

N71-14819

CASE FILE
COPY

FLAT CABLE APPLICATIONS STUDY PHASE III FINAL REPORT

VOLUME I

NASA
78 10252-

FACILITY FORM 602

(ACCESSION NUMBER)	(THRU)
(PAGES)	(CODE)
(NASA-CR OR TMX OR AD NUMBER)	(CATEGORY)

7
09

JULY 1968



PHASE III FINAL REPORT
FLAT CABLE APPLICATIONS ENGINEERING STUDY
CONTRACT NAS8-20751

VOLUME I

DOUGLAS REPORT DAC-56659
JULY 1968

PREPARED FOR:
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION/
GEORGE C. MARSHALL SPACE
FLIGHT CENTER
HUNTSVILLE, ALABAMA

PREPARED BY:
SATURN RELATED PRODUCTION PROGRAMS



APPROVED BY: J. R. JONES
PROGRAM MANAGER
SATURN RELATED PROGRAMS

DOUGLAS MISSILE & SPACE SYSTEMS DIVISION
SPACE SYSTEMS CENTER — HUNTINGTON BEACH, CALIFORNIA

ABSTRACT

This report, DAC-56659, Flat-Cable Systems Engineering Study, Phase III Final Report, was prepared by McDonnell Douglas Corporation (MDC), Missiles and Space Systems Division (MSSD), Huntington Beach, California, for the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC), Huntsville, Alabama, under Contract NAS8-20751.

The tasks required by this contract were:

- a. Develop a practical, efficient, and reliable, shielded flat-cable and termination method.
- b. Investigate mechanized-design techniques to aid in the design and production of a flat-cable system, by defining wire-harness layout, cable-assembly design, and checkout procedures.
- c. Develop and document high-reliability, flightworthy flat-cable clamps and installation techniques.
- d. Establish specifications for production-type, flat-cable system components which meet or exceed aerospace qualification.
- e. Prepare a flat-cable handbook suitable for use by all engineering, manufacturing, and inspection technologies.
- f. Establish complete and detailed inspection procedures for all types of cables, cable termination, and connector hardware.
- g. Establish production manufacturing techniques and process control guidelines, including flow plans, outline procedures for subassembly of selected cable-connector configurations per the handbook, and include nondestructive inspection criteria and techniques for use in the preparation of a Preliminary Inspection Plan.
- h. Based on prior flat-cable experience, provide technical assistance to Astrionics Laboratory of MSFC in the incorporation of flat cabling in current programs, as applicable.

The major tasks performed by MDC were a, d, and e, above. The efforts expended and results for all the above tasks are explained in Volume I and II of this report.

All Engineer Drawings and Engineering Orders (EO's) called out in this report are included in Volume II, Section II-2.

T A B L E O F C O N T E N T S
V O L U M E I

Paragraph		Page
S E C T I O N I		
1.	INTRODUCTION AND SUMMARY	1-1
1.1	Introduction	1-1
1.1.1	Program Objectives	1-1
1.2	Program Summary	1-2
1.3	Program Conclusions	1-5
S E C T I O N I I		
2.	SHIELDED TERMINATION SYSTEM	2-1
2.1	Introduction	2-1
2.2	System Shielding Requirements	2-1
2.2.1	Survey for Shielding Requirements	2-2
2.2.2	Selection of Shielding System Requirements	2-3
2.3	Shielded FCC	2-4
2.3.1	Cable-End Preparation	2-5
2.3.2	Shielding Materials	2-5
2.3.3	Proposed Shielded FCC Cable Constructions	2-6
2.3.4	Shielded FCC Configurations Considered	2-7
2.3.5	Final Selection of FCC Cable	2-11
2.3.6	Suggested Shielded FCC Construction for Optimum Stripping	2-14
2.3.7	Suggested Procedure for Optimum Magnetic Shielded FCC	2-15
2.4	Shielded Plug Design	2-15

Paragraph		Page
2.4.1	Initial Development	2-16
2.4.2	Prototype Design	2-17
2.4.3	Prototype Parts Procurement	2-20
2.4.4	Shielded Plug Assembly	2-21
2.5	Magnetic Backshell Connectors	2-24
2.6	Summary	2-24

S E C T I O N I I I

3.	SPECIFICATIONS.	3-1
3.1	Introduction	3-1
3.2	Nonshielded FCC Specification	3-2
3.2.1	Initial Draft Preparation, MIL-C-55543, dated March 1967.	3-2
3.2.2	Second Draft, MIL-C-55543, dated June 1967	3-3
3.2.3	Third Draft, MIL-C-55543, dated September 1967	3-4
3.2.4	Fourth Draft, MIL-C-55543, dated November 1967	3-4
3.2.5	Fifth Draft, MIL-C-55543, dated January 1968	3-5
3.2.6	Other Effort	3-5
3.3	FCC Connector Specifications	3-5
3.3.1	General Comments to MSFC-SPEC-219A	3-6
3.3.2	Inputs to MIL-C-55544, FCC Connector Specification	3-6
3.4	Shielded FCC Specification	3-7

Paragraph		Page
-----------	--	------

S E C T I O N I V

4.	MECHANIZED DESIGN	4-1
4.1	Introduction	4-1
4.2	Mechanized Design General Description	4-1
4.2.1	What Mechanized Design Can Do	4-2
4.2.2	Computer Description	4-3
4.2.3	Computer Program Design Requirements	4-4
4.3	Mechanized Harness Assembly Design	4-4
4.3.1	Scope	4-4
4.3.2	General System Design Philosophy	4-4
4.3.3	Limitations and Unique Features of Flat Cable Systems	4-6
4.3.4	Flat-Cable Mechanized Design Procedures	4-9
4.3.5	Computer Program Design Requirements	4-11
4.3.6	Computer Description	4-13

S E C T I O N V

5.	CLAMPS AND INSTALLATION	5-1
5.1	Introduction.	5-1
5.2	Clamps	5-1
5.2.1	Clamps from FCC Development Program	5-1
5.2.2	Revisions and New Clamp Designs by MDC	5-2
5.2.3	NASA/MSFC Clamp Designs	5-4
5.3	FCC Installations	5-5
5.4	Conclusions	5-6

S E C T I O N V I

6.	HANDBOOK PREPARATION	6-1
6.1	Introduction	6-1
6.2	Sources of Information	6-1
6.3	Accumulation of Existing Data	6-1
6.4	Generation of New Data	6-5
6.4.1	Electrical Characteristics Data	6-5
6.4.2	Shielding Effectiveness and EMC Philosophy	6-8
6.4.3	Quality Control	6-8
6.4.4	Other Data	6-8

S E C T I O N V I I

7.	EVALUATION TESTS	7-1
7.1	Introduction	7-1
7.2	Initial Test Plans	7-1
7.2.1	Preliminary Test Plan - Shielded Termination System, Electrical and Mechanical	7-2
7.2.2	Preliminary EMC Test Plan	7-3
7.3	Actual Tests Performed (or to be performed)	7-5
7.3.1	Clamp Tests	7-6
7.3.2	Temperature-Cycling Tests	7-6
7.3.3	Electrical Tests	7-8
7.3.4	Flexing Tests	7-9
7.3.5	Tensile Testing of Lashclad Shielding Material	7-9
7.3.6	Harness Assembly Tests (to be performed)	7-11

Paragraph		Page
7.4	Electromagnetic Compatibility Tests	7-13
7.4.1	Introduction	7-13
7.4.2	Spurious Coupling in Cables	7-13
7.4.3	Evaluation of Electromagnetic Coupling in Cabling	7-15
7.4.4	Test Methods	7-15
7.4.5	Data Format	7-16
7.4.6	Transmission Losses	7-17
7.4.7	Capacitance and Inductance	7-18
7.4.8	Test Equipment	7-18
7.4.9	Test Facility	7-18
7.4.10	Conclusions and Recommendations	7-18

S E C T I O N V I I I

8.	MANUFACTURING	8-1
8.1	Introduction	8-1
8.2	Component Fabrication	8-1
8.2.1	Cable Fabrication	8-1
8.2.2	Premolded Shielded Plug Assembly	8-5
8.3	Harness Assemblies	8-6
8.3.1	Cable Preparation	8-7
8.3.2	Plug Preparation	8-7
8.3.3	Plug-and-Cable Assembly	8-7
8.4	Cable Stripping	8-9
8.4.1	Polyimide	8-9

Paragraph		Page
8.4.2	Mylar	8-11
8.4.3	H-Film FEP Teflon Bonded Cable	8-12
8.4.4	Unshielded TFE Teflon Cable	8-13
8.5	Sources of Materials	8-15
8.5.1	Molding Materials	8-15
8.5.2	Insulation Material	8-16
8.5.3	Bonding Material	8-17
8.6	Conclusions and Recommendations	8-18

S E C T I O N I X

9.	MATERIALS RESEARCH AND PRODUCTION METHODS (MR&PM)	9-1
9.1	In-House Development, Shielded Flat-Cable	9-1
9.2	Chemical Stripping of Cable Insulation and Shielding	9-2
9.2.1	Masking and Stripping Procedures	9-2
9.3	Plating	9-5
9.4	Connector Potting	9-6
9.5	Bonding the Connector Backshell to the Plug Body	9-7
9.6	All-Polyimide Insulation System	9-7
9.7	Flat-Cable Bonding	9-8

S E C T I O N X

10.	TECHNICAL ASSISTANCE TO NASA/MSFC FOR FCC APPLICATION	10-1
10.1	Introduction	10-1
10.2	Review of ATM Requirements	10-1

Paragraph		Page
10.3	Review of NASA/MSFC FCC Design Guidelines	10-2
10.4	ATM Systems Coordination Trip to NASA/MSFC	10-2
10.5	Conclusions	10-6

S E C T I O N X I

11.	INSPECTION AND TEST	11-1
11.1	General	11-1
11.2	Time Domain Reflectometry	11-2

S E C T I O N X I I

12.	SUGGESTIONS FOR FUTURE FLAT-CABLE EFFORT	12-1
12.1	Introduction	12-1
12.2	General Areas Requiring Additional Development	12-1
12.3	Proposed Tasks for Future Effort	12-2
12.3.1	Shielded-Cable Development	12-2
12.3.2	Qualification of Cable and Connectors to the Military Specifications	12-2
12.3.3	Additional Effort for Conductor-Contact Shielded-Plug Assemblies	12-3
12.3.4	Preparation of a Military Specification for Shielded Flat Cable	12-3
12.3.5	Connector Development for 50-Mil Centerline Spacing and Hermetically-Sealed Connectors	12-3
12.3.6	Development of Multiconnector Distribution Units	12-4
12.3.7	Development of a Connectorless Termination System	12-4
12.3.8	Flat-Cable Systems Development Timetable	12-5

(For Volume I)

L I S T O F T A B L E S

Table		Page
1-1	Deliverable End Items Flat-Cable Systems Engineering Study	1-3
4-1	Reference Designation List	4-12
4-2	Material Summary	4-12
7-1	Shielding Material Tensile Tests	7-10
7-2	Test Equipment	7-19
8-1	Stripping Maskants	8-10
8-2	Stripping Solutions for Removal of Insulation and Shielding	8-10
9-1	Loss of Light Transmission through Witness Plates Caused by Condensation of Components of Leffingwell #185 Epoxy	9-6

(For Volume I)

L I S T O F I L L U S T R A T I O N S

Figure		Page
2-1	NASA/MSFC FCC Connector Assemblies	2-26
2-2	Shielded Cable Preparation for Plug Termination	2-27
2-3	Off-Center Edge Conductors	2-27
2-4	Spot-Faced Contact Areas	2-28
2-5	Corrugated Contacts	2-28
2-6	Dimpled Contact Areas	2-29
2-7	Pierce-Contact Areas	2-29
2-8	Contact With Conductive Epoxy	2-30
2-9	Welded or Soldered Typed Contact	2-30
2-10	Continuous Shield (Tower Coated)	2-31
2-11	Continuous Shield (Collator Coated)	2-31
2-12	Crimped-Contact Type	2-32
2-13	Roll-Formed Shield Contacts	2-32
2-14	With Roll-Formed Shield Assy	2-33
2-15	Round-Wire-Contact Type	2-33
2-16	Shielded Plug Assembly Initial Development	2-34
2-17	Shielded Plug Assembly Machined Parts	2-35
2-18	Shielded FCC With In-Line Conductors	2-36
2-19	Shielded Plug Assembly Final Development	2-37
2-20	Copper-Plated Nonshielded FCC	2-38
2-21	Vacuum Deposition Copper-Plated Nonshielded FCC	2-39

(For Volume I)

L I S T O F I L L U S T R A T I O N S

Figure		Page
4-1	Flow Diagram -- Illustrating Steps Involved in Mechanized Design of FCC System.	4-15
4-2	Flow Diagram -- Illustrating Steps Involved in Mechanized Design of RWC Systems	4-16

(For Volume I)

L I S T O F I L L U S T R A T I O N S

Figure		Page
5-1	Velcro Lap Clamp	5-7
5-2	Metal Cushioned Clamp	5-8
5-3	Velcro Clamp Test Setup	5-9
5-4	Lap Clamp Assembly, Single, 100°C	5-10
5-5	Lap Clamp Assembly, Double, 100°C	5-11
5-6	Lap Clamps Assembly, Triple, 100°C	5-12
5-7	Metal Noncushioned Clamps, 200°C	5-13
5-8	Metal Cushioned Clamp, 200°C	5-14
5-9	Metal Cushioned Clamp, Double Grip, 200°C	5-16
5-10	FCC Separator	5-16
5-11	Separator Installed Between Clamps	5-17
5-12	Separator Installed Under Clamp	5-17

(For Volume I)

L I S T O F I L L U S T R A T I O N S

Figure		Page
7-1	Electrolytic Copper - Deposited on Diallyl Phthalate Potting Cups	7-23
7-2	Plating Samples.	7-24
7-3	Samples Plated by Shipley Electrolytic Processes	7-25
7-4	Shielded Plug Assembly Test Samples	7-26
7-5	Test Fixtures for Shielded Plug Assembly Development	7-27
7-6	NASA/MSFC Conductor Contact Photo-Type FCC Receptacle	7-28
7-7	Flat Cable EMC Test Signal Source.	7-29
7-8	Block Diagram - Magnetic Coupling Tests	7-30
7-9	Block Diagram - Electric Coupling Tests	7-30
7-10	Flat-Cable EMC Test Monitoring Instrumentation	7-31
7-11	Block Diagram - Transmission Loss Tests - 100,000 Ohms	7-32
7-12	Block Diagram - Transmission Loss Tests - 100,000 Ohms	7-32
7-13	Capacitance Measurements	7-33
7-14	Inductance Measurements	7-34
7-15	Flat-Cable Shielded Test Assembly	7-35
7-16	Flat-Cable Shielded Test Assembly - Face Detail	7-36
7-17	Flat-Cable Shielded Test Assembly - Access Control Cover Detail	7-37
7-18	Flat-Cable Test Specimen Mounted in Shielded Assembly - Fully Assembled View	7-38
7-19	Flat-Cable Bulk Test Specimen Mounted in Shielded Assembly - Exploded View	7-39
7-20	Flat-Cable Test Harness Mounted in Shielded Assembly - Exploded View	7-40

(For Volume I)

L I S T O F I L L U S T R A T I O N S

Figure		Page
8-1	Typical Laminating Machines	8-19
8-2	Photo Etch Process	8-20
8-3	MDC Design, Premolded Plug Assembly	8-21
8-4	Shielded - Plug Dies	8-22
8-5	Backshell and Dies	8-23
8-6	Retainer Assembly	8-24
8-7	Shielded - Plug Parts	8-24
8-8	Unshielded Molded-On Plug	8-25
8-9	Typical Makeup of a Premolded Plug Termination	8-26
8-10	Shielded Plug Parts.	8-27
8-11	Stripped Cable	8-27
8-12	Inserting Stripped Conductors	8-28
8-13	Cleaning Tool	8-29
8-14	Conductor Insertion Tool	8-30
8-15	Conductor Folding Tool	8-31
8-16	Bonding Filler	8-32
8-17	Curing Potting Fixture	8-33
8-18	Curing Potting Fixture	8-34
8-19	Potting Plug	8-35
8-20	Alternate Plug Design Configuration	8-35
8-21	Stripping Method Charts.	8-36

Figure		Page
8-22	Unshielded Polyimide Cable	8-38
8-23	Masked and Stripped Cable	8-39
8-24	Maskcoat Coated and Stripped Cable	8-40
8-25	Shielded Polyimide Cable	8-41
8-26	Mylar Cable Configuration	8-42
8-27	NASA/MSFC Developed Mechanical Stripper	8-43
8-28	Schematic of Cold Stripper for Back Stripping	8-44
8-29	Measuring Contacts.	8-45
8-30	Insulation Peeling	8-45
8-31	Insulation Peeling Tool	8-45
8-32	Applying Heat with Heat Glue	8-46
8-33	S.S. White Airbrasive Unit.	8-47

(For Volume I)

L I S T O F I L L U S T R A T I O N S

Figure		Page
9-1	Unshielded Polyimide Cable	9-24
9-2	Unshielded Polyimide/FEP Cable	9-24
9-3	Shielded Polyimide Cable.	9-25
9-4	Shielded Polyimide/FEP Cable	9-25
9-5	Stripping Data for 2-mil Polyimide with MER-1	9-26
9-6	Polyimide Stripping Data for MER-1 at 94 C	9-26
9-7	Dynamic Weight Loss	9-27

(For Volume I)

L I S T O F I L L U S T R A T I O N S

Figure		Page
11-1	Flat Cable Inspection Device.	11-4

SECTION I

1. INTRODUCTION AND SUMMARY

1.1 Introduction

The Flat-Cable Systems Engineering Study, Phase III was the by-product of the completed Flat-Cable Development Program, Phase I and Flat-Cable Applications Study, Phase II. The Phase III study was designed to bring the state-of-the-art of flat-cable technologies to that point where it can be applied effectively and economically to current and/or near-future programs.

The guidelines for the Phase III study were based on the tasks outlined in paragraph 1.1.1 below.

This two-volume final report contains the results of the study and the McDonnell Douglas Corporation (MDC) recommendations.

1.1.1 Program Objectives

This 15-month study was oriented to the following objectives:

- a. Develop a practical, efficient, and reliable, shielded flat-cable and termination method.
- b. Investigate mechanized-design techniques to aid in the design and production of a flat-cable system, by defining wire-harness layout, cable-assembly design, and checkout procedures.
- c. Develop and document high-reliability, flightworthy flat-cable clamps and installation techniques.
- d. Establish specifications for production-type, flat-cable system components which meet or exceed aerospace qualification.
- e. Prepare a flat-cable handbook suitable for use by all engineering, manufacturing, and inspection technologies.
- f. Establish complete and detailed inspection procedures for all types of cables, cable termination, and connector hardware.
- g. Establish production manufacturing techniques and process control guidelines, including flow plans, outline procedures for subassembly of selected cable-connector configurations per the handbook, and include nondestructive inspection criteria and techniques for use in the preparation of a Preliminary Inspection Plan.

- h. Based on prior flat-cable experience, provide technical assistance to Astrionics Laboratory of MSFC in the incorporation of flat cabling in current programs, as applicable.

1.2 Program Summary

On 21 February 1967, Contract NAS8-20751, authorizing the Phase III study of flat-cable systems, was received. Of the eight tasks outlined in section 1.1.1, three were of prime magnitude. They are:

- a. Preparation of a flat-cable handbook for industry-wide use.
- b. Development of an efficient and reliable, shielded flat-cable termination system.
- c. Preparation of draft military specifications for flat-cable components.

The other tasks, though important, did not require equal emphasis. This placement of emphasis was established at the NASA/MDC Task Plan Coordination Meeting which took place during March 1968.

For the most part the program was not a smooth one. However, in all cases, the basic intent of the contract was met. The status of deliverable items is illustrated in table 1-1.

Several serious problems were uncovered, and additional effort was expended to resolve them or, as a minimum, to define a plan for their solution. Consequently, the study did not achieve the in-depth technical accomplishment that was initially desired.

An area of uncertainty was the availability of shielded flat cable. At the inception of the program, it was believed that existing, or at least minimal, modifications to existing shielded cable would be adequate for use in the program. Once the study was underway and many available shielded cables had been reviewed, it became apparent that a major shielded-flat-cable-development effort was mandatory, as the availability of shielded cable was the basic prerequisite to several major tasks. The technical emphases of the program tasks were realigned to accrue manhours for the effort.

Table 1-1
DELIVERABLE END ITEMS FLAT-CABLE SYSTEMS ENGINEERING STUDY

Nomenclature	Delivered	Remarks
1. (PROPOSED) MILITARY SPECIFICATION, CABLE, ELECTRICAL, FLAT MULTICONDUCTOR, FLEXIBLE, UNSHIELDED.	Yes	One reproducible and 20 carbon copies of final draft submitted.
2. (PROPOSED) MILITARY SPECIFICATION, CONNECTORS, ELECTRICAL, ENVIRONMENT RESISTANT, FOR USE WITH FLEXIBLE, FLAT CONDUCTOR CABLE.	Yes	Specification sheet data for the MDC designed shielded plug assembly were furnished, together with general comments on the specification.
3. (PROPOSED) MILITARY SPECIFICATION, CABLE, ELECTRICAL, FLAT MULTICONDUCTOR, FLEXIBLE, SHIELDED.	Yes	One reproducible and 20 carbon copies of draft submitted, MIL spec number not assigned.
4. HANDBOOK FOR FLAT-CABLE SYSTEM DESIGN AND MANUFACTURING.	Yes	One camera-ready copy submitted.
5. FLAT-CABLE SYSTEMS ENGINEERING STUDY, PHASE III, FINAL REPORT.	Yes	One reproducible and 25 carbon copies submitted.
6. MONTHLY PROGRESS AND FINANCIAL REPORTS.	Yes	Fourteen carbon copies submitted monthly for twelve months.

Flat-cable designs were generated and shielding materials evaluated. In July 1967, Purchase Orders were placed with material suppliers, annealing and plating firms, and a flat-cable manufacturer, the latter for final assembly. Difficulty was experienced throughout the procurement cycle. The vendors, though meaning well, had not worked with thin film materials and, consequently, destroyed much of the material. This caused repeated delays, and it was February 1968 before MDC received the required magnetic shielded cable for testing and stripping. However, 100 feet of similar cable with copper shielding was received in December 1967. With the program scheduled for completion on 2 March 1968, it was recognized in January 1968 that a program extension was necessary. In March, a 60-day extension was approved in order that the Handbook would reflect the in-house activity performed on the shielded cable.

The second major problem lay in the area of stripping the shielded flat-cable. The first several months of the study were spent stripping the array of available shielded cable configurations with flat-cable strippers currently available. In addition, flat-cable samples were sent to outside sources for stripping. In all cases, a suitable stripper could not be found to strip an H/FEP shielded cable in the manner described in the text (see figure 9-4 for a profile view). When viewed under glass, FEP residue could be seen on copper conductors. Some of the problem resulted from the conductor variation from their nominal plane; the mechanical tools depended on conductor orientation. The cable samples, in general, varied in bond strength and in workmanship. A new technique was sought to adequately strip H/FEP shielded cable systems. By the end of the study, prototype techniques and tools had been developed to strip shielded H/FEP cable as required for plug assembly. However, additional development is necessary to achieve a production level.

The accumulation of electrical data for flat-cable was another area of concern. Primarily, this task was to be one of accumulating existing data, with secondary testing to be performed by MDC. Reports furnished from industry indicated that much less electrical-characteristic data were available for handbook design information than had been anticipated.

Therefore, in order to maintain handbook integrity, MDC generated much of these required basic data.

1.3 Program Conclusions

Perhaps the most significant milestone in the history of flat-cable development occurred during this program with the generation of the tri-service military specifications for unshielded flat-cable and flat-cable connectors. This one task has brought together, under cover, the knowledge acquired through years of independent research by several organizations. It is believed that this common recognition of flat-cable by the services will establish a standardization of products and qualification and, ultimately, hardware acceptance by the aerospace industry.

The complement to the above is the flat-cable handbook, which presents pertinent information for hardware selection, design, manufacturing, and quality control necessary for flat-conductor cable interconnecting harness application. The document is a prime necessity for those delving into the use of flat-cable systems for the first time, and is an excellent reference source for those familiar with flat-cable design, development, and applications.

SECTION II

2. SHIELDED TERMINATION SYSTEM

2.1 Introduction

One of the most important tasks of this program was the development of a practical, efficient, and reliable prototype shielded flat cable and termination system. The shielded cable assemblies used on the FCC development program had wire-mesh shielded cable and nonshielded (plastic body with no metal backshell) plugs. The method used to strip the wire-mesh cable was very time consuming and nonproductive. The wire-mesh shielded cable and plugs, without metal backshells, provided very inefficient shielded harnesses for shielding effectiveness.

Shielded cable was to be selected to meet aerospace system and environmental requirements, and also to be production manufacturable into shielded harness assemblies. The electrical characteristics of the cable(s) selected were to be verified by calculation and electrical measurements.

A shielded-plug assembly was to be designed and prototype manufactured and assembled. This plug assembly was to mate with the existing NASA/MSFC FCC receptacles, figure 2-1, and maintain EMC shielding across the shielded cable, shielded-plug assembly, and FCC receptacle interfaces.

Manufacturing and quality control processes were to be developed to assemble the shielded-plug assemblies under production manufacturing conditions.

2.2 System Shielding Requirements

The shielded harness-assembly system requirements had to be defined prior to the selection of the shielded-cable and connector systems.

Shielded round-wire harness used in the past generally provided a circumferential cable shield with metal backshell connectors. In many instances,

the cable shields stopped 1 or 2 inches from the connector backshell, and there were no requirements for circumferential continuity or EMC sealing between connector-mating surfaces. In other cases, additional requirements were established for circumferential continuity between the cable shield and the connector backshell, and between the plug and receptacle mating areas.

It was very important to establish realistic shielding requirements for the FCC system before shielded cable and plug assemblies could be defined and developed. Originally, it was proposed to obtain the shielding requirements through the use of an industry-wide survey.

2.2.1 Survey for Shielding Requirements

This survey was to be prepared and distributed to government agencies and major contractors to compile current and proposed shielding requirements for interconnecting harnesses on airborne and ground support systems for military and commercial programs.

The first survey draft was distributed on 19 June 1967 within MDC, to personnel contacts in six government agencies and to three major contractors for comments. Many suggestions were made to improve the survey format, and for changes which would provide more useful information and which would make the survey easier to complete. Detailed comments ranged from: "The survey is so complicated that there will be no response" to, "The results of such a survey would be extremely helpful for establishing future shielding requirements."

Copies of the second survey draft, with the suggested changes incorporated, were sent on 18 August 1967 to NASA/MSFC and the other agencies which had responded to the first draft. It was suggested at this time that the final survey be distributed by the Astrionics Laboratory of NASA/MSFC to enhance its probability of favorable response.

The third, and supposedly final draft, was submitted to NASA/MSFC on 19 October 1967. Upon its receipt, several major changes were suggested by NASA/MSFC.

After as many of these changes were incorporated as possible without jeopardizing the survey objectives, 150 copies of the final survey together with a draft letter for survey transmittal, were sent to NASA/MSFC the first week of December 1967. Each survey package contained:

- 1 copy of "General Survey Information"
- 1 copy of "Section A of the Survey"
- 4 copies of "Section B of the Survey"

On 7 December 1967, a suggested distribution list for the survey was submitted to NASA/MSFC. This list contained 28 addressees for government agencies and 104 addressees for major contractors. Copies of the final survey and suggested distribution list are included in volume II.

By the time the surveys were approved for distribution, the FCC shielded-termination-system requirements had already been defined to meet the program schedule. This, together with the complexity of the survey and the anticipated difficulty in its completion, prompted NASA/MSFC to relinquish the survey effort. However, the conclusions by the technical personnel involved were that the survey requested the system requirements needed for future design of standard hardware for shielded interconnecting harnesses.

2.2.2 Selection of Shielding System Requirements

Early in the program it became obvious that information on shielding requirements for interconnecting harnesses could not be obtained on schedule from the proposed survey. Therefore, the requirements were established from a series of meetings held with MDC design personnel having experience on many past and current programs, and those active on proposed programs. It was agreed that the requirements would be established on the high side, in the hope that the FCC systems developed could meet or exceed the current RWC shielded system performance. In those areas where it became very difficult or expensive to meet the established requirements, reconsideration would be given. It was suggested that the basic

design requirements for FCC shielded systems might be relaxed to meet less-stringent shielding requirements. These relaxed configurations would generally use less-expensive hardware which would be easier to assemble. However, because of the uncertainty of the interconnecting harness shielding requirements during the design of the electronic units, it was agreed that all FCC plugs and receptacles should be mechanically and electrically interchangeable, even though they were not electro-magnetically interchangeable.

The shielding requirements agreed upon were:

- a. The system should provide 60 dB attenuation from 20 cycles to 1 megahertz for electric and magnetic fields and should be capable of replacing most twisted, shielded pairs in existing and proposed systems.
- b. A peripheral composite shield made up of many very thin layers of copper and thicker high-permeability, nickel-iron alloy is desired. The total shield thickness should be as great as possible with a minimum acceptable thickness of 0.5 mil. The top and bottom shields should be in intimate electrical and mechanical contact with each other, with the magnetic material continuous around the cable edges. If this is not possible, then the magnetic path interruption should be minimized.
- c. The FCC plugs and receptacles should have metal or metalized composite shields similar to the cable shield, except of one magnitude or greater in thickness. The connector shields or shells should be in intimate electrical contact with the outer shield layers of each cable. A conductive RF shield between the plug and receptacle is adequate if the metal gap is held to a minimum.

2.3 Shielded FCC

It became apparent early in the program that the shielded FCC configuration(s) selected for this program would be a compromise. The problem was to meet the shielding performance requirements with an FCC construction that could be manufactured for a reasonable price, and that could be production-assembled into the final shielded-plug harnesses.

2.3.1 Cable-End Preparation

The cable-end preparation for the shielded cable was established very early in the program on the "New" release of 1B67953. This cable preparation on stripping, shown on figure 2-2, did not change during the remainder of the program.

2.3.2 Shielding Materials

The established system performance of 60 dB attenuation for electric and magnetic fields made it necessary to use a high-permeability, magnetic shielding material.

The agency which had made the largest investigation of FCC magnetic-shielding materials was Picatinny Arsenal, Dover, New Jersey (reference 2-1). Mr. E. M. Eckhardt of Picatinny Arsenal was contacted for suggested shield materials and sources. He had not been able to procure very-high-permeability shielding materials in the very-thin foils (1 mil or less) required for FCC constructions, and he recommended the composite-layer Lashclad shielding material electrodeposited on polyimide film.

The original shielding procurement effort and design application was limited to the Lashclad KX material. The 1.5-mil total thickness material was made up of 0.9-mil Kapton, 0.3-mil electrolytic copper, plus 0.3-mil high-permeability, nickel-iron alloy. The initial permeability of the nickel-iron alloy was greater than 2,000.

The shielding effectiveness of this Lashclad material made it mandatory to have the shield magnetically continuous around the edges of the FCC. Thus, the first requirements for shielded cable with the known and available materials were established.

As mechanical testing disclosed the limited mechanical properties of the Lashclad material in tension, other materials and methods were investigated. Various forms of vacuum deposition, electrolytic deposition, electroless deposition, and gaseous deposition were investigated. In addition, very-high-permeability foils, such as MU30 and HYMU 80, were investigated.

Preliminary testing on very-high-permeability 1-mil and 0.5-mil foils verified that, when fully annealed for maximum permeability, they had the proper ductility for FCC construction required for bending and flexing. An investigation of the published curves for shielding effectiveness indicated that 0.5-mil foils with 50 microinches each of copper and nickel plating would meet the system shielding requirements without inter-connecting the shields at the cable edges.* These open shields would actually permit the cable to operate in much higher density fields before shield saturation occurred. The problems associated with cable fabrication, when plating or deposition processes were used, plus the many apparent advantages of the very-high-permeability foil led to the selection of the foil as the shielding material to be used on this program.

2.3.3 Proposed Shielded FCC Cable Constructions

A series of cable-construction proposed sketches for shielded FCC by NASA/MSFC were supplied to all cable vendors. These are shown on figures 2-3 through 2-15. A brief explanation follows:

Figure 2-3, with offset-edge conductors, reflects currently used shielded configurations for reference only. The shield continuity is not provided around the cable edges, and the production plug-assembly requirements are not met by this construction.

Figure 2-4, with the spotface contact areas, was tried by Methode Electronics and discarded on the NASA/MSFC shielded cable for ATM. The memory of the insulation system was not adequate to assure shield continuity under temperature cycling and aging conditions.

Figures 2-5, 2-6, and 2-7 were suggestions for other mechanical methods for making spot contacts between the shields and edge conductors. However, the magnetic-shielding requirements could not be met with the spot contacts proposed by methods of figures 2-4 through 2-7.

Figure 2-8 shows a continuous, conductive epoxy contact. There are many problems associated with conductive epoxys in the initial cable fabrication, plus changes in properties with high-temperature aging.

*It was later determined by testing the completed shielded cable and subsequent analysis that the shields must be in intimate contact at the cable edges for the required magnetic field attenuation.

Figure 2-9 shows a welded or soldered continuous-contact method. A short-length cable, using a continuous solder process, was made by ECS. Although the handling and temperatures are critical, this method shows promise for a reliable, continuous joint between edge conductors and shields.

Figures 2-10 and 2-11 show continuous shields which could be deposited directly to the nonshielded FCC outer insulation and to the exposed edges of the edge conductors. These methods offer the most promise for future magnetic-shielded cable with the shield continuous around the cable edges. Various plating and deposition systems would permit many very thin layers of alternate copper and high-permeability shielding materials. However, developing production techniques and achieving the required mechanical elongation properties present major problems.

Figure 2-12 presents a simple cross section, but one which is very difficult to implement in production cable fabrication. The composite edge conductors would also present major termination, and cable stripping problems.

Figure 2-13 is similar to 2-12, except the rolled shield would be used as the edge conductors.

Figure 2-14 is a simple, straightforward solution in which the roll-formed shield assembly would feed into the cable laminating machine to fabricate the shielded cable in one lamination pass. The added cable thickness in the edge conductor areas would enhance the probability of making and maintaining the required continuous contact.

Figure 2-15 shows a simple approach in which round conductors are used between the shields and edge conductors. W. L. Gore fabricated a prototype, laminated cable sample using this construction. Since the insulation thickness between the conductors and shield should be 2 mils or greater for voltage breakdown, it is possible to have a round wire that will fuse during lamination to provide a continuous soldered contact.

2.3.4 Shielded FCC Configurations Considered

During the first few months of the program, when 2,000 initial permeability shielding materials were considered, the requirement existed for the top and bottom shields to be in intimate contact with each other. Phone calls to, and meetings with, many FCC manufacturers at the MDC Huntington Beach facility apprised them of our requirements and solicited their suggestions

and recommendations for proposals for the required shielded cable.
Vendors contacted included:

ACI - Division of Kent Corporation
ECS - Electronic Connective Systems, Inc.
Flexible Products, Inc.
W. L. Gore & Associated, Inc.
Hughes Aircraft Company
Methode Electronics, Inc.
Poly Cable, Inc.
Rogers Corporation
G. T. Schjeldahl Company

2.3.4.1 With Lashclad Shield Material

Numerous shielded-cable configurations were considered, using Lashclad composite shielding material. Sample prototype cables made by MDC, Hughes Aircraft, and ECS experienced shield cracking when flexed over a 0.5-inch-diameter mandrel. One cable configuration manufactured by ECS, with a carefully applied FEP filler, showed better bending properties than the other configurations considered. However, since the ECS cable had only copper Lashclad shielding, and it also failed to meet the 0.25-inch mandrel bending test, use of the Lashclad shielding material was abandoned.

2.3.4.2 With Vacuum Deposition

Vacuum deposition has been successfully applied commercially for metallic deposition on plastic materials. A classic example is the aluminum deposition on Mylar used for the Echo Satellite Balloon.

Two companies currently active in vacuum deposition were contacted for proposals for shield configurations as shown on figures 2-10 and 2-11. The objective was to have alternate layers of copper and nickel-iron alloy deposited directly to the outer surface of nonshielded FCC.

Schjeldahl furnished samples of vacuum-deposited aluminum on Mylar sheets. The metal thickness was limited to several microinches. They questioned the feasibility of obtaining the 0.5-mil composite thickness required, and did not offer any further development effort or suggestions.

The Temescal Metallurgical Corporation, a division of Air Reduction Company, Inc., has a high-production, vacuum-deposition facility at Berkeley, California. Mr. Hugh Smith, the president of Temescal, reviewed the FCC shield-application requirements and concluded that it was feasible to technically and economically apply the required composite shield with vacuum deposition. Mr. Smith's predicted cost estimates for shield application were:

- a. Two thousand dollars for a continuous transporter system and associated equipment which would be installed inside the vacuum chamber.
- b. Fifty dollars per hour operating charge. At an estimated operating speed of 10 feet per minute, and with two passes for the composite shield, this resulted in a cost of approximately 16 cents per foot for shield application.
- c. Five hundred dollars for each additional setup charge for new batches of assorted cable widths.

With each vacuum chamber setup described above, all cable widths could be accommodated. The continuity of the shielding would be maintained around the cable edges.

Sample vacuum-deposition plating was accomplished on various H/FEP and all polyimide nonshielded-cable configurations, as shown in figure 2-16. Samples 1, 2, and 3 were accomplished on H/FEP insulation, and samples 4 and 5 were accomplished on all-polyimide insulation. The sample plating involved only a very thin layer of 50 microinches or less of copper. In each case, the excessive heat of the vacuum-deposition processes resulted in blistering and nonuniform plating.

It was Mr. Smith's belief that, with proper funding to develop reduced cable temperatures, the required vacuum deposition could be applied successfully on future programs. Neither funds nor schedule permitted additional vacuum-deposition investigations on this program.

2.3.4.3 With Electrolytic Deposition

Electrolytic deposition was first suggested by Mr. H. Gorden of Rogers Corporation as the optimum method of achieving the required shield shown on figures 2-10 and 2-11. Electrolytic deposition of copper shielding material was accomplished on a nonshielded-cable sample by two different companies.

Rogers Corporation applied several microinches of copper to an all-polyimide, nonshielded FCC. The adhesion between the deposited copper and the polyimide was very good and, even after temperature cycling, the plating remained on the cable when formed over a 0.25-inch-diameter mandrel. The application of the required composite 0.5-mil shield would have required addition of development which could not be accomplished to meet the program schedule.

United-Carr Corporation of Newton Highlands, Massachusetts, has successfully manufactured a plaxial coaxial cable with electrolytically deposited outer conductor. The shielding requirements of figure 2-10 were discussed with Mr. G. C. Smily of United-Carr, who concluded that the electrolytic-deposition methods developed by United-Carr could be used for this program.

Samples of nonshielded FCC with H/FEP and all-polyimide insulations were furnished to United-Carr for sample plating. One plating sample is shown on figure 2-17. Inadequate adhesion and plating blistering resulted from improper surface preparation. However, United-Carr personnel concluded that it is technically feasible to apply the required plating with a proper development program for surface preparation and plating procedures. The technical difficulty of accomplishing the continuous plating around the cable edge, and of making continuous contact with the edge conductor, presented problems which United-Carr felt might not be resolved.

With the sample plating results described above, and with the very limited ductility experienced with the Lashclad electrodeposited shielding, all effort for this method of shield accomplishment was terminated,

2.3.4.4 With Very Thin Foil

The difficulty experienced in achieving a satisfactorily deposited shield around the perimeter of a nonshielded FCC, plus the ductility limitation of the electrolytic-deposited material, prompted a new survey effort for the procurement of very thin (1.0 mil or less) high-permeability shield-foil material. It was discovered that MU30 nickel-iron alloy in 1-mil thicknesses was available from existing stock. Also, that 4-79 moly permalloy, in 0.5-inch thicknesses, was available on special order.

In July 1967, 100 feet of MU30, 2 inches wide by 1 mil thick, nickel-iron alloy, shielding material was ordered from Russell Industries, Linbrook, New York. Crude sample shielded-cables were made by MDC to test the flex capability of the MU30 material. Shield samples were also sent to various cable manufacturers for short, laminated-shielded cable prototypes. The results of the initial prototype was very encouraging. The ductility of the alloy shield material was excellent, and the handling and cable-lamination requirements were easily accommodated.

MDC shielding-effectiveness analysis indicated that the moly permalloy shield with its very-high initial permeability would provide the required shielding effectiveness with the two shield foils not in contact with each other.* A plating of 50 microinches of copper and 50 microinches of dull electroless nickel would provide the composite shield layers for increased, overall shielding efficiency.

With all these apparent advantages of the foil shielding material, this method was selected, and the basic shielded cable construction shown in figure 2-18 was selected.

2.3.5 Final Selection of FCC Cable

The decision was made to use high-permeability, 0.5-mil foil, plated for multilayer shielding performance, and the cable cross section shown on figure 2-18.

*Later testing of the moly permalloy shielded cable disclosed that continuous magnetic shielding is required around the edges of the cable.

Since the shielded cable concept, with the plated, high-permeability shield foil was a new development, it was necessary for MDC to negotiate directly with the various companies to:

- a. Procure the required shielding material
- b. Have the required plating accomplished
- c. Obtain the shielded FCC

Five pounds (approximately 1,200 linear feet) of 0.5-mil, 1.84 inches wide, 4-79 moly permalloy shielding material was ordered from Arnold Engineering Company, Fullerton, California. The material was to be furnished in the fully annealed condition with an initial permeability of approximately 36,000.

A purchase order was placed with Precious Metal Platers of Hopkins, Minn., to plate the 4-79 shielding material with 50 microinches each of copper and dull nickel.

Negotiation with various FCC cable manufacturers was undertaken to obtain a cable construction per figure 2-18, which would meet the mechanical and electrical requirements of the proposed MIL-C-55543 FCC specification, and one which could be stripped with a high-reliability production method.

Problems were encountered in all three areas. First, Arnold Engineering melted two batches of mill (partially) annealed shielding material during their attempts to perform the fully annealed operation. After two failures, they would only furnish mill annealed material with an initial permeability of much less than 36,000 (approximately 5,000). Magnetic Metals Incorporated of Camden, New Jersey, accepted an order to perform the full annealing operation in a strip furnace. By placing orders with both companies, the required shielding material was obtained without further incident.

Second, when Precious Metal Platers received the fully annealed 4-79, 0.5-mil shielding material, they discovered that they could not accomplish the continuous strip plating without making an elaborate, very expensive feedback tracking system to maintain material alinement on the roller

system through the various cleaning and plating solutions. Neither schedule nor available funds would permit the tracking system to be developed. Therefore, six pieces of material, 6 feet long each, were plated using the same procedures that had been used for prototype samples. These samples were used for EMC testing by MDC. The remainder of the material was used nonplated for shielded-cable fabrication. Precious Metals Platers supplied a report on their plating attempts, explaining the problems they encountered, which is included in volume II. It is believed that the required plating could be accomplished efficiently and economically on a production quantity program.

The third problem was in the selection of the shielded-FCC final configuration and its procurement. With the selection and procurement action completed on the shielding material, and with the cross section defined per figure 2-18, it was necessary only to select the proper combinations of insulation materials and fabrication method. A major consideration, in addition to meeting the electrical and mechanical requirements of MIL-C-55543, was to obtain cable that could be stripped in a highly reliable production manner. Numerous tests and investigations by MDC Manufacturing R&D personnel had disclosed that the most desirable method to bare and strip the 0.5-mil foil shield was chemically. The two insulations which could be stripped chemically were polyester and polyimide. Since polyester insulation would not meet the +200°C temperature requirements, all effort was concentrated on an all-polyimide insulation system. Two companies, Schjeldahl and Rogers, offered all-polyimide, nonshielded FCC, and ECS, with thin tower-coating capabilities was also a potential supplier. All three companies were requested to submit proposals. After lengthy discussions and investigations, it was concluded by all three companies that they could not furnish all-polyimide, shielded FCC to meet the program schedule requirements. A major problem is the proper curing of the B-stage polyimide adhesive under the solid-foil shield. All previous cable fabrication had permitted this curing to be accomplished through the outer polyimide insulation.

A conventional H/FEP-insulation system had been developed by Methode Electronics for NASA/MSFC for solid-copper-foil shielding material to be used on the Apollo Telescopic Mount (ATM) Program. Numerous detail fabrication methods had been used, and the major electrical and mechanical tests had been performed satisfactorily on the developed configuration. Therefore, to meet the program schedule and funding requirements, the H/FEP cable construction developed for NASA/MSFC was selected, knowing that major problems would be encountered in cable stripping.

Procurement drawing 1T11017 was prepared, defining the shielded FCC requirements, and the FCC manufacturers were requested to submit informal cost and delivery quotations. Methode Electronics, the supplier of the similar shielded cable, was selected on the basis of their capability of meeting the schedule requirements with the highest probability of supplying satisfactory cable. The latter was based on the fact that Methode had already produced a very similar cable construction that had passed the major specification tests. An order was placed with Methode for 200 feet of shielded cable per 1T11017. MDC was to supply the high-permeability shielding material. A 100-foot length of 0.5-mil-copper-foil shielded cable was expeditiously delivered to aid MDC in their stripping techniques and in their plug assembly development. Upon the receipt of the nonplated, magnetic-shielding material from MDC, Methode manufactured and supplied an additional 200 feet of shielded FCC. As anticipated, the H/FEP-insulated shielded cable proved difficult to strip. In addition, the voltage breakdown between the shields and conductors was marginal. It is recommended that all future cable development and/or procurement have the primary H-film insulation between the shields and conductors increased from the 1 mil used to 2 mils.

2.3.6 Suggested Shielded FCC Construction for Optimum Stripping

After many cable constructions and stripping methods have been evaluated, the following electrostatic shielded FCC construction is suggested for production stripping. The outer insulations should be tower-coated polyimide, polyimide film with polyimide adhesive, or polyester film with polyester

adhesive. This will permit the outer insulation to be removed to bare the shield, and the removal of the shield in the required areas by chemical stripping. The inner cable insulation and construction should be selected to meet the program termination requirements. If the NASA/MSFC-type conductor-contact connector system is used, then H/FEP inner insulation could be removed with a cold blade stripper. If weld-through-insulation termination is used, the inner insulation could be mylar or teflon.

2.3.7 Suggested Procedure for Optimum Magnetic Shielded FCC

The studies performed by MDC on magnetic-shielded FCC were not conclusive. However, it was determined that very-high-permeability shielding material (initial 36,000) wrapped around an FCC cable and spot welded on the open edge did not provide the anticipated magnetic field attenuation. Therefore, any new effort to develop shielded FCC for magnetic fields should start with simple, prototype cable*tested in accordance with the shielding-effectiveness tests described in detail in section 7. After verification of the system performance of the prototype has been accomplished, effort for production implementation can be undertaken.

2.4 Shielded Plug Design

The established requirements for a shielded plug were:

- a. To mate with NASA/MSFC 2-inch-wide cable receptacle (figure 2-1). This includes the use of the existing receptacle clips. If modification is required to the receptacles, they should still mate properly with existing NASA/MSFC molded and premolded FCC plugs.
- b. Metal backshell with EMC shielding provisions.
- c. EMC shielding provisions between the mating surfaces of the FCC plug and receptacle.

*This prototype could be as simple as a nonshielded FCC wrapped with the 4-79 permalloy material, remaining from this program, that has been roll-seam or flame-welded in a continuous manner along the open edges of the shield.

- d. Plugs should be capable of assembly into FCC shielded harnesses in a production high-reliability manner.

2.4.1 Initial Development

The objective of the initial development was to design and fabricate sample shielded plug assemblies meeting the requirements of 2.4. The problems associated with this development would then be analyzed for the required design improvements to be incorporated in the program prototype shielded-plug assembly.

Since the shielded plug was required to mate with the existing NASA/MSFC receptacle, the interface requirements were well defined. The initial development requirements could be accomplished for the model fabrication pursuing one of three courses:

- a. The existing plug-injection molding dies could be modified to accommodate the metal backshell of the plug.
- b. Existing premolded parts, manufactured by Amphenol and Methode Electronics, could be reworked to accommodate the required metal backshell and shielding requirements.
- c. All new parts could be designed and fabricated.

After careful consideration, it was decided to rework existing premolded-plug parts to fit into a newly designed backshell. This permitted expedient fabrication and assembly with a minimum cost outlay for the plug body parts. The Amphenol premolded plug assembly per drawing 100-6073-15, and the Methode Electronics assembly per drawing 134-112-05-00, were considered. The Methode premolded parts were selected because the assembly potting was accomplished from the rear of the plug assembly and, in general, they could be adapted more easily to the model design. Fifty each plug body parts were ordered. Drawing 1B67953 (Layout, Model Connector Assembly, Flat Cable Phase III) was released for initial development fabrication and assembly. The Methode premolded parts were machined to fit into a new metal backshell. Tecknit wire-mesh shielding material was used at the rear of the connector for the EMC shield continuity. Parts fabricated per this initial design are shown in an exploded view in figure 2-19.

A number of plug assemblies were fabricated and evaluated. In addition, two shielded-plug-assembly harnesses, using these plug parts and Methode wire-mesh shielded cable, were furnished to NASA/MSFC for shielding tests to be performed by the Boeing Company in Huntsville, Alabama. One harness had the shields in continuous contact with the plug shells, and the other had the shields isolated from the plug shells. Due to funding limitations, the tests were not run.

The initial model plug development proved the feasibility of the proposed design concept, pointed out the cable-shortening possibilities encountered in using the Tecknit wire-mesh shielding material, and gave a preview of plug assembly and bonding problems to be encountered.

2.4.2 Prototype Design

The design, fabrication, and assembly experience gained from the model shielded FCC plug assembly provided a sound basis for the prototype plug design.

2.4.2.1 Initial Selection of Materials and Concepts

2.4.2.1.1 Plug Body

After careful consideration of performance, fabrication, and plug assembly requirements, it was decided to transfer mold glass-filled diallyl phthalate material into premolded plug parts. This current tried and proven method for connector body or insert fabrication provided the highest probability of successful, initial parts procurement. The premolded parts would permit various assembly development techniques to be investigated, without making changes to the molds for the plug parts.

2.4.2.1.2 Surface EMC Shield

Two basic methods of achieving the required outer surface EMC shield were considered.

First, extensive effort was made to investigate the practicality of providing this shield with an external plating. It was necessary for the shield to be a minimum of 10 mils thick; 15 mils was more desirable for EMC performance and mechanical properties. This plated shield must adhere tenaciously to the diallyl phthalate plug body during temperature cycling, aging, and handling.

Numerous plating and other metal-deposition methods were investigated. The initial results were discouraging, as shown by figures 7-1 and 7-2 of Section VII, and the decision was made to use a separate metal backshell. Later, test samples provided by AVCO Corporation (figure 7-3) and United Carr Incorporated, were most encouraging, and should be considered for new design concepts.

The Shipley plating process, used by AVCO Corporation, deposited 10 to 15 mils of copper on the Amphenol Flex-1 218 diallyl phthalate plug body and the two diallyl phthalate potting cups. Shipley copper-plating solution, mix number 328, with catalyst number 6F and accelerator number 19, was used. All plating surfaces were properly prepared prior to plating.

United-Carr performed sample plating on two different types of glass-filled diallyl phthalate, with and without flame retardant, and No. 22262 black Durez phenolic. The sample parts were machined by MDC, 1T10649 EO"P", to be representative of the prototype, shielded-plug body parts. All samples were satisfactorily plated by United-Carr and passed temperature cycling without experiencing plating failure.

The process used by United-Carr is explained as follows:

Electroless copper was deposited in the standard fashion, i.e., dip in solution of tin followed by palladium and then commercial electroless copper solution. The copper was built up with a standard acid-copper electrolytic bath to approximately 1 mil. Permalloy and copper layers were then alternated with approximately 1 mil each to a finished plating thickness of 6 to 7 mils.

The Permalloy solution was one of the Watts baths, with some sodium chloride. The cathode half-cell potential was 1.1 volts, and the current density was approximately 4.5 amps per square foot. Plating was done at room temperature with a nickel anode, and the bath was mildly stirred. The plate was deposited under potentiostatic conditions to maintain a near-constant alloy composition.

2.4.2.3 EMC Sealing

EMC sealing was required between the shields of the FCC and the plug metallic backshells, and between the mating surfaces of the shielded plug and receptacle.

Experience with the initial model shielded-plug design eliminated the use of woven-mesh shielding for the shield-to-shell contact, because of the high probability of causing cable conductor shorting by loose strands in the woven mesh. Therefore, silver-filled silicone and silver-filled potting materials were investigated.

Tests with Emerson & Cuming, Inc. and Chomerics, Inc., conductive potting materials, in the test fixtures shown in figure 7-5 and detailed in drawing 1B67951EO"B", with conductive path dimensions of 0.125 inch or more as required by the shielded plug design, could not be satisfactorily maintained through temperature cycling with the materials investigated. Temperature tests with silver-filled silicone compounds under compression indicated that this material would meet the design requirements.

A combination RF and pressure-seal gasket for the interface between the plug and receptacle was considered. The companies furnishing wire-shield material imbedded in rubberized or silicone gasket material verified that it was impractical to furnish such a part in the space limitation imposed by this design. Therefore, sample cross sections of silver-filled silicone compounds were obtained and tested for pressure leakage and EMC conductivity (see figure 7-5 and 1B67951EO"A") both before and after temperature cycling. The test results were satisfactory, and this material was selected for the required combination RF and pressure seal.

2.4.3 Prototype Parts Procurement

2.4.3.1 Plug Body

The plug body design was accomplished on drawing 1T10900. E.O. "New" was released for procurement of six pieces each of plug body parts to be machined from diallyl phthalate stock. E.O. "A", for bid, was issued for procurement of 150 each of the molded-plug body parts.

It was intended to procure the six sets of machined plug-body parts within 3 weeks from issuance of a purchase order. These pieces would then be assembled in sample shielded-plug assemblies to determine the problems involved and suggested design changes. It was intended that these changes would be incorporated, prior to the issuance of a purchase order for 150 each of the molded pieces. Although Aero Precision Machine Company of Los Angeles performed sample machining operations on diallyl phthalate prior to the acceptance of the purchase order, they encountered many difficulties in attempting to machine the finished plug-body parts. The problems encountered were so extensive that considerable time was lost. Finally, as a last resort, MDC approved the use of plexiglas for the main plug-body parts, and sample pieces of questionable quality were furnished. However, the parts were not received in time to effect the initial design of the molding dies for the production pieces.

After reviewing the vendor proposals for the molded plug pieces, the order was given to Raykar, Inc., of Los Angeles. Suggestions from their mold-die designers were incorporated in the MDC drawing, for improvement in parts and to make the mold design more feasible. The molded parts were furnished on schedule by Raykar. Initial, minor difficulty experienced with flash in the conductor entry areas was largely overcome in the production-run parts.

2.4.3.2 Backshells

Both die-cast aluminum and magnetic-backshell constructions were considered. The cost and delivery schedule for the latter were prohibitive. Therefore,

bids for the aluminum backshells were obtained from Sunbank Electronics and Glenair, both from the Los Angeles area. A purchase order was issued to Sunbank Electronics for 150 parts, plated with 0.5 mil of electroless nickel over 0.5 mil of copper. Satisfactory parts were delivered on schedule. An order was placed with Aero Precision for six machined-aluminum backshell parts to be used with the machined plug parts for initial assembly evaluation. These parts were also delivered on schedule.

2.4.3.3 EMC Sealing Parts

With the decision made to use silver-filled silicone material for the two previously described EMC seal areas, further coordination was accomplished with Emerson & Cuming and Chomerics, the two known suppliers of this material. Copies of 1T10900 were sent to these companies for tooling and gasket bids. After evaluation of the bids, Chomerics was selected, and a purchase order was placed for the design and fabrication of the die, and for 150 gaskets. Satisfactory parts were delivered on schedule.

The EMC seal between the FCC shields and the plug backshells was made with Chomerics' silver-filled silicone rod material available from stock.

2.4.4 Shielded Plug Assembly

The prototype shielded-plug assembly was made using the parts described in 2.4.3 and the techniques developed in the assembly of the model connector as described in 2.4.1 and as shown in figure 2-19.

2.4.4.1 Engineering Drawings

Drawing 1T10900 defines the detail plug parts procured for the prototype shielded-plug assembly. After the parts were received and the assembly techniques developed, NASA/MSFC drawing format was used to prepare a series of 50M drawings to detail all plug parts and their assembly. Drawing 1T16061, "Connector Variation, Final Drawing versus Prototype", was prepared to define the plug body variations required for future design. All drawings are included in Volume II, Section VII.

2.4.4.2 Assembly Problems

Both the machined plug parts, as shown on figure 2-20, and the production parts, as shown in figure 2-21, were used to develop the assembly techniques for the shielded plug assembly. Numerous problems were encountered.

2.4.4.2.1 Conductor Insertion

The rectangular openings in the plug body, provided for conductor insertion, were purposely made with a minimum of clearance to reduce the amount of adhesive material which could flow forward into the plug contact area. This presented a problem in the simultaneous insertion of the stripped FCC conductors. Although tapered sections were included in the initial molded design, it was still very difficult to accomplish the required simultaneous insertion. The plug body insertion area has been redesigned as shown on drawings 1T16061 and 50M72656. It is believed that these revisions will greatly facilitate conductor insertion.

2.4.4.2.2 Bonding Backshell to Plug Body

The initial design of the die-cast aluminum backshell and molded-plug body, as shown on drawing 1T10900, provided inadequate bonding between these two parts. After extensive temperature cycling testing of sample bonded assemblies, two corrective actions were taken for bonding improvement. First, additional bonding space was provided between the two parts to increase the bonding-layer thickness from less than 1 mil to approximately 10 mils. Second, the inside bonding surface of the plug metal backshell was roughened to enhance bonding. Sample assemblies on parts having these two corrections provided adequate bonding through the required temperature range. Drawings 1T10900 EO"G" and 50M72657 have these changes incorporated. However, it should be noted that the production-plug loose parts remaining on this program do not have these changes incorporated.

2.4.4.2.3 EMC Sealing Shield-to-Shell

Considerable difficulty was encountered in attempting to accomplish the required continuous electrical contact between the shields of the FCC and the plug metal backshell. The silver-filled silicone conductive retainer shown in figure 2-21 provided the required contact prior to potting. Because of the very small areas involved and the viscosity or creep tendency of the adhesive used, the required conductivity was invariably degraded during the potting operation and subsequent temperature cycling. There was no known solution developed for this problem.

2.4.4.3 Changes for Future Procurement

2.4.4.3.1 Metal Backshell

The metal backshell should have the inside surface preparation described above and as defined by drawing 50M72657.

2.4.4.3.2 Plug Body

Modifications should be made to the transfer-molded plug bodies furnished for this program, as defined by 1T16061 to:

- a. Provide adequate bond thickness between the plug body and backshell
- b. Provide the proper seal compression at the plug-receptacle interface
- c. Facilitate the installation of the conductors into the rear of the plug
- d. Provide the proper registration for the rear retainer.

These changes have been incorporated in drawing 50M72656.

2.4.4.3.3 EMC Sealing Shield-to-Shell

It should be verified by laboratory testing and analysis that a continuous contact between the FCC shields and the metal backshell is a true requirement. If it is not required, then the existing shielded-plug assembly

design can be used with an insulating resilient retainer in the rear of the plug assembly, with the cable insulation remaining over the cable shields in the plug backshell contact area. This would eliminate the problems previously encountered, and provide an assembly with very good electrical and mechanical characteristics.

If it is determined that the shield-to-shell continuous contact is a requirement, then the plug assembly must be redesigned in the cable entry area.

2.5 Magnetic Backshell Connectors

It was originally intended to assemble and test a prototype, magnetic-shielded FCC with plug and receptacles having magnetic backshells.

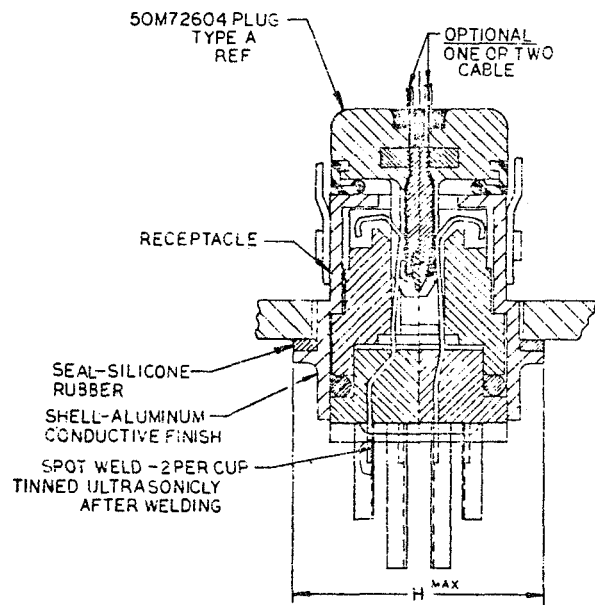
A 1-inch-diameter bar of HYMU high-permeability material was procured from Carpenter Steel in Los Angeles. Aero Precision machined two each metal backshells for the NASA/MSFC solder receptacle and the MDC shielded plug. The parts were given a high-permeability anneal by Magnetic Metals in Costa Mesa, California.

