High-Density Ribbon Fiber Optic Cable & Tooling for Shipboard Installations

NSRP Panel Project No. 2018-453-030

Final Report

Revision -

Submitted by Ingalls Shipbuilding, a division of HII on behalf of the Integrated Project Team members

May 31, 2024

Abstract

Shipboard network infrastructure is rapidly evolving and will impact the fiber optic cables on future ship programs. The changes are driven by the need to transfer larger amounts of data for newer shipboard systems. Navy ship programs are planning to use high-density fiber optic cable configurations to meet increasing demands of shipboard networks. These new cable designs allow for expanded use of fiber optics while reducing congestion in the cableway. New cable configurations such as ribbon fiber optic cables that provide higher density than current technology will require new tooling, processes, and training in order to be successfully deployed on U.S. Navy ships.

The Naval Sea Systems Command (NAVSEA) has developed and published new specifications for MIL-PRF-85045 that incorporate high-density ribbon fiber. The new configurations enable a 12x increase in optical paths within the same cable outer diameter as standard MIL-PRF-85045 cable designs.

Through this project, ribbon fiber technology was identified and evaluated. Both commercial off the shelf (COTS) products and products designed to the M85045 standard were included in the study. The new cable configurations were evaluated for impact to tooling and processes currently used in shipyard fiber optic deployment. New interconnection methods and potential connector options were identified and reviewed. Shipyard trials were conducted in the laboratory and shipboard environments. New fusion splicers and associated tools as well as new mass fusion splicing processes were included. Cable assemblies were fabricated and laboratory testing conducted. Feedback was provided to support updates to installation processes and optimal designs for the ship construction environment.

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List of Abbreviations

APC	Angled Physical Contact
BOF	Blown Optical Fiber
CID	Commercial Item Description
CUT	Cable Under Test
DLA	Defense Logistics Agency
HD	High Definition
IL	Insertion Loss
LSA	Least Squares Analysis
MAL	Maximum Allowable Loss
MPO	Multi-fiber Push On
MTP	Multi-fiber Termination Push-on
NAVSEA	Naval Sea Systems Command
OBR	Optical Backscatter Reflectometer
OFCC	Optical Fiber Cable Component
OLTS	Optical Loss Test Set
ORL	Optical Return Loss
OTDR	Optical Time Domain Reflectometer
PDL	Polarization Dependent Loss
RL	Return Loss
UPC	Ultra-Physical Contact
USN	United States Navy

1.0 Introduction

This is the Final Report for the National Shipbuilding Research Program (NSRP) Electrical Technologies Panel Project, " High-Density Ribbon Fiber Optic Cable & Tooling for Shipboard Installations”.

1.1 Objective

The objective of this project was to evaluate impacts of implementing new, high-density fiber optic cable configurations into U.S. Navy shipbuilding programs. The overall goal of the project was to identify process and tooling impacts required when implementing this new cable type into current shipbuilding and ship repair processes.

1.2 Scope

The scope of this project included technology research and hardware evaluations of high-density fiber optic cable configurations. Laboratory and shipboard evaluations were conducted on prototype MIL-PRF-85045 ribbon fiber products. The project identified and evaluated impacts to current shipbuilding and ship repair processes and tooling.

1.3 Background

Shipboard network infrastructure is rapidly evolving and will impact the fiber optic cables on future ship programs. The changes are driven by the need to transfer larger amounts of data for newer shipboard systems. U.S. Navy ship programs are planning to use high density fiber optic cable configurations to meet increasing demands of shipboard networks. These new cable designs allow for expanded use of fiber optics while reducing congestion in the cableway. New cable configurations such as ribbon fiber optic cables that provide higher density than current technology will require new tooling, processes, and training in order to be successfully deployed on U.S. Navy ships. This project worked to identify process impacts, identify tooling impacts, and provide industry feedback to facilitate a smooth transition to this new technology.

The goal of this project was to evaluate the impact of new, high-density fiber optic cable configurations for U.S. Navy shipboard applications. New connectors and interconnection methods were included. The primary objective was to identify process and tooling impacts of using this new technology. Shipboard trials were conducted to evaluate potential environmental impacts to fusion splice performance.

1.4 Integrated Project Team and Technical Tasks

The integrated project team (IPT) was led by Ingalls Shipbuilding. The IPT included Penn State Applied Research Lab (PSU ARL), KITCO Fiber Optics (KITCO), Naval Surface Warfare Center – Dahlgren Division (NSWC-DD), and Newport News Shipbuilding (NNS). Table 1 provides a summary of the roles for each organization.

Table 1. Team Members and Roles

Organization	Role
Huntington Ingalls Incorporated – Ingalls Shipbuilding Division	Project lead, development of project plan, project management, technical leadership of all activity, technology transfer and implementation
Penn State Applied Research Lab	Engineering and technical support in identification and evaluation of fiber optic technologies.
KITCO Fiber Optics	Engineering and technical support in identification and evaluation of fiber optic technologies. Provide cable samples and equipment for the evaluation process.
NSWC Dahlgren Division	Engineering support in the identification and evaluation of ribbon fiber options, connection methods, and Navy qualification process.
Huntington Ingalls Incorporated – Newport News Shipbuilding Division	Engineering support in the identification and evaluation of shipboard applications and technology transfer opportunities.

It should be noted that additional organizations, including Amphenol, Sumitomo Electric Lightwave, Prysmian Group, General Cable, and Marmon Aerospace and Defense provided support over the course of this project. Support included input on hardware options, tooling, as well as material samples for the Field Trial activity.

2.0 Discussion

2.1 Current M85045 Cable Designs

Fiber optic cables are widely used on U.S. Navy ship programs. Requirements for fiber optic cable design are detailed in MIL-PRF-85045. Common cable configurations used today include 4-fiber cable, 8-fiber cable, 18-fiber cable, and 36-fiber cable per MIL-PRF-85045/18, /17, /22, and /20 respectively. The cable construction consists of an optical fiber cable component (OFCC), strength members, water blocking material, and polyethylene outer jacket. Each OFCC includes a single 125 um silica optical fiber. Both single mode (9um core) and multimode (62.5um core) options are widely used today. Figure 1 provides an example of the four-fiber cable construction.

Figure 1. M85045 Cable Example (Single OFCC, 4-Fiber Cable)

2.2 Ribbon Fiber Cable

Ribbon fiber is commonly used in the commercial market; however, this cable type has not been implemented yet on a U.S. Navy ship. Commercial ribbon fiber is available in multiple cable configurations including flat ribbon and “rollable ribbon”. The ribbon fiber consists of multiple optical paths attached to one another in a subunit cable. A common configuration is a twelve-fiber subunit – this will be the primary focus for this project as the Navy designs utilize twelve fiber subunits. An example of a flat ribbon fiber cable is the TLC Ribbon Cable illustrated in Figure 2.   This cable is available in standard 4, 6, 8, and 12 fiber options. Other commercially available ribbon fiber designs are illustrated in Figure 3. Rollable ribbon products offer multi-axis flexibility of the cable that is beneficial to installation processes. In either of these cable designs, the optical fibers must be organized in a linear configuration and in the proper color order for the fusion spicing process. Special tooling is available to facilitate this process. This will be discussed later in this report.

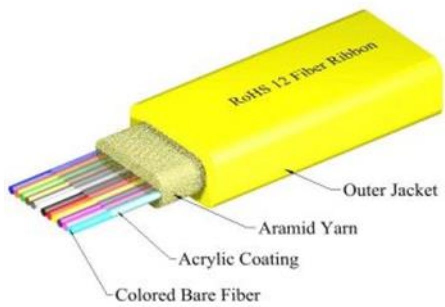


Figure 2. TLC 12 Fiber Ribbon Cable Example – COTS (FIS)

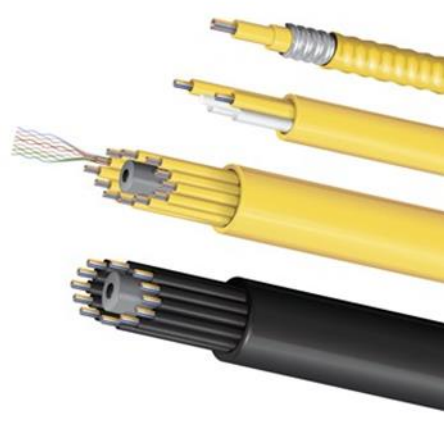


Figure 3. COTS Ribbon Fiber Cable Examples (Belden)

2.3 M85045 Rolled Flexible Cable Design

NAVSEA has developed specifications for ribbon fiber cable designs targeted for U.S. Shipboard applications. The design of the MIL-PRF-85045 ribbon fiber cable includes a flexible subunit that allows for the optical fibers to be tightly packed and facilitate multi-axis flexing of the cable. The "rolled-flex" subunit design provides flexibility necessary for installation in shipboard applications. Each subunit contains twelve individual optical fibers (Figure 4). The fibers are attached to one another to form a cylindrical matrix. The intended design allows for the cable to be easily positioned into a linear ribbon after removal of the subunit jacket. The fiber order (color sequence) placement in the ribbon would be maintained; thereby, allowing for ease of placement in the fiber holder and splicing processes.

Specifications for four cable configurations are provided below. The specifications have been published by NAVSEA and the Defense Logistics Agency (DLA). The most updated versions are available on the ASSIST website[1].

