National Shipbuilding Research Program
Electrical Technology Panel - Panel Project 2015-442

ALTERNATIVES TO FIBER OPTIC CONNECTORS

Final Technical Report

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Project Lead:
John Mazurowski
The Penn State Electro-Optics Center, 222 Northpointe Boulevard, Freeport, PA 16229
(724) 295-7000 x7139 jmazurowski@eoc.psu.edu

Sponsoring Shipyard:
Jason Farmer
Ingalls Shipbuilding
(228) 935-7573 jason.farmer@hii-ingalls.com

Program Technical Representative:
Walter Skalniak
Panduit Corporation
(757) 309-6344 wjsk@panduit.com

Government Technical Representative:
Christopher Good
NSWC Dahlgren Division
(540) 653-0627 christopher.good@navy.mil

Project Team Member:
Dan Morris
KITCO Fiber Optics
(757) 216-2220 dan.morris@kitcofo.com

Project Team Member:
Ariel Castillo
General Dynamics Electric Boat
(860) 867-2810 acastill@gdeb.com

EXECUTIVE SUMMARY

The objective of this project was to increase the number of situations in which fiber optic fusion splices could be utilized in shipbuilding to replace fiber optic connectors. Due to instability and the need for extreme cleanliness, it is recommended that fiber optic connectors be used only in applications where frequent mating and de-mating are required. Connectors require craftsmanship to assemble, and take considerable time when assembled on location.

Fusion splicing is an automated process which uses a fusion splice machine to permanently join pieces of optical fiber. Insertion loss of fusion spliced connections are much lower and more stable than connectors. The splices are housed in enclosures for physical and environmental protection. Fusion spliced connections are intended to remain stable over the lifetime of the fusion splice, with no further maintenance required. The initial cost of fusion splicing equipment is a potential deterrent, but the incremental cost of fusion splices is low. <u>Equipment payback based on labor alone is approximately 200 splices.</u>

This project took a number of tasks to explore all possible replacement devices for fiber optic connectors. Applications were identified where fiber optic connectors, in semi-permanent or permanent installations, could be replaced. The project team considered devices that are qualified, or in the process of being qualified, in order to eliminate redundant work.

Some tests were run on fusion spliced cables to test their durability in rugged environments. Fusion splices were left un-secured inside enclosures and tested at 120 percent of commercial vibration and shock limits. Fluctuations in optical performance were negligible.

<u>Use of fusion splices in lieu of fiber optic connectors provides savings in excess of 70% per connection</u>, and avoids the following costs associated with fiber optic connectors:

- The cost of managing thousands of connector components and spares.
- Craftsmanship required for terminus and connector assembly.
- Concern for end face inspection for quality and geometry.
- Concern for epoxy shelf life and curing.
- Field maintenance for permanent fiber optic connections.

Fiber optic connectors that do not require frequent mating and de-mating can be avoided. Fusion splices provide low loss, stable optical connections. We envision that future equipment be delivered with fiber optic pigtails and integral or nearby splice enclosures.

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1.0 PROJECT OVERVIEW

1.1 Problem

Fiber optic connectors are meant for situations where frequent mate / demate is required. In Navy ships, present fiber optic link loss could be reduced if the connector loss and its instability were reduced. Splices (particularly fusion splices) are an alternative to fiber optic connectors, and are commonly used in commercial applications. Fusion splicing is a useful alternative, but few cable restoration methods and splice enclosures are available.

1.2 Objective

The objective for this project is to increase the number of situations where splices can be used, by identifying candidate splice methods, cable restoration methods, and splice enclosures. Naval platforms which use fusion splicing in lieu of fiber optic connectors may improve affordability based on the benefits listed below:

- Cost avoidance for connector parts that are no longer needed.
- Longer viable link lengths due to reduction in loss.
- Increased stability in link loss due to no moving parts.
- Less difficulty with control of End Face Quality (see previous NSRP project).
- Significant increase in optical connection reliability when fusion splices are used.
- Less fiber optic connector maintenance- fusion splices are meant to be permanent.

2.0 TECHNICAL TASKS

The project has two technical phases:

The first phase is divergent. Within SOW tasks 3.1 through 3.3, team members identify a) devices- splices, cable restoration methods, and splice enclosures- that would be useful for implementing splices, and b) applications / needs where splices would be useful in ships. Presumably the supplier team members would emphasize identification of the devices, and the shipyard / government team members would emphasize identification of the applications / needs.

The second phase is convergent. Within SOW tasks 3.4 through 3.6, team members evaluate the feasibility of the devices identified, and consider each of them in light of the applications / needs. The team will consider performance and other parameters in down-selecting the devices found to be most promising of further consideration. Finally, with concurrence of the government, nominal tests will be run on the most promising candidates for future use in the shipbuilding industry.

The team could also decide that there are promising devices whose designs require further development to meet the needs of the shipbuilding industry.

The project Statement of Work (SOW) has six tasks, shown in the table below:

Table 1. Statement of Work (SOW) tasks.

TASK NUMBER	TASK DESCRIPTION
3.1	Identify Alternatives
3.2	Identify Applicable Situations
3.3	Identify Qualified Devices
3.4	Identify Qualification Gaps
3.5	Identify Promising Candidates
3.6	Nominal Qualification Activities

3.0 RESULTS

The section below cover the performance of each project task. The project analyzed the intersection of alternative devices, identified in Task 1, with applicable situations, identified in Task 2. The analysis consisted of first identifying qualification and approval activity already in progress, and then identifying qualification gaps where effort is needed.

Promising candidates were those alternative devices which require further effort for approval and qualification. The project team engaged downstream users to verify that promising candidate devices were indeed useful. Finally, testing was performed to identify substantial shortcomings that would prevent qualification or approval.

3.1 Identification of Alternatives

The purpose of identifying alternatives is a first cut at candidates for consideration. The alternatives themselves can be fully qualified ship hardware to COTS concepts that are being developed.

There are three components to alternative optical interconnections, and all three are described within this section:

a. Splice Methods- method of joining each optical fiber.

b. Cable Restoration- method of adding mechanical strength and environmental isolation around connected fibers, where enclosure protection is not used.

c. Splice Enclosure- method of enclosing and protecting joined optical fiber, when cable restoration is not used.

The three tables below (2, 3, 4) contain descriptions of alternative devices.

Table 2. Summary of alternatives for splice methods area.

