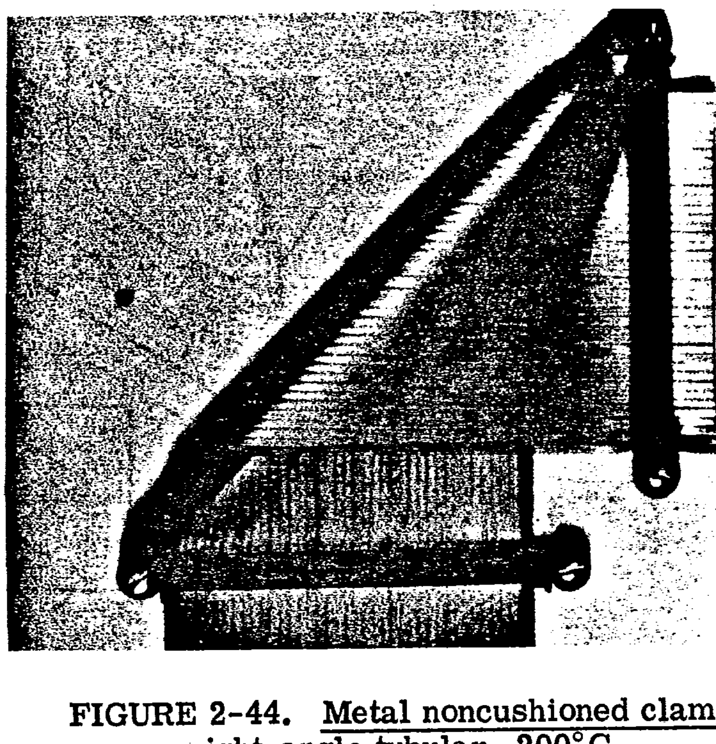


FIGURE 2-44. Metal noncushioned clamp, right-angle tubular, 200°C.

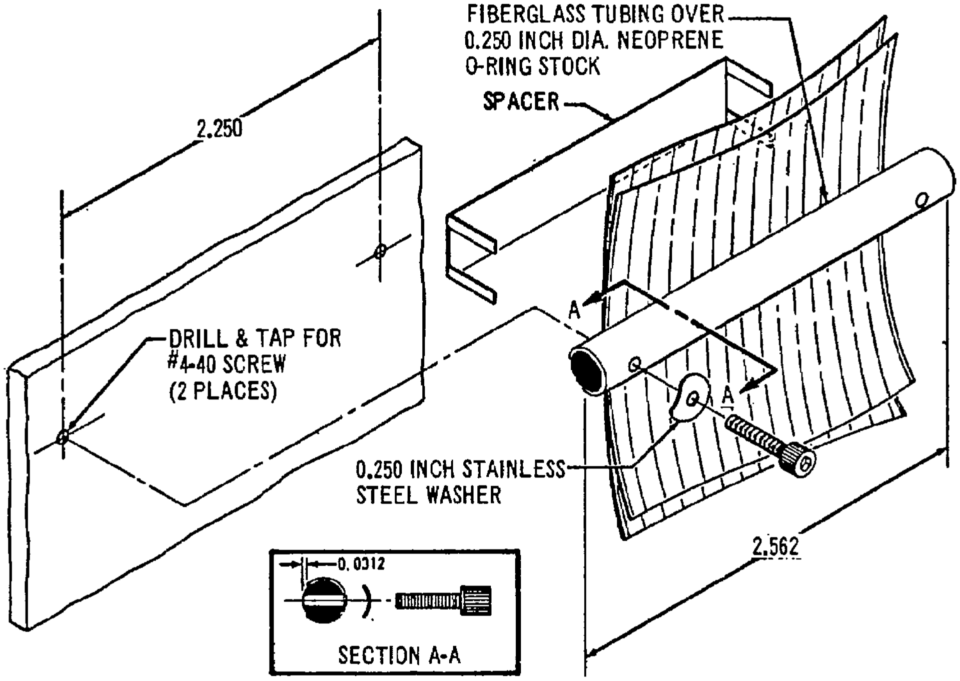


FIGURE 2-45. Tubular clamps with screw fasteners, 100° C.

