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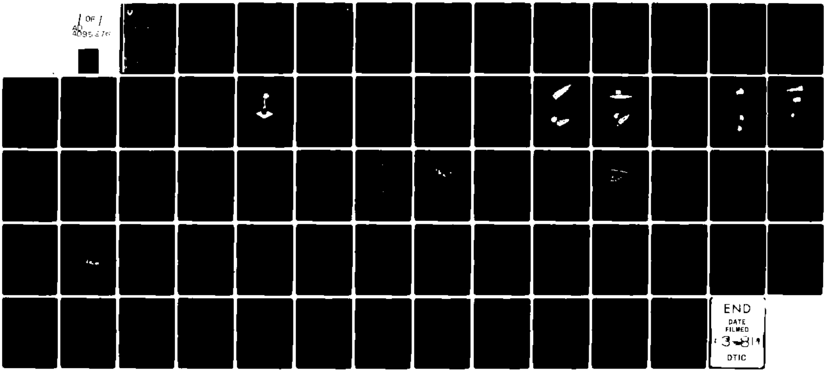

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM-CONTRACT NUMBER DAAK80-79-C-0771

EXPLORATORY DEVELOPMENT MODEL HERMAPHRODITIC FIBER OPTIC CONNECTORS

J. F. Dalgleish
H. H. Lukas
BELL-NORTHERN RESEARCH
OTTAWA, CANADA

NOVEMBER 1980

FINAL REPORT

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This final technical report documents the fiber alignment concept, a description of the connector plug and bulkhead receptacle, detailed installation procedures and a summary of the test results. Recommendations are made concerning final development of the connector.

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APPROVALS

EXPLORATORY DEVELOPMENT MODEL HERMAPHRODITIC
FIBER OPTIC CONNECTORS

FINAL REPORT
TR: 1D42-07-80
NOVEMBER 1980

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PREFACE

This final report describes work performed for the Communications System Center, Multichannel Transmission Division of CORADCOM by Bell-Northern Research under Contract DAAK80-79-C-0771 awarded by Ft. Monmouth, New Jersey. The effort was directed toward fulfilling the objectives of Technical Guidelines dated 10 July 1978 and in general support of the U.S. Army's Fiber Optic Development Program.

This period covered by this report is May 1979 to November 1980.

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1. INTRODUCTION

A developmental model, hermaphroditic, 6-fiber optical fiber connector system has been developed by Bell-Northern Research (BNR) under contract to the U.S. Army Communications Research and Development Command (CORADCOM), Fort Monmouth, New Jersey. This report details the results of the development. Specifically, this report contains;

a) a description of the fiber alignment concept (section 2).
b) a description of the connector plug and bulkhead receptacle designs (section 3),
c) detailed installation procedures (section 4),
d) a summary of test results (section 5), and
e) recommendations concerning final development (section 6).

In addition to this final report, the following documentation has been provided to CORADCOM;

a) BNR Test Report TR-1D42-03-80, and
b) Engineering Drawings to MIL-D-1000, Level 1.

The intended application configuration for this connector system is illustrated in Figure 1.1. A hermaphroditic plug is used to terminate both ends of a cable section. The hermaphrodicity of the plug allows the cable assemblies to be deployed and mated in any orientation. At equipment locations the cable assemblies are terminated in a bulkhead receptacle. The receptacle accepts individual (uncabled) fibers which are connected to opto-electronic transmitters and receivers.

The connector employs a fiber alignment concept that was developed by BNR prior to this contract[1].

As per contract requirements, the connector was designed for and tested with an ITT external strength member optical fiber cable. The cross-section of this 6-fiber cable design is shown in Figure 1.2. Cable samples were supplied by CORADCOM as identified in Table 1.1. The specified and measured fiber parameters are listed in Table 1.2.

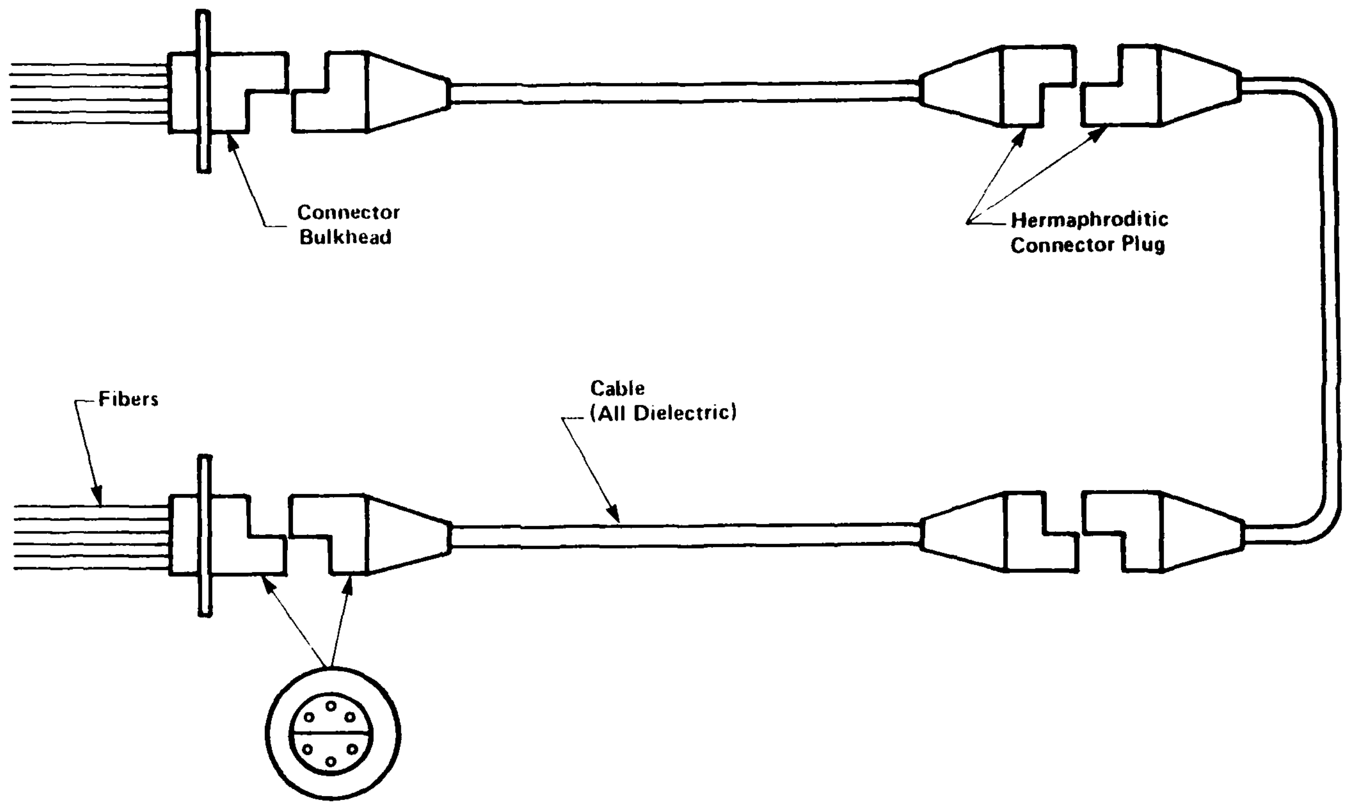


FIGURE 1.1: CONNECTOR APPLICATION CONFIGURATION

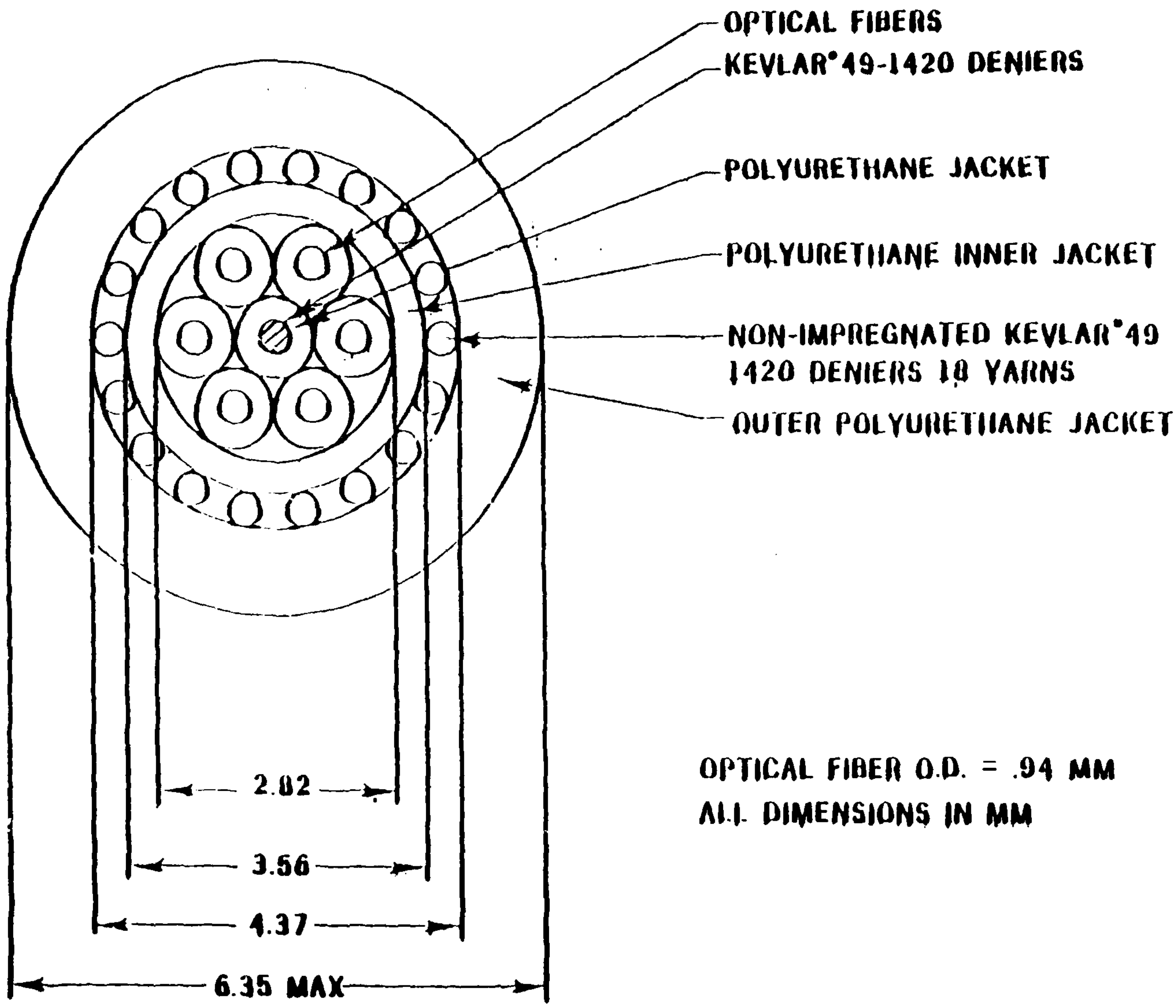


FIGURE 1.2: ITT CABLE CONSTRUCTION

TABLE 1.1: ITT CABLE SAMPLES FROM CORADCOM

Cable Identification	Nominal Length	Usage
120378-ZA-II	500 m	Initial development and investigative testing.
030279-MA-2	310 m	Development testing and formal test program. Terminated with connector plugs and returned to CORADCOM.
020979-MA-2	310 m	Terminated with connector plug and returned to CORADCOM.
022679-MA-2	310 m	Terminated with connector plug and returned to CORADCOM.