AREA	DESCRIPTION
Splice	**Fusion splicer equipment update: Fitel splicer line, AFL 50S / 60S / 70S, Sumitomo splicer line, Quantum core-alignment splicer.** The commercial fusion splicers are evolving with features to make splicers more rugged, fusion splicer operation more routine, and results more statistically consistent. Core alignment is now a common feature.
Splice	**Splice protector improvements: deletion of metal rod, compact designs.** Fusion splice protectors have gotten more compact, however this could possibly conflict with Navy approved splice protectors. The metal rod once used for strength and temperature uniformity is disappearing, which decreases cost.
Splice	**Mechanical splice update: 3M FibrLok, AMP / TE Corelink, TE Lightcrimp.** New commercial mechanical splice models improve alignment, increase yield, and decrease cost.
Splice	**Mechanical splice improvements: NAVAIR splice.** Mechanical splices compatible with harsh environments were solicited in the SBIR and STTR programs. There is a tube-based mechanical splice that exceeds pull strength requirements.
Splice	**Index matching adhesive:** Developed under Navy SBIR, Tetramer offers a new index matching adhesive that meets environmental requirements for stability.
Splice	**Mechanical splicing economics:** There is some commercial acceptance of mechanical splice use to avoid cost of fusion splicing equipment. Fusion splicers cost $15,000 to $75,000. Mechanical splice tooling is under $1,000.
Splice	**Splice-on connectors.** Commercial splice-on connectors are available to reduce labor needed for in-situ assembly. For ship and submarine applications, they are valuable in providing high quality end face geometry and quality. MIL 29504 termini have achieved MIL qualification and now available.

Table 3. Summary of alternatives for cable restoration area.

AREA	DESCRIPTION
Cable Restoration	**TFOCA in-cable splice enclosure.** The TFOCA cable assembly was designed for use in dirty, tactical environments. It is popular today. An associated in-cable splice enclosure might be a candidate for use in ship cable repair.
Cable Restoration	**Double backshell in-cable splice enclosure.** This was a concept developed in a Navy ManTech project, consisting of two backshells coupled with a threaded tube between the two. It can be made into a very compact splice enclosure that could connect two pigtails.

Table 4. Summary of alternatives for splice enclosures area.

AREA	DESCRIPTION
Splice Enclosure	**Rack based enclosures.** The rack enclosure is used commonly in ships and subs. More varieties are available, and these should be reviewed for useful advances.
Splice Enclosure	**Wall-mount enclosures.** Advances in this area are important, both for when rack space is not available, and to facilitate compact splice connections.
Splice Enclosure	**Non-metallic splice enclosures.** Many commercial splice enclosures are designed for exterior use, and are made from non-metallic materials.
Splice Enclosure	**Splice enclosure sizes and mounts.** A variety of commercial splice enclosure sizes are available to facilitate compact connections between cable and equipment.
Splice Enclosure	**Double backshell in-cable splice enclosure.** This was a concept developed in a Navy ManTech project, consisting of two backshells coupled with a threaded tube between the two. It can be made into a very compact splice enclosure that could connect two pigtails.

3.2 Applicable Situations

“Applicable situations” are areas in which alternative connection methods can be used in ships. There will be a dialog with the Government Technical Representative, who may have concerns for where alternative hardware may or may not be used. It is assumed, however, that environmental and therefore qualification requirements may be different for the same part in different situations.

The three tables below (5, 6, 7) cover splice methods, cable restoration, and splice enclosures respectively.

Table 5. Summary of applicable situations for splice methods area.

AREA	DESCRIPTION
Splice	**Fusion splicer equipment update.** New features that make fusion splicers more amenable for use in ship and submarine manufacturing, and also splicers that reduce splice loss in ship production environments.
Splice	**Splice protector improvements.** The team discussed availability of newer fusion splice protectors. NSWC-DD and project team criteria is that splice protectors a) be as small as possible, b) be compatible with approved splicing equipment, and c) allow as many suppliers as possible. This opens consideration for common splice protectors that reduce size and cost.
Splice	**Mechanical splice improvements.** Improvements in splice protectors to increase reproducibility of field repairs, improve commonality of repair methods, and reduce acquisition cost are needed.
Splice	**Index matching adhesive.** Index matching compounds that meet shelf life requirements and perform over severe environmental ranges are needed.
Splice	**Splice-on connectors.** These types of connectors are available for commercial applications, and are under development for military applications. For ship and submarine applications, they are valuable in providing high quality end face geometry and quality. MIL 29504 termini have recently achieved MIL qualification.

Table 6. Summary of applicable situations for cable restoration area.

AREA	DESCRIPTION
Cable Restoration	**In-cable splice enclosure for repair.** This is suggested by the shipyards as a way to a) reduce costs connected with rework of damaged deployed cables, and b) facilitate field repairs. Project team discussions have been held, and there is reluctance in allowing rework splicing of cables in a production environment. In-cable splice enclosures are necessary for field repairs, and should be as compact as possible.
Cable Restoration	**In-cable splice enclosure for equipment connection.** Connection of equipment to cable infrastructure via fusion splices versus panel connectors makes sense a) physically due to the stability and low loss of fusion splices, and b) logistically due to questions about ownership of the connection.

Table 7. Summary of applicable situations for splice enclosures area.

AREA	DESCRIPTION
Splice Enclosure	**Rack based splice enclosures.** Rack enclosures are commonly used in ships and submarines. More varieties in splice trays and holders to hold more fibers in less space are desirable.
Splice Enclosure	**Compact splice enclosures.** To facilitate increased use of fusion splicing, advances that save space are necessary. Particularly useful are enclosures that connect equipment to cables; it may be possible to connect equipment pigtails to the cable infrastructure and decrease loss, increase stability, and reduce cost. Cable entrance area to splice enclosures is open for improvement.
Splice Enclosure	**Enclosures that reduce possible damage to cables and fibers.** This could involve new designs that reduce sharp edges, or enclosures made from non-metallic materials.
Splice Enclosure	**Enclosures that are easy to use.** In particular, enough fiber length is necessary to reach a fusion splicer, and then be stored. Industrial solutions for fiber storage, or to reduce the length of fiber required for splicing would be welcome. Enclosures that reduce the number of component parts reduce cost.

3.3 Qualified Devices

From the merger of Alternatives and Applicable Situations, there are hardware devices that are already qualified or qualified in other situations. This task identified those devices that are presently acceptable for use in the areas of splice methods, cable restoration, and splice enclosures respectively.

- A qualified device has been fully qualified in accordance with a military specification and is listed in a Qualified Parts List (QPL).
- An approved device is approved in accordance with a Commercial Item Description (CID) and is listed by NAVSEA as an approved part.

Table 8. Summary of qualified / approved devices for splice methods area.

