

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



LEVEL

12

RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM-79-0789-2

**MANUFACTURING METHODS AND TECHNOLOGY PROGRAM
FOR RUGGEDIZED TACTICAL FIBER OPTIC CABLE**

R.HOSS & R. KOPSTEIN

ITT ELECTRO-OPTICAL PRODUCTS DIVISION
7636 Plantation Rd., Roanoke, Va. 24019. Telephone (703) 563-0371

DTIC
ELECTE
JUL 14 1980
S D
C

**SECOND QUARTERLY PROGRESS REPORT
FOR PERIOD
OCTOBER 1, 1979 - DECEMBER 31, 1979**

APPROVED FOR PUBLIC RELEASE ; DISTRIBUTION UNLIMITED

CORADCOM

**US ARMY COMMUNICATION RESEARCH & DEVELOPMENT COMMAND
FORT MONMOUTH, NEW JERSEY 07703**

ADA 086706

DDC FILE COPY.

DISCLAIMER STATEMENT

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DEPOSITION INSTRUCTIONS

Destroy this report when it is no longer needed. Do not return it to the originator.

ACKNOWLEDGEMENT STATEMENT

This project has been accomplished as part of the U.S. Army Manufacturing Methods and Technology Program which has as its objective the timely establishment of manufacturing processes, techniques, or equipment to insure the efficient production of current or future defense programs.

ITT *Electro-Optical Products Division*

12

DTIC
ELECTE
JUL 14 1980
S D C

MANUFACTURING METHODS AND TECHNOLOGY
PROGRAM FOR RUGGEDIZED TACTICAL
FIBER OPTIC CABLE

SECOND QUARTERLY PROGRESS REPORT

For the Period of October 1979-December 1979

Contract No DAAK80-79-C-0789

Prepared for:

U.S. Army Communications
Research and Development Command
Procurement Directorate, Procurement Division D
Fort Monmouth, New Jersey 07703

Prepared by:

ITT Electro-Optical Products Division
P. O. Box 7065
Roanoke, Virginia 24019

Approved for public release; distribution unlimited

Doc Id No: 80-03-07b

Roanoke, Virginia

80 7 11 10

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM	
1. REPORT NUMBER CORADCOM 79 0789-2	2. GOVT ACCESSION NO. AD-A086706	3. RECIPIENT'S CATALOG NUMBER progress	
4. TITLE (and Subtitle) MANUFACTURING METHODS AND TECHNOLOGY PROGRAM FOR RUGGEDIZED TACTICAL FIBER OPTIC CABLE		5. TYPE OF REPORT & PERIOD COVERED QUARTERLY REPORT, no. 2, OCTOBER-DECEMBER 1979	6. PERFORMING ORGANIZATION NUMBER
7. AUTHOR(s) R. BOSS R. KOPSTEIN	8. CONTRACT OR GRANT NUMBER(s) DAK80-79-C-0789	31	
9. PERFORMING ORGANIZATION NAME AND ADDRESS ITT ELECTRO-OPTICAL PRODUCTS DIVISION P. O. BOX 7065 ROANOKE, VIRGINIA 24019		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS	
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. ARMY COMMUNICATIONS RESEARCH AND DEVELOPMENT COMMAND PROCUREMENT DIRECTORATE, PROCUREMENT DIVISION D ATTN: DRDCO-PC-D, FT. MONMOUTH, NEW JERSEY 07703		12. REPORT DATE 26 JAN 1980	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES 60	
12 65		15. SECURITY CLASS. (of this report) UNCLASSIFIED	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
14 ITT-80-03-07B			
18. SUPPLEMENTARY NOTES			
19 79-0789-2			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Fiber Optic Cable, Fiber Optic Communications Fiber Optic			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report covers the second quarter, October through December 1979, of the Manufacturing Methods and Technology Program for Ruggedized Tactical Fiber Optic Cable. The scope of this quarter's effort, as reported herein, includes the following tasks and achievements: 1. Cable Process Optimization			

189750 JW

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

- a. Complete first engineering samples; test, select optimized fiber buffering
 - b. Complete lay length evaluation samples; test, select optimized lay length
 - c. Receive polyurethane materials (four types, four manufacturers)
2. Use of Facilities
- a. High speed strander set up and operational; achieve 50% of production rate
 - b. Extruder set up and operational
 - c. Fiber optic measurement station design complete, and partial fabrication
3. Secondary Performance Milestones - None in second quarter

In addition to reporting progress on these milestones the report covers any revisions or improvements in process, equipment, tooling manufacturing flow, and specifications. Any changes in key personnel on the program are identified. The program milestones for the next quarter are listed.

Accession For	
NTIS GRA&I	<input checked="" type="checkbox"/>
DDC TAB	<input type="checkbox"/>
Unannounced	
Justification	
By _____	
Distribution/	
Availability Codes	
Dist	Avail and/or special
A	

ITT *Electro-Optical Products Division*

MANUFACTURING METHODS AND TECHNOLOGY PROGRAM
FOR RUGGEDIZED TACTICAL FIBER OPTIC CABLE

SECOND QUARTERLY PROGRESS REPORT

For the Period of October 1979-December 1979

Object of Program:

To Establish an Automated Production Process for
Ruggedized Tactical Fiber Optic Cable

Contract No DAAK80-79-C-0789

Prepared by:

R. Hoss, Program Manager

R. Kopstein, Project Engineer

Approved by:



R. J. Hoss,
Program Manager

Approved by:



F. R. McDevitt, Director,
Fiber Optics R&D and Systems

Approved for public release; distribution unlimited.

Roanoke, Virginia

ABSTRACT

This report covers the second quarter, October 1979 through December 1979, of the Manufacturing Methods and Technology Program for Ruggedized Tactical Fiber Optic Cable. The scope of this quarter's effort, as reported herein, includes the following tasks and achievements:

1. Cable Process Optimization
 - a. Complete first engineering samples; test, select optimized fiber buffering
 - b. Complete lay length evaluation samples; test, select optimized lay length
 - c. Receive polyurethane materials (four types, four manufacturers)
2. Use of Facilities
 - a. High speed strander, set up and operational; achieve 50% of production rate
 - b. Extruder set up and operational
 - c. Fiber optic measurement station design complete and partial fabrication
3. Secondary Performance Milestones - None this quarter

In addition to reporting progress on these milestones the report covers any revisions or improvements in process, equipment, tooling, manufacturing flow, and specifications. Any changes in key personnel on the program are identified. The program milestones for the next quarter are listed.

Roanoke, Virginia

PURPOSE

The purpose of this Manufacturing Methods and Technology (MM&T) Program is to establish automated production processes for Ruggedized Tactical Fiber Optic Cables in accordance with Specification MMT-789898 dated 2 February 1978, and ECIPPR No 15.

Roanoke, Virginia

GLOSSARY

- Fused Coupler - Optical coupler for power splitting formed by fusing two or more optical fibers
- Injection Fiber - Illuminated fiber used as a measurement light source
- ITT EOPD - ITT Electro-Optical Products Division
- Lock-In Amplifier - Amplifier used for precise instrumentation measurements in which offset drift is compensated by using a chopped source signal as a reference
- NA - Numerical aperture
- PCS Fiber - Plastic clad silica fiber
- RTV - Silicone buffer coating (room temperature vulcanizing)
- PIXEL - Picture element

TABLE OF CONTENTS

<u>PARAGRAPH</u>	<u>TITLE</u>	<u>PAGE</u>
	ABSTRACT	ii
	PURPOSE	iii
	GLOSSARY	iv
1.0	NARRATIVE AND DATA	1-1
1.1	Device	1-1
1.1.1	Ruggedized Cable Design	1-1
1.1.1.1	Primary Buffer	1-3
1.1.1.2	Secondary Buffer	1-3
1.1.1.3	Center Filler	1-4
1.1.1.4	Polyurethane Inner Jacket	1-4
1.1.1.5	Kevlar [®] Strength Member	1-4
1.1.1.6	Polyurethane Outer Jacket	1-5
1.1.2	Optimization Process	1-5
1.1.2.1	Fiber Buffer Optimization (Phase I)	1-5
1.1.2.2	Lay Length Evaluation (Phase II)	1-6
1.1.2.3	Pressure Versus Tubing Inner Jacket	1-6
1.1.2.4	Outer Jacket	1-6
1.1.3	Purpose of Phase I Optimization	1-6
1.1.3.1	Phase I Optimization	1-7
1.1.3.2	Manufacturing Problems	1-7
1.1.3.3	Phase I Conclusions and Recommendations	1-7
1.1.4	Purpose of Phase II Optimization	1-10
1.1.4.1	Phase II Optimization	1-10
1.1.4.2	Manufacturing Problems	1-10
1.1.4.3	Phase II Conclusions and Recommendations	1-11
1.2	Process, Equipment, and Tooling	1-14
1.2.1	Cable Manufacturing Process	1-14
1.2.1.1	Fiber Rewind Station	1-14
1.2.1.2	Fiber Continuity Check Station	1-16
1.2.1.3	Kevlar [®] Jacketing Station	1-17
1.2.1.4	Respooling Station for Polyurethane Jacketed Kevlar [®]	1-17

TABLE OF CONTENTS (continued)

<u>PARAGRAPH</u>	<u>TITLE</u>	<u>PAGE</u>
1.2.1.5	Optical Core Stranding Station	1-18
1.2.1.6	Optical Core Jacketing Station	1-18
1.2.1.7	Kevlar [®] Stranding of Core Station	1-19
1.2.1.8	Final Jacketing Station	1-19
1.2.1.9	Final Cable Respooling Station	1-19
2.0	FIBER AND CABLE TEST STATION	2-1
2.1	Fiber End Preparation Station	2-1
2.2	Pulse Dispersion Station	2-3
2.3	NA Test Station	2-6
2.4	Attenuation Measurement Station	2-6
2.5	Dimensional Measurement Station	2-9
3.0	FLOW CHART OF MANUFACTURING PROCESS	3-1
3.1	Data and Analysis	3-1
3.2	Results	3-5
4.0	CONCLUSIONS	4-1
5.0	PROGRAM FOR NEXT INTERVAL	5-1
6.0	PUBLICATION AND REPORTS	6-1
7.0	IDENTIFICATION OF PERSONNEL	7-1
APPENDIXES		
A	TEST RESULTS OF PHASE I	A-1
B	DISTRIBUTION LIST	B-1

LIST OF ILLUSTRATIONS

<u>FIGURE</u>	<u>TITLE</u>	<u>PAGE</u>
1	Basic MM&T Cable Design	1-2
2	Cable Fabrication Flow Chart	1-15
3	Original Fiber Positioning Fixture	2-2
4	Modified Fiber Positioning Fixture Design	2-4
5	Dispersion Test Measurement Station	2-5
6	Ninety Percent Power NA Measurement Station	2-7
7	Attenuation Measurement Station	2-8
8	Fiber Dimensional Measurement Station (1979 Case Study Development)	2-10
9a	Cable Fabrication Flow Chart	3-2
9b	Incoming Inspection and Quality Control Flow Chart	3-3

LIST OF TABLES

<u>TABLE</u>	<u>TITLE</u>	<u>PAGE</u>
1	Summary of Data	1-9
2	Attenuation Data	1-12
3	Mechanical Testing	1-13
4	Production Rate by Operation	3-4
5	Personnel Working on the MM&T Program	7-2

1.0 NARRATIVE AND DATA

The following information covers a physical description of the device, performance, effects of processes, and measurement techniques used on this program.