The solder-type receptacles were assembled by NASA/MSFC for the proposed testing. Because of the inadequacy of the magnetic-shielded FCC procured for this program, the shielded-plug assemblies with the magnetic backshells were never made, and all effort was terminated.

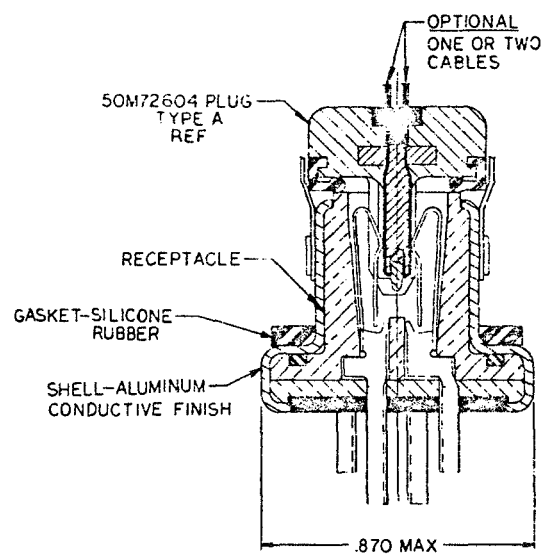
2.6 Summary

Development has been accomplished on a shielded FCC termination system. Prototype shielded cable and plugs have been procured and assembled. Many problems were encountered. Suggestions for future effort in the selection and testing of the shielded cable were given in 2.3.7. Extensive, additional EMC testing should be performed on shielded-plug assemblies to determine the actual requirements of having the shields in continual contact with the backshell. If this is not a requirement, then the existing design with the suggestion defined in 2.4.4.3 is efficient and adequate.

If the continual EMC contact between the FCC shield and the metal backshell is a requirement, then consideration should be given to revise the design to accomplish the contact with a conductive gasket in compression similar to the design now shown in the MIL-C-55544 pin-and-socket connector system. All potting material should be eliminated from the shield-to-shell contact areas. Electrical tests on a sample MIL-C-55544 pin and socket connector, using the compressed conductive gasket, indicated that adequate contact could be made and maintained with this design.



**MACHINED RECEPTACLE
SHELL
(NASA/MSFC)**



**DEEP DRAWN
RECEPTACLE SHELL
(AMPHENOL)**

Figure 2-1 NASA/MSFC FCC Connector Assemblies

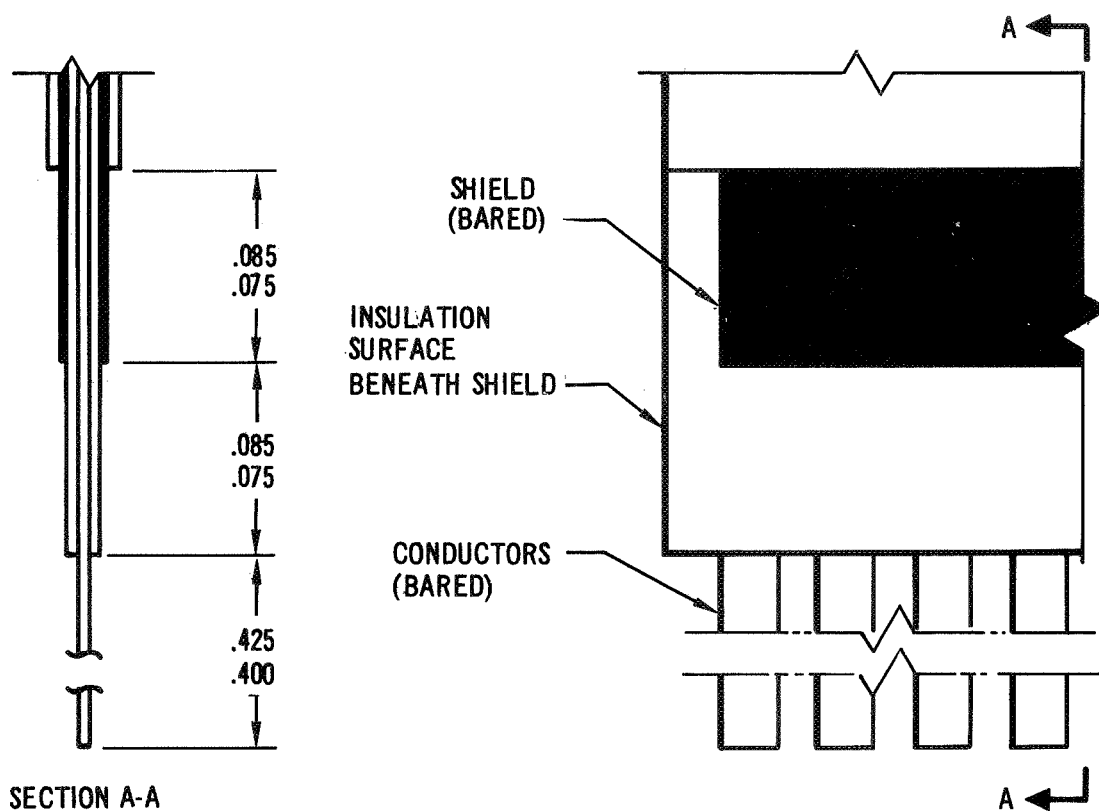


Figure 2-2. Shielded Cable Preparation for Plug Termination

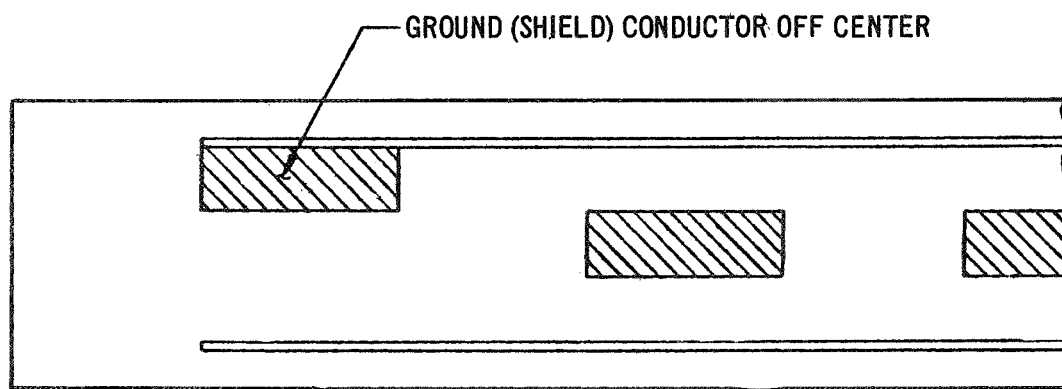


Figure 2-3 Off-Center Edge Conductors

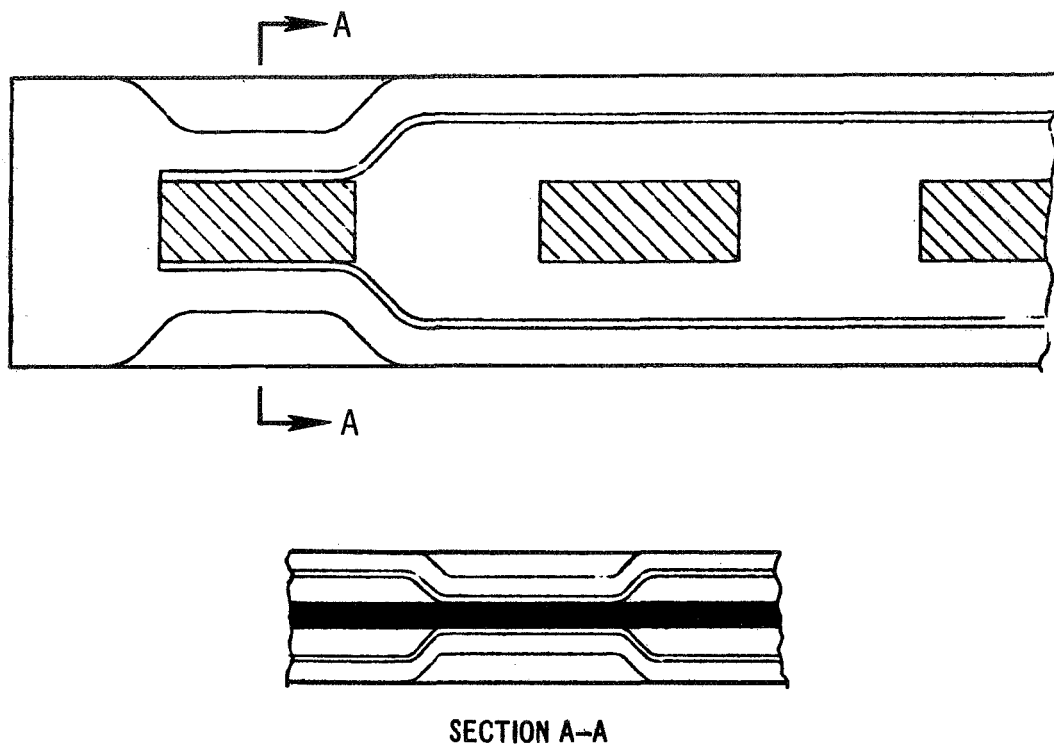


Figure 2-4 Spot-Faced Contact Areas

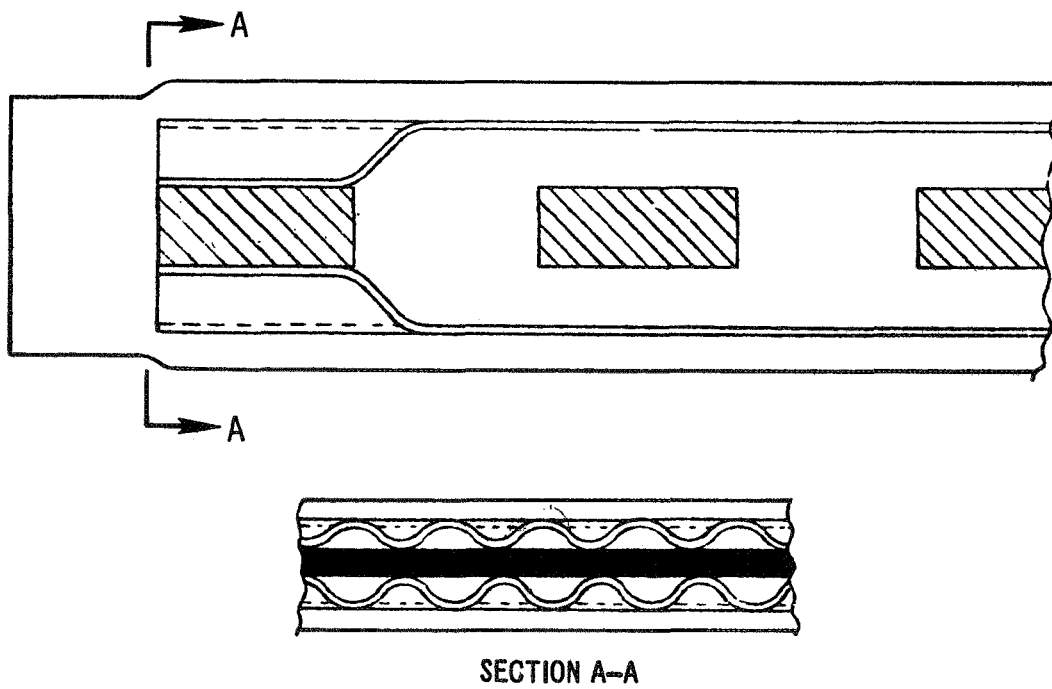


Figure 2-5 Corrugated Contacts

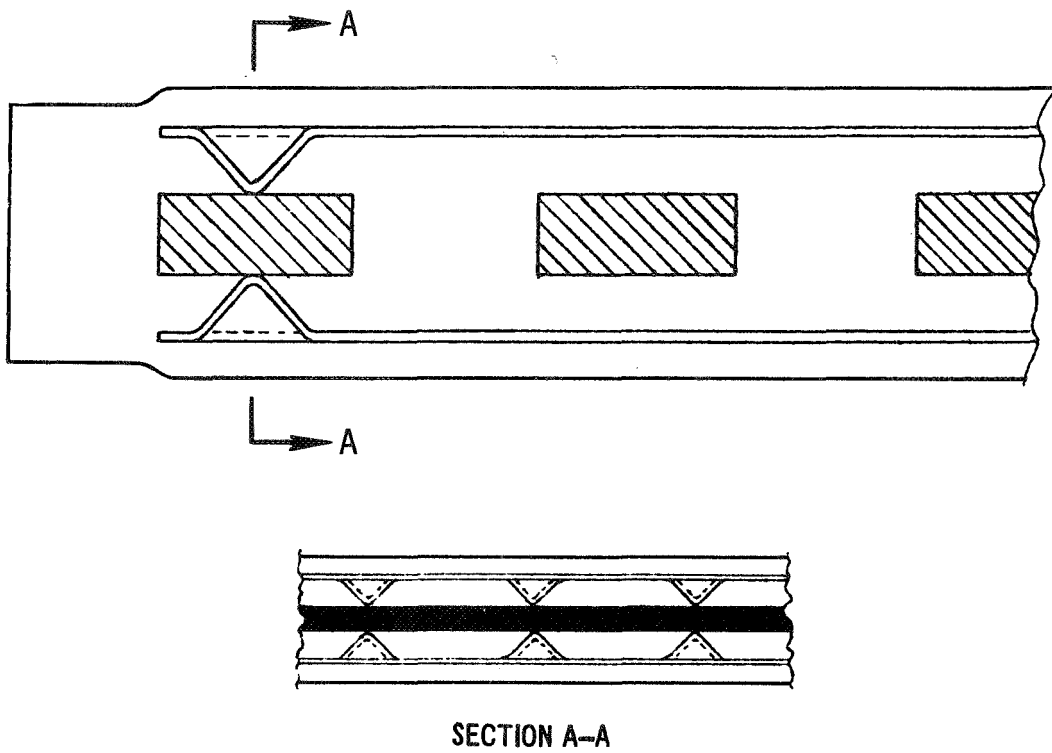


Figure 2-6 Dimpled Contact Areas

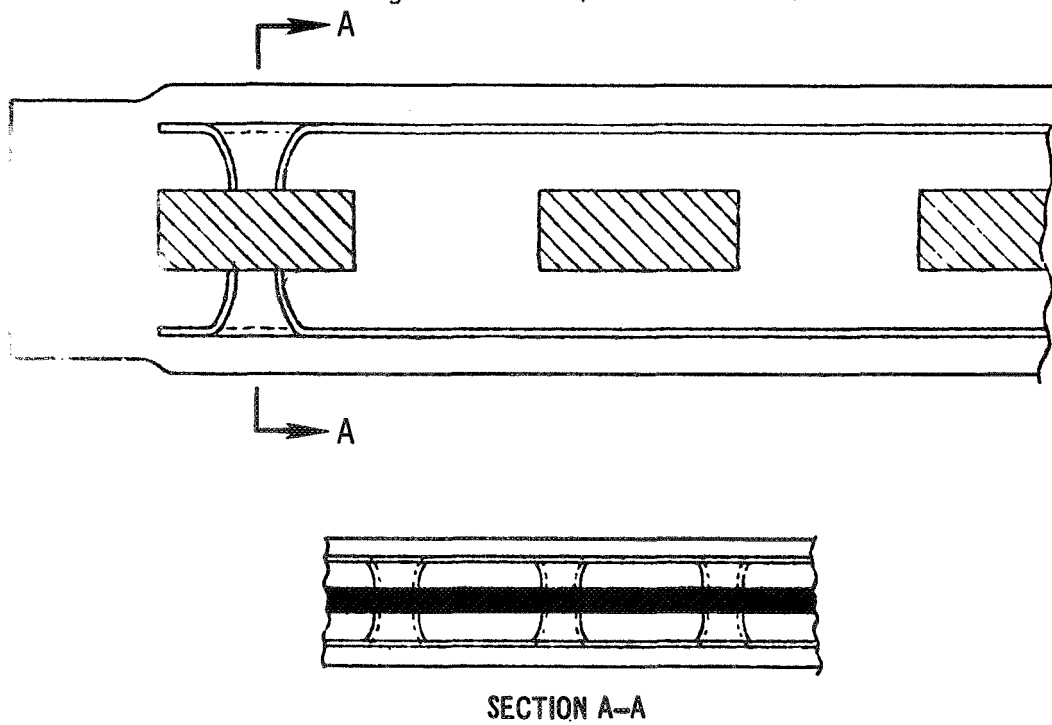


Figure 2-7 Pierce-Contact Areas

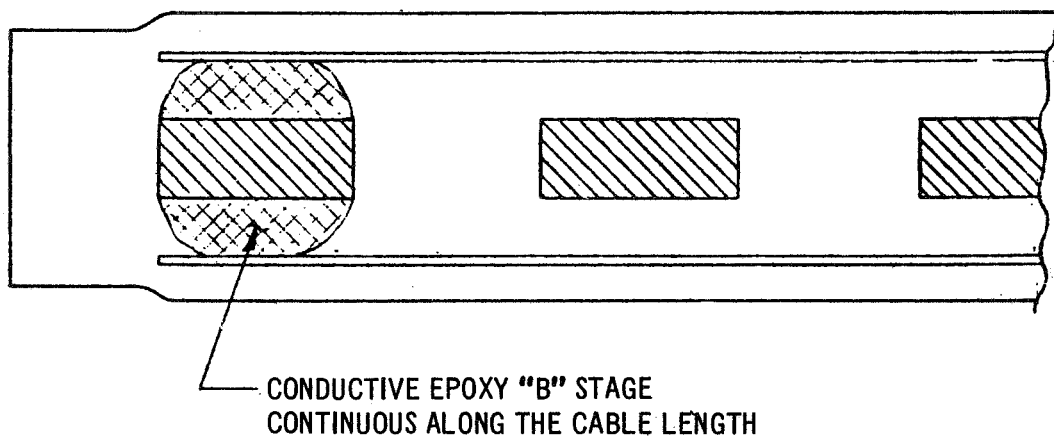


Figure 2-8 Contact With Conductive Epoxy

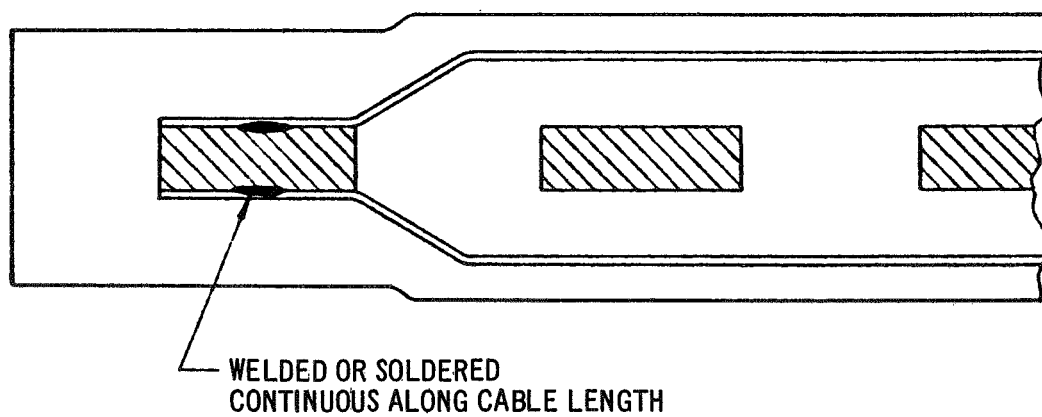


Figure 2-9 Welded Or Soldered Typed Contact

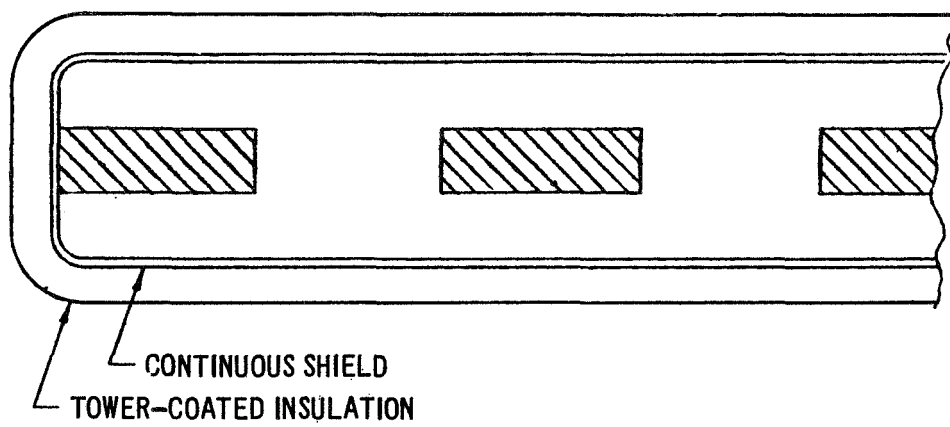


Figure 2-10 Continuous Shield (Tower Coated)

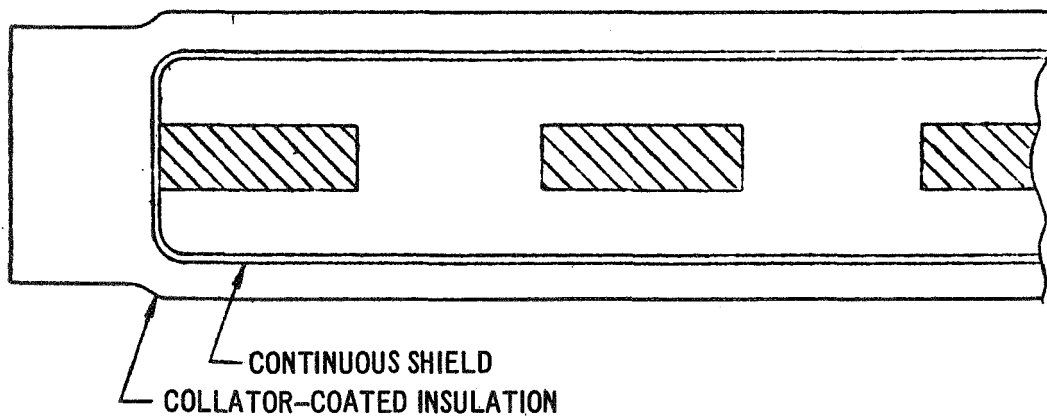


Figure 2-11 Continuous Shield (Collator Coated)

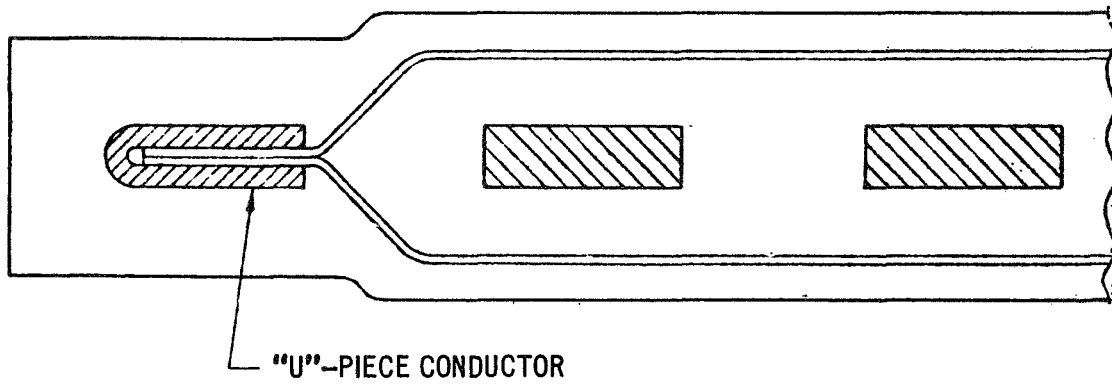


Figure 2-12 Crimped-Contact Type

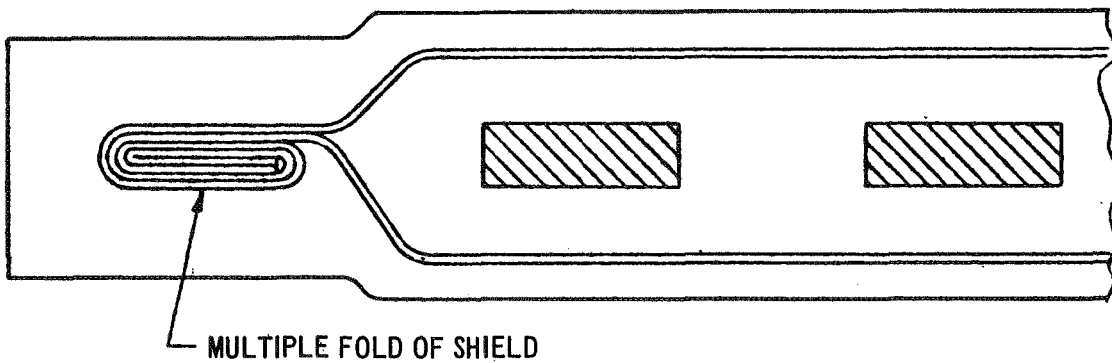


Figure 2-13 Roll-Formed Shield Contacts

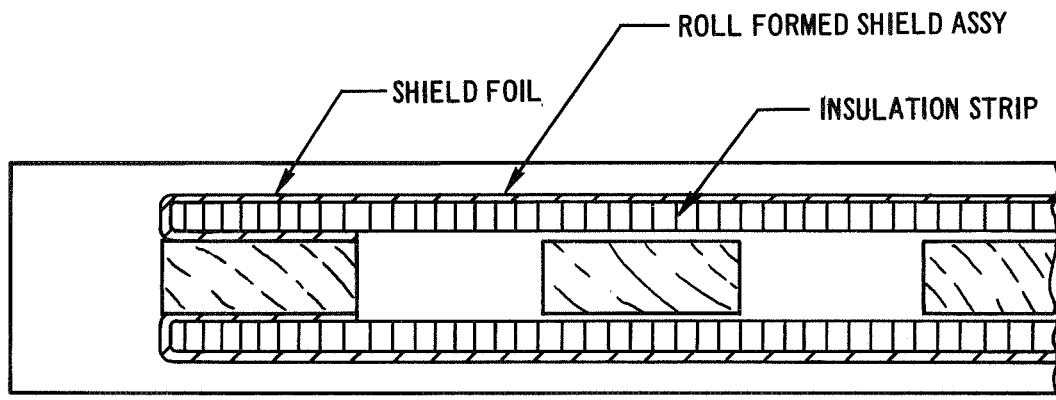


Figure 2-14 With Roll-Formed Shield Assy

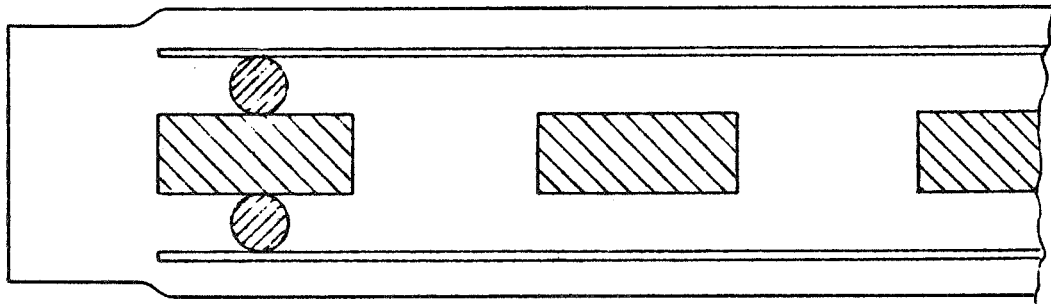


Figure 2-15 Round-Wire-Contact Type

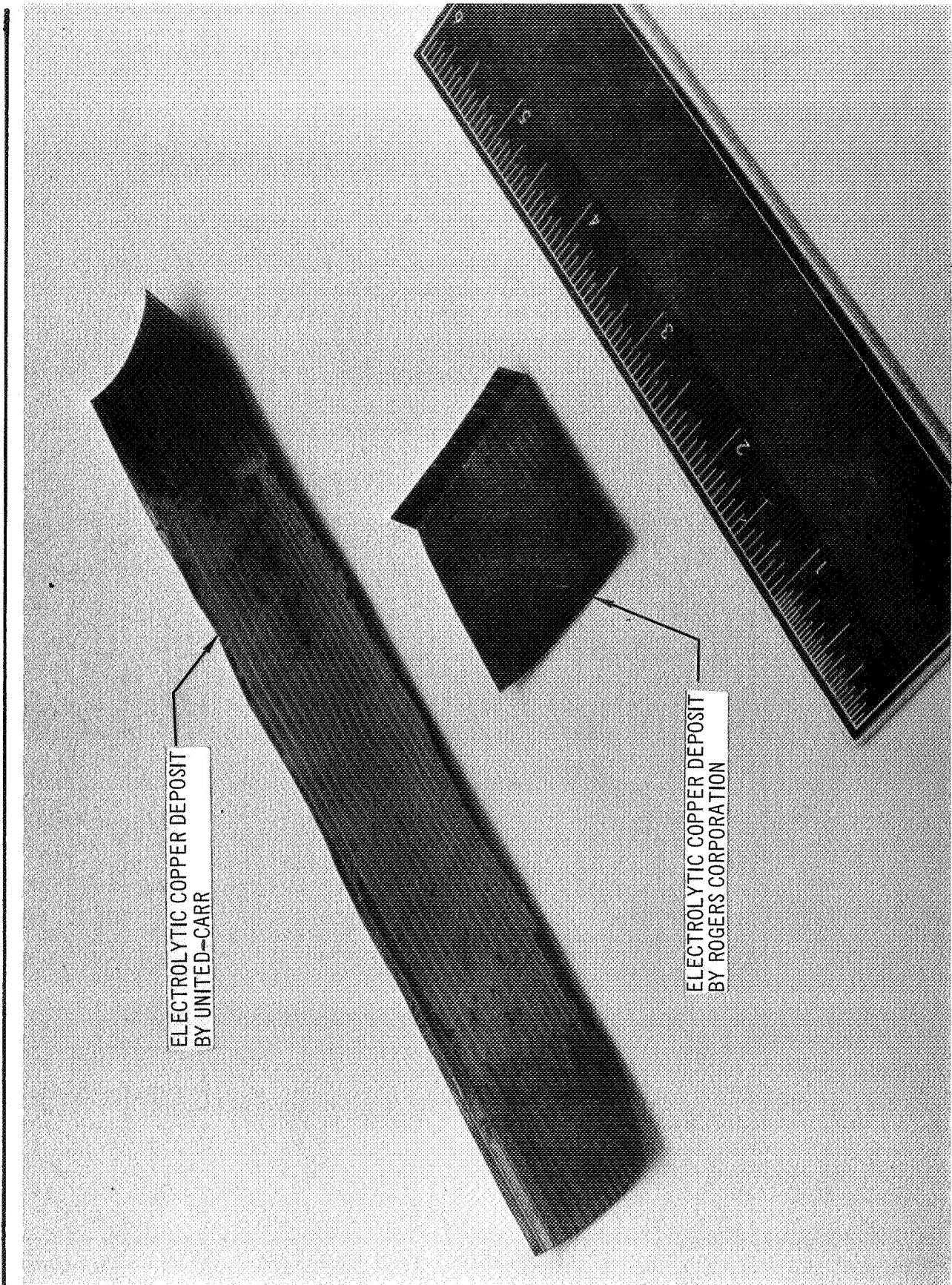


Figure 2-16 Shielded Plug Assembly
Initial Development

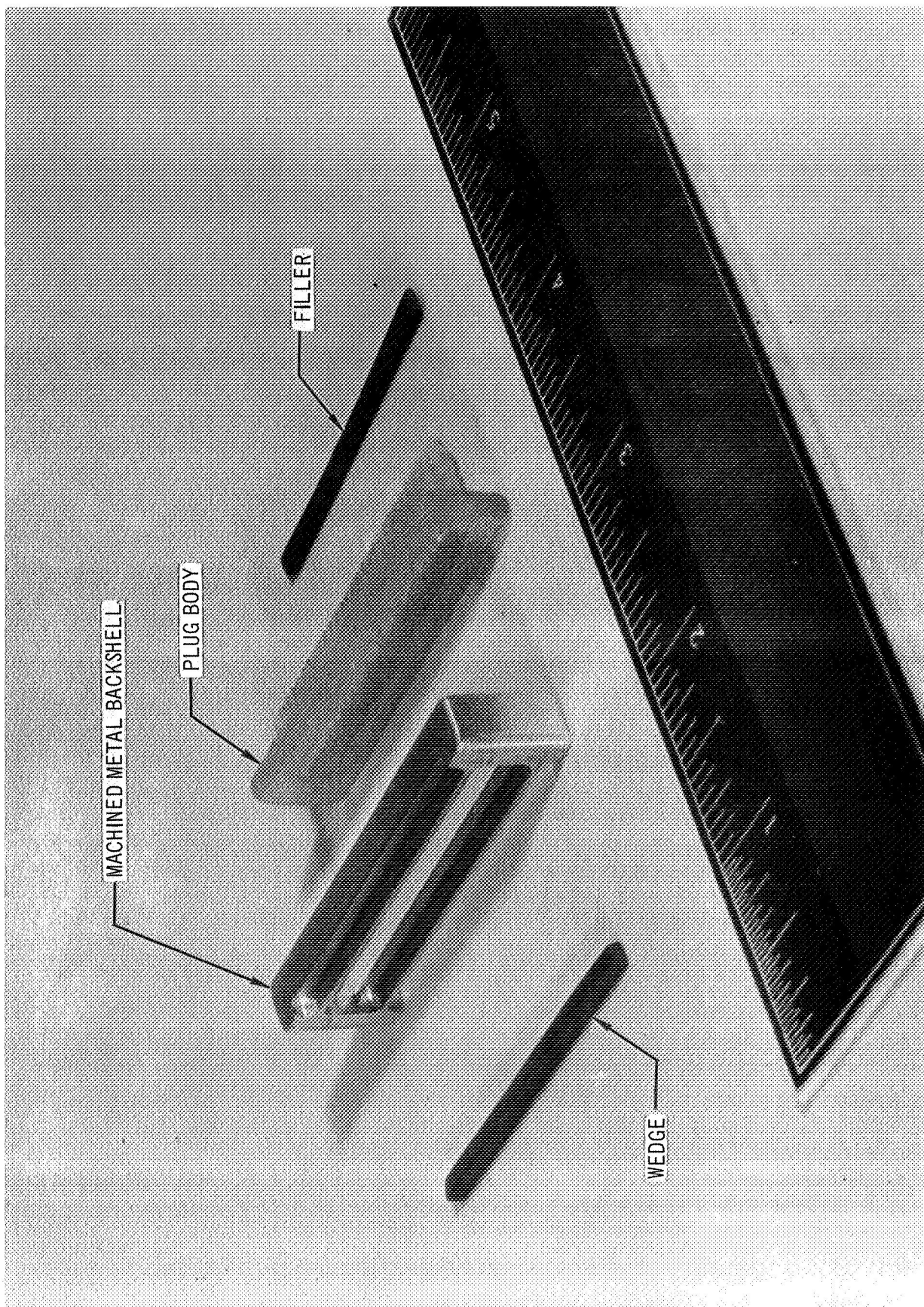


Figure 2-17 Shielded Plug Assembly
Machined Parts

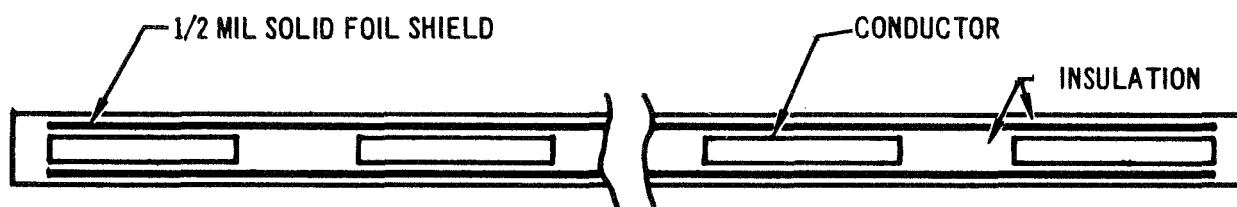


Figure 2-18. Shielded FCC With In-Line Conductors.

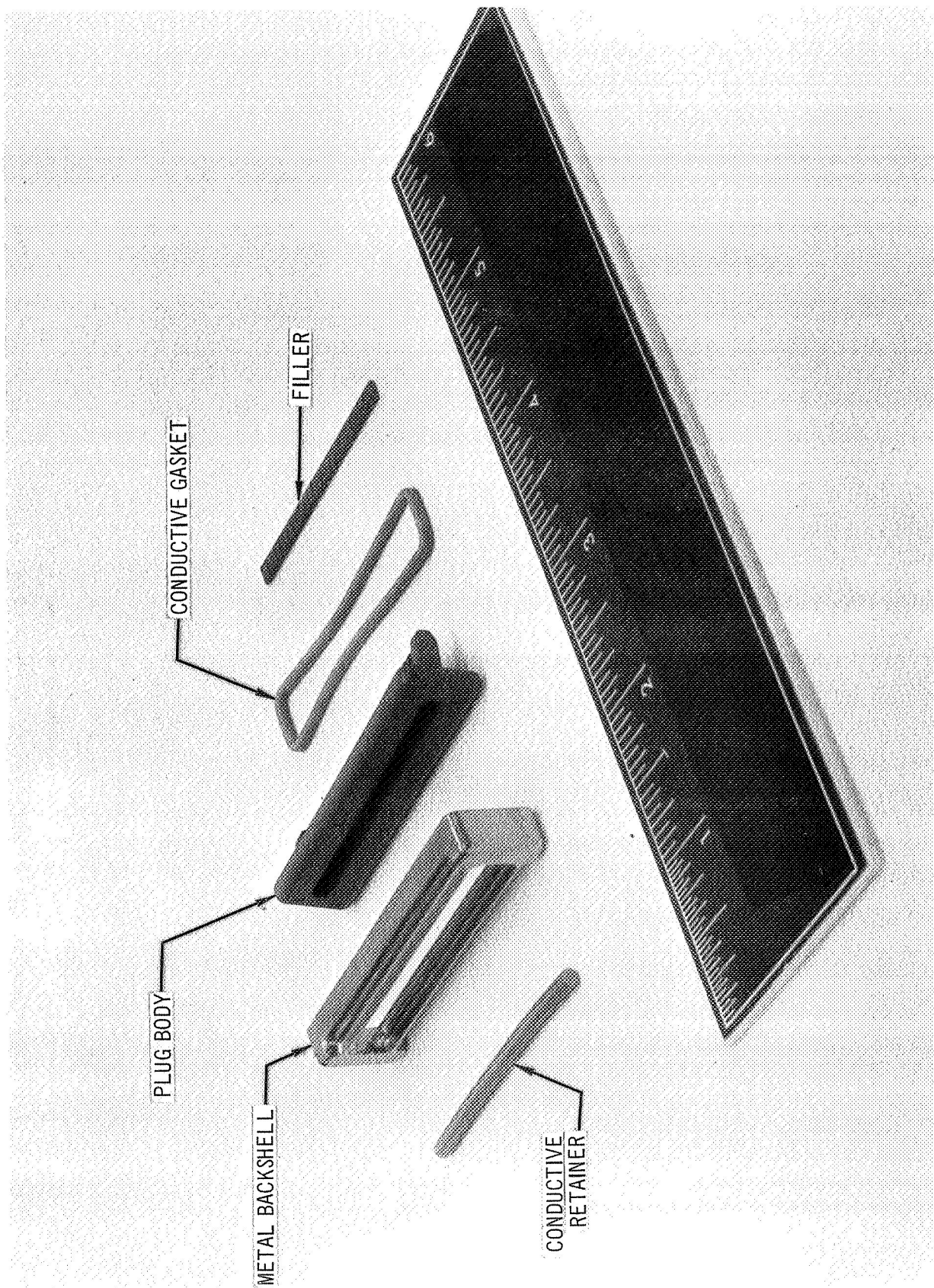


Figure 2-19 Shielded Plug Assembly
Final Development

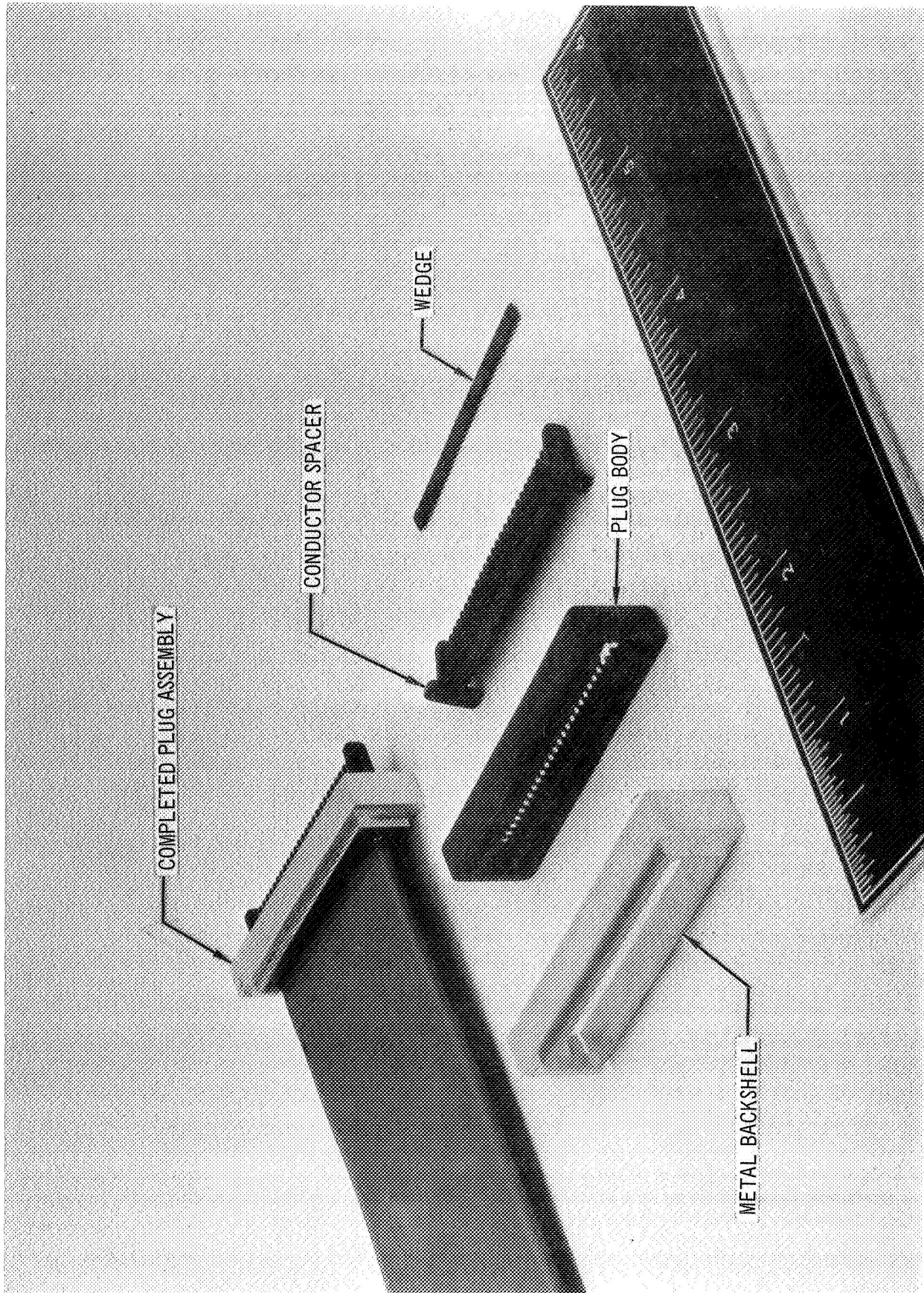


Figure 2-20 Copper-Plated
Nonshielded FCC

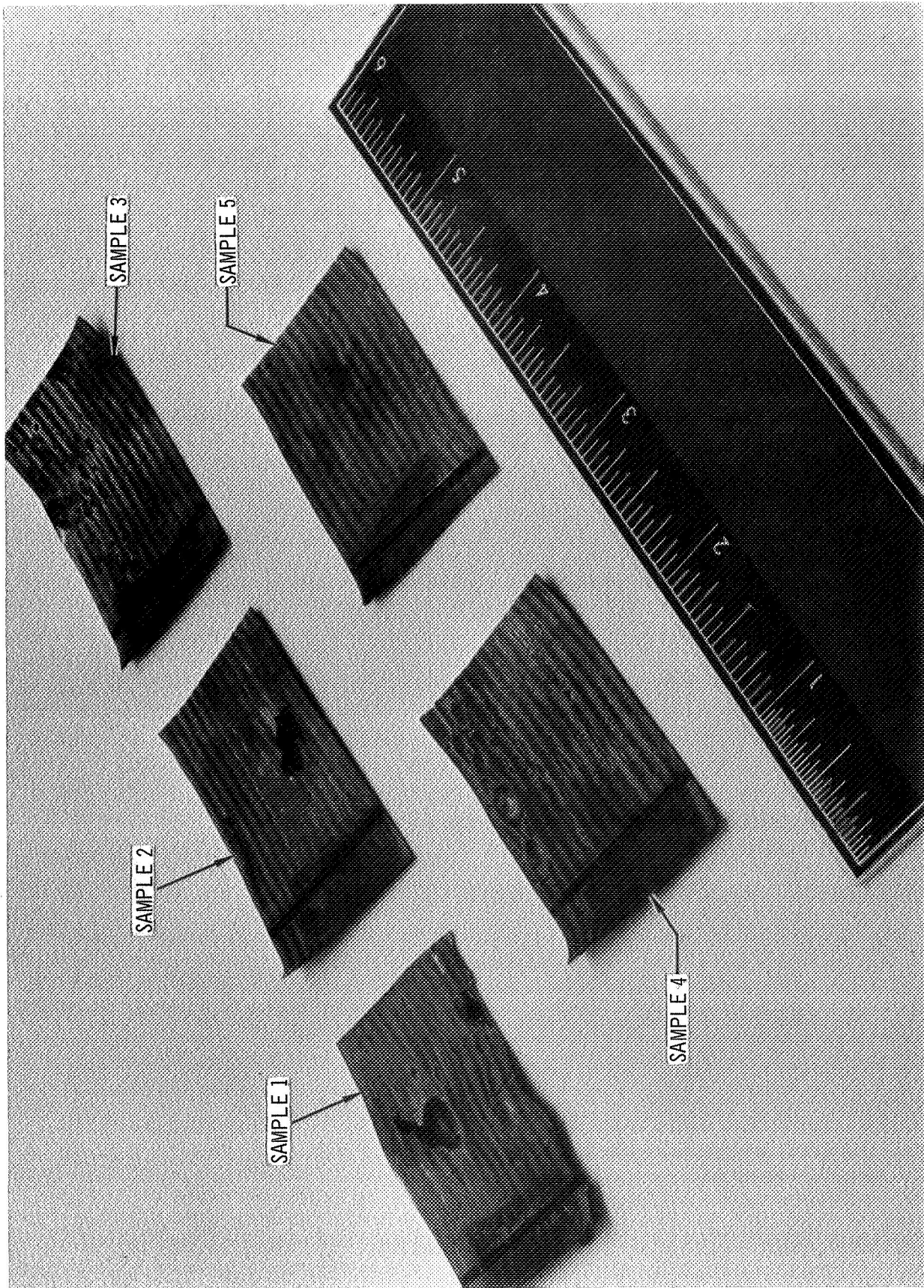


Figure 2-21 Vacuum Deposition Copper-Plated
Nonshielded FCC

SECTION III

3. SPECIFICATIONS

3.1 Introduction

The program initial work statement defined the specification effort for FCC and FCC connectors as follows:

- a. Revise the existing specifications MSFC-SPEC-219 A, "Connectors, Flat Conductor, Flexible, Electrical Cable," and MSFC-SPEC-220 B, "Flat Conductor, Flexible, Electric Cable" to include the determinations resulting from programs previously conducted by Douglas Aircraft Company under S-IVB Stage NASA Contract NAS7-101, under titles of "Flat Cable Installation Study" (Phase I) and "Flat Cable Engineering Study" (Phase II); and the present and "near-term" predicted aerospace qualification requirements.
- b. Append MSFC-SPEC-219 A, to include the configurations, and design and qualification requirements for shielded terminations to be developed on the "Flat Cable System Engineering (Phase III).
- c. Create a new specification to be released in the MSFC system, similar to MSFC-SPEC-220 B, and cover the configurations, detail design criteria, and qualification requirements for various required types of shielded cable.

During the initial customer program meeting at MDC on 9 and 10 March 1967, it became apparent that the bulk of the actual effort to be expended on FCC specifications would be directed toward the proposed military specifications for FCC and FCC connectors. An MDC assignment from this first meeting was to prepare, print, and distribute the completed drafts of the proposed MIL-C-55543 FCC specification. MDC was further requested to act in the capacity of committee chairman for Mr. W. Angele, the officially appointed, government-agent chairman of the FCC Specification Committee. Therefore, the specification effort required on the program was actually revised as follows:

- a. Represented the tri-service chairman in the preparation, printing, distribution and meeting coordination in the preparation of MIL-C-55543, (Proposed) Military Specification--Cable, Electrical, Flat Multiconductor, Flexible, Unshielded.

- b. Submit comments and provide specification sheet data for the new military specification MIL-C-55544, Initial Draft (Proposed), Military Specification--Connectors, Electrical, Environment Resistant, For Use With Flexible, Flat Conductor Cable.
- c. Prepare a new specification for shielded FCC to follow the format of MIL-C-55543. This "no number" specification would be the basis for the later preparation of a new military specification for shielded FCC. Specification sheets were to be included for the NASA/MSFC shielded cable configuration developed for the Apollo Telescopic Mount (ATM) program and for the shielded cable configuration(s) to be developed by MDC on this program.

It was anticipated early in the program and later verified that the effort required by the revised specification tasks was far in excess of that which would have been required by the initial work statement.

3.2 Nonshielded FCC Specification

The effort required for the nonshielded FCC specification, MIL-C-55543, included the preparation, printing, distribution, coordination, and conducting or chairing the Tri-Service Military FCC Committee Member Meetings.

3.2.1 Initial Draft Preparation, MIL-C-55543, dated March 1967

The request that MDC prepare the initial draft of MIL-C-55543 was made during the 8, 9 March 1967 customer meeting at MDC, as previously stated. On 16 March 1967, 10 copies of the completed draft, with specification sheets for various cable configurations, were shipped to New York City for the Tri-Service FCC Committee Meeting to be held in conjunction with the spring IPC meeting on 20, 21 March 1967.

Data for the preparation of this specification draft were obtained from the following sources:

- a. MSFC-SPEC-220B, dated January 28, 1966.
- b. Preliminary copy of Military Specification for flat cable, presented to MDC by NASA/MSFC on March 8, 1967.

- c. Preliminary copy of Mr. R. F. Van Ness' Military Specification for flat-cable connectors, furnished by NASA/MSFC on March 11, 1967.
- d. Typical current Military Specifications.
- e. Douglas comments to MSFC-SPEC-220B, prepared on the Flat-Cable Phase II Contract.
- f. Numerous coordination telephone calls with Messers W. Angele and R. F. Van Ness during March 13, 14 and 15, 1967.

Because of the very limited time available to prepare this specification, there were missing slash sheets, "to be determined" paragraph numbers, and other abnormalities. In addition, it was believed that this document could be much improved by: (1) the addition of requirements and criteria for a "Reliability Program Plan," per MIL-STD-790, which requires potential suppliers to produce evidence of their capability of producing consistently reliable products; and (2) by the issuance of a Military Standard similar to MIL-STD-275 covering various items of criteria peculiar to flat-cable technology for general information, and as a source for future cable specification references.

The March 1967 draft of MIL-C-55543 was not reviewed in detail during the March IPC meeting. Instead, a coordination meeting was held at NASA/MSFC on 16, 17 May 1967 with the Tri-Service Committee members attending. Mr. E. U. Baker of MDC attended this meeting as the committee chairman representative. Member comments were collected and distributed by Mr. Baker prior to the meeting. All agreements and Action Items were coordinated for the next specification revision. See Volume II for MDC comments to the March draft of MIL-C-55543.

3.2.2 Second Draft, MIL-C-55543, dated June 1967

Data, agreements, and completed Action Items from the FCC Tri-Service Committee Meeting held at NASA/MSFC in May 1967 were used to prepare the second draft proposal of MIL-C-55543. Thirty copies of the proposal were furnished for the Tri-Service Joint Agency Committee Meeting held in Washington, D.C. on 6, 7 June 1967.

Comments to this draft issue were coordinated with MDC personnel acting as the FCC Specification Committee chairman representative. All suggested revisions were coordinated, together with major revisions to the detailed specification sheets. Sample specification sheets were sent to all FCC committee members for their comments.

3.2.3 Third Draft, MIL-C-55543, dated September 1967

This third draft was prepared to incorporate the suggested revisions made at the 6, 7 June 1967 coordination meeting held in Washington, D.C. Copies were transmitted to all FCC committee members for their review prior to the succeeding coordination meeting to be held at MDC, Huntington Beach, California, on 20, 21 September 1967.

The September coordination meeting was held as scheduled. Written inputs from all committee members were reproduced, distributed, and reviewed. The MDC comments are shown in Volume 2. The meeting was chaired by MDC personnel who prepared minutes of the meeting, which are included in Volume 2.

3.2.4 Fourth Draft, MIL-C-55543, dated November 1967

The fourth draft was prepared and distributed to all FCC committee members on 3 November 1967 in preparation for the joint cable and connector committee member meeting held in Atlantic City, New Jersey, on the 26, 27 November 1967. This draft contained the coordinated agreements, plus completed Action Items from the FCC Specification Coordination Meeting held at MDC in September 1967. Additional suggestions and inputs from Messrs. Angele, Godwin, Rothstein, and Van Ness were included.

Mr. R. O. McHarg from MDC attended the joint FCC and Connector Coordination Meeting in Atlantic City, coordinated the comments and suggested changes to the specification.

3.2.5 Fifth Draft, MIL-C-55543, dated January 1968

The fifth draft was prepared to incorporate all changes suggested at the November 1967, Atlantic City Joint Coordination Meeting. Per the directions of NASA/MSFC, the original bond sheets of the specification were transmitted directly to Mr. Jack Rothstein of the U.S. Army Electronics Command, Fort Monmouth, New Jersey. Mr. Rothstein has the responsibility for printing the draft specification for distribution to other government agencies and to industry for comments.

Copies of the specification were submitted to NASA/MSFC to meet the contract requirement for the nonshielded FCC specification.

3.2.6 Other Effort

All the detailed specification sheets, pages 2 through 10 for ten configurations, were revised to correct coding errors and to make the conductor thickness range more logical. These 30 original bond sheets, together with a revised table 1 for conductor dimensions, were sent to Mr. Jack Rothstein on 27 March 1968 for subsequent incorporation into the next specification issue.

The spring IPC meeting was attended in New York City during March 1968 by MDC personnel to actively participate in the industry review of the MIL-C-55543 specification.

It can be concluded that MDC's active participation has been a major contribution in the preparation of MIL-C-55543, Nonshielded FCC Specification.

3.3 FCC Connector Specifications

As previously explained, the major program effort for the FCC connector specifications was preparation and coordination of the new MIL-C-55544 FCC connector specification. This included the submittal of the detail specification sheets and proposed method drawings for the NASA/MSFC shielded-plug assembly developed by MDC on this program.

Past experience with MSFC-SPEC-219A Flat Conductor Connector Specification, NASA/MSFC connector hardware, other FCC connector development, and general knowledge and experience with connector specifications were all used in this specification task effort.

3.3.1 General Comments to MSFC-SPEC-219A

During the Reference 2 study, MDC prepared numerous comments to the above NASA specification. See Volume II. Highlights of these comments included:

- a. Proper dimensional control must be specified for plug and receptacle to assure mating and performance.
- b. Performance levels must be established to meet the Saturn program requirements.
- c. The required connector configurations must be included to meet the program requirements.

3.3.2 Inputs to MIL-C-55544, FCC Connector Specification

Direct coordination with Mr. R. F. Van Ness, the chairman of the FCC Connector Specification Tri-Service Committee, assured the general format coordination between MIL-C-55543 and MIL-C-55544.

The requirements for the MS method drawings for assembly of NASA/MSFC conductor-contact connectors were established with Messrs. W. Angele and R. F. Van Ness. MDC generated the initial format for the required drawings and for establishing drawing dimensional tolerance methods to meet military standards.

M55544/11, detail specification sheets, were prepared in coordination with Messrs. Angele and Van Ness for the NASA/MSFC shielded conductor-contact plug assembly developed by MDC. MS75081, proposed method drawing, "MS55544/11 Flat Conductor Cable Shielded Plug Assembly Instructions" was prepared to define the assembly procedures for the M55544/11 shielded plug assembly. The drawings prepared by MDC were simulated by NASA/MSFC for their nonshielded plug assembly specification drawing preparation. Numerous versions of both of the above drawings were prepared and

coordinated prior to submittal of the final, original drawings for inclusion in the MIL-C-55544 specification. Final copies are included in Volume II.

Two sets of written comments were furnished for various issues of MIL-C-55544. The first set was submitted to NASA/MSFC on 4 October 1967. The second set was submitted to U.S. Army Electronics Command at Fort Monmouth, New Jersey, on 5 March 1968 in answer to their written request for comments. Both sets of comments are included in Volume II.

3.4 Shielded FCC Specification

The format used for the MIL-C-55543 nonshielded specification and the techniques developed in its preparation were used to prepare a "no number" proposed draft of a shielded FCC specification. This draft can be used as a basis for a military specification to be issued in the future.

The draft specification included in Volume II is a complete document in itself and does not depend on MIL-C-55543 for any of its requirements or procedures. This will permit the simultaneous development of the two specifications without any restrictions which would be experienced if the shielded cable specification listed only the differences or changes required over the nonshielded specification.

The initial draft contains two slash-sheet cable configurations. Both utilize H/FEP insulation throughout. The /1 drawing has one-half mil, bare-copper shield on both sides, while the /2 drawing has one-half mil, Permalloy magnetic shield on both sides. The shields for the /2 are plated on one side only (the outer sides of the completed cable) with 50 microinches of dull nickel over 50 microinches of copper. Both platings are electrodeposited.

A list of general comments to the proposed specification draft follows:

- a. The shielded cable specification has not been updated to the changes incorporated in proposed MIL-C-55543, dated January 1968.

- b. The revision to be made to MIL-C-55543 by the U.S. Army Electronics Command at Fort Monmouth, New Jersey, as the result of industry comments, should also be considered in updating the shielded cable specification.
- c. It is recommended that the thickness of the primary insulation between the shield and conductor be increased to a minimum of 2 mils H/Film, or equivalent. This is required to maintain the voltage-withstand test values specified, and will also make cable stripping more practical.
- d. The requirements for the magnetic-shielded cable should be reviewed. Tests by MDC have indicated that continuous, circumferential, molecular magnetic shielding will be required. In addition, many major problems were encountered in obtaining prototype magnetic shielding with 50 microinches of copper and nickel plating.
- e. After the final shield configurations has been defined, developed, and tested, shielding performance requirements should be added to the specification.

SECTION IV

4. MECHANIZED DESIGN

4.1 Introduction

The mechanized design tasks defined by the program work statement were to describe how mechanized design (through the use of computers) could be applied to the design, fabrication, testing, and installation of FCC interconnecting harness networks. Then, depending on the available program time and funds, mechanized design was to be applied to an actual FCC application program to perform the detail design and prepare the drawings, to illustrate what could be done by computerized design for future programs. However, about midway through the program, it was agreed with NASA/MSFC personnel that the extra nonanticipated effort required on other higher priority tasks precluded the possibility of performing an actual detailed, mechanized design on a typical vehicle electronics system. Therefore, the mechanized design effort was limited to defining how mechanized design could be applied to FCC interconnecting harness systems.

Paragraph 4.2 and its subparagraphs essentially contain the mechanized-design summary data included in the FCC handbook. Paragraph 4.3 and its subparagraphs contain the preliminary mechanized-design data prepared by the Information Processing Systems Department of the Information Systems Subdivision with the Saturn Electronics design personnel, both from MSSD of MDC.

4.2 Mechanized Design General Description

A large portion of the design of FCC harnesses can be mechanized with the use of a digital computer and appropriate programs. This can aid designers of a complex electronic system by providing relief from much of the repetitive, tedious, and time-consuming phases of harness design processes.

4.2.1 What Mechanized Design Can Do

A mechanized harness-design system can accomplish much of the routine assignment of identification information, bookkeeping, and drawing effort that would ordinarily be done by designers aides.