AREA	DESCRIPTION
Splice	**A-A-59799 Fusion Splicer.** Commercial item description (CID) that describes splicing equipment that produces a core aligned splice of 24 mm length in fibers compliant with MIL-PRF-49291 / 6 (multimode) and MIL-PRF-49291 / 7 (single mode). Acceptable cladding diameter ranges from

	80-150 micron, and coating / buffer diameter ranges from 100 – 1000 microns. (MIL-STD-2042C Method 5C2)
Splice	**MIL-PRF-24623/6A Splice Protector.** Specific 40 mm x 3 mm splice protector with strength member, within MIL-PRF-24623 family. Compatible with MIL-49291 / 6 (multimode) and MIL-49291 / 7 (single mode) fibers and splice trays / splice tray holders compliant with MIL-DTL-24728 / 8. To be used with splicing equipment defined in A-A-59799.

Table 9. Summary of qualified / approved devices for cable restoration area.

AREA	DESCRIPTION
Cable Restoration	**A-A-59917 Mechanical Splice.** Commercial Item Description (CID) that describes a field installable mechanical splice. Maximum overall length is 40.5 mm and the maximum diameter is 4.5 mm. Preparation of the fiber and installation of the splice is attainable using defined standard Navy tool kits (Part #: 0701-7030, Shipboard ST/28876 Conn Kit). Compatible with 250 micron coating diameter, 900 micron buffered fiber, or 2 mm jacketed fiber.

Table 10. Summary of qualified / approved devices for splice enclosures area.

AREA	DESCRIPTION
Splice Enclosure	**MIL-DTL-24728 / 8 Splice Tray and Splice Tray Holder.** Splice tray and splice tray holder within MIL-I-24728 family. Covers splice tray holder M-24728 / 8-50 and splice tray M-24728 / 8-51. Splice tray dimensions are 177.8 mm x 127 mm x 10.6 mm (7 in X 5 in X 0.4 in). Splice tray holder dimensions are 254 mm max x 217.42 mm max x 111.25 mm max (10 in max x 8.56 in max x 4.38 in max). Splice tray capacity is 12 splices. Splice tray holder capacity is 4 splice trays. (MIL-STD-2042 Method 2K1, MIL-STD-2042 Method 2K3)
Splice Enclosure	**MIL-DTL-24728 / 11 Splice Tray Holder** Splice tray holder capacity is 8 splice trays of type M24728 / 8-51.
Splice Enclosure	**COTS approved splice tray (limited use):** Splice tray dimensions are 254 mm x 127 mm x 10.6 mm (10 in X 5 in X 0.4 in). Splice tray capacity is 24 splices. (MIL-STD-2042 Method 2K2)
Splice Enclosure	**COTS Fusion splice tray shelf:** Storage of MIL-24623 fusion splices within a MIL-24728/51 splice tray or COTS approved 10" tray.

3.4 Qualification Gaps

NAVSEA Device Qualification

There is solid agreement between the project team and NSWC Dahlgren Division (NSWC-DD), who as the Tech Warrant Holder (TWH) Designee as Engineering Manager is responsible for shipboard fiber optics in the U.S. Navy, that there are more situations in which fusion splices could be used.

This group is active in providing requirements, drawings, and specifications in military specification (MIL SPEC) form or in commercial item description (CID) form for items for use in shipboard fiber optic cable plants (FOCP). The group is also active in guiding and providing qualification for items that they determine are necessary for specific situations on ships.

Process Observations

Within the Alternatives to Fiber Optic Connectors project, the objective is to increase number of situations where splices can be used. An observation is that, while qualification processes are consistent and their execution is consistent, many platform decisions are made by the program offices, who are responsible for designs, expenditures, and management of risk for specific platforms.

Presently fusion splices are not used consistently across the Navy (all platforms included). There are several reasons for this:

- Optical fiber may not be used widely in a specific platform, and so previously legacy methods (using connectors) are used for design and maintenance.
- Use of fusion splice equipment for manufacturing and maintenance is not a priority for a specific platform due to the cost of equipment and lack of personnel experience and training in fusion splicing procedures.
- Use of splicing as a connection method is restricted in some ship specifications.
- Use of fusion splices, along with conventional cabling or Blown Optical Fiber (BOF), has not been chosen as a method for optical fiber deployment in a specific platform.
- Historically, design engineers who are used to designing electrical cabling are accustomed to using connectors in many situations in lieu of fusion splices.
- Fusion splicing has not been considered due to space and weight allocated to connectors, and the perception that use of fusion splicing could not save either.

This project has uncovered several specific issues where yields are affected by use of legacy methods. One situation involves a platform where long multi-fiber cables are used; some of these are over 1,000 feet long. These cables suffer from a high probability of physical damage during deployment and installation. Due to critical signals transmitted in some fibers and tight loss budgets, it is not acceptable to add additional connection points in the link. . Splices in unplanned locations is not allowed for reasons of traceability and configuration control. A method to document planned splice locations in engineering documentation would be needed along with an assessment of impact.

Ship specifications drive the approach taken for optical fiber deployment. Some programs are willing to accept the cost of defects and rework against the higher cost of investing in new technology that would substantially reduce those defects.

Splice Methods

During the course of the project we have learned that there is an approved supply chain that supports fusion splicing. It is outlined below.

Table 11. Summary of qualification gaps for the splice methods area.

AREA	DESCRIPTION
Splice	**A-A-59799 Fusion Splicer.** Present Commercial Item Description is adequate, and includes multiple suppliers. NO QUALIFICATION GAPS; NO ACTION REQUIRED
Splice	**MIL-PRF-24623/6A Splice Protector.** Specific 40 mm x 3 mm splice protector with strength member, within MIL-PRF-24623 family. Compatible with MIL-49291 / 6 (multimode) and MIL-49291 / 7 (single mode) fibers and splice trays / splice tray holders. Newer smaller devices are available; however the length and size of the present splice fits the holders in the splice trays. NO QUALIFICATION GAPS; NO ACTION REQUIRED
Index Matching Epoxy	**Index Matching Epoxy Development under Navy SBIR.** Stability of index matching fluids used in mechanical splices is a concern for rugged environments. A new index matching epoxy has been developed that remains stable under rugged operating conditions. This development is occurring under the supervision of the Naval Air Systems Command. QUALIFICATION IS OCCURRING; NO ACTION REQUIRED
Mechanical Splice	**Mechanical Splice Development under Navy SBIR.** Pull strength is a substantial concern for mechanical splices. A new glass tube based mechanical splice is being developed by the Naval Air Systems Command for potential use in battle damage repair. The splice uses the index matching epoxy described above and achieves >20 lb. pull strength. QUALIFICATION IS OCCURRING; NO ACTION REQUIRED
Splice-On Connector	**Splice-on connectors.** NSWC-DD has defined requirements for splice-on connectors (ST, SC, LC, and M29504 termini meant for M28876). This could be extended to M29504 termini meant for M64266 connections). Efforts to approve/qualify have resulted so far in the approval of devices for some specific applications. Status by connector:

	▪ Splice-on LC: 1 supplier. ▪ Splice-on ST: 0 suppliers. ▪ Splice-on SC: 0 suppliers. ▪ Splice-on M29504/14-15 for M28876: 1 supplier. ▪ Splice-on M29504 for M64266: Requirements in process. At this time the qualification / approval process is working, and qualification / approvals are manufacturer driven. QUALIFICATION/APPROVAL IS OCCURRING; NO ACTION REQUIRED

Cable Restoration

Cable restoration is done for two purposes: a) for planned cable repair, and b) unplanned or emergency cable repair in the field. Cable restoration devices can potentially house connectors, mechanical splices, or fusion splices depending on the internal volume.

