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ULTRA LOW LOSS OPTICAL FIBER CABLE ASSEMBLIES.(U)
MAY 79 J C SMITH, R E THOMPSON DAAB07-78-C-2922

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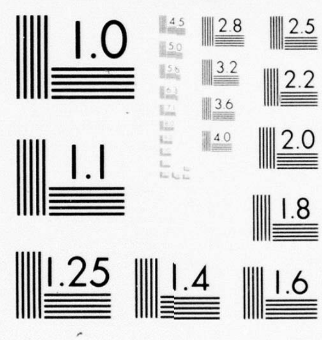

MICROCOPY RESOLUTION TEST CHART

LEVEL

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM- **CONTRACT # DAAB07-78-C-2922**
ITT PROJECT # 36027

ULTRA LOW LOSS OPTICAL FIBER CABLE ASSEMBLIES

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SEMI-ANNUAL REPORT FOR PERIOD APRIL 1978 - NOVEMBER 1978

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report describes the progress made from April to November, 1978, in the development of Ultra Low Loss Fiber Optic Cable Assemblies for Time Division Multiplexed (TDM). This effort includes the fiber optic cable as well as the connectors needed to terminate them. Optimization of the optical fiber fabrication process is in progress, the objective is to increase the fiber yield against the cable specification. → next page

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Further ruggedization of the cable is needed in order to achieve the 100% fiber survivability in the impact testing per MIL-C-13777. It is also necessary to keep the excess cabling losses at a minimum.

The three sphere connector concept has been selected for full development, and the jeweled ferrule concept as a back up.

ITT Electro-Optical Products Division

ULTRA LOW LOSS OPTICAL FIBER

CABLE ASSEMBLIES

B003

Draft Semi-Annual Report

April through November 1978

for

U.S. Army Electronics Command
Fort Monmouth, N.J.

Contract #DAAB07-78-C-2922
ITT Project #36027

Prepared by

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J.E. Goell, Vice President &
Director of Fiber Otpics
Laboratory

Roanoke, Virginia

1.0 INTRODUCTION

The objective of this contract (#DAAB07-78-C-2922), entitled "Ultra Low Loss Optical Fiber Cable Assemblies", is to develop optical fiber cable assemblies for the Army tactical field data transmission at 20 Mb/sec over eight kilometers without repeaters.

The contract effort includes the development of rugged cable, cable connectors and bulkhead connectors which are jointly optimized for Army tactical field application.

ITT Electro-Optical Products Division has spend considerable time in the search of a suitable sub-contractor who is technically qualified and acceptable to CORADCOM and at the same time willing to work within the financial frame of this contract. The following companies were approached and invited to bid for the connector development phase of the contract:

- ITT Cannon
- ITT Leeds
- ITT Components (Europe)
- Hughes Connecting Devices Division
- Deutsch
- Cablewave
- Amphenol
- AMP

Only two companies were interested in bidding: ITT Cannon Electric Division and Hughes Connecting Devices Division.

Personnel from ITT Electro-Optical Products Division met with both Hughes Connecting Devices Division and ITT Cannon Electric Division. It was judged that the three sphere and the jewelled ferruled approaches of ITT Cannon had more merits than the free floating mechanism of the Hughes Connecting Devices six channel hermophroditic connector. Therefore, ITT Cannon Electric Division was selected as the as the Connector Subcontractor. The connector vendor solicitation and selection effort has taken longer than originally planned and has delayed protions of the program.

2.0 CABLE DEVELOPMENT

The cable development phase of this contract includes the optimization of the optical fibers as well as the design of a rugged fiber optic cable.

The fiber optimization phase has benefited from progress achieved through the ITT internal R&D program. Table 1 shows the attenuation, dispersion and length of optical fibers recently developed.

Emphasis has been placed upon the improvement of optical properties. The data in Table I is most encouraging in that 73% of fibers exhibit less than 5 dB/km and 60% less than 4.5 dB/km (attenuation measured on spool). Therefore, the intrinsic attenuation of fibers is lower than the reported values. During the first quarter of 1979, considerable effort will be expened under ITT funded programs to further reduce attenuation and dispersion while still maintaining high tensile strength (100,00 psi proof testing).

ITT-EOPD has performed some work toward the development of a 62 μm optical core fiber. This approach was considered preferable to meet the 1 dB coupling loss specification for the connector. However, this work has not been aggressively pursued because of strong indications that a 50 μm core fiber

TABLE 1

CVD#	LENGTH (Kilometers)	ATTENUATION (dB/km @ 0.85 μm)	DISPERSION (ns/km @ 0.9 μm)
20449	2.6	4.6	1.2
20450	2.3	3.6	.9
20451	1.2	4.1	1.6
20452	1.6	5.6	.98
20453	1.3	4.0	1.7
20454	1.2	3.9	1.7
20461	3.1	4.2	.65
20462	4.5	4.4	2.3
20463	1.9	4.4	1.3
20467	1.4	5.8	.95
20469	2.5	4.6	.42
20474	2.5	5.4	1.6
20480	2.7	5.3	2.1
20481	2.8	4.0	1.2
20485	4.1	4.9	1.3

will become the international standard.

All the fibers used in this program are being proof tested at 1% elongation (100,000 psi). This proof testing is an insurance against catastropohic failure when the fiber is strained during manufacturing, installation or service.

2.2 Ultra Low Loss Optical Fiber Cable Design

The cable design plan submitted contains the current approaches which ITT-EOPD believes have the best potential to meet the Technical Guidelines of the Ultra Low Loss Fiber Optic Cable Contract,and at the same time can be mass produced.

Based on the experience acquired in the Low Cost Fiber Optic Cable Assemblies for Local Distribution Systems contract (DAAB07-77-C-2681), an external strength member cable with 1 mm buffered optical fibers not only exhibits low excess cabling losses, but meets almost all the mechanical requirements. The exception of that is that the above contract required 90% survivability while the Ultra Low Loss Fiber Optic Cable Contract requires 100% survivability. This requirement is achievable with the proposed cable design, but it still has to be demonstrated.

Table 2 shows the optical attenuation of the external strength member cables using plastic clad silica fibers.

Table 2

Attenuation - External Strength Member Cable

Cable Batch #	Fiber #	Attenuation (dB/km) .65 µm	.79 µm	.82 µm	1.05 µm	Cable Length
110678-CA-II	1	8.02	5.80	9.40	13.54	367m
	2	9.53	6.63	10.56	16.41	
	3	8.81	6.80	10.66	17.11	
	4	8.09	6.76	10.50	14.84	
	5	8.67	6.98	10.84	15.09	
	6	7.62	5.79	9.51	14.52	
	7	7.45	5.84	9.46	14.30	
	Average	8.31	6.37	10.31	15.12	
110778-BA-II	1	7.48	6.04	9.61	13.53	378m
	2	11.16	8.28	11.97	19.97	
	3	8.74	6.82	10.61	16.63	
	4	7.85	6.06	9.89	16.77	
	5	7.54	6.07	9.84	17.20	
	6	8.79	6.94	10.88	18.29	
	7	8.43	6.98	10.62	15.67	
	Average	8.57	6.74	10.48	16.72	

*Note: The fibers of cables 110678-CA-II and 110778-BA-II were made with fibers having Shin Etsu RTV silicone cladding.