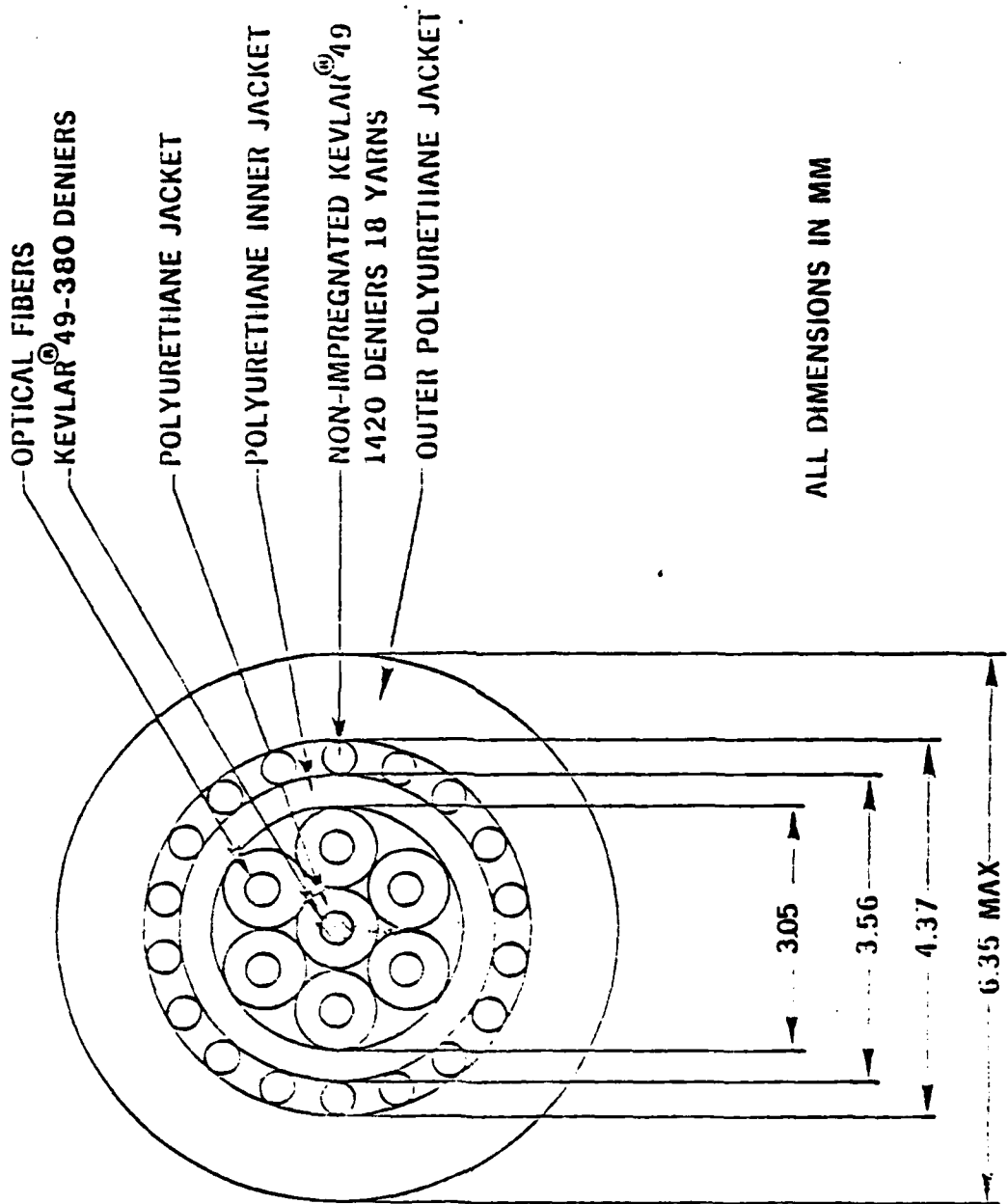
1.1 Device

The following paragraphs define the methods used to optimize the ruggedized tactical fiber optic cable, manufacturing processes, and measurement techniques.

1.1.1 Ruggedized Cable Design

The purpose of this program is to establish an automated production process for a ruggedized tactical fiber optic cable. Figure 1 shows the general cable configuration to be optimized on the program.

The light transmitting elements of the optical cable are the optical fibers consisting of a glass core and glass cladding. To preserve the mechanical strength of the glass fibers, they are coated with plastic buffers, the buffer being a solid plastic coating surrounding the optical fiber.



30° 10757

Figure 1. Basic MMGT Cable Design.

ITT *Electro-Optical Products Division*

The graded-index optical fibers are to meet the following specifications at 0.82 μm wavelength after proof loading at 100,000 psi:

- | | |
|--------------------------------------|-------------------------------------|
| a. Fiber core | $\geq 50 \mu\text{m}$ |
| b. Fiber od | $125 \mu\text{m} \pm 6 \mu\text{m}$ |
| c. Attenuation | $\leq 5.0 \text{ dB/km}$ |
| d. Dispersion | $\leq 2.0 \text{ ns/km}$ |
| e. Numerical aperture
(90% power) | ≥ 0.20 |

1.1.1.1 Primary Buffer

A room temperature vulcanizing (RTV) silicone protective coating, Dow Corning Sylguard[®] 184, is applied by dip coating to a finished diameter of 300 μm immediately after drawing. This protective coating guards the fibers from any initial handling or foreign substances that may damage or reduce the quality of the product and is compatible with the buffering materials.

1.1.1.2 Secondary Buffer

All fibers have a Hytrel[®] 7246 buffer layer for additional protection. This layer is extruded to a finished diameter of 0.5 mm. An additional layer is extruded to 1.0 mm to provide the optimum mechanical and environmental performance. The 1" extruder is used for this operation.

Roanoke, Virginia

Hytrell[®] has a very low expansion/contraction coefficient, thereby improving the high/low temperature performance.

1.1.1.3 Center Filler

The center filler shall be a Kevlar[®] 49 (380 denier) coated with polyurethane (Roylar[®] E-80) to a diameter of 1.0 mm. The center filler provides a cushioning to improve impact resistance.

1.1.1.4 Polyurethane Inner Jacket

The polyurethane inner jacket is extruded after the cabling operation. The polyurethane used is a polyether based compound. It is chosen because of its extreme toughness, abrasion resistance, low temperature flexibility, resistance to hydrolysis, fungus resistance, and excellent stability to atmospheric conditions. This jacket supplies support for the fiber making up the cable core and provides a buffer layer between the fiber and Kevlar[®] reducing abrasion.

1.1.1.5 Kevlar[®] Strength Member

Kevlar[®] 49 has been chosen as the strength member for this application because of its strength versus weight and durability. A total of 18 yarns (1420 denier) is applied

helically with a 4.0 in lay length. The lay length was selected to be greater than that of the fibers to ensure that the Kevlar[®] takes the tensile load. The strength member will provide 400 lb tensile strength at 1% elongation. One percent elongation is the 100 kpsi fiber proof test point.

1.1.1.6 Polyurethane Outer Jacket

The outer jacket material is identical to the inner jacket. Composition will be evaluated on this program.

1.1.2 Optimization Process

The basic fiber optic cable will be optimized in four specific areas or phases. The three sets of engineering samples will be selected from this four-phase optimization process.

1.1.2.1 Fiber Buffer Optimization (Phase I)

Three buffered fiber diameters of 0.94 mm, 1.02 mm, and 1.14 mm with Hytrel[®] 7246 were evaluated. Also, fibers were evaluated at 1.0 mm with Hytrel[®] 4056, Hytrel[®] 5556, and polyurethane Roylar[®] E-80. This phase is completed and cable samples from this phase were shipped as the first set of engineering samples. Test data is included in Appendix A.

1.1.2.2 Lay Length Evaluation (Phase II)

Cables are being evaluated with fiber lay lengths of 2.0 in, 2.5 in, and 3.0 in. It is felt that lay lengths shorter than 2.0 in would cause induced microbending losses and lay lengths greater than 3.0 in would cause additional tensile load stresses along with high bending stresses.

1.1.2.3 Pressure Versus Tubing Inner Jacket - Phase III

The inner jacket will be optimized by evaluating pressure versus tubing extrusion process.

1.1.2.4 Outer Jacket - Phase IV

The polyurethane will be optimized by evaluating four different manufacturers of polyether grade urethanes.