- MIL-PRF-85045/33: Performance Specification; Cable, Fiber Optic Rolled Flexible Ribbon, Twelve Fiber, Single Subunit, Cable Configuration Type 4 (Ribbon Cable), Applications A and B (Airborne and Shipboard), Cable Class SM and MM
- MIL-PRF-85045/34: Performance Specification; Cable, Fiber Optic, Four Subunits, Twelve Fibers Rolled Flexible Ribbon Subunit, Enhanced Performance, Cable Configuration Type 4 (Ribbon Cable), Cable Class SM and MM
- MIL-PRF-85045/35: Performance Specification; Cable, Fiber Optic, Eight Subunits, Twelve Fibers Rolled Flexible Ribbon Subunit, Enhanced Performance, Cable Configuration Type 4 (Ribbon Cable), Cable Class SM and MM
- MIL-PRF-85045/36: Performance Specification; Cable, Fiber Optic, Thirty-Six Subunits, Twelve Fibers Rolled Flexible Ribbon Subunit, Enhanced Performance, Cable Configuration Type 4 (Ribbon Cable), Cable Class SM and MM

[1] https://quicksearch.dla.mil/qsSearch.aspx

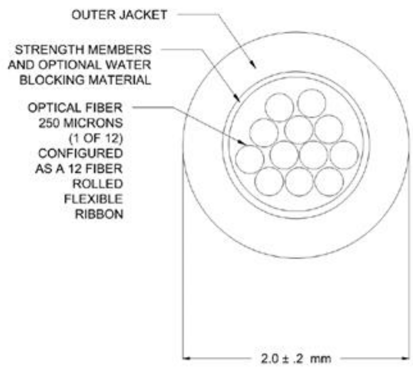


Figure 4. MIL-PRF-85045, 12-Fiber Subunit

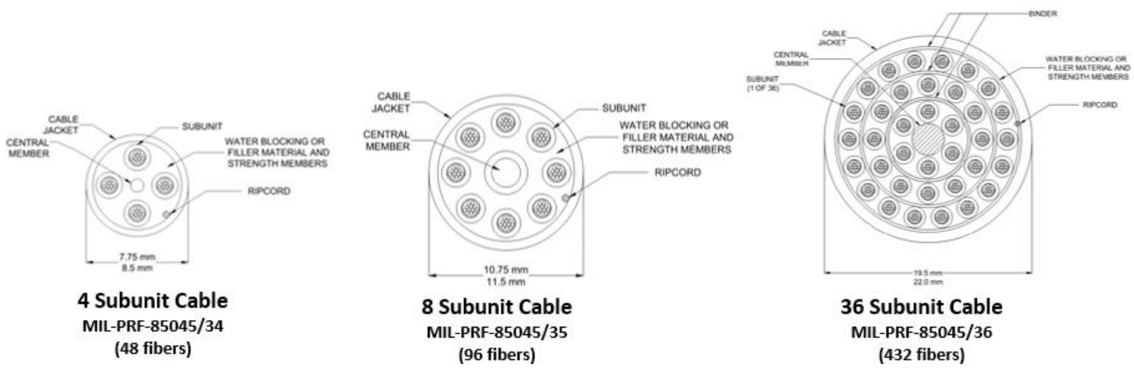


Figure 5. Cable Configurations, M85045 Ribbon Fiber

2.4 Requirements - Installation Processes

Installation and testing requirements are covered in MIL-STD-2042, "Fiber Optic Cable Topology Installation Standard Methods for Surface Ships and Submarines". The implementation of new cable designs will impact multiple areas of the fiber optic cable plant commissioning process, including equipment, connectors, and interconnects. Current installation processes are being updated to facilitate the implementation of ribbon fiber into U.S. Navy ship programs.

MIL-STD-2042, Part 2 addresses fiber optic equipment installation. A draft Method 2K4 has been developed to addresses subunit cable installation. The method includes requirements for routing, shaping, and forming into M24728/8-51 7-inch splice trays. MIL-STD-2042, Part 5 addresses fiber optic interconnections including fusion splicing. A draft Method 5C3 (Appendix A) has been developed to provide processes for fusion splicing of multiple fiber (ribbon) cables. The project team reviewed the draft methods in preparation for the Field Trial.

Updated requirements covering NAVSEA approved installation tools and connector hardware are also required for implementation of ribbon fiber. Significant efforts led by NSWC-DD on behalf of NAVSEA have been accomplished to revise and publish necessary standards. Table 2 provides a summary of requirements identified that will be impacted with the implementation of ribbon fiber technology on U.S. Navy ship programs. Section 2.5 provides additional information on requirements impacting equipment and tooling necessary for shipboard applications.

Table 2. Requirements Summary

REQUIREMENT	DESCRIPTION	NOTES
MIL-STD-2042	Fiber Optic Cable Topology Installation Methods	Part 1 – Cables Part 2 – Equipment Part 3 – Cable Penetrations Part 4 – Cableways Part 5 – Connectors & Interconnections Part 6 – Tests Part 7 – Pierside Connectivity Cable Assemblies and Interconnection Hardware
MIL-PRF-85045	Cable, Fiber Optic	Slant sheets added for ribbon fiber configurations
MIL-PRF-24623/8	Ribbon Splice Protector	Increased size and added structure for ribbon fiber
MIL-DTL-24728/8B	Spice Tray and Tray Holder Module	Increases spacing necessary for ribbon splice
CID A-A-5799	Ribbon Splicer	Rev B updated to include ribbon splicing
Ship Spec 408	Ship Specification for Fiber Optic Cable Plant	
MIL-STD-2052	Fiber Optic System Design	

2.5 Requirements - Equipment

2.5.1 Fusion Splicer

The standard fusion splicing equipment in-use at shipyards today is a single-fiber, core alignment fusion splicer. Requirements for ribbon splicing tools are included in CID A-A-5799. Revision B has recently been updated to include requirements for ribbon splicing. There are currently two fusion splicer models that meet the CID requirements. The splicer models are included on the NSWC-DD list of recommended tools[2]; Sumitomo Q101-KIT-G

[2] https://www.navsea.navy.mil/Portals/103/Documents/NSWC_Dahlgren/FiberOptics/docrep_partlist/Tools

and AFL 90S. Both of these units are capable of fusion splicing standard MIL-PRF-85045 fiber optic cable that includes a single optical fiber. The implementation of ribbon fiber will require new splicing tools designed for ribbon fiber splicing. As illustrated in Figure 6 the ribbon splicer is capable of splicing multiple fibers in a single operation. No specific ribbon splicer models are currently listed on the Navy Shipboard Fiber Optics Recommended Tools List (Appendix B); however, two mass fusion splicer models were included in this project. The Sumitomo Q102-M12^{+} (Figure 7) and AFL Fujikura 90R (Figure 8) were used for splicing processes by the project team and included in the Field Trial.

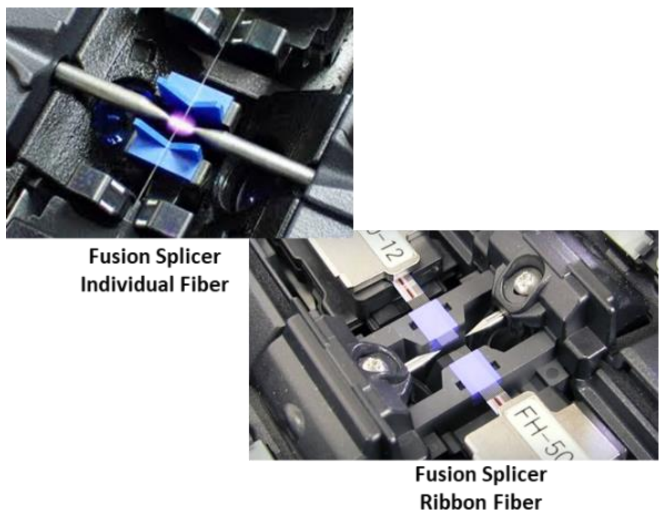


Figure 6. Fusion Splicer Comparison (Individual and Mass Fusion Splicer)

Figure 7. Mass Fusion Splicer - Sumitomo Q102-M12+

Figure 8. Mass Fusion Splicer – Fujikura 90R Fusion Splicer

Each fusion splicer option requires additional tooling for the ribbon splicing process. The tools are included in a “kit”. At a minimum, ribbon fiber holders, thermal jacket remover, cleaver, and fiber arrangement tools are needed. The following sections provide information on these tools.

2.5.1.1 Ribbon Fiber Holders

Fiber holders are used throughout the preparation and splicing process. The tool allows the fiber leads to be mechanically held in the proper order (color sequence) and positioned into the other tools involved in the fusion splicing process (jacket remover, cleaver, and fusion splicer). While the holders may work with different splicer models, it is recommended to use the fiber holder specific to the fusion splicer model being utilized. Figure 9 provides an example of fiber holders for mass (ribbon) splicing.

Figure 9. Ribbon Fiber Holders

2.5.1.2 Thermal Jacket Remover

Typical fiber optic cable preparation utilizes a standard mechanical cable stripping tool. A thermal jacket remover is needed when preparing ribbon fiber. The thermal jacket remover allows for removal of the fiber’s protective jacket and buffer coating. The tool allows for preparation of all twelve fibers in a single operation. Figure 10 illustrates two options that were used in this project.

Figure 10. Thermal Jacket Remover, Sumitomo JR-7 and Fujikura RS01

2.5.1.3 Cleaver

Fiber cleaving tools made for mass (ribbon) splicing are used to perform the cleaving process. This tool cleaves all twelve fibers in a single operation. As mentioned above this tool is part of the fusion splicing kit. The tool has fittings dimensioned specific to the fiber holder. Once in position, the fiber length is established allowing for consistent cleave lengths needed for proper positioning in the fusion splicer. Figure 11 illustrates an example of a cleaver used in the Field Trial.