Note that for other than emergency field repairs, cable splices in unplanned locations are not presently allowed. We would need to develop a method to assess impact and provide traceability.

Table 12. Summary of qualification gaps for the cable restoration area.

AREA	DESCRIPTION
Cable Restoration	**TFOCA style cable restoration.** This device had been previously approved for Tactical Fiber Optic Cable Assembly (TFOCA) applications (not shipboard) for cable restoration and protection of fusion splices. PROOF OF FEASIBILITY REQUIRED; MEDIUM PRIORITY
Cable Restoration	**Double backshell cable restoration.** This device consists of two standard connector backshells which provide strain relief, combined with a threaded metal sleeve. The three parts form a simple cable strain relief device that can also serve as a splice enclosure. PROOF OF FEASIBILITY REQUIRED; MEDIUM PRIORITY

Splice Enclosure

There is a variety of qualified splice enclosures under MIL-DTL-24728, which provide wall mount protection for fusion splices. Each is compatible with standard splice trays and holders (refer to MIL-DTL-24728 / 8). Submersible and spray tight versions are included.

Some equipment is evolving from use of connectors toward pigtail fiber connections. A perceived need by the project team is splice enclosures that can be used in cable-to-cable or cable-to-pigtail applications where previous splice enclosures (wall or rack mount) would not fit. An ultimate solution would be to provide splice enclosures inside the equipment.

In particular, submarine manufacturers have successfully implemented fusion splicing using splice enclosures in accordance with MIL-DTL-24728. Wall mounted splice protection via interconnection boxes are used with cable and Blown-Optical Fiber (BOF). Rack mounted splice protection via 1U shelves are used to terminate and distribute optical fiber to equipment (boxes). Some boxes (rack mounted and wall mounted) include integral splice trays for the purpose of housing fusion splices.

Table 13. Summary of qualification gaps for the splice enclosures area.

AREA	DESCRIPTION
Splice Enclosure	**TFOCA style splice enclosure.** This device had been previously approved for Tactical Fiber Optic Cable Assembly (TFOCA) applications for cable protection of fusion splices in cable-to-cable applications. Potential to adapt solutions to cable-to-connector or cable-to-feed through applications in ships. PROOF OF FEASIBILITY REQUIRED; HIGH PRIORITY
Splice Enclosure	**Double backshell cable restoration.** This device consists of two standard connector backshells which provide strain relief, combined with a threaded metal sleeve. The three parts form a simple cable strain relief device that can also serve as a splice enclosure for cable-to-cable situations. PROOF OF FEASIBILITY REQUIRED; HIGH PRIORITY
Splice Enclosure	**Commercial splice enclosure options.** Options are available for both bulkhead and rack mounted applications. These enclosures are widely used in commercial applications and available from multiple manufacturers. Additional enclosure options would increase design flexibility with some level of life-cycle cost savings and benefit. The enclosures are smaller and lighter weight than legacy FOICB options. PROOF OF FEASIBILITY REQUIRED; MEDIUM PRIORITY

3.5 Promising Candidates

Previous tasks, as shown in the sections above, have done the following:

- Identified device alternatives to connectors.
- Looked at situations in shipbuilding where devices could be applied.
- Found situations where devices had already been qualified.
- Identified gaps in the qualification process, with respect to specific devices, that require further work.

Promising candidates, identified below, have been scrutinized and would be useful to the shipbuilding industry:

- Devices, such as splice-on connectors, are already undergoing qualification activity driven by NAVSEA,
- Cable restoration devices for unplanned cable repair, are not allowed within present shipbuilding policy.

However, cable-to-cable splices may be used to connect equipment that is accessible through fiber optic pigtails; these have been grouped for this application along with splice enclosures.

The project team further examined the devices with qualification gaps. Shipbuilding production personnel were consulted to assure that a promising device, recommended by the project team, was something that would find value in the shipbuilding industry.

Table 14. Summary of promising candidates for the splice enclosures area.

AREA	DESCRIPTION
Splice Enclosure	**TFOCA style splice enclosure.** This device had been previously approved for Tactical Fiber Optic Cable Assembly (TFOCA) applications for cable protection of fusion splices in cable-to-cable applications. Potential to adapt solutions to cable-to-connector or cable-to-feed through applications in ships. HIGH PRIORITY
Splice Enclosure	**Double backshell splice enclosure.** This device could consist of two standard connector backshells which provide strain relief, combined with a threaded metal sleeve. The three parts form a simple cable strain relief device that can also serve as a splice enclosure for cable-to-cable situations. HIGH PRIORITY
Splice Enclosure	**Commercial splice enclosure options.** Options are available for both bulkhead and rack mounted applications. These enclosures are widely used in commercial applications and available from multiple manufacturers. Additional enclosure options would increase design flexibility with some level of life-cycle cost savings and benefit. The enclosures are smaller and lighter weight than legacy FOICB options. MEDIUM PRIORITY

Summary descriptions of the promising devices are shown below.

TFOCA Style Splice Enclosure

This device had been previously approved for Tactical Fiber Optic Cable Assembly (TFOCA) applications for cable protection of fusion splices in cable-to-cable applications. Potential to adapt solutions to cable-to-connector or cable-to-feed through applications in ships.

Figure 1. Photo of a typical TFOCA splice enclosure.

Known Risk Items:
- Material selection for flammability, toxicity, etc.
- Capability for storage in cableway
- Mechanical pull strength
- Tolerance to shock and vibration
- Securing fiber and splice internally

Double Backshell Splice Enclosure

This device can consist of two standard connector back shells which provide strain relief, combined with a threaded metal sleeve. The three parts form a simple cable strain relief device that can also serve as a splice enclosure for cable-to-cable situations. Possible versions of this device could come with features for mounting on equipment or in a rack.