A description of tasks that can be performed effectively by the computer system is offered. This system can:

- a. Read, compile, and file (e.g., magnetic tape) information on approved parts, with appropriate performance characteristics and specifications from which harness assemblies may be fabricated.
- b. Read, compile, and file point-to-point wiring requirements.
- c. Process and analyze wiring requirements, and sort out those which cannot be met by available approved parts. The system can then analyze the remaining requirements to group conductors into cables, and within each cable, according to the location of each conductor termination and to EMC zoning criteria.
- d. Assign cable network path routing from information generated in item c, above, including a specified quantity of spares for each network path. It can then assign, from the approved parts list, the type and quantity of cable.
- e. The computer system can select the type and required quantity of approved connectors to meet the cable-termination requirements.
- f. The computer system can sequentially assign identification numbers for each cable segment.
- g. The computer system can prepare wiring and fabrication information for automatic placement and pictorialization on manufacturing drawings.
- h. The program should be documented sufficiently to facilitate interpretation and modification. Comment cards should be associated with each decisive statement, to reflect what the program is doing. Each subroutine should be documented in the following manner:
 1. The purpose of the subroutine.
 2. Input arguments.
 3. Output arguments.
 4. Error returns.
 5. Internal variables used.
 6. Restrictions to using the routine.
 7. Names of all subroutines used by this subroutine.

4.2.2 Computer Description

The system described in this report, if written in a machine-independent language such as FORTRAN IV, could be run on almost any medium or large-scale computer. The extent to which this system is implemented is the only major variable in the extent of machine configuration. Examples of machine configurations are the UNIVAC 1108; IBM SYSTEM 360, MODEL 65; and the SDS 9300.

A basic system hardware configuration should include the following:

- a. Console and Mainframe - Used by the computer operator to control operation of the program.
- b. 32K words of Core Memory - Holds system software and controls execution of program.
- c. Card reader - Input options and control information.
- d. Typewriter - Messages to operator for mounting of tapes, system errors.
- e. Off-Line Printer - Generate printed output.
- f. Magnetic Tape Units - Means for inputting standard files for program access.
- g. Random Access Bulk Storage Unit - Store large amounts of data to be operated on by the program.

An optional but desirable subprogram within the mechanized design system would be a routine to optimize the cable routing and layout, in conjunction with equipment layout, according to some objective function (e.g., weight, total cost of materials and labor) within limits of specified constraints (e.g., location of mechanical obstructions, specified minimum percentage of spares in each path of the cable network, and EMC isolation requirements). This is compared with a simpler assignment of cable routing according to preestablished ground rules, which may give reasonably good, but less than optimal, results. Because of the complex nature of such a subprogram, it would be appropriate to add it to the system at a later date, after the simpler routines are adequately checked out and operate satisfactorily.

4.2.3 Computer Program Design Requirements

The computer program and subroutines written to accomplish automated flat-cable design should be written and documented to meet the following requirements:

- a. The program should provide the capability of allowing the user to extend the contents of data tables to add items previously undefined. This extended capability should be allowed with little or no program modification, and without causing obsolescence of existing data files.
- b. The program should be modularly constructed to facilitate addition of extended capabilities and to facilitate modifications. Each discrete function should become a subroutine. All subroutines should be under control of a supervisory routine or executive.
- c. Programming should be done in a higher level machine-independent language such as FORTRAN IV. This facilitates implementation of the program on more than one computer hardware configuration.

4.3 Mechanized Harness Assembly Design

4.3.1 Scope

The following system description discusses and illustrates the principles and techniques of automated design as applied to flat-cable interconnecting systems. The system described is an aid to design personnel for eliminating the repetitious parts of the design procedure. The description is organized under the following outline:

- Section 4.3.2 - General System Design Philosophy
- Section 4.3.3 - Limitations and Unique Features of Flat-Cable Systems
- Section 4.3.4 - Flat-Cable Mechanized Design System
- Section 4.3.5 - Computer Program Design Requirements
- Section 4.3.6 - Computer Description

4.3.2 General System Design Philosophy

A design system, utilizing mechanized or automated design, normally contains three design effort phases. These are (1) the definition of the

design problem, (2) preliminary design and analysis, and (3) detail design and drawing preparation. Each phase contains its own computer programs and subroutines. Each phase is designed to follow efficient and standardized design procedures.

4.3.2.1 Definition of the Design Problem

A design problem is characterized by the performance requirements it must satisfy. Functional and physical aspects of the design are established initially; the hardware system configuration then evolves. Functional requirements of the system are defined in broad terms, are grouped, and the result is a tentative list of hardware units. As the design requirements are changed and finalized, the size and quantity of proposed hardware units will fluctuate. When the performance requirements have been finalized, the design problem will have been defined.

4.3.2.2 Preliminary Design and Analysis

During the preliminary design phase, varying solutions to the design problem are considered. As preliminary analysis progresses, certain standards are established for approved part numbers, ground rules for application, etc. As the preliminary design is finalized, point-to-point wiring is established and loaded into a data base for use in establishing interconnecting cable assemblies. Prior to the detailed design effort, the data base is assessed for the wiring list, and all wires not applicable to the type of cabling being used are rejected.

4.3.2.3 Detail Design and Drawing Preparation

The majority of the tedious and repetitious design jobs eliminated by automated design aids occurs in the detail design phase. Conductor groupings can be made, and cross-sectional areas, cables and connectors can be selected for each cable assembly. All these tasks can be performed more efficiently and more rapidly by using mechanized design. Pin numbers can be automatically assigned, and spare wires can be provided in each cable assembly. Tabulated printout can be made for each cable assembly

drawing, including the list of material. Schematic drawings and test requirement drawings can be generated for the FCC interconnecting system.

4.3.3 Limitations and Unique Features of Flat Cable Systems

Several unique features of FCC require the addition of routines to RWC mechanized design systems.

4.3.3.1 Ground Rules for Cable Selection

Certain wiring requirements are generally not applicable to FCC. Following are typical ground rules which might be used for cable selection:

For Conductor Conductivities:

- a. Use standard FCC for conductor requirements of 21 AWG or smaller.
- b. Use high-density FCC for conductivity of 20 AWG.
- c. Use power FCC for conductivity requirements of 8 through 19 AWG. For special cases, the paralleling of non-power FCC conductors may be used for 16 through 19 AWG requirements.
- d. Use RWC if conductivity requirements are larger than 8 AWG.

Coaxial cables shall not be converted to FCC. (keys)

4.3.3.2 Distribution Boxes

The geometry of FCC and the termination "by layer" to the FCC connectors limit the pin-assignment change capability of the FCC system. Wiring change flexibility can be achieved through the use of strategically located distribution boxes. Pin-assignment changes can then be made by rewiring the distribution boxes and not changing the FCC cable assemblies or the electronic units. Factors which must be considered in the selection of distribution units include:

- a. Design the distribution system for minimum connectors and maximum simplicity of the interconnecting cable assemblies.
- b. Provide for easy installation and replacement of the distributors.

- c. Use distributors which can easily accommodate simple wiring changes in the field.
- d. Consider the added weight of the distributors. The net weight will still be less for the FCC system.
- e. Consider the increased number of circuit junctions added by the distributors.

4.3.3.3 Electrical Grouping

Electrical grouping provides isolation between certain classes of conductors. Conductors which are highly susceptible may be grouped together, and conductors which are interferers may be grouped together. FCC generally can be grouped in three classes. A typical example follows:

Class A - Low-level signals, susceptible to outside interferences, such as:

- a. Dc signals less than 5 volts.
- b. Low-level ac signals less than 1 volt.
- c. Slowly varying dc signals less than 5 volts.

Class B - Signals not as susceptible as those of Class A, but not the interfering type of Class C:

- a. Dc power of 5 to 28 vdc.
- b. Slowly varying dc signals of 5 to 28 volts.

Class C - Signals which cause interference such as:

- a. Ac signals greater than 1 volt.
- b. Bilevel switching signals.

The nature of FCC provides two methods of electrical grouping.

4.3.3.3.1 Within a Single Cable

Electrical grouping may be done in a single cable by grouping conductors as:

CLASS A, CLASS B, AND CLASS C

4.3.3.3.2 In Several Cables

Electrical grouping may be done by grouping a single conductor class (A, B, or C) in individual cables and then routing all cables of each class in separate bundles.

4.3.3.4 Method of Selecting FCC

Selection of FCC, between electronic units, requires the determination of the number of cable segments required, the types of insulation, and the conductor cross sections. A complete description will not be given on the selection criteria, but each area will be briefly touched.

4.3.3.4.1 Number of Cable Segments

The objective here is to use the minimum number of cable segments without degrading system performance. The following factors must be considered:

- a. Ensure adequate separation of group classes.
- b. Examine each circuit for unusual electrical characteristics requiring special consideration.
- c. Leave excess conductors for use as spares.

4.3.3.4.2 Selection of Cable Insulation

The selection of insulation is primarily determined by the voltage, dielectric constant, temperature requirements, and the termination system selected. See examples below:

<u>Type</u>	<u>Cable Insulation</u>	<u>Conductors</u>	<u>Ratings</u>	
			<u>Voltage</u>	<u>Temperature</u>
Standard	Polyester	Nl coated Cu	600 v	100° C
Hi-Density	Polyester	Nl coated Cu	300 v	100° C
Standard	H/FEP	Nl coated Cu	600 v	200° C
Hi-Density	Polyester	Bare Strip Cu	300 v	100° C

4.3.3.4.3 Selection of Optimum Conductor Cross Sections

The conductor cross section in FCC is directly related to the cable width, the number of conductors in the cable, and the cable thickness. The objective is to select common cross sections which will enable all, or as many as possible, of the conductors in a given class to satisfy both electrical requirements and the cable assembly termination requirements. There are several methods of accomplishing this.

- a. Select centerline spacings which are the same or are a multiple of the centerline spacings of the connector contacts.
- b. Limit the final conductor cross sections selected to the smallest number which can logically meet the system conductivity and special electrical characteristics requirements.

4.3.4 Flat-Cable Mechanized Design Procedures

The following routines describe the mechanized design procedures for FCC application. The subroutines are described in the order in which they occur. The main program or executive program is described first. Figure 4-1 is a flow chart of the Flat-Cable Mechanized Design System (Figure 4-2 indicates a round-wire cable design system for comparison that is presently in operation at MDC). Each subroutine description contains a code name and descriptions of the purpose of input and output data used and generated by the routine.

4.3.4.1 EXEC

EXEC is the executive or controlling program. It accepts all control card inputs and, from these, decides which subroutines are to be called. After each subroutine is finished with its unique application, it returns control to the EXEC and the EXEC calls the next subroutine. This process continues until all design requests have been completed.

4.3.4.2 FCD01

As standard hardware and cable specifications become approved, they are assembled into two data bases which can be assessed later in the design

phase. One data base contains approved connectors; the other contains approved cable specifications. FCD01 accepts these specifications on user-loaded cards and records the data for subsequent use.

4.3.4.3 FCD02

The preliminary design phase calls for the designer to load wiring data. This is accomplished by entering point-to-point terminations on loadsheets. Point-to-point is defined as unit-to-unit, reference designation-to-reference designation, etc. Data describing each wire are also entered. FCD02 assigns each termination a unique identifying number and stores the file on magnetic tape.

4.3.4.4 FCD03

This routine is used to retrieve certain wiring records from the wiring file. The retrieval is done by system, assembly number, unit number, or reference designation, depending on what the designer requests on the master load sheet. The retrieved records are assembled into a form which will be operated on by other subroutines and made into cables. Therefore, although all wiring data for a vehicle are on tape, FCC selection can be done for small sections at any time.

4.3.4.5 FCD04

Certain types of wire requirements are not applicable to FCC use. This routine checks all wire requirements and eliminates those which cannot be met by FCC. The rejected requirements are noted in a printout.

4.3.4.6 FCD05

This routine selects the number, type, and location for any distribution units which may be needed. Previously established ground rules are used.

4.3.4.7 FCD06

The purpose of FCD06 is to sort the circuits selected for flat-cable application. This sorting serves to aid in providing logical conductor

grouping assignments within each cable. The wires are sorted by class and unit-to-unit path. Previously established ground rules are used.

4.3.4.8 FCD07

This routine selects the FCC for each logical grouping of circuits. The logical grouping, taken by the unit-to-unit path and grouped in FCD06, is assigned a percentage of spare wires and then assigned a cable number. The cable is selected from the FCD01 hardware file and the circuit wiring from the FCD02 wiring file. All spare wires are assigned the function name SPARE. The generated cables are placed in a new table.

4.3.4.9 FCD08

This routine selects connector hardware from the hardware file of FCD01 to match the cables in the cable design file of FCD07. The connectors are selected by centerline spacing, number and cross section of conductors, and number of layers of cable.

4.3.4.10 FCD09

This routine sequentially assigns reference designation and/or pin numbers from blocks entered on the master loadsheet.

4.3.4.11 FCD10

The purpose of FCD10 is to generate all of the required printouts - including the "Reference Designation List," table 4-1 and "Material Summary," table 4-2. This routine uses data files from FCD01, FCD02, and FCD07.

4.3.5 Computer Program Design Requirements

The computer program and subroutines written to accomplish automated flat-cable design should be written and documented to meet the following requirements.

Table 4-1

REFERENCE DESIGNATION LIST

Ref Des.	Connector Part No.	Mating Ref Des.	Connector Part No.
1AJ29	2BC 359-2	2BC53	2DA 643-1
1AJ54	2CA 531-12	1CC41	2DC 512-7
.			

Table 4-2

MATERIAL SUMMARY

Part Number	Part Name	Quantity
2BC359-2	Connector	3
2CA531-12	Connector	1
1Z4957-1	Cable Segment	1
2Z4395-2	Cable Segment	4
3C1135	Distribution Unit	1
.		

4.3.5.1 Data Table Flexibility

The program should provide the capability of allowing the user to extend the contents of data tables to add items previously undefined. This extended capability should be allowed with little or no program modification and without causing obsolescence of existing data files.

4.3.5.2 Modular Programming

The program should be modularly constructed to facilitate addition of extended capabilities and to facilitate modifications. Each discreet function should become a subroutine. All subroutines should be under control of a supervisory routine or EXEC.

4.3.5.3 Programming Language

Programming should be done in a higher level, non-machine-oriented language such as Fortran IV. This facilitates implementation of the program on more than one computer hardware configuration.

4.3.5.4 Program Documentation

The program should be documented sufficiently to facilitate interpretation and modification. Comment cards should be associated with each decisive statement to reflect what the program is doing. Each subroutine should be documented in the following manner:

- a. The purpose of the subroutine
- b. Input arguments
- c. Output arguments
- d. Error returns
- e. Internal variables used
- f. Restrictions to using the routine
- g. Names of all subroutines used by this subroutine.

4.3.6 Computer Description

The system described, if written in a non-machine-oriented language such as Fortran IV, could be run on almost any medium or large scale computer. The extent to which this system is implemented is the only variable affected by machine configuration. Examples of machine configurations are the UNIVAC 1108; IBM SYSTEM 360, MODEL 65; and the SDS 9300. A basic configuration for implementation is described in 4.3.6.1 and 4.3.6.2.

4.3.6.1 System Hardware

A basic system hardware configuration should include the following:

- a. Console and Mainframe - Used by the computer operator to control operation of the program.
- b. 32K words of Core Memory - Holds system software and controls execution of program.

- c. Card reader - Input options and control information.
- d. Typewriter - Messages to operator for mounting of tapes, system errors.
- e. Off Line Printer - Generate printed output.
- f. Magnetic Tape Units - Means for inputting standard files for program access.
- g. Random Access Bulk Storage Unit - Store large amounts of data to be operated on by the program.

4.3.6.2 System Software

The basic system software necessary to implement the program consists of:

- a. Language (such as Fortran IV) Compiler - changes the statement language commands to machine language commands (instructions which the machine understands).
- b. System Subroutine Library - A set of routines which facilitates using a statement language. These are usually provided with the machine. For example, algebraic functions and input/output routines.

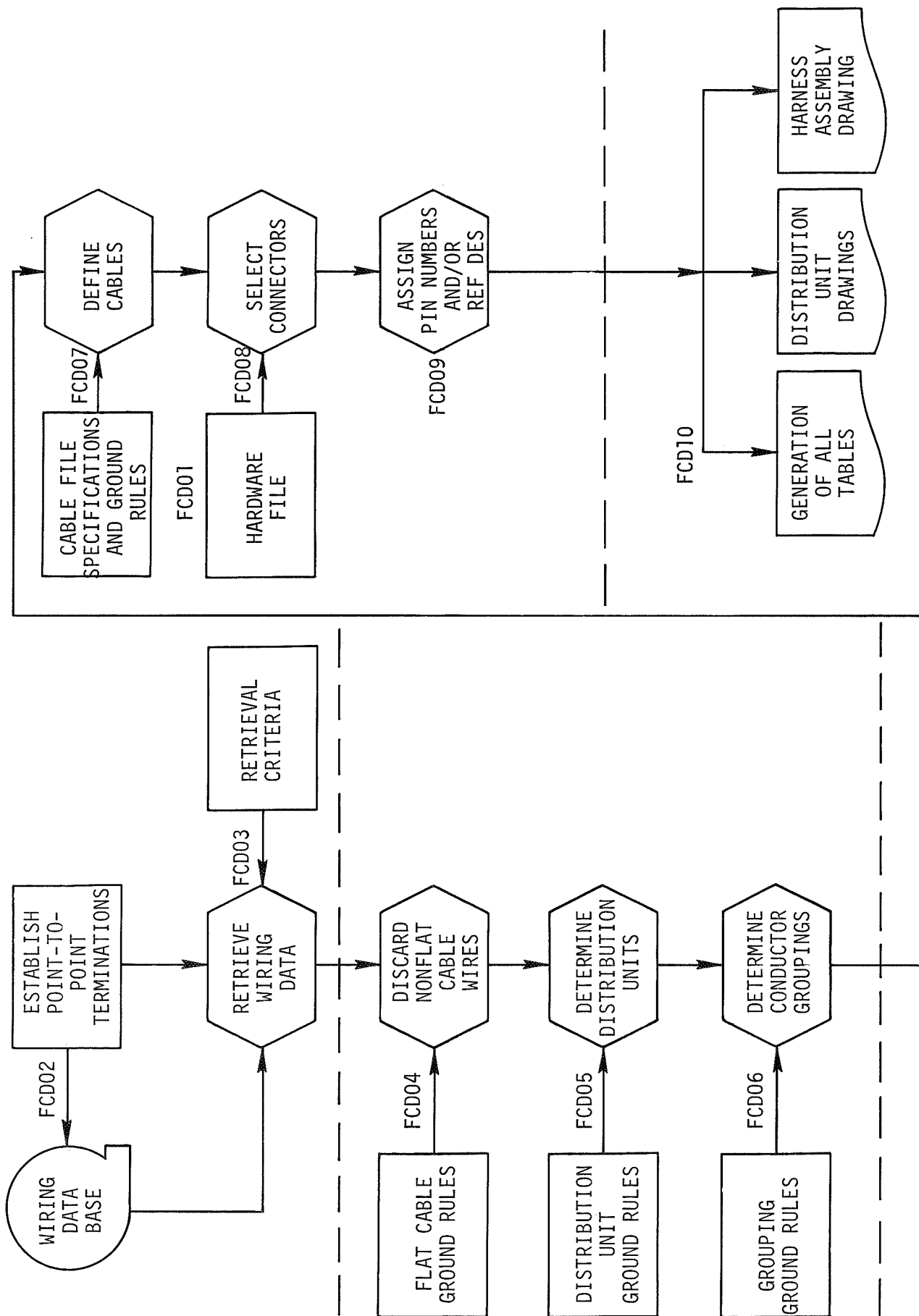


Figure 4-1. Flow Diagram -- Illustrating Steps Involved in Mechanized Design of FCC Systems

SECTION V

5. CLAMPS AND INSTALLATION

5.1 Introduction

During the Phase I Flat Cable Development Program, over 100 FCC cable assemblies were defined, development, manufactured and installed in a 180 degree mockup section of the aft skirt of the Saturn S-IVB/V vehicle. Many clamping and installation problems were defined, ground rules were established, and clamp hardware and installation techniques were developed.

The clamp and installation work statement for this program required the development of high-temperature clamps (200°C), and improved methods of initial installation and replacement of cable segments in major bundle runs. Limited evaluation testing was to be performed, as permitted by the program funds, to determine the suitability of the hardware and methods developed for space application. Because of subsequent increased effort on higher priority program tasks, the evaluation testing was held to a minimum.

5.2 Clamps

5.2.1 Clamps from FCC Development Program

Two separate FCC clamp types were developed on the FCC Development Program. They were the metal-cushioned clamp, figure 5-1, and the Velcro lap clamp, figure 5-2. Both clamps used the Hartwell nylon fasteners, which limited them to a maximum operating temperature of +100°C.

Both type clamps were subjected to numerous evaluation tests during the FCC Development Program, including vibration, high temperature, and cable slippage tests. Even though the Velcro lap clamps passed these tests, subsequent failures were noted on the 180 degree mockup. With aging at room temperatures, the Velcro nylon material pulled or tore out of the Hartwell fasteners in the compressed, or mounting, areas. Therefore,

known required clamp improvements included higher temperature fasteners for the metal-cushioned clamps and an improvement to the Velcro lap clamp to prevent tear-out in the fastener mounting areas.

5.2.2 Revisions and New Clamp Designs by MDC

5.2.2.1 Clamp Design Goals

The following design goals were established for FCC clamps:

- a. Simple and lightweight
- b. Utilized captivated hardware (no loose parts)
- 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.

5.2.2.2 Industry Survey

With the FCC development program clamp design and testing experience, this program's clamp temperature requirements, and paragraph 5.2.2.1, Design Goals, an industry survey was made to review all existing and proposed clamp designs.

The Hartwell Corporation was contacted for possible new development in satisfactory higher temperature "lap" materials and higher temperature expanding fasteners. Neither was available. Trade magazines were reviewed, and all known clamp manufacturers were contacted for existing and proposed clamps suitable for use with FCC. Various companies engaged in FCC development studies, including Lockheed Aircraft of Burbank, California, and McDonnell Aircraft of St. Louis, Missouri, were contacted and their clamp designs were reviewed. This background information was then used to make a series of clamp proposals.

5.2.2.3 Clamp Proposals

A series of clamp proposals was made by a layout designer who was guided but not inhibited in his original concepts for FCC clamp designs. Using the design goals of 5.2.2.1, and the results of the industry survey of 5.2.2.2, a total of 17 different design-proposal sketches was made and presented to NASA/MSFC at the third informal review held at MDC/MSSD on 12 and 13 December 1967. The type clamps included were: cushion clamps with quarter-turn fasteners, tubular clamps with captivated screw and spring fasteners, spring bodies, multiple-coil springs, controlled spacing from mounting surface, and those for right-angle cable routing with 2-hole mounting. The 17 different sketches are included in Volume II with a further explanation of each.

During the December review, it was agreed that the MDC Velcro lap clamp with metal grommets, metal-cushioned clamp with quarter-turn fasteners, and the metal C-channel clamp with captivated fasteners would be included in the FCC handbook.

5.2.2.4 Velcro Lap Clamps, 100°C

A series of tests was conducted on Velcro lap clamps made from nylon hook-and-pile material, with metal grommets installed in the fastener areas.

Two methods were considered for strengthening the Velcro nylon material in the fastener areas to prevent the cold-flow failures experienced with aging on the Saturn aft-skirt mockup. A plastic grommet, molded in position, was discarded because of initial cost and opinions that this would increase the time period required for cold-flow, but would not prevent its occurrence. Metal grommets were installed in a number of sample Velcro clamps by the Hartwell Corporation. One loose end of the single clamps was fastened to a vertical support, and weights were attached to the other loose end (see figure 5-3). Weights of up to 15 pounds were applied at ambient temperatures for 1 week with no apparent

cold-flow of the Velcro nylon material. It was concluded that this accelerated testing was more stringent than the actual conditions to be encountered. The metal grommet design was selected. The final Lap Clamp assemblies for 100°C operation are shown on figures 5-4 (Single), 5-5 (Double), and 5-6 (Triple).

5.2.2.5 All-Metal Clamp, 200°C

Figure 5-7 shows the all-metal, C-section body, captivated screw clamp selected. Tests conducted by NASA/MSFC on this type clamp indicated that maximum screw torque can be applied with Polyimide FCC over an extended time period without mechanical or electrical degradation of the FCC. The C-section body of this clamp could be coated with silicone rubber to provide additional insulation, greater retention forces, and improved load distribution.

5.2.2.6 Metal-Cushioned Clamp, 200°C

Figure 5-8 shows the metal-cushioned clamp selected. This clamp, with its silicone cushion and rubberized standoffs, provides the maximum protection to FCC at 200°C operating temperature. The quarter-turn Expando Grip fasteners, manufactured by the Adjustable Bushing Company of North Hollywood, California, requires only a round hole in the support structure for mounting.

5.2.3 NASA/MSFC Clamp Designs

The NASA/MSFC PM11450 "Clamp Assembly Flat Conductor Cable" drawing and its detail drawings were reviewed, and written comments were submitted (see Volume II). In general, the comments submitted for this clamp design, figure 5-9, apply to the others selected by NASA/MSFC for inclusion in the FCC handbook. These figures are listed below:

- Figure 2-46 - Tubular Clamps With Nylon Fasteners, 100°C.
- Figure 2-47 - Tubular Clamps With Screw Fasteners, 100°C.
- Figure 2-49 - Metal Noncushioned Clamp, Right-Angle Tubular, 200°C.

- Figure 2-50 - Metal Noncushioned Clamp, Right-Angle Sheet Metal, 200°C.
- Figure 2-52 - Metal-Cushioned Clamp, Double Grip, 200°C.
- Figure 2-53 - Metal-Cushioned Clamps, For Angle Fold, 200°C.

The above figure numbers are from the FCC handbook and with the exception of figure 2-52 (figure 5-9) are not included in this report.

The comments to the NASA/MSFC clamp designs include:

- a. In general, the designs are simple, lightweight, low cost, and perform the clamping action well.
- b. Lack of captivated hardware would increase the probability of "loosing" parts during installation and subsequent servicing.
- c. The many parts of some clamp designs would greatly increase the installation times and make installations in congested areas very difficult.
- d. Inadequate provisions to protect the FCC edges from becoming pinched and/or shorted.
- e. The triangular mounting holes for the right-angle clamps would require much heavier and more complicated support brackets than the normal vertical or horizontal two-hole mounting clamps.

5.3 FCC Installations

The ground rules and methods established for FCC installations during the reference FCC development program are still generally applicable to future programs. However, there were two closely associated problems which required correction. The first was the problem of routing and maintaining each FCC segment in its preassigned bundle position. The second was to assure that the cable segments would remain in their assigned positions after they were initially installed.

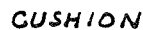
A method of using H/Film tape around all cable segments in each layer, to assure the initial and maintained registrations, was used on the development program. It was very difficult to make the initial installation with the required registration; and on those bundle runs made up of a number of cable segments in each cable layer, the segments gravitated toward the bottom of the bundles with time.

Figure 5-10 shows the FCC separator developed on this program. Figures 5-11 and 5-12 show this separator installed between and under clamps on typical FCC installations.

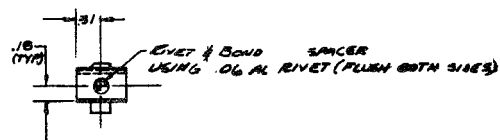
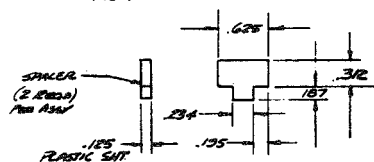
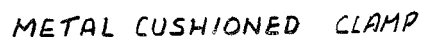
Although there was neither time nor funds available on this program to develop a mockup section using the FCC separator described above, its use on future programs should greatly simplify the initial registration of each cable segment and assure that this registration is maintained throughout the life of the installation.

5.4 Conclusions

Clamp hardware, FCC separators, and installation techniques have been developed which are suitable for use on aerospace, military, and commercial programs. These are defined in the FCC handbook, and in this section of this report.



DIM. "A"	DIM. "B"	WT. #
1.92	.37	.004
1.92	.50	.005
2.42	.37	.010
2.42	.50	.015
3.42	.37	.020
3.42	.50	.025
2.42	.125	.002



DIM. A	DIM. B	F/C SIZE	WT. #
3.50	3.00	1 1/2"	.010
4.00	3.50	2 "	.020
5.00	4.50	3 "	.030

1. ALL CUSHIONS TO BE INSTALLED TO CLAMPS, USING RTV-731 CEMENT.
2. PRODUCTION CUSHIONS WILL BE MADE OF, "COMB 2006 SILICONE RUBBER FOAM 5/8" THICK SHEET PER MIL-STD-670-TE3."
3. MOCK-UP CUSHIONS WILL BE MADE OF, "P-411-N RUBBER FOAM, 5/8" THICK SHEET FROM: RUBATEX CORP. L.A., CALIF.

Figure 5-2. Metal Cushioned Clamp

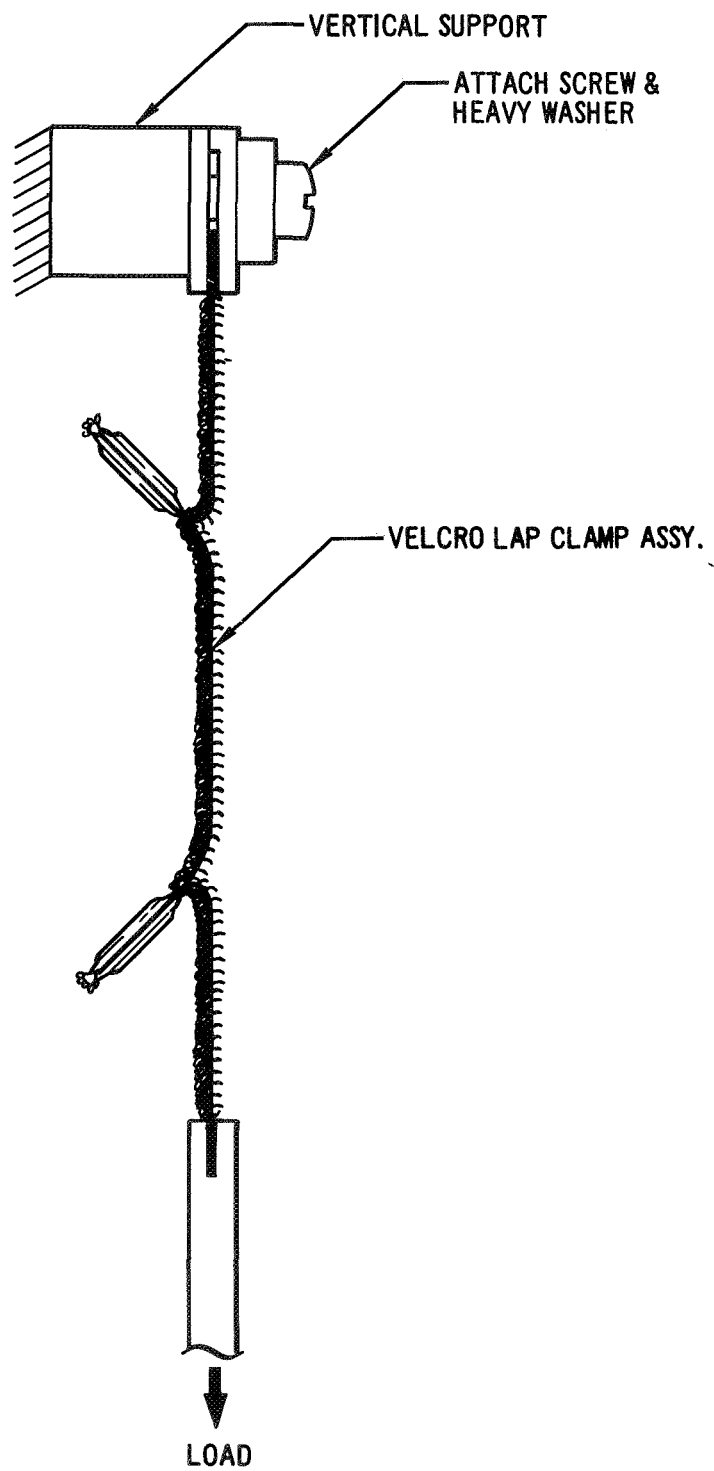


Figure 5-3. Velcro Clamp Test Setup

LAP CLAMP ASSEMBLY SINGLE, 100° C

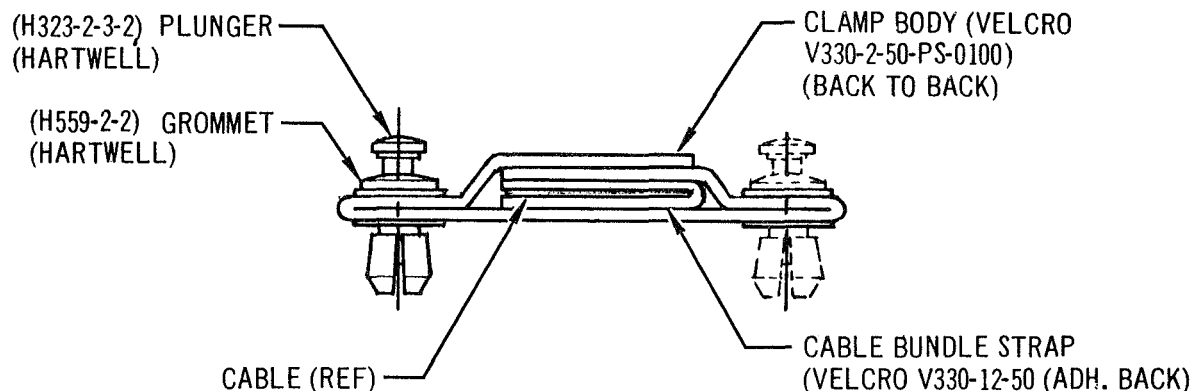
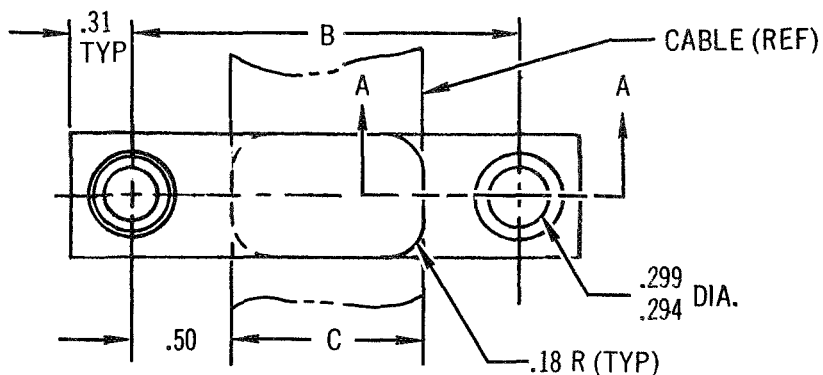
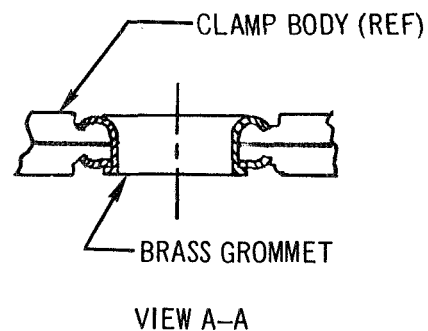


TABLE I			
CLAMP ASSY TYPE	CABLE WIDTH IN INCHES	B DIM.	LAP DIM. C
I	1/2" - 1"	2"	1"
II	1 1/2" - 2"	3"	2"
III	2 1/2" - 3"	4"	3"



GENERAL NOTES:

1. PROVIDE .314 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 5-4. Lap Clamp Assembly, Single, 100°C

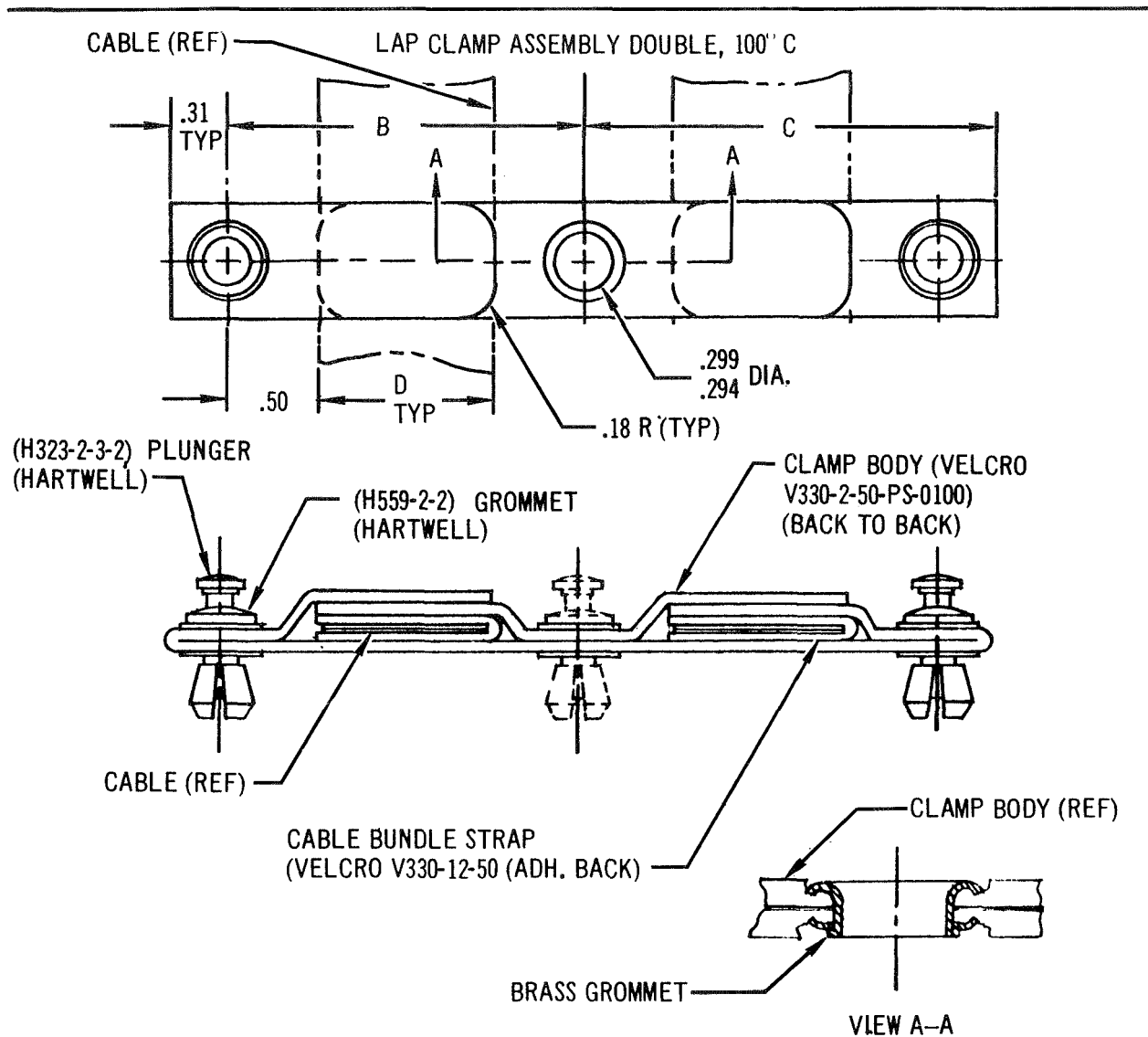


TABLE I				
CLAMP ASSY TYPE	CABLE WIDTH IN INCHES	B DIM.	C DIM.	LAP DIM. C
I	½" – 1"	2"	2"	1"
II	1½" – 2"	3"	3"	2"
III	2½" – 3"	4"	4"	3"

GENERAL NOTES:

1. PROVIDE $\frac{.314}{.312}$ 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 5-5. Lap Clamp Assembly, Double, 100°C

LAP CLAMP ASSEMBLY TRIPLE, 100° C

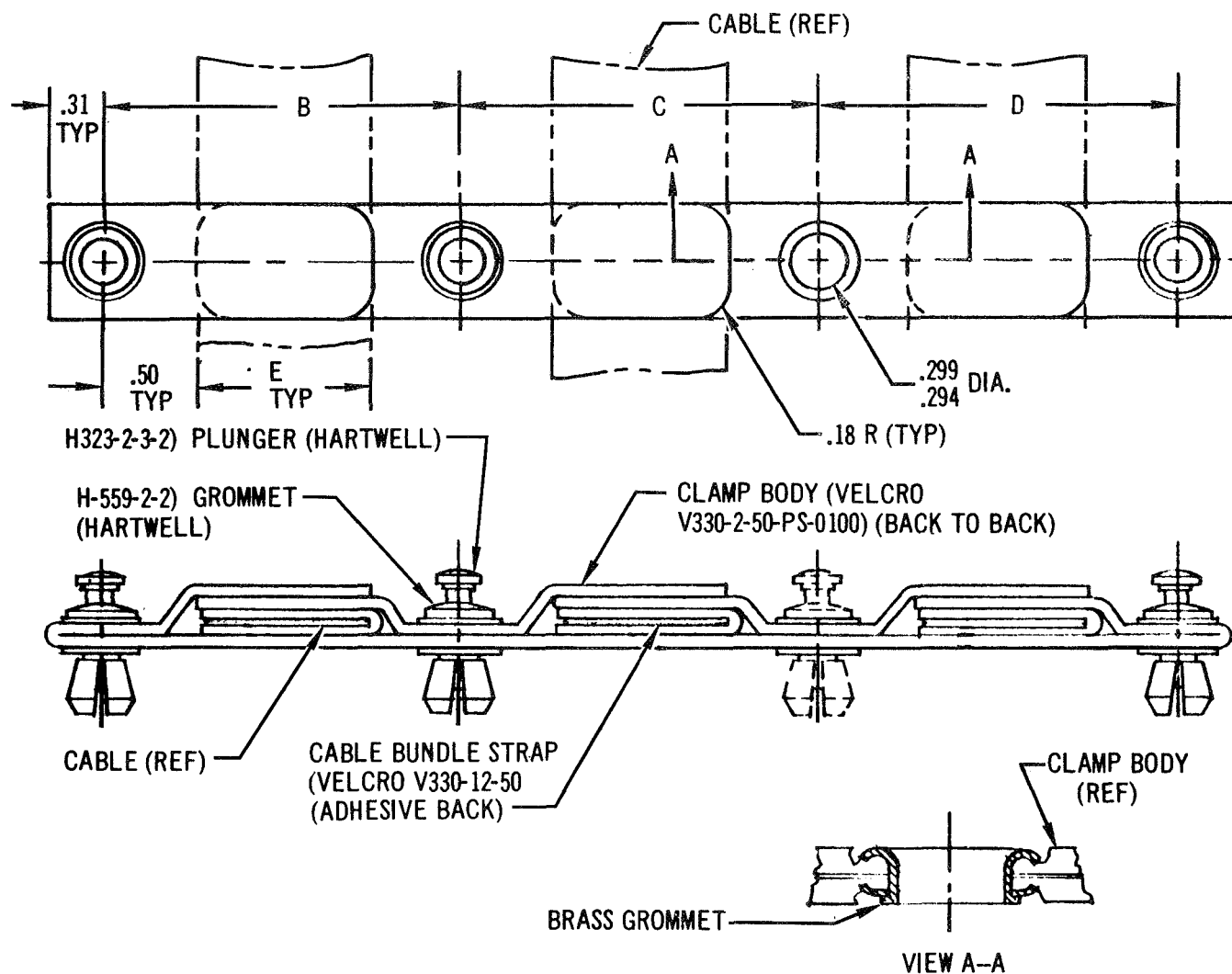


TABLE I					
CLAMP ASSY TYPE	CABLE WIDTH IN INCHES	B DIM.	C DIM.	D DIM.	LAP DIM. E
I	½" – 1"	2"	2"	2"	1"
II	1½" – 2"	3"	3"	3"	2"
III	2½" – 3"	4"	4"	4"	3"

GENERAL NOTES:

1. PROVIDE $\frac{.314}{.312}$ 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 5-6. Lap Clamps Assembly, Triple, 100°C

METAL CLAMP ASSEMBLY + 200° C

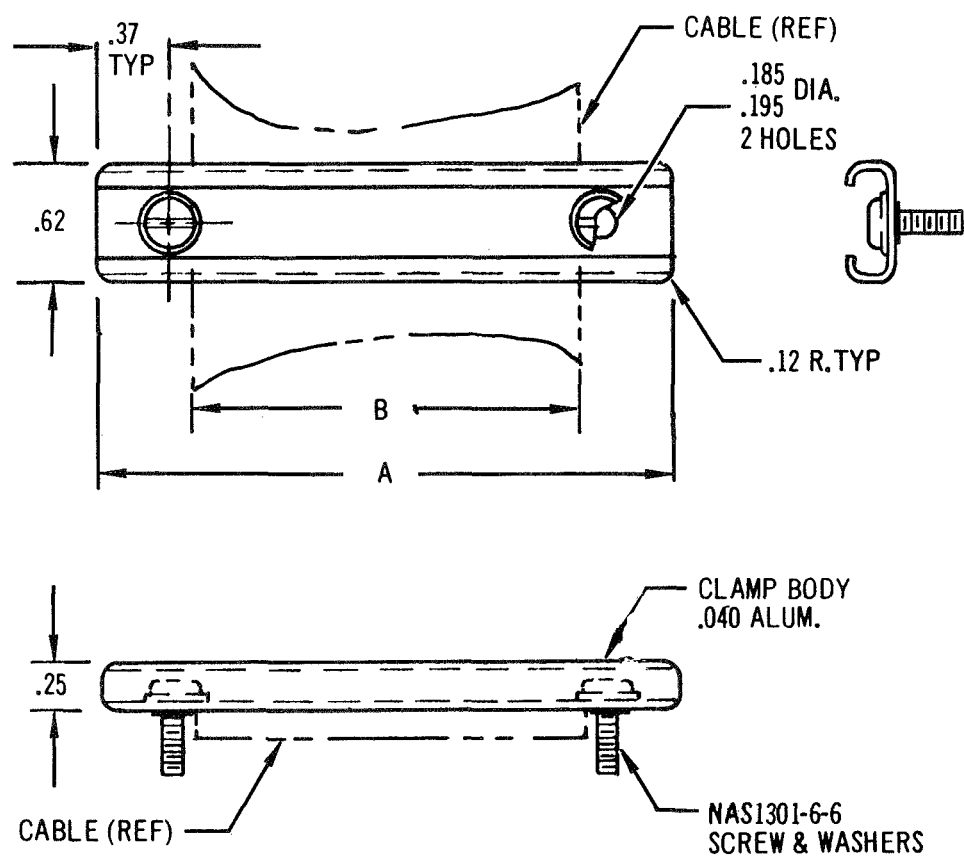


TABLE I			
CLAMP ASSY TYPE	CABLE WIDTH IN INCHES	A DIM.	B DIM.
I	½" - 1"	2"	1"
II	1½" - 2"	3"	2"
III	2½" - 3"	4"	3"

GENERAL NOTES

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

Figure 5-7. Metal Noncushioned Clamps, 200°C

CUSHION CLAMP ASSEMBLY +200° C

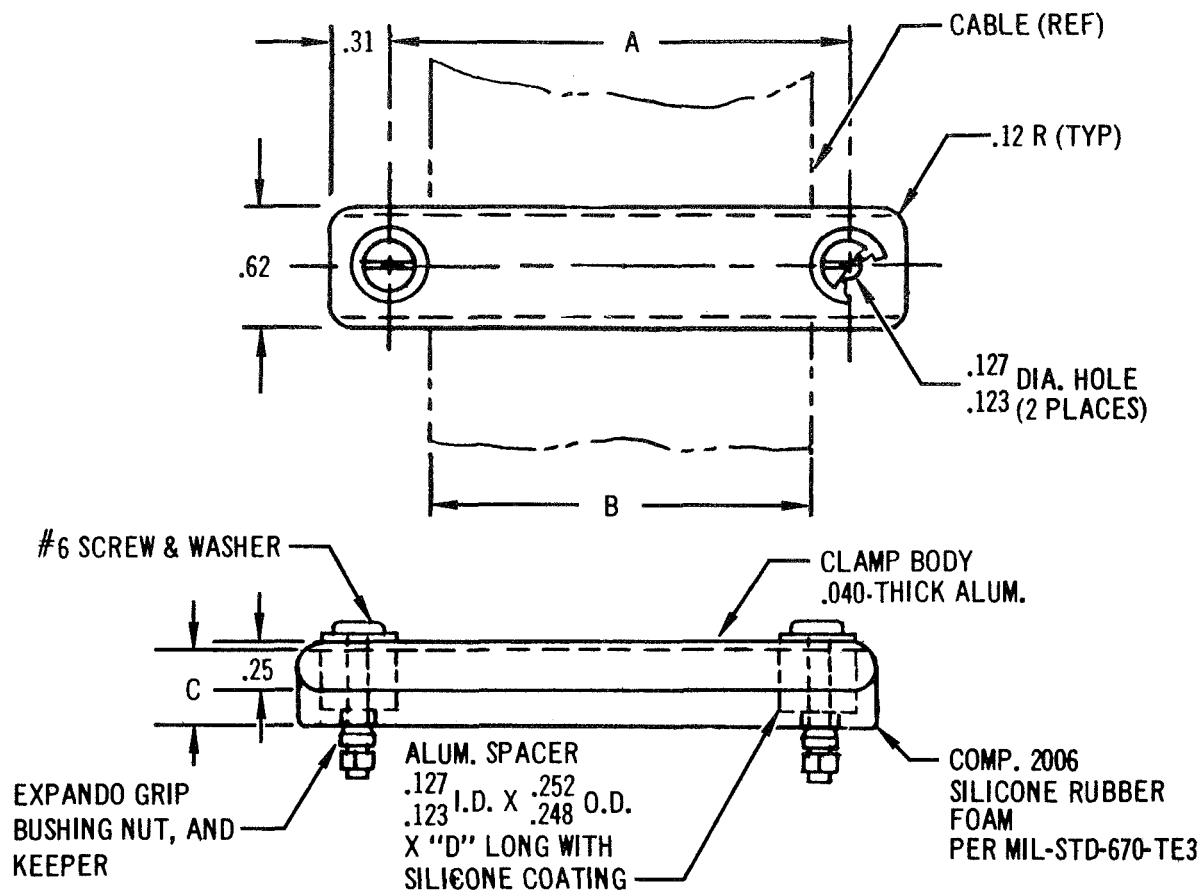


TABLE I					
CLAMP ASSY TYPE	CABLE WIDTH IN INCHES	A DIM.	B DIM.	C DIM.	D DIM.
I	½" - 1"	1.38	1"	.50	.30
IA	½" - 1"	1.38	1"	.60	.40
II	1½" - 2"	2.38	2"	.50	.30
IIA	1½" - 2"	2.38	2"	.60	.40
III	2½" - 3"	3.38	3"	.50	.30
IIIA	2½" - 3"	3.38	3"	.60	.40

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 5-8. Metal-Cushioned Clamp, 200°C (Sheet 1 of 2)

CUSHION CLAMP ASSEMBLY + 200° C

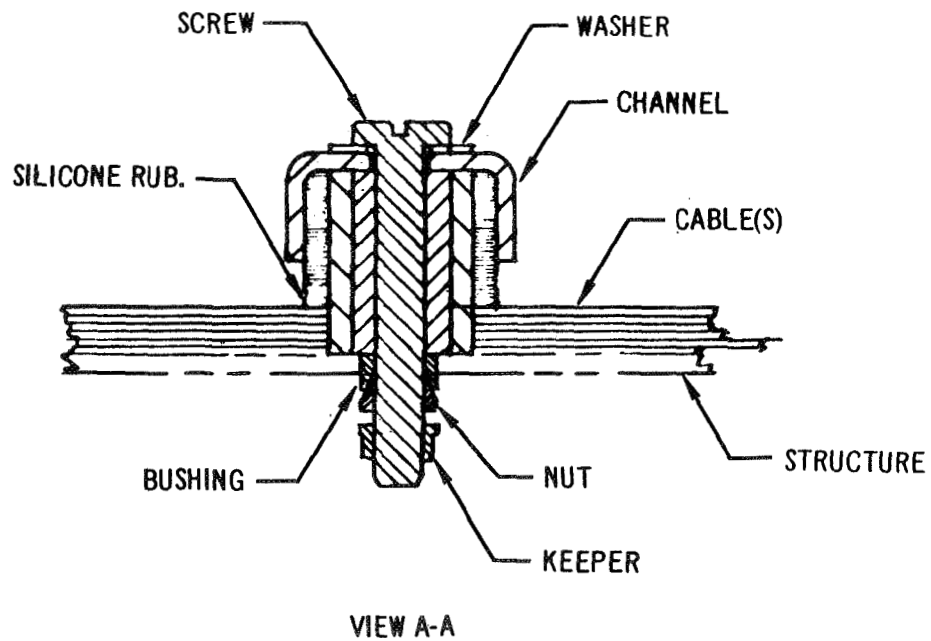
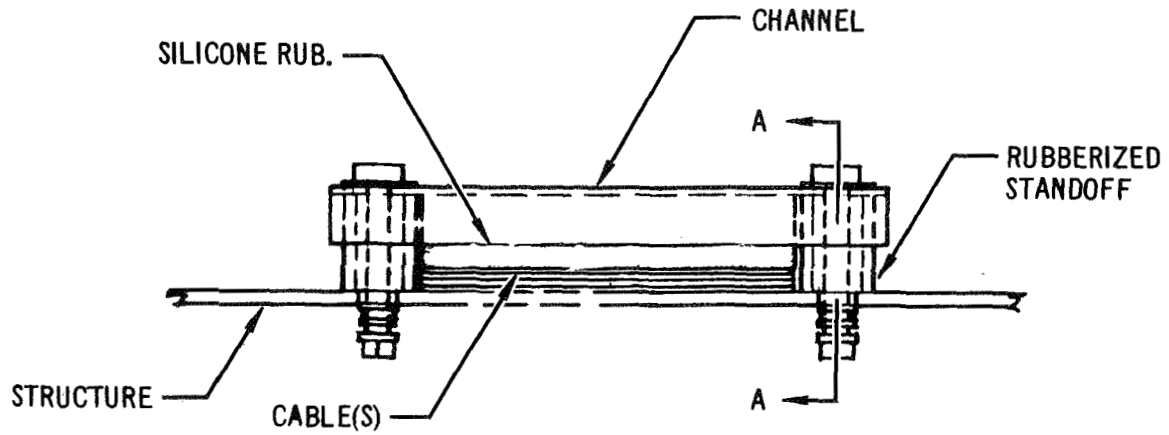


Figure 5-8. Metal Cushioned Clamp, 200°C (Sheet 2 of 2)

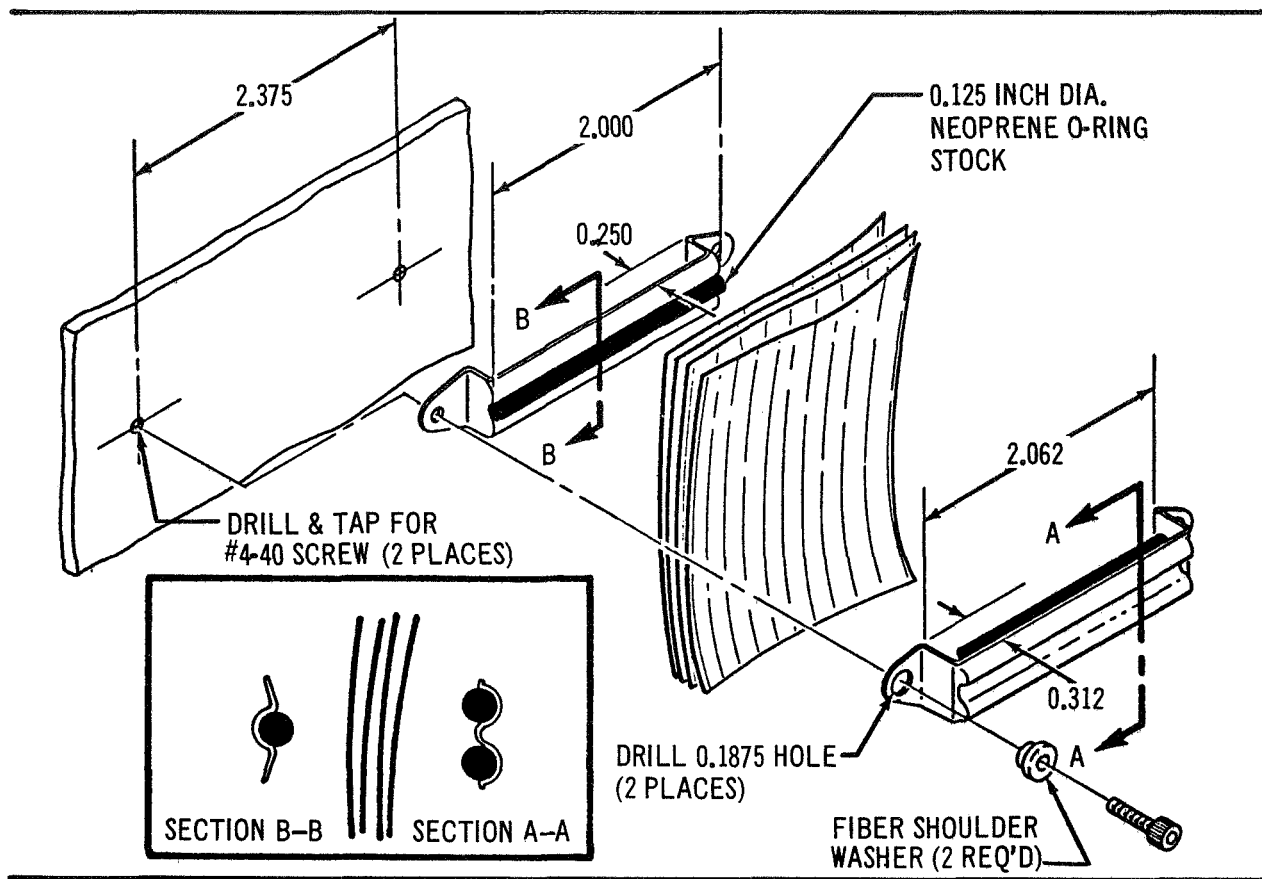


Figure 5-9. Metal Cushioned Clamp, Double Grip, 200°C

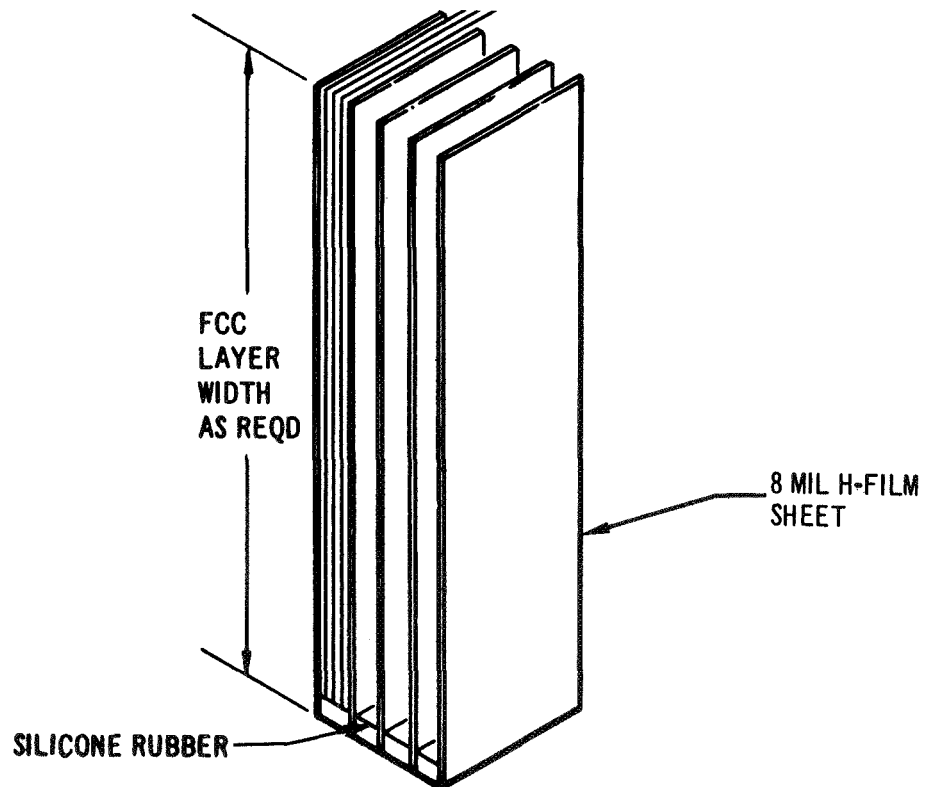


Figure 5-10. FCC Separator

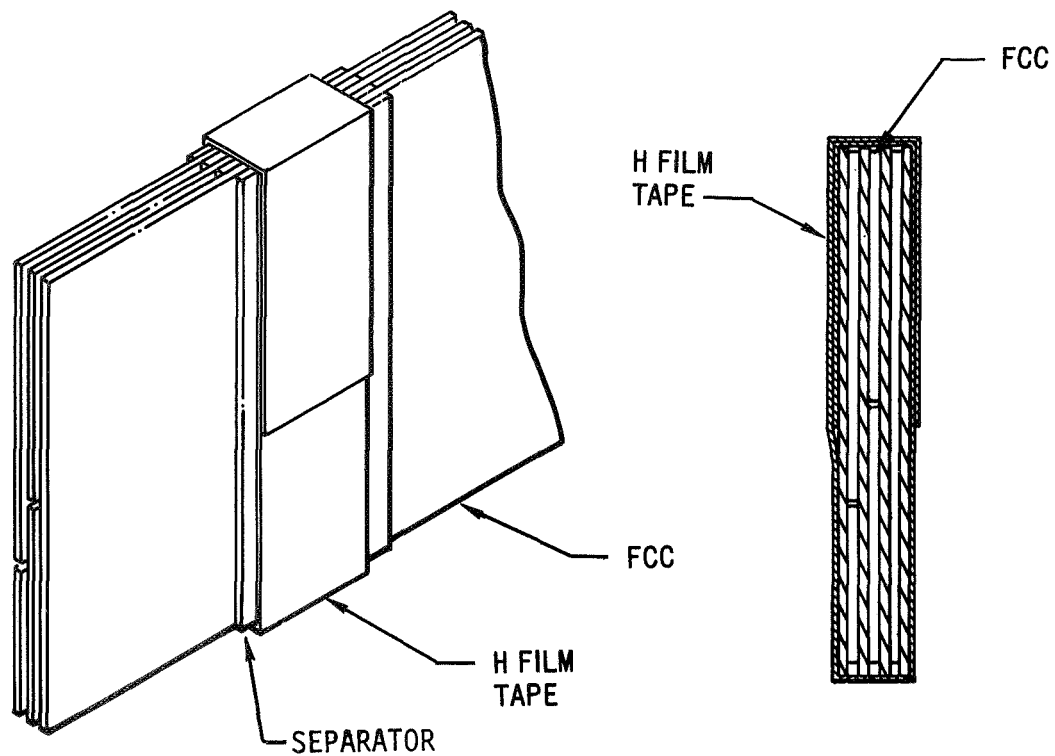


Figure 5-11. Separator Installed Between Clamps

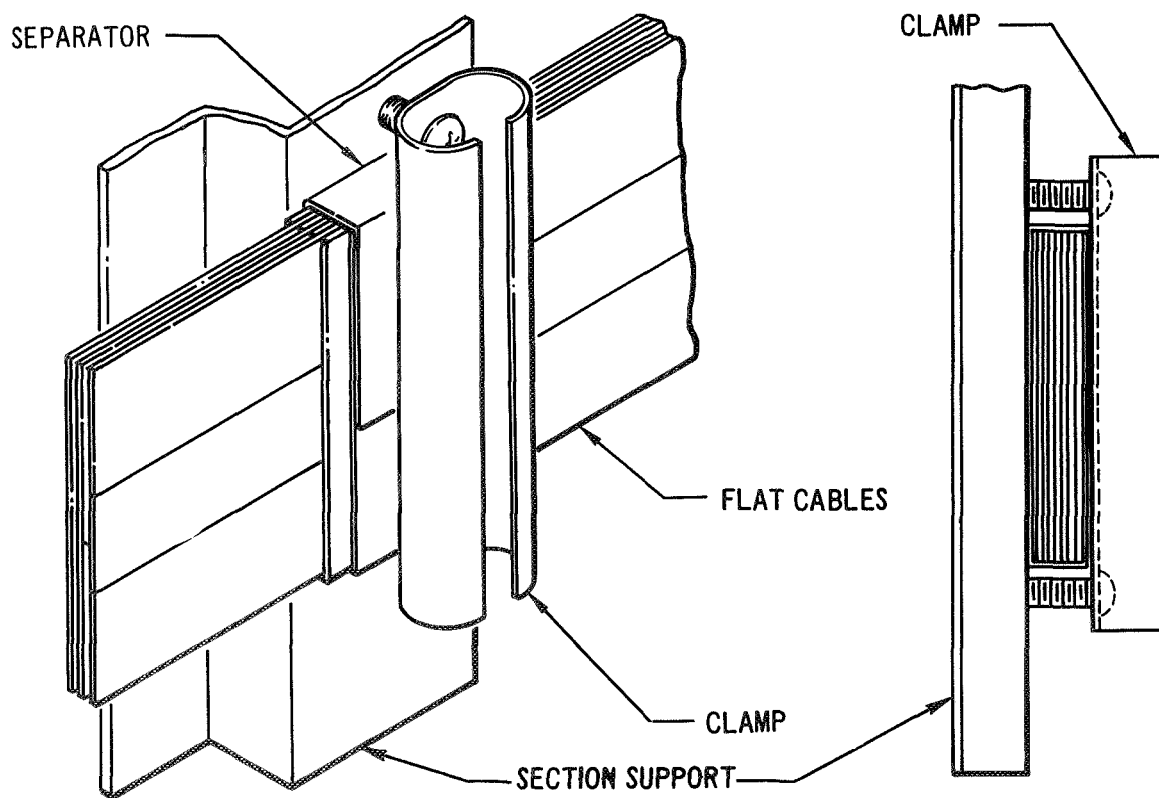


Figure 5-12. Separator Installed Under Clamp

SECTION VI

6. HANDBOOK PREPARATION

6.1 Introduction

One of the major and most important tasks of this program was the preparation of a handbook for FCC system design and manufacturing. The purpose of this handbook was to assist the technologies engaged in the design, manufacturing, and quality control of FCC electrical interconnecting harnesses for aerospace, defense industry, and commercial programs.