Figure 11. Ribbon Fiber Cleaver, Sumitomo Electric

2.5.1.4 Fiber Arrangement Tools

Fiber arrangement tools and "ribbonizing" tools are needed if the attachment points of the ribbon fiber matrix are removed in the jacket removal process. In this event, the individual fibers have become separated. The individual fibers must be put back in order (color sequence) and organized in linear configuration for the (ribbon) splicing process. Options for these tools vary from those that support organization of the fibers into the fiber holder and options for applying an epoxy layer to “ribbonize” the cable. It should be noted that fiber arrangement tools were evaluated in the Field Trial activity. Additional information is included later in this report.

AFL Fiber Arrangement Tool

AFL Ribbonizing Tool

Sumitomo Fiber Arrangement Tools

Figure 12. Fiber Arrangement Tool Examples

2.5.2 Splice Protector

Splice protectors designed for mass (ribbon) splices differ from the standard splice protectors used in shipyards today. The ribbon splice protectors are larger in size to accommodate the twelve-fiber ribbon. These splice protectors include two metal strength members to provide mechanical protection of the splice region. The requirements for NAVSEA approved splice protectors are given in MIL-PRF-24623/8.

2.5.3 Splice Tray

The splice tray design has been updated to allow for the increased spacing necessary for ribbon splices. MIL-DTL-24728/8B gives the updated design requirements. The new splice tray design will accommodate single splice and mass (ribbon) splice storage. The cover has been redesigned at the cable entry points and the cover can be modified for additional spacing necessary with ribbon splices.

2.6 Shipyard Field Trials

Field trials were conducted at Ingalls Shipbuilding on January 23-24, 2024. The goal of the event was to evaluate ribbon fiber technology in the ship production environment and gain feedback from the installation teams on the technology, tools, and processes. The event was supported by the following organizations:

- General Cable Company
- Ingalls Shipbuilding
- KITCO Fiber Optics
- Marmon Aerospace and Defense
- Naval Surface Warfare Center, Dahlgren Division
- Penn State University Applied Research Laboratory
- Sumitomo Electric Lightwave

The two-day event began with a general overview of ribbon fiber technology. Commercial off the Shelf (COTS) ribbon fiber was reviewed and common tools used for mass fusion splicing were presented. Following the introduction to ribbon fiber, the shipyard teams conducted hands-on laboratory exercises to become familiar with ribbon fiber and tooling required for fusion splicing this cable type. The first activity utilized COTS ribbon fiber designs. One jacketed cable design and two subunit COTS designs were included.

The next activity focused on M85045 ribbon fiber designs. Prototypes of two M85045 subunit options were included in the trail.

Table 3 provides a list of material and Table 4 provides a list of equipment for the field trial.

Table 3. List of Materials for Field Trial

PRODUCT	DESCRIPTION	MANUFACTURER	Part Number
Ribbon Fiber Cable	12 Fiber SMF28 Ultra Riser yellow (COTS)	TLC	S09RB12CZNRY
Ribbon Fiber Subunit, 12 Fiber	Ribbon EZ Branch 12 SM – PureAccess (COTS)	Sumitomo Electric Lighwave	
Ribbon Fiber Subunit, 12 Fiber	Ribbon, FreeForm 12F PAF 250u (COTS)	Sumitomo Electric Lighwave	
Ribbon Fiber Subunit, 12 Fiber	M85045 Rollable Ribbon Fiber, 12-Fiber Subunit	Marmon A&D	
Ribbon Fiber Subunit, 12 Fiber	M85045 Rollable Ribbon Fiber, 12-Fiber Subunit	General Cable	
Splice Protector	Mass Fusion Splice Sleeve, 40 mm, glass ceramic strength member	Sumitomo Electric Lighwave	FPS-6-5P
Splice Protector	Mass Fusion Splice Sleeve, 40mm, stainless steel strength members	Splice Technologies	MFSS-SS40D

Table 4. List of Equipment for Field Trial

EQUIPMENT DESCRIPTION	MANUFACTURER	Part Number
Mass Fusion Splicer	Sumitomo Electric Lightwave	Q102-M12+
Fiber Holder	Sumitomo Electric Lightwave	FHM-12V
Fiber Cleaver	Sumitomo Electric Lightwave	FC-6R+
Thermal Jacket Remover	Sumitomo Electric Lightwave	JR-7
Fiber Arrangement Tool	Sumitomo Electric Lightwave	AFA-02
Mass Fusion Splicer	Fujikura	90R
Fiber Holder	Fujikura	FH-70-12
Fiber Cleaver	Fujikura	CT50
Thermal Jacket Remover	Fujikura	RS01
Ribbonizing Tool	Fujikura	RT-02
MPO Optical Loss Test Set	Exfo	PXM/LXM

New cable designs that are being developed for MIL-PRF-85045 configurations were reviewed by the group. Prototype M85045 twelve-fiber subunits were provided by two manufacturers for the evaluation. Each manufacturer fabricated six test cables for the evaluation. The test cables were each 20 meters in length. Multi-fiber Push On (MPO) connectors (Figure 13) were installed on each end of the test cables to facilitate optical performance testing.

Figure 13. MPO Connector

Labels were installed on each end of the test cables and the cables were cut in half in preparation for the fusion splicing activities. Cable segments were assigned splice tray positions (see Table 5) and the corresponding assemblies were prepped for the splicing process to be conducted shipboard.

Table 5. Splice Tray Detail

SPLICE TRAY	TRAY POSITION	CABLE GROUP	CABLE ASSEMBLY	CABLE LENGTH	CONNECTOR
1	1	A	A-1	20m	MPO APC Male
	2	A	A-2	20m	MPO APC Male
	3	A	A-3	20m	MPO APC Male
	4	A	A-4	20m	MPO APC Male
	5	B	B-1	20m	MPO UPC Male
	6	B	B-2	20m	MPO UPC Male
2	1	A	A-5	20m	MPO APC Male
	2	A	A-6	20m	MPO APC Male
	3	B	B-3	20m	MPO UPC Male
	4	B	B-4	20m	MPO UPC Male
	5	B	B-5	20m	MPO UPC Male
	6	B	B-6	20m	MPO UPC Male

The populated splice trays were packaged and moved to a ship under construction for the splicing process. This allowed for the team to evaluate environmental impacts to the splicing process in a realistic ship production environment.

2.6.1 Shipboard Fusion Splicing Activity

Two splicing stations were set-up onboard the ship. The splicing stations were located in the same compartment. Each splicing station included a Sumitomo Q102-M12^{+} mass fusion splice kit. The kit includes the following tools:

- Table-top cleaver (FC-6+)
- Hot jacket remover (JR-7)
- Fiber Holders
- Fiber Arrangement tool (OFA-02)
- Carrying case with worktable (CC-72)

Fusion splicing was conducted in accordance with the standard process provided with the Q102-M12^{+} fusion splicer. The first step included removal of the subunit jacket material to expose the individual fibers. The individual fiber jacket color code per TIA-598 is illustrated in Figure 14. The subunit was installed in the provided fiber holder, noting correct orientation of the fiber lead color to the holder's hinge position (Figure 15). Fiber lead #1 (Blue) should be closest to the hinge. The fiber and holder are then loaded into the JR-7 thermal jacket remover (Figure 16) to remove the buffer coating and expose the optical fiber. A lint free wipe dampened with alcohol/cleaning fluid is used to clean the fibers. The fibers are then loaded into the FC-6^{+} cleaver and cleaved to the proper length. The fiber holder with the cleaved fibers installed are then transferred to the fusion splicer (Figure 17). The steps are repeated for the second side. Once both sides are properly installed into the fusion splicer, the operator adjusts as needed to ensure proper placement of the fiber in the machine's v-groove. The fusion splicer evaluates position of each fiber and makes minor adjustments as needed, then executes the splicing process. After the splicing process is completed, the operator carefully removes the fiber from the machine and moves the splice protector to the center of the splice region. The splice protector is cured in the splicer oven in accordance with the machine's prompts. After the splice region has cooled, the assembly is then removed from the splicer and installed in the splice tray in accordance with MIL-STD-2042, Method 2K4, Section 4.2.

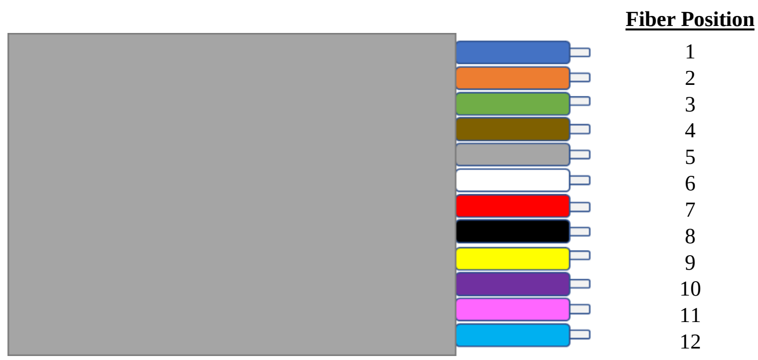


Figure 14. Twelve Fiber Ribbon Cable Color Sequence

Figure 15. Installation of Ribbon Fiber in Holder

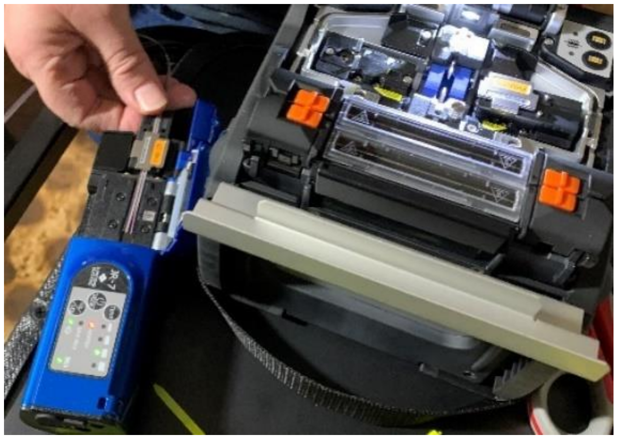


Figure 16. Loading Fiber into Thermal Jacket Remover

Figure 17. Fiber Loaded into Fusion Splicer

It was noted that the construction of ribbon differed between the two subunit designs. One product included additional epoxy points that allowed the ribbon "matrix" to remain intact during the preparation process. This allowed the fibers to lay flat in the proper color sequence with minimal intervention by the operator.