1.1.3 Purpose of Phase I Optimization

Phase I of the MM&T program was designed to evaluate the effects of buffered fiber diameter and material type and hardness on the cable performance as follows:

- a. Buffered fiber diameter, Hytrel[®] 7246 (0.94 mm, 1.02 mm, 1.14 mm)
- b. Hytrel[®] hardness effects (4056, 5556, 7246)
- c. Material comparison (Hytrel[®] versus polyurethane)

1.1.3.1 Phase I Optimization

This optimization evaluates the optical fiber buffer material. Six cables have been constructed under this phase using the basic cable design of Figure 1 with the following variations:

- a. Design #1 - Hytrel[®] 7246 fibers, 0.94 mm
- b. Design #2 - Hytrel[®] 7246 fibers, 1.02 mm
- c. Design #3 - Hytrel[®] 7246 fibers, 1.14 mm
- d. Design #4 - Hytrel[®] 4056 fibers, 1.02 mm
- e. Design #5 - Hytrel[®] 5556 fibers, 1.02 mm
- f. Design #6 - Polyurethane (Rohlar[®] E-80) fibers, 1.02 mm

1.1.3.2 Manufacturing Problems

All cables were constructed without any problems or difficult areas. Therefore the various optical fiber bufferings do not affect the manufacturing difficulty.

1.1.3.3 Phase I Conclusions and Recommendations

Detailed data from the phase I optimization is contained in the first engineering sample test report. The data from the phase I samples was used to select an optimized fiber based

on three areas of comparison. The method and reason used to select the optimized fiber are illustrated in Table 1 and Appendix A. The following conclusions were drawn:

- a. Buffered fiber diameter, Hytrel[®] 7246
 - (1) 0.94 mm - Fibers cannot withstand impact testing
 - (2) *1.02 mm - Best overall performance
 - (3) 1.14 mm - Cable outer jacket splits
- b. Hytrel[®] hardness effects
 - (1) 1.02 mm Hytrel[®] 4056 fibers - Poor performance, attenuation versus temperature
 - (2) 1.02 mm Hytrel[®] 5556 fibers - Average performance, attenuation versus temperature
 - (3) *1.02 mm Hytrel[®] 7246 fibers - Best overall performance
- c. Hytrel[®] versus polyurethane comparison
 - (1) *1.02 mm Hytrel[®] 7246 fibers - Best overall performance
 - (2) 1.02 mm polyurethane E-80 fibers - Partial bonding of fibers to inner jacket, high residual attenuation after temperature cycling

Based on the above results, Hytrel[®] 7246 fiber (1.02 mm) is recommended as the optimized fiber for phase II.

*Optimum performance

Table 1. Summary of Data.

Test Performed	Design Number*					
	1	2	3	4	5	6
Attenuation	Very Good	Good	Fair	Very Good	Very Good	Excellent
Impact	Poor	Very Good	Excellent	Excellent	Very Good	Good
Twist	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Bend	Excellent	Excellent	Excellent	Excellent	Very Good	Excellent
Low Temperature Attenuation	Very Good	Very Good	Poor	Poor	Very Good	Excellent
High Temperature Attenuation	Excellent	Excellent	Excellent	Excellent	Excellent	Good
Residual Cyclic Attenuation	Excellent	Very Good	Good	Poor	Fair	Good
Tensile Load	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Cold Bend	Excellent	Excellent	Excellent	Excellent	Excellent	Excellent
Cable Rating	38	40	35	34	38	39

Excellent = 5
 Very Good = 4
 Good = 3
 Fair = 2
 Poor = 0

*Design No 1 - Hytrel 7246 fibers, 0.94 mm diameter
 Design No 2 - Hytrel 7246 fibers, 1.02 mm diameter
 Design No 3 - Hytrel 7246 fibers, 1.14 mm diameter
 Design No 4 - Hytrel 4056 fibers, 1.02 mm diameter
 Design No 5 - Hytrel 5556 fibers, 1.02 mm diameter
 Design No 6 - Polyurethane (Roylar E-80) fibers, 1.02 mm diameter

1.1.4 Purpose of Phase II Optimization

Phase II of the MM&T program optimizes the fiber lay length (2.0 in, 2.5 in, 3.0 in).

1.1.4.1 Phase II Optimization

This optimization evaluates the cabled fiber lay length. Three cables have been constructed using the high speed strander at 50% of production rate under this phase II program following the basic cable design of Figure 1 with 1.02 mm Hytrel[®] 7246 fibers and the following variations:

- a. Design no 1 - 2.0 in lay length, 770 m/hr stranding rate
- b. Design no 2 - 2.5 in lay length, 965 m/hr stranding rate
- c. Design no 3 - 3.0 in lay length, 1160 m/hr stranding rate

1.1.4.2 Manufacturing Problems

All cables were constructed without any problems; therefore the lay length of the cabled optical fibers does not affect the manufacturing difficulty but does have a direct relationship to the manufacturing rate.

1.1.4.3 Pressure Versus Tubing, Inner Jack Optimization

It was decided at the onset of this phase to evaluate tubing versus pressure extrusion of the cable core in the event that the cable could not pass the impact testing requirement. Tubing extrusion was selected over pressure extrusion without

further engineering samples because the fibers already withstand the impact test and pressure extrusion would only improve impact performance but would have the following disadvantages:

- a. Lower production speed
- b. Poor concentricity
- c. Lower production yield
- d. Equal optical and mechanical performance
- e. More material scrap

Construction of engineering samples to evaluate pressure versus tubing performance was not a requirement in the MM&T program.

1.1.4.4 Phase II Conclusions and Recommendations

The data from the Phase II samples (see Tables 2 and 3) was used to select the optimized lay length from the optical and mechanical results. All three cables had excellent optical results. One of the fibers was broken in the 2.0 in lay length cable because of stepper, motor problems with the high speed strander. The motor was replaced and no further problems have developed. The large excess loss on one fiber in the 3.0 in lay length cable can be attributed to fiber bend sensitivity. The cause of the sensitivity is being examined and only occurs on a small portion of production fibers.

Table 3. Mechanical Testing.*

	Design No 1 2" Lay Length	Design No 2 2.5" Lay Length	Design No 3 3.0" Lay Length
Impact Resistance			
Total fibers	36	36	36
Failures	1	0	0
Percent surviving fibers	97.2	100.0	100.0
Twist Test			
Total fibers	18	18	18
Failures	0	0	0
Percent surviving fibers	100.0	100.0	100.0
Bend Test			
Total fibers	18	18	18
Failures	0	0	0
Percent surviving fibers	100.0	100.0	100.0
Tensile Load Test			
Total fibers	6	6	6
Failures	0	0	0
Percent surviving fibers	100.0	100.0	100.0

*All testing was conducted at room temperature

ITT *Electro-Optical Products Division*

The mechanical testing data showed excellent results also with only one fiber failure on the 2.0 in lay length cable during the room temperature impact testing. This fiber failure is caused by brittleness which varies with draw conditions and preform fabrication.

A 3.0 in lay length was selected for Phase IV based on the test results and because an increase in stranding rate can be realized over the shorter lay lengths. Stranding speed is a direct function of lay length. Further information will be included in the test report for the second engineering samples.

1.2 Process, Equipment, and Tooling

This section covers the process, equipment, and tooling on the program.

1.2.1 Cable Manufacturing Process

Each station in the cable manufacturing process is described in this section.

1.2.1.1 Fiber Rewind Station

This station (Figure 2, Operation E1) will be used to respool and inspect fibers in preparation for the subsequent stranding operation. The equipment consists of a rewinder, an optical lump detector to examine the fiber buffer jacket for any nonuniformities, and a constant-tension compensating payoff to eliminate any fiber breaks due to high tension levels.

Roanoke, Virginia

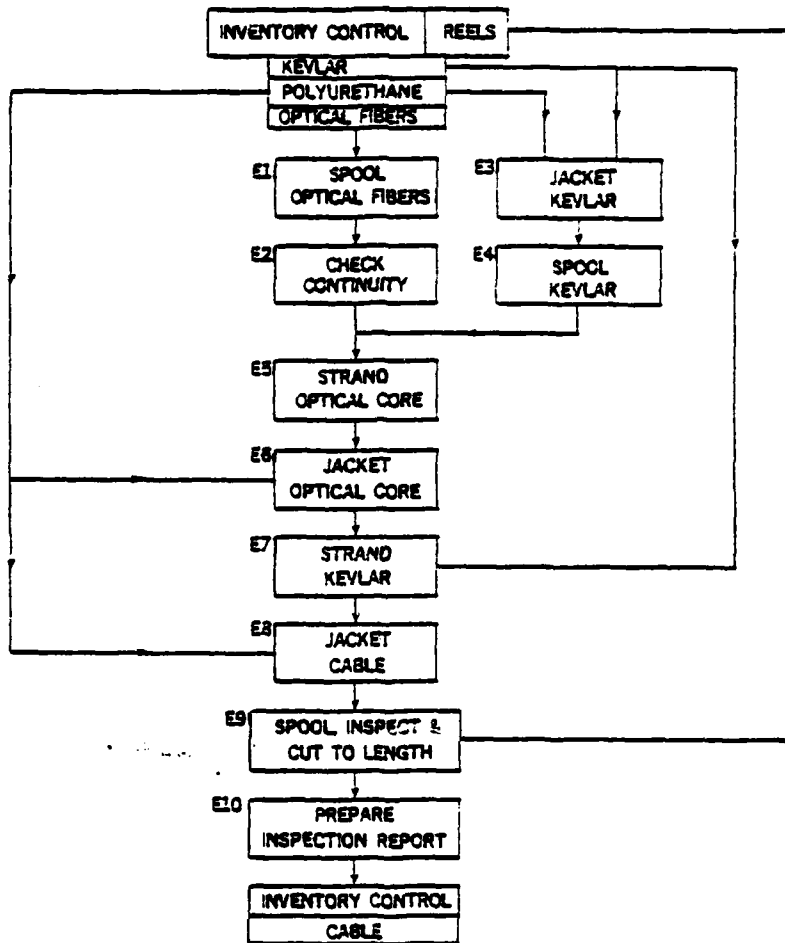


Figure 2. Cable Fabrication Flow Chart.

ITT *Electro-Optical Products Division*

This unit will allow fibers to be inspected for buffer jacket flaws optically at control tensions. The rewinding speed was found to be 8600 m/h, 200 m/h more than reported in the First Quarterly Report.

The equipment has been received and installed. A new circuit board needed to correct a traverse direction problem will be installed in January.