6.2 Sources of Information

Information for the preparation of the FCC handbook was obtained from NASA/MSFC, other government agencies, major contractors, and hardware manufacturers who had been actively engaged in FCC hardware fabrication and/or system application. NASA/MSFC assisted MDC, as required, to obtain all available, appropriate data with the required approval for its inclusion in the handbook.

6.3 Accumulation of Existing Data

Innumerable technical papers and reports, handbooks, vendor catalogs, trade magazines, specifications, and other published data were reviewed for appropriate information which would be included in the FCC handbook.

This effort included reading and reviewing the following:

- a. The many technical FCC reports published by the Astrionics Laboratory of NASA/MSFC.
- b. Twenty-one (21) large notebook folders on FCC accumulated by J. D. Hannum of Flexible Products, Inc., including a variety of reports prepared under government contract as well as numerous other technical reports, magazine articles, vendor data, etc.
- c. All FCC data generated by Hughes Aircraft under NASA/MSFC contract number NAS 8-11384 were reviewed. Direct contact was made with the Hughes personnel who had worked on this program, and the incompleted rough data prepared by Hughes were transmitted to MDC for evaluation. Every effort was made to utilize all applicable information.

- d. All FCC shielding data, generated by Picatinny Arsenal, Dover, New Jersey, under contract to NASA/MSFC were reviewed. This contract remained active during the performance period of the MDC contract.
- e. ATM 335 A FCC evaluation report by Bendix Systems Division for the Lunar ALSEP program.
- f. A series of reports prepared by AVCO Corporation to consider the use of FCC on the MARK 17 Minuteman Program.
- g. FCC reports, prepared by Lockheed Aircraft Company of Burbank, California, on the application of FCC to a typical aircraft installation.
- h. FCC reports prepared by McDonnell Douglas of St. Louis, Missouri, on use of FCC harnesses to interconnect three electrical systems on a modern fighter aircraft.
- i. Flexible Flat Cable Handbook published by IPC, dated 1965.
- j. Multilayer Printed Circuit Board Technical Manual published by IPC, dated 1966.
- k. Flexprint Circuit Design Handbook prepared by Sanders Associates of Nashua, New Hampshire.
- l. FCC technical data reports prepared by St. Olaf College for the G. T. Schjeldahl Company.
- m. Development of Printed Circuits, Volume III, Final Report Handbook prepared by North American Aviation, Inc., Columbus, Ohio.
- n. D5-15682 "Saturn V Wiring Practice Analysis" and D5-18683 "Wiring Practice for Electromagnetic Interference Control" prepared by the Boeing Company.
- o. Technical reports ECOM 2775 "Thin Film Shielding Techniques" and ECOM 2798 "Thin Film Shielding Measurements" prepared by U.S. Army Electronics Command, Ft. Monmouth, New Jersey.

Written comments for items c, d, f, and l were submitted to NASA/MSFC to inform them of the useful, or lack of useful, information which could be applied to the FCC handbook. These comments are contained in Volume II.

Additional activities by MDC personnel included:

- a. Active participation in the IPC, including the Electromagnetic Shielding Committee. Meetings attended were: August 1967, IPC shielding meeting at the Picatinny Arsenal, Dover, New Jersey; September 1967, IPC fall meeting at Los Angeles, California; and March 1968, IPC spring meeting in New York City.

- b. Preparation and presentation of two technical papers on FCC accomplishments by MDC on NASA/MSFC-funded contracts:
 - 1. DAC paper number 4186, Electrical Flat Cable Harness Assembly and Installation.
 - 2. DAC paper number 4187, Flat Cable Engineering Studies for Saturn S-IVB vehicle.

These papers, requested by NASA/MSFC, were presented at the IPC/EDN seminar at the University of Southern California on 20 June 1967.

- c. Participation in Flat Cable Technology School at the University of Alabama, Huntsville, Alabama, 20 - 26 June 1968. MDC personnel conducted the Flat Cable Application portion (4 hours) of the school. A similar participation is scheduled by MDC for the third school to be held 26 - 30 August 1968.
- d. Active participation in government tri-service committees for the preparation of proposed military specifications for FCC and FCC connectors. MDC personnel represented NASA/MSFC as the committee chairman for the FCC specification. See Section II for more details.

It can be concluded that these extra activities greatly contributed to the general knowledge of FCC hardware and application, and thus were very helpful in the preparation of the FCC handbook.

In general, the major categories of handbook data available from the efforts of the previously described data review and additional activities can be listed as follows*:

- Section I. Introduction - general information only.
- Section II. FCC Hardware - Vendor contacts and reference information, plus specific information for NASA/MSFC system.
- Section III. Design Application - general information with specific data on thermal characteristics of FCC.
- Section IV. Wire Changes - specific information for NASA/MSFC wire change devices and general information for others.
- Section V. Reliability - general information only.
- Section VI. Manufacturing and Installation Techniques - specific information for NASA/MSFC hardware systems and cable stripping. General information for others.
- Section VII. Quality Assurance - general information only.

* The sections listed are those used for the FCC handbook.

The method used to compile the hardware data (Section II) on FCC connector systems, other than those covered by MIL-C-55544 (NASA/MSFC conductor-contact connectors and Picatinny Arsenal pin-and-socket connectors), is described in detail as follows.

The list of vendors to be contacted for FCC connector data inputs was compiled and coordinated with NASA/MSFC. Each vendor listed was contacted by phone by MDC personnel; an explanation of the FCC handbook was given; and a request was made for available FCC connector data. Each vendor was to clarify his product(s) as production, prototype, or proposed. Each was requested to furnish gloss prints and a summary description of the various configurations submitted. Table 6-1 shows the vendors contacted and their individual response.

All vendor data received were reviewed with NASA/MSFC, and the connector data to be included in the FCC handbook were selected. These data, modified as required for handbook format and consistency, were then added to the FCC handbook.

TABLE 6-1 FCC CONNECTOR DATA FOR THE FLAT CABLE HANDBOOK (OTHER)

<u>VENDOR</u>	<u>CONTACT</u>	<u>RESULTS</u>
ACI	Richard Renner	Data Furnished
AMP	Dick Crees	Data Furnished
Amphenol	Fred Horn	Data Furnished
Bendix	Dave Luzadis	Data Furnished
Burndy	Russ Fieberg	No Input
Cinch	Roy Whitte	Data Furnished (Not Used)
Deutsch	Hendrick Comea	No Input
Digital Sensors	Lee Griswald	Data Furnished
ECS	Larry Travis	Data Furnished
ELCO	Clive Harding	Data Furnished
Flexible Products	Jim Hannum	No Input
Hughes Aircraft	John Mitchell	No Input
Methode Electronics	Frank Desio	Data Furnished
Rogers Corporation	Herman Gordon	Data Furnished
Schjeldahl	Ed Beavan	No Input

6.4 Generation of New Data

As previously described, considerably more new data generation was required for the preparation of the handbook than was originally anticipated.

New data required for FCC harness design and application, comparison between FCC and RWC systems, shielding effectiveness and EMC philosophy were anticipated, generated as required, and included in the handbook.

Other new data requirements for the handbook, which necessitated greater effort than that originally anticipated, included the generation of FCC electrical characteristic data for capacitance, inductance, characteristic impedance and velocity of propagation; and the preparation of a quality control section for FCC cable, connectors, harness assemblies and installation. It was indicated in the beginning of the program that the required electrical characteristic data would be available from previously funded NASA/MSFC programs, and it was believed that detailed documentation on quality control for the NASA/MSFC system would also be available.

6.4.1 Electrical Characteristics Data

6.4.1.1 Capacitance

An initial survey was made to evaluate published test and technical data on the capacitance of various flat-conductor cable configurations. Textbooks, technical articles, and test reports were reviewed.

The effort was then concentrated on the determination of capacitance for various configurations of unshielded flat cable in free air. The capacitance curves, found in Sanders Flexprint Circuit Design Handbook, were adjusted to account for different insulation thicknesses and dielectric constants. From the adjusted curves, it was possible to read the capacitance between two adjacent conductors for all configurations of MIL-C-55543 cables. Values from these curves were then compared with test results, other published values, and the output from a computer program. Correlation was acceptable. However, it became evident that tolerance of conductor-spacing and insulation thickness play an important part in the capacitance values.

Similar information was generated for double-shielded wire by utilizing information from the Sanders Flexprint Circuit Design Handbook and unpublished material from Mr. Seck of Hughes Aircraft. As with unshielded wire, manufacturing tolerances cause a broad range of capacitance values. In the handbook, methods were provided to the designer to derive capacitance values for nonstandard FCC. These are analytical methods derived by W. B. Boast in "Principles of Electric and Magnetic Fields," Harper and Bros., 1948, for unshielded cable and curves from unpublished material by Mr. Seck of Hughes Aircraft Company, for double-shielded FCC.

The W. B. Boast analytic method of determining capacitance between two conductors in a flat cable was mechanized to facilitate the many calculations required. Three computer programs were written to calculate:

- a. Capacitance between adjacent conductors (edge-to-edge) in a flat cable.
- b. Capacitance between two conductors (edge-to-edge) with intervening conductor(s), (C2 and C6), in a flat cable.
- c. Capacitance between adjacent conductors (flat-to-flat) in stacked flat cables.

These programs are written in Fortran IV language for the Univac 1108 Computer. The capacitances C1, C2, C3, C4, and C5 are equivalent to the capacitances C_A , C_3 , C_C , C_D , and C_E shown in section III of the handbook. All samples of output results are for: thickness = .004 inch, width = .040 inch, and spacing = .035 inch.

Further explanation of the use of the computer program to derive FCC capacitances, together with examples of computer printouts, is included in Volume II.

6.4.1.2 Inductance

Self-inductance and mutual inductance were calculated for adjacent pairs of unshielded flat conductors running in a straight line. This was done for 23 standard cable configurations, both on an edge-to-edge basis within a cable and on a flat-to-flat basis for conductors in stacked cables. These calculations were made for cable lengths of 0.1 through 100 feet. From these calculated data, the total inductance of these pairs of conductors was computed for connection in a current-opposing circuit, as in transmission lines.

The inductance calculations were performed with the aid of a Univac 1108 digital computer programmed in FORTRAN IV language. As input data, the computer reads cable length, width and thickness of conductors, center-line spacing between conductors, geometric mean distance, and geometric correction factor (the latter two were determined from tabulated data by Grover ⁽¹⁾).

Further explanation of the use of the computer program to derive FCC inductances together with examples of computer printouts are included in Volume II.

Total inductance of the transmission-line pairs is presented in the FCC handbook, Section III.

6.4.1.3 Transmission-Line Characteristics

The characteristic impedance and velocity of propagation were computed for adjacent, unshielded pairs of conductors in edge-to-edge and flat-to-flat arrangements for each of 23 standard FCC configurations. These computations were made under assumptions of negligible series-resistance and shunt conductance. They are presented in the FCC Handbook, Section III, paragraph 3.2.3.1.6 and 3.2.3.1.7, respectively.

(1) Grover, Frederick W., Inductance Calculations: Working Formulas and Tables. Dover, 1962.

6.4.2 Shielding Effectiveness and EMC Philosophy

Considerable new data were generated for shielding effectiveness and EMC philosophy for FCC application. Detailed explanations are contained in section VII of volumes I and II of the final report, and section III of the FCC handbook. Concurrent with the shielding-effectiveness testing on FCC, a large number of capacitance and inductance measurements was made on all available FCC configurations to provide empirical data to be used with the electrical characteristic curves, charts, and formulas included in the FCC handbook.

6.4.3 Quality Control

The lack of published quality-control data for cable, connectors, and assembly of FCC harnesses caused MDC to initiate new, detailed quality-control requirements. After much coordination with NASA/MSFC, section VII "Quality Assurance - Inspection Test Procedures" was prepared for the FCC handbook.

6.4.4 Other Data

Other data generated for the FCC handbook include the FCC separator and its use, as described in section V of this report, and a new concept for a universal, multiple-connector distribution unit described in section IV of the FCC handbook.

SECTION VII

7. EVALUATION TESTS

7.1 Introduction

It was initially proposed to conduct a series of tests on clamps, FCC, and FCC connector assemblies to verify the flight suitability and system performance of the hardware and system philosophy developed on this program. The proposed tests can generally be categorized as follows:

- a. Mechanical tests
- b. Temperature Cycling tests
- c. Electrical tests
- d. EMC tests

The mechanical tests would include static and dynamic loads, vibration, flexing, et cetera. The temperature-cycling test agreed upon was: +200°C for 45 minutes, then -65°C for 45 minutes for one complete cycle. Three complete cycles would be made to verify suitability of the system to perform satisfactorily over the expected temperature range. The electrical tests would include continuity, insulation resistance, and voltage-withstand for FCC and FCC connector assemblies. The EMC tests would verify the shielding effectiveness of the shielded termination system selected. Additional laboratory testing would provide limited electrical characteristic data required to compile capacitance and inductance data for the handbook.

7.2 Initial Test Plans

The initial test plans for the developed shield-termination system are given in 7.2.1 and 7.2.2. NASA/MSFC was to furnish test specimens for hardware which they had developed and manufactured. MDC defined these requirements, and the specimens were delivered by NASA/MSFC on schedule. These included various cable types, and connector assemblies with FCC plugs as required.

7.2.1 Preliminary Test Plan - Shielded Termination System, Electrical and Mechanical

7.2.1.1 Scope

The purpose of these tests is to evaluate the shielded flat-cable and termination system developed by MDC on the Flat Cable Phase III Study conducted for NASA.

7.2.1.2 Test Specimens

Tests will be made on various shielded cables including:

- a. Methode screen shield
- b. W. L. Gore perforated shield
- c. Methode solid-copper shield for NASA/MSFC ATM
- d. Methode solid Moly Permalloy shield developed by MDC

Tests will be made on various shielded cable assemblies including:

MDC premolded, shielded-plug assembly with aluminum backshell with:

1. Methode solid-copper shielded cable
2. Methode solid Moly Permalloy shielded cable

7.2.1.3 Tests to be Performed

In general, the test procedures for the tests to be performed are in accordance with MIL-C-XXXXX, which Douglas has prepared for shielded flat-conductor cable and in accordance with MIL-C-55544 for flat-cable connectors.

7.2.1.3.1 Cable Tests

Cable tests would consist of the following:

- a. Temperature Cycling and Shrinkage
- b. Bend Test - high and low temperature

- c. Vibration
- d. Flexure - high and low temperature
- e. High Voltage
- f. Insulation Resistance
- g. Moisture Resistance
- h. Tensile and Elongation - shield material
- i. Thermal Shock
- j. High Temperature at Low Pressure

7.2.1.3.2 Connector Assembly Tests

Connector assembly tests would consist of the following:

- a. Temperature Cycling
- b. Mating and Unmating.
- c. Vibration
- d. Endurance Flexing
- e. High Voltage
- f. Insulation Resistance
- g. Voltage Drop
- h. Moisture Resistance
- i. Leakage
- j. Low Pressure Altitude

7.2.2 Preliminary EMC Test Plan

7.2.2.1 Scope

The purpose of these tests was to be evaluation of the shielded flat cable and termination system developed by MDC on the Flat Cable Phase III Study conducted for NASA/MSFC.

7.2.2.2 Test Specimens

FCC, both shielded and nonshielded, plug assemblies, and harness assemblies of various configurations were to be prepared for testing.

7.2.2.3 Tests to be Performed

7.2.2.3.1 Bulk Cable Tests Shielded and Nonshielded

Tests were to be performed on shielded and nonshielded cables provided by various flat cable vendors, and on separate copper and magnetic foils between nonshielded cables, plus dielectric spacers between nonshielded cables, as follows:

- a. Capacitance measurements
 - 1. Conductor-to-conductor mutual capacitance
 - 2. Conductor-to-shield shunt capacitance
- b. Inductance measurements
 - 1. Conductor-to-conductor mutual inductance
 - 2. Conductor self-inductance
 - 3. Shield self-inductance
- c. Resistance measurements
 - 1. Conductor series resistance
 - 2. Conductor leakage resistance to both shield and other conductor
 - 3. Shield series resistance
 - 4. Shield plane-to-shield plane contact resistance (where applicable)
 - 5. Shield plane-to-shield conductor contact resistance (where applicable)
- d. Transmission loss versus frequency measurements
- e. Shielding effectiveness from audio through radio-frequency spectrum.
 - 1. Cable coupling
 - (a) Magnetic
 - (b) Electrostatic
 - 2. Radiated field
 - (a) Magnetic
 - (b) Electrostatic
 - (c) Plane wave

7.2.2.3.2 Connector Assembly Tests (One connector with short lengths of cable)

Connector assembly tests were to be performed as follows:

- a. Shielding effectiveness from audio through radio frequency spectrum
 - 1. Radiated field
 - (a) Magnetic
 - (b) Electrostatic
 - (c) Plane wave

These tests were also to be performed with magnetic-shielded cable and magnetic shells on plug and receptacle.

7.2.2.3.3 Harness Assemblies (6-foot harnesses with plugs at both ends)

Tests were to be performed as follows:

- a. Shielding effectiveness from audio through radio frequency spectrum
 - 1. Cable coupling
 - (a) Magnetic
 - (b) Electrostatic
 - 2. Radiated field
 - (a) Magnetic
 - (b) Electrostatic
 - (c) Plane wave

7.3 Actual Tests Performed (or to be performed)

As the result of the greater-than-anticipated effort required in the specification, shielded-termination system development, and accumulation of technical data for the handbook, the actual testing performed on the program in some areas was less than that originally anticipated. However, the EMC testing, as explained in detail in 7.4, was even greater than

that originally proposed. This was necessitated by the lack of EMC and electrical-characteristic data which were supposed to be available from Hughes Aircraft and Picatinny Arsenal studies funded by NASA/MSFC.

7.3.1 Clamp Tests

The testing of FCC clamps was limited to the cold-flow tensile-load tests performed on the metal grommited Velcro lap clamps. This test setup is shown in figure 5-3, and the test description is given in Section V.

7.3.2 Temperature-Cycling Tests

A large number of temperature-cycling tests were made to evaluate various FCC cable constructions, hardware, and methods of assembly for shielded-plug assemblies.

Encapsulated and polished sections of various FCC cable constructions, both shielded and nonshielded, were prepared, and 8-1/2 x 11 colored microscopic photographs were made. Douglas colored prints, numbers 23122 through 23151, show the cross sections of the cable as received from the manufacturer and after temperature-cycling as described in 7.1. A set of the colored prints, together with an evaluation explanation of them, was furnished to NASA/MSFC in December 1967. These microscopic colored prints contain a wealth of information for FCC evaluation and suggestions for future fabrication methods and development.

Temperature cycling tests were performed on various shielded FCC plug parts and assemblies to evaluate their ability to meet the established program requirements.

Various plating techniques were evaluated for possible plating of the required conductive outer shield directly to the plug body.

Figure 7-1 shows three diallyl phthalate potting cups which have been electroplated with aluminum and then temperature-cycled. Although the small cup had no defects, the two larger cups had extensive blister areas where the plating separated from the cup material.

Figure 7-2 shows three more plating techniques, with the results after temperature cycling. The glass-filled epoxy plug body, electroplated with several microinches of aluminum, satisfactorily withstood the temperature cycling. The potted module with the aluminum plasma spray blistered and peeled badly. The electrolytic copper deposit on the diallyl phthalate bar flaked off during temperature cycling.

Figure 7-3 shows three samples electroplated by the Shipley process. The Amphenol Flex-1 218 diallyl phthalate plug body offered a good simulation of the actual parts required. The thin walls of the potting cups gave the plating adhesion an even greater test during temperature cycling. All the plating, which was 10 to 15 mils thick, successfully withstood the required temperature cycling.

Additional samples, as defined by drawing 1T10649 E0 "P" and plated by United-Carr, Inc., satisfactorily passed the temperature cycling. These parts had approximately 7 mils of multilayer plating with alternate layers of copper and permalloy.

The plating methods for the Shipley process and the United-Carr process are further explained in section 2.0.

Figure 7-4 shows typical shielded-plug-assembly test samples after temperature cycling. The design objective was to make and maintain electrical continuity between FCC shields and the metal backshell of the plug. The copper sheet was soldered to the FCC shield to facilitate the taking of bridge measurements. Tests results continually indicated inconsistencies in the continuity between the shields and the backshell. The dissected cross section shows some of the mechanical and electrical problems associated in the development of this plug design concept.

Figure 7-5 shows the test fixtures developed for evaluation of conductive potting materials, bonding of plug assemblies in the cable entry area, and bonding of backshells to plug bodies. Temperature cycling, followed by dissection of the specimens, permitted evaluation for design suitability.

Figure 7-6 shows a NASA/MSFC solder-type FCC receptacle which has been temperature cycled. The potting material in the rear of the receptacle has charred and cracked from the 200°C temperature exposure.

7.3.3 Electrical Tests

A series of electrical tests was conducted on various shielded-plug-assembly configurations. Continuity was measured between the FCC shields and plug metal backshells, and insulation resistance and voltage withstand was measured between the FCC conductors and cable shields or backshells. Figure 7-4 shows a typical specimen on which these tests were performed.

Resistance measurements between the FCC shields and the metal backshell ranged from 3 to 50 milliohms prior to temperature cycling, and from 3 to several hundred milliohms after temperature cycling. However, there were inconsistent high-resistance readings, several ohms to open, in a number of cases both before and after temperature cycling. It was concluded that the method of making the shield termination to the plug backshell was not reliable and could not be predicted from connector to connector.

The insulation resistances between the conductors and the plug backshell were inconsistent. In many instances, this resistance, measured with a 500-volt DC megohm meter, was essentially zero. However, for the majority of conditions, the resistance was in excess of the required 5000 megohms. It was concluded that the low-resistance cases resulted primarily from cable insulation damage incurred during cable stripping.

The voltage-withstand testing at 1500 volts, 60 cycles rms, caused a large percentage of conductor failures. It was suspected that the failures were the result of a voltage high-stress field at the edge of the stripped shield. To verify this suspicion, a one-half mil copper foil was clamped with styrafoam to a nonshielded FCC with the half-mil foil ending approximately 1 inch from the end of the nonshielded cable. At the other end, the copper foil curved gently away from the insulated FCC. When the voltage-withstand test was performed on this specimen, failure occurred consistently at approximately 1500 volts rms. Next, the shield was folded back on itself on the end which was clamped to the nonshielded FCC. This increased the average breakdown voltage to 2500 volts rms, thus verifying that the voltage stress-field at the stripped edge of the cable contributed significantly to voltage breakdown. Increasing the insulation thickness between the shield and conductors, or folding the shield at the cable end, will increase the final assembly voltage-withstand capability.

7.3.4 Flexing Tests

Magnetic-shielded FCC specimens, per drawing 1T11017, were furnished to NASA/MSFC for cable flexure tests as specified in paragraph 3.5.9 of MIL-C-55543. The number of flexures for the high and low temperatures was 500 each. It was reported verbally by NASA/MSFC that the furnished shielded cable met the specification requirements.

Two shielded-plug assemblies, with the same type of magnetic-shielded FCC assembled so that the cable shields were floating (not connected to the plug backshell), were furnished to NASA/MSFC for flexure tests as specified in paragraph 3.15 of MIL-C-55544. The results of these tests were never furnished to MDC.

7.3.5 Tensile Testing of Lashclad Shielding Material

Samples of Lashclad shielding material were tensile tested on a 5K Baldwin testing machine. These tests were prompted by shielding

mechanical failures in prototype samples prepared with Lashclad shielding materials. The shield cracked when the prototype cables were formed over a one-half inch mandrel. The primary purpose of the tensile testing was to determine the percentage elongation for the Lashclad composition material (one mil Kapton plus electrodeposited shielding material of less than one mil) prior to tensile failure.

Four each, standard necked-down specimens were prepared for the Lashclad type K and type KX materials. Table 7-1 lists the results of the tests. The elongation of approximately 2 percent for the KX type (copper and nickel-iron) and approximately 5 percent for type K (copper) is inadequate for shielded FCC construction. Annealed copper and Moly Permalloy shielding foils will elongate approximately 30 percent. After this testing was completed, the Lashclad material was no longer considered as a suitable shielding material for this program.

Table 7-1
SHIELDING MATERIAL TENSILE TESTS

Speci- man No.	Code	CROSS SECTION			Yield		Ultimate		In/In Elonga- tion
		Width	Thick	Area	Load	P.S.I.	Load	P.S.I.	
1	Type K	0.250	0.00125	0.00031	6.2	20,000	9.8	31,610	0.071
2	Type K	0.250	0.00125	0.00031	6.2	20,000	8.3	26,775	0.021
3	Type K	0.250	0.00125	0.00031	6.5	20,965	8.5	27,420	0.037
4	Type K	0.250	0.00125	0.00031	6.4	20,645	9.7	31,290	0.063
5	Type KX	0.250	0.00140	0.00035	15.5	44,285	20.4	58,285	0.016
6	Type KX	0.250	0.00140	0.00035	17.5	50,000	21.1	60,285	0.015
7	Type KX	0.250	0.00140	0.00035			20.1	57,430	0.012
8	Type KX	0.250	0.00140	0.00035	14.1	40,285	17.9	51,140	0.027

7.3.6 Harness Assembly Tests (to be performed)

Many of the electrical and mechanical tests listed on the 7.2.1 proposed test plan could not be accomplished because of specimen availability, and program funding and schedule restrictions. In lieu of testing only one FCC assembly configuration, four separate systems are to be included on harness evaluation tests to be performed by MDC for another space application program.

7.3.6.1 FCC Test Specimen Description

The FCC harnesses to be tested are described as follows:

- a. The NASA/MSFC 75-mil center conductor-contact connector system, as defined by the proposed MIL-C-55544 FCC connector specification. (Drawings PM11472 and PM11473).
- b. The Picatinny Arsenal, Dover, New Jersey, pin-and-socket connector system, as defined by the proposed MIL-C-55544 FCC connector specification. (Drawing P9232091).
- c. The Cannon ITT Micro D metal backshell connector system. Pin-and-socket contacts on 50-mil centerline utilize the insulation weld-through technique for conductor termination. (Drawing ME1588-0000).
- d. The Microdot connector, designed especially for FCC with 50-mil centerline pin-and-socket contacts. The weld-through technique is also used on this design. (Drawing 095-0507-0009).

Additional drawings prepared for the FCC harness installations on the test fixtures are:

- | | | |
|----|---------|--|
| a. | 1T16044 | Harness Installation, Flat Cable, Test |
| b. | 1T16027 | Bracket, Plug Assembly |
| c. | 1T16019 | Clamp, Metal, Assembly |

All the drawings listed above are included in Volume II of this report.

Each FCC test-harness configuration contains one FCC plug assembly with FCC plugs at both ends, and two RWC* receptacle assemblies which mate with the FCC plug assemblies. The other ends of the RWC harnesses will be connected to the test instrumentation. The FCC assemblies will be subjected to the environmental tests to be performed.

*Round wire cable

7.3.6.2 RWC Test Specimen Description

The test-specimen wire-harness assemblies will consist of various wire sizes and connector types used throughout the vehicle program. Included will be multiple-conductor wire, shielded and unshielded wire harness-crimping techniques, various connector pin sizes and arrangements, receptacle mounted methods, and bundling or wrapping materials to be used. The assemblies will be mounted on simulated vehicle structure.

7.3.6.3 Test Objectives

The test objectives are the evaluation testing of the wire harness assemblies, wiring, and wiring installation methods for the intended purpose. Pull tests will be performed on specified connectors to determine that crimping methods will adequately retain the wire without applying damaging pressure to wire and connector pins. Wire harness assemblies will be subjected to a humidity test which will evaluate the moisture penetration with resulting insulation degradation.

7.3.6.4 Test Environments and/or Conditions

The test specimens will be tested to the environments specified below.

- a. Vibration - Random vibration of 2.1 g^2 per cps average 58-1/2 g (rms) for three minutes each on each axis. Harnesses will be monitored for continuity during vibration. The units under test will be examined for abrasion, wire integrity, and continuity following the vibration cycle.
- b. Vacuum Testing - The units under test will be subjected to thermo-vacuum testing at the anticipated shroud temperatures; 8 hours at low temperature and 18 hours at high temperature, with wire carrying rated current.
- c. Humidity - Humidity testing per Air Force Standard 810 Methode 507-1 will be conducted.
- d. Hypergolic Fuel Compatibility - Fuels per MIL-P-27402, MIL-P-27404 and MIL-P-26539 will be used. Mist Test - These fuels will be sprayed on the specimens at a 45-degree angle until they are thoroughly wetted. They will then be air-dried for 24 hours. Gaseous Test - The test specimens will be exposed to the above fuels in a gaseous state at 70 degrees for 1 hour. Then the specimens will be air-dried for 24 hours.

After each of the above testing and preparation procedures, the harness shall be visually checked, and electrical tests for continuity and dielectric strength will be performed.

The following environmental tests are now scheduled:

Functional	Vibration
Humidity	Temperature Altitude
Vacuum	Hypergolic Compatibility

The current schedule for the completion of these tests is the end of 1968.

7.4 Electromagnetic Compatibility Tests

7.4.1 Introduction

Most of us are familiar with the slapstick comedy in which a handyman makes plumbing repairs, and water spurts from the light fixture when the switch is turned on. Complex electronic systems have exhibited similar tendencies under far less humorous conditions. The success of a recent lunar photography probe was seriously jeopardized when interference from an electric motor triggered a camera shutter prematurely, causing the high-resolution photographs to be smeared. A major portion of the useful result of a multimillion dollar space program might easily have been lost, without hope of retrieval, because the motor and shutter mechanism were electromagnetically incompatible.

7.4.2 Spurious Coupling in Cables

Electromagnetic compatibility is the branch of electrical/electronic engineering evaluation and reduction of spurious coupling between sources of electrical interference and electrical circuits susceptible to such interference. The interconnection wiring, external to electrical/electronic packages, is frequently the critical item in an electromagnetically compatible system. The long runs of cable provide an

exceptional opportunity for spurious-coupling paths to develop. The physical relationship of conductors, and the type of cable, are the only major factors in system cabling that can be modified to reduce spurious coupling.

Spurious-coupling paths are combinations of distributed electrical parameters and lumped circuit constants that form a series of frequency-sensitive voltage or current divider networks. These frequency-sensitive divider networks are extremely simple circuits that are readily understood once the knack of visualizing distributed parameters is acquired. The three basic modes of spurious coupling are common impedance, and magnetic and electric coupling.

When a conductor is shared by several circuits, the flow of current from one circuit through the common impedance of a conductor produces a voltage drop that may affect the operation of other circuits sharing the same conductor. If the common impedance is a signal return for several similar channels, interchannel crosstalk will occur. At low frequencies, the common impedance is primarily resistive, but above the low audio frequencies conductor reactance may become the dominant factor.

The mere existence of a longitudinal conductor creates a small but finite inductor. When two conductors are in close proximity to each other, they form a transformer due to their magnetic coupling or mutual inductance. Any variation in the voltage applied across, or the current flowing through, one conductor is inductively coupled into the other conductor as a voltage or current, due to this transformer action.

When two conductors are in close proximity to each other, they form a small but finite capacitor. The conductors are capacitor electrodes, and the insulation and any other nonconductive materials form the capacitor dielectric. Any variation in the voltage applied to one of the conductors is capacitance-coupled into the impedances connected to the other conductor.

7.4.3 Evaluation of Electromagnetic Coupling in Cabling

The spurious coupling that occurs between cable conductors is a function of the distributed electrical parameters of the cable conductors, the termination impedances at the ends of the conductors, the interference waveform or frequency components, and a few basic physical laws. Since the detailed electrical parameters of the conductors, the terminating electrical/electronic hardware, and the interference waveform are rarely available, theoretical solutions and classic laboratory experiments utilizing electrical simulations are generally impractical.

Laboratory measurements must utilize actual cables in typical cable-stack geometries to ensure the inclusion of all distributed electrical cable parameters and conductor geometry considerations necessary for valid test results. The electrical characteristics of the transmitting transducer, the receiving transducer and the geometry of the two transducers, and the intervening propagation path have a significant effect on the results of crosstalk and shielding effectiveness tests.

7.4.4 Test Methods

Magnetic crosstalk between adjacent conductors in the same cable layer, or adjacent conductors in stacked cables, was measured by passing a current through one conductor and measuring the resultant current induced in the adjacent conductor. The excited conductor was inserted between the structural ground plane and the low-impedance end of the signal source (Figures 7-1 and 7-2) load resistance to minimize the potential on the conductor and discriminate against electric coupling. The sensing conductor was connected between the structural ground-plane and the 50-ohm input of the monitoring instrumentation (Figures 7-8 and 7-10) to minimize the sensing-circuit impedance and discriminate against electric coupling. The monitoring instrumentation consisted of a series of sensitive audio- and radio-frequency receivers with signal level indicators used as tunable voltmeters. Since the receiver input impedance was known, the input voltage could be converted to current. The ratio of exciting current to sensed current was plotted versus frequency.

Electric crosstalk between adjacent conductors in the same cable layer, or adjacent conductors in stacked cables, was measured by applying a voltage to one conductor and measuring the resultant voltage induced on the adjacent conductor. The excited conductor was connected to the high-impedance end of the signal source (Figures 7-7 and 7-9) load, and the far end was open-circuited to prevent the intentional flow of current and discriminate against magnetic coupling. The sensing conductor was connected to the high-impedance input of the monitoring instrumentation (Figures 7-9 and 7-10), and the far end was open-circuited to prevent the flow of induced current and to discriminate against magnetic coupling. The monitoring instrumentation consisted of a high-impedance audio-frequency receiver with a signal-level indicator used as a tunable voltmeter and an ultrasensitive, high-impedance oscilloscope. Above 200 kilohertz the 50-ohm radio receivers were used, due to the lack of more suitable, commercially available instrumentation. The ratio of exciting voltage to sensed voltage was plotted versus frequency.

7.4.5 Data Format

Magnetic crosstalk between adjacent conductors in the same layer of shielded conductors was plotted versus frequency. A reference curve, showing magnetic crosstalk versus frequency for the equivalent unshielded-conductor configuration, was shown. The difference between the two curves was plotted as magnetic-crosstalk reduction versus frequency for the shield configuration shown.

Electric crosstalk was plotted using the same basic procedure.

Magnetic coupling, between adjacent conductors in stacked cables isolated by a shield, was plotted versus frequency. A reference curve, showing magnetic crosstalk versus frequency for the equivalent, unshielded-conductor configuration, was shown. The difference between the two curves was plotted as magnetic-shielding effectiveness versus frequency for the shield configuration shown.

Electric-shielding effectiveness was plotted using the same basic procedure.

Curves showing crosstalk coupling and shielding effectiveness are shown in Volume II, Section II-7, figures 3-38 thru 3-56 and 3-58 thru 3-73.

7.4.6 Transmission Losses

The distributed-series inductance and shunt capacitance of a conductor form a distributed low-pass filter that attenuates high-frequency energy transmitted down the conductor. Transmission loss is measured by applying a known voltage or current to one end of the conductor and measuring the voltage or current appearing at the other end of the conductor.

The termination impedances at the two ends of the cable have a significant effect on the measured transmission loss. Since most electronic systems utilize mismatched transmission systems, the transmission loss was measured at the two extreme termination impedances normally anticipated, 1 ohm and 100,000 ohms. The ratio of excitation voltage to sensed voltage was plotted versus frequency for these two impedances.

The same signal sources (Figure 7-7) and monitoring instrumentation (Figure 7-10), used for cable and connector spurious-coupling measurements, was also used for transmission-loss measurements. The 50-ohm signal-source impedance was reduced to 1 ohm by inserting a 1-ohm resistance between the low-impedance end of the 50-ohm load and the structural ground-plane, and connecting the cable conductor to the junction (Figure 7-11). The monitoring instrumentation input impedance was reduced to 1 ohm by connecting a 1-ohm resistance between the input connector and structural ground plane (Figure 7-11).

The 50-ohm signal source impedance was increased to 100,000 ohms by inserting a 100,000-ohm resistance between the high-impedance end of the 50-ohm load and the conductor (Figure 7-12). The audio-frequency monitoring instrumentation had a 100,000-ohm input impedance available (Figure 7-12). The oscilloscope input impedance of 1 megohm was reduced to 100,000 ohms by connecting a 110,000-ohm resistance between the input connector and structural ground plane (Figure 7-12).

Curves showing transmission losses are included in Volume II, Section II-7, figures 3-112 through 3-115.

7.4.7 Capacitance and Inductance

The capacitance and inductance of the flat-cable conductors was measured, using the electrical bridges and cable form shown in Figures 7-7 and 7-8.

7.4.8 Test Equipment

The test equipment used on this program is listed in Table 7-2.

7.4.9 Test Facility

The test was performed in an electromagnetically shielded enclosure. The test specimen and monitoring instrumentation were located inside the enclosure (Figure 7-4). The signal sources were located outside the enclosure (Figure 7-1). The enclosure served as an isolation shield between the signal sources and monitoring instrumentation to prevent inadvertent signal leakage around the test specimens. The shielded test assembly provided the necessary isolation for the signal source interconnection wiring attached to the test specimen between the points where this wiring entered the shielded enclosure and the ends of the test specimen (Figures 7-9 through 7-14).

7.4.10 Conclusions and Recommendations

7.4.10.1 Cables

Flat, nonferrous-shielded cables and metallic and dielectric spacer strips do not produce a significant reduction in magnetic crosstalk, and do not exhibit a useful magnetic-shielding effectiveness in the frequency range at which these cables are useful for the transmission of information and at the frequencies generally utilized in electronic systems. Flat ferrous-shielded cables are theoretically capable of providing a generally useful magnetic-shielding effectiveness. Flat, ferrous-shielded cables also produce theoretically greater crosstalk between conductors within the same shield. Circumferential continuous, ferrous-shielded test specimens were not available for evaluation during this study contract.

Flat, metallic-shielded cables and metallic spacer strips, either nonferrous or ferrous, produce some reduction in electric crosstalk between conductors within the shield and exhibit an excellent electric-shielding effectiveness. Dielectric spacer strips do not produce a generally useful reduction in electric crosstalk and do not provide the equivalent of a significant shielding effectiveness.

Table 7-2
TEST EQUIPMENT

Type	Range	Manufacturer	Nomenclature	Figure No.
Signal Sources	20 Hz through 5 MHz	Hewlett Packard	650A Test Oscillator	7-7
		Hewlett Packard	467A Power Amplifier	7-7
Sensing Equipment	10 MHz through 400 MHz	Hewlett Packard	608D Signal Generator	7-7
		Hewlett Packard/ Boonton	230A Signal Generator Power Amplifier	
	20 Hz through 200 Hz (Electrical Fields only)	Singer/Empire Devices	NF315 Noise and Field Intensity Meter	7-10
		Tetronix	1A7/545A Preamplifier/Oscilloscope	7-7
	20 kHz - 20 MHz (Magnetic Fields only below 500 kHz)	Singer/Empire Devices	NF-105/TX/TA Noise and Field Intensity Meter	7-10
		Hewlett Packard	606A Signal Generator	7-10
		Hewlett Packard	205A Audio Signal Generator (20 kHz Magnetic Fields Only)	7-10
	50 MHz - 10 MHz	Singer/Empire Devices	NF-105/T-1 Noise and Field Intensity Meter	7-10
		Hewlett Packard	606A Signal Generator (50 MHz)	7-10
		Hewlett Packard	608 Signal Generator (100 MHz)	7-10
	200 MHz - 400 MHz	Singer/Empire Devices	NF-105/T-2 Noise and Freeze Intensity Meter	7-10
		Hewlett Packard	608D Signal Generator	7-7

Table 7-2 (Cont)

Type	Range	Manufacturer	Nomenclature	Figure No.
	Electrical Bridges and Miscellaneous Hardware	Electro Scientific Industries	701 Capacitance Measuring System	7-13
		General Radio	1608A Impedance Bridge (Inductance Measurement)	7-14
		Sierra	160-20FN 50 ohm 20 watt Dummy Load	None
		Hewlett Packard	355D 50 ohm Variable Attenuator	None

Powdered-ferrite shielded cables do not produce a useful magnetic or electric shielding effectiveness because the binders used to provide a flexible ferrite compound reduce the effective permeability and increase the resistivity of the shield to an impractical extent.

Flat-conductor cables tend to have a narrower transmission bandwidth, due to the higher shunt capacitance of this conductor geometry and the thin dielectrics used; therefore, the transmission losses become significant at somewhat lower frequencies than for round conductor cables.

7.4.10.2 Connectors

NASA plastic plugs limit the potential magnetic and electric shielding effectiveness of flat-cable shields to a value adequate for many electronic systems, but inadequate for some critical applications. NASA/MDC aluminum connectors are capable of providing excellent electric-shielding effectiveness, approximately equal to that of the basic shielded cable. The magnetic-shielding effectiveness of connectors with aluminum backshells is theoretically inadequate.

Magnetic-shielding effectiveness tests were inconclusive because the measured magnetic-shielding effectiveness of the test specimen was limited to relatively low values by the attached, shielded flat cable. The magnetic and electric-shielding effectiveness of connectors with ferrous backshells is adequate, theoretically. Magnetic-shielding effectiveness tests could not be performed because the circumferentially continuous, ferrous-shielded cable necessary for this test was not available.

7.4.10.3 Recommendations for Future Effort

Some form of thin-deposited, alternate layers of high-permeability ferrous and nonferrous material over an all-polyimide dielectric, seems to have the best potential for a magnetically and electrically shielded, high-production flat cable. Since a shield, capable of reducing magnetic coupling from external conductors and other sources, also tends to increase magnetic crosstalk between conductors within the shield, the capability of shielding individual conductors or small groups of conductors within a cable is desirable.

An unshielded cable with relatively narrow and thin over-and-under conductors separated by a very thin dielectric, utilized as a balanced signal-transmission and return path pair, seems to have the best potential for the cancellation of external magnetic and electric interference. The increased usage of integrated differential and balanced circuitry indicates a potential requirement for balanced pairs of conductors. Most conductors in electronic systems carry relatively low currents and voltages; therefore, conductor sizes and dielectric thicknesses are generally not a limitation except for power conductors.

Combining a low-profile, multiple-layer conductor core with a deposited, multiple-layer ferrous shield seems to have the best potential for the development of an optimum, modular, all-purpose, shielded cable adapted to high-production manufacturing techniques.

Available shielding theory and design information is inadequate for the development of the relatively thin shields in flat-cable shield configurations especially for low frequency magnetic fields; therefore, additional test and study effort is required for the evaluation of thin shields in flat-cable shield geometries.

For specific electrical characteristics required for many special applications, tighter tolerance control than is now specified by MIL-C-55543 must be imposed and special cross section configurations will be required.

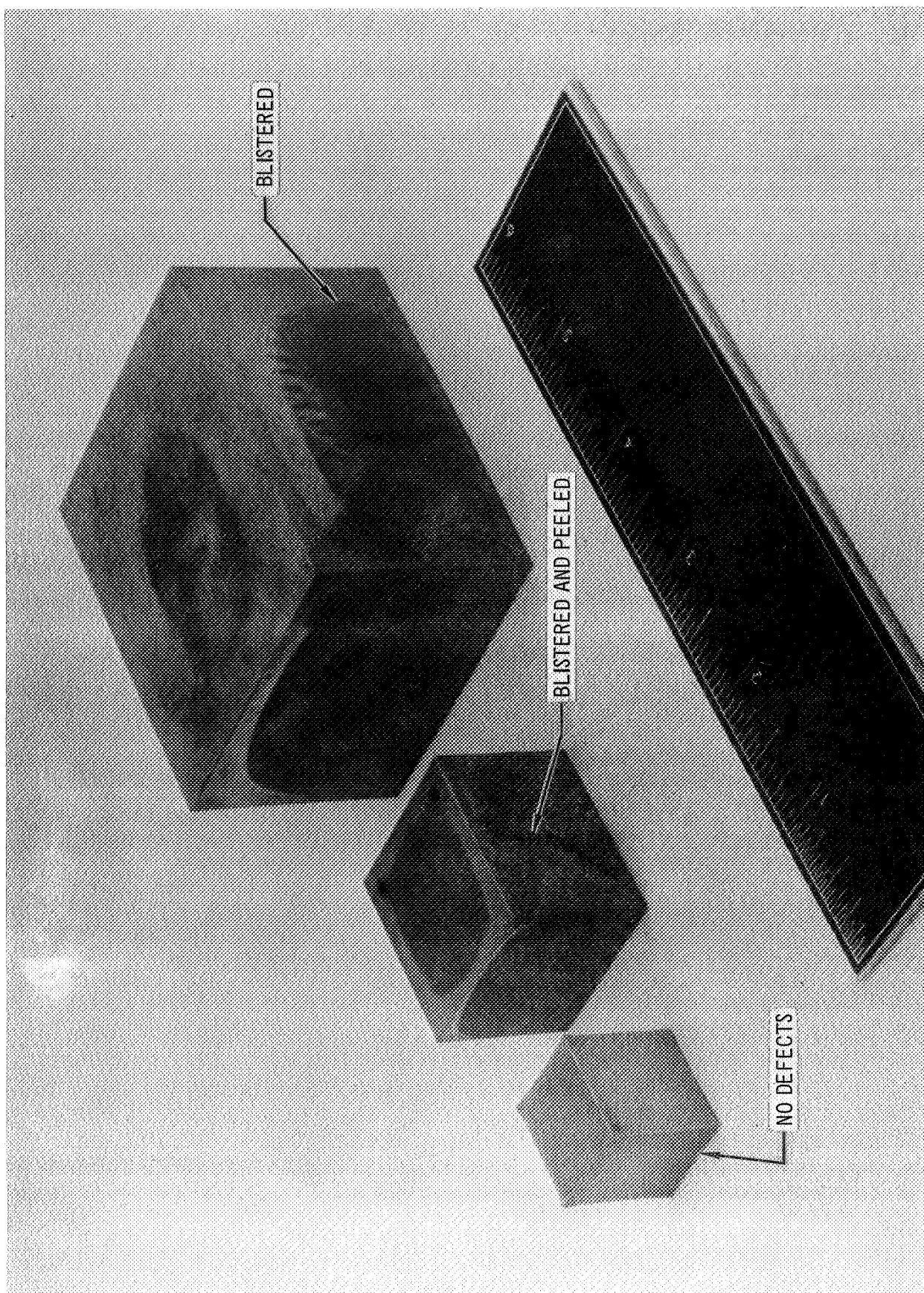


Figure 7-1 Electrolytic Copper—Deposited On Diallyl Phthalate Potting Cups

PLASMA ALUMINUM SPRAY ON POTTED MODULE
(BLISTERED AND PEELED)

ELECTROLYTIC ALUMINUM DEPOSIT ON GLASS-FILLED
GLASS EPOXY (METHODE PRE-MOLDED PLUG BODY)