There are a few known suppliers of this type of device:
- Glenair
- Delphi
- Ingalls Shipbuilding (prototype)

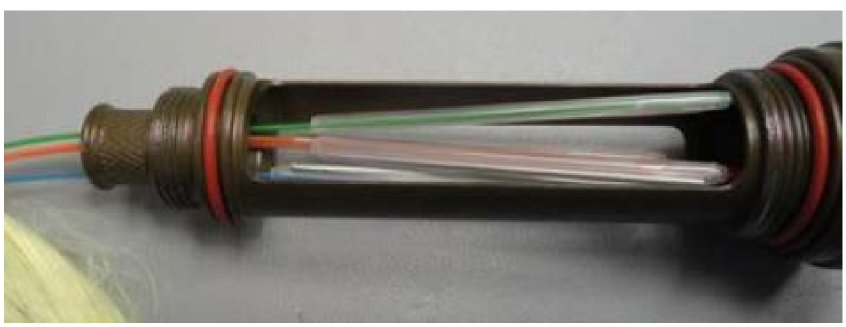

Figure 2. Photo of a typical double back shell splice enclosure.

Known Risk Items:
- Capability for storage in cableway
- Damage to adjacent cables if in proximity
- Tolerance to shock and vibration
- Securing fiber and splice internally

Splice Tray, Mass Fusion Splices- Corning M67-110

This splice tray system has the capacity to store and protect mass fusion splices and the associated fiber.

“Corning Cable Systems splice trays use proven designs and fiber organization technology to provide optimum physical protection for fusion and mechanical splicing methods. The trays are engineered for use with indoor or outdoor splice hardware with both loose tube and tight-buffered optical cable designs.”

“The metal-tray series consists of a rugged aluminum base and cover with crimpable metal tabs for buffer tube strain-relief. Additional strain-relief points are available for securing buffer tubes or pigtails to the trays using cable ties. The black powder coating allows easy fiber identification and additional protection. Designed for use with Corning Cable Systems interconnection hardware and splice closures, these splice trays are an integral part of a complete splicing system.”

Figure 3. Photo of Corning M67-110 Splice Tray.

Known Risk Items:

- Material selection for flammability, toxicity, etc.
- Entry of fiber and OFCC / BOF

Splice Enclosure, Wall Mountable - Corning WSH-16SPT

This wall mounted enclosure stores Corning splice trays.

“Corning Cable Systems Wall -Mountable Splice Housing (WSH) provides storage and protection of fiber splices in individually accessible trays. The wall -mountable housing is designed to store the optical fibers being spliced within the tray and can accommodate either (16) 0.2 in (Type 2S or 2R) or (11) 0.4 in (Type 4S or 4R) splice trays.”

“The front door of the housing is a work surface that can support the weight of a fusion splicer and features a lip around the door to help retain loose items. Multiple cable entry/exit locations are provided on the top and bottom and grommets prevent dust from entering the housing. Depending on the entry location of the cables into the housing, the strain -relief bracket can be moved to a variety of positions. The design also includes the Corning Cable Systems Universal Cable Clamp and provisions for mounting an optional grounding kit."

Figure 4. Photo of Corning WSH-16SPT splice tray enclosure.

Known Risk Items:

- Material selection for flammability, toxicity, etc.
- Watertight / spraytight performance
- Environmental seal against dust
- Cable entry to box
- Cable entry compatibility with approved methods
- Tolerance to shock and vibration
- Entry of OFCC / BOF into splice trays

<u>Splice Storage, Rack Mount 1U- Hubbell (as documented by General Dynamics)</u>

Capacity of 1U Fiber Interconnection Cabinet (FIC):

- QTY 3, 7" Splice Trays (12 fibers each tray), Type M24728/8-51, or
- QTY 3, 10" Splice Trays (24 fibers each tray) (COTS)

FSS01A 1U Unit Design Features:

- Splice trays mount in holder on post using through hole in splice tray.
- The Military splice trays include pads and/or mylar sheets which will require modification for post mounting trays.
- Cable entry in rear with sufficient internal storage area for 5mm microduct (1 Loop) and OFCC slack.
- Swing out shelf self-manages OFCC & microduct slack loop.
- Additional bracket/support at rear of tray holder is required.

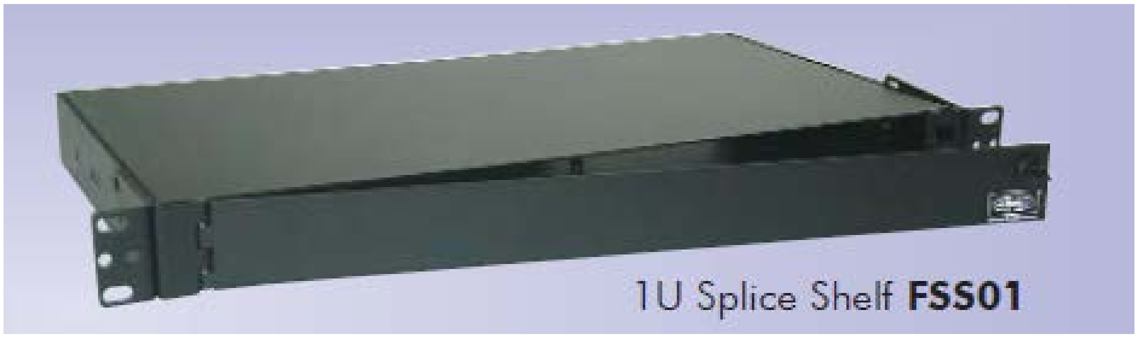

Figure 5. Photo of Hubbell FSS01 1U Fiber Interconnection Cabinet (FIC).

Known Risk Iems:

- Compatibility with equipment rack space and mounting
- Environmental seal
- Cable entry to box
- Tolerance to shock and vibration in conjunction with rack
- Concurrence with GFE / equipment owner

Splice Enclosure, Wall Mount- Panduit OPTICOM Line

Wall mount enclosures store Panduit splice trays.

“Wall mount enclosures shall be constructed of steel material. Enclosures shall provide cable bend radius protection. Enclosures offer optional discrete locking capability between installer and user segments.”

Dimensions:	FWME2: WxHxD=12x10.18x2.32in. (304.8x258.6x59.1mm) FWME4: WxHxD=16.11x12.25x3.52in. (409.2x311.0x89.4mm) FWME8: WxHxD=16.11x20.25x3.52in. (409.2x514.2x89.4mm)
Splicing tray and holder capacity:	FWME2: Holds (1) FSTHS which accommodates up to 2 FSTKs FWME4: Holds (1) FST6H4 which accommodates up to 4 FST6s FWME8: Holds (2) FST6H4s which accommodates up to 4 FST6s each
Packaging:	Includes accessory kit and labels.

Figure 6. Photo of Panduit Opticom wall mount splice enclosure.

