

## *Fiber Optic Tester with Go-No-Go Acceptance Criteria – Final Report*

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## 1. EXECUTIVE SUMMARY

The NSRP Electrical Technologies Panel submitted a project request to investigate the development of an automated inspection process for fiber optic connectors. The project was approved and funded in August 2010. This report provides the background, findings and conclusions of the project. Commercially available automated inspection equipment was leveraged and evaluated during the project.

## 2. PROJECT ABSTRACT

There is an opportunity to remove subjectivity in the inspection of fiber optic end face and replace it with an objective process. This improved process will improve productivity, reduce rework and improve the lifecycle of the fiber optic system.

### 2.1. Concept Description

Automating the inspection process can remove human subjectivity and ensures a strong level of process control can be implemented and maintained over time. Develop a Mil-Std-2042B compatible endface inspection profile to be used with an automated fiber optic connector quality assessment device that provides a "Go/No-Go" result for shipyard and fleet technicians. Investigate utilizing current hardware and software platforms.

### 2.2. Project Goals and Objectives

This project is being submitted to reduce excessive re-work/replacement of fiber optic connectors during ship construction caused by poor endface quality and contamination due to subjective inspection and cleaning procedures. Root cause analysis typically does not occur in the shipyard environment for this type of failure. The associated re-work with wasted labor and materials costs are not appropriately captured. Therefore cost increases specifically related to poor connector endface quality are not tracked or associated back to the actual problem.

### 2.3. Task Description

Task 1: Hold a kick-off meeting with key players, NSWCDD, JDSU, KITCO and Northrop Grumman Shipbuilding – Newport News to perform a development analysis. This includes a test plan identifying the number of test samples that are needed, size and type of defect that will be introduced into the endface and what type of optical performance tests will be performed. During these discussions the group will understand what current data already exists to assure duplicate testing is not performed.

***Timeline - Within the two weeks after project is funded***

***Participants – KITCO / NGSB-NN / JDSU***

Task 2: Identify and procure the necessary material to manufacture appropriate test assemblies that were identified in task 1.

***Timeline - One month after Task 1 is completed***

***Participants - KITCO***

- Task 3: Manufacture test assemblies to include specific defects identified in task 1.  
***Timeline – Two months after Task 1 is completed***  
***Participants - KITCO***
- Task 4: Conduct bi-monthly teleconferences to updates the entire team on progress and status to-date.  
***Timeline – Two months after Task 1 is completed***  
***Participants – KITCO / NGSB-NN / JDSU***
- Task 5: Perform optical testing on all assemblies. This will include insertion loss, return loss, cable link loss and cable channel loss. The purpose of these tests is to help establish the go-no-go acceptance criteria. Once these tests are completed, the data will be entered into the software to create the criteria.  
***Timeline – Three months after Task 1 is completed***  
***Participants - KITCO***
- Task 6: Compile test samples and data obtained from testing and send to NSWCD for evaluation.  
***Timeline – Four months after Task 1 is completed***  
***Participant - KITCO***
- Task 7: Conduct bi-monthly teleconferences to updates the entire team on progress and status to-date.  
***Timeline – Four months after Task 1 is completed***  
***Participants –KITCO / NGSB-NN / JDSU***
- Task 8: Hold a meeting with NSWCD to review project to-date. The goal of this meeting is to review all of the testing and data to-date and agree upon the recommended go-no-go criteria. Also agree upon the number of tests and the number of shipyards needed to participate in the prototype field testing.  
***Timeline – Five months after Task 1 is completed***  
***Participant – KITCO / NGSB-NN / JDSU***
- Task 9: Identify and procure the necessary material to manufacture appropriate test assemblies that were identified in task 8 for field testing at shipyards.  
***Timeline – Five months after Task 1 is completed***  
***Participant - KITCO***
- Task 10: Manufacture field test assemblies identified in task 8. The objective of this test is to assure the shipyards are capable of producing cable assemblies that can pass the go-no-go criteria.  
***Timeline – Six months after Task 1 is completed***  
***Participant - Northrop Grumman Shipbuilding – Newport News, Northrop Grumman Shipbuilding – Gulf Coast and General Dynamics – BIW. KITCO to support on site manufacturing of assemblies at each shipyard***

- Task 11: Conduct bi-monthly teleconferences to updates the entire team on progress and status to-date.  
***Timeline – Six months after Task 1 is completed***  
***Participants – KITCO / NGSB-NN / JDSU***
- Task 12: Perform additional optical performance on shipyard manufactured field test assemblies.  
***Timeline – Seven months after Task 1 is completed***  
***Participants - KITCO***
- Task 13: Conduct bi-monthly teleconferences to updates the entire team on progress and status to-date.  
***Timeline – Eight months after Task 1 is completed***  
***Participants – KITCO / NGSB-NN /JDSU***
- Task 14: Generate a report that provides NAVSEA with the appropriate data and research that supports Go-No-Go inspection criteria.  
***Timeline – Nine months after Task 1 is completed***  
***Participants – KITCO / NGSB-NN / JDSU***
- Task 15: Hold a Final Project meeting with NSWCD to review project success.  
***Timeline – Ten months after Task 1 is completed***  
***Participants – KITCO / NGSB-NN / JDSU***

### **2.3.1. Milestones**

- MS 1: Completion of Kick-Off meeting  
***Output –Completion of Presentation Materials and Meeting Notes***  
***Verification - Acceptance of Presentation Materials and Meeting Notes***  
***Status:*** A kickoff meeting was held at the Washington Navy Yard on July 22, 2010. Briefing material and notes can be found in Appendix A.
- MS 2: Procurement of Project Materials  
***Output– Completion of Project Material Procurement***  
***Verification – Certification by Contractor of Material Procurement and Receipt***  
***Status:*** Project material procurement was completed on October 11, 2010. Milestone completion notification can be found in Appendix B.
- MS 3: Completion of Test Cables Builds and Preliminary Test Results  
***Output– Completion of Cable Builds and Test Report to NSWCD***  
***Verification – Certification by Contractor of Cable Build Completion and Receipt of Preliminary Test Report***  
***Status:*** Test cable builds and Preliminary Testing was completed on October 11, 2010. Milestone completion notification can be found in Appendix B.
- MS 4: Completion of Shipyard A Field Test  
***Output– Completion Report of Shipyard A Field Test***  
***Verification – Receipt and Acceptance of Shipyard A Field Test Report***

- Status:** Field Testing at Shipyard A was completed on December 10, 2010.
- MS 5: Completion of Shipyard B Field Test  
**Output– Completion Report of Shipyard B Field Test**  
**Verification – Receipt and Acceptance of Shipyard B Field Test Report**  
**Status:** Field Testing at Shipyard B was completed on December 14, 2010.
- MS 6: Completion of Shipyard C Field Test  
**Output– Completion Report of Shipyard C Field Test**  
**Verification – Receipt and Acceptance of Shipyard C Field Test Report**  
**Status:** Field Testing at Shipyard C was completed on December 16, 2011.
- MS 7: Completion of Final Project Report  
**Output– Final Project Report**  
**Verification – Receipt and Acceptance of Final Project Report**  
**Status:** Completed May 30, 2011

### **3. BACKGROUND – ORIGINAL WHITEPAPER**

#### **3.1. Problem**

Excessive re-work/replacement of fiber optic connectors during ship construction caused by poor endface quality and contamination due to inadequate inspection and cleaning procedures. Root cause analysis typically does not occur in the shipyard environment for this type of failure and the associated re-work with wasted labor and materials costs are not appropriately captured. Therefore cost increases specifically related to poor connector endface quality are not tracked or associated back to the actual problem.

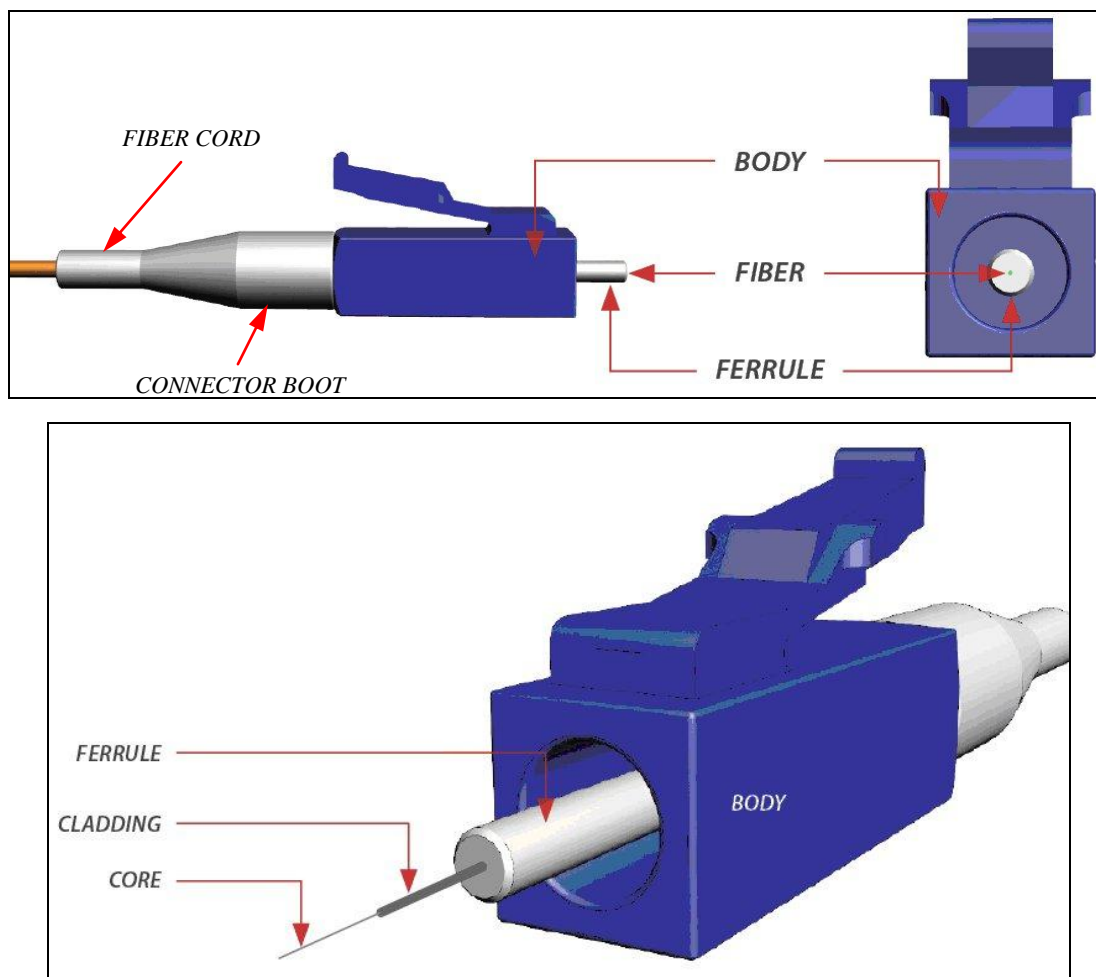
For harsh environment programs this cost can be substantial. A recent presentation by NAVAIR indicated that “Dirty/contaminated fiber resulted in \$3.67m of unnecessary Weapons Replaceable Assembly “repairs” during one FY for the F/A-18 E/F program.