Table 3 shows the number of surviving and broken fibers when the cable was tested over a wide temperature range using three different impact loads (4.07, 4.41, and 4.75 Newton-meters). Note that the poor performance at -55°C was due to the use of a dull polyurethane jacket material (a flame retardant grade). That jacket has been replaced with a non-filled polyurethane compound, which previously had shown good performance at that temperature.

Table 4 shows the number of impacts before the fiber breaks. Note that since there was no light transmission at -55°C, the number of transmitting fibers was found by counting the transmitting fibers after the temperature returned to 25°C.

Flex and Twist Tests were performed, on the Low Cost Fiber Optic Cable, in accordance with MIL-C-13777. All fibers survived these tests at the the extreme temperatures as well as at room temperature.

ITT-EOPD has selected the cable design developed under the Low Cost Fiber Optic Cable Contract as Design I (Figure I) because it meets or nearly meets all the cable mechanical and environmental objectives and can be produced with low excess cabling losses. However, realizing that CORADCOM

Table 3

IMPACT RESISTANCE

IMPACT LOAD	TESTING TEMP.	# OF SAMPLES	# TRANS/ # FAIL	% SURVIVA-BILITY
4.07 Newton Meter	R.T. (25°C)	42	39/3	93%
4.41 " "	" "	"	33/9	79
4.75 " "	" "	"	33/9	79
4.07 Newton Meter	40°C	42	42/0	100%
4.41 " "	"	"	42/0	100
4.75 " "	"	"	40/2	95
4.07 Newton Meters	60°C	42	40/2	95%
4.41 " "	"	"	42/0	100
4.75 " "	"	"	38/4	90
4.07 Newton Meters	85°C	42	40/2	95%
4.41 " "	"	"	37/5	88
4.75 " "	"	"	38/4	90
4.07 Newton Meters	-5°C	42	42/0	100%
4.41 " "	"	"	42/0	100
4.75 " "	"	"	42/0	100
4.07 Newton Meters	-30°C	42	42/0	100%
4.41 " "	"	"	42/0	100
4.75 " "	"	"	42/0	100
4.07 Newton Meters	-55°C	42	26/16	62%
4.41 " "	"	"	13/29	31
4.75 " "	"	"	16/26	38

Table 4

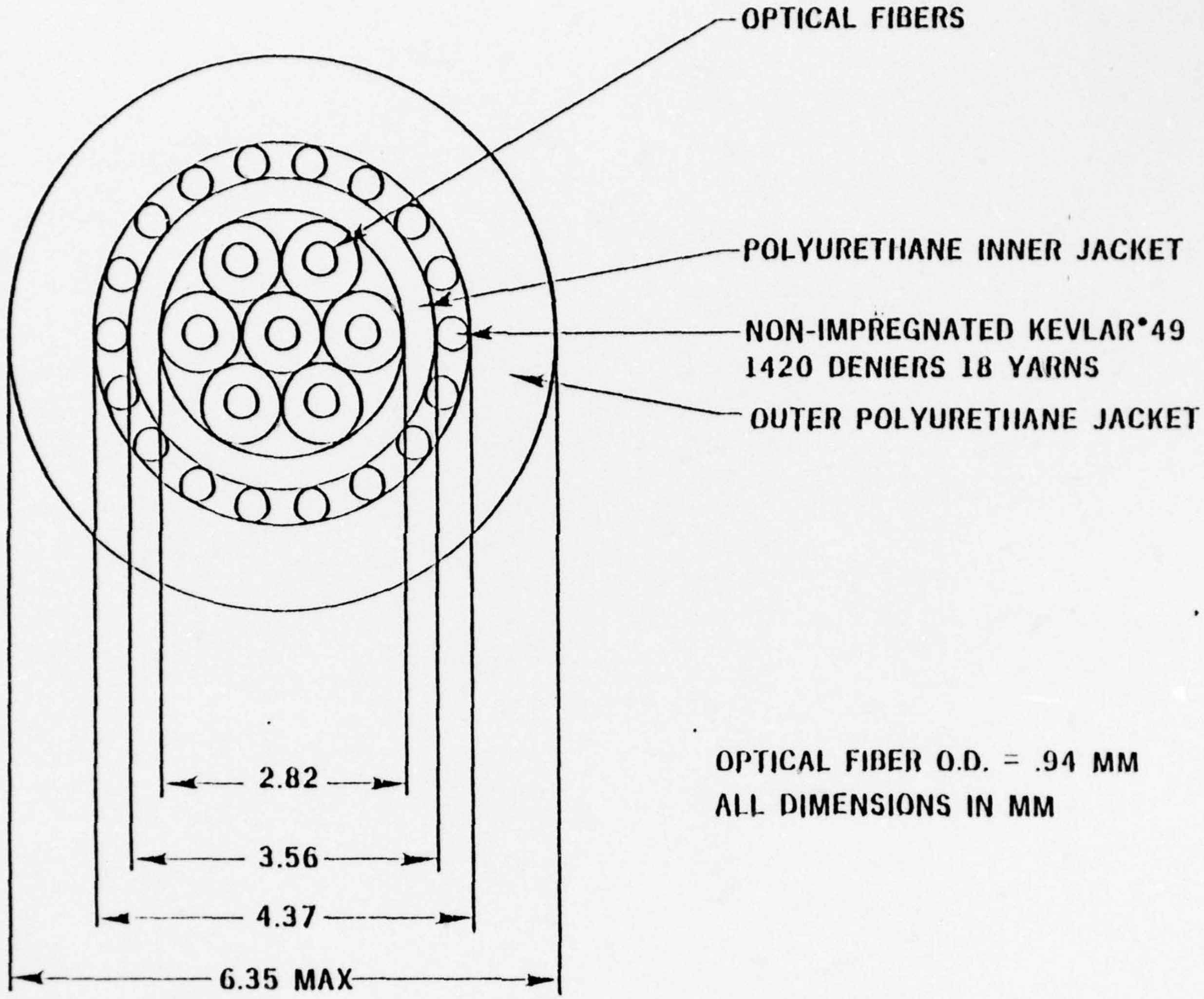
IMPACT RESISTANCE

Energy Level/ Sample #		Room Temperature Break Location/ Fiber Trans	+85°C Break Location/ Fiber Trans	+60°C Break Location/ Fiber Trans	+40°C Break Location/ Fiber Trans	5°C & -30°C
4.07 Newton Meter	S1	--/7	--/7	116/6	--/7	No fiber breakage at these two temp. levels. The outer polyurethane jacket had a slight indentation. -30°C seems to be the light transmittance transition level, because output oscillated as the temp. changed from -25°C to -35°C.
	S2	--/7	178/6	--/7	--/7	
	S3	149,192/5	144/6	173/6	--/7	
	S4	--/7	--/7	--/7	--/7	
	S5	--/7	--/7	--/7	--/7	
	S6	*/6	--/7	--/7	--/7	
4.41 Newton Meter	S7	--/7	151,182/5	--/7	--/7	
	S8	127/6	82/6	--/7	--/7	
	S9	108,135/5	--/7	--/7	--/7	
	S10	49,69/5	65,67/5	--/7	--/7	
	S11	49,69/5	--/7	--/7	--/7	
	S12	116,132/5	194/6	--/7	--/7	
4.75 Newton Meter	S13	95/6	67,167/5	127/6	48/6	
	S14	--/7	91/6	--/7	--/7	
	S15	89(2)/5	--/7	82/7	--/7	Impact Resistance at -55°C was measured by the number of transmitting fibers, after temperature was increased to 25°C.
	S16	19(2),89/4	--/7	--/7	--/7	
	S17	68/6	158/6	150/6	--/7	
	S18	57,62/5	--/7	126/6	--/7	See Table 3-3 for surviving fibers.