The other design did not include as many epoxy points, resembling more of a loose tube design. This resulted in the operator needing to use a ribbon organizer tool to re-arrange the fibers in the proper color sequence. This presented a significant challenge in the shipboard environment. With the tooling available at the time of the shipboard trial, the operators were only able to splice one of the Group B cables. It should be noted that alternate tools to aid the fiber organization process were discussed and may have resulted in higher yield of Group B cables. This could be evaluated further; however, based on feedback a ribbonized subunit cable design is needed to support splicing processes in this environment.

2.6.2 Field Testing at the Shipyard

Testing for optical performance was conducted at the shipyard following the field activity. Testing was conducted in the laboratory using an EXFO MPO Optical Loss Test Set (OLTS). Due to connector interface incompatibility on some of the test cables with the available test equipment, this initial testing process was only conducted on the test cables from Group A. The provided MPO test equipment included the MPO APC male connector interface. Test equipment with an MPO UPC male connector interface was not available at the shipyard. It should be noted that additional testing was conducted following the field activity as described later in this report.

Table 6 provides a summary of the test results from the six Group A subunits. The table provides worst case insertion loss by subunit. The loss values include connector loss, splice loss, and cable loss. The maximum allowable loss (MAL) is calculated as follows:

(Loss Budget = 0.75dB (connector 1) + 0.75dB (connector 2) + 0.2dB (splice) = 1.7dB

As noted in the table, five of the six cables passed post-splice link loss for all 12 channels. One of the cables (subunit A-1) exceeded the MAL due to one of the twelve fibers in this subunit being damaged. A complete summary of test results from this series of testing is included as Appendix C. It should further be noted that loss values presented are end-to-end insertion loss and do not isolate the splice region. Additional testing was conducted to isolate the splice region and will be discussed later in this report.

Table 6. Insertion Loss Testing Summary

P/F	Identifiers	Wavelength (nm)	Worst Loss (dB)	Polarity	Length (km)	Date Time	Notes
✗	A-1	1310	>40.50	Type A (Straight)	0.0204	1/23/2024 6:54:40 PM (GMT-08:00)	Fiber 7 broken
		1550	>40.67				
✓	A-2	1310	1.34	Type A (Straight)	0.0204	1/23/2024 6:54:06 PM (GMT-08:00)	
		1550	1.27				
✓	A-3	1310	1.52		0.0202	1/23/2024 7:06:55 PM (GMT-08:00)	
		1550	0.96				
✓	A-4	1310	0.55		0.0204	1/23/2024 7:21:49 PM (GMT-08:00)	
		1550	0.70				
✓	A-5	1310	1.16	Type A (Straight)	0.0204	1/23/2024 7:53:41 PM (GMT-08:00)	
		1550	1.41				
✓	A-6	1310	1.07	Type A (Straight)	0.0207	1/23/2024 7:55:25 PM (GMT-08:00)	
		1550	0.70				

2.6.3 Process Evaluation

In support of the Field Trial activities, Ingalls Industrial Engineers evaluated the splicing process. Observations were made on the new tooling, process impacts, and yield comparisons. While the process and tooling are similar to the standard (single fiber) fusion splicing currently used, there are impacts of the ribbon fiber tools and products. The use of ribbon cable compared to a single fiber optic cable allows for more efficient use in limited space. Tolerance is tighter when performing splices on the ribbon product, as the operator is working to ensure alignment of all twelve individual fibers within the ribbon; however, when the alignment is achieved, the process yield is much higher as twelve fibers are spliced with a single splice operation. The preparation process takes up to 43% of the overall process time. This would be expected to decrease (improve) with increased technician experience with the ribbon products and tooling.

The overall splicing process was observed and each step was grouped into several categories for analysis. Table 7 provides the process descriptions and category assignments for the study. An analysis of process times was conducted. A comparison of process time for each category grouping is given in Figure 18. It was noted that preparation accounts for approximately half of the overall process time.

Table 7. IE Process Descriptions

STEPS	PROCESS DESCRIPTION	Sub category
1	Make sure your fusion splicer is powered on, be sure to perform the pre-fusion splicer steps.	Initial prep
2	Clean splicer	
3	Set splicer and heat program	
4	Perform an arc test	
5	Place the ribbon into the holder (Wire 1)	Ribbon prep
6	Stripping the ribbon (Wire 1)	
7	Cleaning the stripped fibers and then cleaving the fibers (Wire 1)	
8	Open the hood. Insert the fiber holders with cleaved fibers, into the respective positions in the splicer	Splicer process
5	Place the ribbon into the holder (Wire 2)	Ribbon prep
6	Stripping the ribbon (Wire 2)	
7	Cleaning the stripped fibers and then cleaving the fibers (Wire 2)	
8	Open the hood. Insert the fiber holders with cleaved fibers, into the respective positions in the splicer	Splicer process
9	Close the hood	
10	To perform the splice. Engage the set icon, on the touchscreen monitor. Fibers will fuse	
11	Engage the set icon splicer. Will inspect the fused fibers	
12	Move the protection sleeve close to the fiber side holder.	Heating prep
13	Gently remove the fiber from the fiber holder	
14	User gravity and vibration to center the sleeve over the splice	
15	Place in the heater oven, press the heater button to start the heating process	Heating process
16	Let the sleeve cool down for a little bit, before continuing	Cooling process

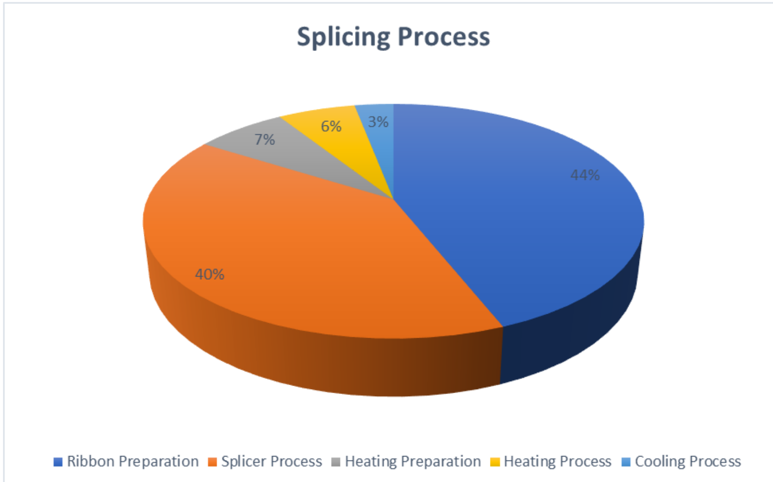


Figure 18. Subcategory Analysis

It was noted that rework takes place mostly in the ribbon preparation and splicer preparation process stages. Ribbon preparation includes alignment of the 12 fibers as well as cleaning or cleaving. On multiple occasions, one or more of the fibers was damaged or misaligned in the process. This resulted in rework to either reposition the fibers such that they are properly aligned or (in the case of a broken fiber) the end needed to be cutback and new cable prep conducted on that end. The machine used in the trial did have a tool that allowed the operator to make minor adjustments to the fiber position by manually tapping the machine platform on either side of the splice point. This was useful in bringing all twelve fibers into alignment and correcting cases where a single fiber was not in the correct position. It was also noted that for the majority of cases, it is not known if rework is needed until the splicer process begins. It is after this point that the splicing machine determines if one or more of the fibers have been damaged or if contamination is present.

2.7 Analysis of Splice Performance

2.7.1 OBR Testing

Following the field trial event, the cable assemblies underwent additional testing to evaluate the performance of the fusion splice on each cable. For this series of testing, an optical backscatter reflectometer (OBR) and optical time-domain reflectometer (OTDR) were used. Testing was conducted at the Penn State University Applied Research Lab (PSR ARL) and KITCO Fiber Optics.

The first series of testing was conducted at PSU ARL using the Luna Optical Backscatter Reflectometer (Model OBR 4200). The testing was targeting insertion loss of the (ribbon) splice region. This effectively ignores connector and cable losses. Five meters of cable on each end of the assemblies (Figure 19) was used for integration on each side of the splice tray. Traces were measured in each direction and averaged. A representative OBR trace is presented in Figure 21. Integration windows were selected on either side of the splice; thereby ignoring all other loss events except the splice. The splice loss is half of the difference in the return loss signals. A comprehensive summary of the testing conducted at Penn State, is included as Appendix D.

The OBR results were reviewed by the Project Team and determined that further analysis was needed. It was later determined that polarization issues may be impacting the results. The equipment set-up used for these measurements was subject to Polarization Dependent Loss (PDL) – which reduced the measurement reproducibility to roughly +/- 0.2 dB. This is an order of magnitude away from what we need to ascertain fusion splice quality.