#### **3.2. Fiber Optic Connectors**

##### **3.2.1. Connector Mechanics**

Fiber connectors enable fiber-to-fiber mating by aligning the two optical fibers. Fiber connectors come in various types and have different characteristics for use in different applications. The main components of a fiber connector are detailed in the following figures:





**Figure 1 – Fiber Connector Components (LC Example)**

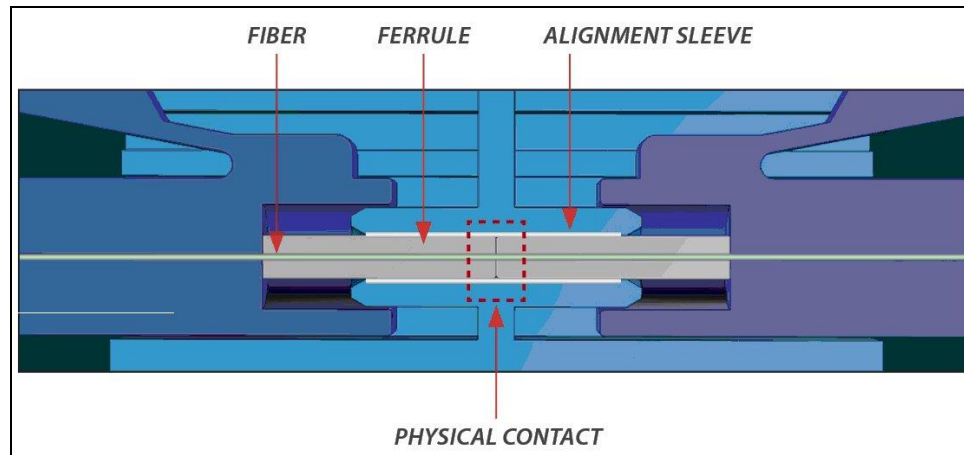
**Body:** Houses the ferrule that secures the fiber in place; utilizes a latch and key mechanism that aligns the fiber and prevents the rotation of ferrules of two mated connectors.

**Ferrule:** Thin cylinder where the fiber is mounted and acts as the fiber alignment mechanism; the end of the fiber is located at the end of the ferrule which is referred to as the ‘endface’ throughout this document.

**Fiber:** CLADDING: Glass layer surrounding the core, which prevents the signal in the core from escaping.

CORE: The critical centre layer of the fiber; the conduit that light passes through.

Fiber connectors join optical fibers using a precision alignment sleeve. The sleeve passively aligns the two ferrules onto a common axis. In each connection there are two connectors. One is typically mounted to a bulkhead (often called the female connector, bulkhead connector, connector port or receptacle) the other is typically in-hand (called the male connector, jumper connector or plug).



**Figure 2 – Fiber Connection**

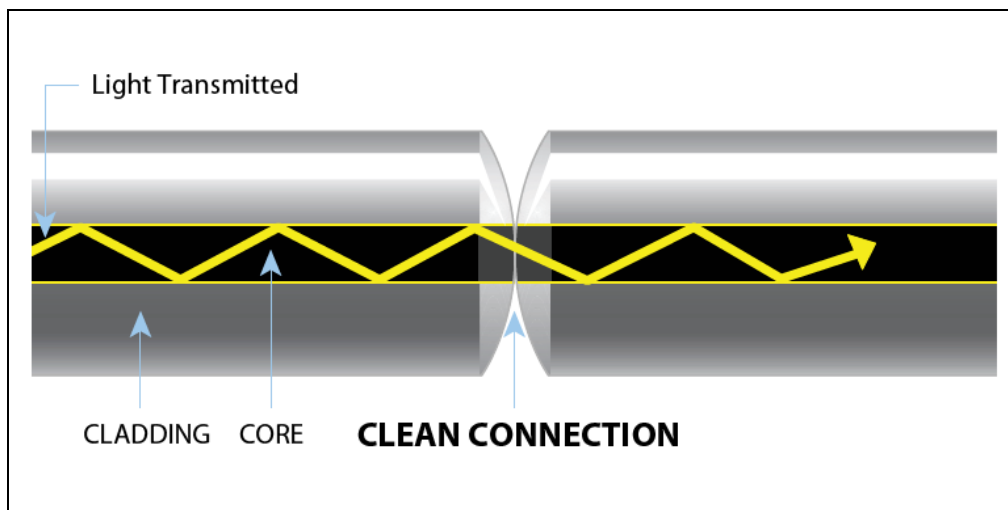
To achieve a proper fiber connection, three things must occur:

1. Fiber core alignment
2. Physical contact
3. Pristine fiber interface

Modern connector designs and production techniques have eliminated most of the challenges to achieving core alignment and physical contact. The remaining challenge, to ensure the fiber endface is clean and free of defects, must be addressed in the field.

### 3.2.2. Failure Modes for Fiber Endfaces

The presence of dirt, debris or defects within the fiber core causes loss of signal power (called attenuation or insertion loss) and also causes a portion of the optical power to be reflected back upstream to the light source (called back reflection). Both insertion loss and back reflection can have a negative effect on system performance. Defects in either connector will affect the performance of the mated connection.



**Figure 3 – Proper Fiber Connection**

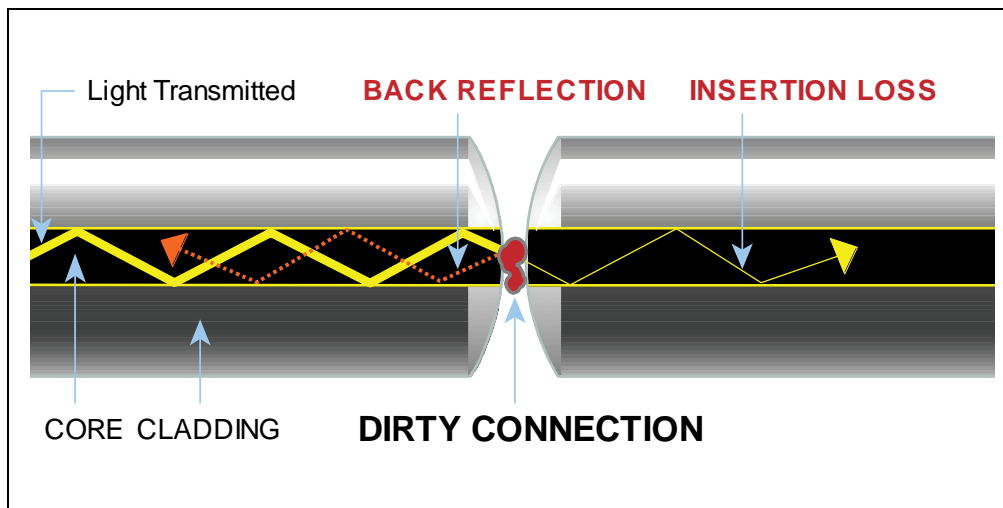
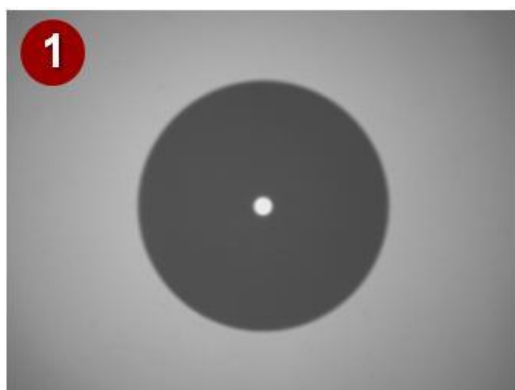
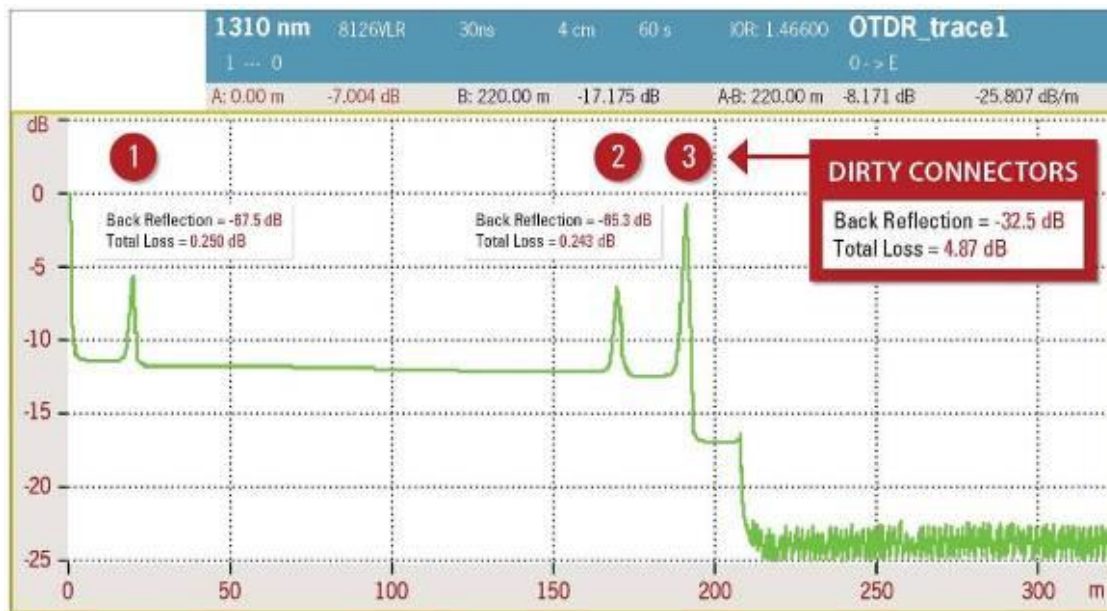
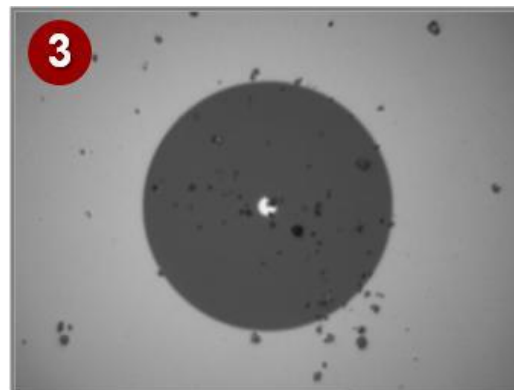