TABLE 1.2: ITT FIBER PARAMETERS

Parameter	Specification	Reported by ITT or Measured by BNR
Index Profile	Graded	-
Core Diameter	56 ± 6 μm	55 to 64 μm, maximum ovality of 4 μm (1)
Cladding Diameter	125 ± 6 μm	119 to 131 μm, maximum ovality of 4 μm (1)
Core/Cladding Concentricity	not specified	-
Numerical Aperature (N.A.)	0.2	0.15 to 0.21 (2)
Buffer Jacket Diameter	940 ± 7 μm	up to 1000 μm (1)
Buffer Jacket Material	Hytrel over silicone	-

Note: (1) Measured by BNR. These are spot-check measurements and are not necessarily representative of all fibers.

(2) Reported by ITT.

2. FIBER ALIGNMENT PRINCIPLE

The fiber interface consists of two ferrules and a formed VEE-groove alignment member as shown in Figure 2.1 (a). The ferrule is a stainless steel tube formed to produce, simultaneously, a flange and a key. The alignment member is blanked, formed, precipitation-hardened beryllium copper sheet consisting of a rigid Vee and two spring tabs, integral in the same part.

Positioning of the fiber in the ferrule is accomplished by casting an alignment bore inside the ferrule as illustrated in Figure 2.1 (b). The position of the alignment bore in the ferrule is controlled by means of a ferrule casting fixture. The fixture has two VEE sections in a fixed relationship with one another. Section 'a' holds the end of the ferrule and section 'b' supports a steel mandrel. The outside diameter of the end of the mandrel is slightly larger (1 to 2 μm) than the outside cladding diameter of the fiber. A low melting point metal (Cerrocast) is then injected through the casting port. After cooling and solidifying (a few seconds) the mandrel is withdrawn, leaving a cast alignment bore which is a close fit to the fiber. The developmental model ferrule casting fixture is shown in Figure 2.2. Because all of the ferrules are cast on the same (or identical) fixtures, the position of the alignment bore in each ferrule with respect to the fixture surfaces 'a' is identical, irrespective of the variation in the outside diameter of the ferrules. In the connector the Vee groove in the alignment member duplicates the surface 'a', thereby aligning the bores of the two ferrules which will contain the installed fibers. That is, dimension 'c' is accurately transferred from the casting fixture to the mated ferrules in a connector with no tolerance build-up due to variations in ferrule diameter.

Symmetry about the vertical centerline is essential for proper fiber-to-fiber alignment. This is achieved by fixing the rotational orientation of each ferrule key and by fixing the rotational orientation of the alignment member using an orientation sleeve within the connector body; that is, the two ferrule keys and the alignment member are all held in a fixed rotational orientation.

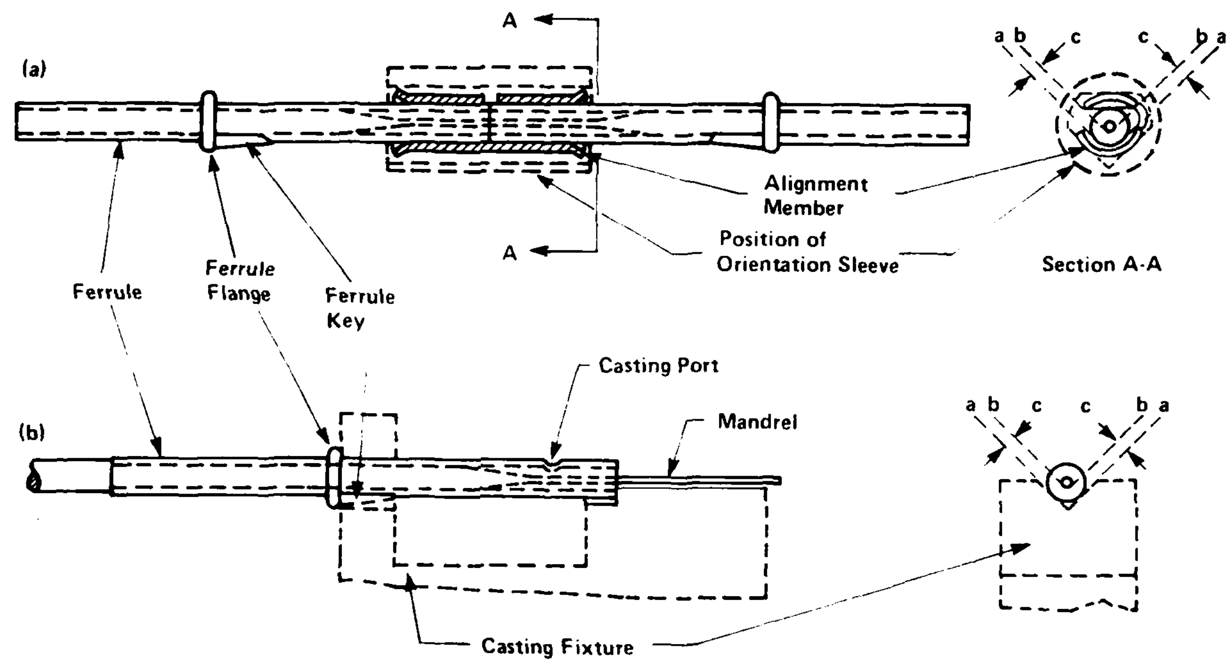


FIGURE 2.1: FIBER ALIGNMENT PRINCIPLE

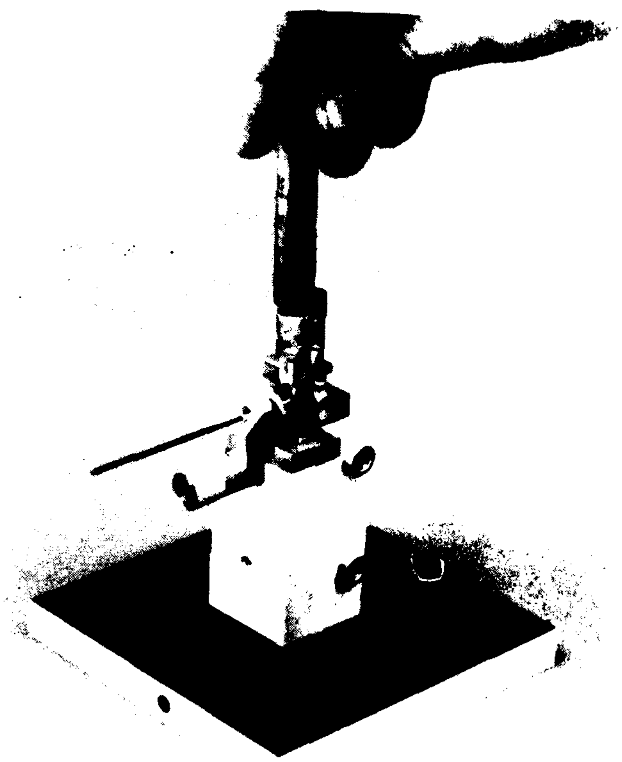


FIGURE 2.2: FERRULE CASTING FIXTURE

3. CONNECTOR CONFIGURATION

3.1 Plug

The interconnection of cable sections is accomplished using the hermaphroditic plug assembly, shown in Figure 3.1. Because the plugs are identical, the cable assemblies can be deployed in any orientation. The three-pronged mating interface contains three alignment members. The interface is keyed to permit mating in only one orientation. A white dot on each mating interface indicates the correct orientation for mating. Six ferrules are independently spring mounted in the inner housing. These extend into the mating interface; three into the alignment members and three into the spaces between the prongs. The ferrules are well protected from accidental damage by the mating interface and the plug housing which extends flush to the end of the ferrules. The ferrule mounting consists of a compression spring and a metal clip (between the spring and ferrule flange). The rotational orientation of the ferrule is fixed by a keyway in the housing which accepts the ferrule's key. A plastic sleeve in each of the three prongs of the mating interface fixes the rotational orientation of the alignment members.

The cable termination hardware is attached at the rear of the inner housing (details below). A cable strain relief nut locks the outer housing in place over the inner housing assembly. A coupling nut is provided on each plug. Only one is required for a plug-to-plug assembly.

The fibers are looped within the plug housing to provide slack fiber. This permits repeated fiber end preparation (when required) during installation of the ferrules and also allows for the repair or replacement of individual ferrules.

Access to the fiber ends and alignment members for cleaning (when required) is achieved by loosening a single screw which allows the mating interface to be removed.

Each plug is provided with a protective cap which is also hermaphroditic, permitting the caps to be mated when the plugs are mated, thereby protecting them from contamination during field deployment.

Figure 3.2 shows the installed connector plug;

(a) with the protective cap in place.

(b) with the protective cap removed.

(c) mated in a plug-to-plug configuration.

(d) with the mating interface removed to gain access to the fiber ends and alignment member for cleaning.

The housings, mating interface, coupling nuts, cable strain relief and protective cap are made of black-anodized aluminum.

3.2 Bulkhead Receptacle

The bulkhead receptacle, Figure 3.3 is used to terminate the connector plug assembly at an equipment location. The receptacle is attached through a D hole in the equipment panel. The mating interface, containing three alignment members, is identical to that used on the connector plug. The six ferrules are spring-loaded and oriented similarly to the plug construction. The ferrules, which are rear-inserted, are individually accessable for repair, replacement or re-arrangement. The coupling nut on the plug threads onto the receptacle to secure the mated assembly.

Each bulkhead receptacle is also provided with a hermaphoriditic protective cap.

Figure 3.4 shows the installed bulkhead receptacle;

(a) with the protective cap in place.

(b) with the protective cap removed.

(c) mated to a plug.

(d) rear view showing the fiber entry.

The housing, mating interface, retention nut and protective cap are made of black-anodized aluminum.

3.3 Features of the Connector

(a) Access to Fiber Ends

The ferrule (and fiber) ends, and the alignment members are easily accessed for cleaning by loosening one screw and removing the mating interface.

(b) Non-contacting Fiber Ends

Each fiber end is slightly (5 to 10 µm) recessed into the end of the ferrule. This prevents fiber-to-fiber contact in the mated condition and avoids damage to the fiber ends.

(c) Slack Fiber

An excess of fiber can be stored within the connector. This allows for repeated fiber end preparation (which is often required because of the inconsistent cleaving characteristics of fibers) without having to replace ferrules during installation. The slack also gives ready access to individual ferrules for repair or re-arrangement.

(d) Small Size

The outside diameter of the connector plug is only 3.8 cm (1.5 in) and the plug length is 11.7 cm (4.6 in). The bulkhead receptacle has a very flat profile behind the equipment panel (i.e. occupies very little space).