The cause of the PDL discrepancy was due to polarization dependence of the measurement instrument (OBR). Addition of a polarization scrambler could possibly improve measurement reproducibility by involving all polarization state and averaging. Further testing would be needed to determine if this arrangement could be used in practical (non-laboratory) conditions.

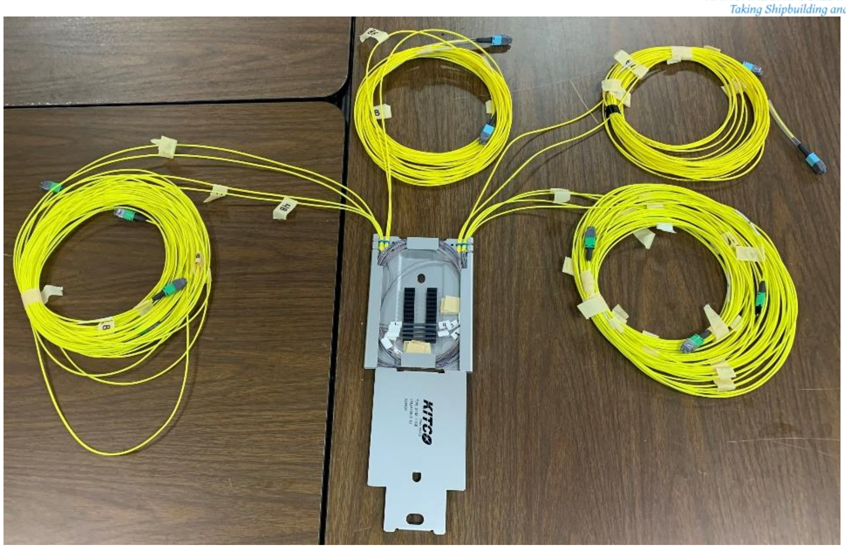


Figure 19. Splice Tray 1

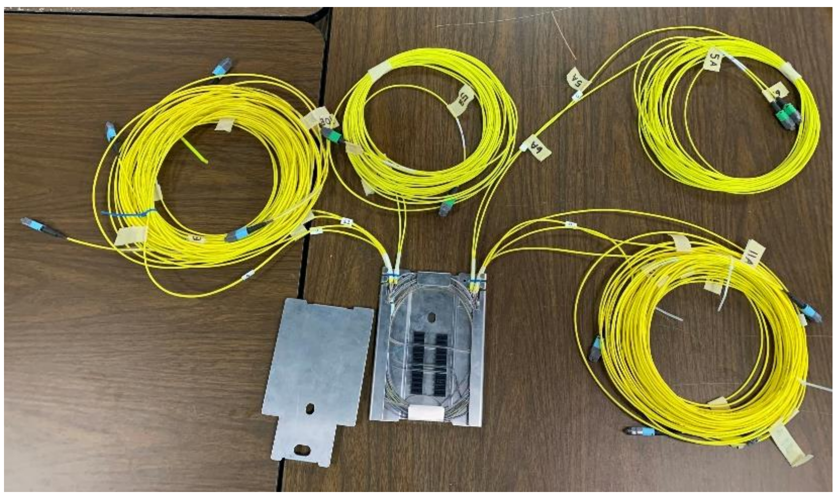


Figure 20. Splice Tray 2

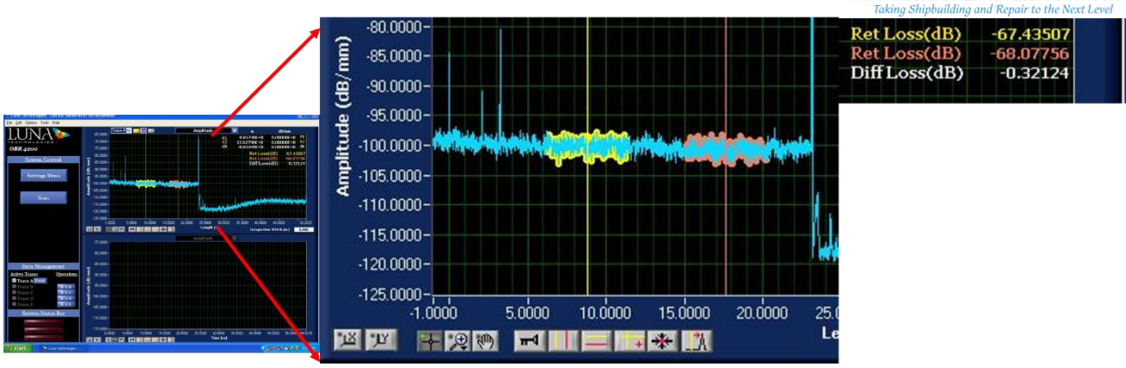


Figure 21. OBR Testing at Penn State

Additional analysis of the splice region was conducted at Penn State. High-definition images of the splice region indicates a broken fiber on cable A-1, Fiber 7. As illustrated in Figure 22, the red lead is broken. This correlates to the test results shown in Table 6. It is noted that the splice protector was not completely covering the exposed glass region. The design of the splice protectors with metal plates obscures the splice region, making alignment more difficult than standard splice protectors.

Figure 22. Cable A-1, Broken Fiber #7 (red fiber)

2.7.2 OTDR Testing

The final series of testing was conducted at KITCO Fiber Optics laboratories. This test event included both OTDR and OBR testing. The cable assemblies were first tested using an EXFO Max-720C OTDR. Each assembly was tested at 1310 nm and 1550 nm using 30ns pulse width. Testing was repeated at the same wavelengths using a 3ns pulse width. The test set-up included a ~50’ launch cable and a ~50’ receive cable. The cable under test (CUT) was approximately 65’ for each assembly; resulting in an overall test assembly length of 165’ – 170’. The splice is located approximately 82.5’ to 85’ from the OTDR on each cable assembly. OTDR markers A and B were set to isolate the splice region. Figure 23 provides an example from one of the cables tested. This example provides test data at 1310 nm for Cable #3 of Tray #1 using a 3ns pulse width. Figure 24 provides the results of the same fiber lead taken using a 30ns pulse width. Marker A is set to 80.1’ and Marker B is set to 100.0’. The splice loss is calculated from these markers. Values for each cable assembly were recorded for insertion loss (A-B LSA loss) and return loss (A-B ORL). It should be noted that the reports indicate a “Fail” in the top right corner. This indicator should be ignored as it is based on non-factored parameters. Appendix E and Appendix F includes a comprehensive listing of all test reports from this series of OTDR testing.

OTDR Report (1310 nm (9 µm))

Fail

General Information

File name:	splice tray 3A_1.trc		
Test date:	3/27/2024	Customer:	
Test time:	1:13:42 PM	Company:	KITCO
Cable ID:	splice tray 3A	Fiber ID:	1
Job ID:			
Comments:			

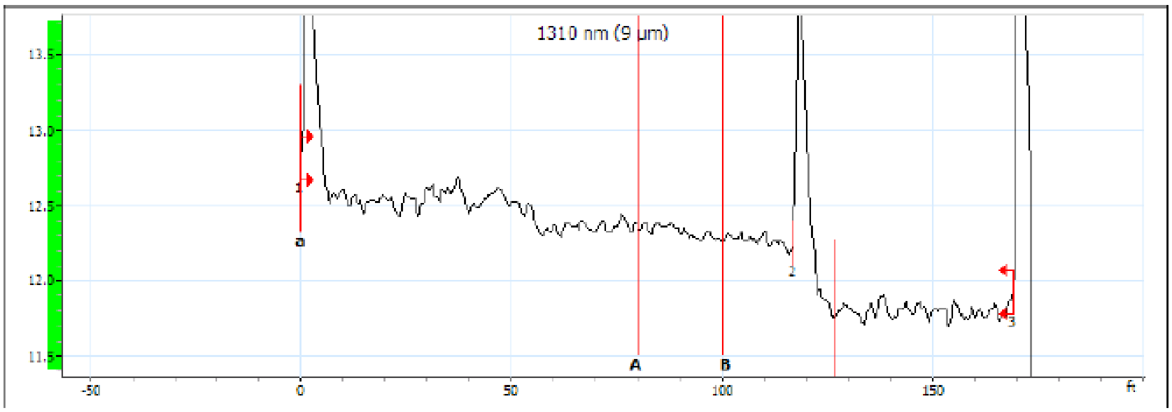
Locations

	Location A	Location B
Location		
Operator	powell	
Model	MAX-720C-Q1-EA-EI	
Serial number	1159555	
Calibration date	5/2/2023 (UTC)	

Results

Span length:	169.1 ft	Average loss:	0.007 dB/ft	Injection level:	12.6 dB
Span loss:	1.168 dB	Average splice loss:	---		
Span ORL:	52.61 dB	Maximum splice loss:	---		

Graph



Markers

Marker	Position (ft)	Value (dB)
a	0.0	12.820
A	80.1	12.360
B	100.0	12.262
b	126.7	11.793

A-B LSA attenuation:	16.642 dB/km	A-B average loss:	16.265 dB/km
A-B LSA loss:	0.101 dB	4-point Event Loss:	0.502 dB
A-B ORL:	61.77 dB	Maximum reflectance:	---

Figure 23. OTDR Test Report (3ns)