ELECTROLYTIC COPPER DEPOSIT ON DIALLYL
PHTHALATE BAR



Figure 7-2 Plating Samples

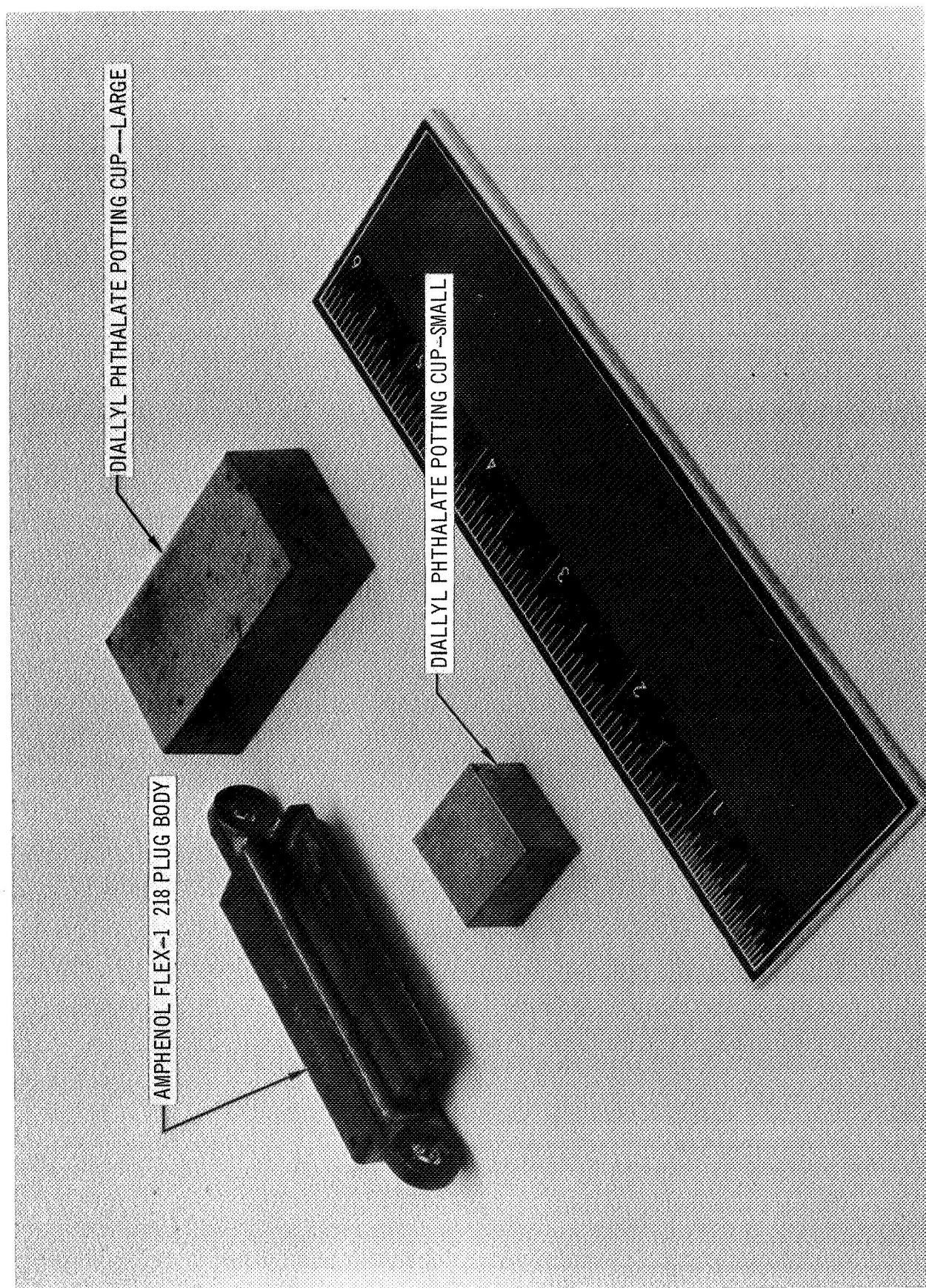


Figure 7-3 Samples Plated By Shipley Electrolytic Processes

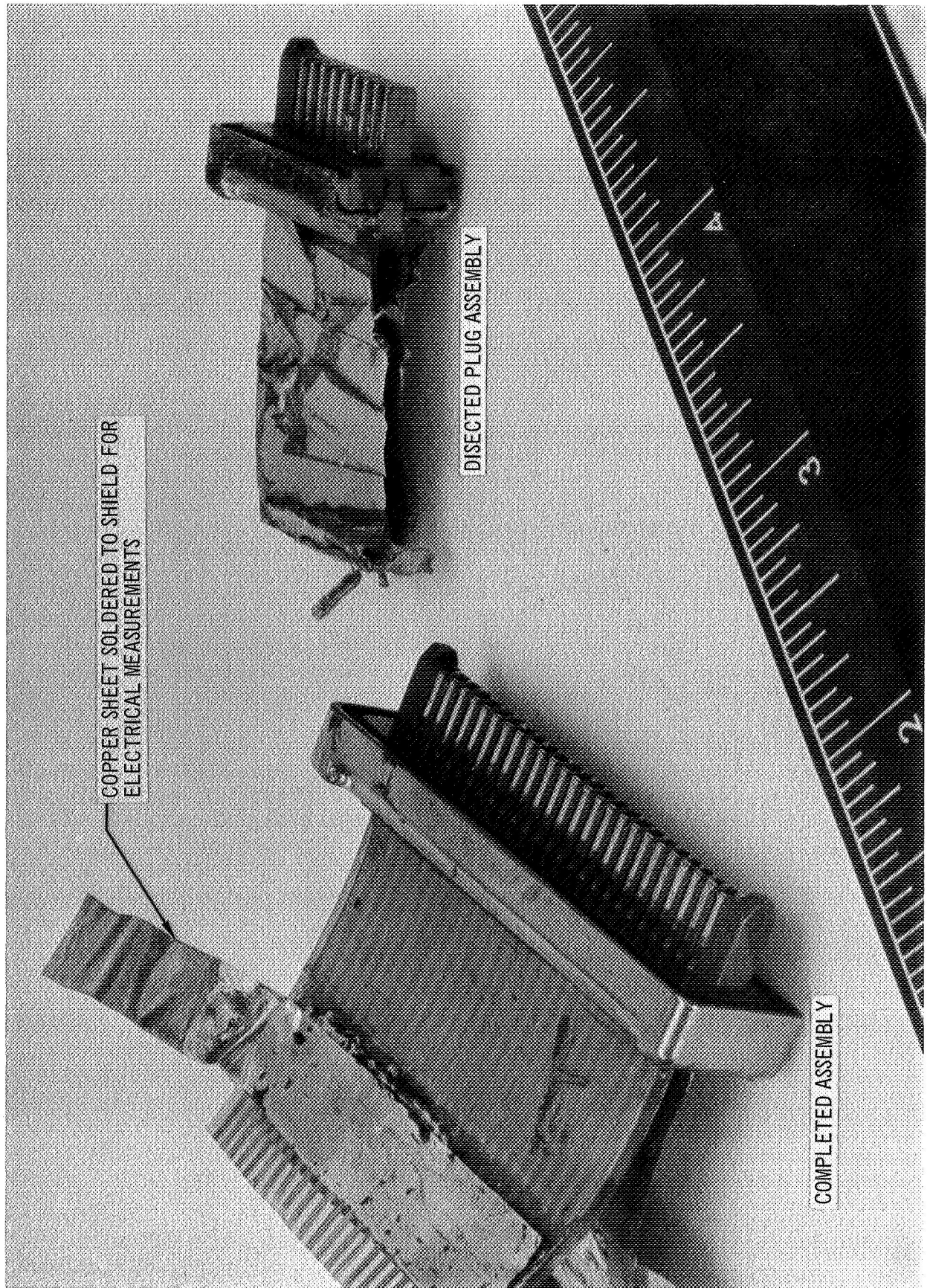


Figure 7-4 Shielded Plug Assembly Test Samples

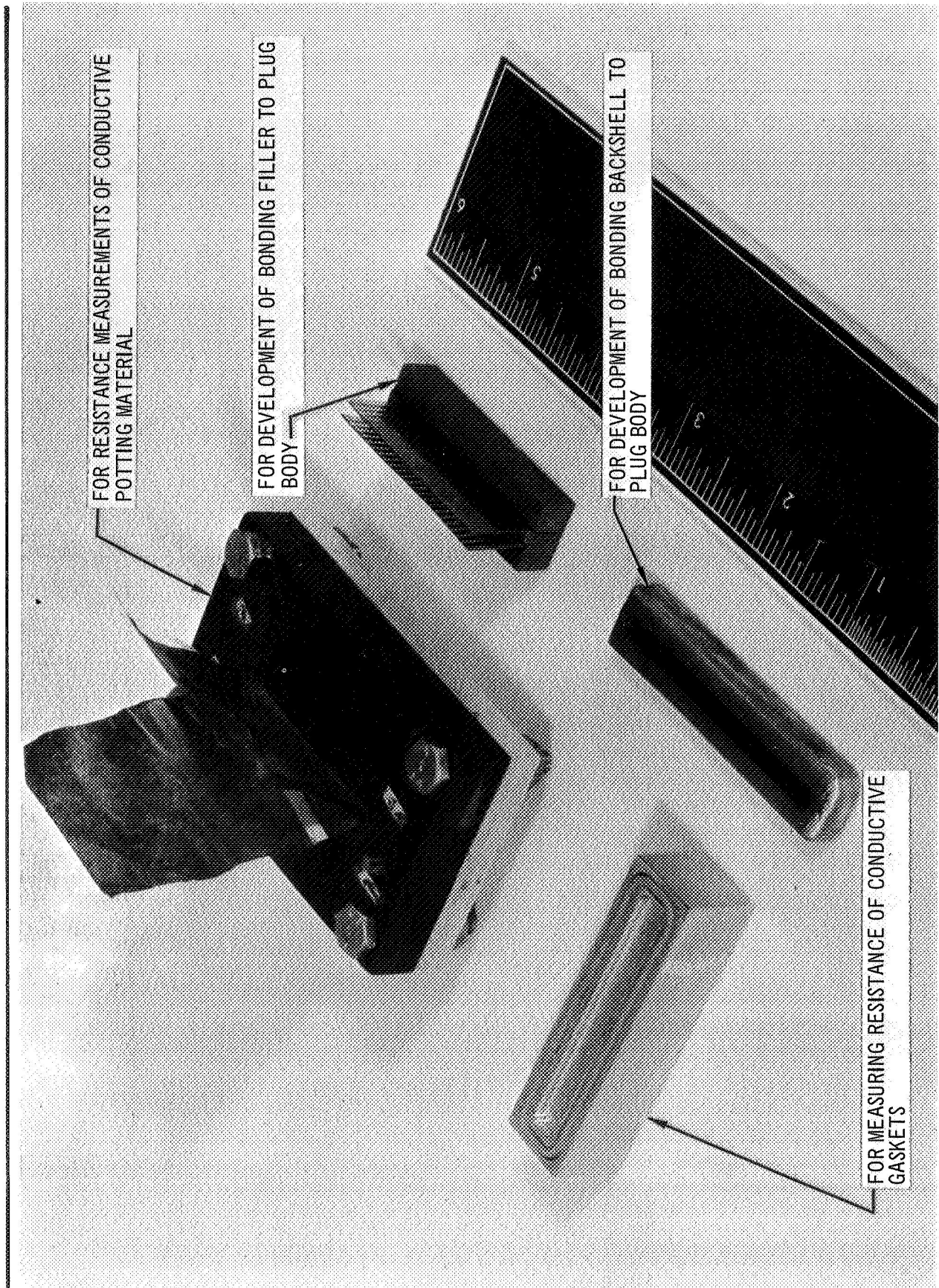


Figure 7-5 Test Fixtures For Shielded Plug Assembly Development

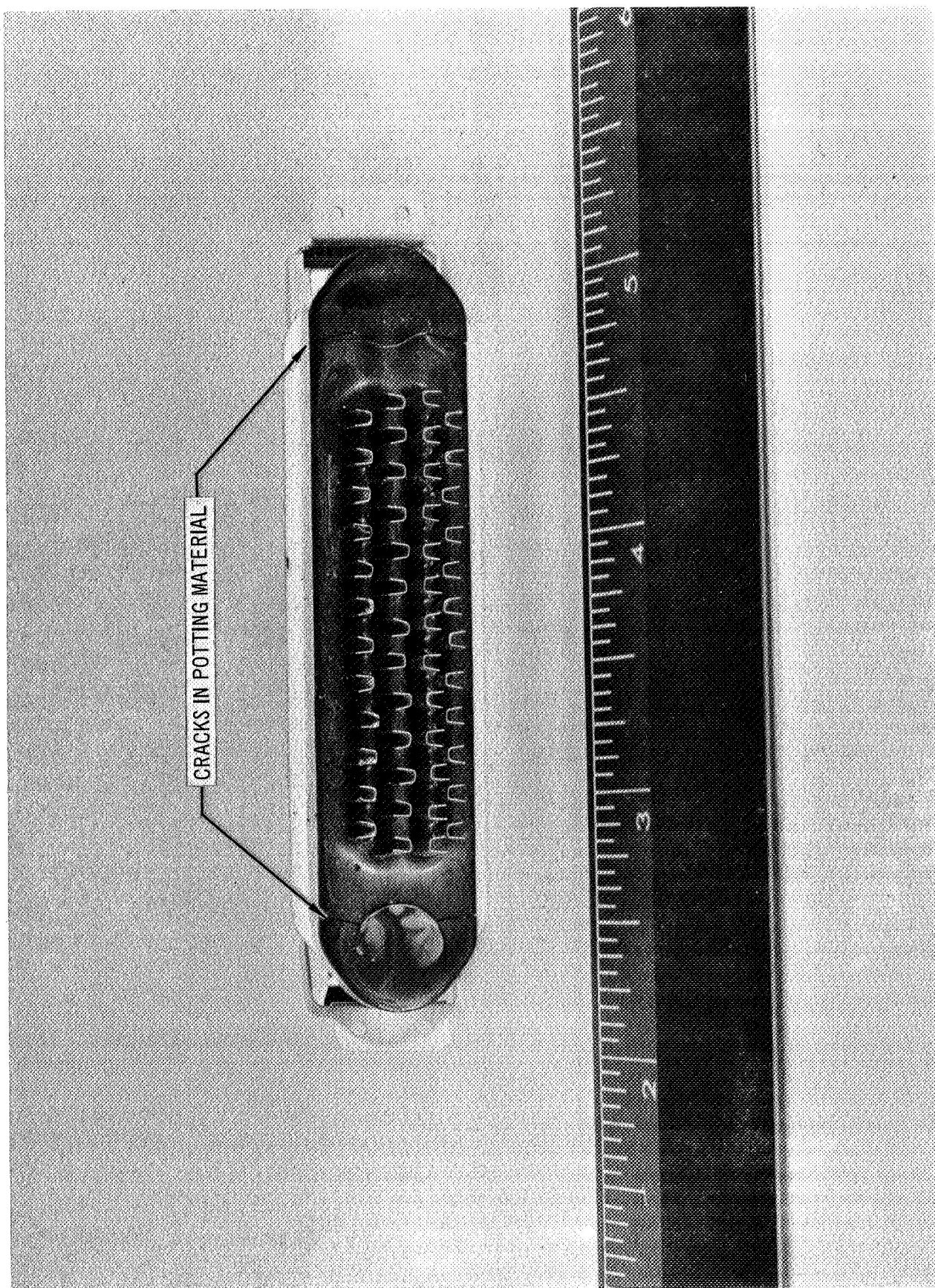


Figure 7-6 NASA/MSFC Conductor Contact Photo-Type FCC Receptacle

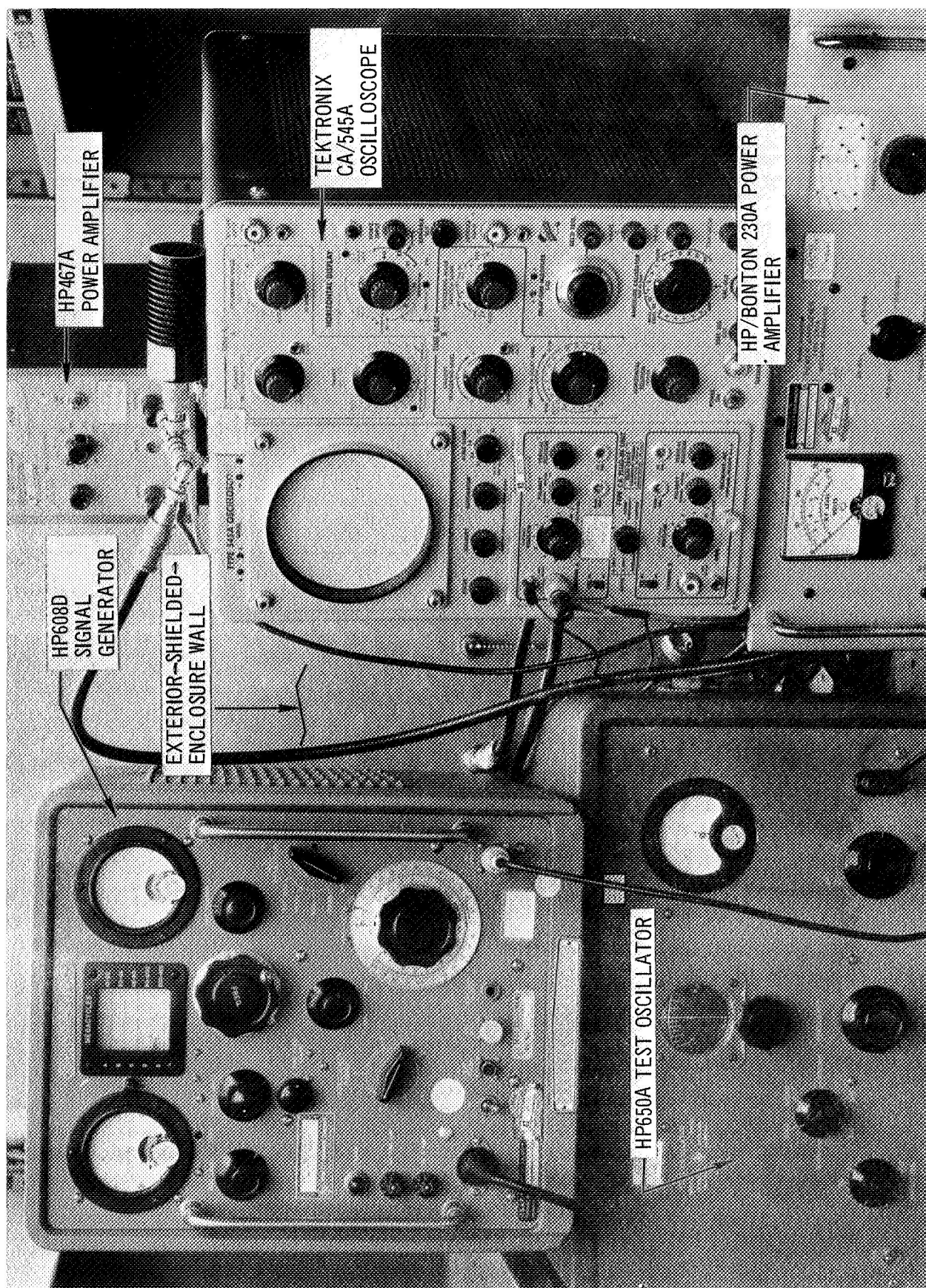


Figure 7-7. Flat-Cable EMC Test Signal Source

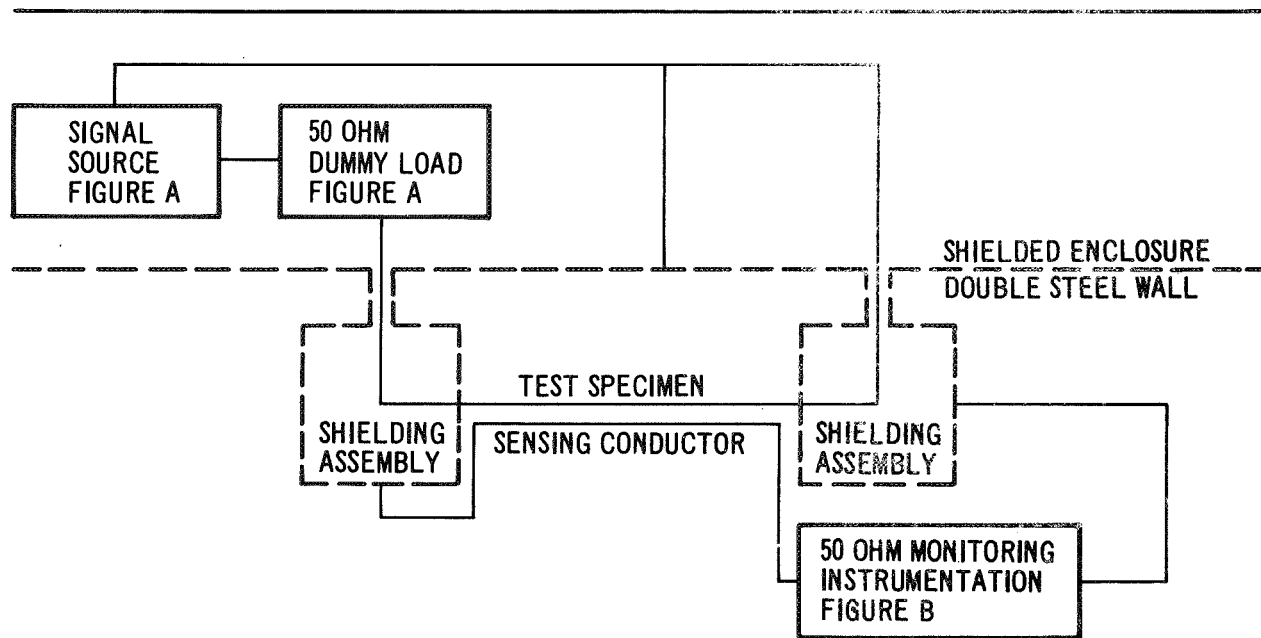


Figure 7-8. Block Diagram—Magnetic Coupling Tests

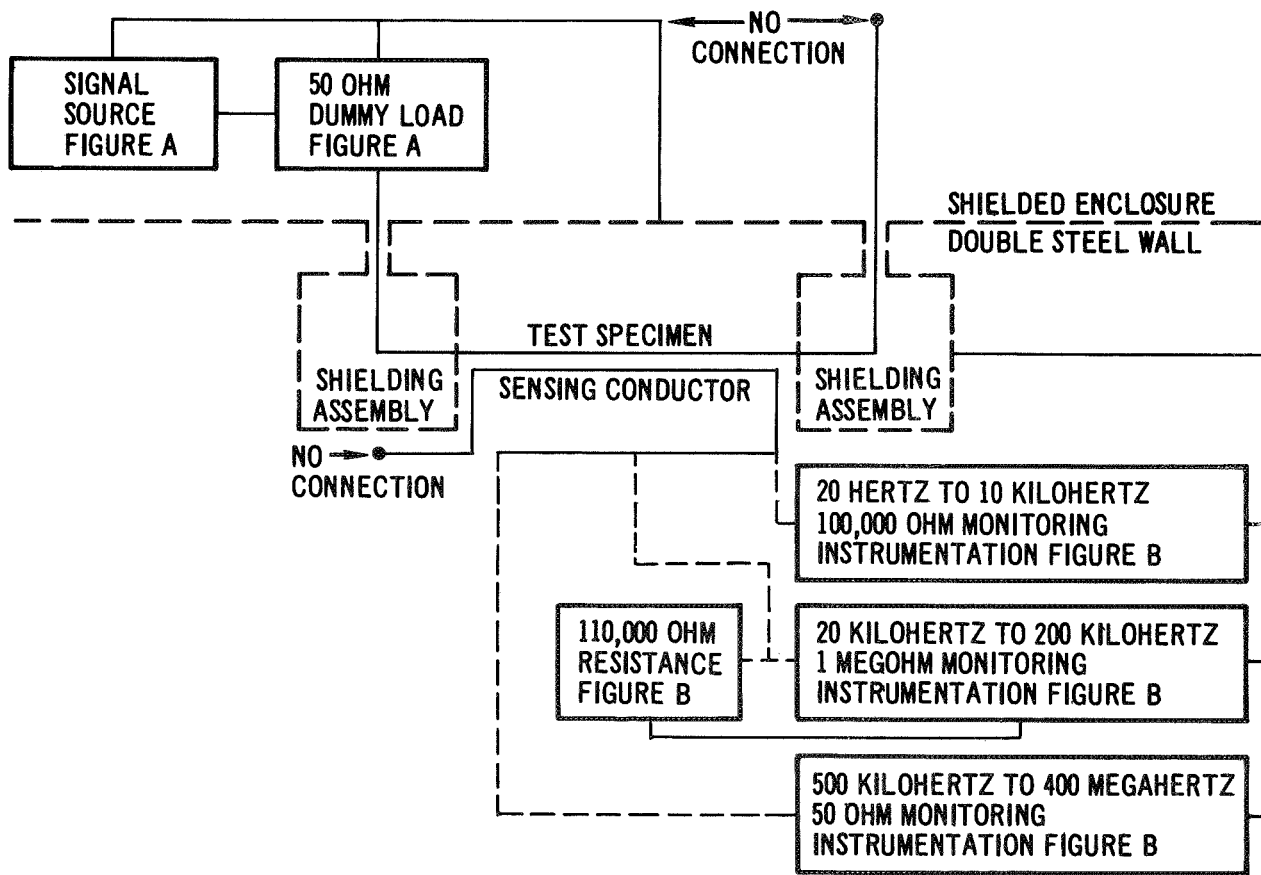


Figure 7-9. Block Diagram—Electric Coupling Tests

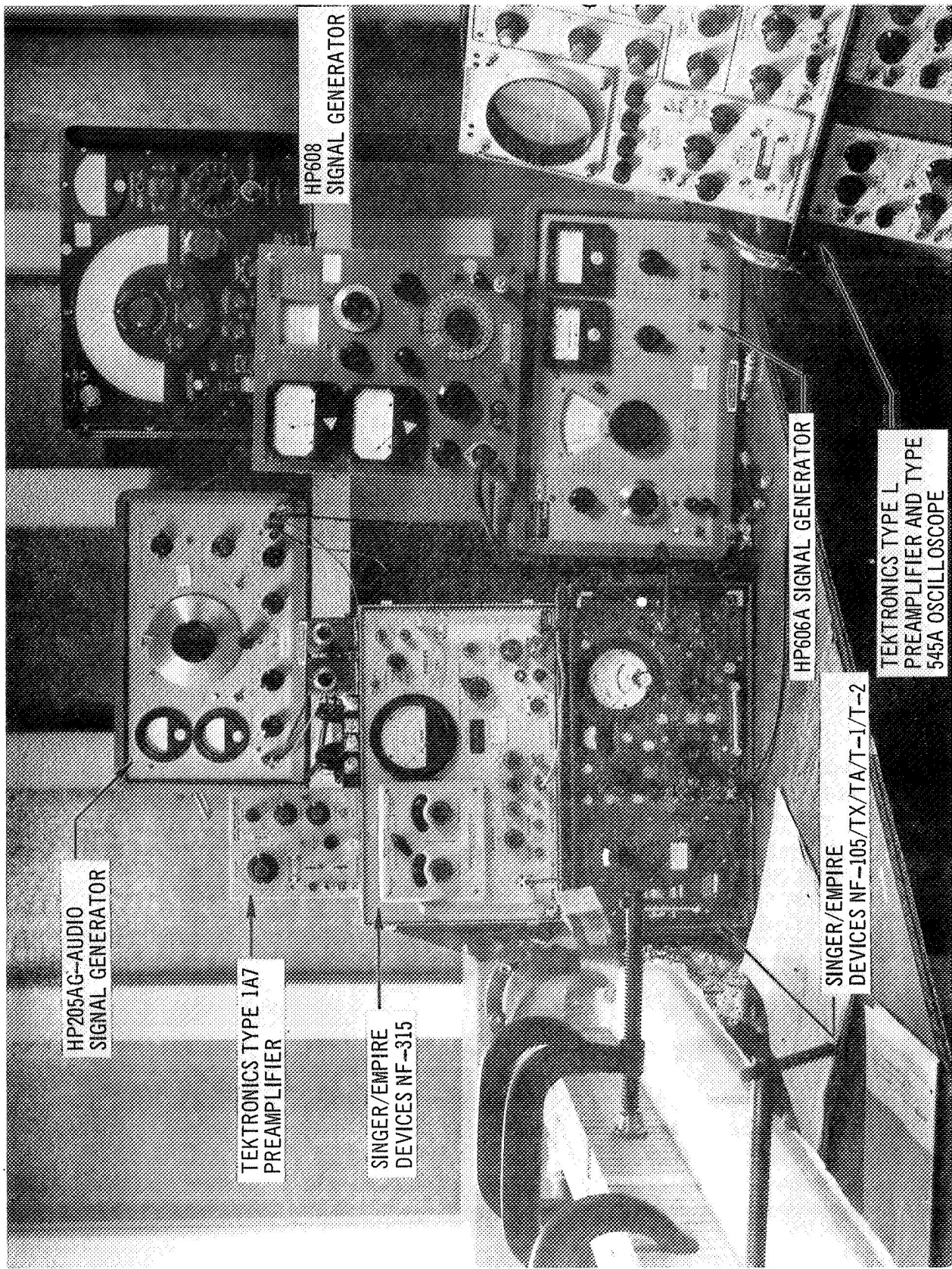


Figure 7-10. Flat-Cable EMC Test Monitoring Instrumentation

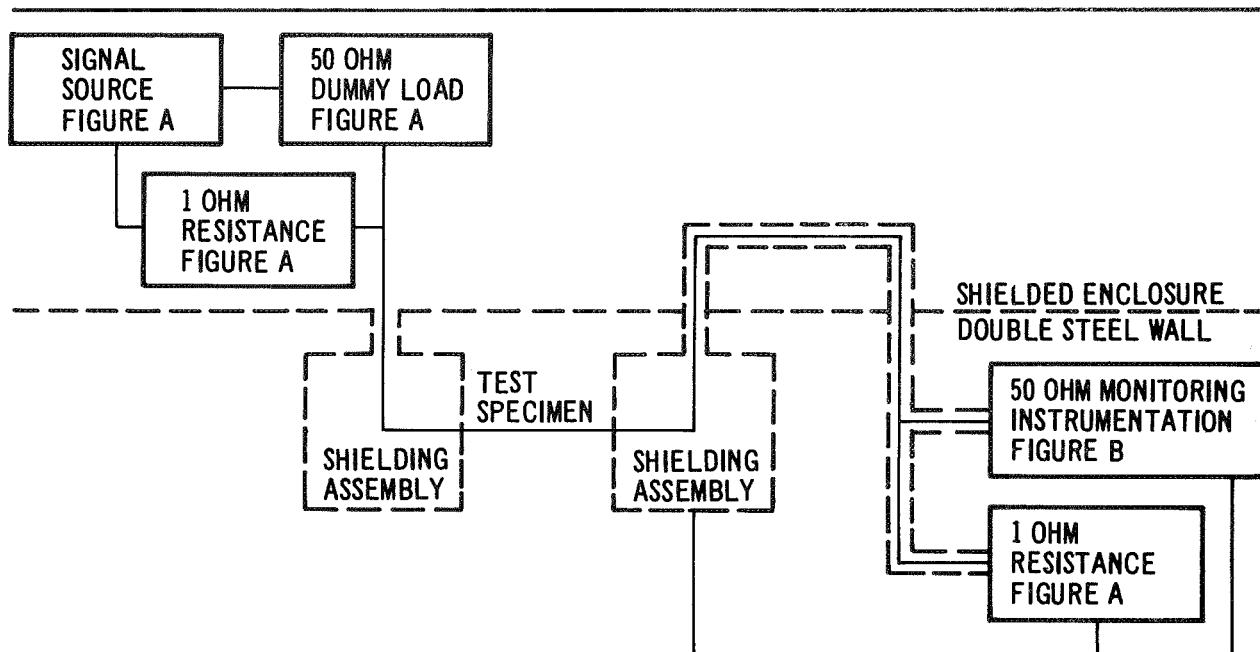


Figure 7-11. Block Diagram-Transmission Loss Tests-1 Ohm

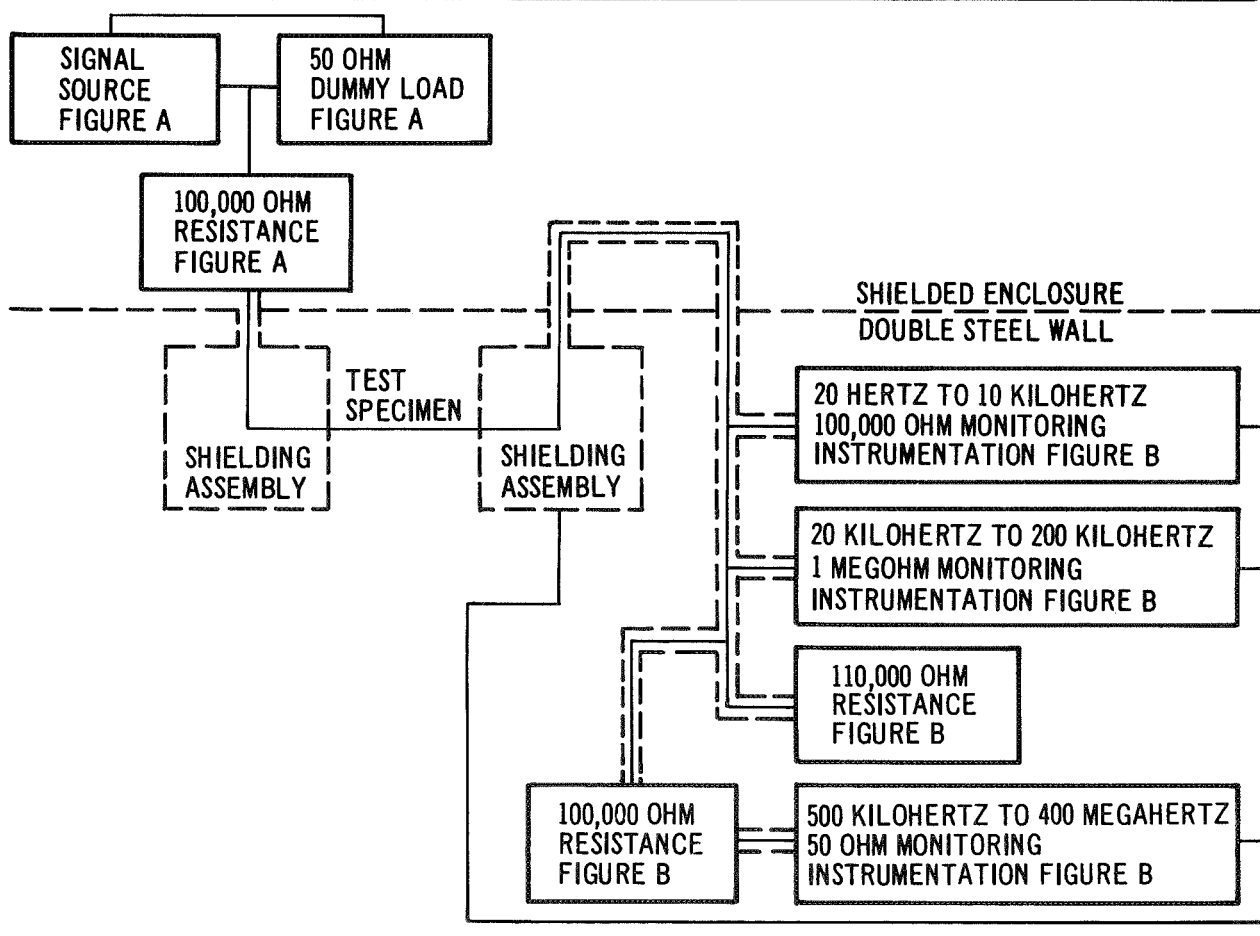


Figure 7-12. Block Diagram-Transmission Loss Tests-100,000 Ohms

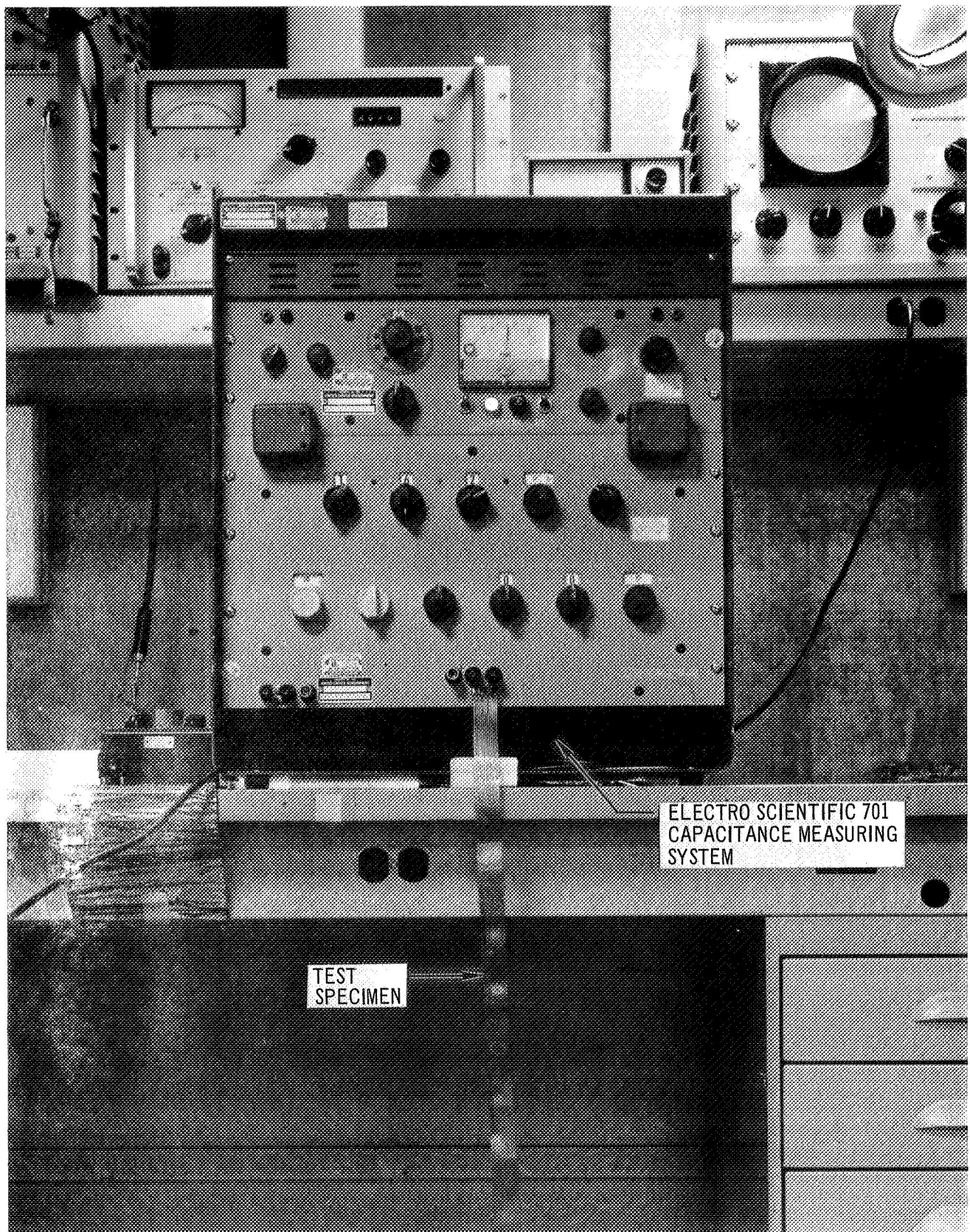


Figure 7-13. Capacitance Measurements

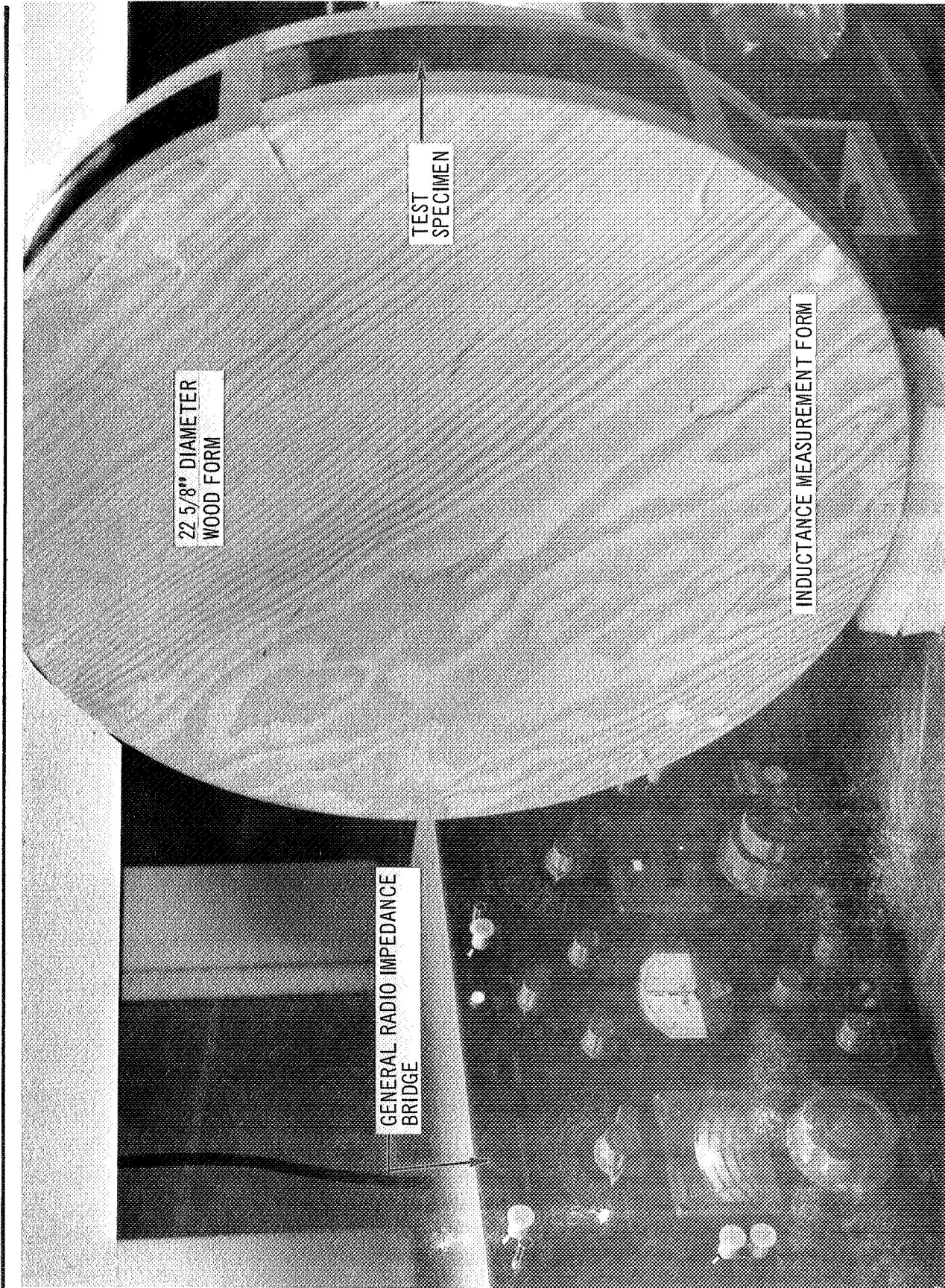


Figure 7-14. Inductance Measurements

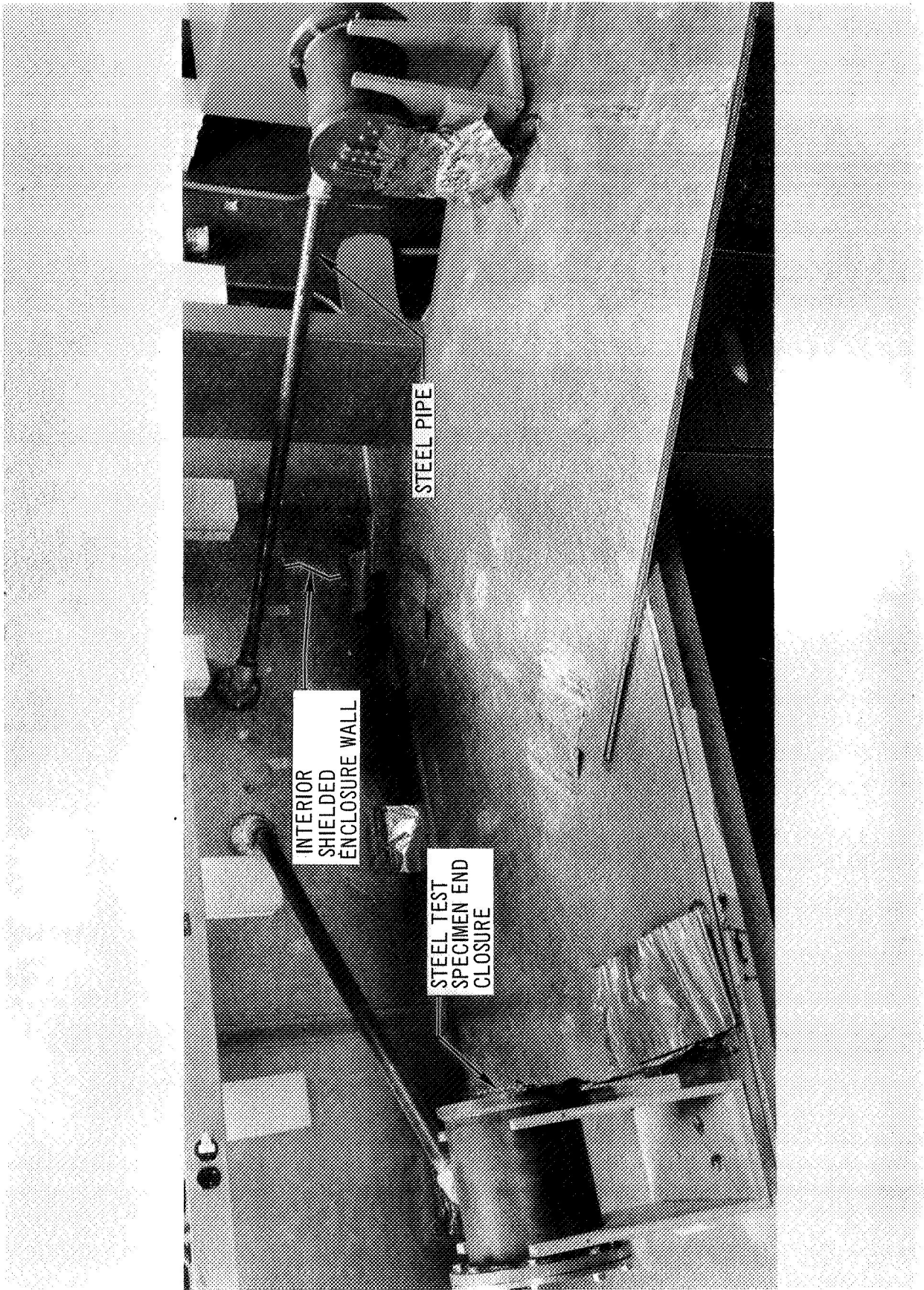


Figure 7-15. Flat-Cable Shielded Test Assembly

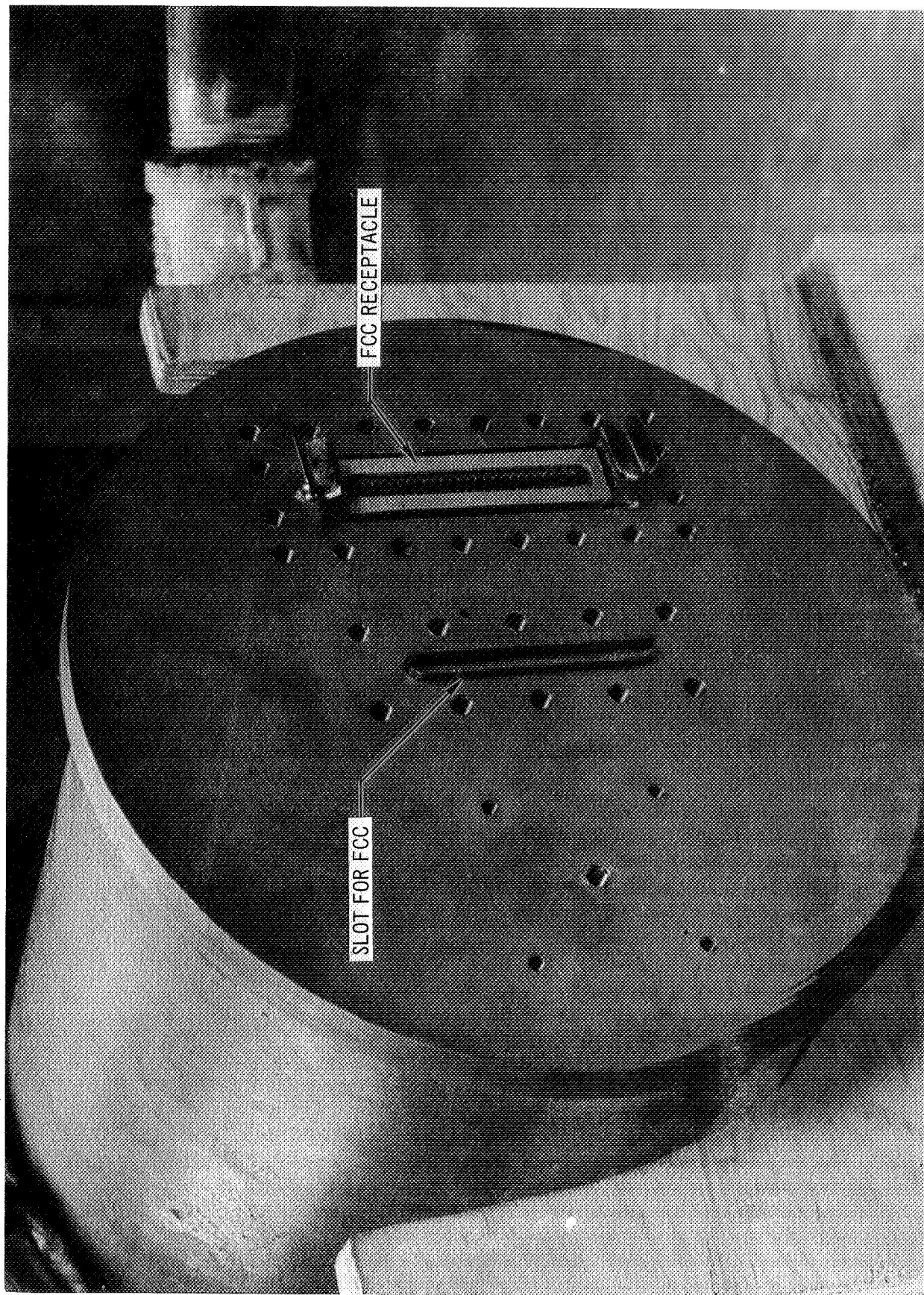


Figure 7-16. Flat-Cable Shielded Test Assembly-Face Detail

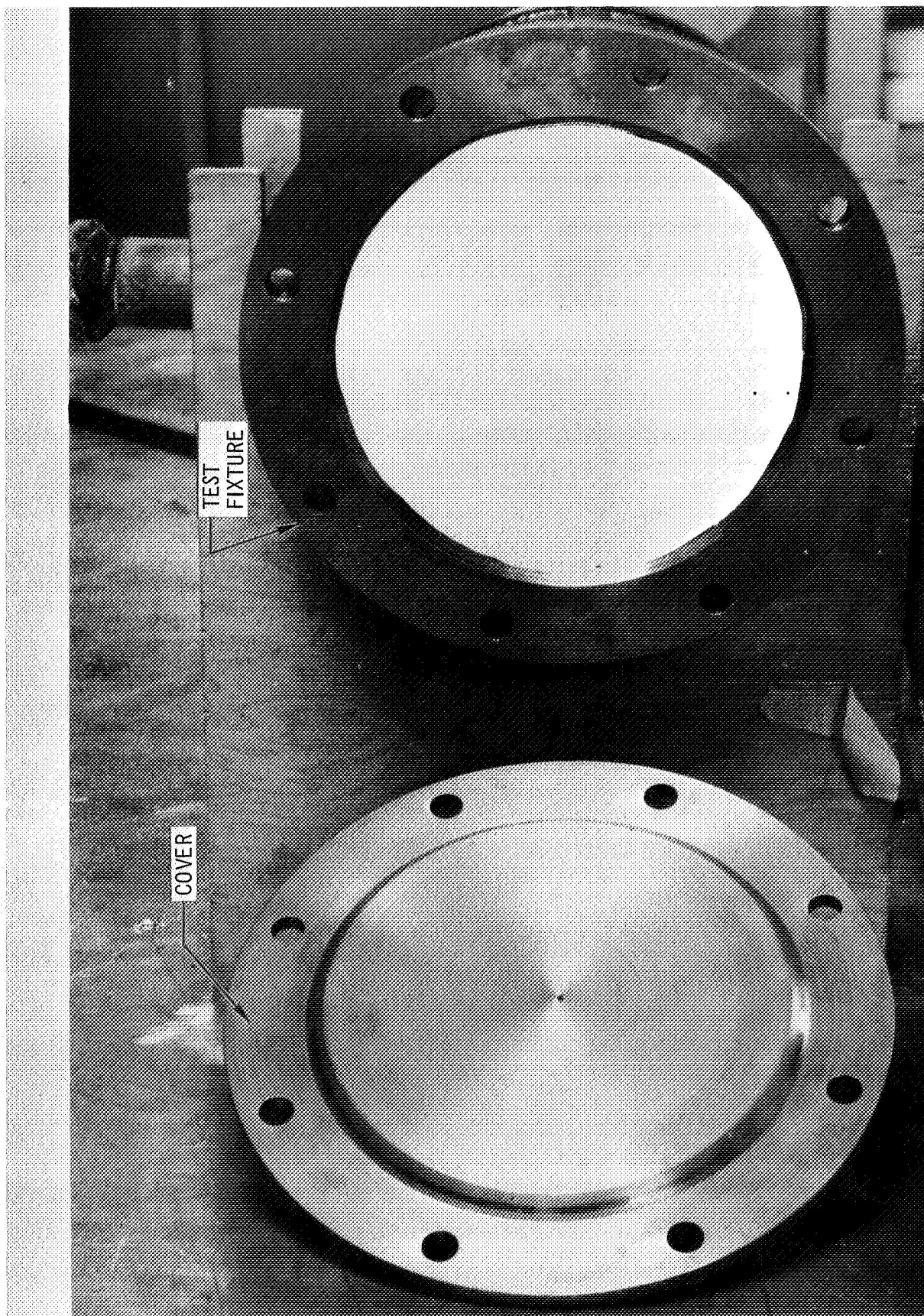


Figure 7-17. Flat-Cable Shielded Test Assembly-Access Control Cover Detail

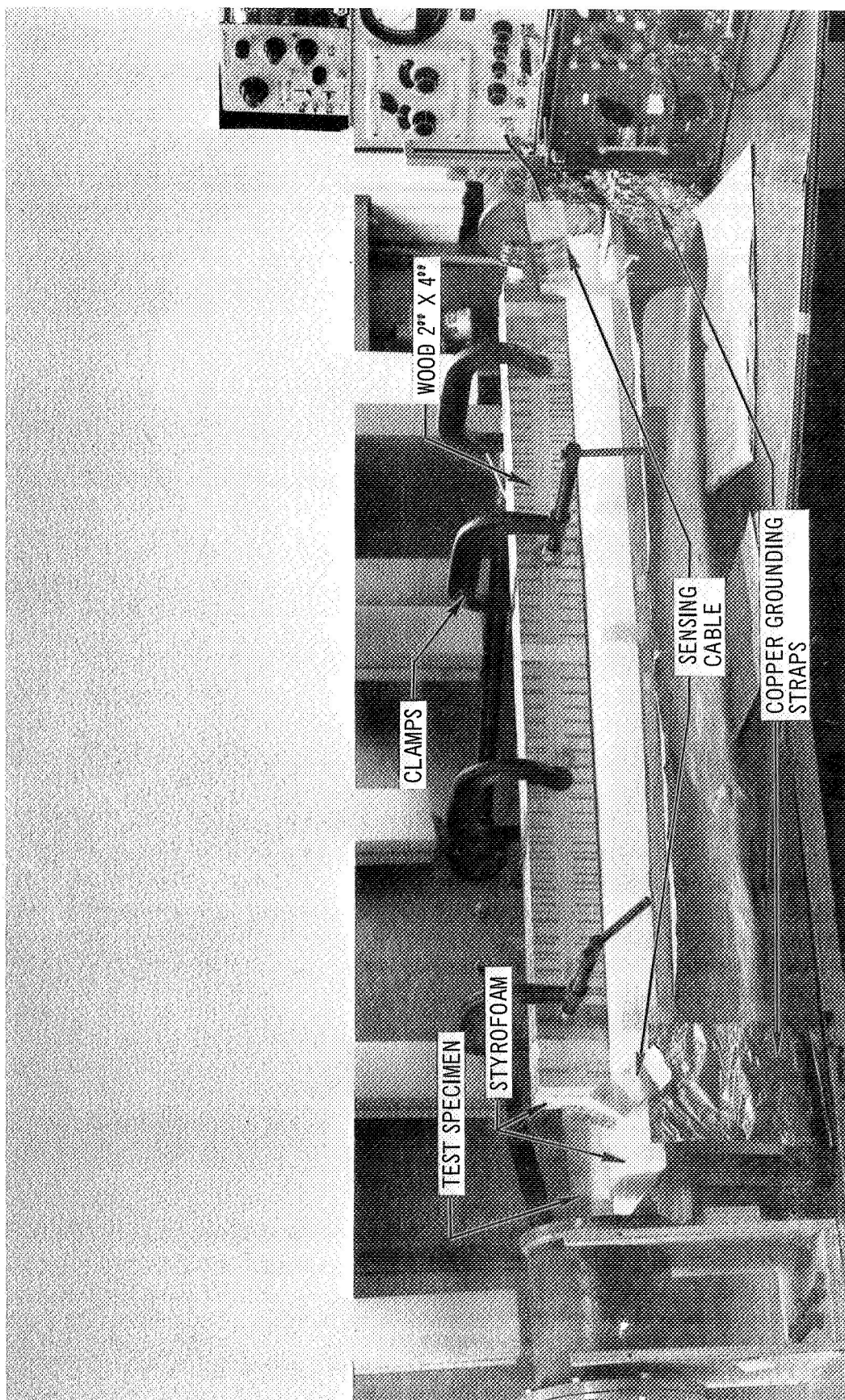


Figure 7-18. Flat-Cable Test Specimen Mounted In Shielded Assembly - Fully Assembled View

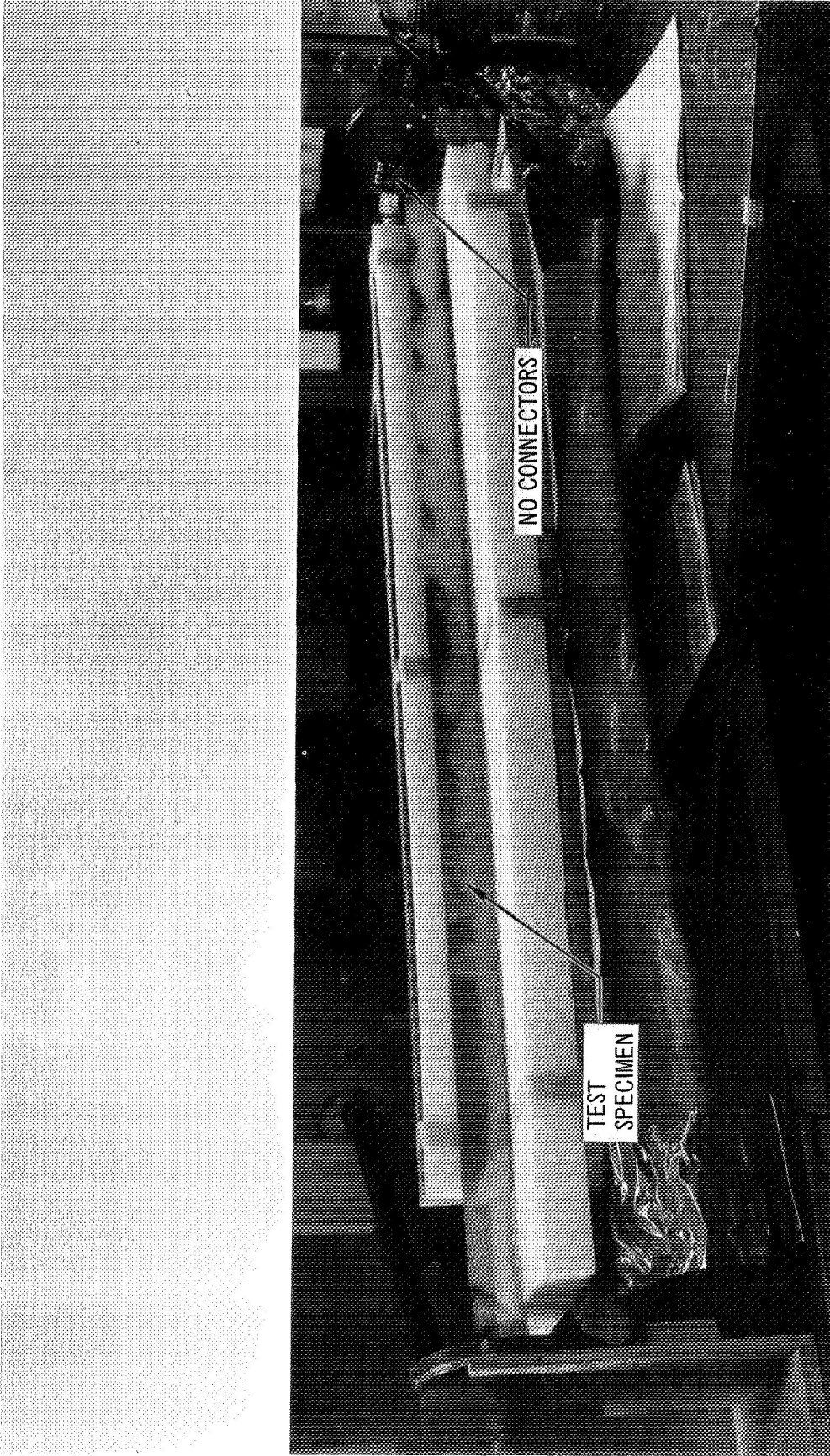


Figure 7-19. Flat-Cable Bulk Test Specimen Mounted In Shielded Assembly-
Exploded View

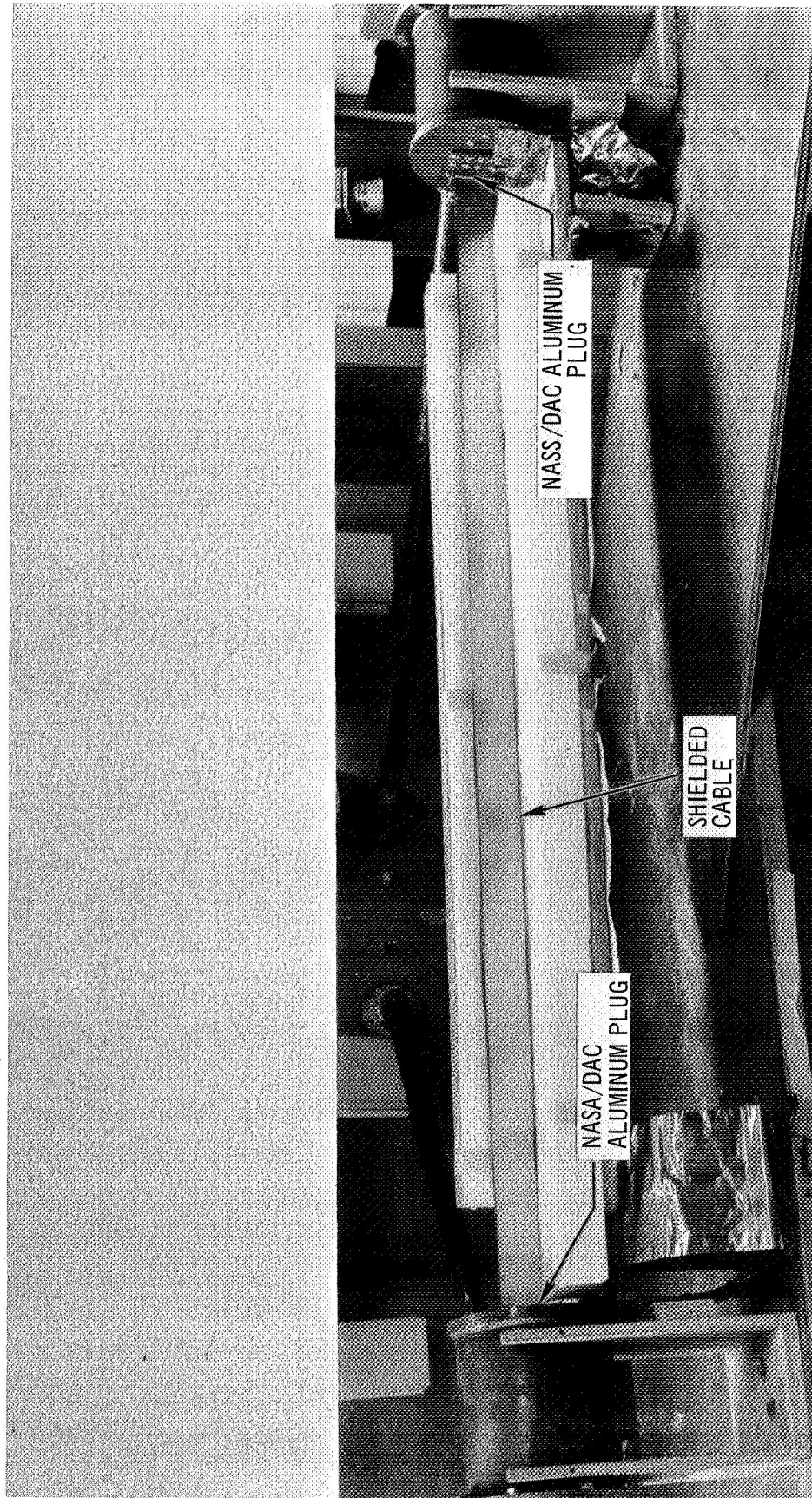


Figure 7-20. Flat-Cable Test Harness Mounted In Shielded Assembly-Exploded View

SECTION VIII

8. MANUFACTURING

8.1 Introduction

The advent of the Space Age, with its attendant requirement for subjection of space vehicles and associated equipment to the extreme temperatures of space environments, and high service temperature in areas of rocket engine exhaust, necessitated the development of a high-temperature, shielded, flat-conductor cable system. Such a system would supplement or replace the conventional, more cumbersome, round-wire cable systems, and provide a bonus of weight and space savings. These requirements imposed the need for development of advanced flat-conductor cable manufacturing and installation techniques.

Fairly reliable, unshielded, flat-conductor cable systems, capable of withstanding service temperature up to 125°C, have been developed, and research and development of more advanced, more sophisticated flat-conductor cable systems continues.

Shielding and insulation materials were evaluated by MDC Manufacturing for selection and design of a shielded flat-cable system which would withstand operating temperatures up to 200°C. Although these materials met the design criteria, further development is needed to facilitate manufacturing of the shielded flat-cable system.

8.2 Component Fabrication

8.2.1 Cable Fabrication

Under this contract, Manufacturing evaluated basic techniques of flat-conductor cable fabrication to determine the process that would produce a cable compatible for use in the MDC shielded-cable system. (MDC has no FCC development manufacturing facilities).

At the beginning of this contract, purchase of shielded cable had been assumed possible; however, many problems were encountered in both the

selection and purchase. These problems, along with possible solutions, are enumerated in the following paragraphs.

8.2.1.1 Preparation of Conductors for Fabrication

The prerequisite for achieving consistently accurate center-to-center spacing is to use straight and flat conductors; even slight deformations will invariably cause irregularities in the spacing. Therefore, the cause of these deformations, however slight, are of prime interest. Flat wires are often wound on a standard spool in the typical helical fashion. At the end of the layer on the coil form, the helix has to be reversed to continue the next layer. The reversal can deform the flat wire permanently; if not straightened, this may cause spacing errors in the flat cable. Additional deformations may occur when the pitch of winding is not accurately adjusted to the width of the flat wire.

A satisfactory method of straightening this wire and also cleaning the wire is described in NASA Technical Memorandum X-53586. After the wire has been straightened, the wire is wound on pancake spools, having a width of one flat wire. These spools can then be used as dispensers for the cable laminating machine.

8.2.1.2 Laminated Cable

The first method evaluated for the fabrication of flat cable was the lamination method in which the cable is run through rollers under heat and pressure, in a sandwich type configuration. Typical laminating machines are shown in figure 8-1.

8.2.1.2.1 Laminating Material

This manufacturing technique works best with bonding materials that can be heat bonded. FEP Teflon was selected for the bonding material, because of the following:

- a. The material is available, and quality control of the material is good.

- b. The material can be bought in sheets, which is compatible with this manufacturing technique.
- c. This material has no cure cycle; when it is heated, it melts, and as soon as it cools down, it cures instantly. Therefore, it lends itself readily to a continuous run through the laminating machine without the necessity for incorporating a cure cycle into the operation.
- d. The material has a high operating temperature of almost 200°C -- a requirement of this contract.

8.2.1.2.2 Laminating Problems

The following problems were encountered when purchasing polyimide FEP laminated flat cable.