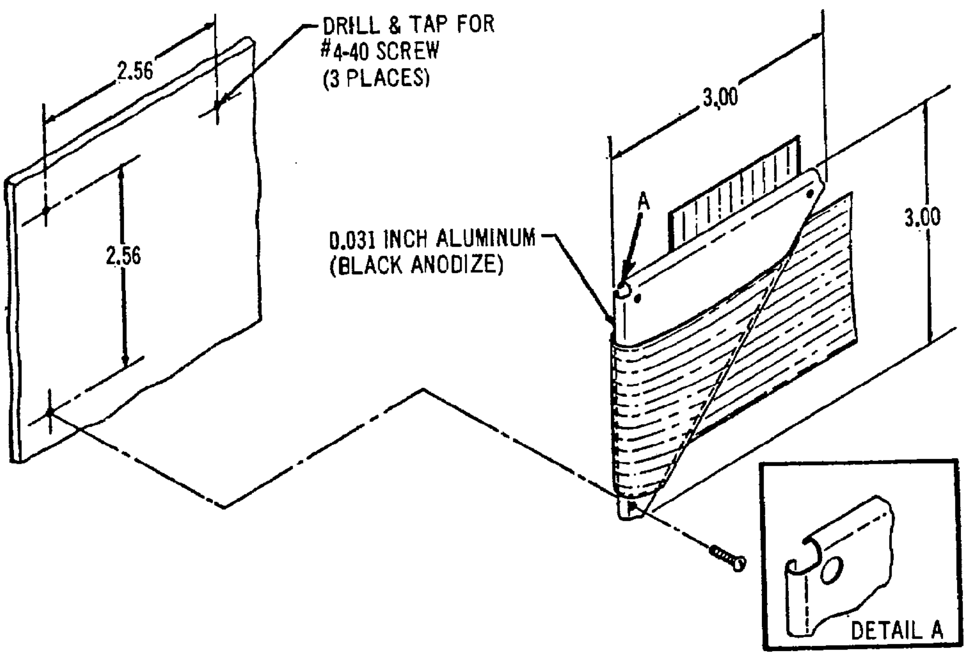
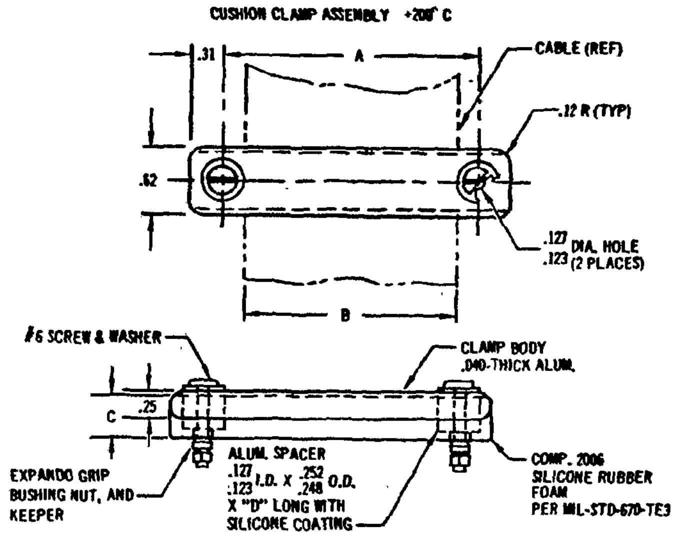


FIGURE 2-46. Metal noncushioned clamp, right-angle sheet metal, 200° C.