*Only 6 fibers were transmitting before testing.

DATA DISTRIBUTION
Optimized Low Cost Fiber Optic Cable

FIGURE 1

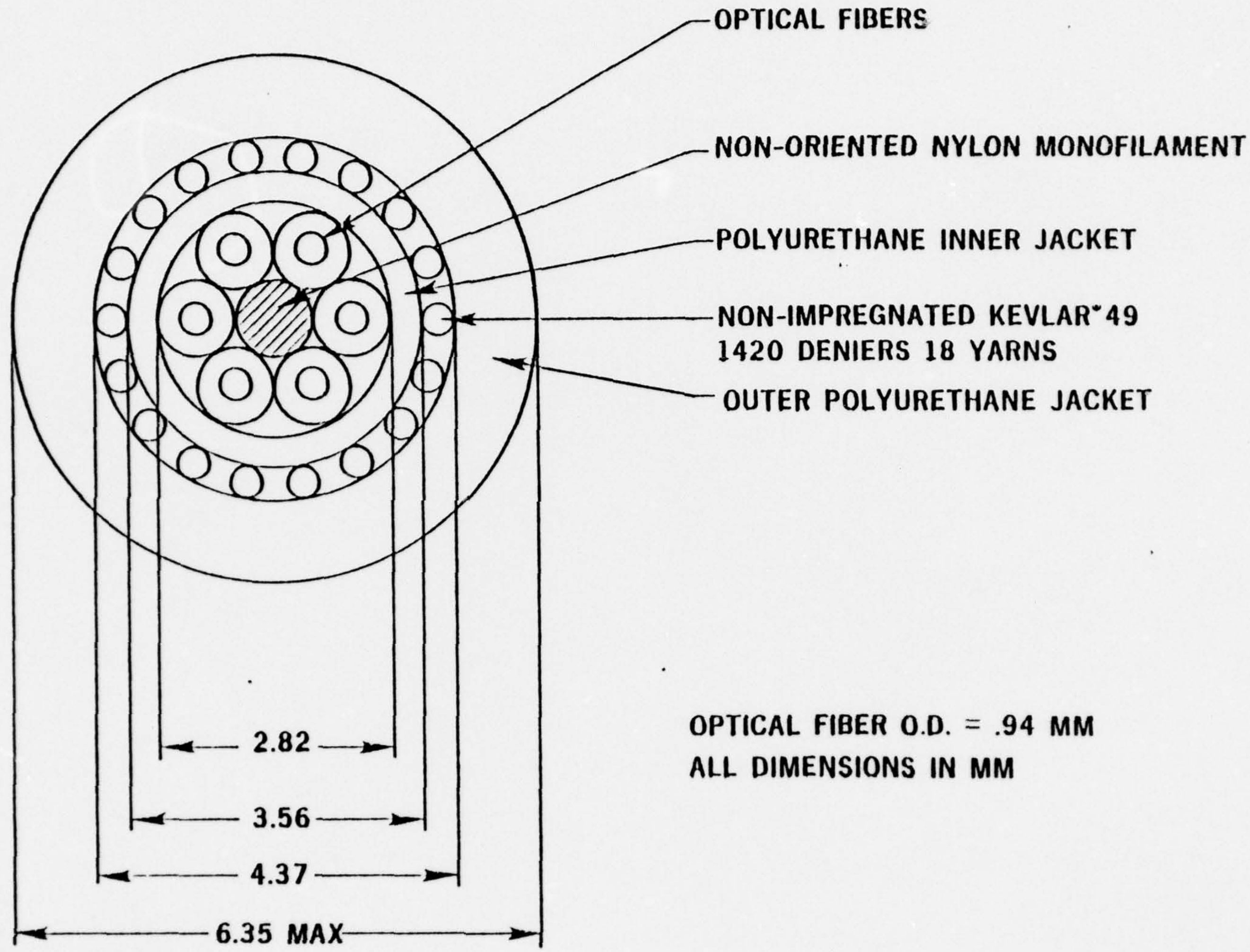


OPTICAL FIBER O.D. = .94 MM
ALL DIMENSIONS IN MM

DESIGN 1. ULTRA LOW LOSS FIBER OPTIC CABLE

102 10755

FIGURE 2



DESIGN 2 ULTRA LOW LOSS FIBER OPTIC CABLE

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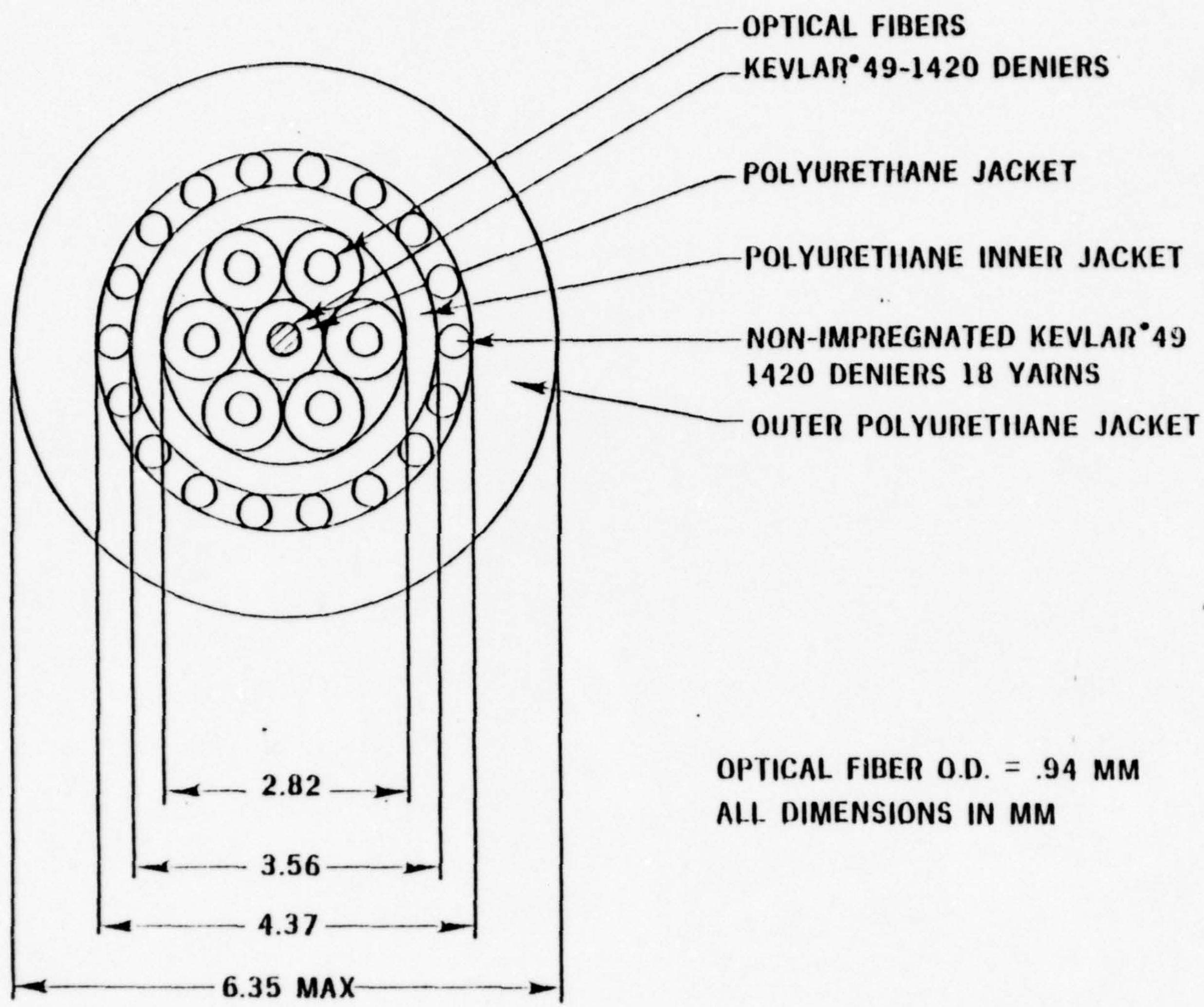
FIGURE 3