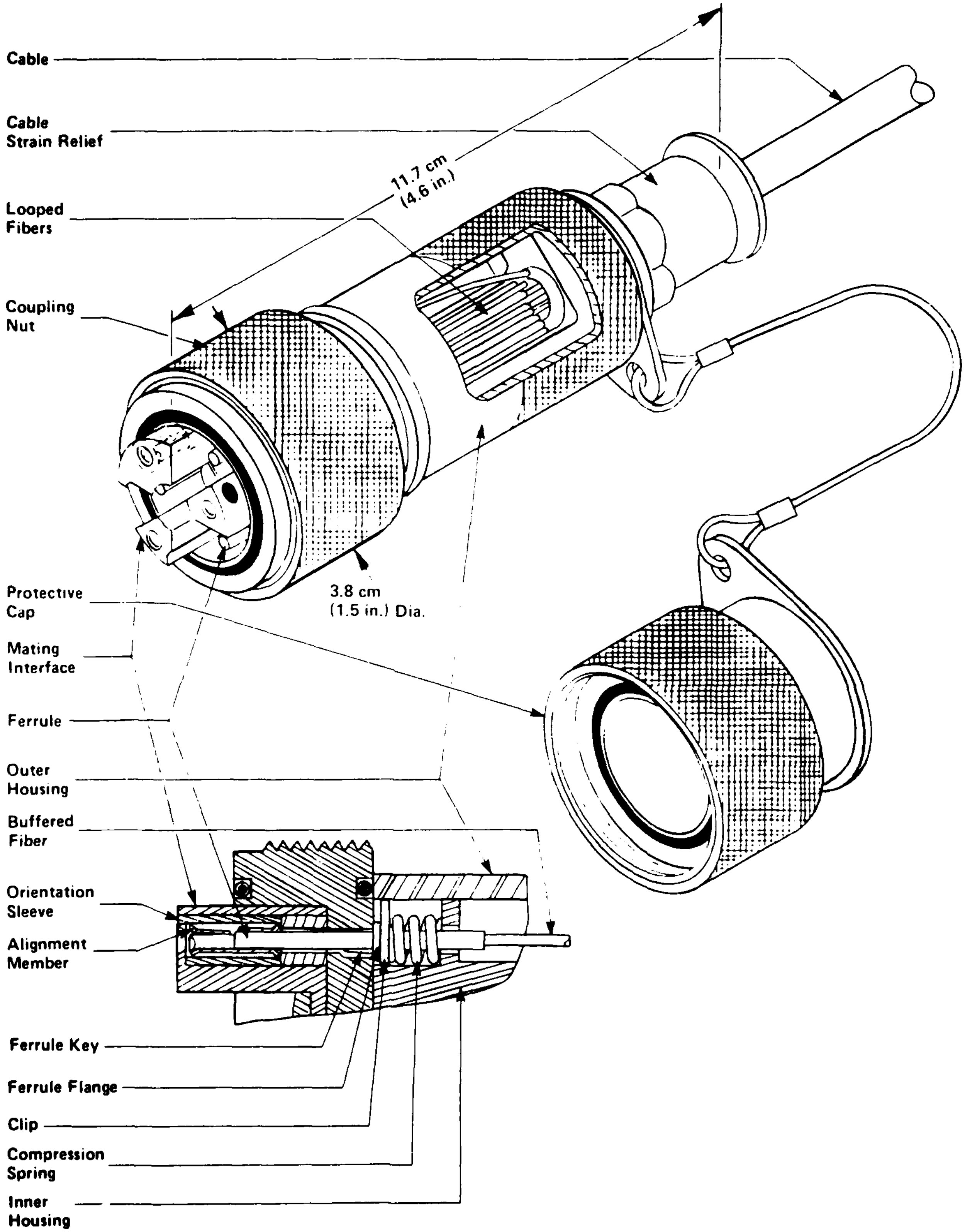
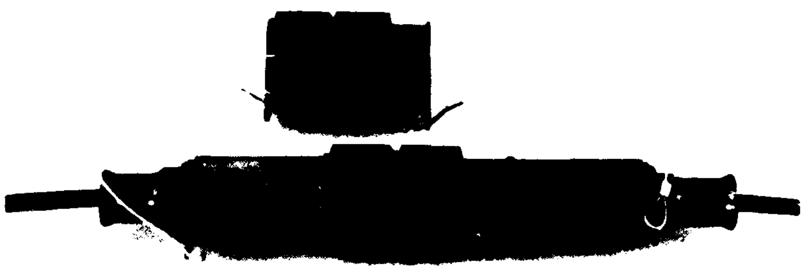


FIGURE 3.1: CONNECTOR PLUG

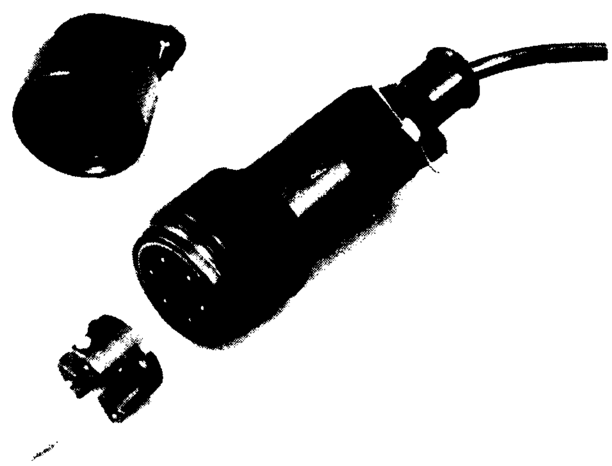
(a) PROTECTIVE CAP IN PLACE

(b) PROTECTIVE CAP REMOVED

FIGURE 3.2: CONNECTOR PLUG



(c) MATED: PLUG-TO-PLUG



(d) MATING INTERFACE REMOVED

FIGURE 3.2: CONNECTOR PLUG

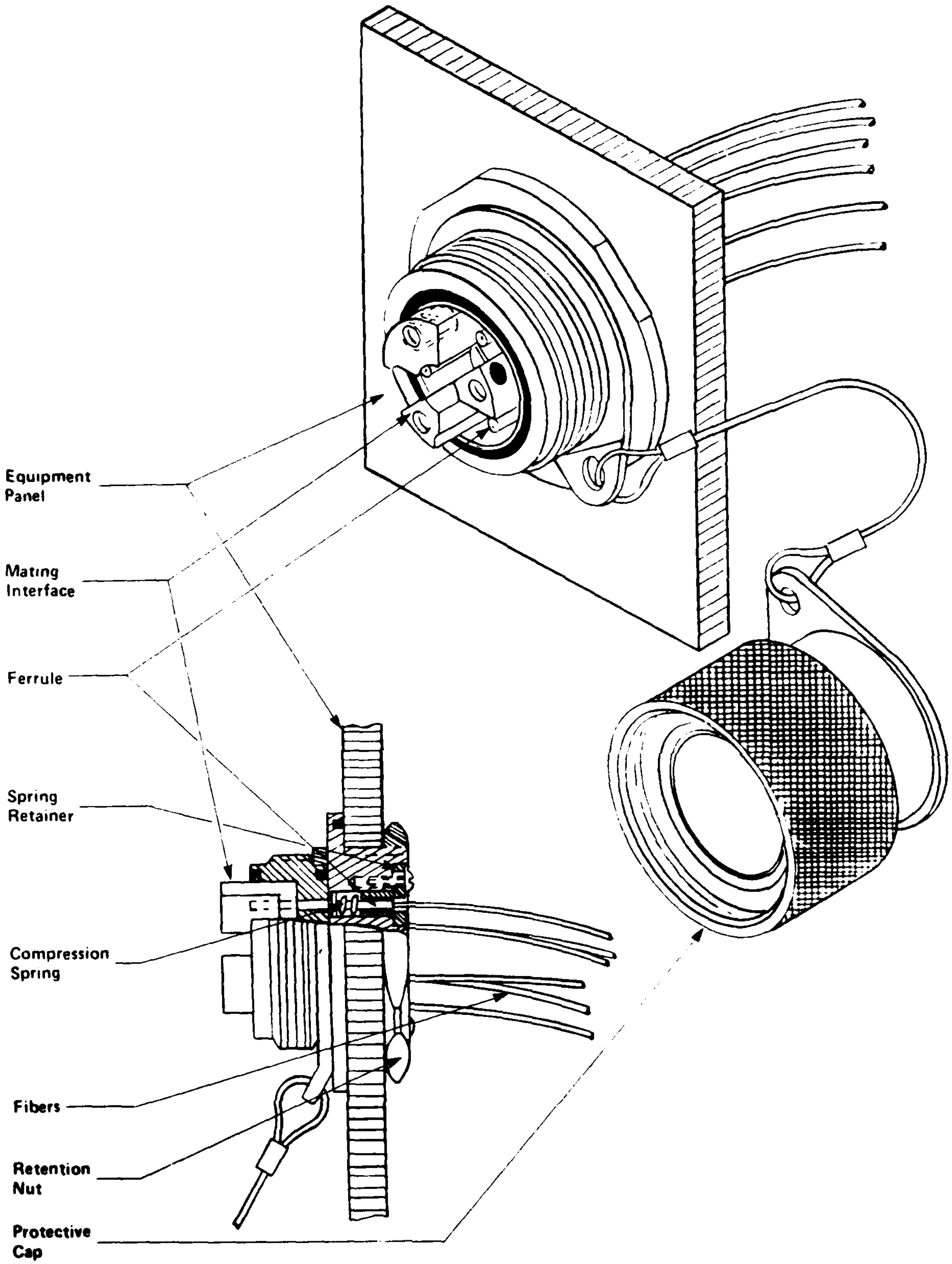
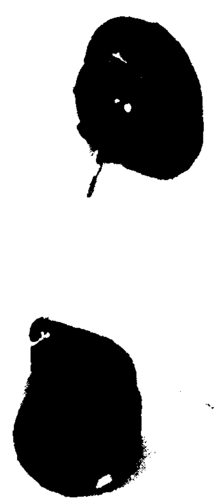


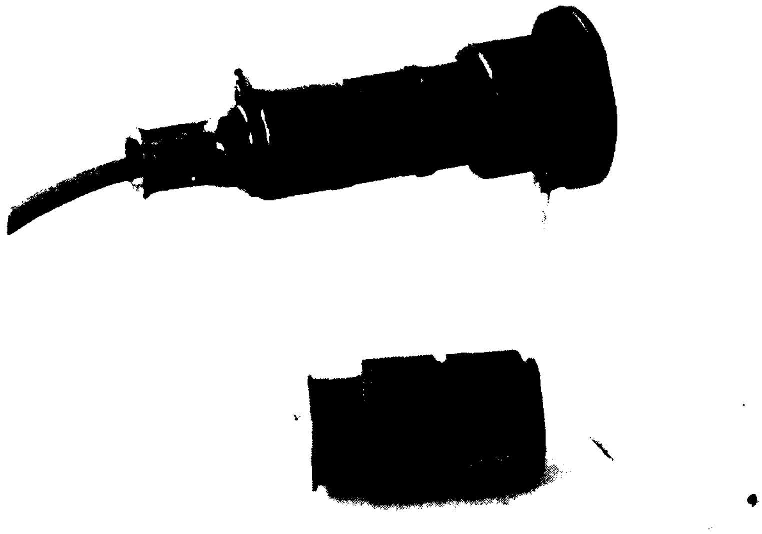
FIGURE 3.3: BULKHEAD RECEPTACLE

(a) PROTECTIVE CAP IN PLACE

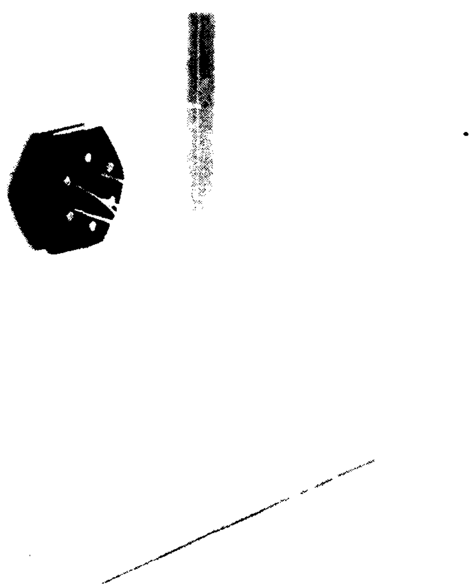


(b) PROTECTIVE CAP REMOVED

FIGURE 3.4: BULKHEAD RECEPTACLE



(c) MATED TO PLUG



(d) REAR VIEW

FIGURE 3.4: BULKHEAD RECEPTACLE

(e) Sealing

The connector plug and bulkhead receptable are sealed against moisture ingress in either the mated or unmated conditions (with the protective cap in place). This is accomplished using '0'-rings and a sealing tape within the plug's cable strain relief.