Figure 4 – Dirty Fiber Connection



Back Reflection = **-67.5 dB**  
Total Loss = **0.250 dB**



Back Reflection = **-32.5 dB**  
Total Loss = **4.87 dB**

Figure 5 – OTDR Trace Showing Effect of Debris

The above figure shows a large impact on system performance from a relatively small amount of debris.

### 3.2.3. Fiber Connector Defects

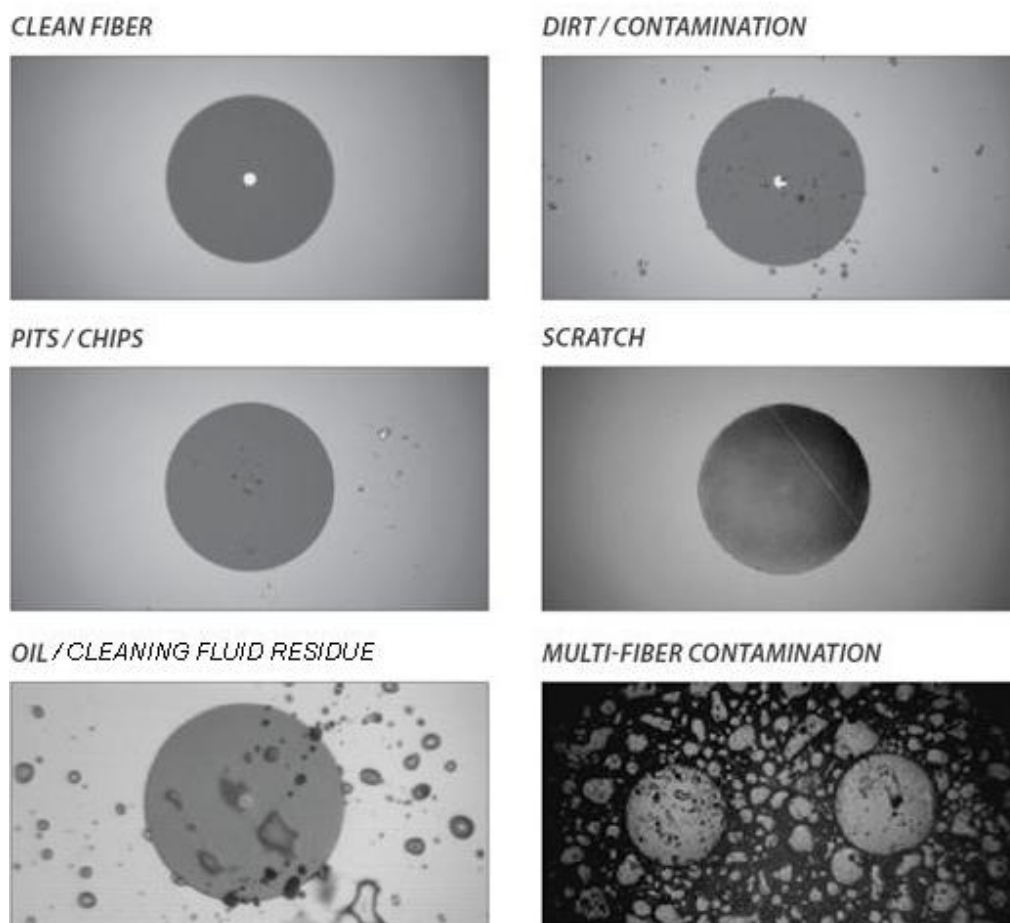
There are many types of defects. Commonly used terminologies include: contamination, particles, pits, chips, cracks, scratches, loose contamination, embedded contamination etc. For this document the defects will form two categories:

1. **Scratches:** Permanent linear surface features.
2. **Defects:** Visible/detectable on the fiber endface. These include contamination particles, debris, pits, chips etc.

Scratches can be the result of improper polishing process or can be created during incorrect cleaning practices or mishandling of fiber connectors. Scratches near and/or across the core are problematic because they can create excessive back reflection.

The most common defect found on fiber endfaces is simple contamination. Dirt is everywhere; a typical dust particle (2–15µm in diameter) can significantly affect signal performance and cause permanent damage to the fiber endface. Most field test failures can be attributed to dirty connectors, and most of them are not inspected until the problem is detected AFTER permanent damage has already occurred.

If dirt particles get on the core surface the light becomes blocked, creating unacceptable insertion loss and back-reflection. Furthermore, those particles can permanently damage the glass interface, digging into the glass and leaving pits that create further back-reflection if mated. Also, large particles of dirt on the cladding layer and/or the ferrule can introduce a barrier that prevents physical contact and creates an air gap between the fibers. To further complicate matters, loose particles have a tendency to migrate.



**Figure 6 – Fiber Connection and Various Connector Endface Views**

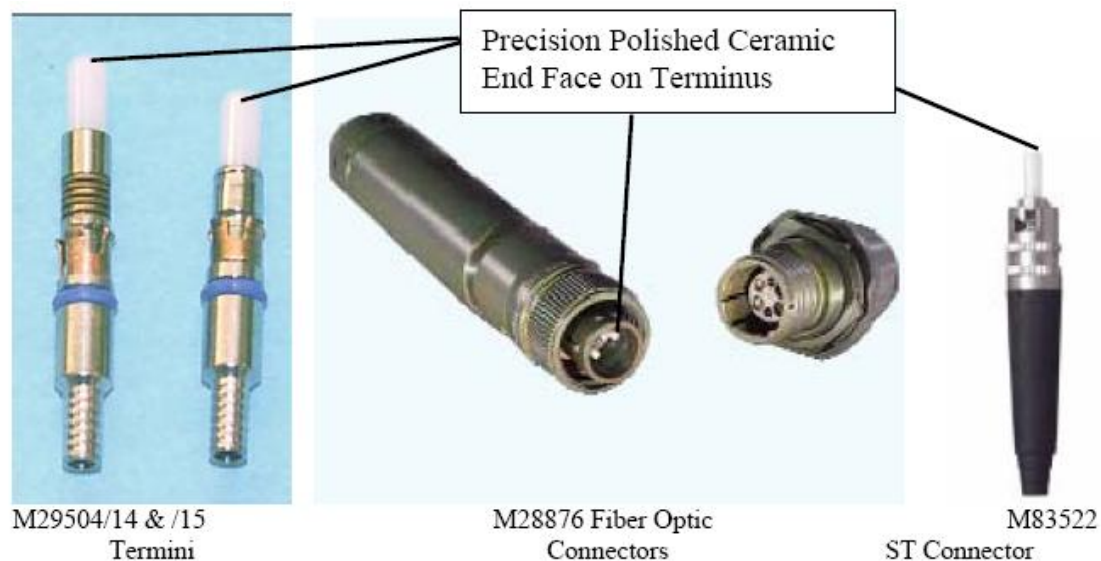
### **3.3. US Navy Specific Connectors & Process**

The United States Navy is deploying fiber optics as the primary communication system for tactical and non-tactical shipboard applications on almost every current and future ship platform.

The current on-hull manufacturing method for fiber optic cable assemblies requires a complex process which is performed using an entirely manual method. Perhaps the most critical step in the process is the quality visual check at the time of fabrication. If this visual check is not done adequately the fiber link may not pass performance testing and require costly re-work or replacement by shipyard personnel. The current process relies heavily on the Technicians level of expertise, eye sight, and equipment quality. The visual inspection criteria identified in Mil-Std-2042-5B is ambiguous and subjective resulting in inconsistent real world quality. When poor workmanship is not identified by the Technician at the time of termination, the cost of troubleshooting and re-work/replacement is very expensive. The typical shipyard repair process is to cut-off the failing connector and replace it with a new one resulting in wasted labor and material. This usually occurs many weeks after initial installation and when removal and repair setup are very inefficient. The troubleshooting process to identify the problem may take the efforts of many different disciplines wasting significant resources. Typically the damaged

connector must be removed from the backshell or Fiber Optic Interconnection Box (FOICB) causing disruption to schedule and space delivery.

Shipboard fiber optic connectors installed by shipyard personnel are typically ruggedized Single Terminus (ST - M83522), SC, LC) or Multi-terminus (MT- M28876) heavy duty connectors. The MT connectors are typically populated with M29504 termini. (Figure 1)



**Figure 7 – Example of Shipboard Fiber Optic Terminations**

Logically, rework should be completed at the time of the initial installation and not as the result of and after testing has been performed. Rework is always inefficient but when performed after multiple connections and testing has been performed wastes significant labor and requires duplication of effort. A tool that would provide an automated and objective Go/No Go during the fabrication process would result in greatly improved quality and efficiency. Development of a Mil-Std.2042B profile and automated inspection device should result in the increased reliability and accuracy for deckplate inspection resulting in much higher utilization yields while reducing waste and scrap. The Navy would receive a better product at a lower price.