Known Risk Items:

- Watertight / spraytight performance
- Environmental seal against dust
- Cable entry to box
- Cable entry compatibility with approved methods
- Tolerance to shock and vibration
- Entry of OFCC / BOF into splice trays

<u>Splice Enclosure, Rack Mount- M4 (as documented by KITCO Fiber Optics)</u>

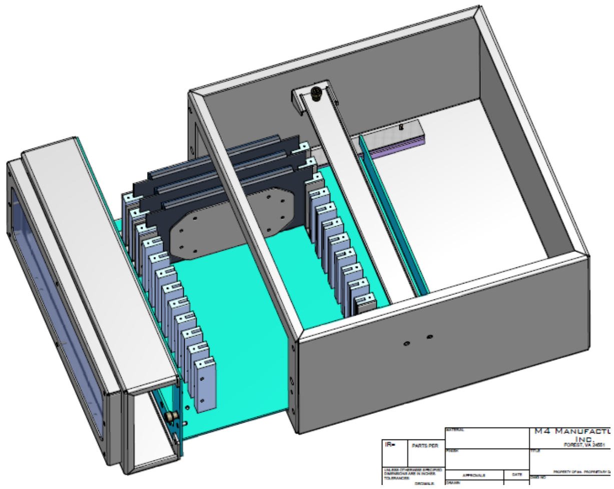

Figure 7. Photo of M4 rack mount splice tray enclosure.

Known Risk Items:

- Compatibility with equipment rack space and mounting
- Environmental seal
- Cable entry to box
- Tolerance to shock and vibration in conjunction with rack
- Concurrence with GFE / equipment owner

3.6 Nominal Qualification Activities

A Work-In-Progress (WIP) chart was constructed by the team to even further identify risk associated with each promising candidate. Risk items identified with respect to specific devices are flammability, hazardous materials, water tightness / spray tightness, environmental seal, damage to adjacent cables, cable pull strength, securing internal cable and fiber, and tolerance to shock and vibration.

Tests were then performed on specific devices using single mode fiber optic cable to observe and communicate most obvious failure modes that could prevent successful qualification or approval. We did not perform qualification measurements.

Fusion splices require physical protection from the environment. A fusion splice used in shipbuilding is surrounded by a splice protector MIL-PRF-24623/6 which measures 40 mm x 2.9 mm. Splice enclosures with splice trays and holders provide protection for single or multiple fusion splices in splice protectors. They also provide room for cable entry / exit, and cable deployment compliant with bend radius requirements. The enclosures provide the required physical protection as well as immersion or spray protection, performance over temperature and humidity ranges, and performance to shock and vibration limits.

The logic of these tests follows the most likely mode of failure, which is physical failure of the hardware or a fusion splice under shock or vibration.

Devices Tested

The devices that were tested and included in this report were:

1) KITCO (TFOCA) Cable–to-Cable Splice Part Number 031-1179. This device came with integral strain reliefs with Kevlar clamps.

2) Ingalls Shipbuilding Cable-to-Cable Splice consisting of two M28876 back shells joined with a threaded tube. This was a custom part designed by Ingalls Shipbuilding as a concept of what a cable-to-cable splice would look like in shipbuilding production.

These devices represent small enclosures that would facilitate use of fusion splicing at the edge of a cable plant, and possibly adjacent to equipment. In the future, it may be possible to mount splice enclosures in equipment in order to form optical connections without connectors at all. Although the devices were constructed to be cable-to-cable splices, they can be mounted using brackets; it is possible that flanges or bosses could be included in the designs to provide surface mounts.

There was one other device that had been selected as one that should be measured. However, at a size of one rack space, it was too large to be compatible with the equipment used for vibration and shock testing. However, there is a clear set of requirements for single space splice racks defined within NAVSEA, so the device could follow the normal qualification process.

The KITCO modified TFOCA was connected using MIL-85045/18-02P four fiber cable and the HII prototype was connected using MIL-85045/17-02P eight fiber cable. Inside each device were fusion splices assembled using MIL-24623/6 splice protectors. No extraordinary protection was used to pad, position, or hold the internal fusion splices. The fusion splices were interdigitated by also fusion splicing the component fibers together at the ends of the cables. The joined splices formed a single signal path through the cable. Figure 8 below shows a representative test device’s optical signal path.

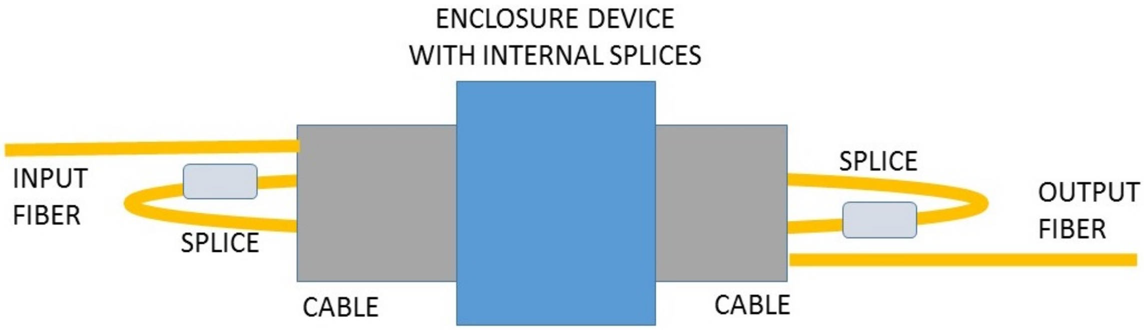

Figure 8. Test device diagram showing single mode optical signal path.

Internal to the KITCO modified TFOCA splice enclosure two pairs of fiber were fusion spliced together using a fusion splicer and the approved 40 mm long splice protectors as described in MIL-PRF-24623/6. Outside of the vibration and shock systems three more splices were used to loop the fibers together and attach the link to the optical power meter (OPM) and the stabilized light source (SLS) for a total of five splices.

Internal to the HII prototype splice enclosure eight pairs of fiber were fusion spliced together using a fusion splicer and splice protectors as above. External to the vibration and shock systems nine more splices with protectors were used to loop the fibers together and to attach the link to the OPM and SLS for a total of seventeen splices.

Description of Tests

Each device was subjected to random vibration using a Thermotron AST-8 HALT / HASS Chamber with the RS-16 vibration table (axes excited: three rotational and three linear). The temperature inside the chamber was held constant at 25° C. The vibration intensity was increased in increments of 2 grms from zero to 12 grms with dwell times at each level. Change-in-Optical-Transmittance and Bit Error Rate (BER) were monitored for successive vibration tests. When testing for bit errors the dwell time was increased, so that 10^{12} bits (PRBS 2^{31} - 1 at 1.25 Gbps) could be successfully sent for each of the vibration intensity levels. Before and after each test, an OFDR scan was taken using a Luna 4200 Optical Backscatter Reflectometer (OBR) to determine if loss had changed, and, if so, which component had changed. Figures 9 and 10 show the two different devices installed inside the test chamber.