(f) Hermaphroditic Protective Cap

The protective caps can be mated together when two plugs or a plug and bulkhead receptacle are mated. This prevents contamination of the internal cavity of the caps.

(g) Adaptability to Fiber and Cable Changes

The connector diameter can be increased if necessary to accomodate a fiber with a larger lossless bending radius (i.e. smaller N.A.). The cable termination is readily adaptable to evolutionary modifications in the external strength member cable design. The cast ferrule is easily adapted to changes in fiber cladding diameter with only a simple change in tooling.

(h) Rear-insertion Ferrules

The ferrules in the bulkhead receptacle are inserted and removed from the rear. This permits removal of individual ferrules for repair, replacement or re-arrangement without having to remove the entire connector.

4. CONNECTOR INSTALLATION

4.1 Equipment

The equipment listed in Table 4.1 is required to complete the installation of the connector plug and bulkhead receptacle.

4.2 Fiber Installation

4.2.1 General

The equipment and procedure used to install a fiber in the connector ferrule is identical for both the plug and bulkhead receptacle. The equipment and procedure are described in this section. The sequencing of this operation is detailed in the following sections.

4.2.2 Ferrule Installation Fixture

Installation of a fiber into a ferrule requires the use of specialized installation fixture, illustrated in Figure 4.1 (a). The main components of this fixture are a ferrule retention clamp, a retractable fiber positioning rod and a fiber clamp.

4.2.3 Procedure

The following procedure is used to install a fiber into a ferrule. The bracketed numbers in this sections refer to the equipment item numbers in Table 4.1.

(a) Set-up the ferrule installation fixture (1) as follows.
Draw back and lock the fiber positioning rod. Lower the fiber clamp.
Place a ferrule into the fixture and hold it in place with the retention clamp (Figure 4.1 (b)).

TABLE 4.1: EQUIPMENT FOR CONNECTOR INSTALLATION

	Item	Description	Function
1.	Ferrule installation fixture	BNR drawing number 1D42 - 1507 Figure 4.1	To position and retain the fiber with respect to ferrule
2.	Hot plate	Corning PC-351 or equivalent	To accelerate curing of the epoxy used to bond the fiber into the ferrule
3.	Epoxy adhesive	Hysol Epoxy Patch Kit (2-part)	To bond the fiber into the ferrule
4.	Mixing sticks	Flat wooden sticks	To mix 2-part epoxy
5.	Mixing plate	Flat, smooth clean metal or glass surface ~5 cm x 5 cm	To mix 2-part epoxy
6.	Cotton swabs	Q-tips or industrial quality cotton swabs	To clean fiber ends
7.	Silicone softening agent	M-Pyrol made by GAF Corporation 140 West 51st St., New York	To remove residual silicone material from stripped fiber
8.	Organic solvent	Methanol or denatured ethanol	To clean fiber ends

TABLE 4.1: EQUIPMENT FOR CONNECTOR INSTALLATION (Con't)

Item	Description	Function
9. Fiber stripper	No-Nik (0.010 in) Clauss Fremount, USA or other suitable tool	To remove protective jacket from fiber end
10. Fiber cleaving tool	Any commercially - available equipment capable of providing a cleaved length of 6 mm with an end angle of 3° or better (Figure 4.2)	To provide a smooth smooth flat end face on the fiber after stripping and prior to installation in the ferrule
11. Knife	Any commerical brand	To cut cable sheath
12. Scissors	Any commerical brand	To trim cable strength members
13. 7/16" wrench	Any commercial brand or adjustable wrench	To tighten cable termination into plug housing
14. 3/4" wrench	Any commerical brand or adjustable wrench	To tighten cable strain relief onto plug housing
15. Small screw driver	Any commerical brand	To attach ferrule retainer to connector bulkhead receptacle

TABLE 4.1: EQUIPMENT FOR CONNECTOR INSTALLATION (Con't)

Item	Description	Function
16. Medium screw driver	Any commercial brand	To attach (or remove) mating interface assembly to connector plug or bulkhead receptacle
17. 1 3/4" wrench	Custom made or commercially available	To attach connector bulkhead receptacle to equipment panel
18. 2 1/64"	Custom made or commercially available	To attach connector bulkhead receptacle to equipment panel
19. 4" needle-point tweezers	Any commercial brand	To facilitate installation of ferrule retention mechanism in connector plug.

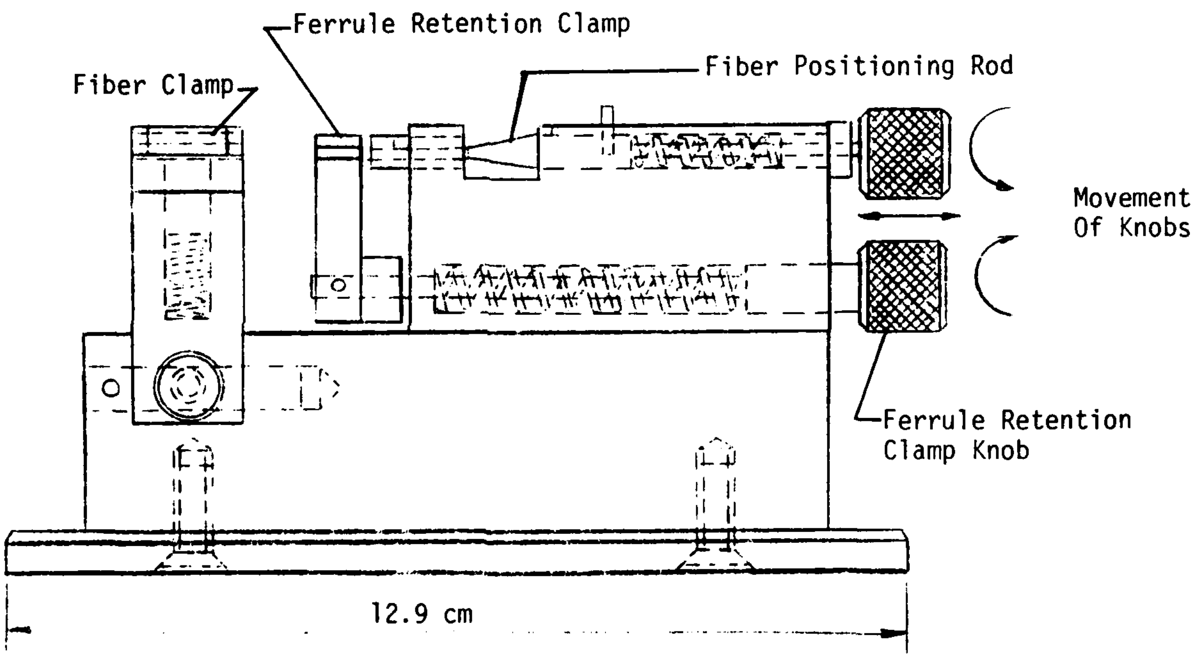
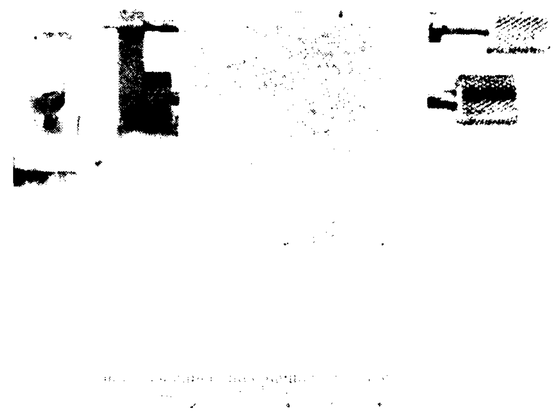
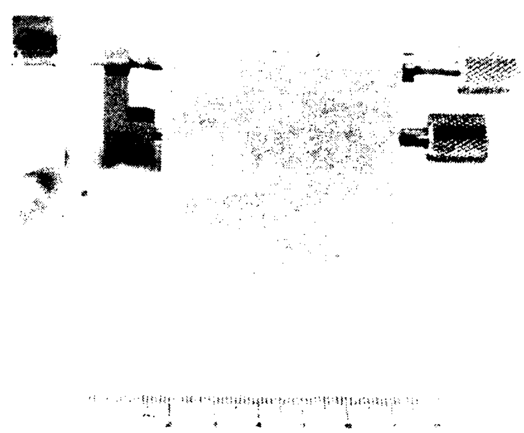


FIGURE 4.1 (a): FERRULE INSTALLATION FIXTURE

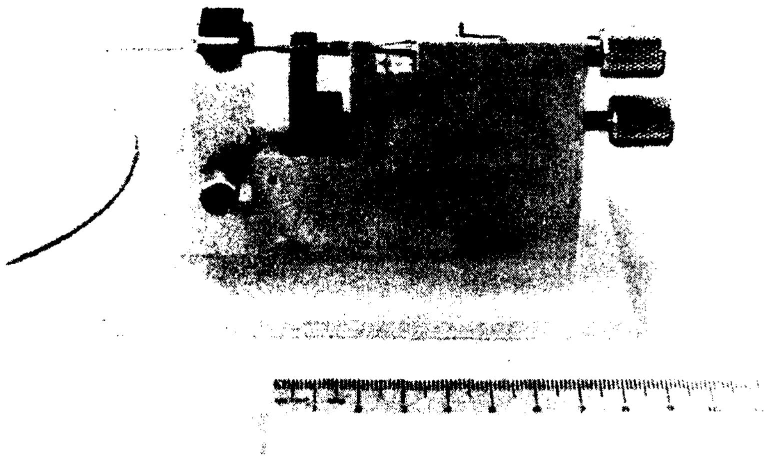


(b) FERRULE LOCATED IN FIXTURE



(c) FIBER INSERTED THROUGH FERRULE

FIGURE 4.1: FERRULE INSTALLATION FIXTURE



(d) FIBER RECESSED IN FERRULE AND CLAMPED

FIGURE 4.1: FERRULE INSTALLATION FIXTURE

(b) Strip approximately 2.5 cm of the fiber coating from the end of the fiber using a suitable stripping tool (9).

(c) Cleave the end of the fiber with a suitable cleaving tool (10) to produce a bare fiber length of 6 mm between the cleaved fiber end and the end of the stripped coating. The fiber end angle should be smooth and a maximum of 3°. An interferometric technique[2] can be used to confirm the quality of the fiber end preparation.

A prototype BNR fiber cleaving tool, illustrated in Figure 4.2, was used for fiber preparation during this development. It works on the "bend-tension-score" principle[3]. The cleaving tool was adjusted for optimum performance with the ITT fibers.