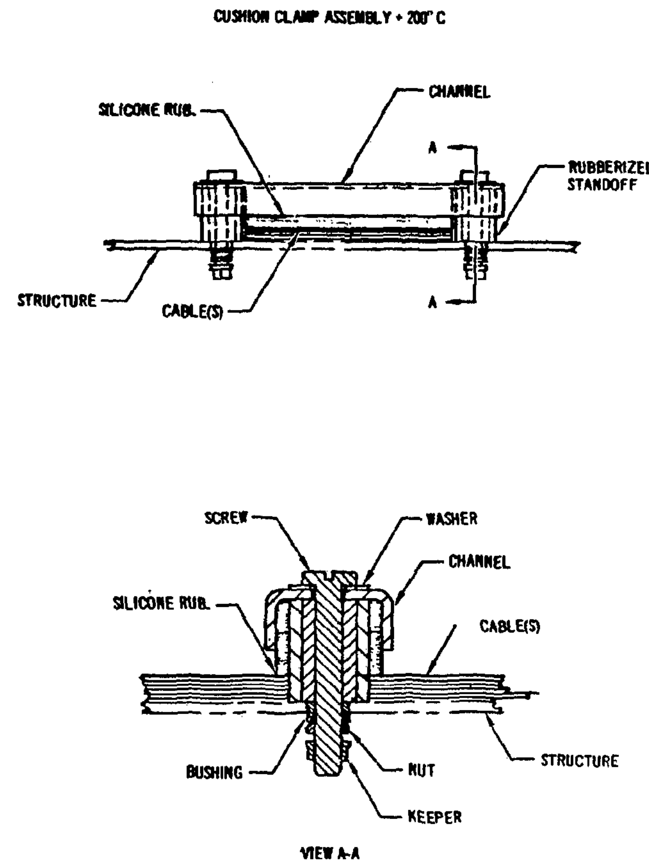


TABLE I

CLAMP ASSY TYPE	CABLE WIDTH IN INCHES	A DIM.	B DIM.	C DIM.	D DIM.
I	½" - 1"	1.38	1"	.50	.30
IA	½" - 1"	1.38	1"	.60	.40
II	1½" - 2"	2.38	2"	.50	.30
IIA	1½" - 2"	2.38	2"	.60	.40
III	2½" - 3"	3.38	3"	.50	.30
IIIA	2½" - 3"	3.38	3"	.60	.40

GENERAL NOTES:

1. PROVIDE $\frac{.317}{.312}$ DIA. MTG. HOLE FOR INSTALLATION OF CLAMP ASSEMBLY.
2. ALL CUSHIONS TO BE INSTALLED TO CLAMPS USING RTV-731 CEMENT.
3. CLAMP ASSEMBLY CONSISTS OF CLAMP BODY, SILICONE RUBBER CUSHION, TWO (2) NO. 6 SCREWS, TWO (2) WASHERS, TWO (2) EXPANDO GRIP BUSHINGS, NUTS, AND KEEPERS, TWO (2) SPACERS.

FIGURE 2-47. Metal-cushioned clamp, 200° C.

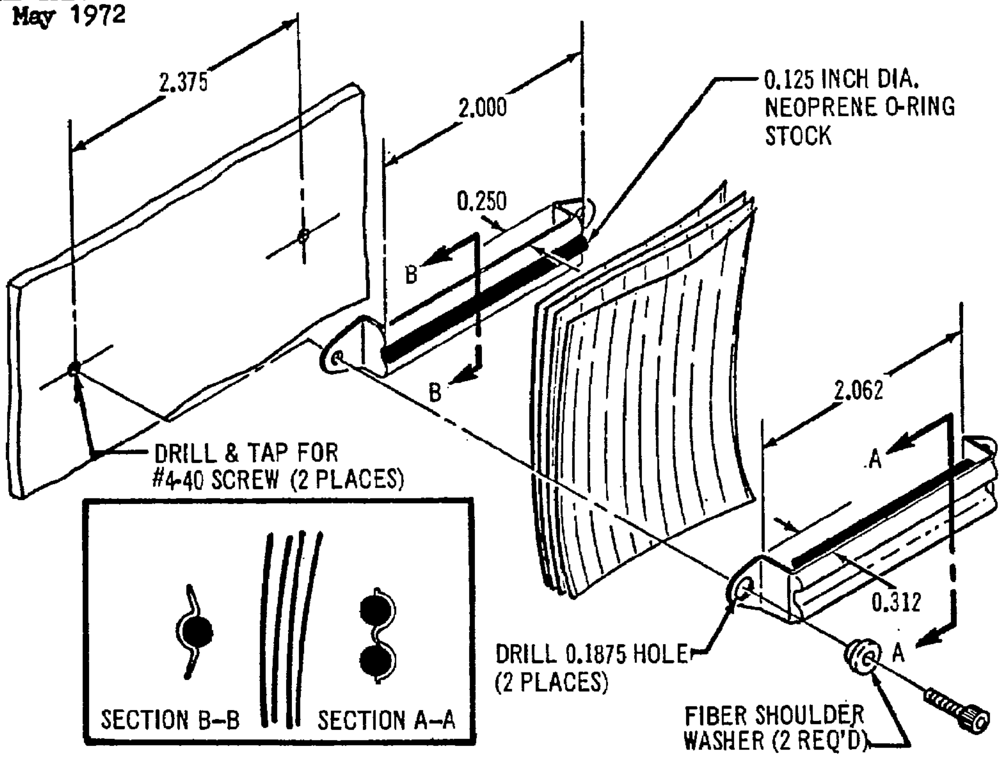


FIGURE 2-48. Metal-cushioned clamp, double grip, 200° C.