1.2.1.2 Fiber Continuity Check Station

Before the fibers are stranded into a cable bundle it is essential that each fiber's continuity be tested and any broken fibers removed to ensure a high production yield. The unit used at this station (Figure 2, Operation E2) will include a large area light emitting diode (LED) and a large silicon detector. The LED and detector will be properly mounted for automatic axial alignment and quick operation to minimize the time required to examine each fiber for light transmission. This station will test for end to end attenuation, but cannot differentiate between high loss and fiber breaks.

To complete this unit, minor modifications to existing equipment are all that will be required.

Roanoke, Virginia

1.2.1.3 Kevlar[®] Jacketing Station

The purpose of this station (Figure 2, Operation E3) is to overcoat a Kevlar[®] 49-1420 denier yarn with a polyurethane jacket which will be used as the central core for the optical bundle. The extruder to be used is a 1 in unit with the capacity of pressure extruding the polyurethane jacket at a rate of 45 m/min.

This unit is an existing production station. An automatic diameter controlling process unit will be installed at the end of January. This unit will detect the diameter of the fiber being extruded and regulate the extruder rpm to provide a constant diameter over the length of a standard production run.

1.2.1.4 Respooling Station for Polyurethane Jacketed Kevlar[®]

This operation will be completed using the fiber rewind station equipment outlined in paragraph 1.2.1.1. The capacity of this unit is ample to complete both fiber rewind and respooling operations (Figure 2, Operation E4).

1.2.1.5 Optical Core Stranding Station

The purpose of this station (Figure 2, Operation E5) is to strand the six optical fibers helically around the Kevlar[®] center core member. To do this operation, a high speed single twist closing unit equipped with a seven bay neutralizing unit will be used.

At the present time, 10 km of cable have been made, no production problems have developed, and the unit is running at 50% of production rate.

1.2.1.6 Optical Core Jacketing Station

This station is to be used to extrude the polyurethane jacket over the optical bundle. The extruder is a 1 1/2 inch extrusion line capable of extruding the above jacket at 30 m/min, well over the required MM&T rate of 20 m/min.

A new payoff has been installed and is in the check out stage. This unit will handle the larger capacity spools needed to run long lengths (4 km) of cable.

1.2.1.7 Kevlar[®] Stranding of Core Station

The purpose of this station (Figure 2, Operation E7), is to strand 18 Kevlar[®] strength members around the jacketed optical core. The modified yarn serving machine has been received and is presently being installed.

1.2.1.8 Final Jacketing Station

The 2-inch extrusion line (Figure 2, Operation E8) will be used to extrude the final jacket on the ruggedized cable. The extrusion line is capable of extruding the final jacket at 25 m/min.

This unit has been trial run, but problems have developed within the takeup unit. The bearing assembly had excessive wear and is being currently replaced. No delays are anticipated on this station.

1.2.1.9 Final Cable Respooling Station

At this station (Figure 2, Operation E9) the cable will be spooled onto the shipping reel, inspected for visual defects, and cut into 1 km \pm 5 m lengths.

ITT *Electro-Optical Products Division*

An Eaton-Dynamatic Multi-Trol system will be used to improve the payoff tension control. This unit, which is in-house at EOPD, will provide a gradual startup to re-spooling speeds and reduce the possibility of peak tensile loading.

1.2.2 Cable Dimension and Weight Stations

Dimensional measurements of the finished cable will be performed using calibrated micrometers by the Quality Control Department.

The cable weight shall be measured in the Shipping Department using a Toledo balanced-beam scale with a 1000 pound capacity and 1 pound increments. This station is calibrated twice a year. The cable weight shall be determined by weighing the finished cable on the reel and then subtracting the weight of the reel.

Roanoke, Virginia

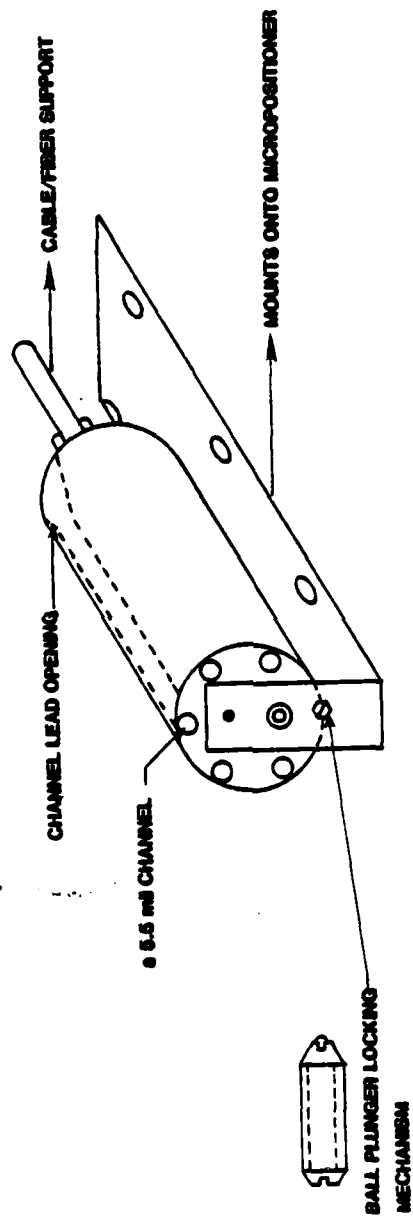
2.0 FIBER AND CABLE TEST STATION

In the second quarter, the effort expended concentrated on completing the evaluation station designs and ordering components.

The station designs were completed by October 15, 1979, as planned, and fixture design/construction and component procurement initiated. The station designs and fiber positioning fixture (Figure 3) described in the First Quarterly Progress Report have been modified since that time. These modifications, the reasons for them, and other efforts during the second quarter are described in the following paragraphs.

2.1 Fiber End Preparation Station

The barrel fixture (Figure 3) described in the previous quarterly report was designed, documented and quotes for fabrication obtained. However, information obtained during 90% power numerical aperture (NA) measurements indicated that the barrel fixture design would increase the minimum distance from the fiber end to the detector surface during the NA measurement significantly. Because this would reduce test accuracy and reproducibility, further refinement of the design was required.



302 12450

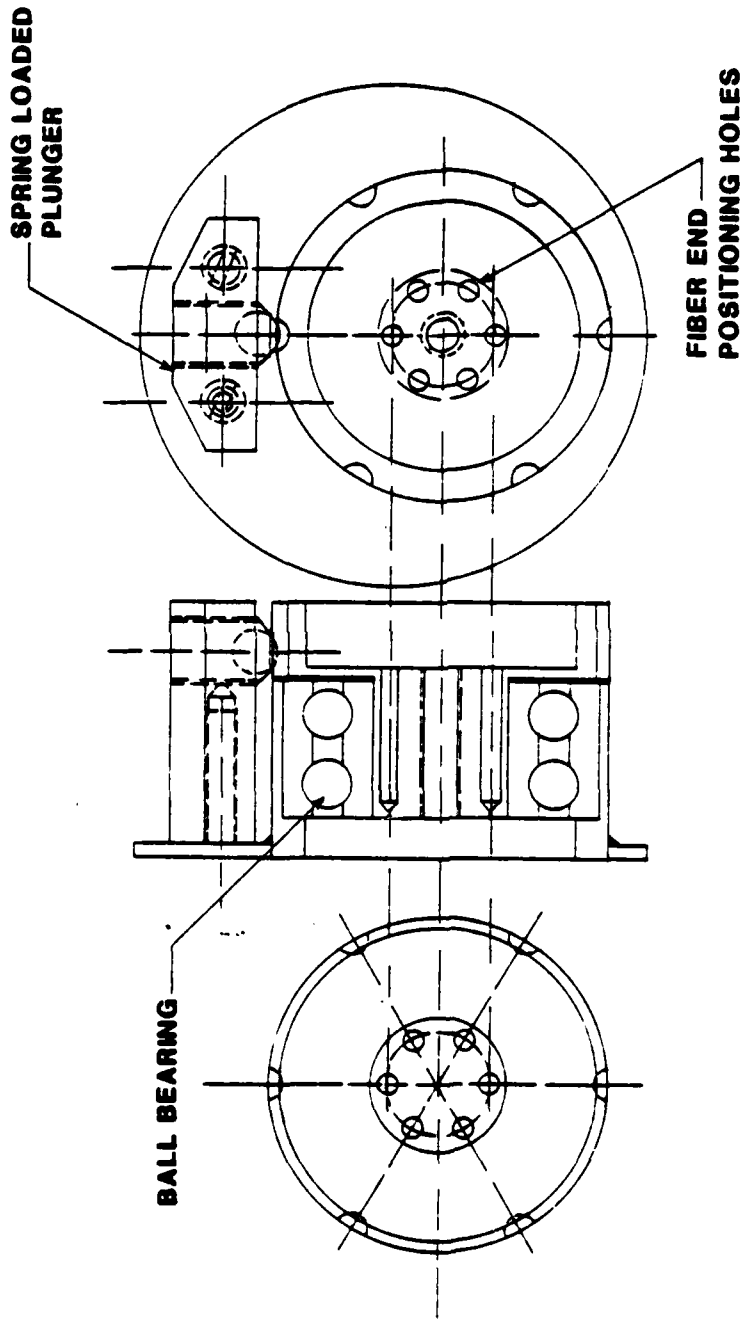
Figure 3. Original Fiber Positioning Fixture.

The refinement, based on a commercial ball bearing structure, has been completed. A composite view of the design is shown in Figure 4. With the new design, the minimum fiber to detector distance is achieved in the NA measurement. The fixture will also be used on the other stations to provide a time saving fiber alignment/handling function.