DESIGN 3 ULTRA LOW LOSS FIBER OPTIC CABLE

302 10757

intends to procure large amounts of cables, modifications of the design to facilitate its production with conventional cabling equipment is being considered.

Conventional cabling equipment can accomodate larger payoff and take up spools, allowing the production of longer cable lengths thus reducing set up time and increasing the equipment utilization. But heavier spools also mean higher tension, therefore, the cable design must provide portection to the optical core during the fabrication processes.

Cable Design 1 is considered marginally suitable for fabrication in conventional equipment. The next two designs will allow cables to be produced that, in addition to being rugged, are also capable of being produced with higher manufacturing tensions than the first design.

Figure 2 shows cable Design 2. This cable is similar to Design 1 except that a non-oriented nylon monofilament is used instead of the central fiber. The central monofilament is the load member during the fabrication of the optical core. The mechanical and optical properties of Design 1 should remain unaltered.

Figure 3 shows cable Design 3. The difference between this design and Design 1 is that the central member is a yarn of Kevlar with a polyurethane jacket. This design provides the highest strength during the optical core fabrication, but its impact performance is unknown. This design involves the concept of a flexible center core that yields under impact, absorbing in this manner part of the energy of the impact.

3.0 CONNECTOR DEVELOPMENT

ITT Cannon has been selected as subcontractor to develop a hermaphroditic connector for the Ultra Low Loss Fiber Optic Cable.

During the reporting period, a study of potential fiber alignment concepts was conducted.

The ability of an alignment concept to provide minimum coupling loss is a function of the design employed and their manufacturing tolerances.

Eleven concepts were critiqued (See Appendix A). These concepts represented the basic techniques currently considered viable within the fiber optic industry. An overall merit rating was given to each approach.

The following parameters were considered while evaluating each concept:

1. Coupling loss potential
2. Physical size - diameter
3. Total number of dimensional tolerances involved in alignment
4. Potential cost

5. Termination technique (including time to terminate)
6. Fragility (care in handling)
7. Environmental consideration
8. Required development effort

As a result of the study, ITT's recommendation is to further development effort on the three sphere concept and perform minimal effort on the jewel ferrule concept as a back up.

The choice of the three sphere concept as the number one candidate is based upon the use of precision ball bearings with diameter tolerances of ten millionths of an inch in the alignment components. As can be seen in the conceptual drawing (Apprendix A), only the spheres are involved in the lateral and gap alignment. Similarly, the use of an available precision watch jewel makes the jewel ferrule concept a second choice.

4.0 WORK SCHEDULED FOR NEXT PERIOD

- o Complete fabrication of prototype samples
- o Submit prototype samples
- o Fabricate fibers for exploratory development cable models
- o Fabricate exploratory development of three sphere connector
- o Submit cable plan
- o Submit bi-monthly and cost reports

APPENDIX A

TRADE OFF OF CONNECTOR ALIGHMENT CONCEPTS

Approach	Overall Merit Rating*
Three sphere	1
Jewel Ferrule	2
Double Eccentric	3
Molded Ferrule	4
Resilient Self Centering	5
Multi-Rod	6
Formed Ferrule	7
V-Groove	8
Capillary Tube	9
Viscous Lens	10
Alignment by Fixturing	11

*1 is best rating
11 is worst rating

ITT CANNON ELECTRIC

DESCRIPTION: THREE SPHERE

FEASIBILITY: (OVERALL RATING) 1

THREE PRECISION SPHERES (BALL BEARINGS) WHEN NESTED IN A PLANE AT 120° INCREMENTS, PROVIDE AN INTERSTITIAL SPACE AT THEIR GEOMETRIC CENTER EQUAL TO THE FIBER DIAMETER. THE FERRULE CAP CONTAINS AN INTERNAL RAMPED RACE WHICH ALLOWS ADJUSTMENT FOR FIBER DIAMETER VARIATION.

COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES	POTENTIAL COST
0.5 dB	APPROXIMATELY 2 mm	ONE - THAT OF THE SPHERE	LOW ☒ MED ☐ HI ☐

TERMINATION TECHNIQUE, (TIME):

FIELD ☒
FACTORY ONLY ☐

FIBER IS CLEAVED, POSITIONED IN FERRULE WITHIN THE SPHERES, AND THE CAP IS ADJUSTED TO TIGHTEN SPHERES ON VARYING FIBER DIAMETER. FIBER IS BONDED IN PLACE. TERMINATION TIME IS 10 MINUTES.

FRAGILITY:

FIBER IS PROTECTED BY THE FERRULE.

ENVIRONMENTAL CONSIDERATIONS:

CONCEPT HAS BEEN EVALUATED UNDER SEVERAL ENVIRONMENTAL CONDITIONS; AFFECT OF SAND AND DUST MUST BE FURTHER CONSIDERED.

DEVELOPMENT EFFORT:

THE ALIGNMENT CONCEPT HAS BEEN THOROUGHLY EVALUATED UNDER LAB CONDITIONS. COUPLING LOSS DATA ON SEVERAL HUNDRED TERMINATIONS IS LESS THAN ONE (1) dB. FURTHER EFFORT IS REQUIRED TO PERFECT THE CONCEPT UNDER ENVIRONMENTAL CONDITIONS AND REFINE THE DESIGN TO A PRODUCTION STATUS. THE MAJOR EFFORTS WOULD ADDRESS: 1) KEYING OF THE SPHERES TO THE FERRULE; 2) BALL RETENTION DURING FIBER ASSEMBLY; 3) MANUFACTURING FEASIBILITY; 4) COST REDUCTION (PRESS FIT INSTEAD OF THREADED PARTS AND/OR CLINCH NUT CAP); 5) FIBER ANTI CRUSHING SPRING RAMP; 6) ELIMINATION OF EPOXY; 7) SELF-CLEAVING OF FIBER DURING TERMINATION.