Because the use of a microscope to perform subjective visual testing is not governed by any type of sight evaluation requirement of the technician; inconsistent results and process variation routinely occur. Resolution, field of view, magnification and focus all factor into the endface inspection results. Technicians using microscopes may accept or reject connectors that other technicians may evaluate with an opposite determination. The key to efficiency is to have all technicians accept and reject connectors appropriately and consistently based on objective criteria.

#### **Mil-Std-2042-5B Quality Check Instruction:**

*Examine the terminus with the optical microscope to ensure that the optical surface is smooth and free of scratches, pits, chips, and fractures. If any defects are present, repeat the polish with the 0.1 um paper (and the ultrafine paper for enhanced polish termini) or reterminate the fiber.*

(NOTE: Do not polish the terminus more than necessary to pass the quality check.) A high intensity back light may be used to illuminate the fiber during the quality check.

NOTE: A small number of very light scratches (e.g. scratches that can barely be seen) is minimally acceptable.

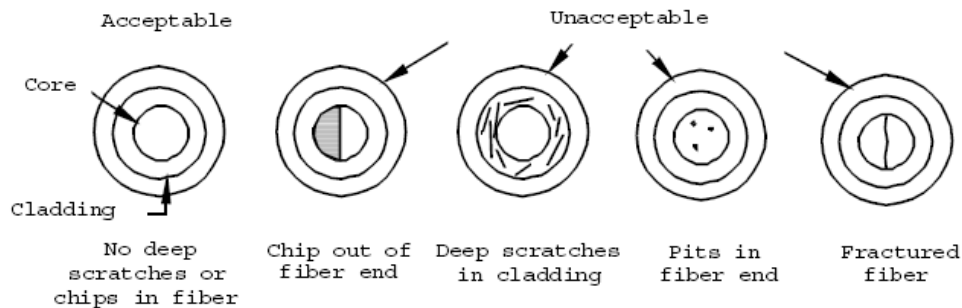


FIGURE 5A1-67. Quality check.

NOTE: Depending on the optical microscope used, viewing quality may be different.

#### Figure 8 – Mil-Std-2042-5B Quality Check Criteria

In addition, endface inspection (and cleaning as required) should always be performed prior to mating fiber connectors. Uninspected or poorly cleaned connectors may result in permanent damage to connectors and electronics. An easy to use and reliable tool will result in much greater application of these important principals.

#### A typical shipboard fiber optic installation scenario may be as follows:

1. Shipboard electrician is provided material and run sheet to fabricate a fiber optic connector on one end of a cable in a specific space.
  - a. The fabrication is performed and a visual inspection using a microscope and Mil-Std-2042B criteria is performed. At this time the other end has not been fabricated. The fiber core is probably not visible making it more difficult to identify defects.
  - b. Dust caps are placed on the connector.
  - c. Approximate fabrication time is identified in Table 1.
  - d. Cable is not ready for performance testing.

Connector Fabrication Time		
Cable Size/Strands Terminated	Connector Type	Technician Time (hours)
4	ST	1.3
4	MT	2
8	ST	2.7
8	MT	4
36	ST	12
36	MT	18

Table 1

2. A month may pass before the electrician is provided the material and direction to fabricate the opposite end of the cable in another space.
  - a. The fabrication is performed and a visual inspection using a microscope and Mil-Std-2042B criteria is performed. At this time the other end has been fabricated. The fiber core is most likely visible making it easier to identify defects.
  - b. Dust caps are placed on the connector.
  - c. Approximate fabrication time is identified in Table 1.
  - d. Cable is ready for performance testing.
3. A month later (two months after first connector is fabricated) the electricians are scheduled to test the completed cable.
  - a. Visual inspection is not performed.
  - b. Cleaning should be performed but is not always done.
  - c. Testing is performed.
  - d. Approximate testing time is identified in Table 2
    - i. If the cable passes dust caps are installed or connectors are mated.
    - ii. If testing fails the connectors are visually inspected. For MT connectors this requires disassembly if a probe is not used. If damage is noted than disassembly is required to attempt repair.
      1. Repair is attempted. Repair time can take between 25% and 100% of the original fabrication time.
      2. The connector is reassembled and tested.
      3. Testing time is then duplicated.
      4. If the test fails again troubleshooting is attempted.
      5. Troubleshooting can take as long as connector fabrication or longer depending on the failure mode. Therefore, typically the connectors are cut off and re-fabricated starting the cycle all over again.
  - e. Once testing is successful the system is ready to be lit off.
  - f. Dust caps are installed or connectors are mated.

Cable Test Time		
Cable Size/Strands Terminated	Connector Type	Technician Time (hours)
4	ST	0.5
4	MT	0.67
8	ST	0.9
8	MT	1.2
36	ST	2.4
36	MT	3.6

**Table 2**

4. A month later (3 months after the first connection is fabricated) the “system” is scheduled for light off testing.
  - a. If the system does not operate the connectors are typically disconnected and troubleshooting is attempted.



- b. A visual inspection is not typically performed until the troubleshooting phase. At that point the opportunity to have contaminated and damaged connectors is high due to the shipboard construction environment.
- c. If visual inspection is performed each time the connectors are mated or de-mated the opportunity for endface damage is reduced by as much as 90%.
- d. If connector endface damage is found at this point the entire fabrication/test cycle may need to be repeated.

Following the above scenario for an 8 channel MT connector could result in wasted labor of 10.4 hours (53%) for one cable. (Table 3)

Fabrication Time	Technician Time (hours)	Wasted Labor (hours)
Connector A	4	
Connector B	4	
Test Time	1.2	
Repair Time	2	2
Retest Time	1.2	1.2
Troubleshoot Time	2	2
Replacement Cycle	5.2	5.2
Total hours	19.6	10.4
% of Wasted Labor		53%

**Table 3**

The above Table does not factor in wasted material or schedule impact. Therefore, it is critical that rework (if required) be limited to the initial fabrication period so labor and material waste can be reduced or eliminated. A Go/No Go visual testing device, used consistently each step along the way will provide tremendous cost savings over current methods.

#### **4. SOLUTION: BEST PRACTICE WITH GO/NO-GO ANALYSIS**

Tier 1 telecom providers take a proactive approach to maintaining their fiber optic connectivity. Companies such as Verizon, AT&T, Telstra, British Telecom, Telefonica and others have established a best-practice for handling fiber optic connectors throughout their network. Technicians are required to visually inspect the condition of both connectors in every connection prior to mating. If necessary, the connectors are cleaned using a well defined process then inspected again. These companies have established pass/fail criteria in line with their network performance needs. As the visual inspection process is subjective when performed by a person, several of the Tier 1 companies use inspection equipment that provides a go/no-go (red light / green light) analysis of the endface condition.

In contrast, Mil-Std-2042-5B does not provide a step by step detailed inspection and cleaning process. It does indicate that before performing the Quality Check the technician should clean the connector “*using a wipe dampened with alcohol and blow it dry with air*”.

Additional guidance found in the testing section of Mil-Std-2042-6B states:

*NOTE: Use a wipe dampened with alcohol to clean the adapters/connectors and blow them dry with air before making connections.*

Training provided to some shipyards does identify and emphasize a step-by-step inspection and cleaning process. However, if all personnel that handle the fiber are not trained or don’t have the necessary materials; inspection and cleaning processes will most likely be inconsistent. Just as all TSA agents at the airport don’t catch the exact same threats; some fiber technicians may not catch the same defects.

A consistent process can help prevent the type of contamination that is the most common cause of fiber damage. Technicians must use consistent and objective criteria when evaluating fiber quality. Establishment of best practice handling along with an automated Go/No Go system should dramatically reduce fiber rework.

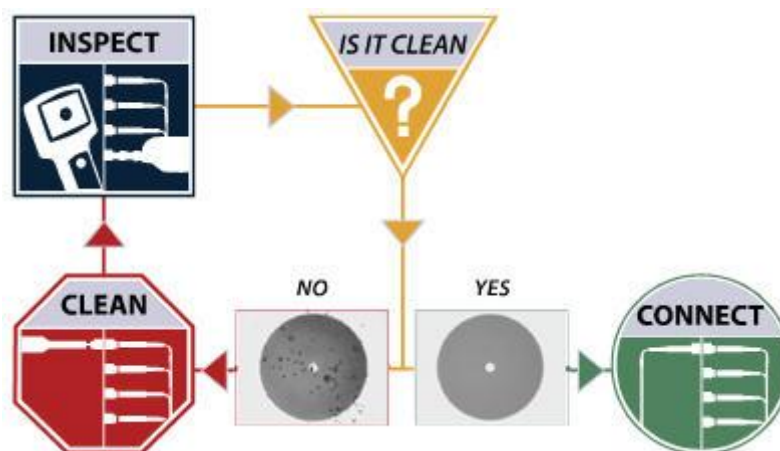
#### 4.1. Establish Best Practice for Handling FO Connectors

Visual Inspection of fiber interconnects is the only way to determine if connectors are free of defects and clean prior to mating them. A video microscope magnifies an image of a connector endface for viewing on either a laptop or portable display depending on the product used.

The requirement to inspect fiber connectors and clean if necessary before connection is mandatory in all cases; this includes the first use of new cords and transceivers or any equipment/panels with fiber interfaces.

##### ***Inspect/Clean/Connect Process Flow:***

Employ the inspect/clean/connect process as per the following diagram and steps.