- a. Irregularities existed in bond strength from side to side of the cable.
- b. Conductor spacing varied, causing a problem when inserting the stripped conductors in the plug.

8.2.1.2.3 Conclusion

Flat-cable laminating techniques need to be improved in the area of capability for controlling bonding pressure and temperature throughout the laminating cycle. A need exists to develop better methods for controlling tolerances between conductors.

8.2.1.3 Tower Coating Cable

The tower coating method utilizes a system of rollers to dip-coat appropriate insulations on flat conductors. Insulation thicknesses can be controlled either by the speed with which the conductors are drawn from the liquid or by the viscosity of the liquid. Tower coating possesses interesting potential, as each conductor can be individually shielded.

For this contract, tower coating was omitted as a fabrication method since it had not been as thoroughly investigated as the laminating techniques.

8.2.1.3.1 Conclusions

An insulation material must be selected that can be dip-coated and cured in a manner that is adaptable to a production operation. This cured material, besides having good physical and electrical properties, must be capable of withstanding a 200°C operating temperature.

8.2.1.4 Photo Etch Process

This process uses a composite conductor-insulation material with a high-strength bond. The possibility of the conductors shifting or swimming is thereby decreased since, under heat, the bond will not soften. Figure 8-2 outlines the manufacturing sequence for this process.

8.2.1.4.1 Conclusions

This process possesses interesting potential because (1) dimensional tolerances can be held extremely close, and (2) this type of process is adaptable to production line manufacturing.

8.2.1.5 Future Considerations

The following criteria should influence the selection of materials for cable fabrication.

- a. The cable should be stripable.
- b. Tolerances must be kept to within ± 0.005 , noncumulative, between conductors.
- c. The cable must be capable of being shielded.

8.2.1.5.1 Polyimide Fabrication

A good possibility for the future is an all-polyimide insulated cable system. Polyimide insulations are being developed to the point where they lend themselves to a tower coating operation. Polyimide insulation will

withstand high temperatures to 300°C, and polyimide insulation is chemically stripable.

8.2.2 Premolded Shielded Plug Assembly

Figure 8-3 shows the configuration of the MDC-designed, premolded plug assembly. This system was developed by MDC to give a completely shielded flat-cable system that will operate efficiently at temperatures up to 200°C.

8.2.2.1 Douglas Premolded Plugs

Diallyl phthalate molded plugs were selected for use, because of their high temperature-resistance and proven molding capabilities. A polyimide molded plug is desirable because of higher temperature resistance and good molding properties.

8.2.2.1.1 Diallyl Phthalate

Plugs molded of diallyl phthalate have an operating temperature of 200°C and are easily molded. A problem is the brittleness of transfer-molded diallyl parts. The plugs are less brittle when compression-molded.

Raker, Inc., Santa Monica, California, designed and built plug-transfer molds, see figure 8-4, and has furnished MDC with acceptable plugs. The dimensions of the plugs are within print tolerances. The MDC design provides a light, high-temperature (200°C) connector for flat-cable application.

8.2.2.1.2 Polyimide

American Cyaninide Co., has developed a transfer-moldable polyimide, and work is continuing on the development of an injection-moldable polyimide. This polyimide developed is a true thermosplastic material and has a temperature rating of 300°C. This material would eliminate the problem of the material in the plug, hence, raise the service temperature of the cable system.

8.2.2.1.3 Epoxy

Glass-filled epoxy is a moldable thermosetting, high-temperature resin that could be used in a system of service temperature ratings between those of polyimides and those of diallyl phthalate (200°C to 300°C). Epoxies mold well and exhibit good resistance to shock.

8.2.2.2 Backshells

Backshells for the MDC shielded, premolded connector were diecast from aluminum. The backshells were electroplated with copper, then plated with a coating of electroless nickel. The plating gives the plug the necessary shielding requirements.

The dies and backshells for the shielded, premolded connector configuration (see figure 8-5) have been developed and fabricated by Sunbank Electronics Co., Burbank, California.

8.2.2.3 Gaskets

Gaskets are molded from conductive gasket material, Number 1221, developed and sold by Chomerics, Inc., Arlington, Massachusetts. This gasket, molded of silicone rubber and impregnated with silver beads, meets the temperature and conductive requirements for this shielded plug assembly.

8.2.2.4 Retainers

The retainers are a resilient, silicone-rubber piece made of the same material as the gaskets. The retainers are used with the shielded-cable configuration to allow a conductive path between the two inner shields, and to cause a pressure fit between the outer shielding and the metal backshell (figure 8-6).

8.3 Harness Assemblies

The NASA design uses the conductors as the contacts without use of a pin contact. This design eliminates a contact point between conductors and pins, and should, therefore, increase the reliability of the system.

8.3.1 Cable Preparation

After quality cable has been fabricated, it must be stripped, and the conductors and/or shield must be gold-plated to prepare it for assembly into the plug. The problem encountered in preparing the cable for stripping is discussed in the section detailing the specific procedures, such as plating and stripping.

8.3.2 Plug Preparation

The plugs are molded from specific dielectric materials that meet the requirements of the system on which they are to be used. Any problems encountered in this area are detailed in the section on plug preparation.

8.3.3 Plug-and-Cable Assembly

Under this contract, the main system looked at was a premolded plug design with shielded cable and plug (figure 8-7). This section delineates this type of design and the associated problems. Other basic types of cable assemblies are mentioned to acquaint the reader with their advantages and disadvantages.

8.3.3.1 Unshielded Molded-On Plugs (M55544/7)

As opposed to the premolded plug, this type of plug (figure 8-8) can be assembled with less chance of damaging the conductors. Since the conductors do not have to be threaded through the small openings that are present on the premolded plug design, the possibility of bending the conductors is lessened considerably.

The two disadvantages to this type of plug are:

- a. The plugs are molded at assembly, and require molding equipment that is not required on the premolded plugs.
- b. The material selected for the plug must have a lower molding temperature than the insulation on the cable, or the insulation will be deformed or melted. This requirement limits the insulation materials selected for the plugs, and significantly lowers the operating-temperature ranges allowed.

8.3.3.2 Unshielded Premolded Plug Assembly (M55544/5)

These plugs (figure 8-9) have been fabricated from a glass-filled epoxy with good heat and mechanical properties. An advantage of these plugs is that they can be assembled at field stations.

8.3.3.3 Shielded Premolded Plug Assembly (M55544/11)

This plug (figure 8-10) was designed to provide a completely shielded flat-cable system. Problems of this system and possible solutions are discussed below.

After the conductors and shield were exposed (figure 8-11), the surfaces were nickel- and gold-plated.

The plugs were molded of diallyl phthalate with good results. One problem area is the threading of the cable conductors through the holes (figure 8-12). This problem can be minimized by cleaning the holes with a tool such as shown in figure 8-13, and by inserting the conductors with the aid of a tool such as shown in figure 8-14.

After the conductors have been inserted, the plug is placed in the conductor folding tool, figure 8-15, and the conductors are secured in the plug.

The assembly is removed from the folding tool, and the filler is bonded in the plug with Lefkowied, type 185, using the tool shown in figure 8-16, then is cured 1 hour at 300°F.

A line of Lefkowied, type 185, is placed along the conductors from the back (figure 8-17). The connector is placed in the tool, as shown in figure 8-18, and cured at 300°F for 1 hour, then potted again, as shown in figure 8-19, and cured.

A problem area has been the great amount of pressure exerted by the retainer on the cable. This pressure has caused shorts between shielding and the conductors. Possible solutions might be the change in shape of either the retainer lining or the edge of the backshell, or change in

design so that the pressure required can be reduced. Figure 8-20 shows some possible methods of alleviating this problem.

8.4 Cable Stripping

Reliability of the flat-cable system requires a good contact between the conductors and the interconnecting devices or termination points. This section defines the different methods for stripping flat cable that were investigated under the Flat-Cable Systems Engineering Study, NASA Contract NAS8-20751. Figure 8-21 illustrates the different stripping methods and the advantages of each. Chemical stripping seems optimum, as it causes the least damage to both the conductors and the shield, and does not limit the thickness of the latter. The appropriate stripping methods are discussed according to the type of material to be stripped.

8.4.1 Polyimide

The most efficient method investigated for stripping polyimide insulation was that which utilized a hot, caustic solution. Economy is an important characteristic of this stripping method, since the cable can be stripped in batches.

8.4.1.1 Unshielded Polyimide Cable

The unshielded cable configuration consists of an all-polyimide system (figure 8-22), in which the cable is masked prior to stripping, to prevent degradation of the insulation beyond the designated areas. Figure 8-23 shows masked and stripped cable. Maskants and stripping solutions which can be used in the removal of insulation and shielding are listed in tables 8-1 and 8-2. A sample of masked and chemically stripped, unshielded and shielded, all-polyimide cable is shown in figure 8-24.

The masked cable is immersed in a beaker containing a heated solution of MER-1 resist remover (or equivalent), until the insulation has been removed.

Table 8-1
STRIPPING MASKANTS

Insulation	Manufacturing	Location
Maskant No. 1 - 2021-66	Organo Ceram, Inc.	Placentia, California
Maskant No. 2	Western Coating Company	Los Angeles, California
TFE-Teflon Tape	Minnesota Mining and Manufacturing Company	St. Paul, Minnesota
Lead Foil Tape	Minnesota Mining and Manufacturing Company	St. Paul, Minnesota

Table 8-2
STRIPPING SOLUTIONS FOR REMOVAL OF INSULATION AND SHIELDING

No.	Solution	Time (minutes)	Temperature (°C)	Manufacturer	Location
1	MER-1	3 to 6	93 to 99	London Chemical Company, Inc.	Melrose Park, Illinois
2	LEA INSUL STRIP	3 to 6	93 to 99	The Lea Manufacturing Company	Waterbury, Conn.
3	PT-%-ML	5 to 8	96 to 99	London Chemical Company, Inc.	Melrose Park, Illinois
4	N L-76	5 to 8	99 to 110	Enthone, Inc.	West Haven, Conn.
5		5 to 10	93 to 99	Clarkson Laboratories	Camden, New Jersey
6	50% NaOH	10 to 15	99 to 110	Laboratory Prepared	

8.4.1.2 Shielded Polyimide Cable

The shielded cable configuration consists of polyimide insulation and a copper shield on high-permeability metal (figure 8-25). The shielded cable can be stripped in the same manner as the unshielded polyimide cable, except that the shield must be stripped with a chemical such as ferric chloride etchant 35° Baume, or 100 parts nitric acid to 2 parts hydrochloric acid by volume.

This is a good system for stripping shielded polyimide flat-conductor cable because the chemical solution does not harm the shield, and eliminates the possibility of shorts due to nicks or scratches in the cable or insulation, which may occur when the cable is mechanically stripped.

8.4.2 Mylar

8.4.2.1 Mylar Cable

Any cable system, having a cover layer of mylar laminated with an adhesive such as polyester, can be chemically stripped in a manner similar to removal of the polyimide film. The solutions listed below were tried and found to be acceptable for removing the mylar.

<u>Solution</u>	<u>Time (Minutes)</u>	<u>Temperature (°C)</u>	<u>Manufacturer</u>	<u>Location</u>
DS101H	3 to 8	99	Method Electronics, Inc.	Chicago, Ill.
H ₂ SO ₄	2 to 4	93 to 99	Commercially Available	

The cable is masked to define the stripping area and to prevent degradation of the adjacent cable. A maskant, such as a lead-backed tape No. 425, Minnesota Mining and Manufacturing Company, is recommended.

8.4.2.2 Shielded Mylar Cable

The shielded-cable configuration consists of a mylar and metal shield lamination (figure 8-26). The cable is masked prior to each stripping operation to prevent degradation of the insulation and shield beyond the designated area. The shielded cable can be stripped in the same manner as the unshielded mylar cable, except that the shield must be stripped with a chemical such as ferric chloride etchant 35° Baume, or 100 parts nitric acid to two parts hydrochloric acid by volume.

8.4.3 H-Film FEP Teflon Bonded Cable

8.4.3.1 Unshielded H/FEP Cable

Mechanical stripability of the H-FEP insulated, unshielded flat cable depends largely upon the bond strength between conductors and H/FEP-films. In order to strip the cable effectively with the NASA mechanical stripper (figure 8-27) the cable must have low bond strength between the insulation and conductor. Nickel plating appears to alleviate some of the problems of too strong a bond.

8.4.3.2 Shielded H/FEP Cable

The most expeditious method developed to date, to consistently strip H/FEP solid-shielded flat cable, is described in this section as are experimentation and results, and the possibility of improving this stripping method.

As with the unshielded cable, low bond-strength between the insulation and conductors is necessary to successfully strip the cable. A step-by-step approach is listed below.

- a. Expose the conductors
 1. Ensure that the end of the cable is cut perpendicular to the conductor.
 2. Backstrip one side of the cable with the NASA mechanical stripper, as shown in figure 8-28.
 3. Tear off the peeled-strip of insulation (figure 8-29).
 4. Measure required distance of 0.475 ± 0.1 shown in figure 8-29. Cut to the required dimensions.
 5. Peel off the back layer of insulation as illustrated in figure 8-30, strip the peeled-back layer of insulation with Tool No. 1T11128 (figure 8-31).
- b. Exposing the shield
 1. Leave the cable clamped in Tool No. 1T11128, and slide the forward block back to position Z.
 2. Secure the block in place with key pins and pressure clamps.

3. Apply heat to the exposed cable with the heat gun, or equivalent, as shown in figure 8-32. The heat gun, upon obtaining a temperature of 750°F, will have an accompanying air blast of 7 cubic ft/min, 1 inch from the nozzle.
4. Loosen the top layer of H-film with the sharp blade of an exacto knife or other sharp instrument.
5. After the layer of H-film is loosened back to the knife edge on the tool, tear off the loose layer of H-film. Tweezers may be used as an aid in tearing the H-film.
6. Loosen the clamps and remove the positioning key pins.
7. Slide the block back to position y, insert the pins, and apply the pressure clamps.
8. Apply heat to the layer of shielding with a knife or equivalent instrument.
9. Peel the layer of shielding back to the knife blade on the tool.
10. Tear off the loose layer of shielding against the knife blade, using tweezers if necessary.
11. Loosen the clamps and remove the positioning key pins.
12. Slide the block to position Z and clamp. The exposed layer of shielding should be visible at the knife.
13. Scrape the area with a dull blade as shown, applying heat as necessary, to remove the residual FEP from the shielding area.
14. After all FEP has been removed in this manner, complete the operation by rubbing the shield briskly with a rubber ink eraser until the metallic surface is free of teflon and oxides.

c. Protect the conductors.

8.4.4 Unshielded TFE Teflon Cable

This cable can be stripped by an abrasive-type stripper. The NASA mechanical stripper can also be used if the bond strength to the conductors is low.

Other methods tested for stripping polyimide FEP cable follow.

8.4.4.1 Induction Heating

An induction heater, in the frequency range that heats the conductors and/or shield but not the insulation, does not heat the cables sufficiently to cause delamination between the insulation and the conductors. If an induction heater is used in the frequency range that heats the insulation, it may cause delamination of the cable and allow stripping. This method requires further investigation.

8.4.4.2 Laser Stripping

A CO₂ laser, developing a 10.6-micron wave length that is reflected by conductors and absorbed by the teflon and an H-film insulation, was focused on a 0.5-mm diameter spot, creating power densities of 2000 watts/cm², and stripped the cable as follows: This concept was used to determine if H-film and/or teflon FEP could be vaporized; in both instances it vaporized the material. Several passes must be made across the cable to remove the insulation. The values stated are not necessarily optimum, but are based on preliminary testing. From the testing accomplished it appears that laser stripping of FCC is not feasible.

8.4.4.3 Grit Blasting

A grit blasting machine developed by S. S. White, and shown in figure 8-33, can be used. The pressure, time, and a basic grit can be varied in any combination. Many types of grits will remove the H-film, but there are problems in removing the FEP without harming the metal shield or conductors.

8.4.4.4 Gore Stripper

The gore stripper was tested with a standard blade and with a modified blade. The standard blade has a tendency to break off the conductors when tension is applied. The modified blade is designed for shielded cable, and works in approximately the same manner for stripping conductors. The modified blade cuts the insulation and pulls it away from the conductors. It will strip fairly well, as long as the conductor or shield is not bonded to the insulation.

8.4.4.5 Cryogenics

H-film, with FEP used as the bonding agent, is not noticeably affected when immersed in liquid helium, nor does it become brittle at cryogenic temperature. Polyimide/FEP flat-conductor cable was immersed in liquid helium and flexed, with no apparent effect on the insulation. It was hoped that the insulation would become brittle when subjected to cryogenic temperature, and could be broken off; however, this was not the case.

8.5 Sources of Materials

The following paragraphs define the effort expended in an effort to determine materials that might improve the fabrication and performance of flat-cable systems.

8.5.1 Molding Materials

Three basic types of molding materials show promise for use in the pre-molded plug assemblies. These are discussed in the order of ascending thermal resistivity.

8.5.1.1 Diallyl Phthalate

This material was selected because of its temperature capabilities to 200°C, and because it has been easily molded in the past with good results. The plugs for this program were injection molded. The material can also be compression molded for a stronger, less brittle plug; however, this method is more costly.

8.5.1.2 Epoxy, Glass-Filled

Types of this material are more heat-resistant than the diallyl phthalate material, but the dimensions may be a little harder to control for small areas because of the glass filling. This filling also tends to make the molded part brittle. Plug design should consider these limitations.

8.5.1.3 Polyimide

This material has very high heat resistance, over 200°C, but it is just emerging from the development stage into the production stage. American Cyanimide Co., has developed a thermoplastic, heat resistant polyimide polymer that is compression-moldable, but only at very high mold temperatures. American Cyanimide is also developing an injection-moldable material. Excellent electrical, thermal, and mechanical characteristics should be achieved.

This material holds the most promise for the future, because of its high thermal resistance and its compatibility with an all-polyimide cable system.

8.5.2 Insulation Material

Several types of high temperature (200°C and above) insulations were evaluated for applicability to flat-cable fabrication. The following is a brief synopsis of the result of this study.

8.5.2.1 TFE Teflon

TFE is milky-clear insulation material with good electrical properties, good temperature properties, 250°C, but rather poor mechanical properties (low tensile strength of 3000 psi). It is impervious to almost all known solvents, which creates a stripping problem. TFE cannot be bonded to other materials without bondizing the surface. This, too, causes a problem in creating a continuous fabrication process which involves other materials.

8.5.2.2 FEP Teflon

FEP has chemical properties similar to TFE teflon, except without special surface preparations it will bond to itself and to other materials. This material lends itself well to continuous-run fabrication.

8.5.2.3 Polyester (Mylar)

This material performs well up to temperatures of 140°C; it is impervious to many chemicals, but can be selectively chemically stripped for use in the NASA connector configuration. It is strong, mechanically, can be

bonded with polyester adhesives, adapts well to a continuous-run fabrication process.

8.5.2.4. Polyimide (H-Film)

This material has excellent thermal characteristics to 300°C. It has good mechanical properties and can be bonded to itself with an adhesive. With the aid of an appropriate adhesive, this material lends itself to continuous-run fabrication.

8.5.3 Bonding Material

Several materials were evaluated for use as high-temperature bonding for flat-cable construction. The following is a brief synopsis of the results of this study.

8.5.3.1 FEP Teflon

FEP, which will withstand temperature to 200°C, can be used in bonding H-film by the methods described under cable fabrication (paragraph 8.2.1). This creates a good bond, but no reliable method has been developed for stripping of shielded cable. However, the unshielded cable can be easily stripped mechanically. FEP cannot be chemically removed, which limits the use of this cable.

8.5.3.2 Epoxy

No epoxy was found that was suited to the required temperatures. Epoxies in the 250°C operating temperature range tend to be too brittle for use as flexible adhesive. Epoxies coming in two or more parts creates a problem for continuous-cable fabrication, but not an insurmountable one.

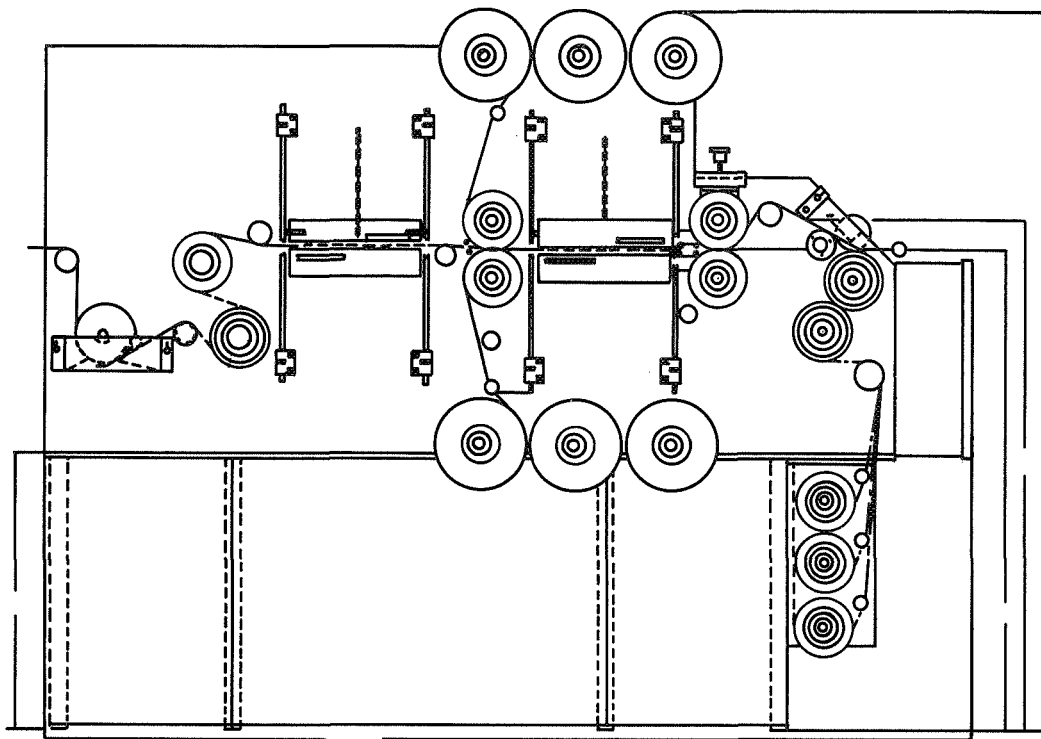
8.5.3.3 Polyimide

These adhesives offer the most promise because they operate over the same temperature range as the polyimide film. They are a one-part adhesive, but require severe curing conditions. Three companies that make

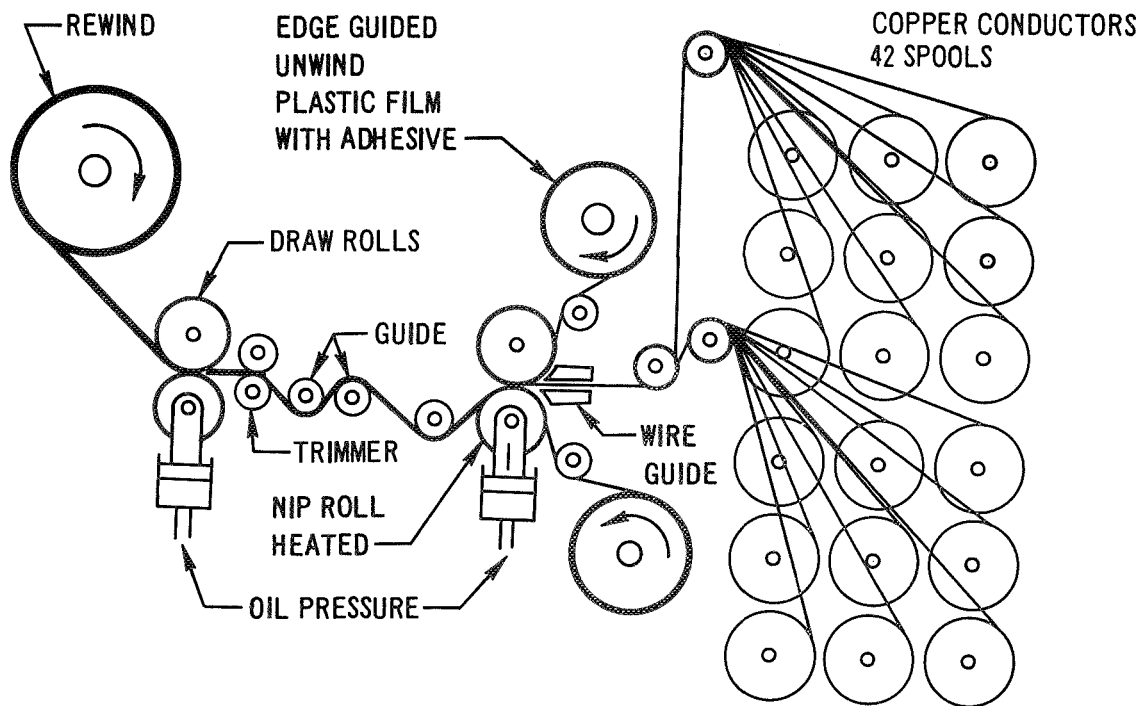
these adhesives are Thermo Resist, Inc., Fullerton, California; Quantum, Inc., Wallingford, Connecticut; and E. I. DuPont, Inc., Wilmington, Delaware.

8.6 Conclusions and Recommendations

During the course of this contract, several methods of fabricating flat-cable configurations were analyzed. H/FEP cable was selected, primarily because of its availability. An all-polyimide cable system, however, is the most promising flat-cable system, because of its high temperature resistance, high strength, and especially its adaptability to chemical stripping--a characteristic that is lacking in H/FEP cable.



A. FULLERTON FLAT CABLE COLD PINCH LAMINATOR – MODEL NO. 1330



B. SCHEMATIC OF FLAT CABLE HOT PINCH LAMINATOR

Figure 8-1. Typical Laminating Machines

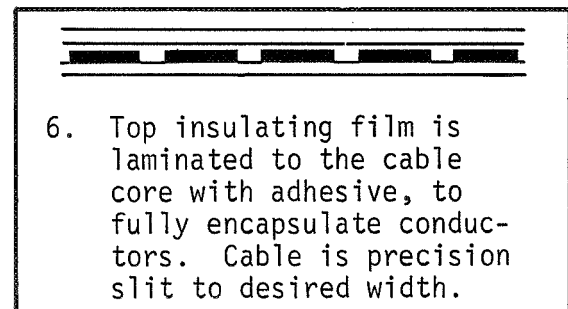
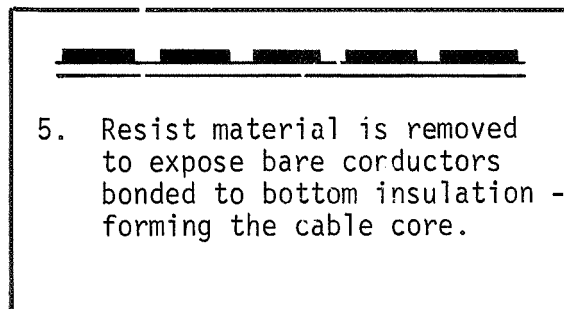
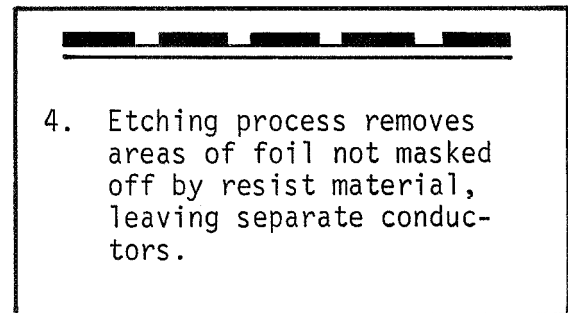
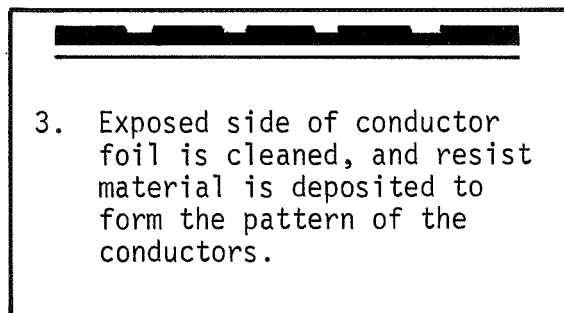
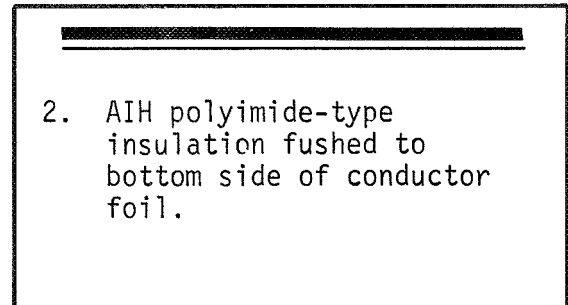
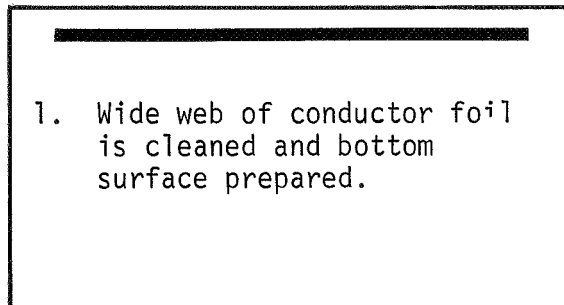


Figure 8-2. Photo Etch Process

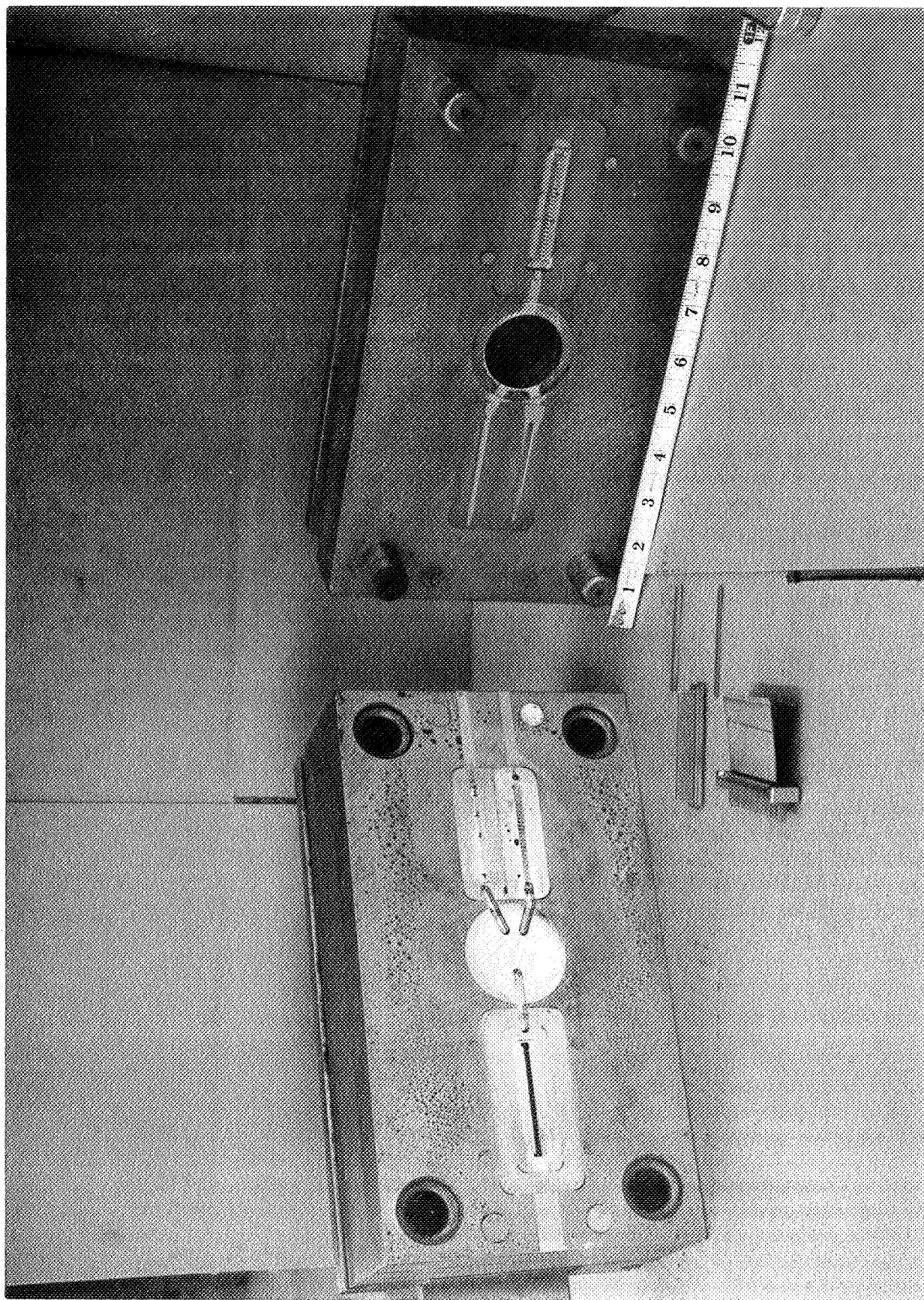


Figure 8-4. Shielded-Plug Dies

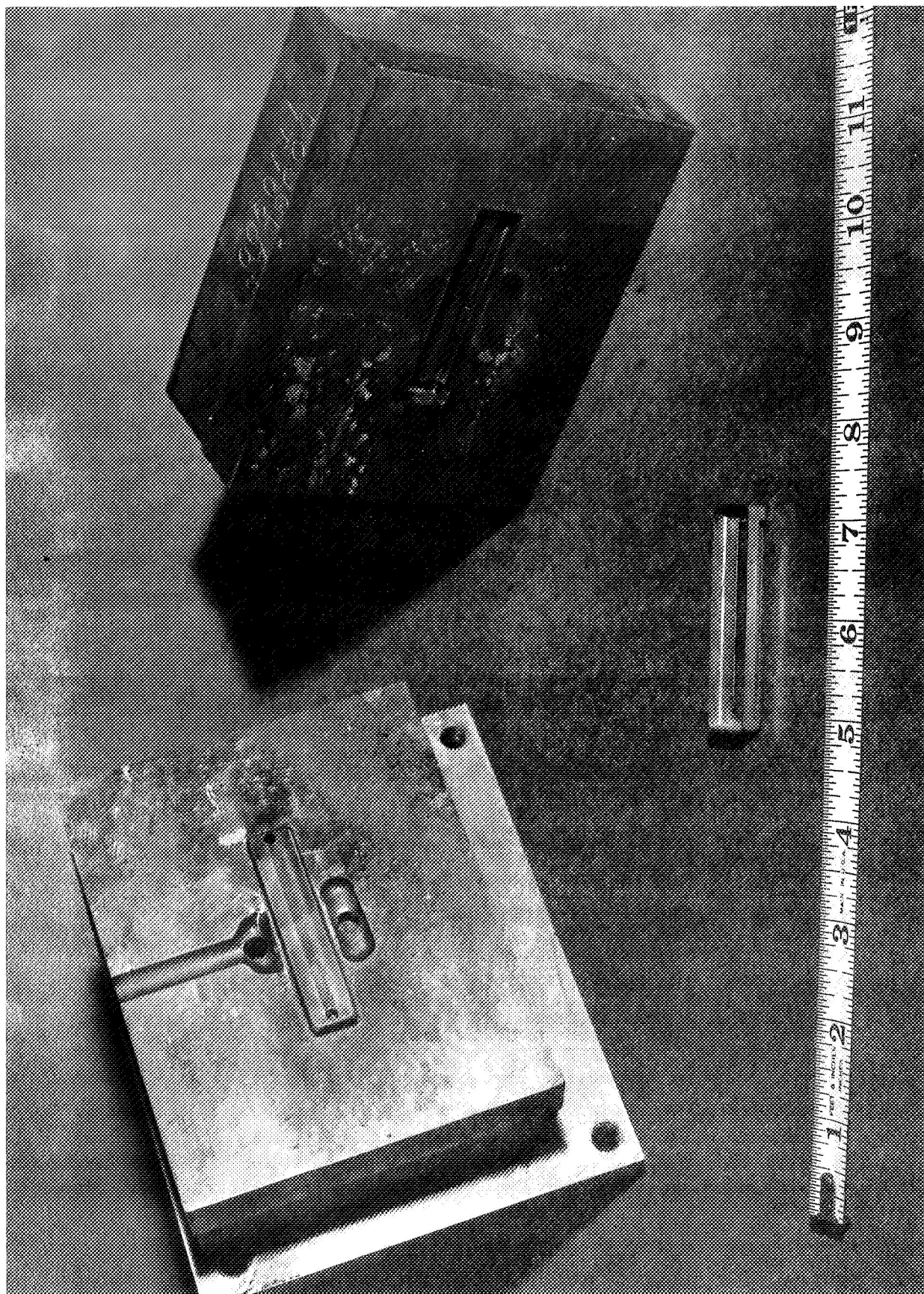


Figure 8-5. Backshell and Dies

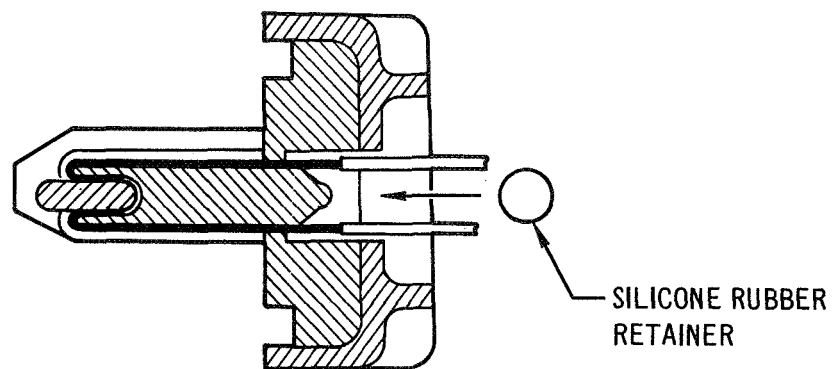


Figure 8-6. Retainer Assembly

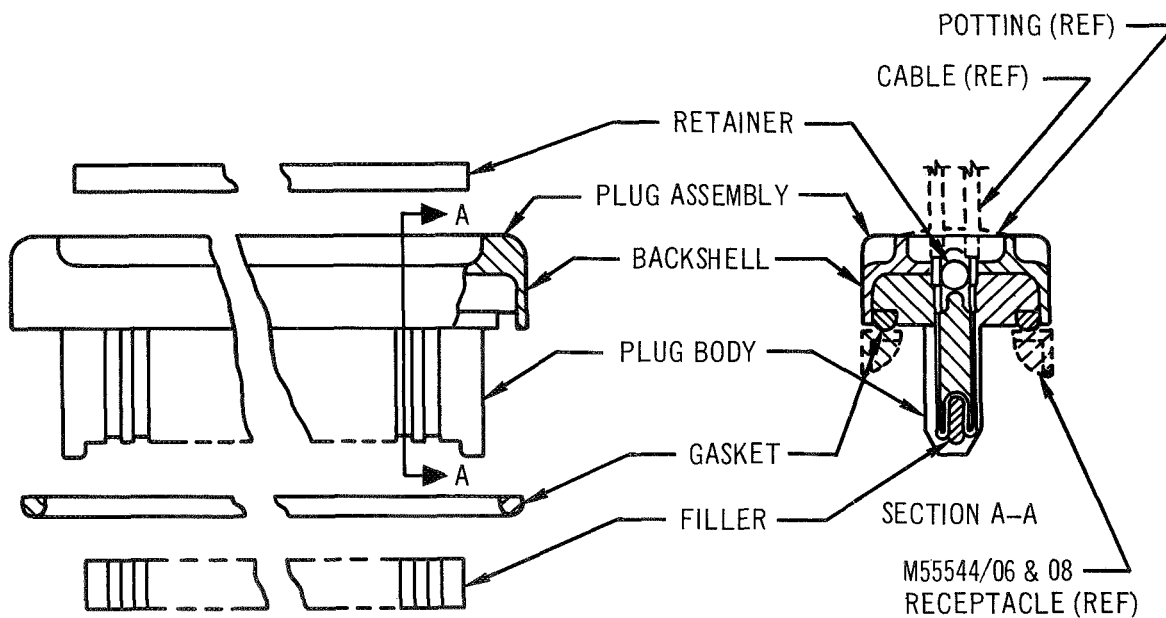


Figure 8-7. Shielded-Plug Parts

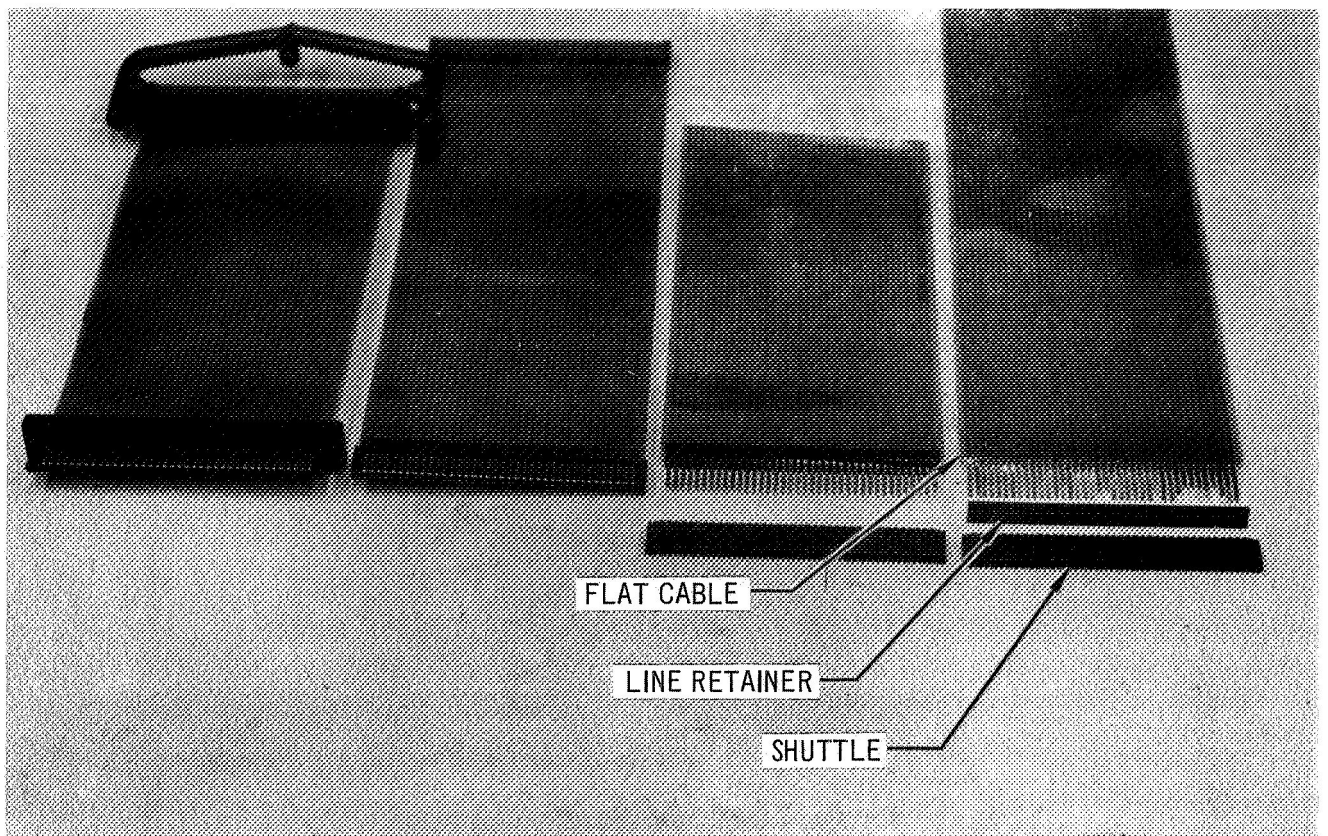


Figure 8-8. Unshielded Molded-On Plug

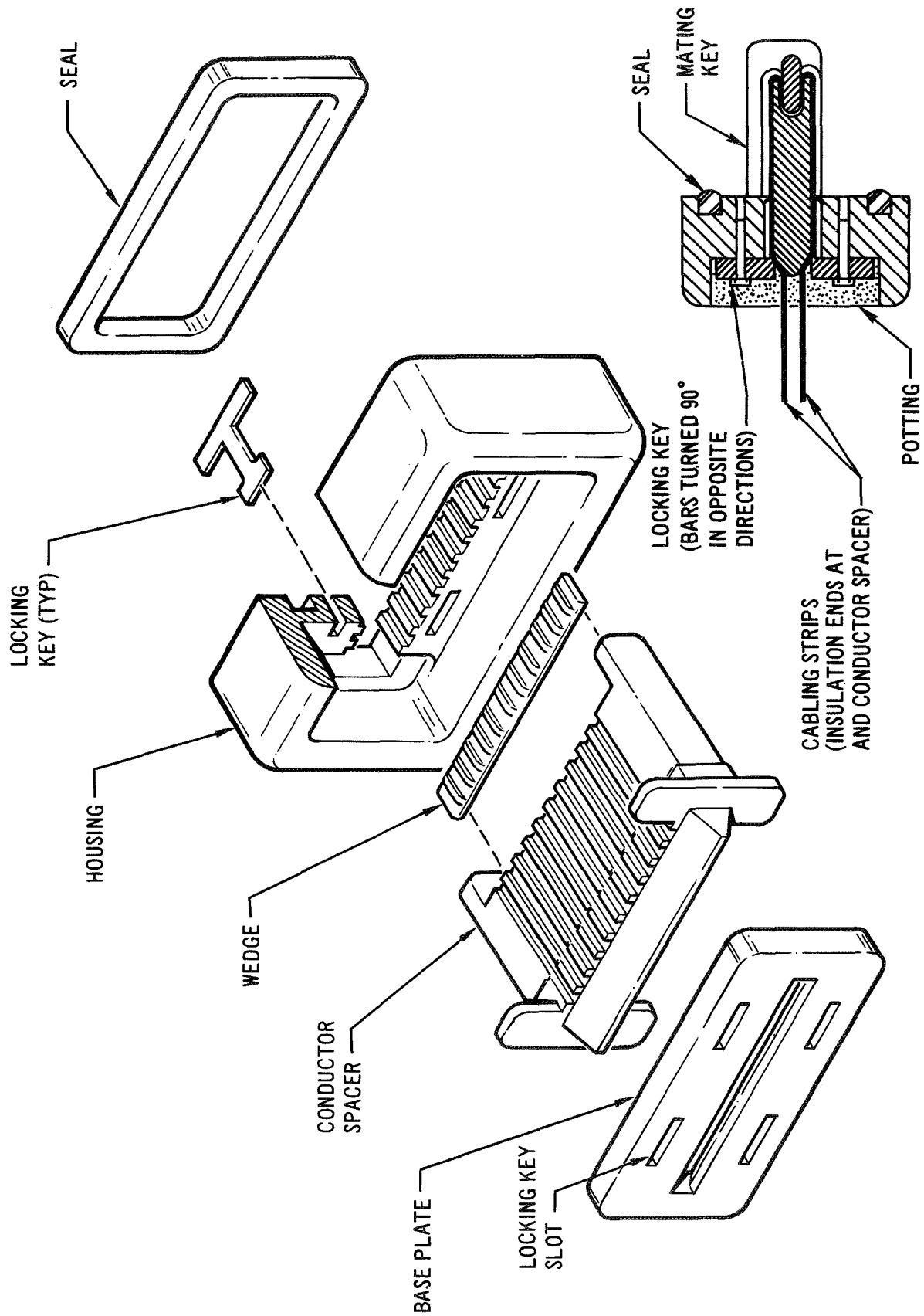


Figure 8-9. Typical Makeup of a Premolded Plug Termination

SHIELDED FLAT
CONDUCTOR CABLE
(REF)

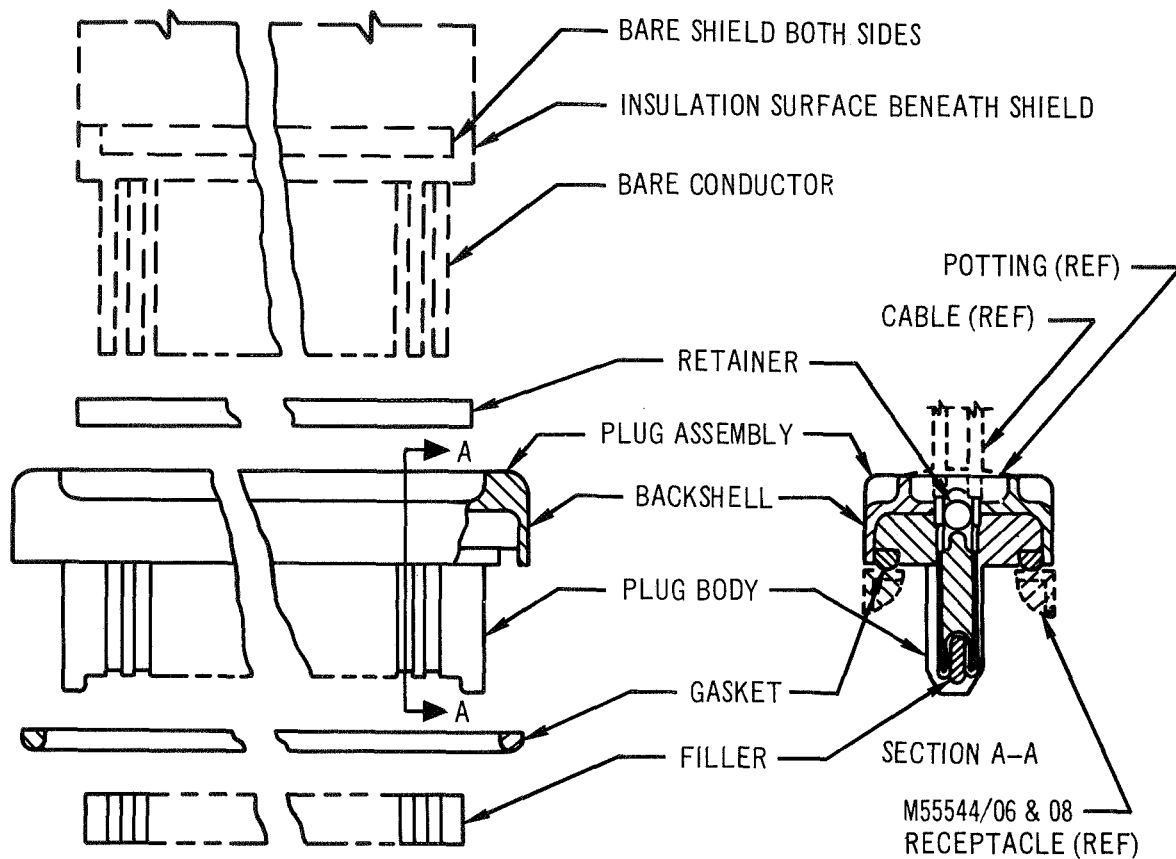


Figure 8-10. Shielded Plug Parts

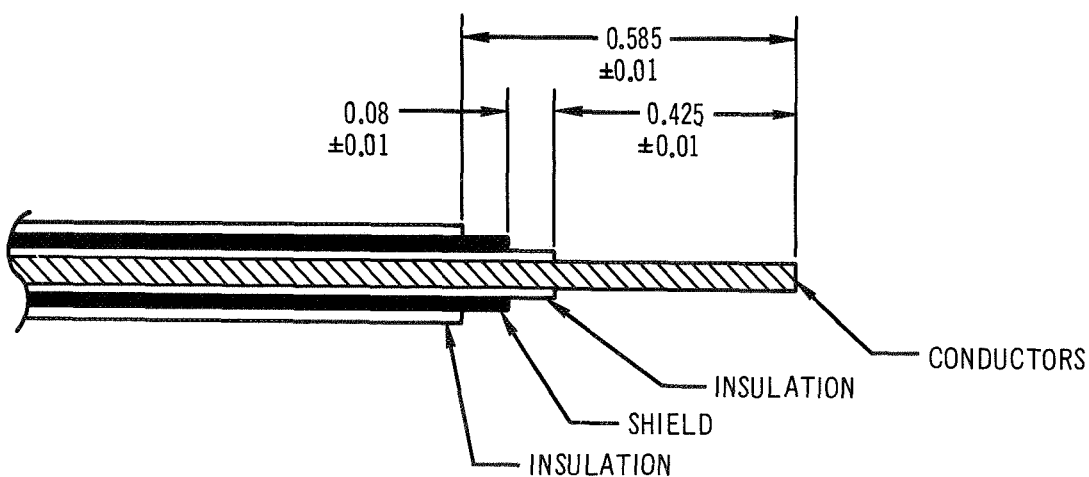


Figure 8-11. Stripped Cable

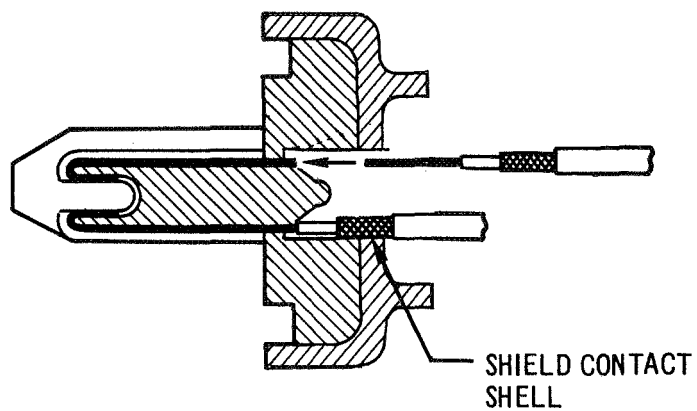


Figure 8-12. Inserting Stripped Conductors

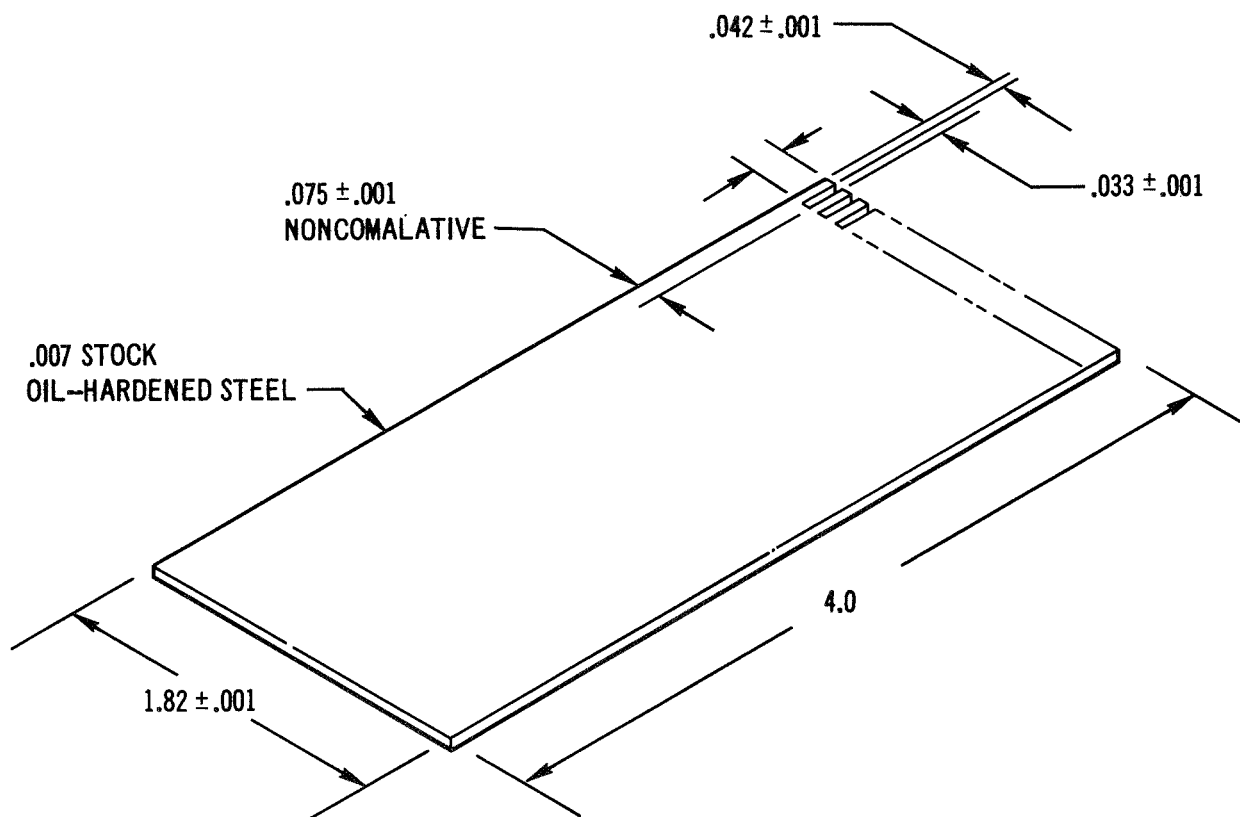


Figure 8-13. Cleaning Tool

PM11200 - GEORGE C.
MARSHALL SPACE
FLIGHT CENTER

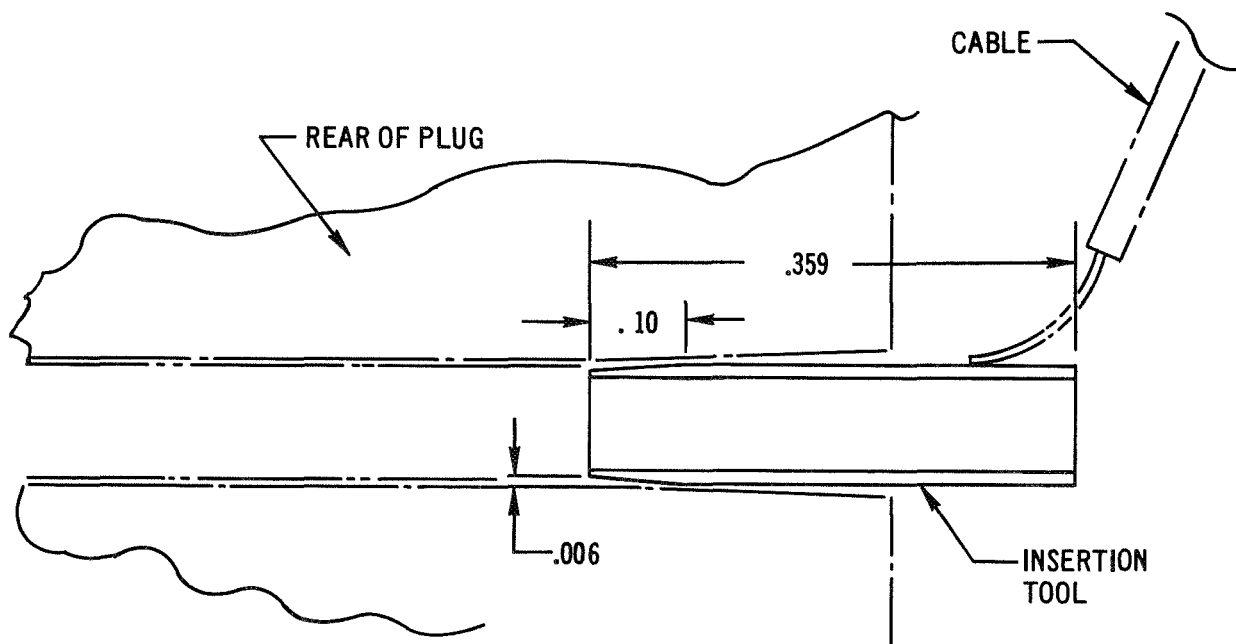
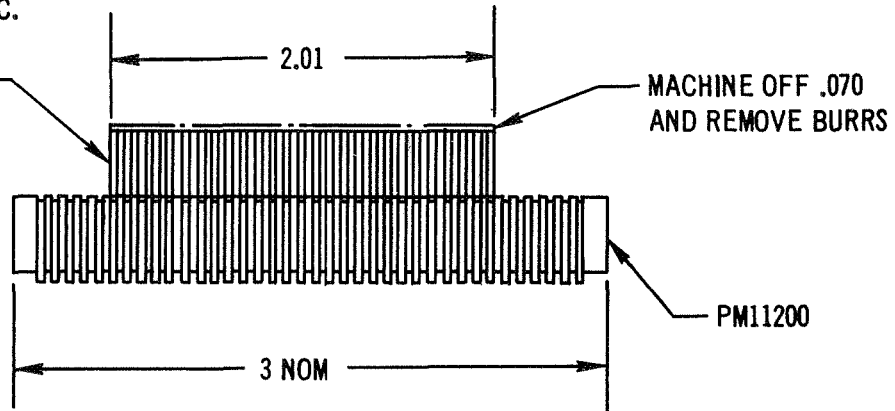