Figure 9: KITCO modified TFOCA enclosure installed in the vibration chamber.

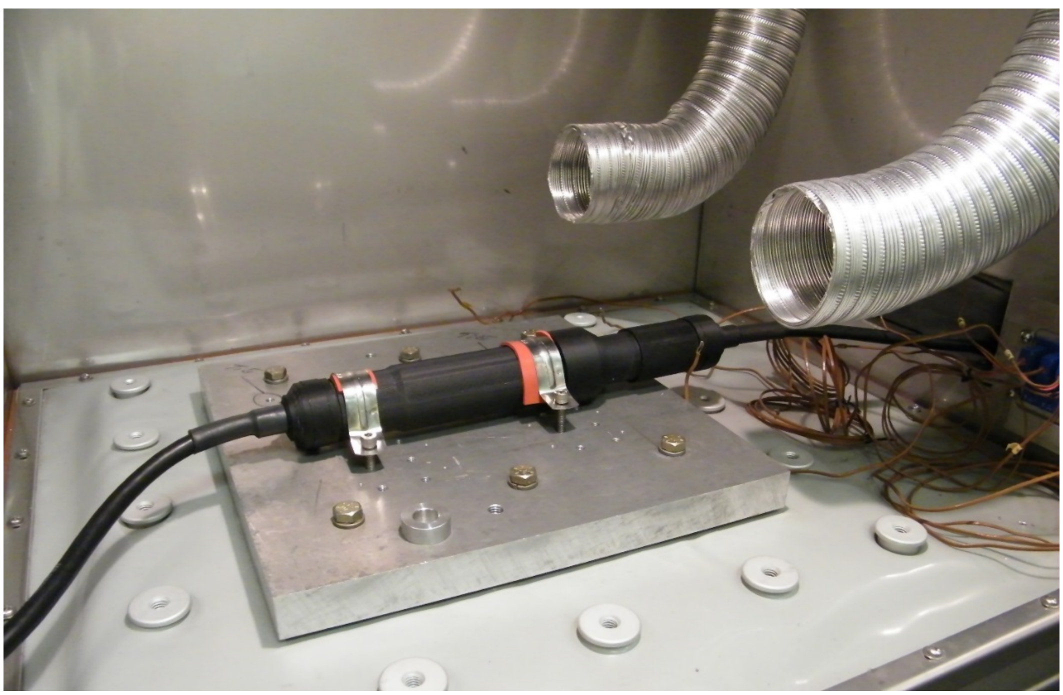

Figure 10: Ingalls prototype splice enclosure installed in the vibration chamber.

Shock Testing

For shock testing, devices were rigidly mounted in a GHI Systems LSM-100 Linear Shock Table. As shock stimuli were applied, bit error rate was monitored at 1.25 gigabits per second using the standard Pseudo Random Binary Sequence (PRBS) 2^{31}-1. When run in entirety, this code would check all permutations of a 31 bit binary word. The code was run while shock stimuli were applied as a method to monitor dropouts, as bit error rate correlates with changes in signal to noise ratio, or in this case, change in optical attenuation.

Peak acceleration exposure was selected at 75 g in agreement with TIA-455-14A. It was difficult to measure low values of shock with acceptable reproducibility, so values of approximately 30 g, 60 g, 75 g, and 90 g were selected for test acceleration values. The device under test would fit the table axially but not radially due to interference with the interlock shield. Consequently, the tests were run with the test devices using axial motion only. Acceleration was first calibrated with the table alone. Test runs were made while monitoring peak shock using an accelerometer.

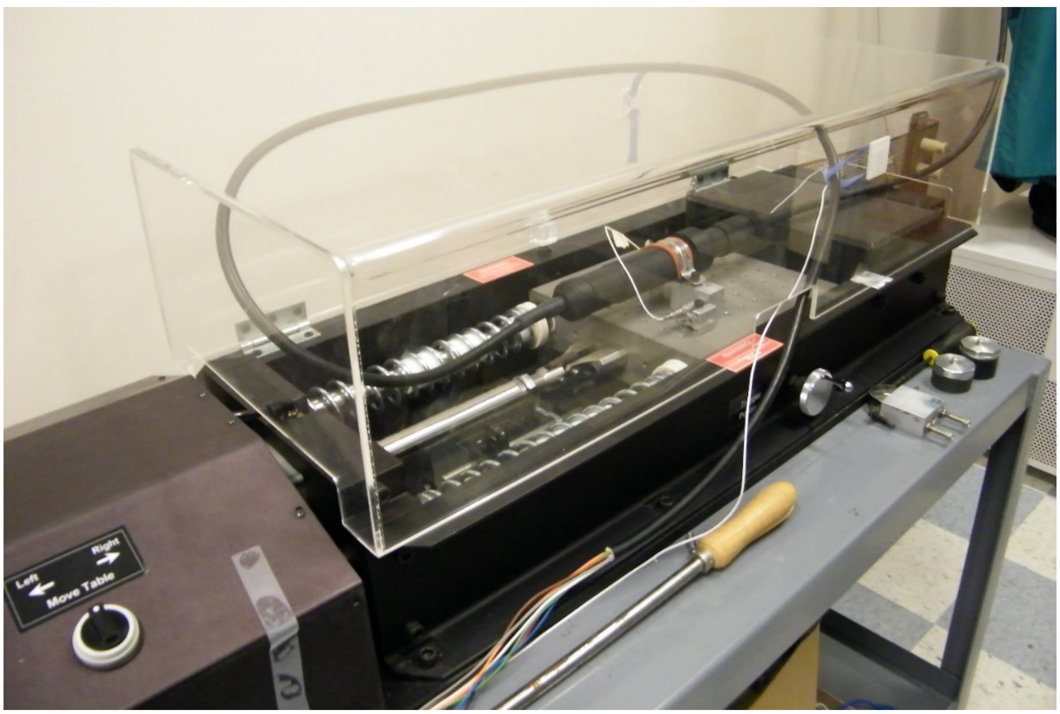

Figure 11: Ingalls prototype splice enclosure installed in the linear shock table.

Vibration and Shock Test Results

Change in Optical Transmittance monitored during random vibration tests showed negligible shifts of -0.011 dB for the TFOCA device and +0.005 dB for the Ingalls prototype. These changes are considered negligible. The tables below show results for Bit-Error-Rate tests run during both random vibration and shock tests.

Table 15. KITCO modified TFOCA observed Bit Errors during vibration.