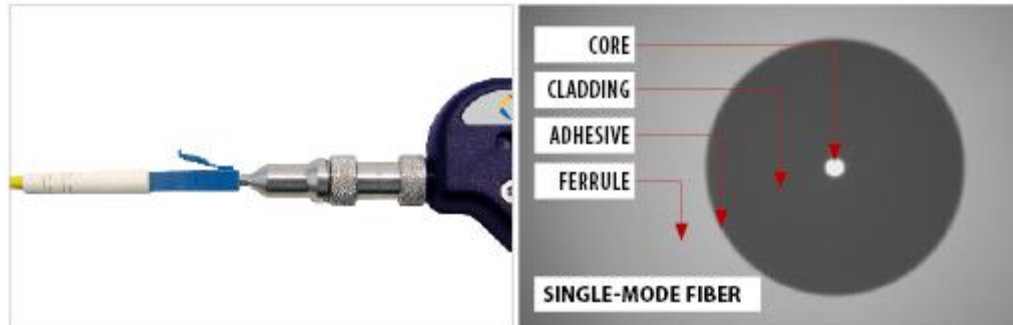
**Figure 9 – Optical Connector Inspect/Clean/Connect Process**

<b>INSPECT</b>	<ol style="list-style-type: none"> <li>1. Select the appropriate tip for the connector/adaptor you are inspecting.</li> <li>2. Inspect both connector endfaces (patchcord/bulkhead/pluggable interface) using the microscope.</li> </ol>
<b>IS IT CLEAN?</b>	
<b>CLEAN</b>	No – Upon inspection, <b>if the connector fails to meet the criteria</b> , clean using a NAVSEA approved cleaning tool then re-inspect.
<b>CONNECT</b>	Yes – <b>If the defects and scratches found are within acceptance criteria limits</b> the fiber interfaces can be connected.

Fiber endface inspections are performed through two different methods. If the cable assembly is accessible, you can insert the connector ferrule into the microscope to do an inspection; this is generally known as patchcord inspection. If the connector is within a mating adaptor on the device or patch panel, you can use a ‘probe’ microscope to insert into the open end of the adaptor and view the connector inside; this is known as bulkhead or through adaptor connector inspection.

#### 4.1.1. Patchcord Inspection

1. Select the appropriate tip that corresponds to the connector type under inspection and fit it on to the microscope.
2. Insert the connector into the tip and adjust focus to inspect.



**Figure 10 – Patchcord Microscope Inspection**

#### 4.1.2. Bulkhead / Through Adaptor Connector Inspection

1. Select the appropriate tip/probe that corresponds to the connector type under inspection and fit it to the probe microscope
2. Insert the probe into the bulkhead and adjust focus to inspect



**Figure 11 – Bulkhead / Through Adaptor Connector Microscope Inspection**

### **4.1.3. IBYC Benefits**

The benefits proactively inspecting both connectors in every connection prior to mating are:

- 1- Identify failing connectors at the time of manufacture
- 2- Reduce time spent reworking bad connectors
- 3- Reduce Network Downtime
- 4- Reduce Network Troubleshooting
- 5- Optimize Signal Performance
- 6- Prevent Network Damage

## **4.2. Establish Acceptance Criteria**

The criteria used to determine if a fiber optic connector endface is good or bad should align with the performance requirements of the network. Several Tier 1 telecoms have adopted a two level approach, using very stringent requirements for beginning-of-life (brand new connectors or assemblies from a vendor) and more pragmatic requirements for in-service (connectors in place, where rework or replacement would be more costly). The network owner must determine if the benefits of this two level approach outweigh the benefits of having a single requirement for all situations.

Separate criteria are used for single-mode and multimode fiber connectors, as performance criteria are different for SM and MM systems and as defects affect these fibers differently.

The most commonly used criteria are found in an international standard for fiber optic connector visual inspection; IEC-6130-3-35. These parameters are often used as beginning-of-life requirements. In-service requirements (when this distinction is made) are typically more forgiving on scratches and defects in the cladding for SM, and in the cladding and core for MM. A common adjustment to pass / fail criteria is to expand the area near the fiber edge excluded

from analysis, as slight chips at the edge or an epoxy gap do not affect connector performance. The IEC requirements are:

**Visual requirements for PC polished connectors, single mode fibre, RL  $\geq$  45 dB**

Zone name	Scratches	Defects
A: core	None	None
B: cladding	No limit $\leq$ 3 $\mu$ m None > 3 $\mu$ m	No limit < 2 $\mu$ m 5 from 2 $\mu$ m to 5 $\mu$ m None > 5 $\mu$ m
C: adhesive	No limit	No limit
D: contact	No limit	None $\Rightarrow$ 10 $\mu$ m
<p>NOTE 1 For scratches, the requirement refers to width.</p> <p>NOTE 2 No visible subsurface cracks are allowed in the core or cladding zones.</p> <p>NOTE 3 All loose particles must be removed. If defect(s) are non-removable, it must be within the criteria above to be acceptable for use.</p> <p>NOTE 4 There are no requirements for the area outside the contact zone since defects in this area have no influence on the performance. Cleaning loose debris beyond this region is recommended good practice.</p>		

**Visual requirements for PC polished connectors, multimode fibres**

Zone name	Scratches	Defects
A: core	No limit $\leq$ 5 $\mu$ m 0 > 5 $\mu$ m	4 $\leq$ 5 $\mu$ m None > 5 $\mu$ m
B: cladding	No limit $\leq$ 5 $\mu$ m 0 > 5 $\mu$ m	No limit < 2 $\mu$ m 5 from 2 $\mu$ m to 5 $\mu$ m None > 5 $\mu$ m
C: adhesive	No limit	No limit
D: contact	No limit	None $\geq$ 10 $\mu$ m
<p>NOTE 1 For scratches, the requirement refers to width.</p> <p>NOTE 2 No visible subsurface cracks are allowed in the core or cladding zones.</p> <p>NOTE 3 All loose particles must be removed. If defect(s) are non-removable, it must be within the criteria above to be acceptable for use.</p> <p>NOTE 4 There are no requirements for the area outside the contact zone since defects in this area have no influence on the performance. Cleaning loose debris beyond this region is recommended good practice.</p> <p>NOTE 5 The zone size for multimode fibres has been set at 65 <math>\mu</math>m to accommodate both 50 <math>\mu</math>m and 62,5 <math>\mu</math>m core size fibres. This is done to simplify the grading process.</p>		

**Figure 12 – IEC-61300-3-35 pass / fail criteria**

In contrast, the Mil-Std-2042-5B requirements are much less defined, and do not differentiate between SM and MM fiber. While there are obvious and simple changes that could improve this specification, the potential benefits must be weighed against the costs of changing an established

requirement. If a change to the existing requirements is considered, the proposed criteria must match the performance requirements and the work environment of the network.

### **4.3. Provide Automated Go/No-Go Analysis**

Visual inspection of fiber endfaces by personnel is a subjective process. Even with perfect repeatability of the microscope (lighting, focus, centering) the comparison to pass/fail criteria and decision as to pass/fail will be subject to technician eyesight and their interpretation of defect size and position. The optimal tool for determining if a fiber endface is acceptable is a hand-held integrated hardware/software system that provides automated analysis of fiber optic end-faces on a repeatable basis. The tool will:

- Display a live image (dual magnification)
- Identify and characterize defects and contamination
- Evaluate based on NAVSEA PASS/FAIL criteria
- Provide PASS/FAIL results at the push of a button
- Provide detailed analysis reports
- Save and archive images and/or test results
- Operate on a hand-held platform, comparable in size to an optical power meter

Automating the inspection process removes human subjectivity and ensures that a strong level of process control can be implemented and maintained over time.

A commercial off the shelf product from JDSU satisfies the criteria above, with the exception of being a truly hand-held device. The P5000 probe microscope and FiberCheck2 software require a Windows based laptop to operate. The system can operate on miniature / ruggedized computing platforms such as the Panasonic ToughBook U1.



**Figure 13 – JDSU FBP-P5000 probe microscope and FiberCheck2 software**



**Figure 14 – Panasonic Toughbook U1**

## 5. PROJECT DEFINITION

- 1) Develop a Mil-Std-2042B compatible endface inspection profile to be used with an automated fiber optic connector quality assessment device that provides a "Go/No-Go" result for shipyard and fleet technicians. The profile will identify acceptable criteria based on critical endface and fiber zones by measuring and grading; pits, scratches and contamination.
- 2) Implement NAVSEA profile on existing probe and laptop based inspection system.
- 3) Develop a handheld automated fiber optic connector inspection device utilizing a probe and LCD display that will provide a "Go/No-Go" result and store the results for field use by shipyard and fleet technicians. The device will utilize the Mil-Std-2042B profile developed above, be battery operated and small in size, and allow shipyard specific data to be captured. The results should be downloadable to a PC in order to print results in report format as may be required.

## 6. PRELIMINARY TESTING

In order to propose a recommended M2042 compatible test profile, KITCO manufactured 20 test specimens of the following configurations:

- (i) M29504/14-4131C-M83522/16-DNX (MM) 5 ea – 2m
- (ii) M29504/15-4171C-M83522/16-DNX (MM) 5 ea – 2m
- (iii) M29504/14-4141C-M83522/16-DNY (SM) 5 ea – 2m
- (iv) M29504/15-4181C-M83522/16-DNX (SM) 5 ea – 2m

Minor defects were intentionally induced on about ½ of the samples. These defects were created using different techniques but primarily by changing the polishing film order or manipulating the number of figure-8's performed. Some of the defects were more obvious than others. A reasonable range of visual quality was obtained.

Four experienced/certified fiber technicians who perform field installations as their primary function were tasked with individually evaluating the 20 specimens in accordance with the MIL-STD-2042B Visual Quality Check criteria to rate them as Pass or Fail.

Optical performance testing in adherence to Mil-STD-2042B was then performed on all cable specimens. Testing for both single-mode (SM) and multimode (MM) included Cable Assembly Link Loss testing (Method 6C1) and for SM only Cable Assembly Return Loss Testing (Method 6K1).

After evaluating the results, a Proposed M2042 Compatible Inspection Criteria Profile was established. Automated testing was performed on all connectors and compared against the results recorded by the technicians.