OTDR Report (1310 nm (9 µm)) Fail

General Information

File name:	Splice tray 1_A-B_12R 3A-3B-1.trc		
Test date:	3/18/2024	Customer:	HIIS
Test time:	1:02:39 PM	Company:	KITCO
Cable ID:	12R 3A-3B-1	Fiber ID:	1
Job ID:	23-0069-HIIS		
Comments:			

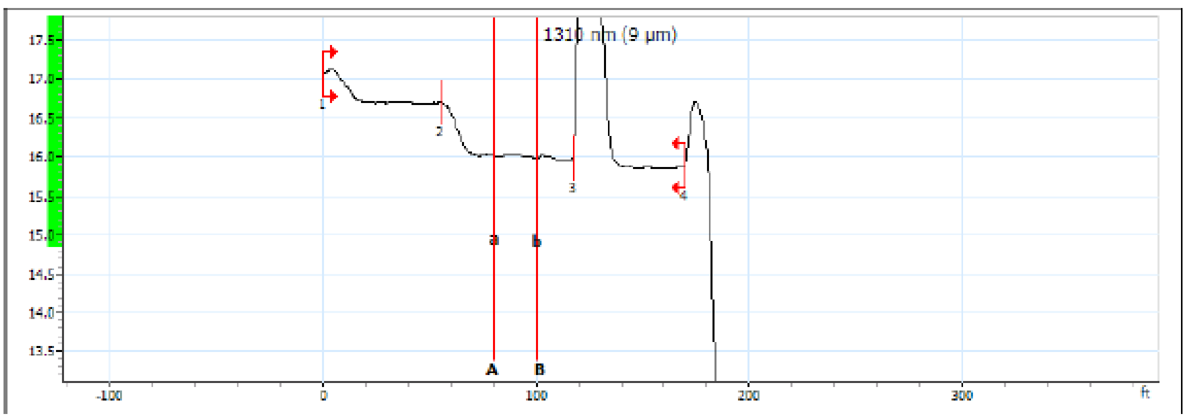
Locations

	Location A	Location B
Location	Splice tray 1	
Operator	C Powell	
Model	MAX-720C-Q1-EA-EI	
Serial number	1159546	
Calibration date	5/11/2023 (UTC)	

Results

Span length:	169.9 ft	Average loss:	0.006 dB/ft	Injection level:	16.7 dB
Span loss:	0.971 dB	Average splice loss:	0.408 dB		
Span ORL:	52.98 dB	Maximum splice loss:	0.663 dB		

Graph



Markers

Marker	Position (ft)	Value (dB)
a	80.1	16.013
A	80.1	16.013
B	100.0	15.982
b	100.0	15.982

A-B LSA attenuation:	4.046 dB/km	A-B average loss:	4.992 dB/km
A-B LSA loss:	0.025 dB	4-point Event Loss:	0.028 dB
A-B ORL:	61.71 dB	Maximum reflectance:	-84.2 dB

Figure 24. OTDR Test Report (30ns)

2.7.3 Test Summary Reports

Test summary reports were compiled for each subunit to allow for comparison of results. The report includes the insertion loss (IL) testing conducted at the shipyard as well as the OTDR and OBR testing conducted at KITCO. This series of OBR testing had better alignment with the IL test results than the OBR testing conducted at PSU. It is noted that the The test results with the B-3 (Figure 31) were not as anticipated. Further study is needed to confirm reliability of test data on this assembly.

FIBER DETAILS

A-1

Length: 0.0204 km

Insertion Loss Measurements (Entire Link) - MPX/LPX					OTDR Loss Measurements (Splice Isolated) - MAX-720C						OBR Luna 4600
Fibers	Loss (dB) 1310 nm	Loss (dB) 1550 nm	Reference (dBm) 1310 nm	Reference (dBm) 1550 nm	Estimated Splice Loss (1310nm) 30 ns pulse 30 second duration	Estimated Splice Loss (1310nm) 3ns pulse 60 sec duration	Estimated Splice Loss (1550 nm)	Estimated ORL (1310 nm)	Estimated ORL (1550 nm)	Splice Event Found by OTDR? Yes or No	Estimated Splice Loss, dB (1550 nm)
1	0.49	0.39	-9.38	-9.40	0.076	0.029	0.107	61.85	64.25	No	0.04
2	0.60	0.53	-9.19	-9.32	0.175	0.005	0.052	62	64.33	No	0.02
3	0.40	0.17	-10.11	-10.11	0.014	0.062	0.035	61.85	64.25	No	0.02
4	0.64	0.49	-9.53	-9.66	0.101	0.173	0.150	61.74	64.15	No	0.08
5	0.98	1.00	-9.59	-9.71	0.005	0.000	0.015	61.72	64.16	No	0.01
6	1.18	1.12	-9.84	-9.64	0.000	0.049	0.139	61.55	64.15	No	0.00
7	>40.50	>40.67	-9.49	-9.32	broken	broken	broken	broken	broken	Yes break visable	
8	0.75	0.58	-9.04	-9.62	0.076	0.000	0.097	61.66	64.12	No	0.01
9	0.64	0.74	-9.86	-9.43	0.057	0.028	0.050	61.7	64.12	No	0.00
10	0.45	0.24	-9.93	-9.65	0.063	0.035	0.011	61.67	64.11	No	0.02
11	0.71	0.59	-9.59	-10.17	0.065	0.124	0.014	61.71	64.1	No	0.01
12	0.82	0.35	-9.73	-9.80	0.056	0.074	0.077	61.76	64.24	No	0.03

THRESHOLDS

Expected polarity: Unspecified

Fibers layout: 1x12 12 fibers

Thresholds: Custom [Fixed]

Minimum link length (km)	Maximum link length (km)	Splice loss (dB)	Connector loss (dB)	First connector loss (dB)	Last connector loss (dB)

Wavelength (nm)	Minimum Loss (dB)	Maximum Loss (dB)	Maximum Attenuation (dB)
1310		1.70	
1550		1.70	

Link Definition		
Fiber type	Number of connections	Number of splices
OS1	2	1

REFERENCE DETAILS

Timestamp: 1/23/2024 6:48:05 PM (GMT-08:00)

Referencing method: One Cord

Test cord grade: Undetermined

Figure 25. Fiber A-1 Testing Summary

FIBER DETAILS

A-2

Length: 0.0204 km

Insertion Loss Measurements (Entire Link) - MPX/LPX					OTDR Loss Measurements (Splice Isolated) - MAX-720C						OBR Luna 4600
Fibers	Loss (dB) 1310 nm	Loss (dB) 1550 nm	Reference (dBm) 1310 nm	Reference (dBm) 1550 nm	Estimated Splice Loss (1310nm) 30 ns pulse 30 second duration	Estimated Splice Loss (1310nm) 3ns pulse 60 sec duration	Estimated Splice Loss (1550nm)	Estimated ORL (1310nm)	Estimated ORL (1550nm)	Splice Event Found by OTDR? Yes or No	Estimated Splice Loss, dB (1550 nm)
1	0.72	0.65	-9.38	-9.40	0.070	0.002	0.000	61.82	64.17	No	0.00
2	0.37	0.26	-9.19	-9.32	0.000	0.000	0.034	61.81	64.18	No	0.01
3	0.42	0.29	-10.11	-10.11	0.012	0.000	0.024	61.7	64.13	No	0.00
4	0.29	0.17	-9.53	-9.66	0.047	0.009	0.072	61.76	64.11	No	0.01
5	0.62	0.71	-9.59	-9.71	0.068	0.080	0.112	61.77	64.18	No	0.03
6	1.34	1.27	-9.84	-9.64	0.038	0.014	0.018	61.76	64.14	No	0.05
7	0.81	0.47	-9.49	-9.32	0.047	0.000	0.053	61.78	64.12	No	0.01
8	0.62	0.47	-9.04	-9.62	0.002	0.080	0.035	61.68	64.18	No	0.02
9	0.35	0.53	-9.86	-9.43	0.099	0.150	0.061	61.77	64.19	No	0.09
10	0.58	0.34	-9.93	-9.65	0.114	0.147	0.013	61.81	64.13	No	0.03
11	0.34	0.24	-9.59	-10.17	0.038	0.069	0.000	61.78	64.09	No	0.00
12	0.85	0.24	-9.73	-9.80	0.011	0.064	0.023	61.76	64.21	No	0.03

THRESHOLDS

Expected polarity: Unspecified

Fibers layout: 1x12 12 fibers

Thresholds: Custom [Fixed]

Minimum link length (km)	Maximum link length (km)	Splice loss (dB)	Connector loss (dB)	First connector loss (dB)	Last connector loss (dB)

Wavelength (nm)	Minimum Loss (dB)	Maximum Loss (dB)	Maximum Attenuation (dB)
1310		1.70	
1550		1.70	

Link Definition		
Fiber type	Number of connections	Number of splices
OS1	2	1

REFERENCE DETAILS

Timestamp: 1/23/2024 6:48:05 PM (GMT-08:00)