(d) Clean the bare fiber end by dipping into a silicone softening agent (7) and then wiping the bare fiber end with a cotton swab (6) soaked in solvent (8).

(e) Mix a small portion of the epoxy adhesive (3,4,5) and apply the adhesive along the sides of the bare fiber and onto the coating. The adhesive should not cover the end of the fiber.

(f) Insert the fiber end through the ferrule in the installation fixture (1) until the cleaved end extends beyond the end of the ferrule (Figure 4.1 (c)).

(g) Clean the fiber end with a cotton swab (6), soaked in solvent (8).

(h) Unlock the fiber positioning rod and advance it to slowly push the fiber back into the ferrule.

A small protrusion on the end of the positioning rod insures that the fiber end is slightly recessed (5 to 10 μm) with the ferrule.

(i) Clamp the fiber in place (Figure 4.1 (d)).

(b) Strip approximately 2.5 cm of the fiber coating from the end of the fiber using a suitable stripping tool (9).

(c) Cleave the end of the fiber with a suitable cleaving tool (10) to produce a bare fiber length of 6 mm between the cleaved fiber end and the end of the stripped coating. The fiber end angle should be smooth and a maximum of 3°. An interferometric technique[2] can be used to confirm the quality of the fiber end preparation.

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A small protrusion on the end of the positioning rod insures that the fiber end is slightly recessed (5 to 10 μm) with the ferrule.

(i) Clamp the fiber in place (Figure 4.1 (d)).

FIGURE 4.2: BNR FIBER CLEAVING TOOL

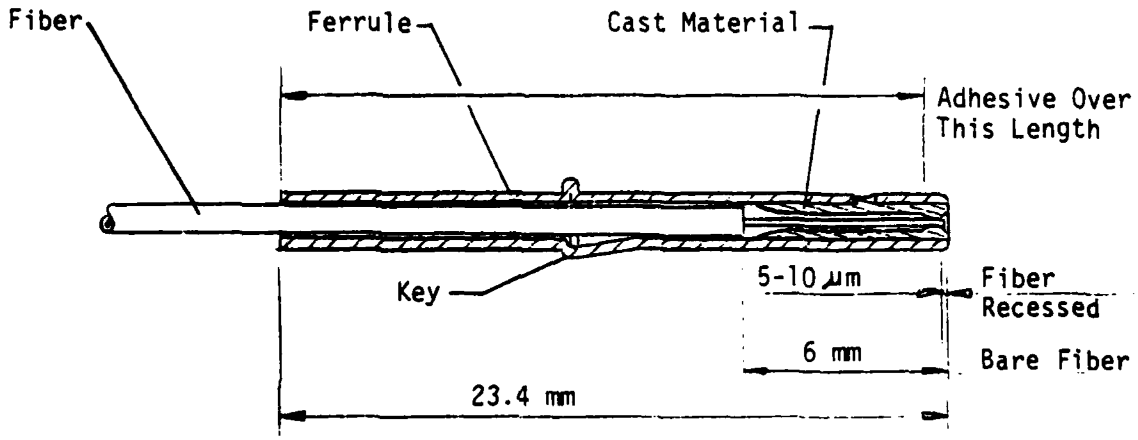


FIGURE 4.3: CROSS-SECTION OF INSTALLED FERRULE

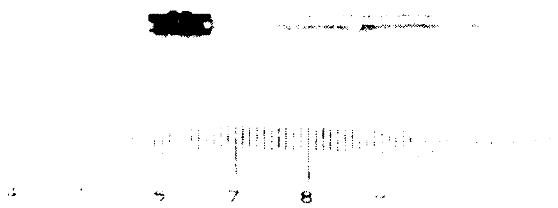


FIGURE 4.4: FERRULES AND ALIGNMENT MEMBER

(j) Place the installation fixture on a hot plate (2), (adjusted to heat the ferrule to approximately 90°C; temperature control set to "low") and allow the epoxy to cure for 15 minutes.

(k) Remove the installation fixture from the hot plate and allow to cool for approximately 5 minutes before removing the ferrule.

A cross-section of the completed ferrule installation is illustrated in Figure 4.3. Samples of the ferrules and alignment member are shown in Figure 4.4

4.3 Plug

The procedure for installing the connector plug to the ITT cable is as follows. The bracketed numbers in this section refer to the equipment item numbers in Table 4.1. The connector hardware items and their relative positions are illustrated in Figure 4.5.

(a) The ITT cable end is prepared, as illustrated in Figure 4.6, by removing the outer and inner sheaths (11) to access the fibers and the strength members.

(b) The fiber ends are prepared and ferrules installed per section 4.2.3.

(c) The cable strain relief, protective cap sub-assembly, outer housing, coupling nut, coupling nut washer and three of the cable termination parts (clamp nut, washer and seal) are placed over the prepared cable end, in the sequence listed (reference Figure 4.5).

(d) The cable termination is completed, as illustrated in Figure 4.7. The internal sleeve is placed on the end of the outer sheath. The Kevlar strands are folded back over the tapered outer surface of the internal sleeve. The external sleeve is placed over the Kevlar strands, trapping them between the two sleeves, and the Kevlar strands are trimmed (12) to the end of the sleeve assembly. The fibers and cable termination

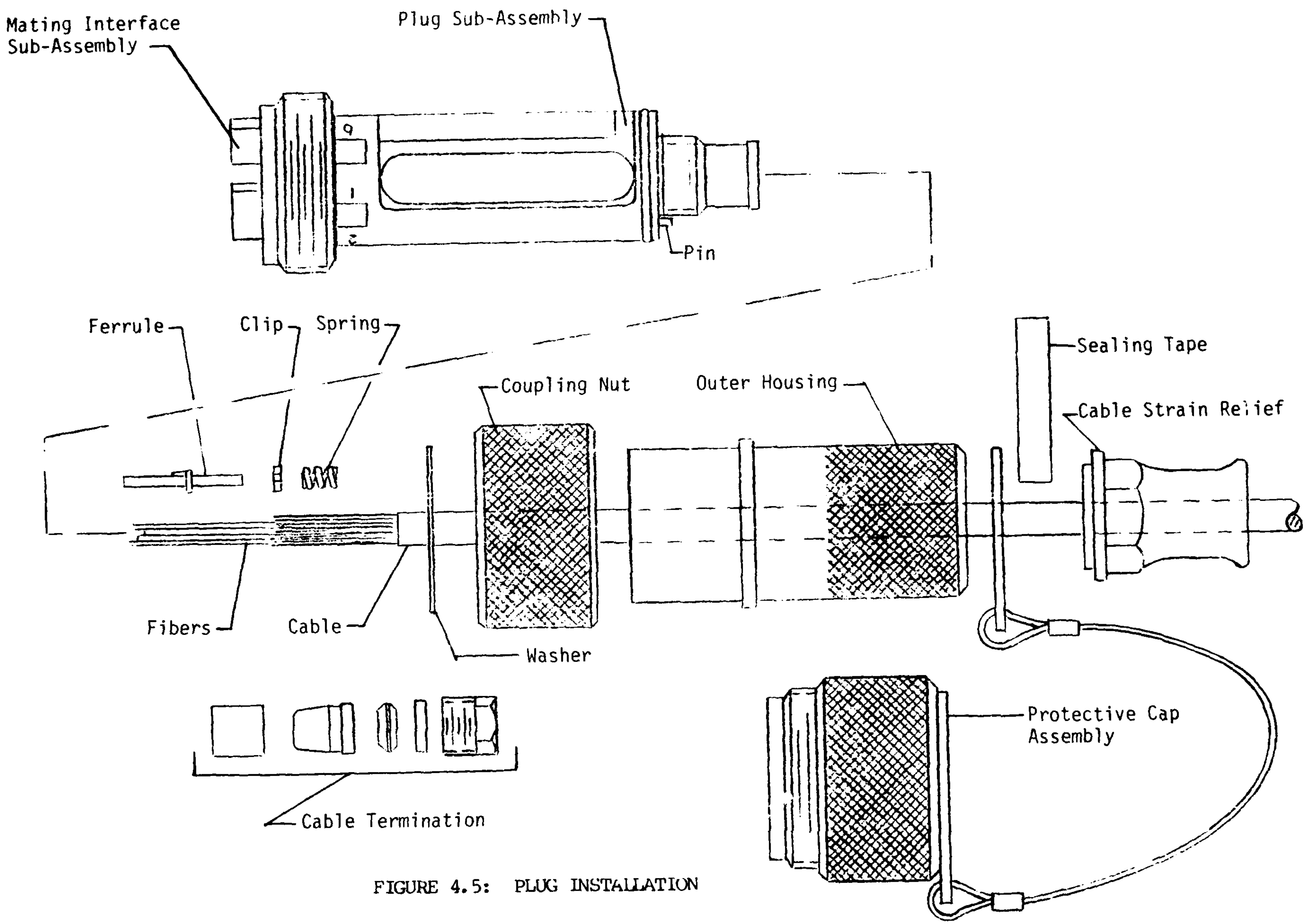


FIGURE 4.5: PLUG INSTALLATION

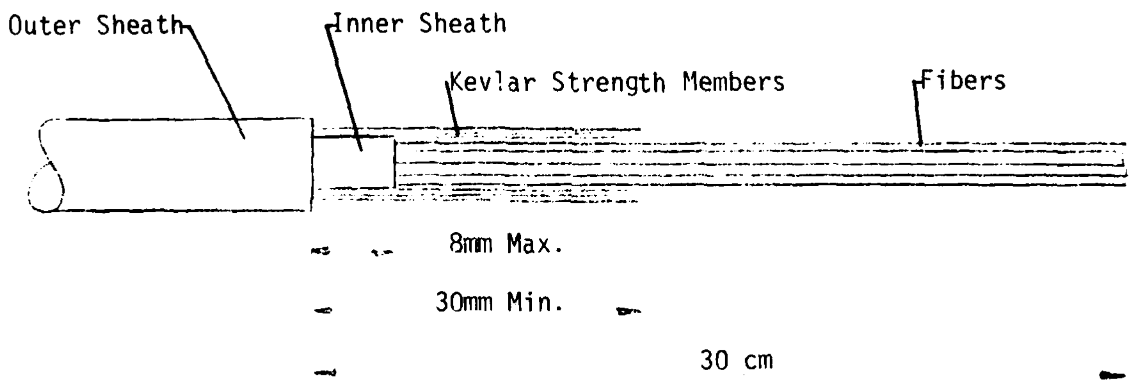
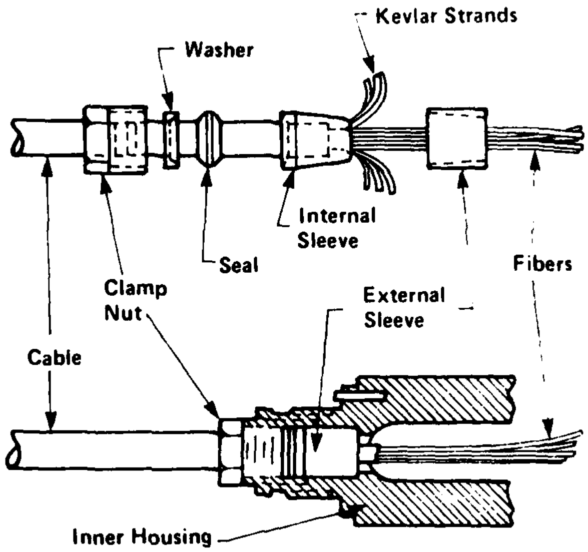
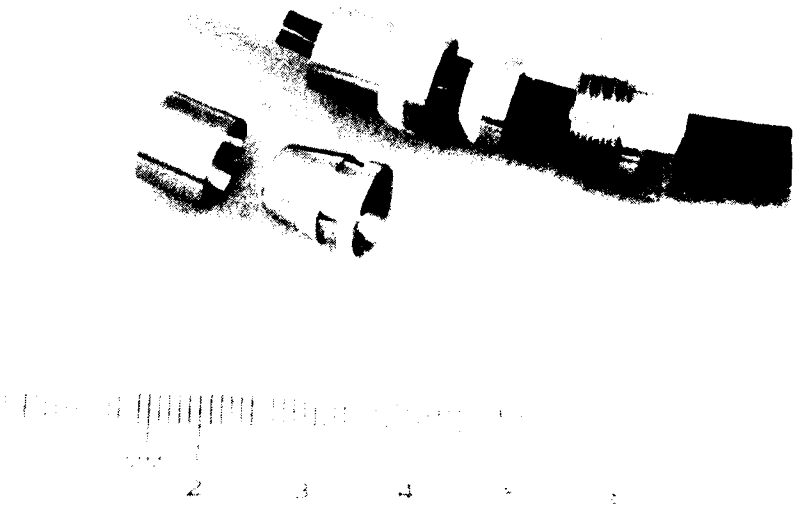