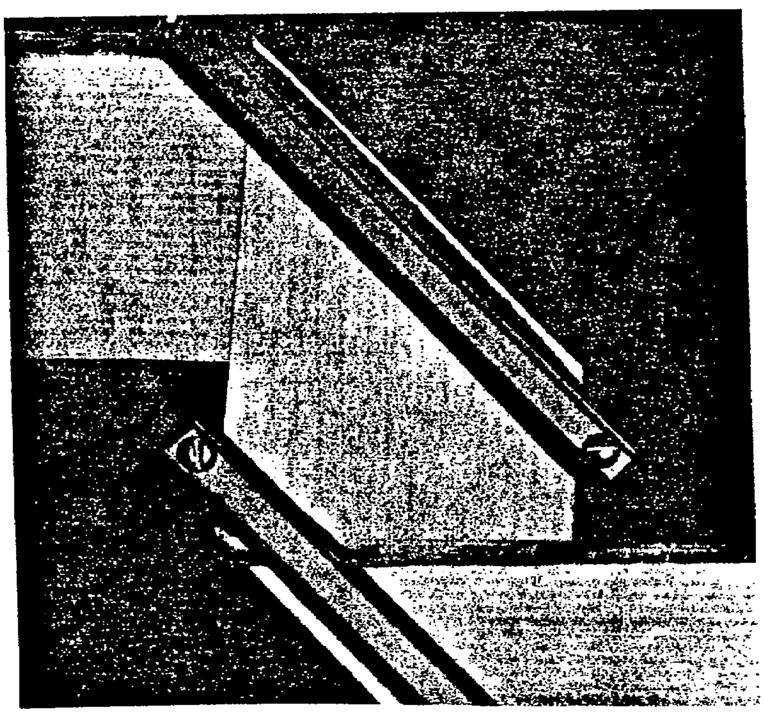
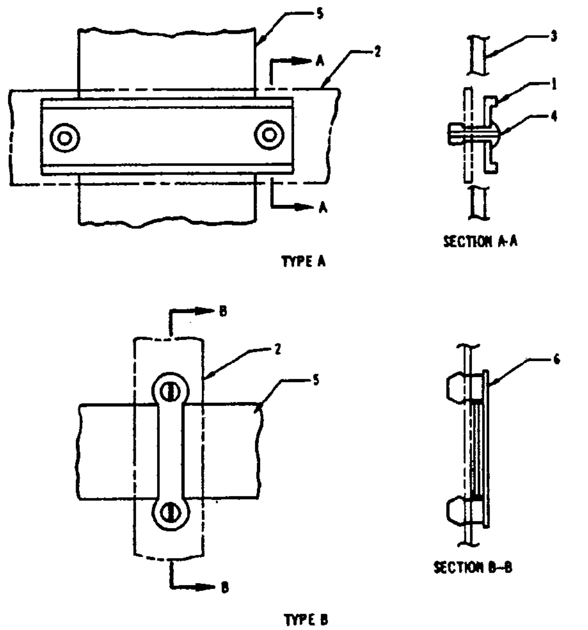


FIGURE 2-49. Metal-cushioned clamps for angle fold, 200°C.



MATERIAL CALLOUT:

1. TEFLON EXTRUSION REMOVED FROM CONVENTIONAL WIRE CLAMP
2. METAL STRUCTURE OR BRACKET FOR SUPPORT
3. SPACE FOR FLAT CABLE
4. FASTEX PLASTIC RIVET 201-120741-00-0101. END EXPANDS WHEN CENTER PIN IS INSERTED
5. FLAT CABLE TO BE CLAMPED
6. FASTEX FASTENER 220-090800-01-010108. INSTALLS BY PUSHING INTO 2

SCALE: FULL

FIGURE 2-50. Plastic clamps and fasteners.