2.2 Pulse Dispersion Station

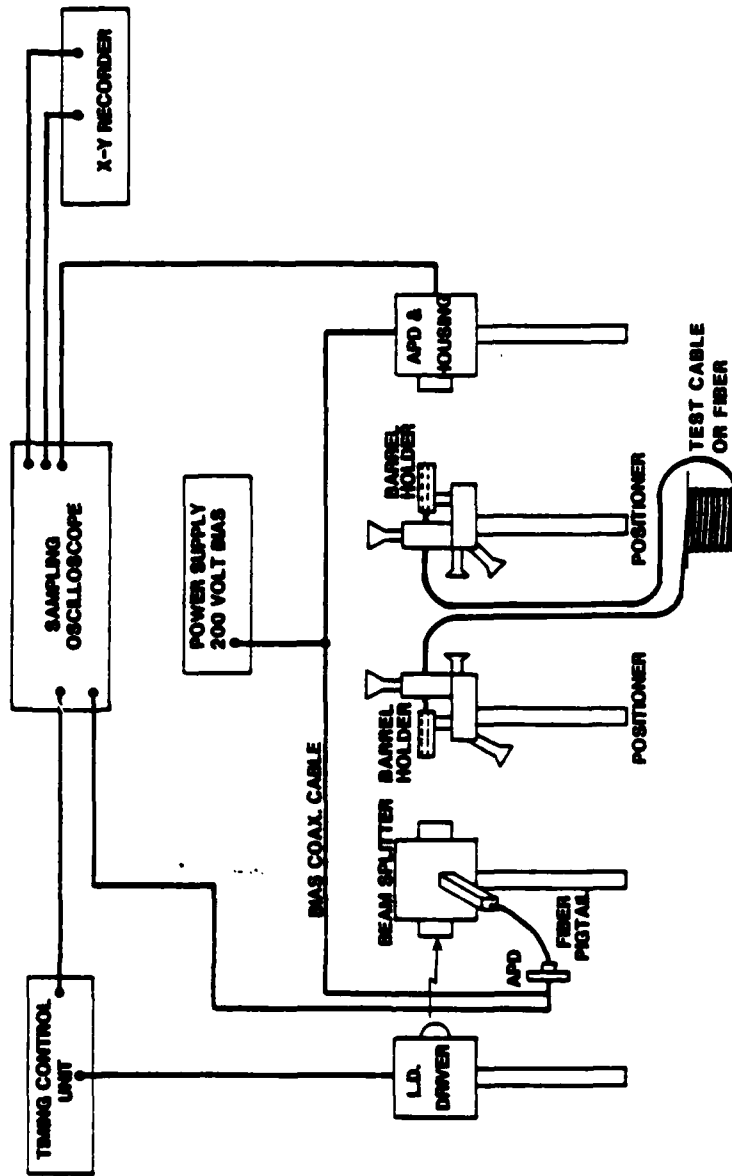
The dispersion station (Figure 5) required the addition of a second avalanche photodiode (APD) detector to provide input pulse monitoring capability. This eliminates the need for cut back measurements to determine the input pulse characteristics and also permits the operator to do troubleshooting, should problems occur, without disturbing the fiber under test. A key requirement is that the two detectors should have similar characteristics at the operating voltage to eliminate the need for separate bias supplies and yet track the input pulse.

Two RCA C30902E detectors were tested for pulse characteristics. The data indicated differences of 35% in the



102 12779

Figure 4. Modified Fiber Positioning Fixture Design.



302 1245A

Figure 5. Dispersion Test Measurement Station.

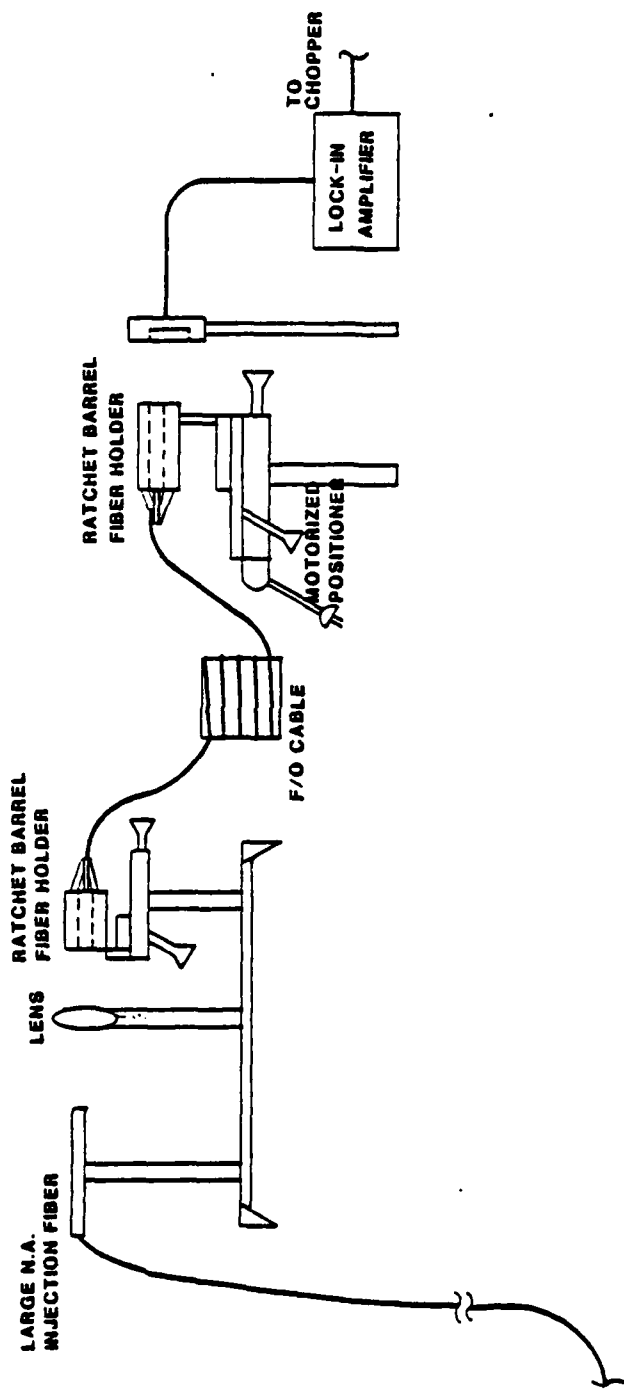
50% pulse width and 18% in the 10% pulse width. Additional detectors were ordered and received. These detectors will be tested for similarity in the next period.

2.3 NA Test Station

The 90% power NA station (Figure 6) used for cable sample testing was rebuilt during the second quarter to improve operation by adding a digitally controlled, motorized micropositioner. During this activity it was discovered that a higher speed positioner was required. The present unit moves at a rate of 0.14 mm/s. Equipment selection is under way for a unit moving at a rate of 0.6 mm/s to reduce the measurement time requirement.

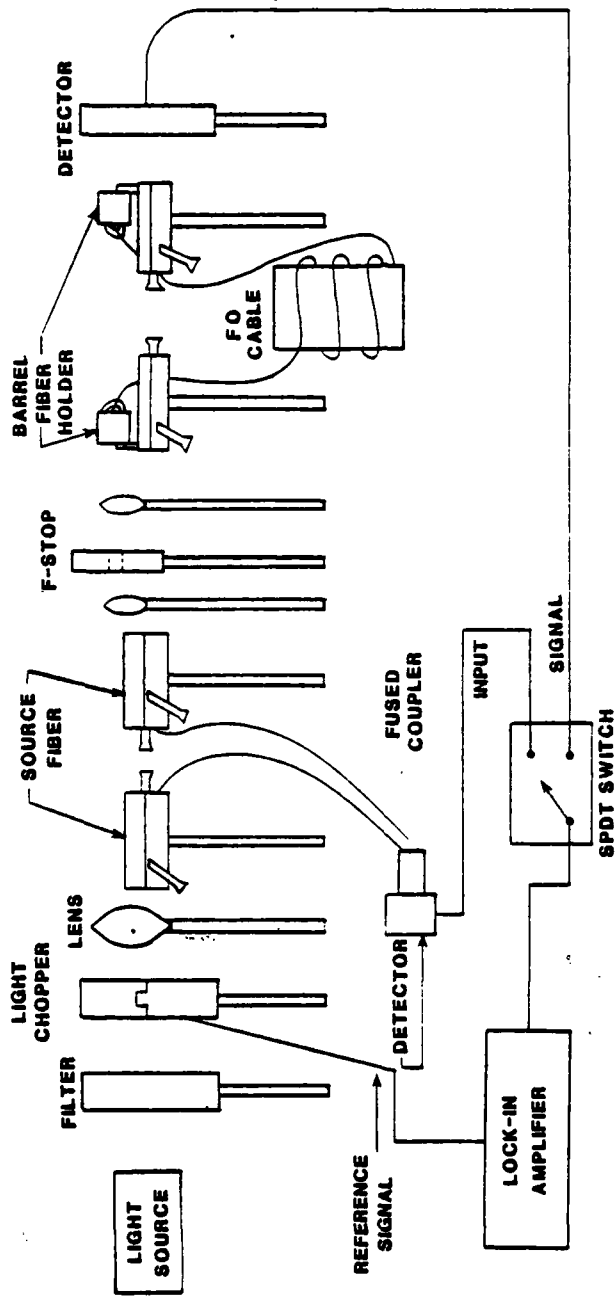
2.4 Attenuation Measurement Station

To improve overall measurement stability, a beamsplitter monitor will be added to the attenuation station (Figure 7) source fiber. This device will monitor the input power level during a fiber measurement and permit correction for any input power variations. It was discovered that the plastic clad silica (PCS) device proposed is no longer available. Therefore, a "Y" coupler made with large core



302 12450

Figure 6. Ninety Percent Power NA Measurement Station.