FIGURE 4.6: CABLE PREPARATION



(a) PART IDENTIFICATION AND RELATIVE POSITIONS



(b) ACTUAL HARDWARE

FIGURE 4.7: CABLE TERMINATION

hardware are fed through the rear of the inner housing. The clamping nut is threaded into the housing and tightened (13).

(e) The ferrule compression springs are loaded into their chambers in the inner-housing.

(f) In turn, each fiber is looped in the inner housing and the ferrule inserted through the compression spring into the mating interface, insuring that the ferrule key enters the keyway in the housing.

The clip is inserted by compressing the spring away from the ferrule flange (18) and placing the clip between the flange and spring.

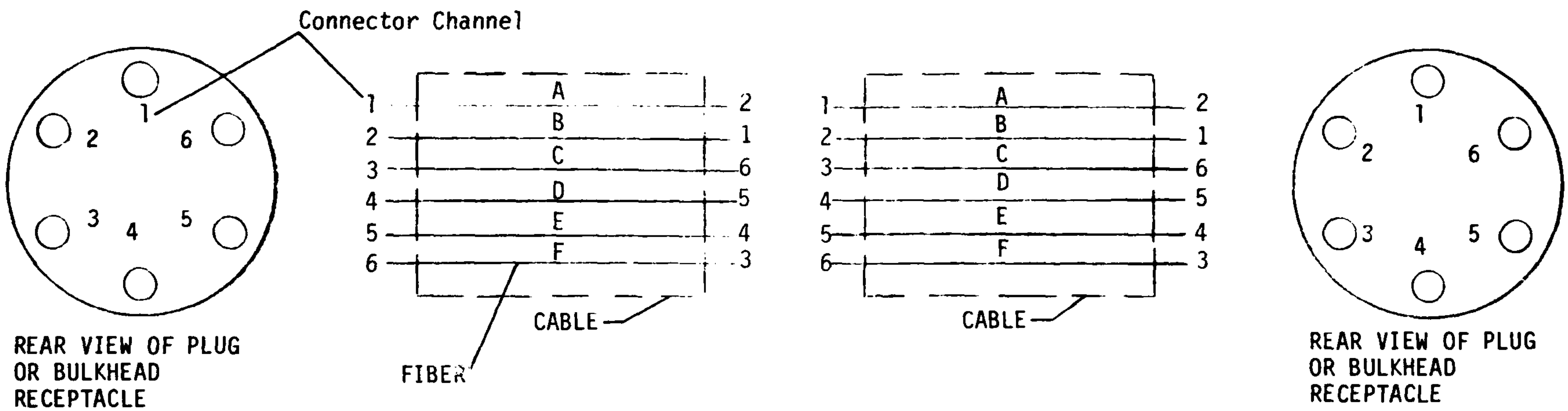
Figure 4.8 indicates the relative positioning of the terminated fibers to insure channel pair continuity irrespective of the number of cable lengths used. This is accomplished by transposing each fiber in each cable length between the mated connector channel pairs (ie fiber A is located in channel 1 at one end and in channel 2 at the opposite end).

(g) The connector is closed by bringing forward the coupling nut washer, coupling nut and outer housing (reference Figure 4.5). The washer is placed over the outer housing, the coupling nut threads engaged and the outer housing rotated until the pin at the rear of the inner housing is felt to be engaged.

(h) The sealing tape is applies over the cable termination clamp nut.

(i) The protective cap sub-assembly and the cable strain relief nut are brought forward and tightened (14).

(j) The protective cap is installed over the mating end of the connector.



MATING CONNECTOR CHANNEL PAIRS

1 - 2
3 - 6
4 - 5

FIGURE 4.8: FIBER POSITIONS IN CONNECTOR CHANNELS

4.4 Bulkhead Receptacle

The procedure for installing the bulkhead receptacle fibers is as follows. The bracketed numbers in this section refer to the equipment item numbers in Table 4.1. The connector hardware items and their relative positions are illustrated in Figure 4.9.

(a) The receptacle sub-assembly is located in the D-hole in the equipment panel (17).

(b) The fiber ends are accessed to provide approximately 30 cm to 45 cm.

(c) The fiber ends are prepared and ferrules installed per section 4.2.3.

(d) In turn a ferrule retainer and compression spring is placed over each ferrule onto the fibers. A clip is placed between the ferrule flange and the compressions spring. The ferrule is loaded into the rear of the receptacle, insuring that the ferrule key enters the keyway in the housing. The spring and ferrule retainer are brought forward and secured in place (15) with the retention screw.

(e) The protective cap is installed over the mating end of the connector.

4.5 Mating Procedure

4.5.1 Plug-to-Plug

(a) Remove the protective caps from both plugs.

(b) Mate the interface assemblies by aligning the white indicator dots (the interfaces are keyed, to mate in only one orientation).

(c) Rotate either one of the knurled coupling nuts to the rear position.

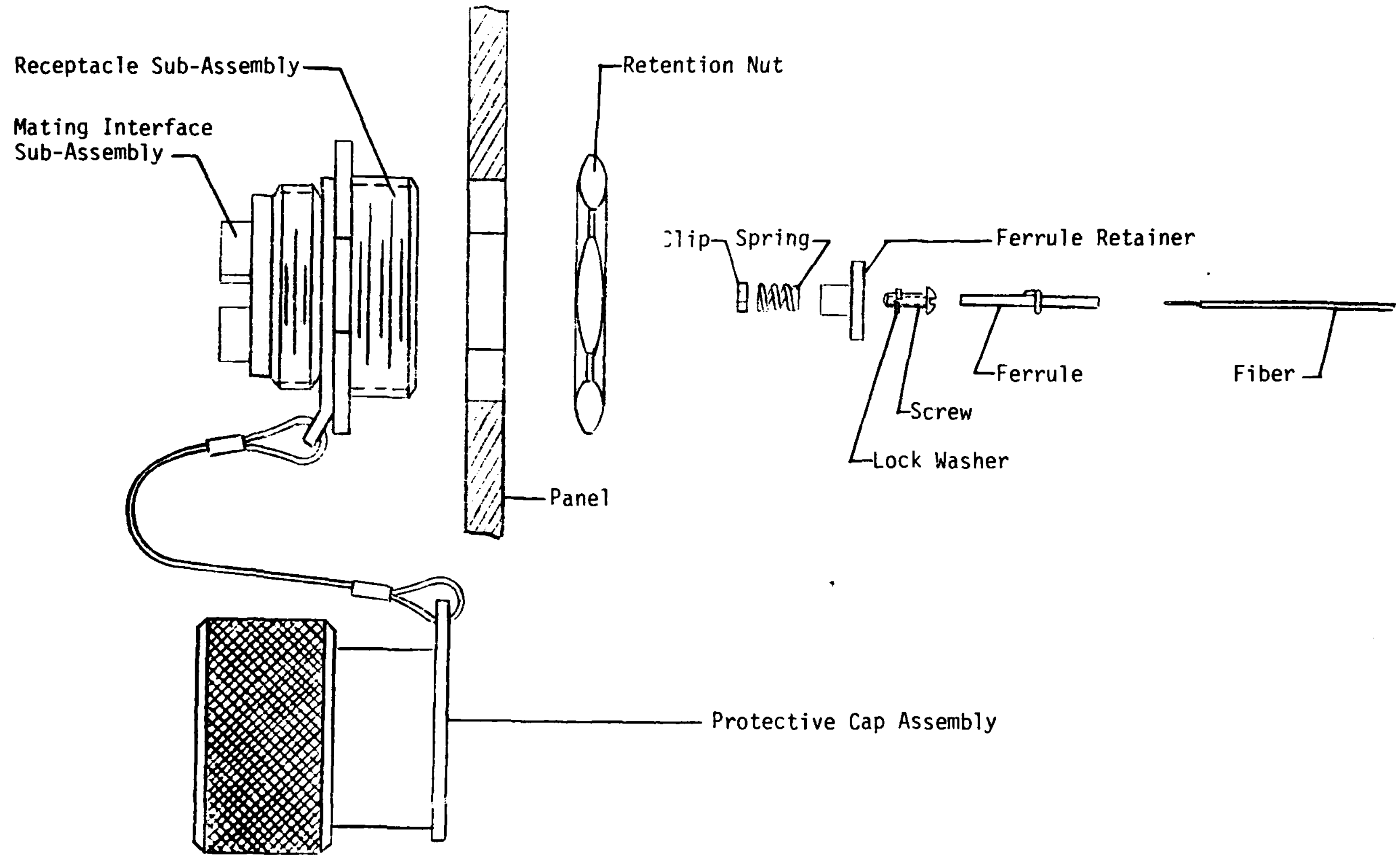


FIGURE 4.9: BULKHEAD RECEPTACLE INSTALLATION

(d) Rotate the remaining coupling nut onto the threaded section of the mating plug and tighten firmly. The coupling nut fully tightens in approximately 2 turns.

(e) Mate the protective caps using one of their coupling nuts.

4.5.2 Plug-to-Receptacle

(a) Remove the protective caps from both the plug and bulkhead receptacle.

(b) Mate the interface assemblies by aligning the white indicator dots. (The interfaces are keyed to mate in only one orientations.)

(c) Rotate the plug coupling nut onto the threaded section of the mating plug and tighten firmly. The coupling nut fully tightens in approximately 2 turns.

(d) Mate the protective caps using one of their coupling nuts.

5. TESTING

5.1 Introduction

A testing program was conducted on the developmental model connector in accordance with a test plan approved by CORADCOM. The detailed results of this testing have been reported to CORADCOM in TR-1D42-03-80 (July 1980). A summary of these results are presented in this section.

5.2 Test Sequence and Test Samples

Two connector assemblies were used for the test program. The tests and test sequence on each sample are outlined in Table 5.1.