Figure 8-14. Conductor Insertion Tool

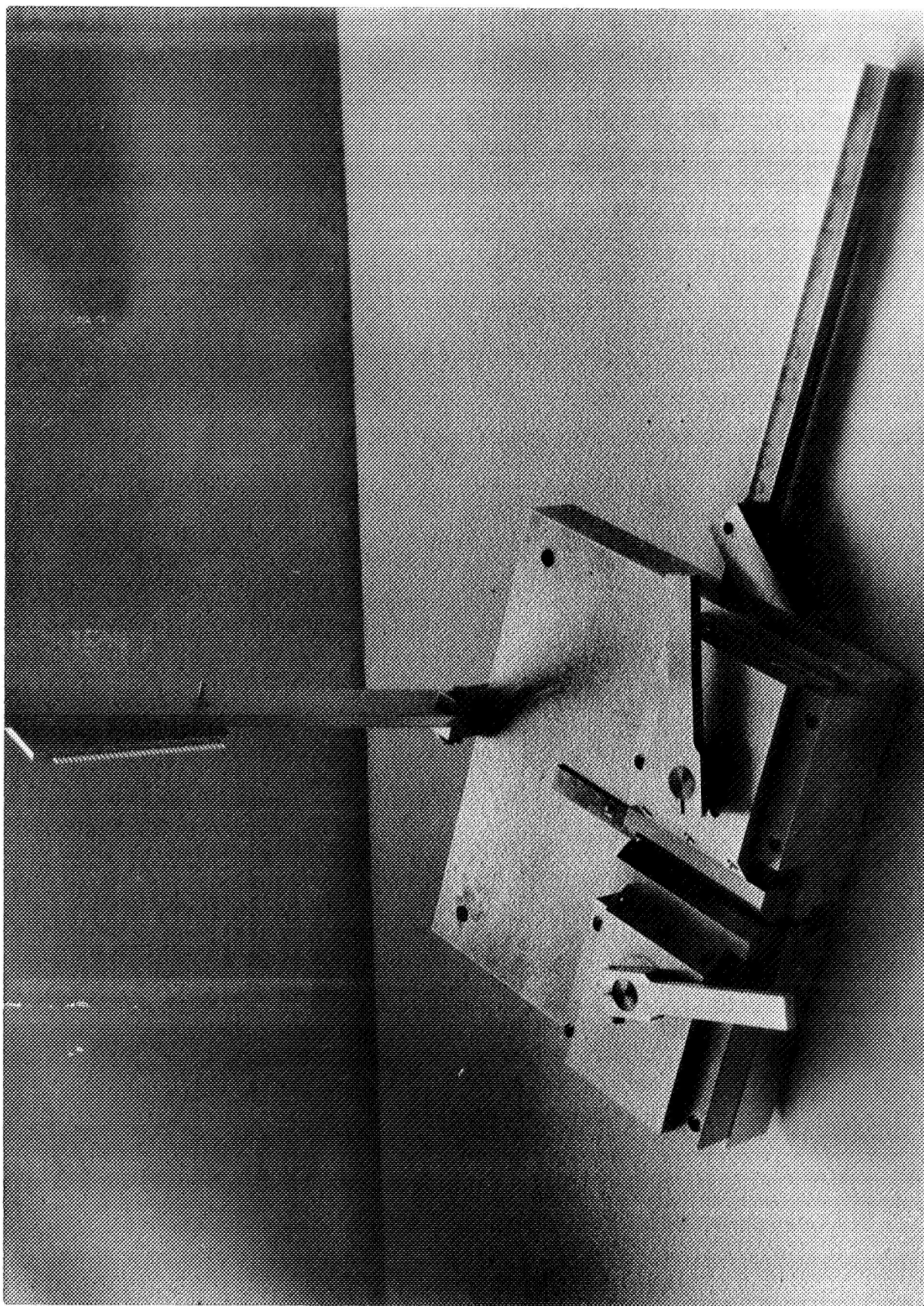


Figure 8-15. Conductor Folding Tool

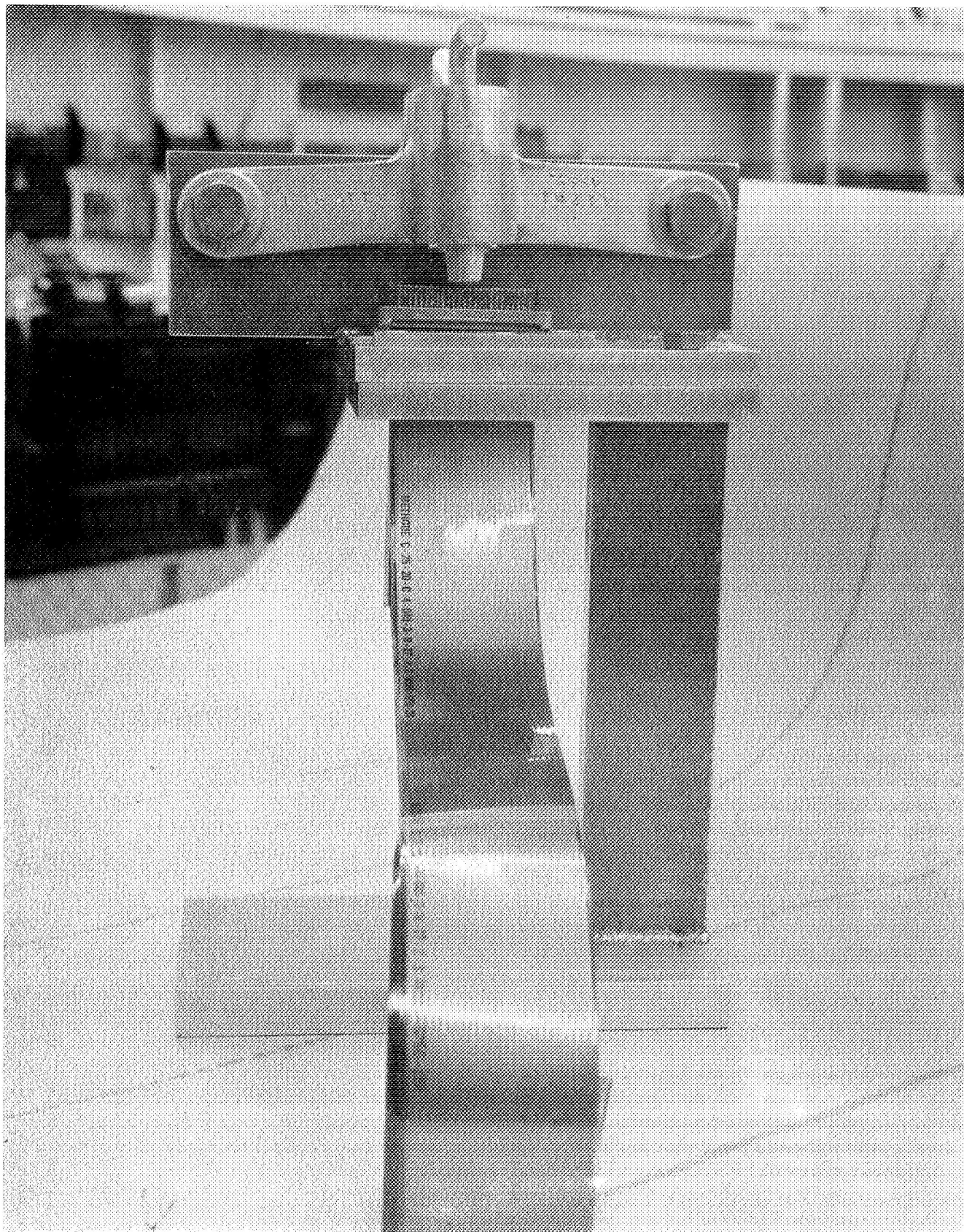


Figure 8-16. Bonding Filler

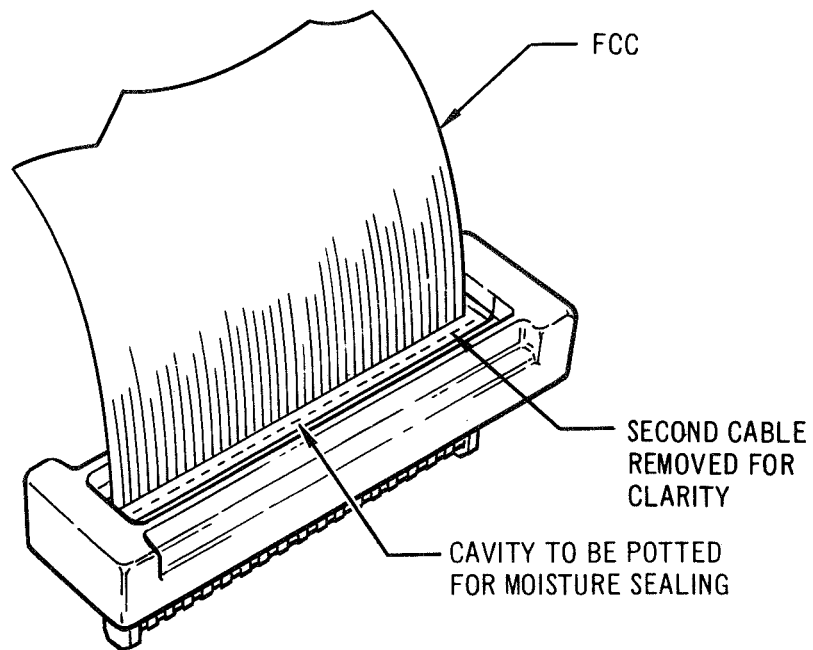


Figure 8-17. Filling Conductor Holes

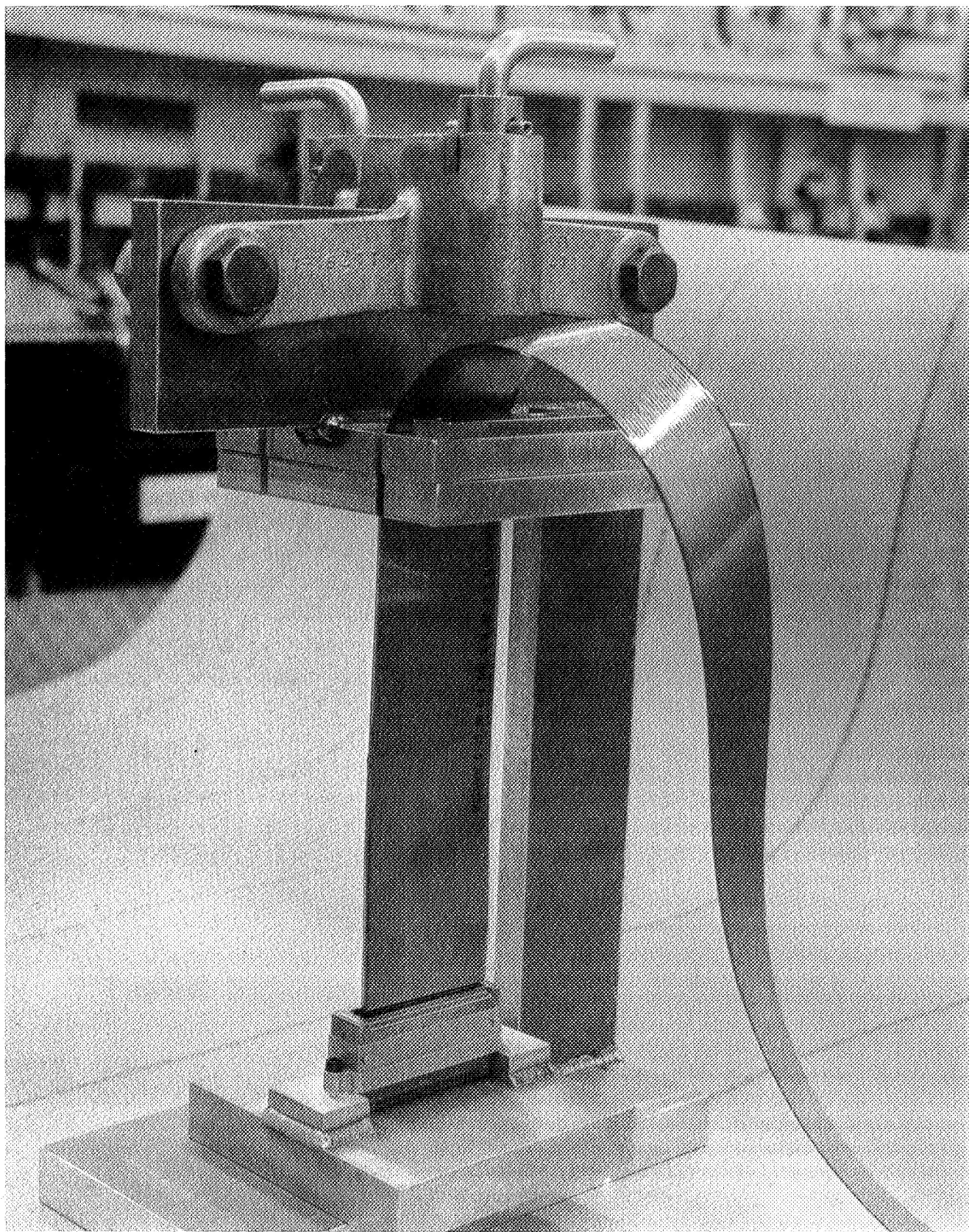


Figure 8-18. Curing Potting Fixture

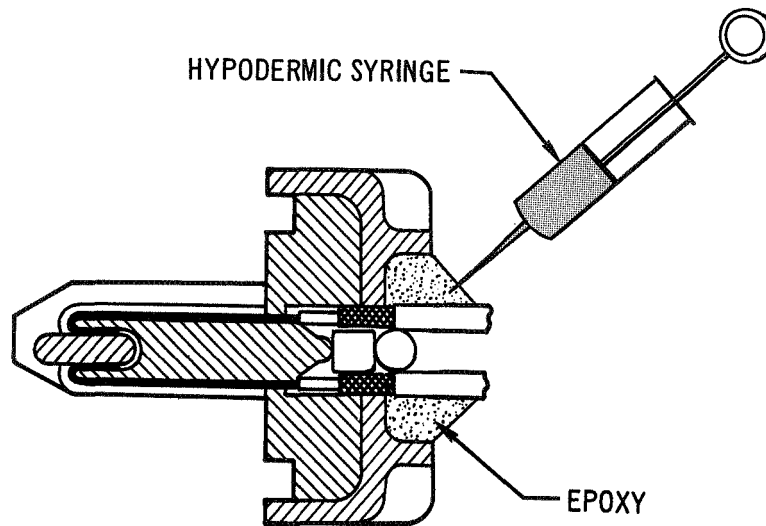


Figure 8-19. Potting Plug

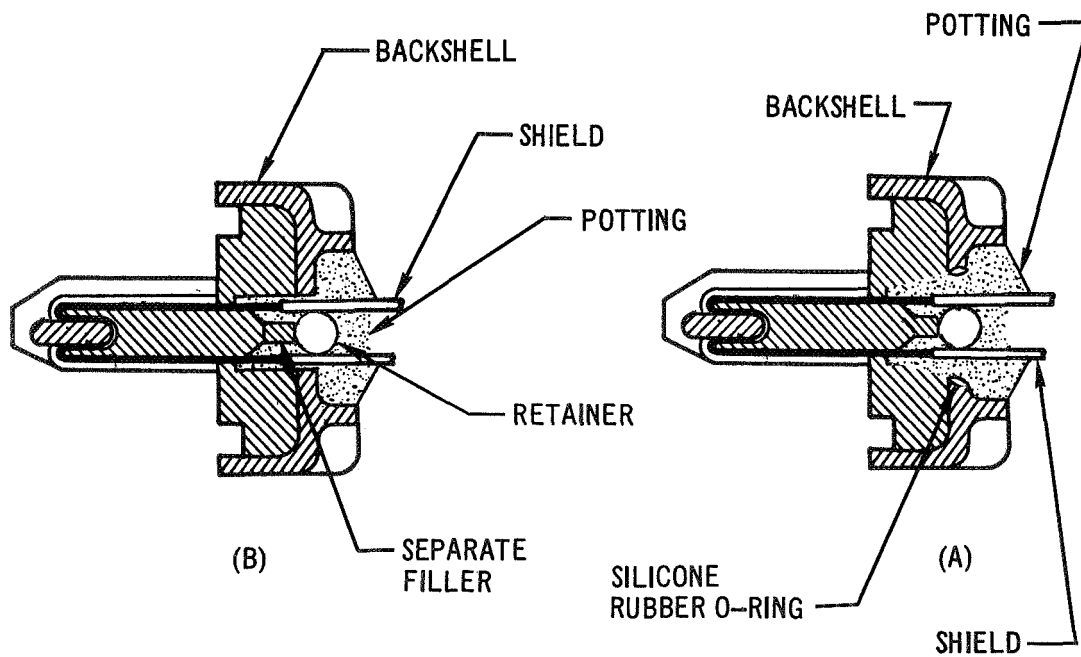


Figure 8-20. Alternate Plug Design Configuration

MATERIAL	STRIPPING METHODS - DACO TESTS - THERMAL & CHEM											
	HOT AIR GUN		INDUCTION		HUGHES		NASA		LASER		CHEMICAL	
	EFFECT	CLASS	EFFECT	CLASS	EFFECT	CLASS	EFFECT	CLASS	EFFECT	CLASS	EFFECT	CLASS
H/FEP SCREEN SHD		1		2		3		4		6		7
H/FEP SOLID SHD		1		2		3		4		6		7
H/FEP PERF SHD		1		2		3		4		6		7
H/FEP PERF SHD		1		2		3		4		6		7
ALL POLY UNSHIELDED		4		4		4		3		6		7
ALL POLY CU SHIELD		4		4		4		4		6		7

CLASS:

1. FEP BONDS DELAMINATE AT $\approx 800^{\circ}\text{F}$. THE LAYERS OF INSULATION CAN BE PULLED BACK AND CUT AS REQUIRED.
2. FEP BONDS DELAMINATE SLIGHTLY BUT NOT ENOUGH TO SEPARATE LAYERS.
3. STRETCHES CONDUCTORS, LEAVES INSULATION.
4. LITTLE OR NO EFFECT.
5. GOOD STRIP.
6. H-FILM AND FEP BOTH REMOVED WITH THE POSSIBILITY THAT A SLIGHT AMOUNT OF INSULATION WILL REMAIN ON CONDUCTORS.
7. H-FILM IS REMOVED WITH A HOT CAUSTIC SOLUTION. FEP IS NOT AFFECTED BY KNOWN CHEMICAL SOLVENTS.



DARKENED AREA INDICATES EFFECTIVENESS IN PERCENT

Figure 8-21. Stripping Method Charts (Sheet 1 of 2)

MATERIAL	STRIPPING METHODS - DACO TESTS - THERMAL & CHEM											
	HOT AIR GUN		INDUCTION		HUGHES		NASA		LASER		CHEMICAL	
	EFFECT	CLASS	EFFECT	CLASS	EFFECT	CLASS	EFFECT	CLASS	EFFECT	CLASS	EFFECT	CLASS
H/FEP SCREEN SHD		1				2		3		4		5
H/FEP SOLID SHD		1				2		3		4		5
H/FEP PERF SHD		1				2		3		4		5
H/FEP UNSHIELDED		1				2		3		4		5
ALL POLY UNSHIELDED		1				2		3		4		5
AL POLY CU SHD		1				2		3		4		5

CLASS:

1. CONDUCTORS BROKE WHEN TRYING TO PULL OFF INSULATION. COULD NOT EXPOSE SHIELD.
2. EXPOSES CONDUCTORS IF THERE IS A LOW BOND BETWEEN CONDUCTORS AND FEP TEFLON WILL NOT EXPOSE SHIELD.
3. CUT CONDUCTORS AND/OR SHIELD.
4. INCONSISTENT REMOVAL OF FEP AND SCRATCHES CONDUCTORS AND/OR SHIELD.
5. REMOVES H-FILM READILY BUT FEP HARD TO REMOVE WITHOUT DESTROYING SHIELD. WORK HARDENS CONDUCTORS.

NOTE: WITH MECHANICAL STRIPPING METHODS, THE CONTOUR OF THE CABLE CAUSES UNEVEN REMOVAL OF THE INSULATION.



DARKENED AREA INDICATES EFFECTIVENESS IN PERCENT

Figure 8-21. Stripping Method Charts (Sheet 2 of 2)

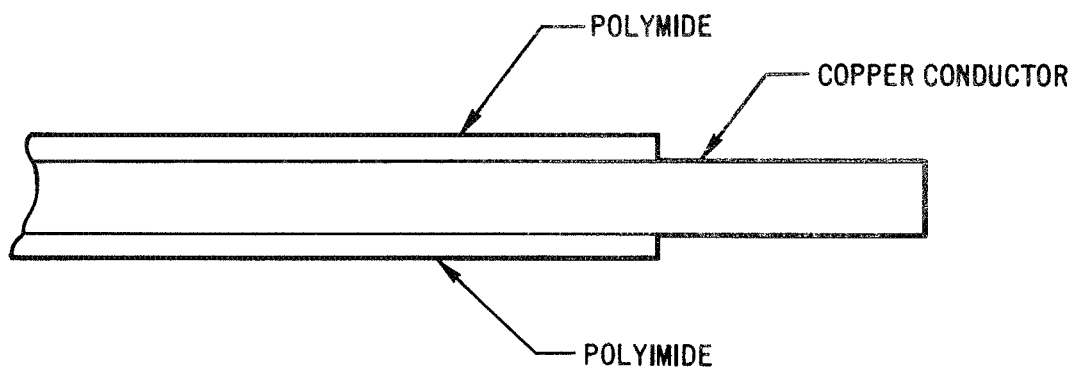


Figure 8-22. Unshielded Polyimide Cable

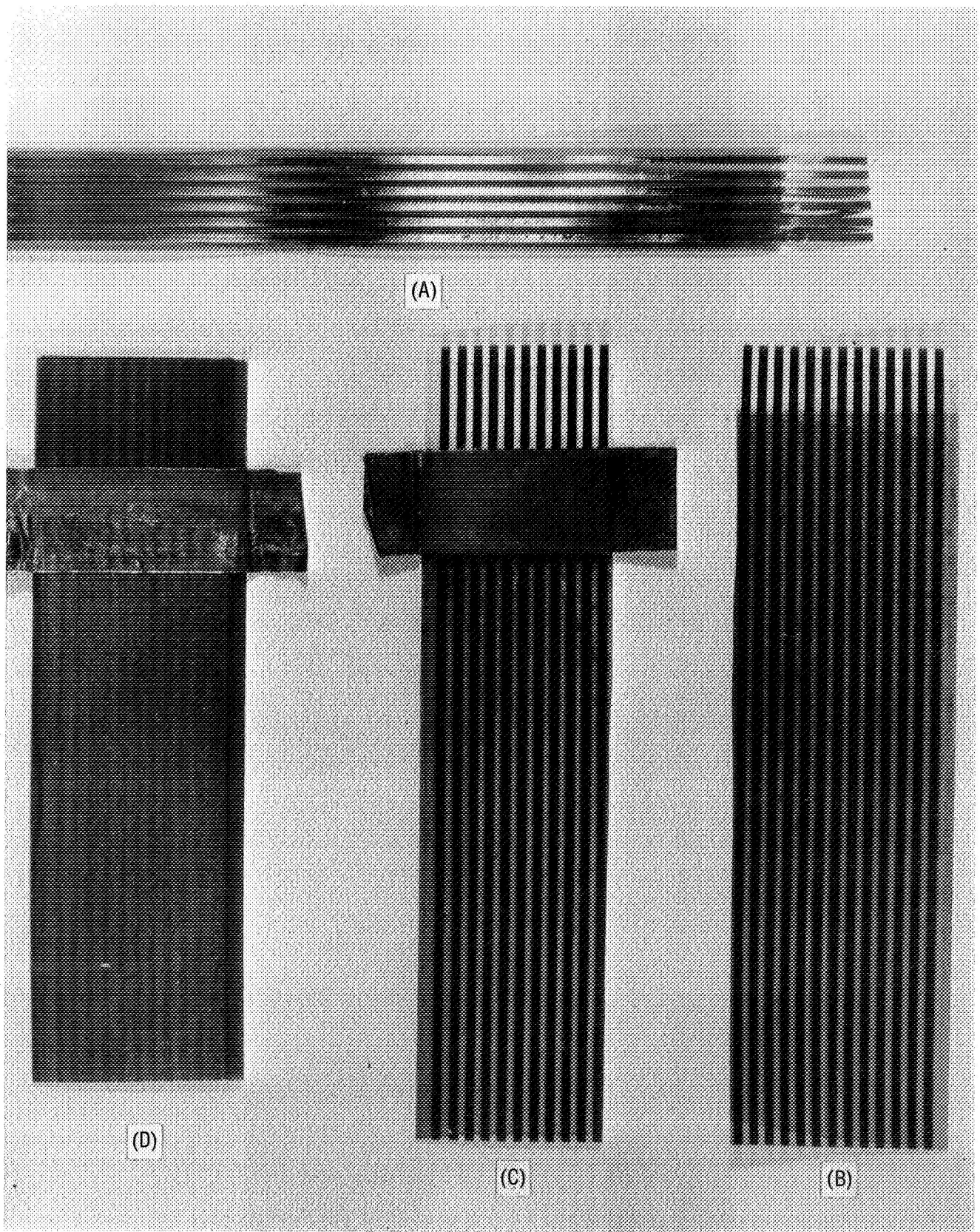


Figure 8-23. Masked and Stripped Cable

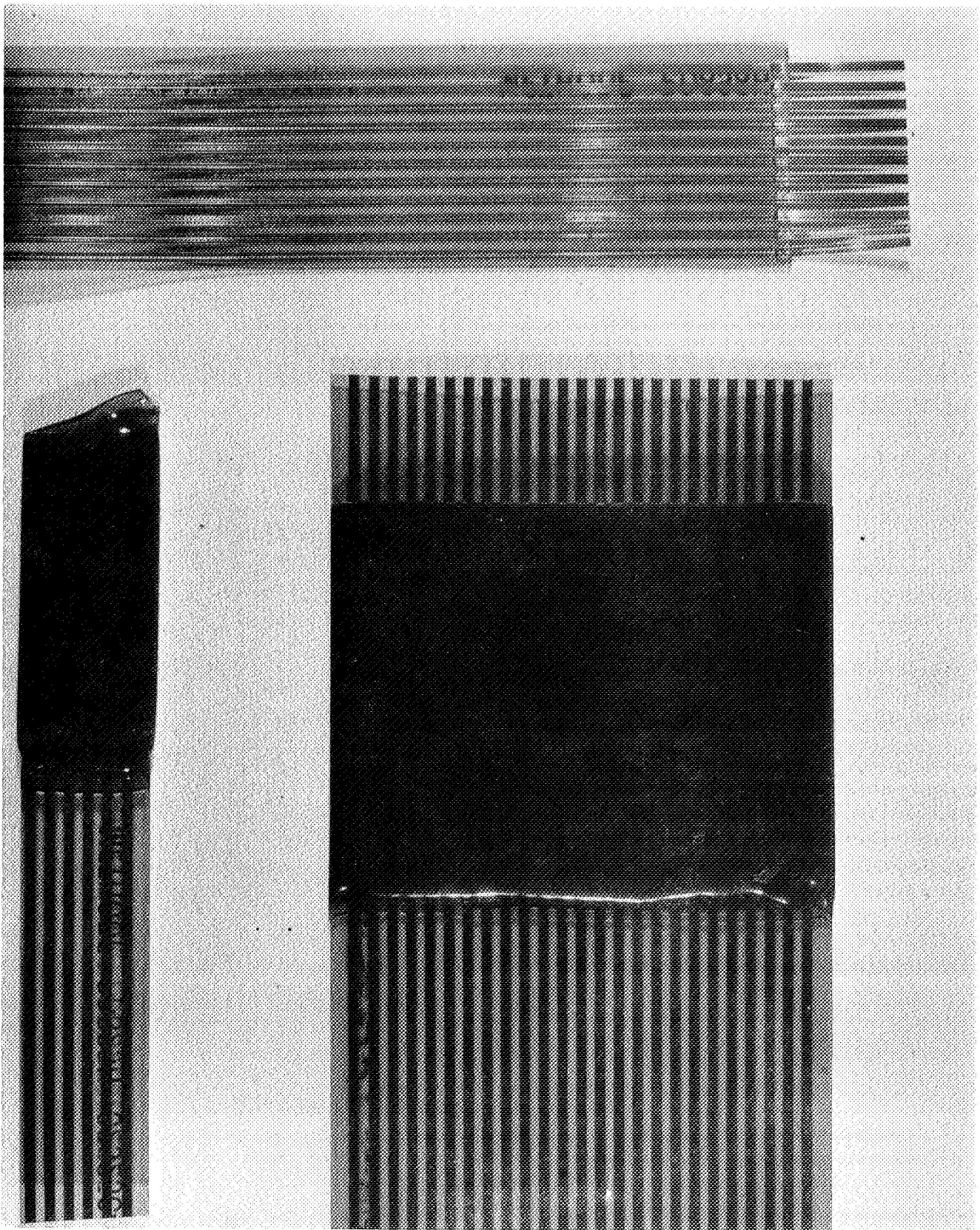


Figure 8-24. Maskcoat Coated and Stripped Cable

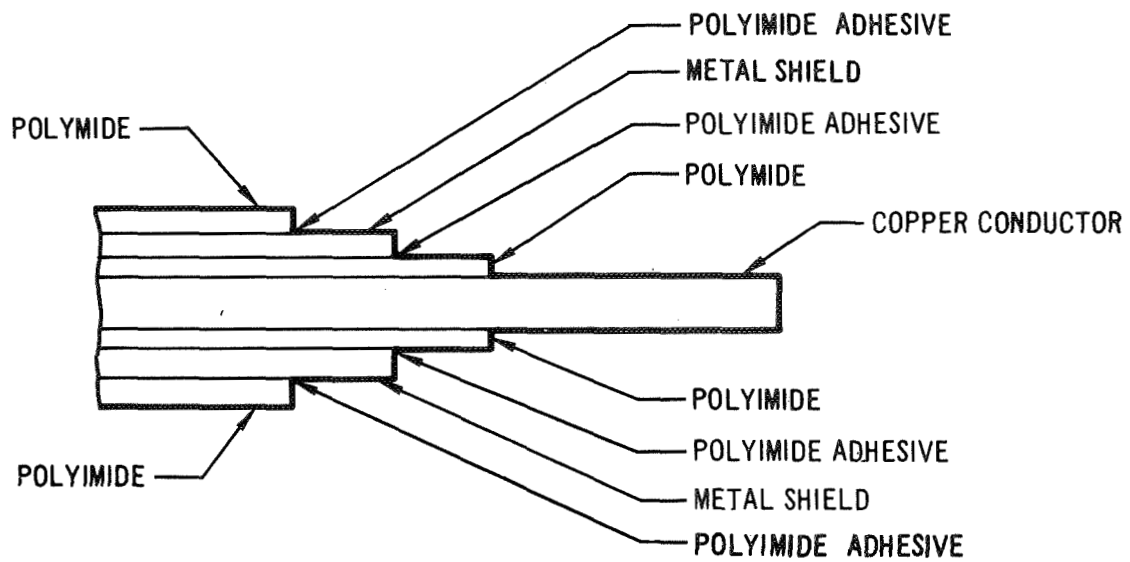
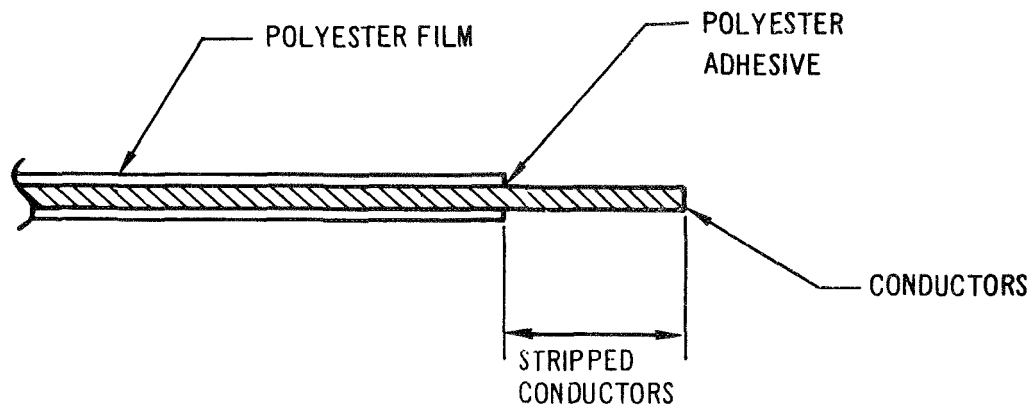
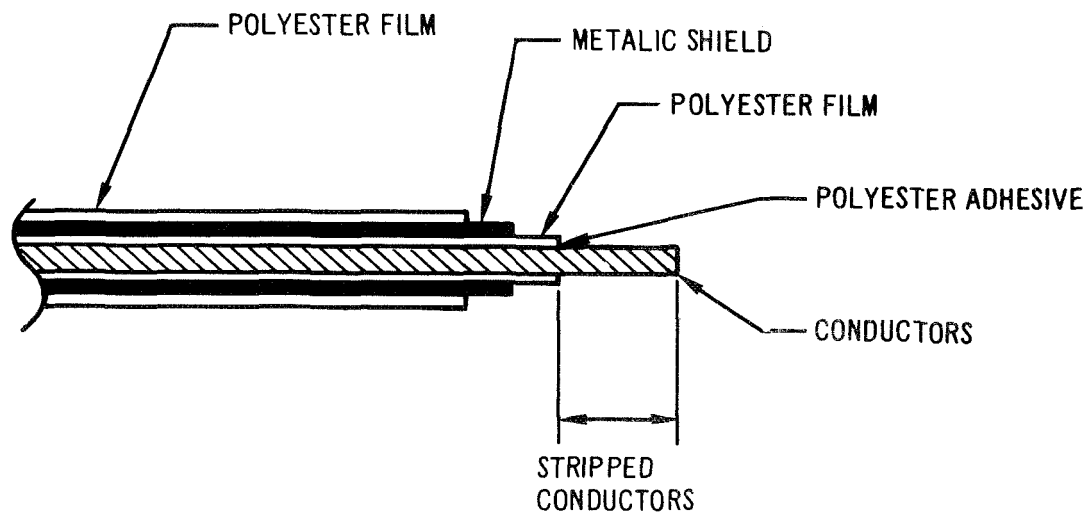


Figure 8-25. Shielded Polyimide Cable



A. UNSHIELDED MYLAR CONFIGURATION



B. SHIELDED MYLAR CONFIGURATION

Figure 8-26. Mylar Cable Configuration

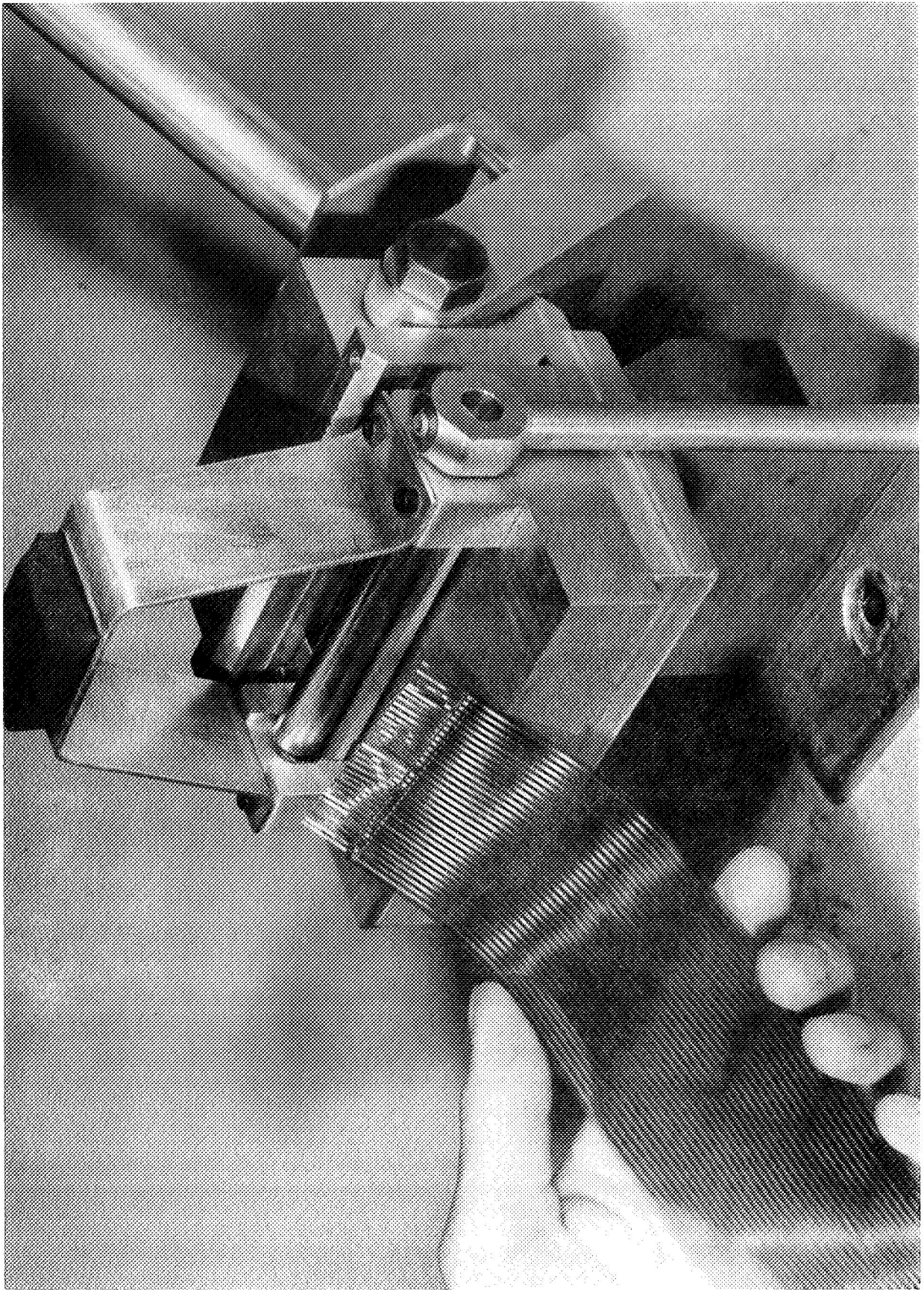


Figure 8-27. NASA/MSFC Developed Mechanical Stripper

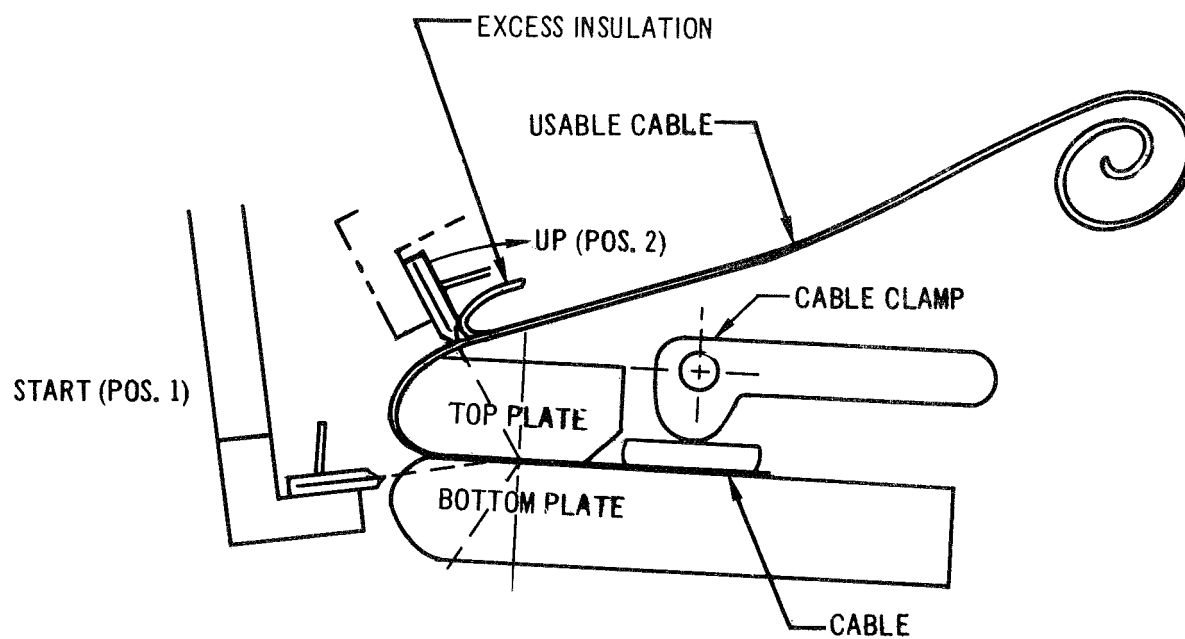


Figure 8-28. Schematic of Cold Stripper For Back Stripping

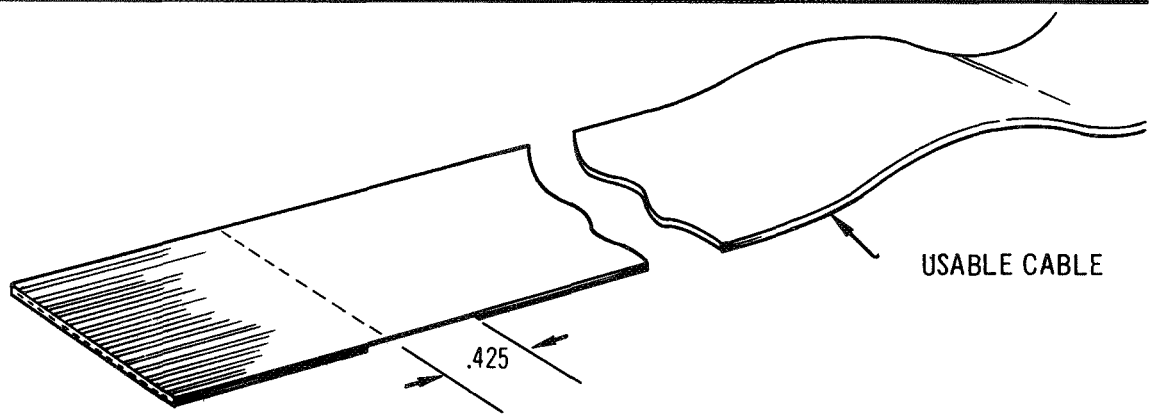


Figure 8-29. Measuring Contacts

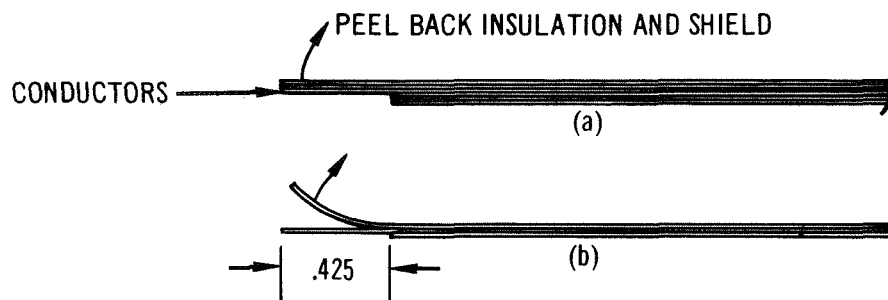


Figure 8-30. Insulation Peeling

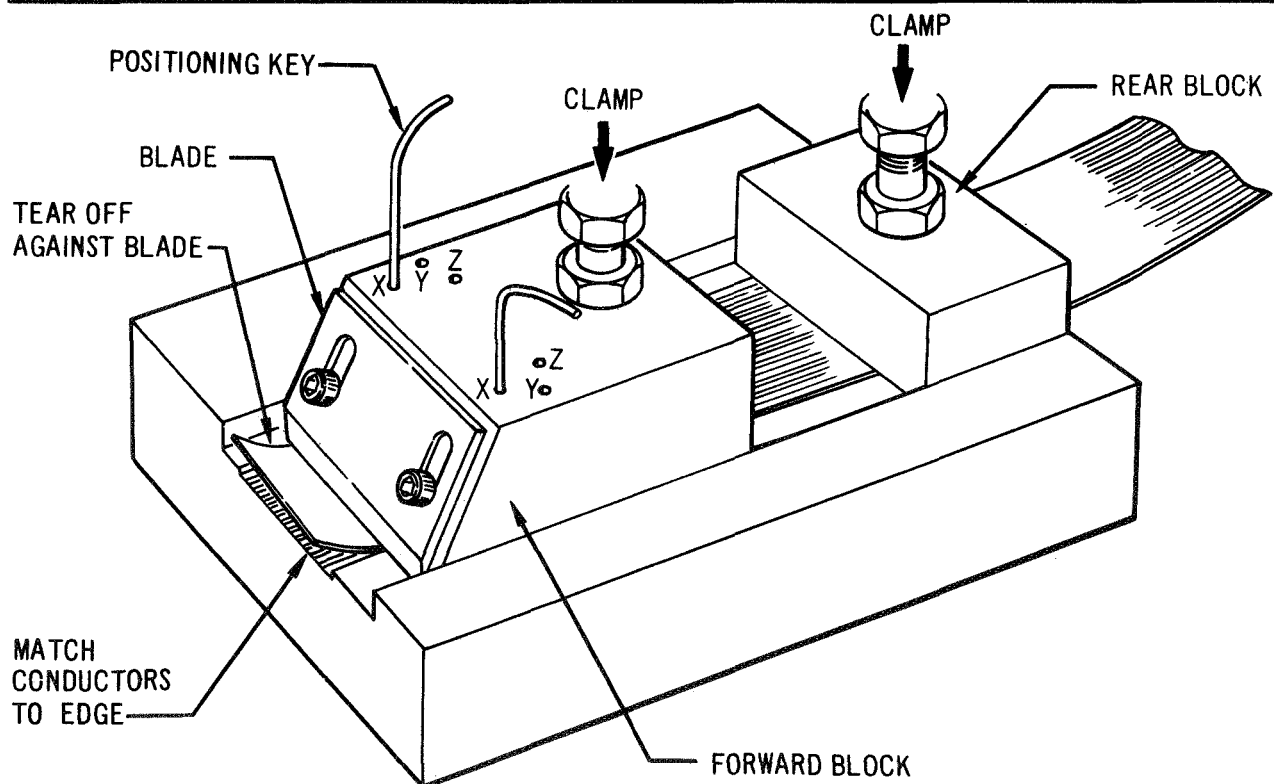


Figure 8-31. Insulation Peeling Tool



Figure 8-32. Applying Heat With Heat Gun

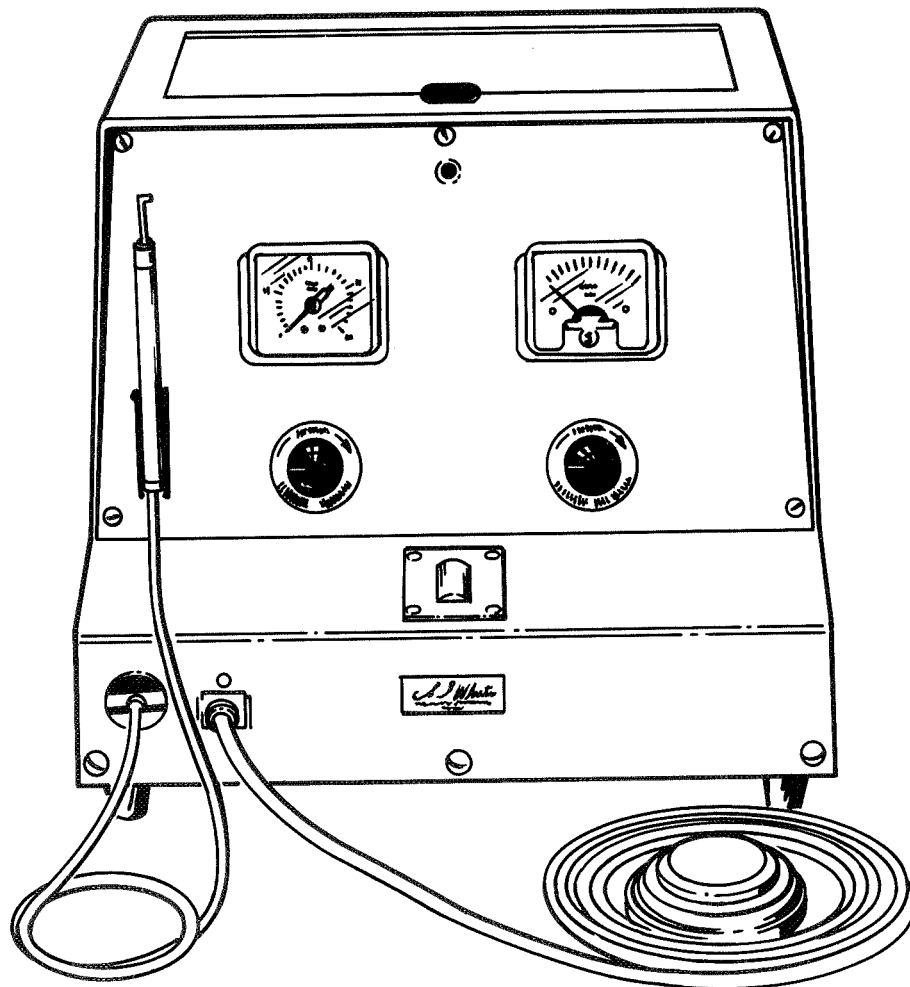


Figure 8-33. S. S. White Airbrasive Unit

SECTION IX

9. MATERIALS RESEARCH AND PRODUCTION METHODS (MR&PM)

9.1 In-House Development, Shielded Flat-Cable

At the outset of this program there was no cable available which utilized a high magnetic-permeability shielding. The work described here was done in an attempt to utilize the following shield materials that were offered for testing:

- a. Lashclad KX high μ material electroplated on Kapton
- b. Lashclad K copper electroplated on Kapton
- c. MU-30

The Lash materials were bonded to Kapton-FEP cables with the metallic side facing both inward and outward from the cables, with and without an outer layer of insulation. In all cases, the layer of shielding material cracked when the test cables were bent over a 1.25-inch-diameter mandrel. Since Lashclad bonded to itself did not crack, it was concluded that the distance from the neutral axis of the shield in the bonded cable, and the low ductility of the Lash material, accounted for the cracking.

A two-foot length of shielded cable was fabricated with 0.001 MU-30 shielding material bonded to a Kapton-FEP cable, using a flexible epoxy adhesive (EPD TC1547). This cable was bent over a 0.25-inch-diameter mandrel without cracking.

Two six-foot lengths of similar cable were fabricated for electrical testing. The shields on both cables were plated on one side with 0.00005 inch of copper and 0.00005 inch of nickel. The shields on one of the cables were joined by soldering.

Testing was also done to determine the feasibility of joining the shields by vapor deposition. Preliminary tests indicated that the shields could be joined by vapor disposition on a laboratory scale. No further work was done on this process to determine whether it were feasible to accomplish it on a continuous basis.

9.2 Chemical Stripping of Cable Insulation and Shielding

An approach to chemically stripping insulation and shielding material from FCC was investigated. It was found that all of the materials in the cable that NASA/MSFC and MDC proposed to use could be chemically stripped, except for the FEP Teflon film used for bonding.

Teflon FEP fluorocarbon film is virtually impervious to all known chemicals and solvents; therefore, any cable system containing FEP as the bonding agent will require a combination chemical stripping and a mechanical, thermal, or other feasible method of removing the FEP.

The termination system developed by NASA/MSFC utilizes the flat conductor itself as the contacting surface for the plug, with no secondary soldering, welding, or other means of terminating required. Inasmuch as the cable conductor serves as the contact surface, the insulation and shield must be removed prior to terminating the cable into the plug.

Bare copper conductors or shields encapsulated in FEP with a polyimide cover layer cannot be chemically stripped unless the exposed end of the cable is suitably masked to prevent the stripping solution from wicking between the conductors and FEP causing a black contaminant to form on the copper surface. Wicking of the solution of 0.50 inch or more is not uncommon. Excessive wicking with bare-copper conductors is due to the porous, metallic surface which promotes capillary action, or a fusion bonding temperature and pressure cycle which does not provide adhesion of the conductors to FEP. Low adhesion of the bond between the FEP and copper used to facilitate mechanical stripping aggravates the wicking condition.

Conductors, plated with nickel before lamination of the insulation, retard wetting of the surface and capillary action by the stripping solution.

9.2.1 Masking and Stripping Procedures

The materials and procedures employed in stripping unshielded and shielded cable are listed below. The unshielded cable configurations

consist of an all-polyimide system shown in figure 9-1 and a polyimide/FEP system shown in figure 9-2. The proposed shielded-cable configuration consists of polyimide and a metal shield lamination (copper or high-permeability metal) as shown in figure 9-3, and polyimide/FEP and a metal shield lamination as shown in figure 9-4. The method of stripping the polyimide from both systems is the same. The polyimide/FEP cable requires an additional step for the removal of FEP.

The following highly alkaline, commercially available solutions and the laboratory prepared solutions were found to be acceptable for removing the polyimide insulation.

<u>Solution</u>	<u>Stripping Time (2-Mil Polyimide)</u>	<u>Stripping Temperature</u>
MER-1	3 to 6 minutes	93-99°C (200-210°F)
PT-5-ML	5 to 8 minutes	96-99°C (205-210°F)
Endox L-76	5 to 8 minutes	99-110°C (210-230°F)
Clarcosub	5 to 10 minutes	93-99°C (200-210°F)
50 percent NaOH	10 to 15 minutes	99-110°C (210-230°F)
66 percent KOH	20 to 25 minutes	99-110°C (210-230°F)

These materials are available from:

- a. London Chemical Company, Inc., Melrose Park, Ill.
- b. London Chemical Company, Inc., Melrose Park, Ill.
- c. Enthane Incorporated, West Haven, Conn.
- d. Clarkson Laboratories, Camden, N. J.

The maskants listed below were applied to the cable and found acceptable in preventing deterioration of the insulation beyond the specified stripping area.

Maskcoat No. 2 - Western Coating Company, Los Angeles, Calif.

Maskant No. 1-2021-66 - Organoceram Inc., Placentia, Calif.

TFE Teflon Tape - 3M Company, St. Paul, Minn.

Lead Foil Tape - 3M Company, St. Paul, Minn.

AR-8-M Screen Resist - London Chemical Company, Melrose Park, Ill.

The materials specified below for the stripping of the insulation and shielding is for the purpose of illustrating the sequence of steps required to expose the conductors. Other stripping solutions and maskants listed can also be used in insulation and shield removal.

9.2.1.1 Stripping Unshielded Polyimide Cable

- a. Apply lead tape around cabling at desired length from cut end of cable.
- b. Immerse the cable in MER-1 resist remover at 93-99°C (200-210°F) for a period of 3 to 6 minutes for an insulation thickness of 2 mils. See figure 9-5 and figure 9-6.
- c. Spray rinse the stripped conductors with water to remove any residual polyimide.
- d. Remove tape. Any tape adhesive remaining on the cable may be removed with acetone and a cotton swab.
- e. Protect stripped conductors.

9.2.1.2 Stripped Shielded Polyimide Cable

The cable is masked prior to each stripping operation to prevent partial degradation of the insulation and shield beyond the designated area.

- a. Apply lead tape around cabling at desired length from cut end of cable.
- b. Immerse the cable in MER-1 resist remover at 93-99°C (200-210°F) for a period of 3 to 6 minutes.
- c. Spray-rinse the stripped conductors with water to remove any residual polyimide.
- d. Remove tape.
- e. Apply lead tape around cabling at desired length from cut end of cable. Be sure tape is pressed firmly against cable to eliminate wicking of the etching solution.
- *f. Strip-metal shield. (Etchant may be used at room temperature.)
- g. Remove tape and apply new tape around the cable at desired length from conductor ends.
- h. Immerse the cable in MER-1 resist remover at 93-99°C until the polyimide is removed.

*Ferric chloride etchant - 45° Baume', commercially available, or 100 parts nitric acid by volume to 2 parts hydrochloric acid by volume.

- i. Clean the stripped conductors with forceful water-rinse to remove any residual polyimide.
- j. Remove Tape.
- k. Protect stripped conductors.

9.2.1.3 Stripping Mylar Insulated Cable

The following solutions were tried and found to be acceptable for removing mylar insulation:

<u>Solution</u>	<u>Stripping Time</u>	<u>Stripping Temperature</u>
DS 101 H	3 to 8 minutes	93-99°C (200-210°F)
Concentrated Sulfuric Acid	2 to 4 minutes	93-99°C (200-210°F)

The cable is masked to define the stripping area and prevent degradation of the adjacent cable. A maskant such as a lead-backed tape #425 from Minnesota Mining and Manufacturing Company is recommended.

9.3 Plating

The plating for this program was done on an as-required basis. The fixturing information for handling cables during plating was supplied by NASA/MSFC. The plating projects were as follows:

- a. Laboratory run to verify handbook process - Results satisfactory.
- b. Copper plating a shield on a Kapton insulated cable - Adhesion to the Kapton was marginal to unsatisfactory.
- c. Plating the edge of a cable which had Lashclad bonded to each side and the edge conductor exposed - The plating solutions caused a failure of the bond between the Lashclad and the cable.
- d. Cu-Ni plate on MU-30 - Results Satisfactory. Plating did not crack or separate when the sample was flexed or folded.
- e. Cu-Ni plating of six-foot lengths of MU-30 for subsequent fabrication of shielded cables for electrical testing - Results satisfactory.

9.4 Connector Potting

Lefkowl 185 (Leffingwell Chemical Co.) was selected for potting the shielded plug. The requirements were that the potting material have a viscosity that would seal the conductor passages on the front of the connector, and have sufficient resiliency after curing to provide strain relief and pass environmental and electrical tests. The apparent viscosity was increased with Cabosil so that the potting would fill the conductor slots but would not run through to the contact area. The faying surfaces on the backshell were sandblasted to produce a surface conducive to bonding.

Dynamic weight loss and deposition on quartz witness plates in a thermal-vacuum test were run on this material. The results are shown in figure 9-7 and table 9-1.

Table 9-1

LOSS OF LIGHT TRANSMISSION THROUGH WITNESS PLATES CAUSED BY
CONDENSATION OF COMPONENTS OF LEFFINGWELL #185 EPOXY

PERCENT TRANSMISSION LOSS

Sample I				Sample II				Sample III			
360mμ	520mμ	700mμ	Avg.	360mμ	520mμ	700mμ	Avg.	360mμ	520mμ	700mμ	Avg.
1.6	0.8	0	0.7	1.1	0.2	0.2	0.7	0.5	0	0	0.1

TEST CONDITIONS

Temperature = 212°F

Test Duration 20 hrs

Vacuum Level 1×10^{-6} Torr

9.5 Bonding the Connector Backshell to the Plug Body

The nickel-plated aluminum backshell is bonded to the diallyl phthallate plug body with Epon 934, a filled epoxy structural adhesive. The faying surface on the backshell was given a light grit-blast treatment to improve adhesion.

Initially, Leffingwell 185 was used in this application with a slip fit between the backshell and plug body. The faying surface of the backshell was not grit-blasted. The bond to the metal backshell failed during temperature cycling. As corrective measures, the following changes were made:

- a. A structural adhesive was substituted for 185 because there was no requirement for dielectric properties, or for the flexibility which 185 afforded.
- b. The bond-line clearance was increased to 8 to 10 mils.
- c. The faying surface of the backshell was grit-blasted.

9.6 All-Polyimide Insulation System

An investigation was conducted to determine the possibility of procuring an all-polyimide insulation system; i.e., all-polyimide insulation on a shielded cable and a polyimide connector body assembled with polyimide adhesive. This would make chemical stripping of the all-polyimide insulated cable feasible, and would provide a system having the temperature capability of polyimide. A request was made to all known cable manufacturers, but none responded with an acceptable proposal. The polyimide adhesives are solvent dispersions, and difficulty is encountered from solvent entrapment under the shields. Limited development work was done in-house to overcome this difficulty, but with little success.

Concurrently, it was noted that American Cyanamid was developing an injection-moldable polyimide material (XP1 182). Vendor coordination disclosed that XP1 182 could not be handled in the Stokes injection-molding machine, located at Huntington Beach, and that further development work was required on the material. The program schedule did not permit further considerations for all-polyimide system.

Through subsequent coordination with American Cyanamid in March 1968, it was learned that they had developed a more easily moldable material (XPl MC154). Except for a lower heat distortion point (437°F rather than 500°F+), this material has physical properties comparable to XPl 182, and merits further investigation if an all-polyimide insulation system is to be pursued on a future program.

9.7 Flat-Cable Bonding

A literature survey was made on flat-cable bonding technology. The field covered included securing of cables fabricated from Mylar, H-film, and Teflon bonded to aluminum with adhesives or pressure-sensitive tapes. Room temperature curing adhesives capable of maintaining a sufficient bond strength over a service temperature range of -195°C (-320°F) to 316°C (600°F) was of prime interest. The six reports summarized below contained applicable information:

a. Summary of Report TMX-53080

Kennedy, B. W. Evaluation of Adhesives for Installing Flat Conductor Cables (U), NASA Technical Memorandum TMX-53080, October 1964.