Device Under Test	Stimulus	Bit Errors (>10^{12} bits sent)
KITCO TFOCA	2 g_{rms}	0
KITCO TFOCA	4 g_{rms}	0
KITCO TFOCA	6 g_{rms}	0
KITCO TFOCA	8 g_{rms}	0
KITCO TFOCA	10 g_{rms}	0
KITCO TFOCA	12 g_{rms}	0

Table 16. Ingalls prototype observed Bit Errors during vibration.

Device Under Test	Stimulus	Bit Errors (>10^{12} bits sent)
Ingalls Prototype	2 g_{rms}	0
Ingalls Prototype	4 g_{rms}	0
Ingalls Prototype	6 g_{rms}	0
Ingalls Prototype	8 g_{rms}	0
Ingalls Prototype	10 g_{rms}	0
Ingalls Prototype	12 g_{rms}	0

Table 17. Observed Bit Errors during shock tests.

MEASURED STIMULUS / BER RESULT	DEVICE UNDER TEST	
	KITCO MODIFIED TFOCA	INGALLS PROTOTYPE SPLICE ENCLOSURE
ACCELERATION 1	33.3 g	25.1 g
BIT ERRORS 1	0	0
ACCELERATION 2	61.4 g	61.7 g
BIT ERRORS 2	0	0
ACCELERATION 3	79.2 g	79.0 g
BIT ERRORS 3	0	0
ACCELERATION 4	91.1 g	87.1 g
BIT ERRORS 4	0	0

Test Conclusions

Random vibration tests (to 12 grms) and shock tests (to 90 g) were performed on cable-to-cable splice enclosures. No signal interruptions were noted during either test. No signal degradation or physical damage were noted during inspection of the devices.

4.0 LIFE CYCLE COST FOR FUSION SPLICING

Equipment Cost

Fusion splicers are widely available. Required components are the fusion splicer, cable and coating strippers, fiber optic cleavers, splice protectors, and cleaning supplies. There are three NAVSEA approved fusion splicer kits listed, and some shipyards use others. Connector and terminus equipment costs are based on generally available termination kits. The estimated incremental cost for equipment supporting connectors and fusion splices is listed below:

- $0.30 cost per connector terminus based on operation and maintenance cost of a termination kit. This varies widely over the existing supply chain.
- $0.20 equipment cost per fusion splice based on operation and maintenance cost for fusion splicer equipment only.

Connection Component and Spares Cost

Each fiber is connected individually. (Note that ribbon fibers are outside the scope of this project.) Fiber optic cable infrastructure is either via cables or Blown Optical Fiber (BOF). The convention used includes a) cost of one connector of a connector pair and b) excludes cost of the fusion splice enclosure.

A fiber optic connector approach requires a terminus for each end of a connection (MIL-PRF-29504), a connector at each end of single or multiple connections, and associated backshells and strain relief for these connections (MIL-PRF-28876 or MIL-PRF-64266). Costs vary depending on the connector material, number of connections, and the degree of protection. Thousands of connector component types must be made available for connections and spares. The estimated termination cost for an 8 terminus connector assembly including connector hardware, consumables, and installation time can exceed $600.00.

Fusion splices for multimode and single mode fiber require cleaning and a fusion splice protector. NAVSEA has a single approved splice protector for all applications (MIL-PRF-24623). Fusion splices are kept inside a splice enclosure (MIL-DTL-24728); this project has identified commercial enclosures as well as additional enclosure concepts. Enclosure costs vary widely depending on the degree of protection and the number of splices. However, since the enclosure does not include precision tolerances for fiber alignment, enclosure costs are much lower than connector costs. Nominal cost per fusion splice is $3.00 including splice protector, solvents, and lint free wipes.

Labor Cost

The convention used assumes that connector assembly time and fusion splice assembly enclosure time are approximately equal.

The cost of terminus and connector assembly at shipyards depends on operator skill. Terminus assembly time can exceed one hour including cable preparation, epoxy cure time, connector assembly, and polishing processes. Efficiency improves with termination quantity at a given time and location. For the purposes of this study, a conservative average of 30 minutes per termini is assumed. The resulting labor cost would be as follows:

- $42.50 terminus assembly cost based on $85 per hour burdened labor cost.

Fusion splicer equipment is automated and controls the required precision alignment. Operators average four fusion splices per hour.

- $21.25 labor per fusion splice based on $85 per hour burdened labor cost.

Acquisition Cost Summary

Total acquisition cost comparison including equipment, supplies, and labor confirm a 70% decrease in cost when using fusion splicing instead of fiber optic connectors. The business case analysis conducted in this project indicates a payback for a fusion splicing unit is approximately 200 connections. Additional savings associated with rework have not been included in this estimate; however, would improve the payback even further.

Life Cycle Cost Summary

With the transition to fusion spliced connections, the following costs are eliminated:

- Supply, inventory, and spares for fiber optic connector components.
- Craftsmanship required for terminus and connector assembly.
- Field maintenance of permanent fiber optic connections.
- Epoxy shelf life management and epoxy curing operations.

The specified fiber optic connector loss limit is 0.75 dB per mated pair. This is subject to handling, cleanliness, and environmental exposure. A fusion splice connection has a nominal loss of less than one tenth of a connector loss. Since a fusion splice is a “weld,” this loss is stable and will not fluctuate over its lifetime.

5.0 CONCLUSION AND RECOMMENDATIONS

This report solves the original problem of justifying the use of fiber optic fusion splices on ships, and avoiding the use of fiber optic connectors where they are not needed. However, in addition the project team found wide agreement and a significant amount of work that had already taken place to qualify components and devices required for fusion splicing. NAVSEA has developed standard dimensions for fusion splice protectors, holders, and jacketed fiber dimensions. The team also justified that fusion splicing is an improvement over other splice methods such as mechanical splicing.

Incremental assembly costs for fusion splicing are 70% less than in situ terminus or connector assembly. Parts and materials required for a fusion spliced cable infrastructure eliminate perhaps hundreds of connector component types. Epoxy shelf life and curing issues associated with connector assembly are eliminated. Use of fusion splices eliminates the variability of end face geometry found in termini assembled on location. Relative to craftsmanship- dependent connector assembly labor, the payback for investment in fusion splicer equipment is approximately 200 splices.

The team verified improvements in link loss and stability associated with fusion splices. We conducted random vibration and shock tests of fusion splices free-float mounted in enclosures (this is worst case), and found them to be rugged.

The obvious recommendation for the shipbuilding industry is to continue increasing the use of fusion splices over fiber optic termini and connectors. The team can extend the vision even further- that equipment connections and infrastructure connections can be made entirely with fusion splices and not require termini or connectors at all. Realization of this vision requires just two things: a) adopt fusion splicing as a manufacturing process, and b) use small fusion splice enclosures that facilitate pigtail connections in lieu of connectors. We envision the future when equipment items are delivered with optical fiber pigtails and integral / nearby fiber optic splice enclosures.