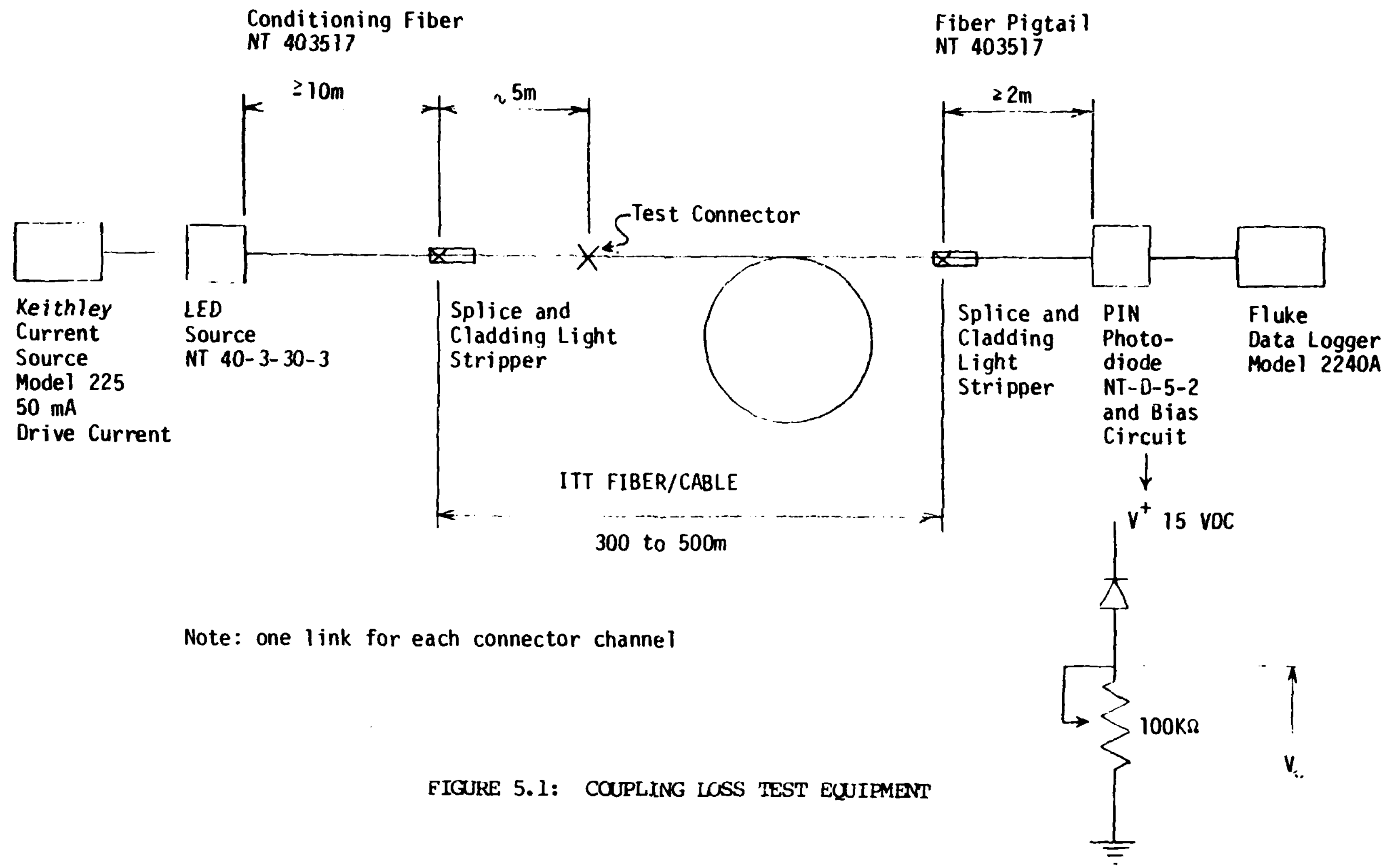
5.3 Coupling Loss (Insertion Loss) Measurement Method

The equipment arrangement for the coupling loss test is shown in Figure 5.1. The light emitting diode operates at a wavelength of approximately 0.83 μm. Permanent attachment to a fiber pigtail insures that the light launching conditions are stable for each test. The length of fiber inserted before the test cable is required to condition the light distribution within the fiber core. The graded-index conditioning fiber has the name nominal core and cladding diameters as the fibers in the test cable.

An equilibrium or steady state mode distribution in low-loss, graded-index fibers is achieved only after transmission through several kilometers of fiber. The use of this much fiber is not practical for test purposes. The use of shorter fiber lengths with non-equilibrium mode distributions generally results in higher insertion loss measurements because of the relatively greater content of high order modes. Therefore a connector passing the insertion loss requirements under these test conditions can be expected to equal or exceed the test performance when installed in longer cable lengths.

TABLE 5.1: TEST SAMPLES AND TEST SEQUENCE

	SAMPLE A	SAMPLE B
Connector Configuration	two plugs	one plug and one bulkhead receptable
Test Sequence	1. Coupling loss	1. Coupling loss
	2. Coupling nut rotation	2. Coupling nut rotation
	3. Mating durability	3. Mating durability
	4. Coupling nut rotation	4. Coupling nut rotation
	5. Strain relief	5. Flexing strength



Note: one link for each connector channel

FIGURE 5.1: COUPLING LOSS TEST EQUIPMENT

Note, however, that the results of an insertion loss measurement do not account for the additional losses expected when different fibers of the same design are coupled through a connector. The magnitude of this fiber mismatch loss is dependent upon the variations in core diameter, cladding diameter, numerical aperature and index profile.

5.4 Summary of Test Results

The developmental model connector has successfully met the contract requirements as evaluated by the contract test plan. Table 5.2 is a summary of the test requirements, methods and results.

5.4.1 Coupling Loss

Because of the wide cladding diameter tolerance range (119 um to 131 μm), two ferrule bore diameters were used (127 μm and 133 μm) to limit the transverse offset between mating fibers. The fiber cladding diameters were measured at the time of installation and a ferrule selected based on the measured diameter. The same ferrule bore diameter was used for both fibers in any one channel of the connector. The average insertion loss on Sample A (plug-to-plug) was 0.9 dB and the average insertion loss on Sample B (plug-to-bulkhead receptacle) was 0.8 dB. All channels on both assemblies were less than the specified 1.5 dB.

The wide range of coupling losses, 0.4 dB to 1.4 dB, is indicative of the combined influence of the large number of parameters within the fiber specification and the connector design (including fiber end preparation). The parameter generally considered to be the most significant is transverse offset between the fiber ends. The factors contributing to this include;

(a) the mismatch between the ferrule bore diameter and the fiber cladding diameter

(b) misalignment of the ferrules due to tolerances in the connector

TABLE 5.2: COMPARISON OF TEST RESULTS WITH REQUIREMENTS

TEST	REQUIREMENT	RESULT	COMMENT
(1) Coupling Loss (Insertion Loss)	Maximum of 1.5 dB on any channel.	Average 0.85 dB Range 0.4 to 1.4 dB	Meets requirements.
(2) Mating Durability	Meet (1) & (6) after 1000 rematings, cleaning permitted.	Average 0.9 dB Range 0.6 to 1.4 dB	Meets requirements with cleaning.
(3) Strain Reflief (Tensile Strength)	No signal change after 180 kg tensile load between plug and cable for 1 minute.	No signal change during or after application of load. No visible slipping or damage.	Meets requirement.
(4) Cable Flexing Strength	No signal change and no cable slippage/damage after 1000 cycles of $\pm$ 90° at connector strain relief.	No signal change slippage or damage.	Meets requirement.
(5) Vibration	Meet (1) & (6) after MIL-STD-202E, Method 204, Cond. A (10g, 10-500 Hz, 12 cycles, 3 Axes).	No signal change. No external damage. Coupling nut remained tight.	Meets requirement. Some wear evident.
(6) Coupling Nut Rotation	Maximum of 0.75 in-lbs after (2) & (5).	Torque of 0.022 in-lbs unaffected by remating or vibration tests.	Meets requirement.

(c) ovality of the fiber cladding diameter, and

(d) eccentricity between the fiber core and cladding.

Other significant parameters include;

(a) mismatch of core diameters (which can occur during remating of the same fiber as the core diameter can very within the length of fiber removed during fiber preparation),

(b) quality of the fiber end preparation (angle and flatness), and

(c) end separation between the fibers, (an order of magnitude less sensitive than transverse offset).

(d) axial tilt between the fibers, and

(e) mismatch of numerical aperatures (which also could occur during remating of the same fiber).

As would be expected with the large number of parameters involved, there is no direct correlation between the coupling loss and the mismatch between the ferrule bore diameter and the fiber cladding diameter.

Because of the reported low N.A. of 0.15 on fiber 6, a series of bending tests were performed to determine if the looping of slack fiber in the connector plug was contributing to the loss. The tests were conducted using the test set-up, shown in Figure 5.2. It is essentially the same as the equipment used for the insertion loss measurement. Two 2.5 cm (1 inch) diameter loops were made at locations (a) and (b) on the test fiber and at location (c) on the 0.17 NA pigtail fiber for comparison. The loop diameter in the connector is approximately 2.5 cm. Location (a) is the approximate position where the connector was installed during testing. Again, for comparison purposes, the tests were conducted before and after the

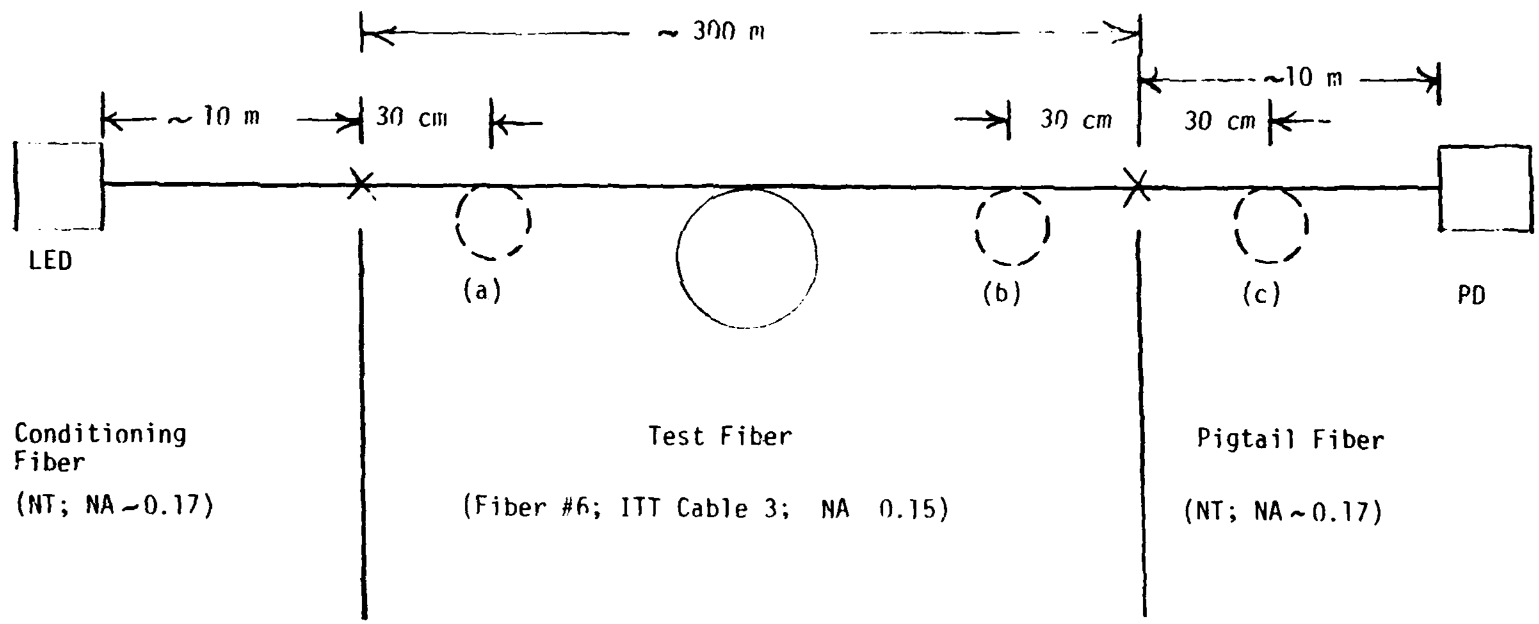


FIGURE 5.2: BEND LOSS TEST LINK

cladding light strippers were in place. The results are shown in Table 5.3. The signal drop with the addition of the epoxy strippers was 30.4%.