## 6.1. Proposed Criteria

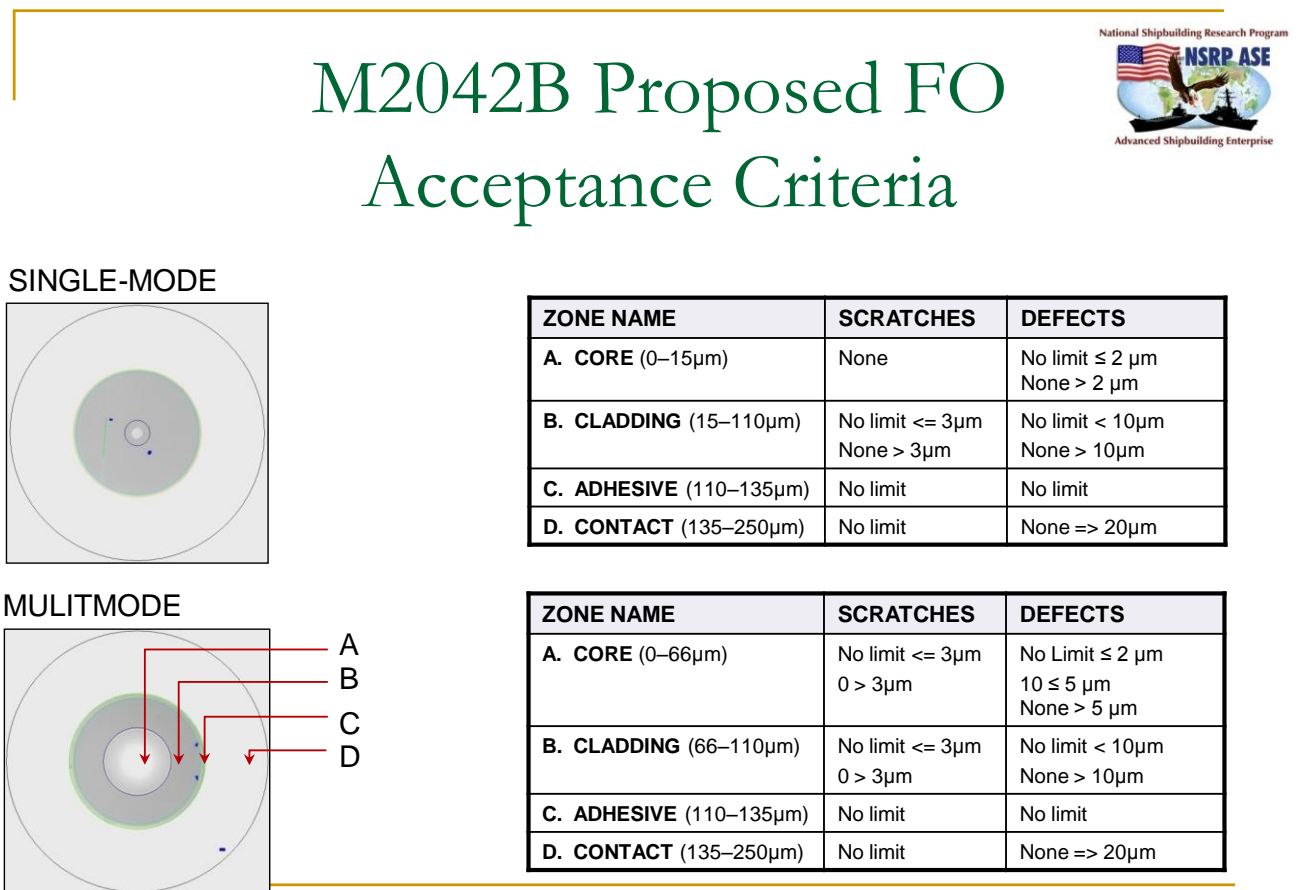


Figure 15 - Proposed M2042 Profile

## 6.2. KITCO Preliminary Test Results

The preliminary test results are shown in Figure 16.

Insertion Loss Pass Criteria:			1.5											
Single Mode Return Loss Pass Criteria:			40											
	Insertion Loss (dB)		Return Loss (dB)		FiberChek2		Technician A		Technician B		Technician C		Technician D	
Cable ID	A to B	B to A	End A	End B	End A	End B	End A	End B	End A	End B	End A	End B	End A	End B
KFO 1-11	0.55	0.42	N/A	N/A	P	P	F	F	P	P	P	P	P	P
KFO 1-12	0.56	0.62	N/A	N/A	F	P	F	P	F	P	F	P	F	P
KFO 3-11	0.49	0.61	N/A	N/A	F	P	F	P	P	P	F	P	P	P
KFO 4-12	0.24	0.31	N/A	N/A	P	P	P	P	P	P	P	P	P	P
KFO 4-15	0.69	0.60	N/A	N/A	P	F	P	F	P	F	P	F	P	F
KFO 1-15	0.55	0.59	N/A	N/A	F	P	F	F	P	P	P	P	P	P
KFO 2-17	0.47	0.53	N/A	N/A	P	F	F	P	P	P	F	P	F	P
KFO 3-16	0.64	0.49	N/A	N/A	F	P	F	F	F	P	F	P	P	F
KFO 4-16	0.48	0.55	N/A	N/A	P	P	P	P	P	P	P	F	P	P
KFO 4-17	0.52	0.46	N/A	N/A	P	P	P	P	P	P	P	P	P	P
KFO 1-10	0.61	0.59	46	45	P	F	P	P	F	P	P	P	P	P
KFO 3-1	0.78	0.82	41	43	F	F	F	F	P	F	P	F	P	F
KFO 4-2	0.57	0.52	46	44	P	P	F	F	F	P	F	F	F	F
KFO 4-3	0.62	0.79	44	41	P	F	P	F	P	P	P	P	P	P
KFO 4-6	0.63	0.57	43	42	F	P	F	F	P	F	P	P	P	F
KFO 1-1	0.66	0.52	42	41	P	F	F	F	P	P	F	P	P	F
KFO 1-4	0.55	0.75	40	41	P	F	P	P	P	F	P	F	F	P
KFO 2-1	0.91	0.69	43	44	P	P	P	P	P	P	P	P	P	P
KFO 3-6	0.56	0.61	42	42	P	P	P	P	P	P	P	P	P	P
KFO 4-1	0.58	0.55	43	40	F	F	F	F	F	F	F	F	F	F
	20	20	10	10	13	12	9	10	15	15	13	14	15	13
	0	0	0	0	7	8	11	10	5	5	7	6	5	7

Figure 16 - KITCO Preliminary Test Results

### 6.2.1. Preliminary Findings

Four (4) experienced Technicians independently evaluated the endfaces for Pass/Fail using currently approved Mil-Std-2042 tools and criteria. The findings indicate that even with experienced technicians there is still disagreement for what constitutes a Pass and Fail condition for fiber optic connectors. When measured with FiberChek2 (FC2) software the proposed M2042 profile was in the majority at least 80% of the time for both ends. The times that it was not in the majority appear to be when 1) there were defects so faint that the technicians all agreed the connectors either Passed but the FC2 measured defects that failed the programmed criteria identified Or 2) where the Technicians believed the location of the defects would warrant failure but the FC2 measured them smaller or outside the critical areas.

For **End A** there were nine (9) instances where all Technicians and the proposed M2042 profile were in agreement.

- In five (5) instances only one of the Technicians disagreed with the proposed profile.
- In two (2) instances two (2) of the Technicians disagreed with the proposed profile.
- In three (3) instances three (3) of the Technicians disagreed with the proposed profile.
- In one (1) instance all four (4) Technicians disagreed with the proposed profile.
- Proposed profile was in the majority 16 out of 20 times (80%)

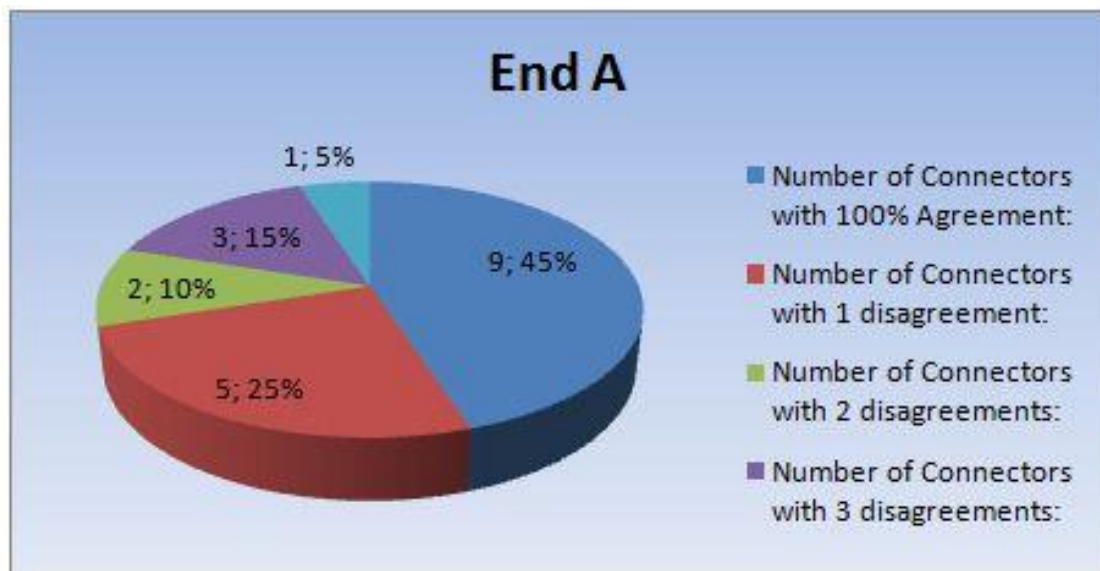


Figure 17 - End A Test Summary

For **End B** there were nine (9) instances where all Technicians and the proposed M2042 profile were in agreement.

- In five (5) instances only one of the Technicians disagreed with the proposed profile.
- In two (2) instances two (2) of the Technicians disagreed with the proposed profile.
- In two (2) instances three (3) of the Technicians disagreed with the proposed profile.