Referencing method: One Cord

Test cord grade: Undetermined

Figure 26. Fiber A-2 Testing Summary

FIBER DETAILS

A-3

Length: 0.0202 km

	Insertion Loss Measurements (Entire Link) - MPX/LPX				OTDR Loss Measurements (Splice Isolated) - MAX-720C					OBR Luna 4600
Fibers	Loss (dB) 1310 nm	Loss (dB) 1550 nm	Reference (dBm) 1310 nm	Reference (dBm) 1550 nm	Estimated Splice Loss (1310nm) 30 ns pulse 30 second duration	Estimated Splice Loss (1310nm) 3ns pulse 60 sec duration	Estimated ORL (1310nm)	Estimated ORL (1550nm)	Splice Event Found by OTDR? Yes or No	Estimated Splice Loss, dB (1550 nm)
1	-0.31	-0.38	-9.38	-9.40	0.025	0.101	61.71	64.19	No	0.01
2	-0.16	-0.18	-9.19	-9.32	0.184	0.230	61.8	64.22	Yes	0.17
3	1.33	0.96	-10.11	-10.11	0.878	1.090	62.15	64.46	Yes	0.44
4	0.05	-0.06	-9.53	-9.66	0.055	0.099	61.72	64.2	No	0.02
5	0.43	0.42	-9.59	-9.71	0.010	0.068	61.72	64.12	No	0.01
6	0.66	0.60	-9.84	-9.64	0.405	0.080	62.13	64.75	No	0.09
7	0.32	-0.06	-9.49	-9.32	0.014	0.000	61.77	64.19	No	0.01
8	-0.38	-0.10	-9.04	-9.62	0.077	0.116	61.77	64.13	No	0.03
9	0.06	-0.21	-9.86	-9.43	0.030	0.110	61.77	64.21	No	0.07
10	0.17	-0.38	-9.93	-9.65	0.060	0.002	61.74	64.14	No	0.05
11	-0.14	0.23	-9.59	-10.17	0.111	0.204	61.76	64.18	No	0.11
12	1.52	0.67	-9.73	-9.80	0.070	0.000	61.77	64.21	No	0.04

THRESHOLDS

Expected polarity: Unspecified

Fibers layout: 1x12 12 fibers

Thresholds: Custom [Fixed]

Minimum link length (km)	Maximum link length (km)	Splice loss (dB)	Connector loss (dB)	First connector loss (dB)	Last connector loss (dB)

Wavelength (nm)	Minimum Loss (dB)	Maximum Loss (dB)	Maximum Attenuation (dB)
1310		1.70	
1550		1.70	

Link Definition		
Fiber type	Number of connections	Number of splices
OS1	2	1

REFERENCE DETAILS

Timestamp: 1/23/2024 6:48:05 PM (GMT-08:00)

Referencing method: One Cord

Test cord grade: Undetermined

Figure 27. Fiber A-3 Testing Summary

FIBER DETAILS

A-4

Length: 0.0204 km

Insertion Loss Measurements (Entire Link) - MPX/LPX					OTDR Loss Measurements (Splice Isolated) - MAX-720C						OBR Luna 4600
Fibers	Loss (dB) 1310 nm	Loss (dB) 1550 nm	Reference (dBm) 1310 nm	Reference (dBm) 1550 nm	Estimated Splice Loss (1310nm) 30 ns pulse 30 second duration	Estimated Splice Loss (1310 nm) 3ns pulse 60 sec duration	Estimated Splice Loss (1550 nm)	Estimated ORL (1310 nm)	Estimated ORL (1550 nm)	Splice Event Found by OTDR? Yes or No	Estimated Splice Loss, dB (1550 nm)
1	-0.22	-0.28	-9.38	-9.40	0.061	0.087	0.047	61.72	64.16	No	0.01
2	-0.68	-0.65	-9.19	-9.32	0.055	0.068	0.011	61.74	64.16	No	0.03
3	0.52	0.18	-10.11	-10.11	0.133	0.147	0.166	61.78	64.21	No	0.07
4	-0.01	-0.12	-9.53	-9.66	0.029	0.000	0.000	61.7	64.1	No	0.02
5	0.54	0.70	-9.59	-9.71	0.045	0.040	0.106	61.71	64.1	No	0.10
6	0.35	0.20	-9.84	-9.64	0.107	0.030	0.037	61.77	64.13	No	0.03
7	0.23	-0.39	-9.49	-9.32	0.087	0.112	0.067	61.76	64.18	No	0.00
8	-0.05	-0.14	-9.04	-9.62	0.005	0.035	0.113	61.7	64.18	No	0.08
9	-0.17	0.05	-9.86	-9.43	0.083	0.078	0.089	61.77	64.15	No	0.04
10	0.38	-0.17	-9.93	-9.65	0.110	0.108	0.075	61.81	64.2	No	0.04
11	0.14	0.54	-9.59	-10.17	0.228	0.240	0.277	61.81	64.29	No	0.23
12	0.55	-0.14	-9.73	-9.80	0.144	0.062	0.135	61.74	64.19	No	0.05

THRESHOLDS

Expected polarity: Unspecified

Fibers layout: 1x12 12 fibers

Thresholds: Custom [Fixed]

Minimum link length (km)	Maximum link length (km)	Splice loss (dB)	Connector loss (dB)	First connector loss (dB)	Last connector loss (dB)

Wavelength (nm)	Minimum Loss (dB)	Maximum Loss (dB)	Maximum Attenuation (dB)
1310		1.70	
1550		1.70	

Link Definition		
Fiber type	Number of connections	Number of splices
OS1	2	1

REFERENCE DETAILS

Timestamp: 1/23/2024 6:48:05 PM (GMT-08:00)

Referencing method: One Cord

Test cord grade: Undetermined

Figure 28. Fiber A-4 Testing Summary

FIBER DETAILS

A-5

Length: 0.0204 km

Insertion Loss Measurements (Entire Link) - MPX/LPX					OTDR Loss Measurements (Splice Isolated) - MAX-720C						OBR Luna 4600
Fibers	Loss (dB) 1310 nm	Loss (dB) 1550 nm	Reference (dBm) 1310 nm	Reference (dBm) 1550 nm	Estimated Splice Loss (1310nm) 30 ns pulse 30 second duration	Estimated Splice Loss (1310 nm) 3ns pulse 60 sec duration	Estimated Splice Loss (1550 nm)	Estimated ORL (1310 nm)	Estimated ORL (1550 nm)	Splice Event Found by OTDR? Yes or No	Estimated Splice Loss, dB (1550 nm)
1	0.48	1.41	-9.38	-9.40	0.075	0.062	0.195	61.75	64.24	No	0.13
2	0.59	0.94	-9.19	-9.32	0.023	0.000	0.141	61.73	64.16	No	0.10
3	0.18	0.42	-10.11	-10.11	0.014	0.043	0.160	61.77	64.24	No	0.09
4	0.38	0.73	-9.53	-9.66	0.012	0.067	0.330	61.68	64.33	No	0.17
5	0.92	1.26	-9.59	-9.71	0.026	0.000	0.324	61.75	64.27	No	0.16
6	0.05	0.71	-9.84	-9.64	0.041	0.089	0.158	61.73	64.2	No	0.13
7	0.34	0.46	-9.49	-9.32	0.000	0.000	0.171	61.74	64.25	No	0.11
8	0.63	0.68	-9.04	-9.62	0.068	0.060	0.367	61.76	64.27	No	0.21
9	0.21	0.80	-9.86	-9.43	0.043	0.160	0.366	61.72	64.33	No	0.20
10	0.27	0.21	-9.93	-9.65	0.094	0.052	0.193	61.72	64.26	No	0.16
11	0.56	0.33	-9.59	-10.17	0.150	0.149	0.340	61.82	64.34	No	0.20
12	1.16	0.48	-9.73	-9.80	0.075	0.126	0.182	61.79	64.28	No	0.12

THRESHOLDS

Expected polarity: Unspecified

Fibers layout: 1x12 12 fibers

Thresholds: Custom [Fixed]

Minimum link length (km)	Maximum link length (km)	Splice loss (dB)	Connector loss (dB)	First connector loss (dB)	Last connector loss (dB)

Wavelength (nm)	Minimum Loss (dB)	Maximum Loss (dB)	Maximum Attenuation (dB)
1310		1.70	
1550		1.70	

Link Definition		
Fiber type	Number of connections	Number of splices
OS1	2	1

REFERENCE DETAILS

Timestamp: 1/23/2024 6:48:05 PM (GMT-08:00)

Referencing method: One Cord

Test cord grade: Undetermined

Figure 29. Fiber A-5 Testing Summary

FIBER DETAILS

A-6

Length: 0.0207 km

Insertion Loss Measurements (Entire Link) - MPX/LPX					OTDR Loss Measurements (Splice Isolated) - MAX-720C						OBR Luna 4600
Fibers	Loss (dB) 1310 nm	Loss (dB) 1550 nm	Reference (dBm) 1310 nm	Reference (dBm) 1550 nm	Estimated Splice Loss (1310 nm) 30 ns pulse 30 second duration	Estimated Splice Loss (1310nm) 3ns pulse 60 sec duration	Estimated Splice Loss (1550 nm)	Estimated ORL (1310 nm)	Estimated ORL (1550 nm)	Splice Event Found by OTDR? Yes or No	Estimated Splice Loss, dB (1550 nm)
1	0.00	0.08	-9.38	-9.40	0.055	0.107	0.854	61.72	64.5	No	0.68
2	0.22	0.19	-9.19	-9.32	0.093	0.062	1.091	61.78	64.59	Yes, 1550 appears as brok	0.80
3	0.27	0.07	-10.11	-10.11	0.027	0.087	0.632	61.68	64.48	Yes, on 1550 only	0.44
4	0.60	0.29	-9.53	-9.66	0.019	0.000	0.469	61.69	64.36	Yes, on 1550 only	0.30
5	0.51	0.70	-9.59	-9.71	0.059	0.059	0.764	61.74	64.53	Splice drops off 1550 onl	0.52
6	0.43	0.68	-9.84	-9.64	0.022	0.034	0.603	61.68	64.45	Yes, on 1550 only	0.40
7	0.64	0.31	-9.49	-9.32	0.041	0.065	0.731	61.7	64.5	Splice drops off 1550 onl	0.60
8	0.91	0.55	-9.04	-9.62	0.084	0.066	1.444	61.75	64.85	Splice drops off 1550 onl	1.01
9	0.30	0.67	-9.86	-9.43	0.148	0.243	0.985	61.77	64.45	Splice drops off 1550 onl	1.06
10	0.57	0.30	-9.93	-9.65	0.077	0.104	0.551	61.75	64.39	Yes on 1550 only	0.46
11	0.57	0.28	-9.59	-10.17	0.069	0.074	0.508	61.71	64.43	Yes on 1550 only	0.40
12	1.07	0.34	-9.73	-9.80	0.060	0.018	0.317	61.74	64.35	No	0.25