These results are unusual in two respects:

(a) The 0.15 NA ITT fiber, (a) and (b), exhibits no bending loss at the 2.5 cm loop diameter compared to a nominally higher NA, fiber (c).

(b) Although the addition of the strippers caused the signal to drop 30.4%, indicating that cladding light was present, it made very little difference in the sensitivity to bending.

A possible explanation would be that different methods of measuring NA have been used.

In conclusion, there was apparently no significant loss due to fiber bending in the connector with the ITT cables supplied by CORADCOM. However, the unexpected insensitivity to bending warrants clarification.

During end preparation, the fibers exhibited variable cleaving characteristics between fibers and at different positions along the same fiber. The ends were cleaved to achieve a maximum end angle of 3 degree as measured on an interferometer[2]. The cleaving tool used was a model of a BNR design (Figure 4.2) which was adjusted to optimize its performance with the ITT fibers. Some fibers regularly yielded acceptable end angles while others required considerable recleaving. Variations in the cladding diameter and residual stress patterns in the fiber are thought to contribute to this phenomenon. Fibers from other manufacturers also exhibit similar characteristics.

As a consequence of these variable cleaving characteristics, the length of fiber stored in the connector plugs varied from 6 inches to 18 inches (15 cm to 45 cm).

TABLE 5.3: BENDING LOSS TESTS ON LOW NA FIBER

Loop Diameter (2 loops)	Without Strippers (dB) (a)	(b)	(c)	With Strippers (dB) (a)	(b)	(c)
2.5 cm (1.0 in)	0.01	0	0.23	0	0	0.18
1.6 cm (0.625 in)	0.02	0.02	0.37	0.03	0.02	0.45
1.0 cm (0.375 in)	0.08	0.12	0.64	0.15	0.12	0.79

The insertion loss of the connector can be reduced by decreasing the transverse offset between the fiber and the ferrule bore diameter. This can be accomplished by tightening the tolerance on the cladding outside diameter (presently ± 6 µm) which in turn will permit the use of a single ferrule bore diameter on all fibers. Provided that a reduction in cladding diameter tolerance is accompanied by a reduction in core diameter tolerance (presently ± 6 µm), there is a good prospect of achieving less than 1 dB insertion loss per channel.

It should be noted that under field conditions different fibers of the same specification will be mated. Consequently, mismatch in core diameter and numerical aperature will produce higher average and worst case losses across a connector, irrespective of the ability of the connector to align fibers with significantly different cladding diameters. This will be counteracted, at least partially, by the more favourable steady-state transmission characteristics expected in long links (ref. section 5.3).

5.4.2 Durability

The intention was to remate the connector plugs 1000 times then clean the connector and perform a final remating. However, after 500 rematings the loss on one channel (4) had increased to 1.9 dB. Examination revealed an accumulation of wear particles, from the beryllium copper alignment member, adjacent to the ferrule contact area on the alignment member. Some of these particles had become imbedded in the ends of the ferrules. On channel 4 particles could be observed at the end of the fiber. Similar wear was observed on all channels. After cleaning, channel 4 improved to 0.5 dB, compared to its initial reading of 0.4 dB. The other channels (with the exception of channel 2) showed modest loss improvements as a result of cleaning.

The improvement in loss with cleaning indicates that the loss increases were caused by the contaminating wear particles rather than increased transverse offset produced by wear. During rematings, one ferrule remains in the alignment member while the other enters and withdraws. Depending upon the initial positions of the fibers in the ferrule bores, the wear could cause a slight improvement in loss if the fibers were being brought into alignment as a result of wear on one half of the alignment member.

AT 1000 rematings the average loss of 0.9 dB did not change as a result of cleaning. Again channel 2 increased in loss after cleaning. This increase from 1.0 dB to 1.4 dB (the initial value before rematings) is probably due to increased sensitivity to loss variations as the amount of transverse offset increases. This is illustrated in Figure 5.3 which is a representation of transverse offset versus loss. Specific loss and transverse offset values are not noted as this data for the ITT fibers is not available. The possible change in transverse offset as a result of remating the connector is represented by the quantity 'd'. This variability is due to the fact that on remating the connector ferrules and alignment member will not take exactly the same relative positions. A connector channel operating in region 1 will show less variability on remating than a channel operating in region 2 (ie. at nominally higher losses) because of the increased slope of the curve. During cleaning, the mating interface containing the alignment members is removed, thereby withdrawing the ferrule that is normally stationary during ratings. The reseating of this ferrule after cleaning can produce additional misalignment resulting in an increase in insertion loss. The subsequent remating of the connector causes an improvement in alignment and loss.

Design modifications to improve mating durability are outlined in section 6.

The cleaning procedure for the ferrules involved the use of a cotton swab soaked in methanol. A "dry" cleaning method wasn't used. Experience has established that a dry material (brush, cloth, etc.) leaves dust particles and consequently frequent recleaning is required. Water was not used because it can leave a residual film and it dries (evaporates) very slowly. Methanol does not leave a film and it evaporates quickly.

The alignment members in the mating interface were cleaned with a dry pipe cleaner.

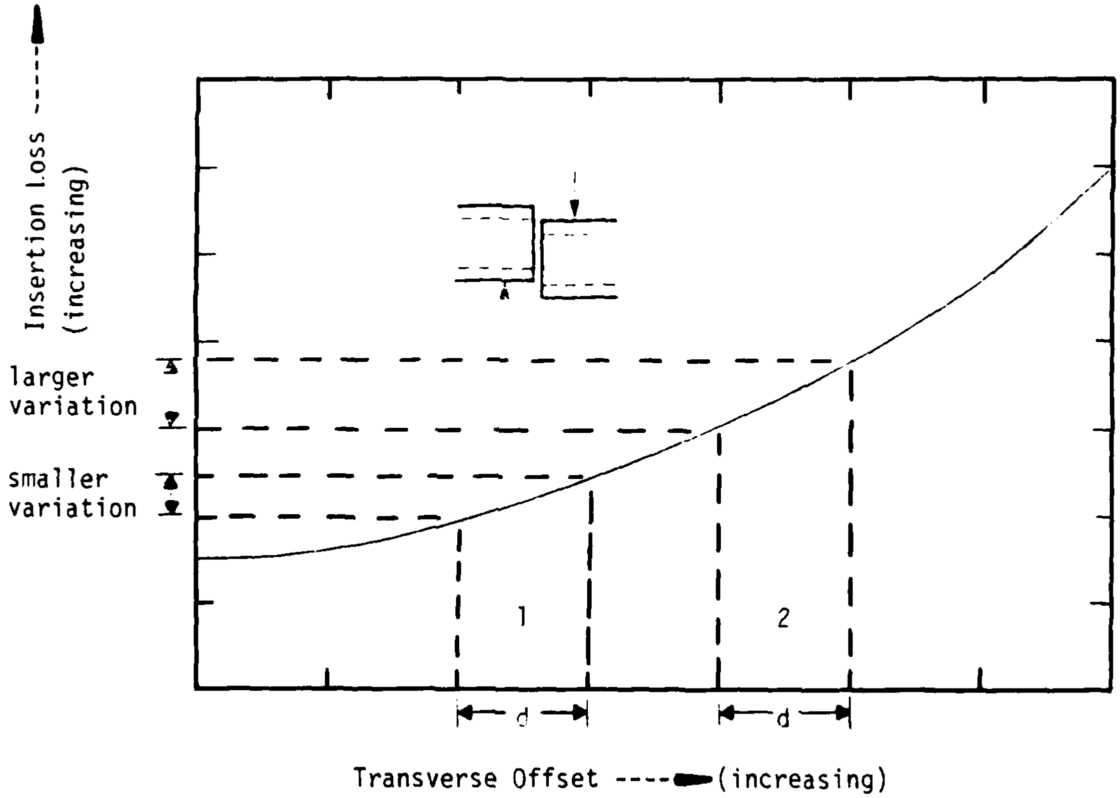


FIGURE 5.3: SENSITIVITY OF INSERTION LOSS TO TRANSVERSE OFFSET

5.4.3 Vibration

The connector assembly withstood the vibration cycling (12 cycles on each of three mutually perpendicular axes) without any change in transmitted signal strength. The coupling nut remained tight after the completion of the test. No significant resonances were found. Some wear to the plastic orientation sleeve which holds the alignment member was observed after the vibration cycling. Loose particles were generated by the rubbing of the alignment member against the orientation sleeve. The orientation sleeve would still function properly after vibration cycling but the particles could cause contamination of the ferrule ends during subsequent rematings. These particules can be easily removed during cleaning.

Design modification to improve the wear characteristics are outlined in section 6.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 The developmental model, hermaphroditic, 6-fiber optical fiber connector has demonstrated the potential to function in adverse environments typical of tactical field applications. The connector has successfully met the specific performance requirements of the contract as evaluated by the test plan.

6.2 Wear in the developmental models during testing involved;

a) the generation of loose particles from the alignment member by the ferrule as a result of rematings, and

b) the generation of loose particles from the alignment member orientation sleeve by the alignment member during vibration cycling.

During final development, the wear can be reduced with relatively minor changes to the connector.

The remating wear on the alignment member can be reduced by decreasing the spring load exerted by the alignment on the ferrule. This can likely be achieved without degrading the performance of the alignment member under vibration.

The vibration wear on the orientation sleeve can be reduced or eliminated by changing from a thermoplastic material to an elastomeric material for this part. The elastomeric material will deflect during vibration, thereby avoiding rubbing with the alignment member.

6.3 Reductions in average and maximum coupling loss (insertion loss) experienced under field conditions (where mismatched fibers are mated in the connector) can be achieved by reducing the tolerance on the fiber's core and cladding diameters, and by reducing the allowable variation in numerical aperature.

The use of a single ferrule bore diameter would also result from tighter control of fiber dimensions.

6.4 The cable and fiber specification should be fixed prior to final connector development. This will insure compatability between the cable and connector.

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2. K.S. Gordon et al., "Fiber-break testing by interferometry: a comparison of two breaking methods", Applied Optics, Vol. 16, No. 4, April 1977, p. 818.

3. D. Gloge et al., "Optical Fiber End Prepartion for Low-Loss Splices", Bell System Technical Journal, Vol. 52, No. 9, Nov. 1973, p. 1579.

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