302 12856

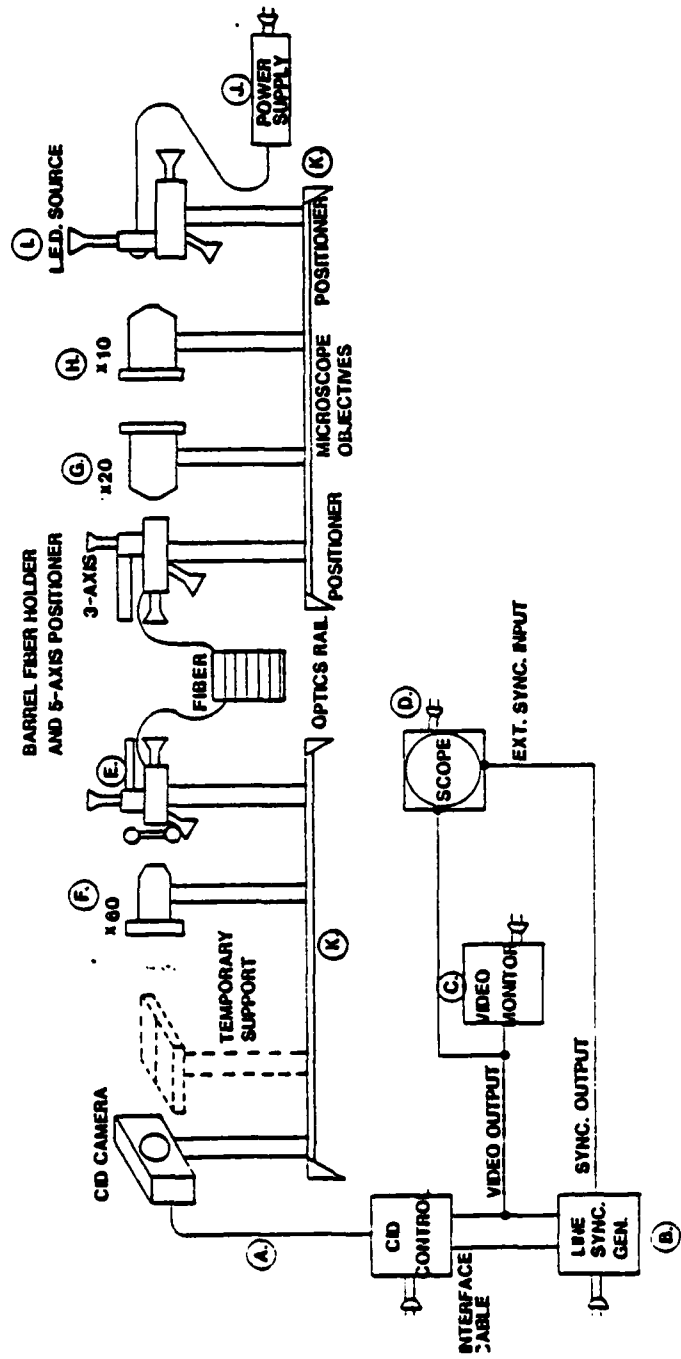
Figure 7. Attenuation Measurement Station.

(100 μm) graded index fiber was ordered. The 100 μm core diameter source fiber will result in a smaller injection spot diameter and a reduced maximum injection NA relative to the PCS source fiber. However, the spot diameter of the 110 μm source fiber and the maximum injection NA of 0.30 exceed the minimum values (55 μm core, 0.20 NA) required for MM&T fiber evaluations.

In order to facilitate all measurement requirements with a single attenuation station, the MM&T station must be able to evaluate fibers at wavelengths from 0.82 μm to 1.2 μm . To avoid the need to switch out silica detectors whose maximum useful wavelength is 1.1 μm with other devices at the coupler output, Judsen germanium detectors were obtained. These devices have useful responsivity from 0.8 μm to 1.7 μm . Tests will be conducted to compare the responsivity variation with position and spectral responsivity characteristics of the germanium devices with the standard silica units.

2.5 Dimensional Measurement Station

The video camera system previously described for the fiber dimensional measurement station (Figure 8) was evaluated



302 12455

Figure 8. Fiber Dimensional Measurement Station (1979 Case Study Development).

ITT *Electro-Optical Products Division*

under an EOPD R&D task. Repeated measurements of a graded index fiber indicated the worst case reproducibility of the station was $\pm 1.8\%$ for the core diameter and $\pm 1.3\%$ for the fiber outer diameter. These numbers are higher than the $\pm 0.5\%$ suggested by calculation due to digitization noise present in the camera unit and pixel resolution limits. However, the reproducibility of the station is sufficient for this application.

Roanoke, Virginia

3.0 FLOW CHART OF MANUFACTURING PROCESS

Figures 9a and 9b show the flow of materials and product through the proposed pilot line production facility. Each station is identified with a letter/number code.

Plans are to produce cables in lengths of 4 km, thus reducing setup time at each station considerably. The expected result of the above is to increase efficiency so that the overall production yield will be 87%.

Table 4 lists all operations with the expected production rate at each work station. (Major work stations have been discussed in paragraph 1.2.) At this time in the program there is no obvious reason to believe that the proposed production rates cannot be met or exceeded.

3.1 Data and Analysis

Table 2 (page 1-12) details the results of the fiber attenuation before cabling, after cabling, and change due to cabling. The attenuation of the fibers before cabling was measured with the fibers on plastic spools with a 6 in drum. Table 3 (page 1-13) summarizes the results of the mechanical testing conducted at room temperature.

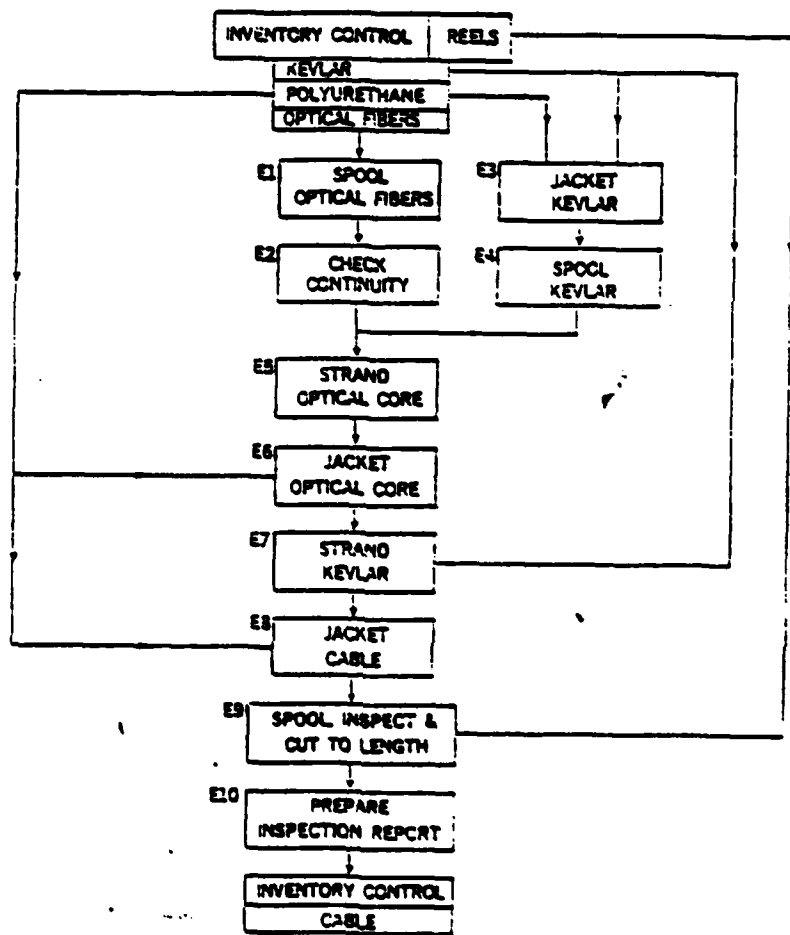


Figure 9a. Cable Fabrication Flow Chart

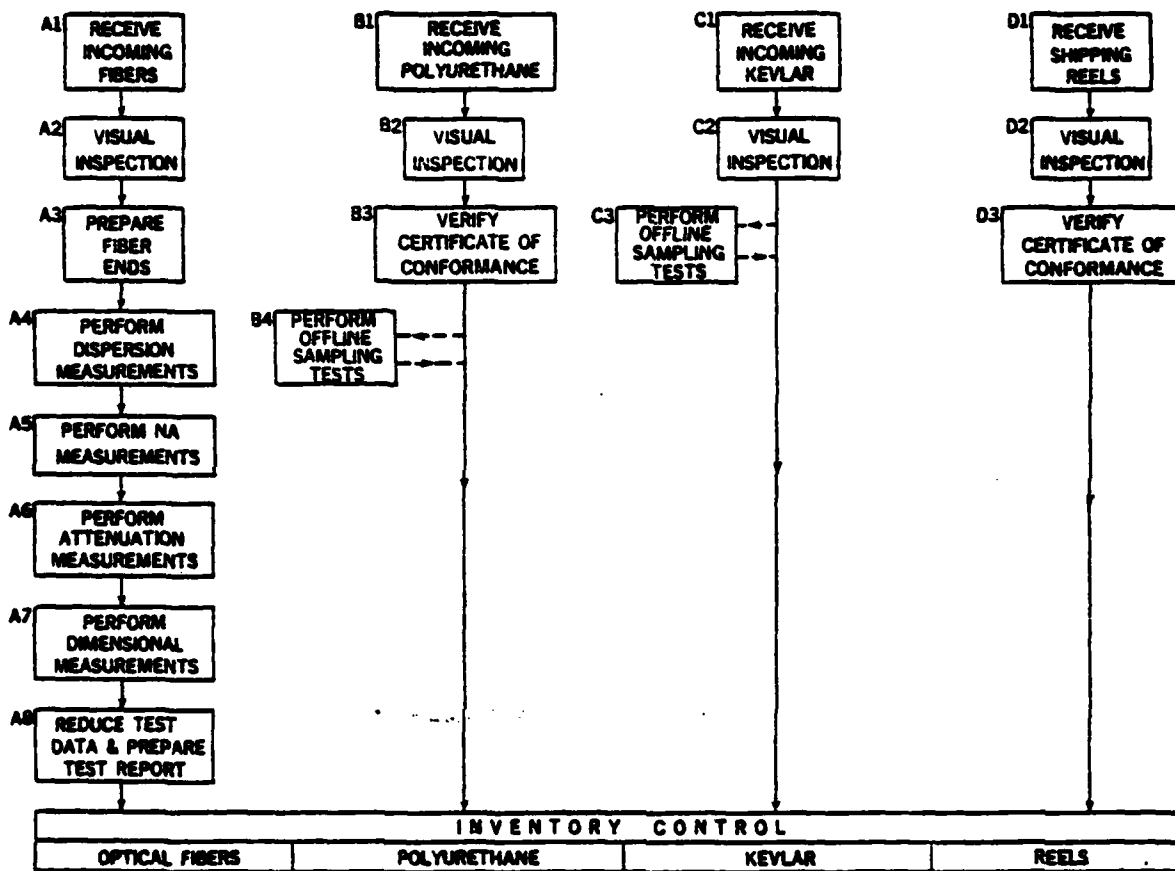


Figure 9b Incoming Inspection and Quality Control Flow Chart.