THRESHOLDS

Expected polarity: Unspecified

Fibers layout: 1x12 12 fibers

Thresholds: Custom [Fixed]

Minimum link length (km)	Maximum link length (km)	Splice loss (dB)	Connector loss (dB)	First connector loss (dB)	Last connector loss (dB)

Wavelength (nm)	Minimum Loss (dB)	Maximum Loss (dB)	Maximum Attenuation (dB)
1310		1.70	
1550		1.70	

Link Definition		
Fiber type	Number of connections	Number of splices
OS1	2	1

REFERENCE DETAILS

Timestamp: 1/23/2024 6:48:05 PM (GMT-08:00)

Referencing method: One Cord

Test cord grade: Undetermined

Figure 30. Fiber A-6 Testing Summary

FIBER DETAILS

B-3

Unknown

Length: 0.0207 km

Insertion Loss Measurements (Entire Link) - MPX/LPX					OTDR Loss Measurements (Splice Isolated) - MAX-720C						OBR Luna 4600
					No IL Measurements were made for this fiber using the Light Source/Power Meter						
Fibers	Loss (dB) 1310 nm	Loss (dB) 1550 nm	Reference (dBm) 1310 nm	Reference (dBm) 1550 nm	Estimated Splice Loss (1310nm) 30 ns pulse 30 second duration	Estimated Splice Loss (1310nm) 3ns pulse 60 sec duration	Estimated Splice Loss (1550 nm)	Estimated ORL (1310 nm)	Estimated ORL (1550 nm)	Splice Event Found by OTDR? Yes or No	Estimated Splice Loss, dB (1550 nm)
1					0.145	0.159	0.132	61.79	64.21	No	0.09
2					Broken	Broken	Broken	Broken	Broken	Broken	
3					Broken	Broken	Broken	Broken	Broken	Broken	
4					Broken	Broken	Broken	Broken	Broken	Broken	
5					0.063	0.177	0.010	61.76	64.12	No	0.07
6					0.015	0.000	0.000	61.76	64.13	No	0.03
7					0.019	0.000	0.001	61.72	64.15	No	0.04
8					0.047	0.359	0.072	61.72	64.18	No	0.03
9					0.063	0.163	0.051	61.79	64.19	No	0.06
10					0.171	0.000	0.249	61.89	64.42	No	0.09
11					0.860	0.987	0.753	62.24	64.65	No	0.05
12					0.122	0.004	0.089	61.83	64.31	No	0.05

*Not reliable measuremer

THRESHOLDS

Expected polarity: Unspecified

Fibers layout: 1x12 12 fibers

Thresholds: Custom [Fixed]

Minimum link length (km)	Maximum link length (km)	Splice loss (dB)	Connector loss (dB)	First connector loss (dB)	Last connector loss (dB)

Wavelength (nm)	Minimum Loss (dB)	Maximum Loss (dB)	Maximum Attenuation (dB)
1310		1.70	
1550		1.70	

Link Definition		
Fiber type	Number of connection	Number of splices
OS1	2	1

REFERENCE DETAILS

Timestamp: 1/23/2024 6:48:05 PM (GMT-08:00)

Referencing method: One Cord

Test cord grade: Undetermined

Figure 31. Fiber B-3 Testing Summary

2.8 Observations Summary

The new fiber optic cable configurations offer potential benefits of decreased cableway congestion and improved installation efficiency. As discussed above, the new designs have the same cable outer diameter as the single OFCC cables. This yields a 12x increase in the amount of fiber optic leads in the same cable jacket size. Additionally, cable installation and hook-up process times would be reduced. While a ribbon splice requires more time than a single splice due to multi-fiber preparation and alignment times, the result is a 12x increase in throughput yield per splice. Additional work is needed to improve optical testing results across all twelve fibers of the subunit.

The fusion splicer is very similar to that of a single fiber, core alignment splicer in use by shipyard fiber optic installation teams today. There were improvements to the new splicer tools that were noted during the trial. These include advanced methods of fiber alignment (automated) and mechanical adjustment platform that can be used to reposition (tap) the fiber into place. This was very helpful in aligning the twelve fibers with the other side of the cable. Additionally, the thermal jacket remover improved the fiber preparation process.

Cleaning processes should be considered for the fusion splicer and associated equipment. The environment onboard a ship under construction may require increased cleaning cycles of the equipment. The tolerances on a mass fusion splicing machine could be impacted with the introduction of dirt and airborne contaminants common to the construction environment.

During the shipboard activity, it was very difficult to work with cables where the ribbon matrix is not intact and the individual fiber leads need to be organized. The use of a fiber arrangement tool was attempted with unsatisfactory results. The small fiber leads are difficult to identify and work with in the shipboard environment. The additional time required to successfully assemble and splice would negatively impact the efficiency gains anticipated with the ribbon splicing process. It is recommended that an intact ribbon design that allows fiber to remain connected to each other be used. A ribbon organizer tool should be available, but should only be needed in limited situations.

3.0 Conclusions and Recommendations

This project evaluated the implementation of new fiber optic cable designs into U.S. Navy shipbuilding and ship repair programs. The Navy has developed updated standards for new high-density fiber optic cable designs for future shipboard applications. This project evaluated ribbon fiber technologies, including cable options, tooling, and installation processes. Both commercial-off-the-shelf (COTS) products and products designed to MIL-PRF-85045 standards were included in the study.

NAVSEA has published specifications for cable and hardware including four MIL-PRF-85045 ribbon cable configurations. The new cable configurations were evaluated for impact to tooling and processes currently used in shipyard fiber optic deployment. In addition, new interconnection methods and potential connector options were identified and reviewed.

Shipyard trials were conducted in the laboratory and shipboard environments. New fusion splicers and associated tools as well as new fusion splicing processes were included. Cable assemblies were fabricated and laboratory testing conducted. Feedback was provided to support updates to installation processes and optimal designs for the ship construction environment.

The project team recommends additional work in this area as MIL-PRF-85045 cable products are finalized and system connection methods and hardware are developed. Work to improve splice yield and development of Navy approved connection methods are needed prior to implementation. New ribbon fiber connector technologies designed for USN applications should be identified and developed. Training on the technology, tools, and process updates for this cable type should be incorporated in the planning strategy.

References

1. MIL-STD-2042, Fiber Optic Cable Topology Installation Standard Methods for Surface Ships and Submarines
2. MIL-STD-2042-5, Method 5C3; Multiple Fiber (Ribbon) Fusion Splicing
3. MIL-PRF-85045, Performance Specification; General Specification for Fiber Optic Cables
4. MIL-PRF-85045/33, Performance Specification; Cable, Fiber Optic Rolled Flexible Ribbon, Twelve Fiber, Single Subunit, Cable Configuration Type 4 (Ribbon Cable), Applications A and B (Airborne and Shipboard), Cable Class SM and MM
5. MIL-PRF-85045/34, Performance Specification; Cable, Fiber Optic, Four Subunits, Twelve Fibers Rolled Flexible Ribbon Subunit, Enhanced Performance, Cable Configuration Type 4 (Ribbon Cable), Cable Class SM and MM
6. MIL-PRF-85045/35, Performance Specification; Cable, Fiber Optic, Eight Subunits, Twelve Fibers Rolled Flexible Ribbon Subunit, Enhanced Performance, Cable Configuration Type 4 (Ribbon Cable), Cable Class SM and MM
7. MIL-PRF-85045/36, Performance Specification; Cable, Fiber Optic, Thirty-Six Subunits, Twelve Fibers Rolled Flexible Ribbon Subunit, Enhanced Performance, Cable Configuration Type 4 (Ribbon Cable), Cable Class SM and MM
8. MIL-PRF-24623/8, Performance Specification; Splice, Fusion, Fiber Optic, Twelve Fiber Ribbon, Protector
9. MIL-DTL-24728/8, Detailed Specification; Interconnecting Box, Fiber Optic, Fusion Splice Tray and Tray Holder Module
10. MIL-PRF-28876, Performance Specification; General Specification for Connectors, Fiber Optic, Circular, Plug and Receptacle Style, Multiple Removable Termini
11. A-A-59799B, Commercial Item Description (CID): Fusion Splicer and Cleaver, Optical Fiber

List of Appendices

Appendix A. **Draft Method 5C3**

Appendix A - Draft
METHOD 5C3_08.22.

Appendix B. **Navy Shipboard Fiber Optics Recommended Tools List**

Navy
Recommended Tool

Appendix C. Test Reports – IL and RL Field Trial Testing

Appendix C - Test Report_All Pages.pd

Appendix D. OBR Test Summary

Appendix D - Penn
State OBR Testing S

Appendix E. OTDR Test Reports – 3 ns Pulse Width

Appendix E - OTDR Test Reports - 3 ns p

Appendix F. **OTDR Test Reports – 30ns Pulse Width**

Appendix F - OTDR Testing - 30 ns puls