NOTES:

ITT CANNON ELECTRIC

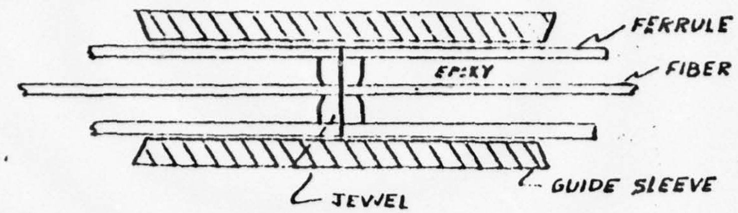
DESCRIPTION:

JEWEL FERRULE

FEASIBILITY: (OVERALL RATING)

2

CONCENTRIC FERRULES CONTAIN A CONCENTRIC, PRECISION WATCH JEWEL TO ALIGN THE FIBER. THE INTENT IS TO USE A SINGLE SIZE JEWEL I.D. WITH A FIBER WHOSE DIAMETER VARIATION IS CLOSELY CONTROLLED.



COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES - EIGHT	POTENTIAL COST
< 1 dB	≤ 2 mm	MAY BE POSSIBLE TO REDUCE TO SIX BY USING A SPRING MEMBER IN THE GUIDE SLEEVE.	LOW ☒ MED ☐ HI ☐

TERMINATION TECHNIQUE, (TIME):

FIELD ☒
FACTORY ONLY ☐

FIBER IS BONDED INTO FERRULE, SUBSEQUENTLY GROUND AND POLISHED. MAY BE ABLE TO DEVELOP TECHNIQUE TO USE CLEAVED FIBER THEREBY REDUCING TERMINATION TIME. CURRENT DATA IS APPROXIMATELY 10 TO 15 MINUTES.

FRAGILITY:

METALLIC FERRULE PROTECTS THE JEWEL AND FIBER, THEREFORE BETTER THAN AVERAGE.

ENVIROMENTAL CONSIDERATIONS:

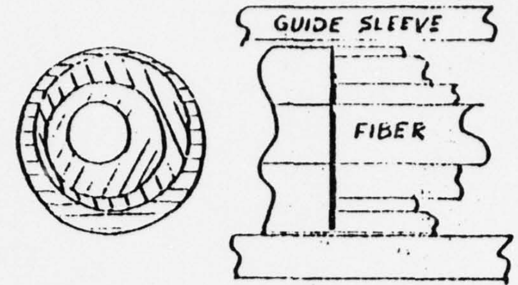
CONCEPT HAS BEEN USED EXTENSIVELY IN VARIOUS ENVIRONMENTS.

DEVELOPMENT EFFORT:

THE FOLLOWING PARAMETERS WOULD BE THOSE NECESSARY TO CONCENTRATE UPON: 1) COST REDUCTION; 2) FERRULE CYLINDRICAL TUBE ID/OD CONCENTRICITY OPTIMIZATION; 3) JEWEL CONCENTRICITY TO 1 MICRON; 4) A MEANS TO IMPLEMENT FIBER CLEAVING TO REDUCE TERMINATION TIME; 5) A SPRING MEMBER GUIDE SLEEVE TO IMPROVE FERRULE ANGULARITY CONTROL; 6) RETENTION OF FIBER BY A MEANS OTHER THAN EPOXY (CRIMP OR LOW TEMP MELTING GLASS).

NOTES:

THE FIBER IS MOUNTED IN AN X-Y ADJUSTABLE FERRULE AND TERMINATED UNDER A MICROSCOPE FOR PERFECT CONCENTRICITY. OPPOSING FERRULES MATE IN A PRECISION BORE GUIDE SLEEVE.



ITT CANNON ELECTRIC

DESCRIPTION: DOUBLE ECCENTRIC

FEASIBILITY: (OVERALL RATING) 3

COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES - TWO	POTENTIAL COST
<1 dB	APPROXIMATELY 4 mm	FERRULE O.D. AND GUIDE SLEEVE I.D.	LOW [X] - PARTS COULD BE MOLDED MED [X] - PLASTIC - BUT ASSEMBLY ARE REQUIRED (ALSO TO COSTS) HI [ ]

TERMINATION TECHNIQUE, (TIME):
FIELD [ ]
FACTORY ONLY [X]

FIBER MUST BE SECURED IN INNER SLEEVE, THEN GROUND AND POLISHED. MAY BE POSSIBLE TO USE CLEAVED FIBER AND POSITI END FACE PRECISELY. THE SLEEVES VARY IN WALL THICKNESS; RELATIVE ROTATION PROVIDES AN X-Y MECHANISM TO ADJUST THE FIBER CORE CONCENTRIC WITH THE OUTER DIAMETER. THIS MUST BE DONE UNDER AT LEAST 200X MAGNIFICATION AND INTRODUCES A HUMAN ELEMENT IN THE ALIGNMENT ACCURACY. TERMINATION TIME: 30 MINUTES.

FRAGILITY:

SOMEWHAT LESS FRAGILE THAN OTHER TYPES OF FERRULES.

ENVIROMENTAL CONSIDERATIONS:

VIBRATION & TEMPERATURE CYCLING MAY CAUSE MECHANICAL SHIFT OF CORE SINCE THREE LAYERS OF MATERIAL MUST FIT TIGHTLY UPON EACH OTHER.

DEVELOPMENT EFFORT:

METHOD OF LOCKING SLEEVES TOGETHER AFTER MICROSCOPIC ALIGNMENT OF CORE WITHOUT SHIFTING CORE. MECHANICAL ASSEMBLY OF SLEEVES. DEVELOP FABRICATION PROCESS TO HOLD DIAMETRIC TOLERANCES (CONCENTRICITY IS NOT IMPORTANT). REDUCTION OF SLEEVE WALL THICKNESS TO MEET FERRULE O.D. REQUIREMENTS. DEVELOPMENT COSTS WILL BE HIGH DUE TO REQUIRED MOLD TOOLS. A MEANS TO RETAIN FIBER IN INNER SLEEVE. MOISTURE ABSORPTION PROBLEMS WITH PLASTIC COMPONENTS MAY CAUSE DIMENSIONAL CHANGE AND INCREASED LOSSES.

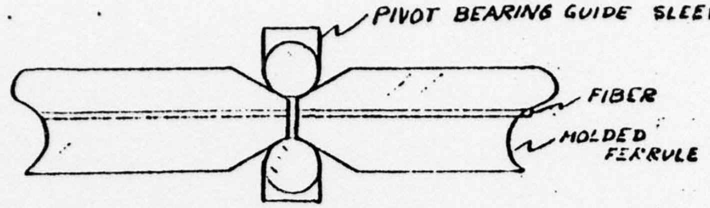
NOTES:

ITT CANNON ELECTRIC

DESCRIPTION: MOLDED FERRULE

FEASIBILITY: (OVERALL RATING) 4

FERRULE IS FORMED BY INSERT MOLDING THE FIBER IN PLACE. FERRULES ARE ALIGNED USING A PRECISION GUIDE SLEEVE.



COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES - THREE	POTENTIAL COST
< 1 dB	AS SMALL AS 1 mm	LATERAL AND GAP ALIGNMENT DEPEND ON FERRULE CONCENTRICITY, TAPER AND SPHERE DIAMETER.	LOW ☒ MED ☐ HI ☐ - FERRULE COST COULD BE LOW BUT TOOLING COST WILL BE VERY HIGH.

TERMINATION TECHNIQUE, (TIME):

FIELD ☐
FACTORY ONLY ☒

CAN BE EITHER GRIND/POLISH OR CLEAVE. IF CLEAVED FIBER IS USED, IT MUST BE PROTECTED DURING MOLDING CYCLE. TERMINATION TIME INCLUDES FABRICATION OF PRODUCT; COULD APPROACH 2 MINUTES.

FRAGILITY:

SINCE THE FIBER IS INSERT MOLDED INTO A FERRULE, IT IS SUSCEPTIBLE TO DAMAGE (END FACE CHIPPING) DURING THE INSERTION INTO THE TOOL. THIS MAY REQUIRE SUBSEQUENT GRIND/POLISH WHICH WILL SHORTEN THE FERRULE AND INCREASE GAP LOSSES.

ENVIROMENTAL CONSIDERATIONS:

1) TEMPERATURE CYCLING MAY CAUSE DIFFERENTIAL EXPANSION OF GLASS AND PLASTIC RESULTING IN LOSS OF FIBER RETENTION AND/OR ALIGNMENT.
2) FIBER END FACES MUST BE INITIALLY SEPARATED (INTENTIONAL GAP) SINCE PLASTIC MATERIAL WILL COMPRESS UNDER MECHANICAL FORCES POTENTIALLY CAUSING FIBERS TO CHIP EACH OTHER.
3) MOISTURE ABSORPTION MAY CAUSE DIMENSIONAL CHANGE IN PLASTIC PARTS.

DEVELOPMENT EFFORT:

THE MAJOR EFFORT WILL BE TO FABRICATE A MOLD TOOL WHICH WILL ALLOW THE FIBER TO BE INSERT MOLDED CONCENTRICALLY WITHIN THE FINISHED FERRULE. EACH NEW TOOL NEEDED WILL REQUIRE THE SAME EFFORT SINCE IT WILL BE AN INTERATIVE PROCESS TO ACHIEVE THE REQUIRED ACCURACY. THE GAP OF FIBER ENDS IS A FUNCTION OF THE TAPER ANGLE AND WILL BE AS CRITICAL AN EFFORT. A MEANS TO CONTROL FIBER ANGULARITY WITHIN THE FERRULE MUST BE DEVELOPED AS WELL AS CONTROL OF FERRULE ANGULARITY WITHIN THE CONNECTOR. AREAS TO CONSIDER ARE: 1) FLASH ON END FACE OF FIBER MAY REQUIRE GRIND/POLISH DUE TO CLEARANCE IN MOLD PILOT HOLE; 2) MOLDING PRESSURE AFFECTS ON GLASS FIBER; 3) RESIDUAL COMPRESSIVE STRESSES DUE TO PLASTIC CURING WILL CAUSE FIBER STRESSES AND DIFFICULTY IN GRINDING/POLISHING; 4) FIBER CLEANLINESS FOR ADEQUATE BONDING.

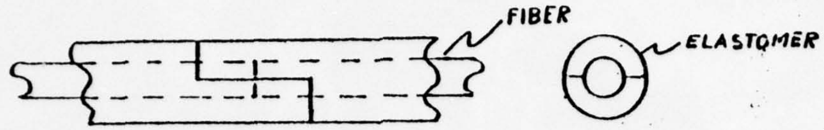
NOTES:

ITT CANNON ELECTRIC

DESCRIPTION: RESILIENT SELF CENTERING

FEASIBILITY: (OVERALL RATING) 5

FIBERS ARE ALIGNED BY UNIFORM COMPRESSION OF A RESILIENT MATERIAL.



COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES	POTENTIAL COST
UNKNOWN - MUST DETERMINE EXPERIMENTALLY	APPROXIMATELY AS SMALL AS THE FIBER	"ABSORBED BY THE ELASTOMER"	LOW ☒ MED ☐ HI ☐

TERMINATION TECHNIQUE, (TIME):

FIELD ☒
FACTORY ONLY ☐

MUST BE CLEAVED AND POSITIONED; POTENTIAL OF MINIMUM TIME TO TERMINATE.

FRAGILITY:

MAY INVOLVE EXPOSED, CANTILEVERED FIBER; ALSO A MAJOR DRAWBACK IS THE ALIGNMENT REQUIRES THE CONTINUOUS APPLICATION OF COMPRESSIVE FORCES ON THE FIBER.

ENVIROMENTAL CONSIDERATIONS:

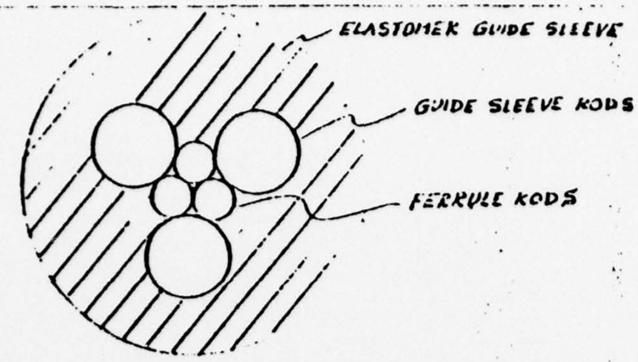
TEMPERATURE ENVIRONMENT MAY CAUSE COMPRESSION SET OF ELASTOMER AND RESULT IN MODULATION OF PULSE DURING SUBSEQUENT VIBRATION; AFFECTS OF ENVIRONMENT ON ELASTOMER MATERIAL I.E., OZONE MUST BE CONSIDERED.

DEVELOPMENT EFFORT:

1) MATERIAL DEVELOPMENT TO OVERCOME COMPRESSION SET AND TO INSURE HOMOGENEITY; 2) A MEANS TO APPLY THE COMPRESSIVE FORCES AFTER MATING; 3) A MEANS TO PROTECT THE FIBER; 4) OPPOSING FIBER GAP CONTROL MUST BE MECHANICALLY PROVIDED; 5) INVESTIGATE DIFFERENTIAL EXPANSION RATES OF GLASS AND ELASTOMER; 6) DEVELOP PRECISION TOOLING TO MOLD OR MACHINE THE ELASTOMER ACCURATELY.

NOTES:

THREE RODS PROVIDE A SPACE AT THEIR GEOMETRIC CENTER FOR THE FIBER. OPPOSING FERRULES MATE WITHIN A GUIDE SLEEVE CONTAINING THREE RESILIENTLY MOUNTED RODS WHICH OVERLAP THE OPPOSING FERRULES.