- In two (2) instances all four (4) Technicians disagreed with the proposed profile.
- Proposed profile was in the majority 16 times out of 20 (80%)

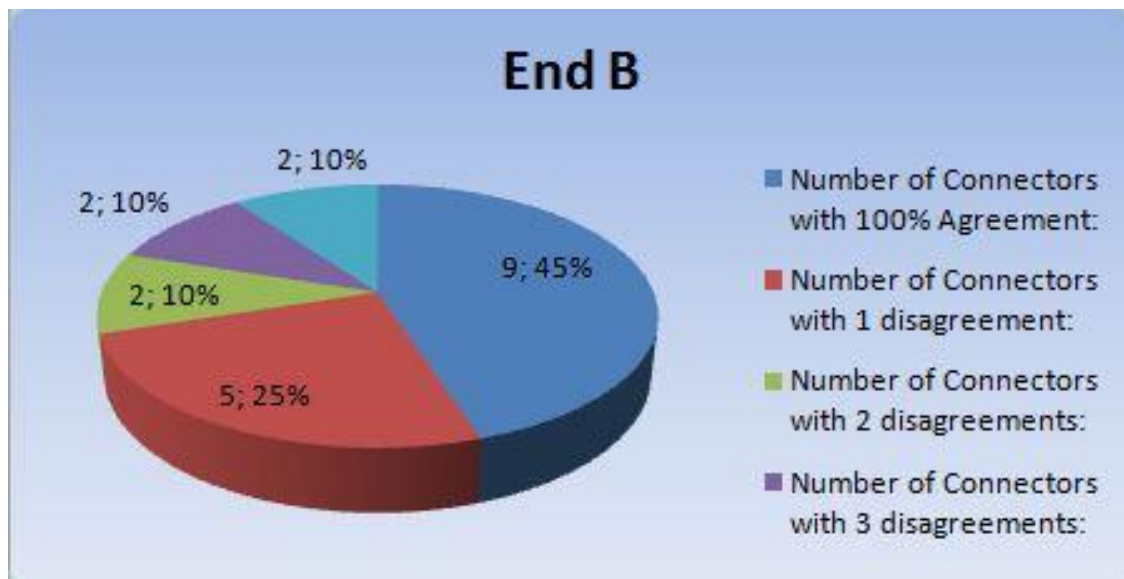


Figure 18 - End B Test Summary

The three cases of FC2 disagreeing with all operators demonstrates typical causes for disagreement:

- 1-10B: FC2 identifies a faint scratch through the core – FC2 fails, the operators pass
  - FC2 can detect smaller features than the operators

## Preliminary Test Samples

### SM KFO 1-10B – FC2 Fails, all Techs Pass

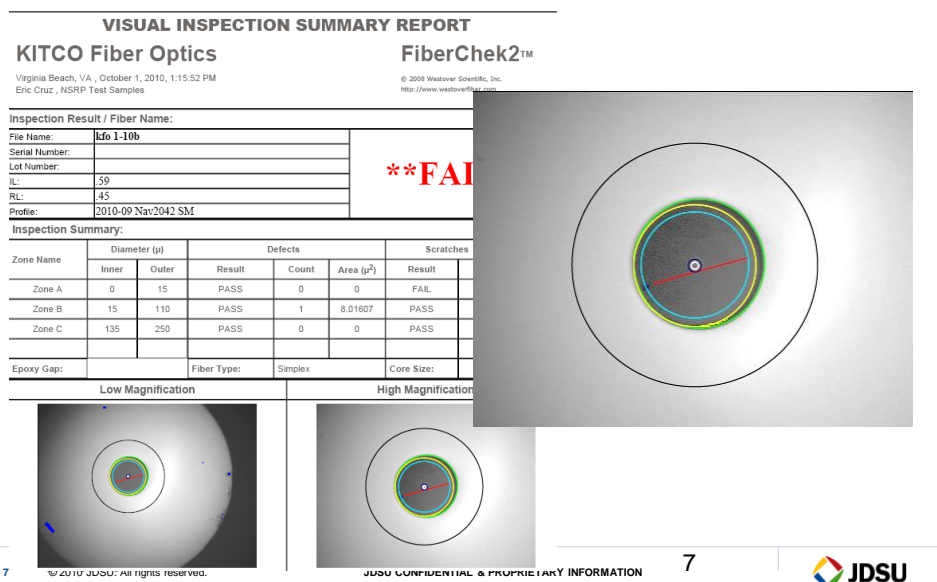
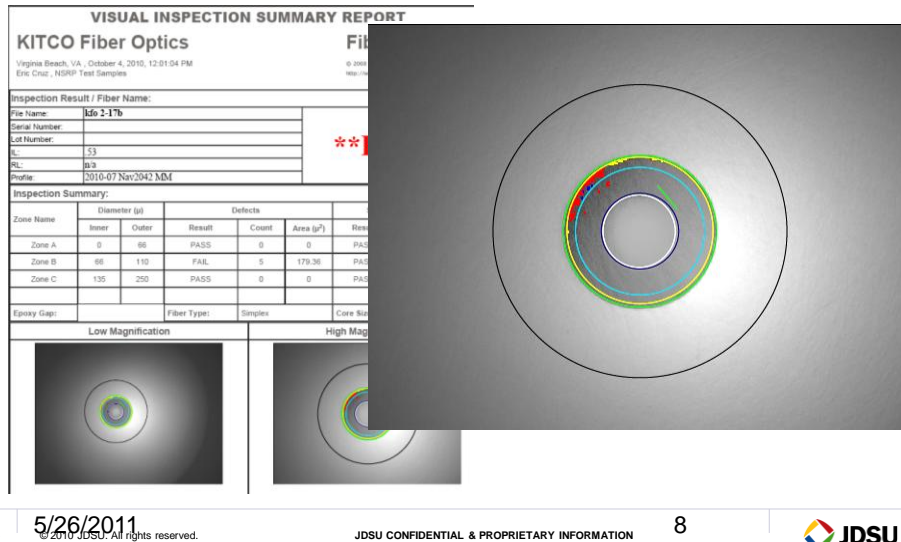


Figure 19 - KFO 1-10B Test Image

- 2-17B: FC2 identifies some feature at the edge of the cladding that reach in past the zone limit – FC2 fails the operators pass
  - FC2 has a rigorous definition of what edge chips / defects are allowed

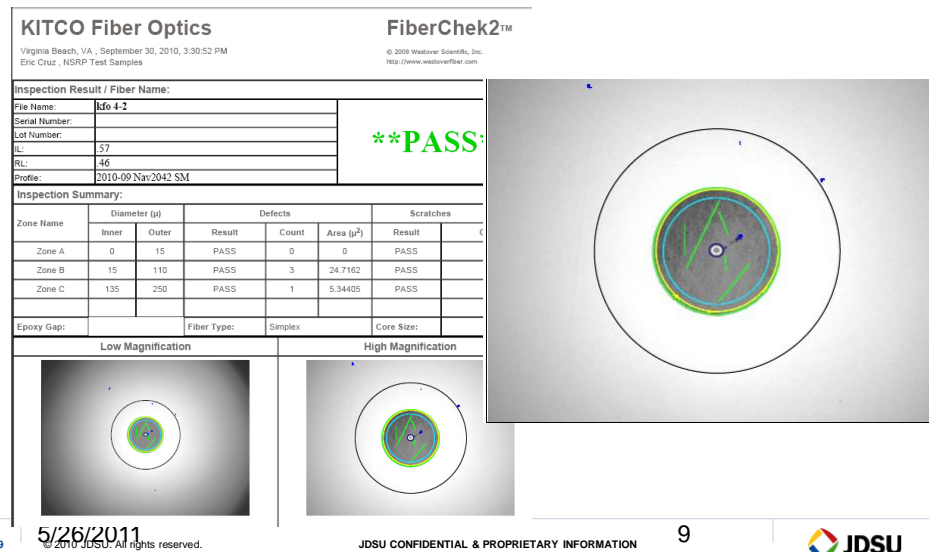
## Preliminary Test Samples SM KFO 2-17B – FC2 Fails, all Techs Pass



**Figure 20 – KFO 2-17B Test Image**

- 4-2A: FC2 identifies scratches but they do not exceed the requirement – FC2 passes, the operators fail
  - FC2 has a set level of allowable scratch/defect

## Preliminary Test Samples SM KFO 4-2A– FC2 Pass, all Techs Fail



**Figure 21 - KFO 4-2A Test Image**

### **6.3. Optical Performance**

Visual quality and optical performance do not always correlate. In many cases connectors that Fail a visual inspection may still pass optical testing requirements. However, this can be very misleading specifically in regards to life-cycle performance. The visual quality check is required to identify and correct fiber connector defects that will likely result in system failures at a later date. This is even more critical for shipboard applications due to the harsh operating environment. Fiber connectors that display visual defects outside of the criteria identified as acceptable by the proposed profile should be rejected and repaired or replaced regardless of the optical performance testing results.

It is also possible for connectors that Pass the visual quality inspection to Fail optical performance testing. Such a scenario is statistically much less frequent but occurs none the less. BOTH acceptable visual and optical performance testing is required to ensure life-cycle and optical system performance as desired.

In the case of the preliminary test specimens 100% passed optical performance testing for both insertion loss of 1.5dB for the two mated pairs (measured in both directions) and return loss of 40dB for the SM assemblies as identified in Figure 15 above.

### **6.4. Preliminary Test Conclusion**

The proposed M2042 profile criterion is consistent with the current visual inspection process while adding an objective and measurable aspect to the inspection process. The proposed profile also provides an achievable and realistic visual verification process for use with field installed connectors compliant to the Mil-Std-2042B. While not as strict as a factory “beginning of life” profile that would be used in clean room type production facility; the proposed profile will provide a visual quality level that is more than acceptable to achieve life-cycle and optical performance required by the Mil Standard. In addition, the level of visual inspection repeatability and consistency for fiber connectors delivered to the fleet will be vastly improved.

The proposed M2042B profile was provided to NSWCD for consideration and comment. The original intention was to obtain such comments and make any necessary modification to the profile prior to the commencement of Field Testing. However, due to difficulties of transferring funds to NSWCD the timing of field testing would have need be delayed significantly. In order to remain on plan the field tests were conducted as originally scheduled. Had NSWCD requested changes to the proposed profile after field testing was completed the software criteria could have been updated and the test results compiled against the new profile criteria. In the end NSWCD did not propose any criteria modifications. However, the proposed profile was not completely accepted as will be discussed in the Project Findings section.

## **7. FIELD TEST PLAN**

Field testing to verify how the automated visual inspection process could benefit the shipbuilding industry was conducted. Results from 3 test sites were aggregated together and analysis performed to determine if the automated inspection process provides specific benefits and cost saving advantages over the incumbent manual method.