Mylar to Mylar or to aluminum joints bonded with 3M's adhesive EC-1099 or Fasson Products Corporation 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 strength.

b. Summary of Report 394-65

Thiokol Chemical Corporation. Development of an Adhesive System for Fastening Mylar (Polyester) and H-Film (Polyimide) Flat Conductor No. 394-65, Contract No. NAS8-11,828, January 1966.

A high initial-tack, quick ambient cure adhesive for fastening Mylar film to various substrates was developed and qualified. The binder system consisted of a hydroxyl-terminated polybutadiene (HTPB) blended with an epoxy-novolak diluted with Bisphenol-A epichlorohydrin, which was cured with toluene diisocyanate and a tertiary amine.

An adhesive for bonding H-Film to various substrates was formulated from a polyimide/polyamide blend which cured in 1 hour at 150°C (302°F).

c. Summary of Flat Cable Technology Report

Angele, W. A Review of Flat Cable Technology in Space Applications, presented to the Electrical Manufacturing Coordination Meeting, Huntsville, Alabama, 5-6 November 1964.

A Nitrophenolic resin was used to mount H-Film and Mylar cables to aluminum. A one-year exposure to outdoor weathering did not deleteriously affect the structural performance of the adhesive joint.

d. Summary of Report DG-TR-4-60

Army Ballistic Missile Agency. Development Report No. 3 on Printed Cables and Connectors, Technical Report No. DG-TR-4-60, 18 February 1960.

Adhesives were submitted by various manufacturers, coded, and used to bond Mylar to aluminum, Teflon, epoxy, phenolic and Mylar substrates. Peel and creep tests were conducted to evaluate the bond strength performance of the adhesives. No single adhesive tested proved superior in all aspects.

e. Summary of MP 1749

Blanchard, G. P. Peel Strength of Narmco 7343/7139 Adhesive When Bonding Mylar to Aluminum, (U), Report No. MP 1749, Douglas Aircraft Company, Inc., 12 December 1963.

A polyurethane adhesive was used to bond Mylar to aluminum. Peel strength (180°) was determined at temperatures ranging from -253°C (-423°F) to 121°C (250°F).

f. Summary of MP 1690, Revision A

St. Cyr, M. C. Barrier Films for Containment of Liquid Propellants, (U), Report No. MP 1690 (Revision A), Douglas Aircraft Co., Inc., 29 July 1963.

The lap shear strength of Mylar and H-Film bonded with a polyurethane adhesive was determined.

Three formal reports, excerpts of which appear in the above text, were prepared on development work performed on this contract. They are MP50653, A Survey of Flat Cable Bonding Technology, MP50839, Evaporation of Volatiles from Leffingwell #185 Epoxy and Deposition on Quartz Witness Plates, and MP50914, Dynamic Weight Loss of Leffingwell #185 Epoxy in Vacuum. The complete texts of these reports follows.



MISSILE & SPACE SYSTEMS DIVISION
DOUGLAS AIRCRAFT COMPANY, INC.

FORM 37-88 (REV. 1-62)

MATERIAL & PROCESS ENGINEERING
LABORATORY REPORT

Catalog No. RD 28709

SERIAL NO. MP 50,653

DATE 10/11/67

TITLE A SURVEY OF FLAT CABLE BONDING TECHNOLOGY

ASSIGNED TO M. C. St. Cyr, A-265

J. L. Kerkmeyer, A-265

1. OBJECT

REQUESTED BY H. R. Pearson, A-265

To survey the literature for data pertinent to the adhesive bonding of flat cables fabricated from Mylar, H-Film or Teflon.

COPIES TO R. A. Welbourn, A3-260

2. INTRODUCTION

The recent development of flat conductor cable 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 literature survey was conducted to determine the state-of-the-art of securing cables fabricated from Mylar, H-Film or Teflon to aluminum with adhesives or pressure sensitive tapes. Room temperature curing adhesives capable of maintaining sufficient bond strength over a service temperature range of -195°C (-320°F) to 316°C (600°F) were of prime interest.

3. PROCEDURE

A literature survey utilizing the library's Automatic Selection of Dissemination Information service and a search of private files was conducted. A secondary screening of the cards and perusal of reports revealed that only six (6) reports contained applicable information.

4. RESULTS

The tests conducted in the various programs and the results of the tests are given in Table I.

4.1 Summary of Report TMX-53080

Mylar to Mylar or aluminum joints bonded with 3M's adhesive EC-1099 or Fasson Products Corporation 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. (1)

4.2 Summary of Report 394-65

A high initial tack, quick ambient cure adhesive for fastening Mylar film to various substrates was developed and qualified. The binder system consisted of a hydroxyl-terminated polybutadiene (HTPB) blended with an epoxy-novolak diluted with Bisphenol-A epichlorohydrin, which was cured with toluene diisocyanate and a tertiary amine.

An adhesive for bonding H-Film to various substrates was formulated from a polyimide/polyamide blend which cured in 1 hour at 150°C (302°F). (2)

4.3 Summary of Flat Cable Technology Report

A Nitrophenolic resin was used to mount H-Film and Mylar cables to aluminum. A one year exposure to outdoor weathering did not deleteriously affect the structural performance of the adhesive joint. (3)

4.4 Summary of Report DG-TR-4-60

Adhesives were submitted by various manufacturers, coded and used to bond Mylar to aluminum, Teflon, epoxy, phenolic and Mylar substrates. Peel and creep tests were conducted to evaluate the bond strength performance of the adhesives. No single adhesive tested proved superior in all aspects. (4)

4.5 Summary of MP 1749

A polyurethane adhesive was used to bond Mylar to aluminum. Peel strength (180°) was determined at temperatures ranging from -253°C (-423°F) to 121°C (250°F). (5)

4.6 Summary of MP 1690, Revision A

The lap shear strength of Mylar and H-Film bonded with a polyurethane adhesive was determined. (6)

5. REFERENCES

1. Kennedy, B. W. Evaluation of Adhesives for Installing Flat Conductor Cables (U), NASA Technical Memorandum TMX-53080, October 1964.
2. Thiokol Chemical Corporation. Development of an Adhesive System for Fastening Mylar (Polyester) and H-Film (Polyimide) Flat Conductor No. 394-65, Contract No. NAS8-11,828, January 1966.
3. Angele, W. A Review of Flat Cable Technology in Space Applications, presented to the Electrical Manufacturing Coordination Meeting, Huntsville, Alabama, 5-6 November 1964.

4. Army Ballistic Missile Agency. Development Report No. 3 on Printed Cables and Connectors, Technical Report No. DG-TR-4-60, 18 February 1960.
5. Blanchard, G. P. Peel Strength of Narmco 7343/7139 Adhesive When Bonding Mylar to Aluminum, (U), Report No. MP 1749, Douglas Aircraft Company, Inc., 12 December 1963.
6. St. Cyr, M. C. Barrier Films for Containment of Liquid Propellants, (U), Report No. MP 1690 (Revision A), Douglas Aircraft Co., Inc., 29 July 1963.

SO 177132-40
EWO 32807
SA 7001

M. C. St. Cyr
M. C. St. Cyr
Adhesive & Plastics Development
Non-Metallics Branch, MR&PM

J. L. Kerkmeyer
J. L. Kerkmeyer
Adhesive & Plastics Development
Non-Metallics Branch, MR&PM

APPROVED BY:

E. W. Neuse 9/21
E. W. Neuse, Section Chief
Adhesives & Plastics Development
Non-Metallics Branch, MR&PM
Development Engineering

TABLE I
PROPERTIES OF ADHESIVE SYSTEMS USED TO BOND FLAT CABLES

Adhesive	Adherend	Adherend
EC-1099	Mylar	Aluminum Anodized 6061
1. <u>Vacuum</u> - After 24 hour cure at room temperature $6.67 \times 10^{-2} \text{ N/m}^2$ ($5 \times 10^{-4} \text{ mm Hg}$) = No bond damage. After 6 days post cure at room temperature $1.33 \times 10^{-2} \text{ N/m}^2$ ($1 \times 10^{-4} \text{ mm Hg}$) = No bond damage. 2. <u>Heat distortion</u> - 198°C (388°F) maximum temperature Increased bond strength due to increased temperature. (turnd dark brown and gave off fumes during test) 3. <u>Cryogenic exposure</u> - -159 to 29°C (-254 to 84°F) - (cycled twice daily for 7 days) Peel strength decreased approximately 10% at lower temperatures, original strength regained at 10°C (50°F). 4. <u>Peel Strength</u> - 24 hour cure - 0.8 kg/cm width 72 hour cure - 1.0 kg/cm width 5. <u>Corrosion tests</u> - 77 days in an enclosed area no corrosive effects noted 6. <u>Creep</u> - Determined by measuring the distance a 2.5 cm wide cable was removed from a supporting surface in 1 hour when pulled at arc angle or 90 degrees by a suspended weight = 150 cm/h under 0.8 km/cm load.		

Adhesive
HTPB*Adherend
Mylar
(primed)

Adherend

Aluminum

Anodized Al

Steel

Painted Steel

Stainless Steel

Acrylic

Diallyl Phthalate

Polycarbonate

Polyurethane

Kel-F

Silicones

Epoxy

Phenolic

1. Peel Strength (pounds/linear inch at temperature)

<u>-65°C (-85°F)</u>	<u>25°C (77°F)</u>	<u>100°C (212°F)</u>
11.3	11.2	8.4
13.6	18.4	12.8
12.3	16.7	12.6
13.0	14.3	12.8
16.0	17.5	10.2
38.1	---	11.5
9.0	17.0	10.4
12.0	15.0	11.6
24.9	20.7	8.2
12.0	14.4	7.7
12.0	---	8.0
12.4	18.5	7.9
16.0	16.6	12.0

2. Creep

Five peel samples of Mylar film to aluminum were exposed to 100°C (212°F). A weight of 15 gram per centimeter was applied. After 1/8 inch creep along the film, the weight was supported without further creep for 72 hours.

3. Thermal Shock

Specimen cycled per MIL-STD-202B, Method 107A, Test Condition B were evaluated at -65°C (-85°F), 25°C (77°F), and 100°C (212°F). Thermal cycling did not degrade the adhesive.

4. Humidity

Subjection to 100% relative humidity at 55°C (131°F for 96 hours did not degrade the bond strength of the adhesive when bonded to Mylar and aluminum.

5. Chemical Resistance

Adhesive is swelled on dissolved by strong organic solvents, unaffected by water or acid. Easy to remove adhesive from cabin.

6. Fungus Test (MIL-STD-810A, Method 508.1)

No fungus was seen on, or in the adhesive panel.

7. Flame Resistance

Cured sheets of the adhesive, 1/8" thick, were exposed to the flames of a Bunsen burner for 15 seconds. Upon removal of flame, the adhesive was immediately extinguished.

8. Corrosion Tests

No corrosion was noted after 10 weeks exposure.

9. Vacuum

After being stored for 96 hours at a pressure of 10^{-7} torr, the Mylar strip was peeled from aluminum at the following strength levels:

-65°C (-85°F)	11.0,	7.5,	14.1 pounds/linear inch
25°C (77°F)	6.8,	7.7,	8.0 " "
100°C (212°F)	7.9,	6.2,	7.0 " "

10. Ultimate Tensile and Elongation

Temperature (°C)	Tensile Strength (psi)	Elongation (%)
-226°C (-375°F)	1720	2-3
- 65°C (-85°F)	412	37
25°C (77°F)	272	60
100°C (212°F)	153	162

11. Dielectric Constant - 3 at 25°C (77°F)

* HTPB Formulation

- 8 parts - Epoxy Novolak
- 2 parts - Diepoxide
- 20 parts - HTPB
- 10 parts - Tetrabromo Bis Phenol A
- 3 parts - Antimony Trioxide
- 2 parts - Toluene Diisocyanate
- 1 part - 2, 4, 6 - tris-dimethylamine methyl pheno! (DPM-30)
- 0.1 part - Dibutyl Tin Dilaurate

Adhesive PMDI/T-46**	Adherend Mylar	Adherend	1. Peel Strength (pounds/linear inch)		
			25°C(77°F)	100°C(212°F)	250°C(482°F)
		Silicone Rubber Epoxy Resin	4.6, 8.6, 6.2	3.8	- - -
			7.5, 10.1, 9.6	8.4, 10.7	- - -
		Polyurethane	9.8		
			7.7, 8.2, 8.6,	6.9, 8.4,	- - -
		Kel-F	6.4	7.9	- - -
			8.5, 9.2, 9.0,	- - -	- - -
		Anodized Aluminum	11.5, 10.8		- - -
			9.2, 10.1, 10.8,	- - -	- - -
		Stainless Steel	16.4		- - -
			8.6, 9.1, 8.2,	8.4, 10.7	7.0, 7.4, 8.1
		Aluminum Steel	8.8		- - -
			8.6, 7.5, 9.0	8.2, 6.0	- - -
			- - -	- - -	7.0

** PMDI/T-46 Formulation

100 parts - Aromatic Diaziridine (T-46)
20 parts - Pyromellitic diimide
20 parts - Sb₂O₃ - Antimony trioxide



MISSILE & SPACE SYSTEMS DIVISION
DOUGLAS AIRCRAFT COMPANY, INC.

37-88 (REV. 1-62)

MATERIAL & PROCESS ENGINEERING
LABORATORY REPORT

Catalog No. RD 28810
SERIAL NO. MP 50,839

DATE January 15, 1968

TITLE EVAPORATION OF VOLATILES FROM LEFFINGWELL
#185 EPOXY AND DEPOSITION ON QUARTZ WITNESS PLATES

ASSIGNED TO S. Fermanaglich, A-263

1. OBJECT:

REQUESTED BY A. Mc Cown, A3-263

To subject epoxy, Leffingwell #185 to pressure of 1×10^{-6} Torr at 212°F and collect by deposition on a quartz witness plate any volatiles resulting under test conditions. The exposed witness plates are to be measured for percent light transmission using an unexposed quartz plate as a reference.

COPIES TO G. E. Dennis, A-260
A. Mc Cown, A3-263
R. M. Washburn, A-263
C. S. Wilkinson, A-265
K. Woomer, A3-263
File

2. PROCEDURE:

See MP Report #50,803.

3. RESULTS:

Data have been summarized in Table I.

The average value is an arithmetic mean obtained from 18 positions on the spectrophotometer chart, taken at 20mμ intervals. In addition, the table shows readings taken at the midpoint of the chart, 520mμ, and the two extremes, 360mμ and 700mμ.

4. SIGNIFICANCE OF DATA:

- 1) There is no direct correlation between optical properties such as distortion, color, etc., and percent transmission loss.
- 2) Average values of transmission loss taken alone do not give an adequate description of the test results. The reason is that the light absorption varies considerable as a function of wavelength. For this reason the losses at the violet end, 360mμ; the midpoint, yellowish green at 520mμ; and the red end, 700mμ, have been included in the table.

5. REFERENCES:

TR 6617 page 25
MP Report #50,803 "Thermal-Vacuum Evaporation of Contamination from Beryllium"
TR 7435 page 10

SO 177 132
EWO 32 808
SA 7003



S. Fermaglich
Non-Metallics Research Projects Section, MR&PM

Approved by: 

R. M. Washburn, Section Chief
Non-Metallics Research Projects, MR&PM

SF:rh

TABLE I

Loss of Light Transmission Through Witness Plates
Caused by Condensation of Components of Leffingwell #185 Epoxy

TEMPERATURE = 212°F

TEST DURATION = 20 hrs.

VACUUM LEVEL = 1×10^{-6} Torr

PERCENT TRANSMISSION LOSS

SAMPLE I				SAMPLE II				SAMPLE III			
360mμ	520mμ	700mμ	Avg.	360mμ	520mμ	700mμ	Avg.	360mμ	520mμ	700mμ	Avg.
1.6	0.8	0	0.7	1.1	0.2	0.2	0.7	0.5	0	0	0.1



MISSILE & SPACE SYSTEMS DIVISION
DOUGLAS AIRCRAFT COMPANY, INC.

FD- 7-66 (REV. 1-62)

MATERIAL & PROCESS ENGINEERING
LABORATORY REPORT

Catalog No. RD 28796
SERIAL NO. MP 50,914

DATE January 18, 1968

ASSIGNED TO C. S. Wilkinson, A-265

REQUESTED BY A. McCown, A3-263

COPIES TO G. E. Dennis, A-260
R. M. Washburn, A-263
R. C. Libby, A3-263
J. G. Weiner, A3-263
File

TITLE DYNAMIC WEIGHT LOSS OF LEFFINGWELL
#185 EPOXY IN VACUUM

SAMPLE:

A cast sample of Leffingwell #185 epoxy resin supplied by A. McCown.

OBJECT:

To measure the dynamic weight loss of the material while subjected to a vacuum of 10^{-6} Torr and a temperature of 100°C .

PROCEDURE:

1. Apparatus:

- a. Edwards Vacuum System, DAC 632824
- b. Cahn Electrobalance, DAC 641837
- c. Speedomax Recorder, NASA 9855
- d. Graphicorder-10, DAC 672545

2. Specimens were cut from the block of cast material and sanded smooth with #320 grit emery paper. They were approximately 1 inch x 1 inch x 1/16 inch. They were cleaned with distilled water and detergent, rinsed in distilled water, wiped with a clean towel, and air dried for about an hour before being placed in the vacuum chamber.
3. Two specimens were mounted in the vacuum chamber. One was in a fixed position, supported by thermocouple leads. The other was suspended from the electrobalance.
4. Pumping was started and a continuous record of the specimen's weight made for one hour at ambient temperature.
5. The electrical heaters were turned on and continuous recording of specimen weight made for an additional 20 hours at 100°C .
6. The test was terminated by turning off the heat, cooling the specimen to room temperature, and venting the chamber to laboratory air.

NOTE: A more detailed description of the test method may be found in the referenced MP report.

RESULTS:

Test data are summarized in Table I. Dynamic weight loss and rate of loss data from the table are plotted in Figure 1.

SIGNIFICANCE OF DATA:

The accuracy of the electrobalance data is limited by laboratory vibration and random electrical interference to approximately ± 0.1 milligram. For specimens of the size used this means an accuracy of approximately ± 0.01 percent.

Temperature readings are estimated to be accurate to within $\pm 2^\circ\text{F}$.

Only one test specimen was tested. Therefore, no estimate can be made of the variability which might be expected between different batches of material or different specimens from the same batch.

At the end of the test period the specimen was still losing weight. The rate was down to less than 0.02 percent per hour, however; and the rate was decreasing very slowly. No changes in the visual appearance of the test specimen could be observed.

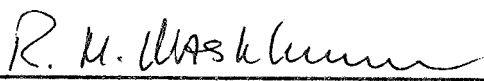
REFERENCES:

MP 50,717, C. S. Wilkinson, "Dynamic Weight Loss of Sealants in Vacuum,"
September 6, 1967

TR 5907, pages 48-50
S.O. 177132
EWO 32808
S.A. 7003



C. S. Wilkinson
Non-Metallics Research Projects Section, MR&PM

Approved by: 

R. M. Washburn, Section Chief
Non-Metallics Research Projects, MR&PM

CSW:prw

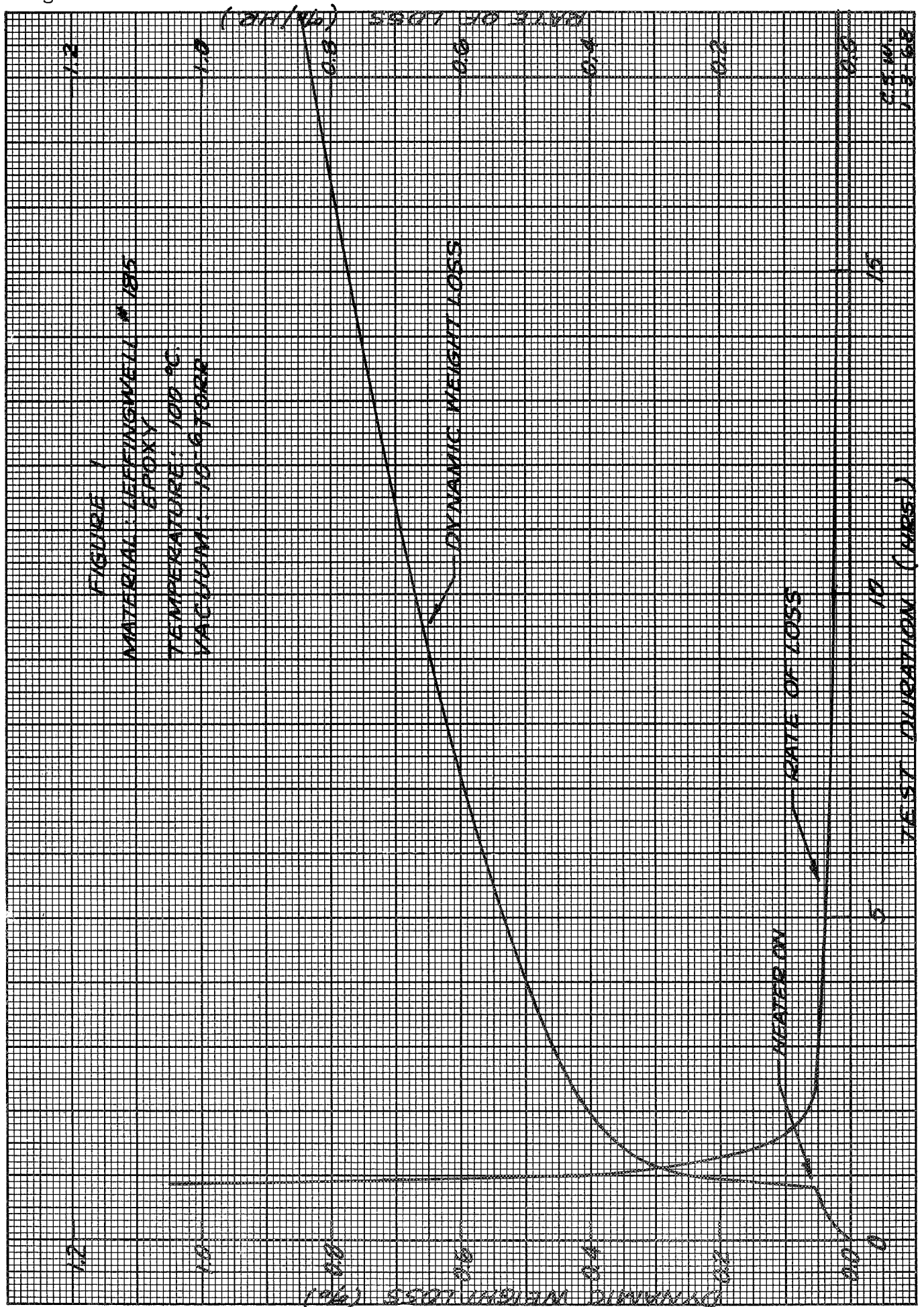
Table I

Dynamic Weight Loss of Leffingwell #185 Epoxy

Test Duration (hr.)	Weight Loss (%)	Rate of Loss (%/hr.)
0.0	0.00	---
0.5	0.04	0.06
1.0	0.19	0.45
1.5	0.37	0.12
2.0	0.40	0.06
3.0	0.46	0.05
4.0	0.50	0.04
5.0	0.53	0.035
6.0	0.56	---
7.0	0.59	---
8.0	0.63	---
9.0	0.65	---
10.0	0.67	0.022
11.0	0.70	---
12.0	0.71	---
13.0	0.73	---
14.0	0.76	---
15.0	0.78	0.02
16.0	0.79	---
17.0	0.81	---
21.0	0.86	0.018

Pressure: 1×10^{-4} Torr to 7×10^{-6} Torr

Temperature: 100°C to 109°C



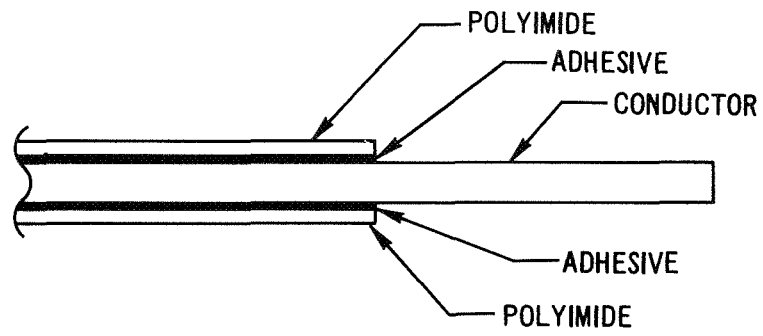


Figure 9-1. Unshielded Polyimide Cable

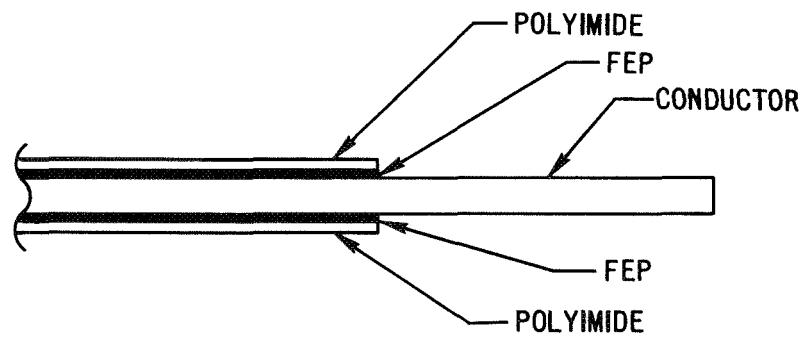


Figure 9-2. Unshielded Polyimide/FEP Cable

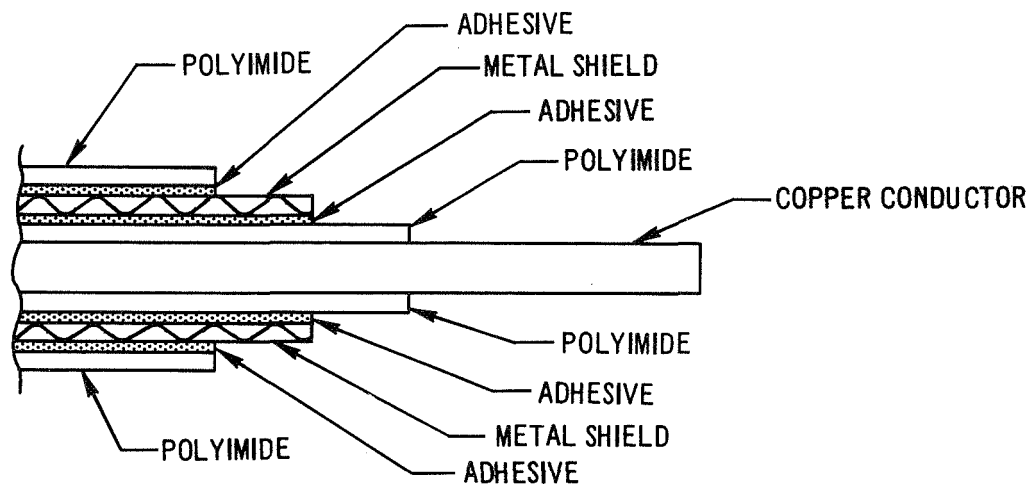


Figure 9-3. Shielded Polyimide Cable

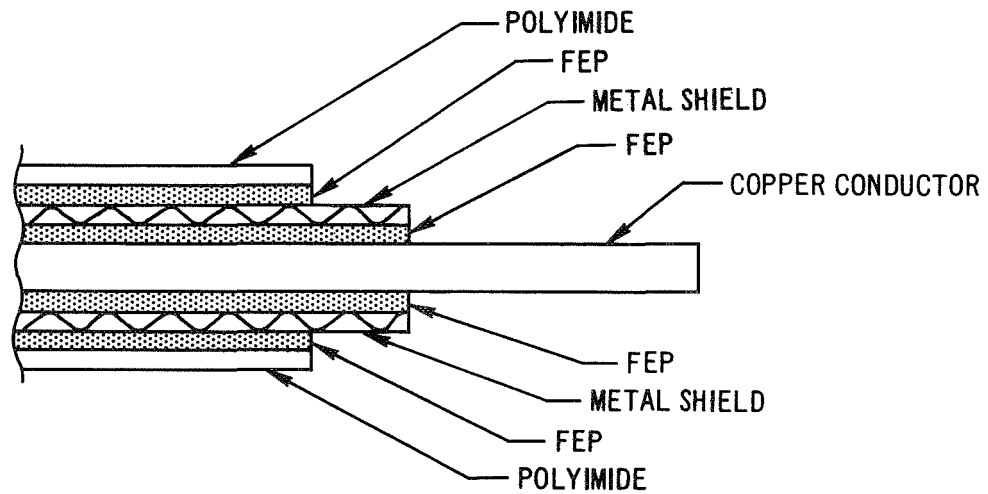


Figure 9-4. Shielded Polyimide/FEP Cable

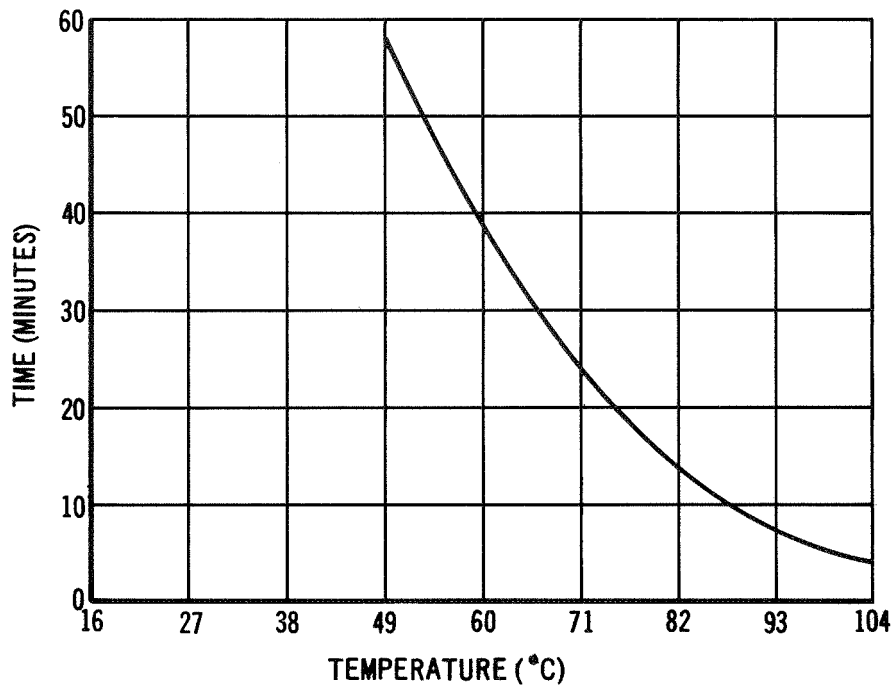


Figure 9-5. Stripping Data for 2-mil Polyimide With MER-1.

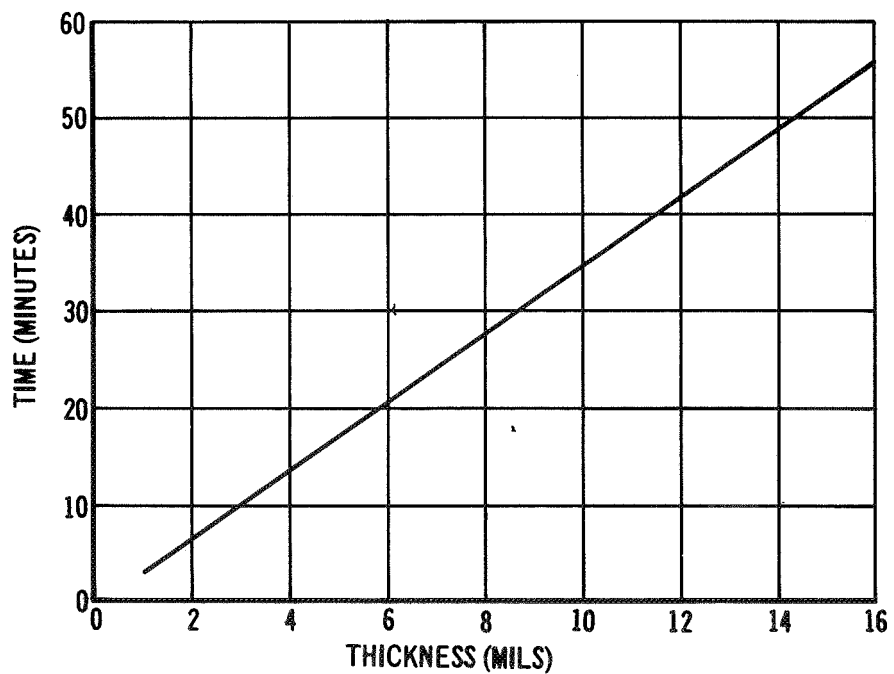


Figure 9-6. Polyimide Stripping Data for MER-1 at 94 C

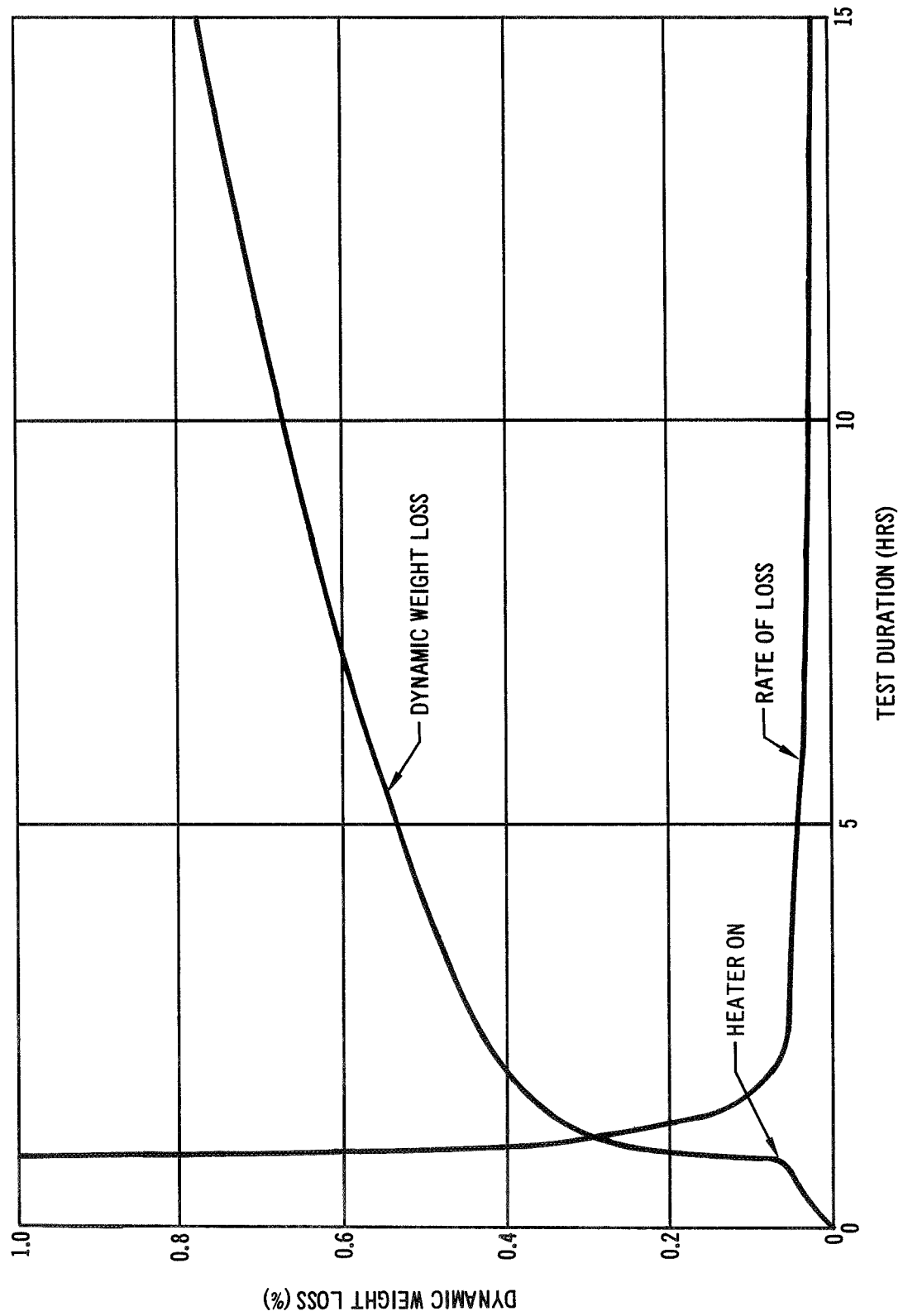


Figure 9-7. Dynamic Weight Loss

SECTION X

10. TECHNICAL ASSISTANCE TO NASA/MSFC FOR FCC APPLICATION

10.1 Introduction

During the Phase I Flat Cable Development Program, MDC designed, manufactured, and installed over 100 FCC harnesses on a 180-degree aftskirt mockup of the Saturn S-IVB/V Missile.

During the reference Flat Cable Applications Phase II Study, MDC performed the preliminary design and consideration definitions for using FCC interconnecting harnesses throughout on a proposed Block I S-IVB stage. This involved harness definition, distribution unit use and evaluation, electronic unit modifications and requalification, and system performance evaluation with FCC interconnecting harnesses on both a telemetry system and a propellant utilization system.

It was logical and desirable to utilize the experience gained on the above-described programs for FCC program applications to be made by NASA/MSFC. Therefore, the technical assistance task to the Astrionics Laboratory of NASA/MSFC was included on this program. Concurrent with the issuance of this program contract, NASA/MSFC was engaged in the application of FCC to the Apollo Telescopic Mount (ATM) Space Vehicle and the MDC assistance was made for this program.

10.2 Review of ATM Requirements

For ATM orientation and preparation in providing FCC application assistance to NASA/MSFC, MDC personnel reviewed all available ATM data, including:

- a. "Apollo Telescopic Mount, Preliminary Project Development Plan," dated July 25, 1966.
- b. Drawing 40M33651, "ATM Cable Interconnecting Diagram."
- c. "No number" drawing, "ATM CCEA Flat Connector vs. Round Connector."

The data and experience from the FCC Phase I and Phase II studies were then applied directly to the ATM requirements to formulate a preliminary plan for FCC application.

10.3 Review of NASA/MSFC FCC Design Guidelines

A series of proposed "Parts and Materials" FCC Design Guidelines, prepared by Mr. S. J. Dobbs of NASA/MSFC Astrionics Laboratory, was submitted to MDC for comments.

The MDC comments were transferred orally to Mr. Dobbs. The major comment involved the engineering method of calling out the NASA/MSFC conductor-contact, molded-plug assembly. Since this assembly is made up of a premolded window and shuttle, conductors from the FCC used for the harness assembly, and the plug body was molded in place around these parts; the completed plug assembly cannot be called out as a separate detail part. Rather, the plug assembly should be a dash number part of the complete FCC harness drawing. Therefore, it was suggested that a method drawing be created to define the molded-plug assembly operations. The FCC harness assembly drawing would call out the detail parts - window, shuttle, front filler rod, forward gasket, and interconnecting FCC, as required. A notation would be placed on this drawing requiring that the assembly be accomplished per the previously described method drawing.

The method described above, which was suggested to NASA/MSFC for incorporation into their design guidelines, was the method subsequently adopted for the MIL-C-55544 FCC connector specification.

10.4 ATM Systems Coordination Trip to NASA/MSFC

MDC personnel (2) were at the NASA/MSFC Astrionics Laboratory on 2, 3, and 4 May 1967 to provide FCC applications assistance for the ATM program.

At the initial meeting with the head of the Astrionics Laboratory, MDC personnel were directed to review, with the various design groups involved, the current status of FCC application to the ATM program, provide coordination and assistance, report back with the results of the review, and make recommendations for future effort.

Detailed coordination meetings were held with the various NASA/MSFC groups as follows:

- a. Jerry Felch, Jim Fuller, and John Lott - Astrionics Laboratory
Responsible for interconnecting harnesses, all J-boxes, wiring lists, cable interconnect diagrams, and integration of all installation and application. Based on ground rules that 0.004 X 0.040 flat-cable conductors be used, cable and connectors had been selected and cable interconnecting diagrams had been prepared.
- b. Cecil Gregg - Astrionics Laboratory, Control Moment Gyro (CMG) System
Had completed his preliminary design using known ground rules. He selected round connectors for 150 vrms because of voltage limitation for flat-cable connectors as stated in the MSFC Design Guidelines. He requested definition of hardware actually available, detailed description of its use, and pointed out a misunderstanding on connector-pin function designation.
- c. H. G. Vick - Astrionics Laboratory, Control Loop and Guidance
Problems existed with 4.8 kilohertz in the modulators and demodulator circuits. Proper selection of shielded cable, combinations into connectors, and routing would be required.
- d. Bill Lewter - Astrionics Laboratory, Instrumentation
This application seemed straightforward and was an extension of previous flat cable used on the I.U. Two measuring racks from the I.U. will retain round connectors and eight new racks will have flat-cable connectors.
- e. Harry Thayer - P&VE, Harness Installation
Responsible for final drawing documentation for all harness installations, support structure, and clamping definition. He has no one experienced in flat-cable routing or support. Mr. L. O. Ramsey of Astrionics will aid in clamp and support selection definition. The ME division will do the actual routing and installation of the harnesses, and the Astrionics Pilot Laboratory will fabricate the flat-cable harnesses.
- f. W. Angele - Astrionics Laboratory, Prototype Development Branch
Responsible for all flat-cable hardware. Procurement action for 17,000 feet each of shielded and nonshielded cable had been initiated. Over 600 flat-cable receptacles will be procured.

A transition--flat cable to conventional round connectors--will be accomplished with an encapsulated splice utilizing the standard window and shuttle for molded plugs. Round wire will be lap-soldered to the exposed flat-cable conductors at one end and inserted normally into the connector crimp contacts at the other end. A lightweight adapter will support the encapsulated splice to the connector backshell.

Additional ATM data were furnished to MDC personnel for further indoctrination and familiarization as follows:

- a. Statement of Work, Apollo Telescope Vernier Pointing Control System, by the Perkin-Elmer Corporation.
- b. Apollo Telescope Mount Flex Cable Study, by Lockheed Missiles & Space Company.
- c. Equipment List and Associated Technical Data, Apollo Telescope Mount, by George C. Marshall Space Flight Center.
This includes all black boxes with outline dimensions and power requirements.
- d. Drawing No. 40M33650, Apollo Telescope Mount Flat Cable Definition, by George C. Marshall Space Flight Center.
- e. Drawing No. 50M22123, Pin Function Diagram, Control Moment Gyro, by George C. Marshall Space Flight Center.
- f. No number, Apollo Telescope Mount Telemetry System Block Diagram, by George C. Marshall Space Flight Center.
- g. No number, ATM CCEA Flat Connector vs. Round Connector, by George C. Marshall Space Flight Center.
- h. Drawing No. PM11390, Cable Power 2 & 3 Conductors, by George C. Marshall Space Flight Center.
- i. Preliminary Flat-Cable Handbook for Practical Design, Fabrication, and Installation of Flat Cables.

The results of the NASA/MSFC review were reported to the head of the Astrionics Laboratory as follows:

- a. All Astrionics groups were making a conscientious effort to apply FCC to the ATM program per the known ground rule requirements.
- b. Additional coordination and definition of the detailed methods of FCC application were required.
- c. Use of FCC with conductor cross sections greater than 4 X 40 mils should be considered; especially, the use of FCC power cables already developed should be considered for high-conductivity requirements in lieu of using a very large number of parallel 4 X 40 mil conductors.
- d. A development mockup should be established as soon as possible to coordinate the development of the FCC harnesses with the development and installation of all other equipment in the applicable areas. Techniques and experience from the previously completed MDC studies should be incorporated in this mockup.

Detailed discussion on electromagnetic compatibility requirements were made with NASA/MSFC Astrionics personnel as described in the following paragraphs:

- a. A review of the ATM electronic systems and wiring practices indicated that the Control Moment Gyro vernier stabilization system for the workshop complex, including sun sensors, the spectography experiments, and the instrumentation system, contained the most critical circuitry and interconnection wiring. The instrumentation system is being designed by personnel with prior flat-cable experience and an awareness of spurious coupling that occurs in interconnection wiring. Good design practices are apparently being applied to the instrumentation system. Information about the spectography experiments was limited because of the number of non-MSFC experiment suppliers involved.
- b. The sun sensors for the stabilization system will be integrated with a preamplifier to provide a high level, and therefore non-critical, output to the analog computer/servo amplifier circuitry. These linear amplifiers are of medium gain and are direct coupled; therefore, no carrier-type amplifiers are involved and beat frequency problems should not exist. High level 4.8 kilohertz modulators and demodulators are used to permit the use of resolvers instead of potentiometers in the direct-current signal paths. The limited information available on interconnection wiring indicated that the wiring designs were based on criteria other than electromagnetic compatibility. Fortunately, the circuitry involved appears to be quite tolerant.
- c. Recommendations were made through the CMG Inverter designer that flat-cable oriented EMC design personnel at MSFC work with the interconnection wiring designers and inverter designers. ATM conducts 4.8 kilohertz square waves with 2- to 3-microsecond rise times through flat cable from the inverter. This practice is not recommended within MDC, due to the lack of magnetic shielding, crosstalk, and pulse distortion produced by the capacitance loading of the normally mismatched flat-cable interconnection wiring systems. The inverter enclosure is also used as a junction box for certain instrumentation circuits, a practice not encouraged at MDC due to potential crosstalk problems.
- d. The inverter synthesizes a 400-hertz pseudo sine wave and an additional 800 hertz output from the 4.8 kilohertz reference output digitally. Therefore, all outputs from each inverter are synchronized. There are three CMG systems with individual inverters and interconnection cables, one system for each axis. Unfortunately, the 4.8 kilohertz references for all three axes are obtained from one of the inverters; therefore, unless the three inverter 4.8-kilohertz clocks are synchronized or slaved, beats may occur between the 4.8-kilohertz reference and the 400-hertz and 800-hertz outputs in two of the three axes.

10.5 Conclusions

The initial MDC assistance to NASA/MSFC for FCC application was made during the ATM Systems Coordination Trip to NASA/MSFC as explained in 10.4. ATM indoctrination data were furnished to MDC, coordination meetings were held, and engineering contacts were established for further detail design and development problems. Suggestions were made for further FCC effort on the ATM program. However, no additional assistance was requested by NASA/MSFC, and MDC personnel directed their efforts toward the many other required tasks of the program.

SECTION XI

11. INSPECTION AND TEST

11.1 General

The determination of those inspections and tests, necessary to verify that the design intent is met in the manufacturing cycle, was pursued in the preparation of Section VII of the Flat-Cable Handbook. Each flat-cable assembly was broken into its individual components along with any associated components - receptacles, etc. No particular problems were encountered in the development of an inspection routine for processes; i.e., potting, plating, etc., and receiving inspection of components, since established procedures existed for the majority of raw materials, components and basic processes (reference Section VII, Flat-Cable Handbook). Flat-cable receiving and harness assembly posed problems in the identification of defects and discontinuities, particularly those which affect the electrical characteristics of the cable.

Various methods of identifying defects were presented. The unshielded cable configurations can be easily inspected on the device as shown in figure 11-1. This device, which utilizes the Moire pattern system, is adequate for identification of gross defects, and out-of-tolerance conductor spacing.

The shielded system can be evaluated (for conductor spacing) by use of a portable x-ray device. This system is adequate for a "quick look" at specific lengths of cable, but may be costly for large production lots.

The inspection of the cable assembly (plug and cable) for noncontinuity between shield and conductor, and for shorts and other detrimental faults, can be done by conventional means, but can present problems in setup time and accurate location of faults along a long length of cable.

Fault and defect identification of flat cable, both on the receiving and manufacturing level, and after long periods of installation, can therefore, present a problem.

11.2 Time Domain Reflectometry

Section VII, paragraph 7.1.1.5.1 of the Flat-Cable Handbook mentions Time Domain Reflectometry (TDR) as a precise method of locating and analyzing cable discontinuities.

The Time Domain Reflectometer (TDR) employs a step generator and an oscilloscope. A voltage step is propagated down the cable under investigation, and the incident and reflected waves are monitored by the oscilloscope at a particular point on the line. This method reveals at a glance the characteristic impedance of the cable. It also shows the position and type of discontinuity along the cable (inductive, resistive, or capacitive). This technique can be particularly helpful in the location of discontinuities not detectable by visual methods or normal electrical means for flat cable.

A Model 1415A TDR supplied by Hewlett Packard Co., was used to sample a length of cable for discontinuities and faults. Because of limited amount of time, a complete analysis of the device with different configurations was not accomplished. The amount of testing done with the TDR was adequate to find that the device can provide an excellent means for flat cable testing.

The TDR is capable of measuring a large range of impedances, both real and reactive; frequency response; attenuation; distances from fractions of centimeters to thousands of feet; and other transmission parameters.

The TDR detects any flaws in flat cables such as:

- a. Conductor-to-conductor shorts
- b. Conductor misalignment
- c. Shield-to-conductor shorts
- d. Shield-to-conductor misalignment.

These flaws result from discontinuities, or abrupt changes, in the otherwise constant characteristic impedance of the cable system.

With the TDR, theoretically ideal cable will appear as a resistive load on a scope display, with no reflections except at the ends of the cable. When a cable exhibits discontinuities, reflections will occur along the line, indicating changes in characteristic impedance. These will appear on the scope as steps or small spikes. The direction of the spike gives pertinent information as to the type of defect existing in the cable being tested, i.e., the characteristic impedance of the line is high over a short section, or a shunt capacitance exists, etc.

The TDR is also capable of identifying multiple discontinuities. Each of the reflections caused by the discontinuities may be measured on the scope.

Determination of the exact location of discontinuities along the cable is another feature of the TDR. A time distance/time scale is calibrated directly in cm to the discontinuity, which can provide a quick efficient method of locating the discontinuity, especially in long lengths of cable.

In evaluating proposed testing methods for flat cable, the TDR should be given consideration. With proper application, TDR testing should provide all the data necessary for checking a flat cable system from the receiving level through installation and use of flat cable in the field. More information of available equipment in the field can be obtained from Hewlett Packard, Tektronix, and General Radio Corporations.

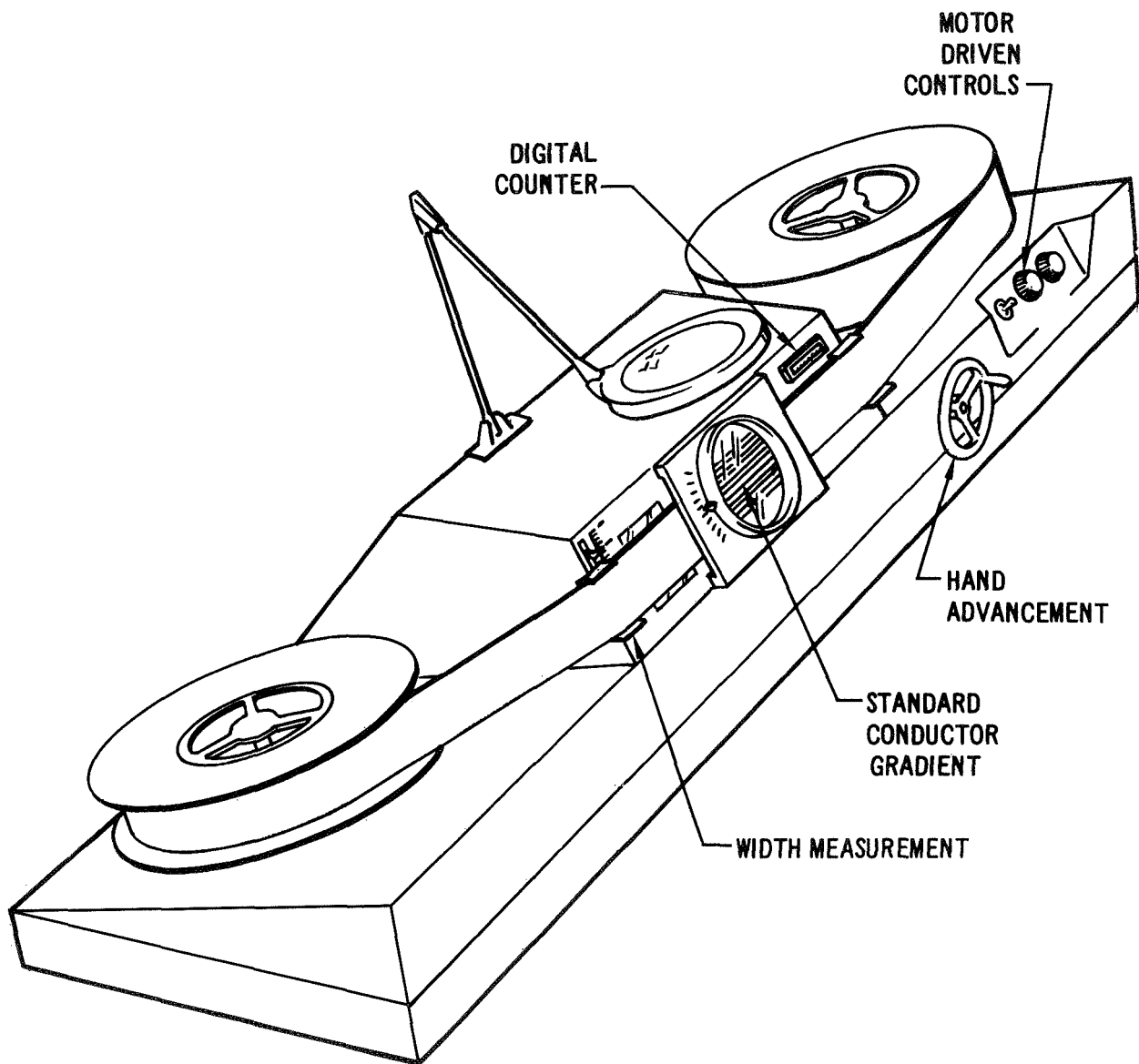


Figure 11-1. Flat Cable Inspection Device

SECTION XII

12. SUGGESTIONS FOR FUTURE FLAT-CABLE EFFORT

12.1 Introduction

Much has been accomplished in the development, specification preparation, evaluation testing, and handbook preparation for flat-cable components, and in design application for electrical interconnecting harnesses suitable for military and government contracts in airborne and ground support systems. Proposed tri-service military specifications have been prepared for nonshielded flat cable and flat-cable connectors, and are currently scheduled for release in late 1968. Numerous flat-cable configurations, both shielded and nonshielded, have been developed and tested. The NASA/MSFC conductor-contact system for premolded and molded plugs in five rectangular sizes, and for two sizes of molded cylindrical plugs, have been developed, tooled, and tested. All the NASA/MSFC development has been for 75-mil centerline spacing. A 100-mil pin-and-socket connector has been developed by, and is being testing for, Picatinny Arsenal, Dover, New Jersey. However, additional effort is required to encourage and assure general flat-cable application throughout industry.

12.2 General Areas Requiring Additional Development

Those areas requiring additional effort to assure extensive usage of the FCC system are:

- a. Develop a shielded FCC utilizing past experience.
- b. Definition, development, and preparation of a military specification for shielded FCC.
- c. Formal qualification of cable and connectors to the military specifications.
- d. Final development and testing of a shielded termination system which will meet shielding performance requirements.
- e. Connector development and testing for 50-mil centerline spacing and hermetically sealed connectors.
- f. Development and testing of special hardware for harness interconnections.

12.3 Proposed Tasks for Future Effort

12.3.1 Shielded-Cable Development

Much effort was expended on this program to define shielded-cable requirements, procure magnetically shielded cable, perform evaluation tests, and develop production stripping methods. However, because of schedule and fund limitations, many of the program objectives were not accomplished. Additional effort is required to:

- a. Define the shielding requirements. Magnetic shielding materials should be used to make model shielded cables for testing shielding effectiveness and to establish optimum shielding configurations.
- b. Procure prototype cables, meeting the requirements of (a) above, and develop production stripping techniques for these cables.
- c. Perform engineering evaluation tests on the prototype shielded-cable configurations, both as a length of cable and as a cable assembly including the shielded plugs.

12.3.2 Qualification of Cable and Connectors to the Military Specifications

Although much testing has been accomplished on various FCC configurations and on NASA/MSFC connector systems, and is being accomplished on the Picatinny Arsenal pin-and-socket connector assembly, formal qualification of the required parts is necessary prior to general FCC application to high-reliability military and other government programs. Therefore, it is necessary to complete the development of the parts required (in those areas where satisfactory parts do not exist) and to formally qualify them to the military specifications. With these parts on the qualified parts list, their use on new programs will be assured.

12.3.3 Additional Effort for Conductor-Contact Shielded-Plug Assemblies

The shielded-plug assembly developed on this contract provided prototype hardware, assembly techniques, and preliminary test results. Additional effort is required to:

- a. Define the EMC and magnetic-shielding requirements. The cable development proposed in 12.3 above should be assembled in existing prototype connectors to verify the system performance. Then, realistic final requirements can be established for EMC shielding.
- b. Modify the existing design for the shielded-plug assembly parts to incorporate the requirements of (a) above.
- c. Build and test prototype connectors to the new design requirements.

12.3.4 Preparation of a Military Specification for Shielded Flat Cable

A tri-service MIL-C-XXXXX specification should be prepared and released for shielded flat cable. The format should follow that of specification MIL-C-55543, and the proposed shielding effort of 12.3.1, plus information available from other government agencies and industry, should be incorporated.

12.3.5 Connector Development for 50-Mil Centerline Spacing and Hermetically-Sealed Connectors

The definition, procurement, and testing of prototype connectors for 50-mil centerline spacing and hermetically sealed connectors should be accomplished, to assure the availability of required hardware for future programs. The set of guidelines for the 50-mil centerline connector system, furnished to industry at the March 1968 IPC meeting in New York City, established a basis for the requirements of 50-mil centerline connector system. Considerations should also be given for a 50-mil centerline system having the same performance requirements based on the NASA/MSFC conductor-contact system.

Hermetically sealed FCC connectors should be developed and tested, following the basic design developed for the 50-mil centerline connector system described above.

12.3.6 Development of Multiconnector Distribution Units

The complexity of modern electronic systems, plus the major advantages gained from simple, two-ended, interconnecting harnesses, establishes a firm requirement for the development and testing of multiconnector distributors. The general requirements for the required distributors are listed in section III of the flat cable handbook.

12.3.7 Development of a Connectorless Termination System

With the accepted general use of integrated circuits, active electronics packages and modules are becoming smaller and smaller, and the electrical current requirements for these modules are very small. FCC has the capability of providing reliable, lightweight, economical, and very small (30 AWG or less) conductor gages. If this cable could be terminated directly to the integrated circuit packages, the weight and space of the connector systems could be eliminated. The design concepts for the connectorless system are:

- a. The FCC would be routed to, and inserted in, the electronic package or module with no cable stripping required.
- b. An operation on the module, such as moving a lever or fastening screws, would effect an environmental seal at the cable entry and would accomplish reliable electrical connections to the module internal circuits.
- c. For replacement or maintenance, it would be possible to reverse the operation to remove the cable from the electronic unit. By trimming the cable and replacing expendable parts of the module, new electrical connections could be made.

The geometry and performance requirements of FCC are such that the above design concepts are feasible.

12.3.8 Flat-Cable Systems Development Timetable

Considering the effort expended to date by MDC and other industrial and Government concerns, a timetable, depicting the evaluation of flat-cable systems development, appears appropriate. Such a timetable is depicted in figure 12-1, and the goals sought are definitized as follows:

- a. Provide a realistic and effective path toward production status.
- b. Minimize duplication of efforts with other government agencies.
- c. Encourage participation of other government agencies in a coordinated effort.
- d. Enhance the participation agencies' position, and raise the level of confidence in flat-cable systems in the eyes of flat-cable manufacturers. Hopefully, this would stimulate the flat-cable components industry.
- e. Seek a source or sources from which funding may be derived.

DESCRIPTORS

Connector (Electrical) - This term designates a mated pair consisting of a plug and receptacle.

Development Fixture - similar to the mockup except the structure and supports are essentially in accord with production drawings, to provide accurate space and dimensional location requirements. Final tubing and electrical harness development can be accomplished on this fixture.

Distributor or Distribution Unit - device used in the electrical, inter-connecting network which simplifies the wiring harnesses and facilitates wiring changes.

Electronic Unit - an active electronic package capable of being interconnected to other electronic units in a system via electrical connectors.

End Unit - a ground support or flight item which is complete in itself and deliverable to a customer. This could be a complete missile, a missile section which is assembled with other end items by the customer or another contractor, or a deliverable piece of ground equipment.

Mockup - 3-dimensional, full-size simulation of end-item simulated structure and installations. Exact dimensional control is usually not maintained. Wooden members are often used to simulate the outline of structure and installations. The mockup is used for initial design coordination and development of the various design technologies.



*MISSILE & SPACE SYSTEMS DIVISION / SPACE SYSTEMS CENTER
5301 BOLSA AVENUE, HUNTINGTON BEACH, CALIFORNIA*

A DIVISION OF DOUGLAS AIRCRAFT COMPANY, INC.