ITT CANNON ELECTRIC

DESCRIPTION:

MULTI-ROD

FEASIBILITY: (OVERALL RATING)

6

COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES - THREE	POTENTIAL COST
<1 dB	FERRULE DIAMETER WILL BE APPROXIMATELY 5 mm BUT GUIDE WILL BE EXCESSIVE IN DIAMETER; THEREFORE, CONNECTOR WILL BE LARGE.	LATERAL ALIGNMENT IS DEPENDENT UPON DIAMETER TOLERANCES OF FERRULE RODS AND GUIDE RODS. GAP CONTROL TO BE DETERMINED.	LOW [X] - MED [ ] HI [ ] — MAY BE ROD BEARINGS AND MOLDED ELASTOMER GUIDE SLEEVE OR SPRING GUIDE SLEEVE.

TERMINATION TECHNIQUE, (TIME):

FIELD [X]

FACTORY ONLY [ ]

FIBER WILL BE CLEAVED, POSITIONING (GAP CONTROL) WILL BE SIMILAR TO THREESPHERE BUT LESS ACCURATE SINCE ROD ENDS MAY NOT BE IN ONE PLANE. FIBER MUST BE EPOXIED INTO RODS. TERMINATION TIME MAY APPROACH 10 MINUTES.

FRAGILITY:

SIMILAR TO MOST OTHER CONCEPTS.

ENVIROMENTAL CONSIDERATIONS:

TEMPERATURE CYCLING MAY CAUSE LONGITUDINAL SHIFT OF FIBER DUE TO DIFFERENTIAL EXPANSION (RODS VERSUS GLASS), THIS SHIFT WILL CAUSE A VARIABLE END FACE SEPARATION.

DEVELOPMENT EFFORT:

1) MEANS TO CONTROL FIBER GAP; 2) PREVENT RODS FROM CRUSHING FIBER; 3) MEANS TO CLOSE RODS ON FIBER AND RETAIN THE F 4) MEANS TO RETAIN GUIDE RODS IN PARALLEL IN ELASTOMERIC GROMMET; 5) MEANS TO LOCATE CLEAVED END FACE WITHIN RODS; 6) MEANS TO ASSEMBLE ROD ENDS IN A PLANE; 7) GUIDE RODS TEND TO PRY FERRULE RODS OPEN, DESIGN MUST CONSIDER GEOMETRY TO PRECLUDE THIS; 8) CONSIDER GUIDE SLEEVE AS OPPOSED TO GUIDE RODS 9) MUST CONSIDER FIBER DIAMETER VARIATION WITHIN ROD LENGTH.

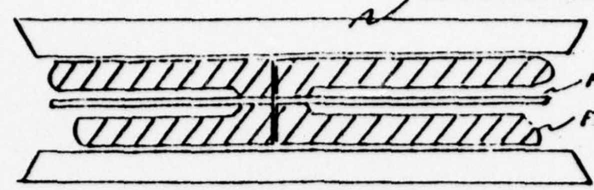
NOTES:

ITT CANNON ELECTRIC

DESCRIPTION: FORMED FERRULE

FEASIBILITY: (OVERALL RATING) 7

THE CONCEPT INVOLVES FABRICATING A PRECISE, CONCENTRIC FERRULE.



COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES	POTENTIAL COST
< 2 dB	< 3 mm	SIX	LOW ☐ MED ☐ HI ☐ TO BE DETERMINED

TERMINATION TECHNIQUE, (TIME):

FIELD ☒
FACTORY ONLY ☐

EITHER GRINDING AND POLISHING OR CLEAVING MAY BE USED. FIBER MUST BE BONDED INTO THE FERRULE. TIME COULD APPROACH 15 MINUTES.

FRAGILITY:

SIMILAR TO OTHER CONCEPTS, I.E., THE JEWELED FERRULE; THE FIBER IS PROTECTED BY THE FERRULE.

ENVIROMENTAL CONSIDERATIONS:

PERFORMANCE WOULD NEED TO BE EVALUATED UNDER VIBRATION AND TEMPERATURE CYCLING.

DEVELOPMENT EFFORT:

THE MAJOR EFFORT WOULD BE TO DEVELOP A FABRICATION PROCESS TO PROVIDE A HOLE (APPROXIMATELY 127 MICRONS) IN THE FERRULE FACE CONCENTRIC TO THE FERRULE O.D. WITHIN FIVE (5) MICRONS. POTENTIAL METHODS ARE; 1) LASER DRILLING; 2) CHEMICAL MILLING (USING PHOTO REDUCTION); 3) SPINNING; 4) COLD HEADING; 5) MOLDING. EACH PROCESS WOULD NEED TO BE REDUCED TO PRACTICE TO DETERMINE FEASIBILITY THEREBY REQUIRING CONSIDERABLE TIME AND EXPENSE.

NOTES:

THE BASIC CONCEPT IS TO ALIGN TWO OPPOSING BARE FIBERS IN A COMMON V-GROOVE. ACCURACY OF ALIGNMENT IS A FUNCTION OF FIBER DIAMETER CONTROL & CORE/CLADDING CONCENTRICITY.

ITT CANNON ELECTRIC

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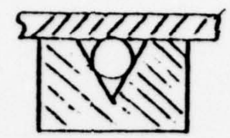
DESCRIPTION: V-GROOVE ALIGNMENT

FEASIBILITY: (OVERALL RATING) 8



COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES	POTENTIAL COST
< 1 dB	TO BE DETERMINED; POTENTIALLY QUITE SMALL RELATIVE TO OTHER CONCEPTS.	DEPENDENT ON FIBER DIAMETER TOLERANCE ONLY.	LOW ☐ MED ☒ HI ☐

TERMINATION TECHNIQUE, (TIME):

FIELD ☒
FACTORY ONLY ☐

FIBER MUST BE CLEAVED IN ORDER TO USE THIS CONCEPT; IT WOULD BE SUPPORTED IN A FERRULE MOST LIKELY BY BONDING. TIME COULD APPROACH 15 MINUTES.

FRAGILITY:

FIBERS ARE EXPOSED IN ORDER TO POSITION IN THE GROOVE DURING CONNECTOR MATING.

ENVIRONMENTAL CONSIDERATIONS:

CONTINUOUS COMPRESSIVE LOAD IS APPLIED TO THE FIBER; POTENTIALLY LESS AFFECTED BY ENVIRONMENTAL CONDITIONS. SUSCEPTIBLE TO VIBRATION DAMAGE AT EXIT OF V.

DEVELOPMENT EFFORT:

THE CONCEPT HAS BEEN PROVEN AS A LAB SET UP; CONSIDERABLE EFFORT WOULD BE NECESSARY TO IMPLEMENT THE CONCEPT INTO FERRULE HARDWARE USABLE IN A HERMAPHRODITIC CONNECTOR. DEVELOPMENT EFFORTS MUST ADDRESS: 1) CANTILEVERED EXPOSED FIBER; 2) GAP CONTROL; 3) FIBER OUTSIDE DIAMETER CLEANLINESS AFTER STRIPPING BUFFER JACKET; 4) FIBER RETENTION IN FERRULE; 5) A MECHANISM TO CLAMP FIBERS AFTER MATING.

NOTES:

ITT CANNON ELECTRIC

DESCRIPTION: CAPILLARY TUBE

FEASIBILITY: (OVERALL RATING) 9

A LOW TEMPERATURE GLASS TUBE IS COLLAPSED ON THE LARGER OF TWO FIBERS. THE SMALLER DIAMETER FIBER IS PLUGGABLE INTO THE TUBE OPENING.

COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES	POTENTIAL COST
<1 dB	<1 mm	ONE	LOW ☐ MED ☒ HI ☐ — FERRULE COST MAY BE SMALL BUT TOOLING COULD BE EXPENSIVE.

TERMINATION TECHNIQUE, (TIME):

FIELD ☐
FACTORY ONLY ☒

CLEAVED FIBERS WOULD BE USED; TERMINATION TIME INVOLVES CLEAVING, MEASURING FIBER DIAMETER, BONDING IN FERRULE AND TUBE COLLAPSE.

FRAGILITY:

FIBERS MUST BE CANTILEVERED FROM THE FERRULES AND REQUIRE MORE HANDLING THAN OTHER CONCEPTS.

ENVIRCMENTAL CONSIDERATIONS:

SINCE THE OPPOSING FIBERS ARE RIGIDLY MOUNTED, EVALUATION UNDER VIBRATION CONDITIONS WOULD BE REQUIRED.

DEVELOPMENT EFFORT:

INVESTIGATION OF GLASS TECHNOLOGY IS REQUIRED; FIBER RESIDUAL STRESSES VERSUS LIFE EXPECTATION MUST BE EVALUATED. CONTAMINATION PARTICLES ON THE FIBER SURFACE MUST BE ELIMINATED TO PRECLUDE MICROBEND LOSSES AND FIBER BREAKAGE DURING TUBE COLLAPSE. A MEANS TO PREVENT END FACES CHIPPING EACH OTHER MUST BE DEVELOPED; TELESCOPING SLEEVE TYPE FERRULES MAY BE NECESSARY. THE COLLAPSING TECHNIQUE MUST BE DEVELOPED TO PRECLUDE TOO SMALL A DIAMETER HOLE TO RECEIVE THE PLUG FIBER. DUE TO THE TEMPERATURE REQUIRED IN THE PROCESS, THE HAZARD MUST BE ADDRESSED.

NOTES:

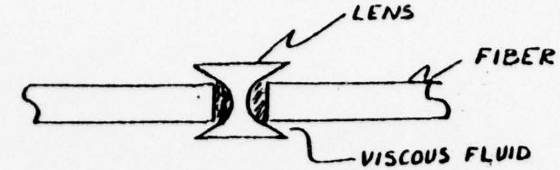
CONCEPT IS <u>NOT</u> APPLICABLE TO HERMAPHRODITIC CONNECTORS SINCE PREDICTION OF WHICH CABLE CONTAINS THE LARGER FIBER IS NOT POSSIBLE & not fully interchangeable.

ITT CANNON ELECTRIC

DESCRIPTION: VISCOUS LENS ALIGNMENT

FEASIBILITY: (OVERALL RATING) 10

FIBER ALIGNMENT IS ACHIEVED THROUGH THE USE OF A DOUBLE CONCAVE LENS AND A VISCOUS INDEX MATCHED FLUID.



COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES	POTENTIAL COST
< 1 dB	1.5 mm	OPTICAL EFFECTS COMPENSATE FOR MECHANICAL TOLERANCES.	LOW ☐ MED ☐ HI ☒ — DUE TO NUMEROUS MATER AND COMPONENTS

TERMINATION TECHNIQUE, (TIME):

FIELD ☒

FACTORY ONLY ☐

FIBER CLEAVING IS APPROPRIATE FOR THIS CONCEPT. 10-15 min.

FRAGILITY:

FIBER MAY BE EXPOSED AND/OR A MECHANISM REQUIRED TO PROTECT THE FIBER AND AUTOMATICALLY RETRACT UPON ASSEMBLY. CAREFUL HANDLING SO AS TO NOT LOSE VISCOUS FLUID MAY BE REQUIRED.

ENVIROMENTAL CONSIDERATIONS:

NUMEROUS QUESTIONS MUST BE ANSWERED IN REGARDS TO AFFECT OF ENVIRONMENT. FOR EXAMPLE: 1) TEMPERATURE LIMIT ON MOLDED PLASTIC LENS, RETENTION OF VERY VISCOUS FLUID UNDER SHOCK, TEMPERATURE, VIBRATION, ETC., 2) CONTAMINATION OF VISCOUS FLUID CAUSING OPTICAL LOSS; 3) DURABILITY.

DEVELOPMENT EFFORT:

1) DESIGN OF LENS; 2) DEVELOPMENT OF VISCOUS FLUID SUCH THAT IT REMAINS IN PLACE UPON REPEATED MATINGS; 3) A MEANS TO SUPPORT THE FIBER IN A FERRULE, PROTECT IT UNTIL MATING AND ALLOW IT TO SEEK ITS OWN CENTERED POSITION IN THE LENS; 4) INVESTIGATE POTENTIAL OF FIBER CLEAVED EDGE SCRAPING THE LENS AND PRECLUDING REPEATED USAGE; 5) LENS MOLDING TECHNIQUE; 6) LENS MATERIAL; 7) MEANS TO MOUNT LEN IN SIX CHANNEL CONNECTOR; 8) MEANS TO ASSEMBLE FLUID INTO LENS. DEVELOPMENT COSTS APPEAR TO BE CONSIDERABLE.

NOTES:

ITT CANNON ELECTRIC

DESCRIPTION: ALIGNMENT BY FIXTURING

FEASIBILITY: (OVERALL RATING) 11

OPPOSING FIBERS ARE PERFECTLY ALIGNED IN A PRECISION FIXTURE, THE CONNECTOR HARDWARE IS PLACED AROUND THE FIBERS AND MAINTAINS THE ALIGNMENT AFTER THE FIXTURE IS REMOVED.

?

COUPLING LOSS POTENTIAL	SIZE (DIAMETER)	NUMBER OF TOLERANCES	POTENTIAL COST
0.4 dB	TO BE DETERMINED	NONE	LOW [X] MED [ ] HI [ ]

TERMINATION TECHNIQUE, (TIME):

FIELD [X]
FACTORY ONLY [ ]

FIBERS WOULD BE CLEAVED AND ALIGNED IN A PRECISION FIXTURE. CONNECTOR COMPONENTS WOULD BE ASSEMBLED AS PA OF THE TERMINATION PROCEDURE. TERMINATION TIME WOULD APPROACH 30 MINUTES.

FRAGILITY:

MORE FRAGILE THAN OTHER CONCEPTS SINCE FIBERS ARE COMPLETELY EXPOSED DURING CONNECTOR ASSEMBLY.

ENVIROMENTAL CONSIDERATIONS:

TO BE DETERMINED; SEPARABLE CONNECTOR WOULD REQUIRE USE OF ASSEMBLY FIXTURE FOR EVERY MATING.

DEVELOPMENT EFFORT:

CONSIDERABLE EFFORT IS NECESSARY TO CONCEIVE THE ARRANGEMENT OF FIXTURE AND CONNECTOR COMPONENTS TO ACHIEV THE CONCEPT GOAL. THE PRECISION FIXTURE COULD BE A V BLOCK OR EQUIVALENT; IT WOULD BE REUSABLE AS A TERMINATION TOOL.

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