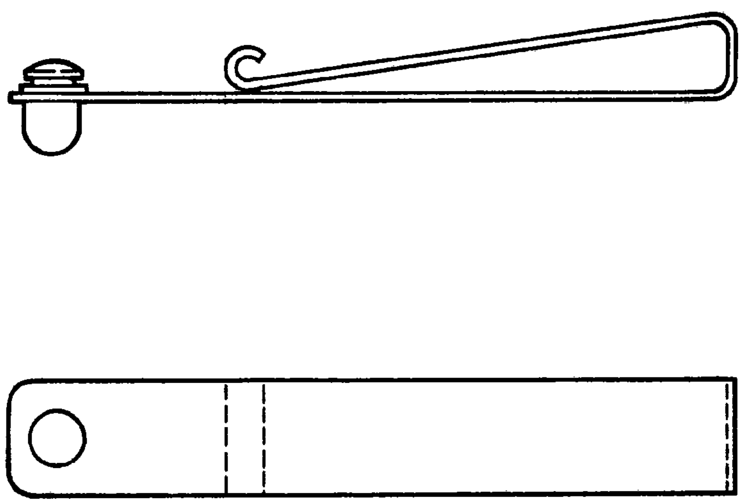


FIGURE 2-51. Shop aid cable support.

2.6 Supports

2.6.1 Introduction. The use of FCC, with the resultant fewer numbers of simpler wire harness runs, reduces the quantity and complexity of the required support system. The philosophy, promoted throughout this report, of considering the FCC interconnection harnesses as system components and including them into the initial design and development encourages careful thought and consideration for a simple, lightweight, efficient support system. Section III and IV contain additional information on FCC supports.

2.6.2 Use of Existing Structure. Every attempt should be made to support the FCC bundles directly to existing structure (Figures 1-1 and 1-2). This practice assures the rigidity, minimum weight, fewest protrusions, and most uniform installation to the structure ground plane. Structure sections of Z's, L's, C's, hats, etc., generally contain rigid, flat surfaces that are ideally suited for FCC bundle support. It is necessary only to drill the required mounting holes for the FCC clamps to be used. In many cases the FCC can be bonded directly to existing structures, thus eliminating even the drilling of mounting holes. Very often, inverted channels and other basic-structure cross-sections provide a high degree of mechanical protection in addition to the support medium.

2.6.3 Added Supports. Added supports may be used if necessary to complete the support system for the FCC bundle runs and clamps.

Stress considerations often prohibit the addition of modular mounting holes in basic structure. However, simple, lightweight sections can be riveted directly to the structure sections to provide the desired mounting brackets (Fig. 2-52).

FCC support sections were developed and installed on the Saturn IV-B development mockup. Figure 6-48 shows typical sections used. The modular mounting-hole pattern shown permits installation of the supports prior to final development. The number, size, and exact installation locations of the FCC clamps can be selected as required without change to the support system. Subsequent changes in production or in the field can also be accommodated with no drilling, riveting, etc., on the end item.

For airborne applications, the support sections will generally be aluminum with the proper finish in accordance with the program requirements. However, for thermal isolation, fiberglass and other nonmetals can be used. The use of high-performance adhesives permits these sections, as well as metal support sections, to be bonded directly to basic structures to eliminate any possibility of degrading the existing structure with attaching mounting holes.

2.7 Adhesives and Tapes

Numerous adhesives and tapes have been evaluated for use with FCC systems. A brief description is given in the following paragraphs.

2.7.1 Adhesives. The recent development of FCC for use in space vehicles has created a demand for more practical and effective methods of securing the cabling to space vehicle surfaces. To meet this demand, adhesive systems have been investigated to eliminate the need for most of the tie-downs, clamps, and other mechanical securing devices generally used in conventional cable installations.

A desirable adhesive system is a pressure-sensitive type which cures at room temperature. The adhesive may be a two-part system which is mixed and brushed on, or it may be a solvent-activated type.

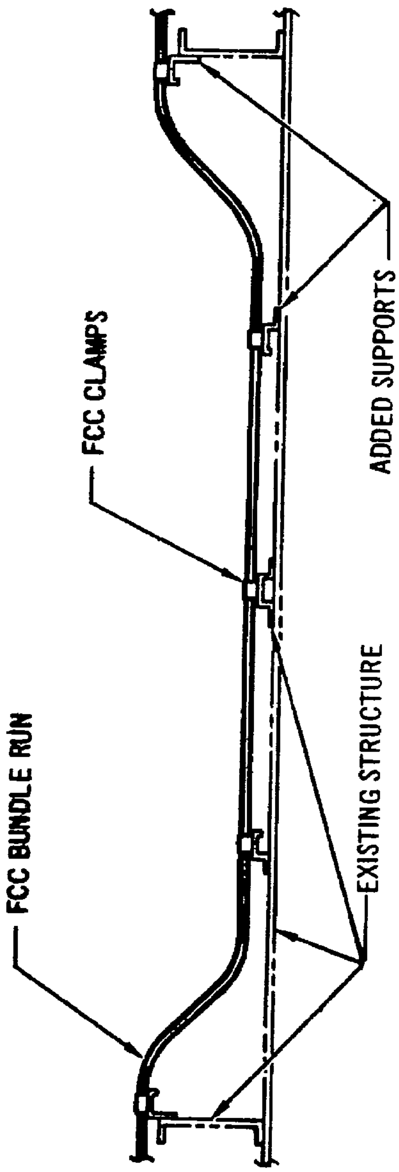


FIGURE 2-52. Typical FCC support installations.