Table 4. Production Rate by Operation.

Operation	Operation Description	Set-up Time hrs/km	Run Time hrs/km	Total Time hrs/km Cable
A01	Receive Incoming Fibers	-	-	-
A02	Visual Inspection	0.020	-	0.184
A03	Prepare Fiber Ends	0.020	-	0.184
A04	Perform Dispersion Measurement	0.050	-	0.459
A05	Perform NA Measurement	0.050	-	0.459
A06	Perform Loss Measurement	0.050	-	0.459
A07	Perform Dimensional Measurement	0.050	-	0.459
A08	Reduce Test Data and Prepare Test Report	0.080	-	0.736
B01	Receive Incoming Polyurethane	-	-	-
B02	Visual Inspection	0.020	-	0.026
B03	Verify Certificate of Conformance	0.010	-	0.013
B04	Offline Sampling Tests	-	-	-
C01	Receive Incoming KEVLAR	-	-	-
C02	Visual Inspection	0.020	-	0.026
C03	Offline Sampling Tests	-	-	-
D01	Receive Shipping Reels	-	-	-
D02	Visual Inspection	0.050	-	0.056
D03	Verify Certificate of Conformance	0.050	-	0.056
E01	Spool Optical Fibers	0.030	0.090	0.827
E02	Check Continuity	0.050	-	0.344
E03	Jacket KEVLAR	0.130	0.370	0.574
E04	Spool KEVLAR	0.030	0.090	0.138
E05	Strand Optical Core	0.060	0.910	1.000
E06	Jacket Optical Core	0.260	0.540	0.918
E07	Strand KEVLAR	0.200	0.410	0.700
E08	Jacket Cable	0.230	0.157	0.918
E09	Spool, Inspect & Cut to Length	0.170	0.630	0.918
E10	Prepare Inspection Report	0.500	-	0.556
F01	Prepare Fiber & Cable Ends	0.750	-	0.833
F02	Perform Dispersion Measurement	0.300	-	0.918
F03	Perform NA Measurement	0.670	-	0.744
F04	Perform Loss Measurement	0.800	-	0.918
F05	Perform Dimensional Measurement	0.300	-	0.918
F06	Prepare Cable Ends for Shipping	0.130	-	0.202
F07	Reduce Test Data and Prepare Test Report	0.660	-	0.734
F08	Offline Sampling Tests	-	-	-
Total Production Time				15.277

3.2 Results

The data in Tables 2 and 3 indicates that from an optical and mechanical standpoint, all cables performed excellently. There was only one fiber failure during impact testing with the 2.0 in lay length cable.

Roanoke, Virginia

4.0 CONCLUSIONS

The data from phase I samples has resulted in the 1.02 mm Hytrel[®] 7246 fibers being selected because of best overall performance. This fiber will be used in all further cable optimization processes.

The data from phase II samples shows excellent optical and mechanical performance. The 3.0 in lay length was chosen for further cable optimization because of an increased cable production rate over smaller lay lengths, without any penalty in performance.

Tubing extrusion was selected over pressure extrusion for the following reasons:

- a. Higher production speed
- b. Better concentricity
- c. Greater production yield
- d. Equal optical and mechanical performance
- e. Less material scrap

No problems have been identified in the equipment or measurement station designs which will adversely affect performance on this contract. All milestones have been achieved on schedule.

Roanoke, Virginia

5.0 PROGRAM FOR NEXT INTERVAL

Milestone achievements for the next quarterly interval are listed below:

- a. Select optimized polyurethane
- b. Complete fungus testing
- c. Complete polyurethane evaluation sample fab and test
- d. Begin optimized cable fabrication for third engineering sample
- e. Deliver second engineering sample and test report (polyurethane and lay length evaluation samples)
- f. Receive DR-5 reels for optimized cable sample and confirmatory sample
- g. Work from 50% of production rate on the high speed strander toward 75% of rate
- h. Install new serving line, start setting up, and operate
- i. Complete 2.0" extruder setup, achieve 0.918 h/km rate, work toward 0.8 h/km rate
- j. Set up and make spooler operational, achieve 50% of production rate, work toward 75% rate
- k. Complete assembly of test stations and run time study
- l. Achieve 0.5 dB/km induced attenuation from cabling operation
- m. Start evaluating yield for 50% goal

6.0 PUBLICATION AND REPORTS

There have been no publications, conferences and/or talks made during the period on or associated with the research, study, or development under contract.

Roanoke, Virginia

7.0 IDENTIFICATION OF PERSONNEL

Table 5 is a list of the names of personnel working on the program who are considered professional and skilled technical personnel. The task performed and the manhours of work performed by each during the interval of the report are given.

Table 5. Personnel Working on the MM&T Program.

<u>Name</u>	<u>Task</u>	<u>Manhours Expended</u>
R. Hoss	Program Management	50
*L. Ptaschek	Cable Production	115
R. Thompson	Technical and Administrative	14
J. Smith	Cable Process Engineering	16
*R. Kopstein	Project Engineer	39
S. Mahurin	Measurements Supervision and Project Engineering	24
J. Ravita	Measurements Engineering	36
T. Armstrong	Quality Control	5

*Due to a change in the ITT EOPD organization in which L. Ptaschek has been promoted to Manager of Cable Production, R. Kopstein has been assigned as Project Engineer. He reports to J. Smith who reports to R. Thompson in the fiber and cable engineering organization. A biography of R. Kopstein is included.

BIOGRAPHICAL INFORMATION

NAME: Robert Kopstein
POSITION: Senior Cable Engineer

EDUCATION:

Mr. Kopstein was awarded a BSEE degree in Electronics from the University of Wisconsin in 1972.

EXPERIENCE:

Mr. Kopstein has been associated with ITT Electro-Optical Products Division for 1 year. As a Cable Engineer in the Fiber Optics Laboratory, his present responsibilities include cable design combined with research and development to improve cable performance characteristics.

Prior to joining ITT, Mr. Kopstein was associated with the Rochester Corporation where he participated in research and development of new materials and designs for better product performance. In 1977 he developed and designed the first diving umbilical cable manufactured at the Rochester Corporation. Some of his other accomplishments at the company included the development of: equations to predict all electrical characteristics of coaxial cables prior to manufacturing; computerized methods to design mechanical characteristics on armored cables and coaxial cables; and improved manufacturing techniques for fiber optics handling and cabling using the available equipment.

ADMINISTRATIVE

From 1972 to 1976, Mr. Kopstein was associated with Underwriters Laboratories, Inc., as Project Engineer. In this capacity he supervised one Engineering Assistant and two technicians. He managed from 30 to 40 projects in his position as Project Engineer.

MANUFACTURING

During his course of study at the University of Wisconsin, Mr. Kopstein developed a system for closed circuit video and TV transmission to all departments at the institution. He also fabricated integrated circuits with current manufacturing techniques.

TECHNICAL

Mr. Kopstein's technical expertise includes design and maintenance of a CCTV station at the University of Wisconsin, product safety evaluation at Underwriters Laboratories, and experience with armored cable at the Rochester Corporation.

ITT *Electro-Optical Products Division*

APPENDIX A
TEST RESULTS OF PHASE I

Roanoke, Virginia

A1.0 TEST RESULTS OF PHASE I

All data is summarized below for the first set of engineering samples.

A1.1 Attenuation Measurement Results

The attenuation was measured on spools with a 6" drum prior to cabling and after the cables were completed. The results of the data are summarized by the maximum, minimum, and average values for the six designs as notes in Table A-1.

The results indicated that by increasing the buffered fiber diameter, there was a corresponding increase in cabling loss. Also, softer grades of buffer material reduced the cabling losses as noted in Table A-1.

A1.2 Pulse Dispersion Measurement Results

The pulse dispersion on all fibers in the six designs performed very well, with all values less than the 2.0 ns/km requirements (see Table A-2).

The pulse dispersion values on most of the fibers were equal to the input pulse width because of the cable length and quality of fibers.

Table A-1. Attenuation Measurement Results.

Cable Design	Attenuation Before Cabling*			Attenuation After Cabling*		
	Maximum	Minimum	Average	Maximum	Minimum	Average
1	4.75	3.55	3.77	5.17	3.34	3.99
2	4.14	3.41	3.58	4.74	3.66	4.19
3	3.83	3.34	3.59	5.52	3.77	4.31
4	5.29	4.15	4.69	5.06	4.81	4.96
5	5.02	4.18	4.46	4.91	4.23	4.64
6	5.33	4.31	4.59	4.83	4.22	4.57

*Measured at 0.82 μm wavelength, 0.089 Injection NA.

Table A-2. Pulse Dispersion Measurement Results.

Cable Design	Pulse Dispersion (ns/km)*		
	Maximum	Minimum	Average
1	.83	≤.63	.70
2	≤.63	≤.63	≤.63
3	≤.68	≤.68	≤.68
4	≤1.49	≤1.49	≤1.49
5	≤1.43	≤1.43	≤1.43
6	≤1.22	≤1.22	≤1.22

*Most pulse dispersion values are below the range of the measuring equipment for shorter length cables.

A1.3 Numerical Aperture Measurement Results

The 90% power NA was measured on the finished cables and compared to the white light NA for each fiber. The results of the data are summarized in Table A-3. The data indicates that even though the white light NA of the fibers is quite high, they do not meet the 0.20 design goal when measured after a 1 km length.

A1.4 Impact Testing Results

The impact testing was conducted in accordance with MIL-C-13777F at room temperature, +71°C (+160°F), and at -54°C (-65°F). In each sample, the jacket split during high temperature impacting. The data indicates that by increasing the fiber buffer od, the impact resistance also increases, but the outer jacket becomes weaker. The only cable designs without any fiber failure were designs no 3 and 4.

Design no 2, with 1-mm Hytrel[®] 7246 fibers, was selected for the next phase because of best overall performance and the fact that the fiber failures can be attributed to a reduction in the cable od and outer jacket wall thickness.

Table A-3. Numerical Aperture Measurement Results.

Cable Design	90% Power NA			White Light NA		
	Maximum	Minimum	Average	Maximum	Minimum	Average
1	.20	.18	.19	.25	.24	.25
2	.20	.18	.19	.27	.22	.24
3	.19	.17	.18	.26	.24	.25
4	.20	.18	.19	.26	.22	.24
5	.19	.18	.19	.25	.25	.25
6	.19	.18	.19	.26	.22	.24

Roanoke, Virginia

The outer jacket splitting at high temperature is caused by a weakness in the Roylar[®] E-80 polyurethane under these severe conditions. The problem will be corrected by using Roylar[®] E-9B polyurethane on all future cable designs.

A1.5 Twist Testing Results

The twist testing was conducted in accordance with MIL-C-13777F at room temperature, +71°C (+160°F), and at -54°C (-65°F). All testing of the six-cable designs was completed without any failures.

A1.6 Bend Testing Results

The bend testing was conducted in accordance with MIL-C-13777F at room temperature +71°C (+160°F), and at -54°C (-65°F). All testing of the six-cable designs was completed without any fiber failures, but the outer jacket had splits during the high temperature (+71°C) bend testing.

A1.7 Low/High Temperature Attenuation Test Results

The low and high temperature attenuation on the six-cable designs was conducted in accordance with MIL-STD-810C at -55°C (-68°F) and +85°C (+185°F).

The test results show that softer grades of Hytrel[®] (4056, 5556) result in a considerable amount of additional attenuation at low temperature (-55°C). Also, increasing the fiber buffer diameter causes a corresponding increase in attenuation at low temperature. The fibers buffered with Roylar[®] E-80 polyurethane exhibited the best performance at -55°C, but there was a high amount of residual excess attenuation upon returning to room temperature. The data from design no 2 indicates that the low temperature attenuation problem is attributed to the fibers and not to the cable designs. Therefore, a major program is underway to correct this deficiency in the fibers.

A1.8 Tensile Load Testing Results

The cables were subjected to a static tensile load of 181.44 kg (400 lb) over a gage length of 6 meters for 1 minute. All testing was completed on this group without any fiber failures or degradation.

A1.9 Cold Bend Testing Results

The cold bend testing was conducted in accordance with MIL-C-13777F at -54°C (-65°F) around a 31.75 mm od mandrel (5x) for 1 cycle. All testing was completed without any fiber or jacket failures.

APPENDIX B
DISTRIBUTION LIST

Roanoke, Virginia

DISTRIBUTION LIST

Defense Technical Information Center
Attn: DTIC-TCA
Cameron Station (Building 5)
Alexandria, VA 22314
(12 Copies)

Director
National Security Agency
Attn: TDL
Fort George G. Meade, MD 20755

Code RL23, Tech Library
DCA Defense Comm Engrg Ctr
1860 Wiehle Avenue
Reston, VA 22090

Defense Communications Agency
Technical Library Center
Code 205 (P.A. Tolovi)
Washington, DC 20305

Office of Naval Research
Code 427
Arlington, VA 22217

GIDEP Engineering & Support Dept.
TE Section
P.O. Box 398
Norco, CA 91760

CDR, MIRADCOM
Redstone Scientific Info Center
Attn: Chief, Document Section
Redstone Arsenal, AL 35809

Commander
HQ Fort Huachuca
Attn: Technical Reference Div
Fort Huachuca, AZ 85613

Commander
US Army Electronic Proving Ground
Attn: STEEP-MT
Fort Huachuca, AZ 85613

Commander
NASA Test & Evaluation Center
Attn: IAO-CDR-T
Fort Huachuca, AZ 85613

Director
Naval Research Laboratory
Attn: Code 2627
Washington, DC 20375

Command, Control & Communications Div.
Development Center
Marine Corps Development & Educ Comd
Quantico, VA 22134

Naval Telecommunications Command
Technical Library, Code 91L
4401 Massachusetts Avenue, NW
Washington, DC 20390

Rome Air Development Center
Attn: Documents Library (TILD)
Griffiss AFB, N.Y. 13441

HQDA (DAMA-ARP/DR. F.D. Verderame)
Washington, DC 20310

Director
US Army Human Engineering Labs
Aberdeen Proving Ground, MD 21005

CDR, AVRADCOM
Attn: DRS AV-E
P.O. Box 209
St. Louis, MO 63166

Director
Joint Comm Office (TRI-TAC)
Attn: TT-AD (Tech Docu Cen)
Fort Monmouth, NJ 07703

Dir., US Army Air Mobility R&D Lab
Attn: T. Gossett, Bldg. 207-5
NASA Ames Research Center
Moffett Field, CA 94035

HQDA (DAM)-TCE)
Washington, DC 20310

Deputy for Science & Technology
Office, Assist Sec Army (R&D)
Washington, DC 20310

Commander, DARCOM
Attn: DRUDE
5001 Eisenhower Avenue
Alexandria, VA 22333

Galileo Electro-Optics Corp.
Galileo Park
Attn: L. Thompson
Sturbridge, MA 01518

Electronics Group of TRW, Inc.
401 N. Broad Street
Philadelphia, PA 19108

Valtec Corporation
Electro Fiber Optic Div
West Boylston, MA 01583

Belden Corporation
Technical Research Center
2000 S. Batavia Avenue
Geneva, IL 60134
Attn: Mr. J. McCarthy

Hughes Aircraft Company
Connecting Devices Division
17150 Von Karman Avenue
Irvine, CA 92714
Attn: Mr. J. Maranto

Harris Government Info Systems Div
P.O. Box 37
Melbourne, FL 32901
Attn: Mr. R. Stachouse

ITT Defense Communications Division
492 River Road
Nutley, NJ 07110
Attn: Dr. P. Steensma

GTE Sylvania Inc.
Communications System Division
189 B Street
Needham Heights, MA 02194
Attn: Mr. J. Concordia

Commander
Naval Ocean Systems Center
Code 8115
San Diego, CA 92152
Attn: Dr. H. Rast

Commander
Naval Avionics Facility
Code D831
Indianapolis, IN 46218
Attn: Mr. R. Katz

Commanding General
Wright-Patterson AFB, OH 45433
AFAL/AAD-3
Attn: Mr. E. Friar

Commander
Naval Ocean Systems Center
Code 4400
San Diego, CA 92152
Attn: Mr. R. Lebduska

Commander
Naval Ocean Systems Center
Attn: Library
San Diego, CA 92152

General Cable Corporation
160 Fieldcrest Avenue
Edison, NJ 08817
Attn: Mr. M. Tenzer

ITT Cannon Electric Div
666 East Dyer Road
Santa Ana, CA 92702
Attn: Mr. R. McCartney

Mitre Corp.
P.O. Box 208
Bedford, MA 01730
Attn: Mr. C. Kleekamp

Project Manager, MSCS
Attn: DRCPM-MSCS-JSPB (Capt. E. Howe)
Fort Monmouth, NJ 07703

National Bureau of Standards
Electromagnetic Tech Div
Boulder, CO 80303
Attn: Dr. G. Day

Defense Logistics Agency
Attn: DESC-EMT (Mr. A. Hudson)
Dayton, OH 45444

Commander
Air Force Avionics Laboratory
Attn: AFAL/AAD-2 (Mr. K. Trumble)
Wright-Patterson AFB, OH 45433

Brand-Rex Company
Willimantic, CT 06226
Attn: Mr. T. Rednarski

CDR, US Army Signals Warfare Lab
Attn: DELSW-OS
Arlington Hall Station
Arlington, VA 22212

CDR, US Army Signals Warfare Lab
Attn: DELSW-AW
Arlington Hall Station
Arlington, VA 22212

Commander
US Army Logistics Center
Attn: ATCL-MC
Fort Lee, VA 22801

Commander
US Army Training & Doctrine Command
Attn: ATCD-TEC
Fort Monroe, VA 23651

Commander
US Army Training & Doctrine Command
Attn: ATCD-EM
Fort Monroe, VA 23651

NASA Scientific & Tech Info Facility
Baltimore/Washington Intl Airport
P.O. Box 8757
Baltimore, MD 21240

Project Manager, ATACS
Attn: DRCPM-ATC
Fort Monmouth, NJ 07703

CDR, US Army Research Office
Attn: DRXRO-IP
P.O. Box 12211
Research Triangle Park, NC 27709

Director
N.S. Army Material Systems Analysis Actr.
Attn: DRXSY-MP
Aberdeen Proving Ground, MD 21005

Advisory Group in Electron Devices
201 Varick Street, 9th Floor
New York, NY 10014

TACTEC
Battelle Memorial Institute
505 King Avenue
Columbus, OH 43201

Ketron, Inc.
Attn: Mr. Frederick Leuppert
1400 Wilson Bldg.
Arlington, VA 22209

R.C. Hansen, Inc.
P.O. Box 215
Tarzana, CA 91356

Times Fiber Comm, Inc.
358 Hall Avenue
Attn: Mr. A. Kushner
Wallingford, Conn. 06492

Bell Northern Research
P.O. Box 3511, Station C
Attn: Dr. J. Dalgleish
Ottawa, Canada K1Y 4H7

Commander
ERADCOM
Fort Monmouth, NJ 07703
Attn: DELET-D

Commander
ERADCOM
Fort Monmouth, NJ 07703
Attn: DFISD-L-S

Commander
CORADCOM
Fort Monmouth, NJ 07703
Attn: DRDCO-COM-D

Commander
CORADCOM
Fort Monmouth, NJ 07703
Attn: DRDCO-SEI

Commander
CORADCOM
Fort Monmouth, NJ 07703
Attn: DRDCO-COM-FM-1
(15 Copies)

Corning Glass Works
Telecommunications Prod Dept
Attn: W. Babcock
Corning, NY 14830

Siecor Optical Cables
631 Miracle Mile
Horseheads, NY 14845

Bunker-Ramo
Amphenol Div
33 East Franklin Street
Danbury, Connecticut 06810
Attn: Mr. J. Makuch