Extensive tests have been conducted by NASA/MSFC with Minnesota Mining and Manufacturing Company's liquid-type EC-1099 adhesive for bonding polyester (Mylar) and polyimide (Kapton) cables to a liquid oxygen tank to test the ability of the adhesive to withstand the severe temperature changes (-160°C to 30°C) over several months without delamination. The bond strength increased with age.

Polyester to polyester or to aluminum joints, bonded with 3M's adhesive EC-1099 or Fasson Products Corporation's pressure-sensitive-type adhesive S-277, passed rigid mechanical and environmental test requirements imposed upon the joint to simulate conditions encountered in space flight. Dow Corning's Silastic 140 passed all environmental tests to which it was subjected, but did not have the desired initial peel and creep strengths.

Adhesives will not adhere to Teflon unless the surface has been treated to make it bondable. Tetra-Etch, prepared by W. L. Gore and Associates, Inc., is either poured on the surface or the cable is dipped into the etchant. All types of adhesives bond well to the carbonaceous film which the etchant forms on the Teflon. It is recommended to follow the manufacturer's etching procedures.

Table 2-4 shows some of the various adhesives and their comparative bonding strength. The bond is tested for creep strength by applying small loads. To determine tear strength, the 1-inch-wide cable is pulled 90 degrees from the surface of the substrate at the speed of 30 centimeters per minute. The force needed to cause tearing is the tear strength per inch width.

TABLE 2-4. TYPICAL ADHESIVES FOR FLAT-CABLE INSTALLATION

Designation	EC1099	Silastic 140	S-277
Mfg Source	3M	Dow Corning	Fasson
Type	Nitrophenolic	Silicon	Polyester
Condition	Liquid	Paste	Film
Application	Brush	Trowel	Hand
Material Bonded	Mylar, H-film	Mylar	Mylar, H-film
Temp. Range (°C)	-160 to +120	-160 to +100	-25 to +100
Cure Temp	Room Temp	Room Temp	Room Temp
Cure Time (hr)	24	24	24
Peel Strength	15 lb/in	12 lb/in	10 lb/in

Good results have been obtained by the use of a nitrophenolic resin for mounting polyimide cable to aluminum.

A polyimide/FEP cable bonded to an aluminum sheet 0.0625 by 6.0 by 48.0 inches was exposed to a weathering test at the southside (sunny side) of NASA/MSFC Laboratory building starting in August 1963. The cables delaminated after 10 months, but the insulation layer, cemented with EC-1099 and Fasson S-277 adhesives to the aluminum substrate, remained in place more than 20 months.

Another test was performed with a polyester (Mylar) cable using the same adhesives and substrate. The bond between the substrate and the cable is in good shape after over 5 years of exposure to the weather. The temperature ranged from -10°C to +50°C, and the humidity varied from dry weather to rain.

Other bonding tests were made at cryogenic temperatures by cementing flat cables to a painted liquid oxygen (LOX) tank. The cables were polyester (Mylar) and polyimide (Kapton), each 10 feet long, and EC-1090 was used to bond the cables to the tank. This test was continued over several months. The LOX tank was filled every Monday and emptied during the week while rocket engines under test were using LOX. Temperature of the tank skin ranged from -160°C to +30°C. Neither icing nor changes in cable length, because of expansion and contraction, broke the bond. These tests indicate the practicality of adhesive bonding.

3M EC-2216 epoxy adhesive has been used successfully for mockup applications, but has not been subjected to extensive physical testing.

2.7.2 Tapes. Permacel EE6379 Kapton adhesive tape has been used in a mockup application, but has not been subjected to extensive physical testing. This material performed satisfactorily at ambient temperatures over a 2-year period. A word of caution is in order regarding the use of pressure-sensitive adhesive tapes. The entended application should be analyzed for possible peel and creep loads, since the pressure-sensitive tape has very low resistance to these loads.