### **7.1. Field Test Goals:**

- Verify shipyard capability to manufacture fiber connectors to meet M2042 automated profile criteria
- Evaluate automated versus manual inspection time improvement

## 7.2. Shipyard Resources

- Four (4) trained fiber optic technicians (experience at discretion of shipyard)
- Four (4) fiber optic tool kits for polishing and manual inspection of ST and M29504/14 & /15 termini
- Space to provide project in-brief for participating personnel (30 minutes)
- Space to emulate typical shipboard construction environment (3.5 hours)

## 7.3. Project Provided Resources

- Project Supervisor
- All consumable materials (including field test samples and polishing material)
- Inspection probe

## 7.4. Field Test Process

- Project in-brief (30 minutes)
- Evaluation of preliminary test sample connectors by shipyard technicians (30 minutes)
- Shipyard technicians to polish shipyard field test samples (2 hours)
- Evaluation of shipyard field test samples by all shipyard technicians (30 minutes)
- Project out-brief and technician comments (30 minutes)

## 7.5. Field Test Steps

### Step 1

#### ■ Project in-brief

- Project Manager (Dan Morris, KITCO) will provide a short project introduction and explanation of the project goals. The introduction will provide a refresher on the current M2042B connector endface inspection process and criteria. The automated inspection profile criteria will also be covered.
- Note: There should be no difference between the expected quality of shipyard produced connectors and those that will pass the automated inspection profile. In theory, 100% of shipyard connectors that pass the manual inspection should pass the automated inspection criteria.

### Step 2

#### ■ Preliminary Test Sample evaluation

- The shipyard technicians will inspect and grade (Pass or Fail) 40 test samples that were produced by KITCO as part of the preliminary testing.
- Each technician will independently (without knowledge of other evaluators opinions) record whether they believe the connectors pass or fail current quality requirements.
- The results will be tabulated and provided as part of the final report.
- Note: Since the current method of inspection is subjective, we expect varying results. The intent of this step is to attempt to record and statically evaluate how different technicians rate the same connectors. The names of the technicians will not be recorded.

### Step 3

#### ■ Shipyard Technicians to polish and inspect field test samples

- Each technician will polish 5 cable assemblies using Mil-Std-2042B or other approved shipboard construction methods.
  - Twenty (20) cables assemblies have been pre-built up to the polishing step. Technicians will perform the air polish thru final polish steps. (Polishing consumable materials to be provided by KITCO.)
  - Technicians will manually inspect the connectors for QA acceptance. (All connectors should be rated as “Pass” by the technician. Re-polish should occur until connectors are rated “Pass” OR the technician believes rework is not possible and the QA inspection is rejected as a “Fail”. The intent is to obtain 100% rated “Pass” by the technician.

Note: The configurations of the 20 field test samples are as follows:

- (i) M29504/14-4131C-M83522/16-DNX (MM) 5 ea
- (ii) M29504/15-4171C-M83522/16-DNX (MM) 5 ea
- (iii) M29504/14-4141C-M83522/16-DNY (SM) 5 ea
- (iv) M29504/15-4181C-M83522/16-DNX (SM) 5 ea
- The test location and technicians should be representative of the environment and skill levels the shipyard desires to verify acceptable performance against.
- Assumption: Technicians will be identified as Technician A thru D. The experience in years will be recorded. Technician names will not be recorded for data collection.

Technician A will polish all type (i) samples

Technician B will polish all type (ii) samples

Technician B will polish all type (iii) samples

Technician B will polish all type (iv) samples

### Step 4

#### ■ Evaluation of all field test samples

- Each technician will independently (without knowledge of other evaluators opinions) record whether they believe the other 30 connectors (15 assemblies) NOT produced by them pass or fail current quality requirements. Time required to inspect will be recorded.
- This will result in 4 QA “Pass” or “Fail” opinions for each of the 40 connectors (20 assemblies).
- Technicians will perform automated inspection using probe and M2042 profile. Results will be saved. Time required to inspect will be recorded.
- The results will be tabulated and provided as part of the final report.



## Step 5

### ■ Project out-brief

- The technicians will have an opportunity to provide comments regarding the automated inspection process.

## Step 6

- The Project Supervisor will take the field test samples back to KITCO for optical performance testing. The test results will be tabulated and included in the Final Report.

Note: Expected Field Test locations:

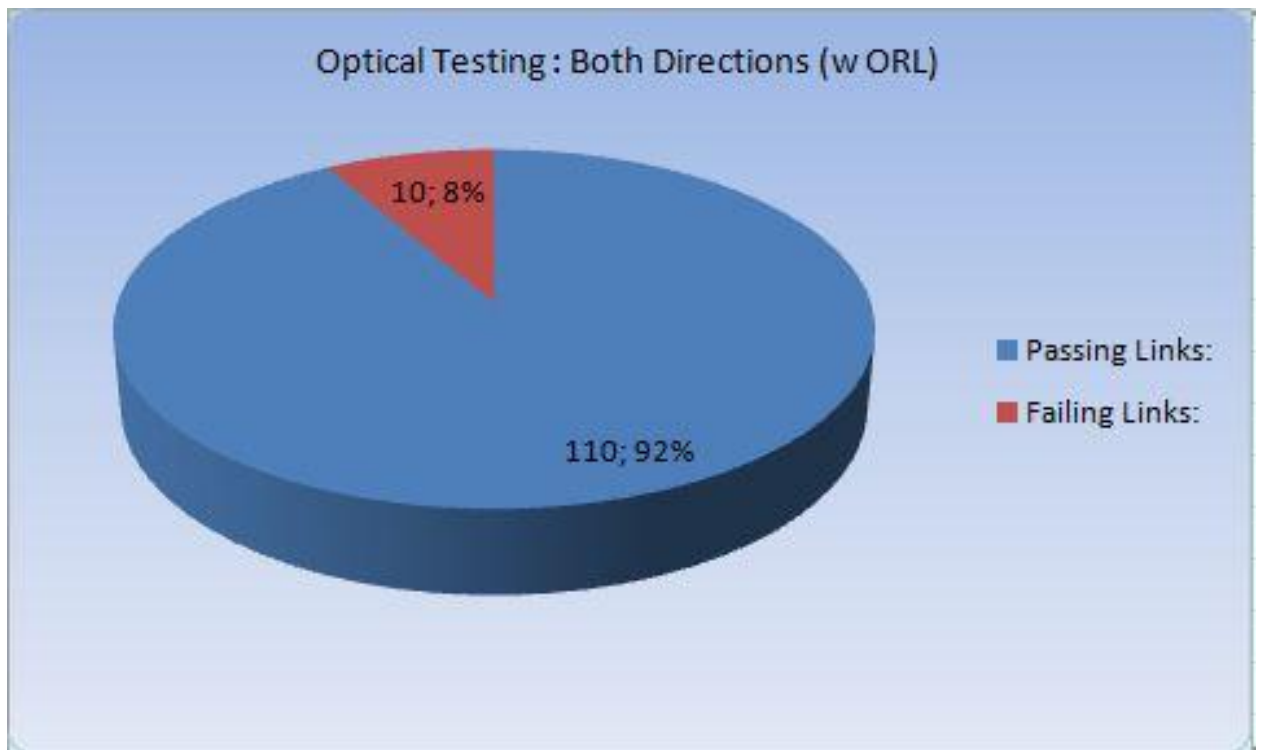
- NGSB-GC
- NGSB-NN
- GD-BIW

## 7.6. Combined Field Test Results

See Appendix C.

## 7.7. Combined Optical Performance Testing

- **92% Passed all Optical Testing**  
**8% Failed Link Loss Testing**



**Figure 22 - Combined Optical Testing Results**

## 7.8. Visual Quality Check Testing results (Technicians w\ Microscope):

- 88% Rated as Pass
- 12% Rated as Fail

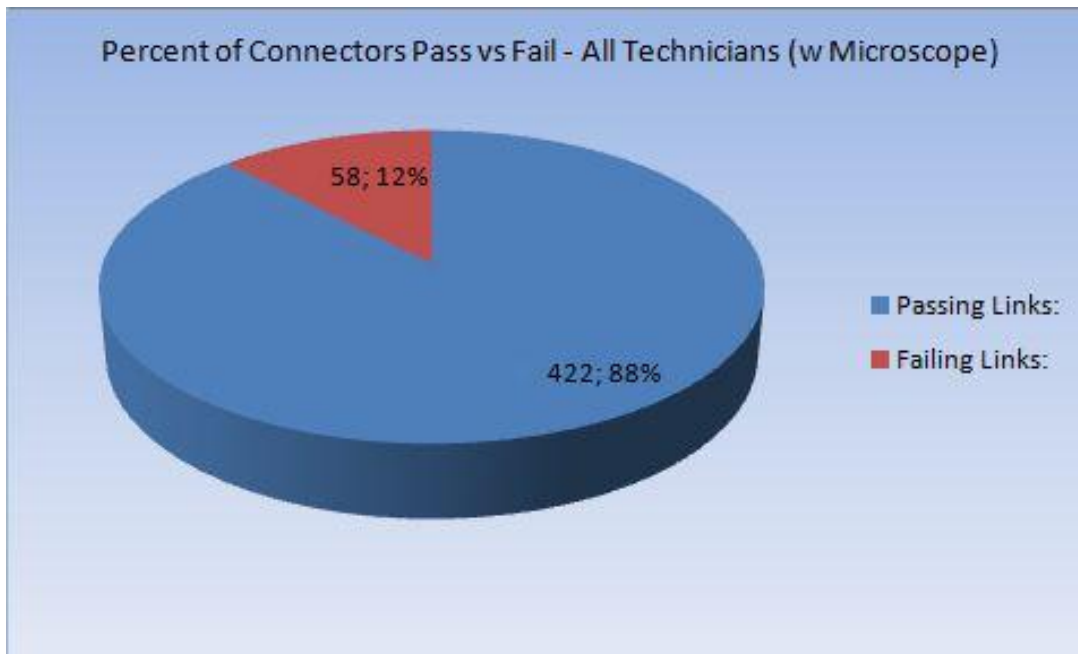


Figure 23 - Combined Visual Inspection Results (w Microscope)

## 7.9. Visual Quality Check Testing results (Automated Inspection):

- 58% Rated as Pass
- 42% Rated as Fail

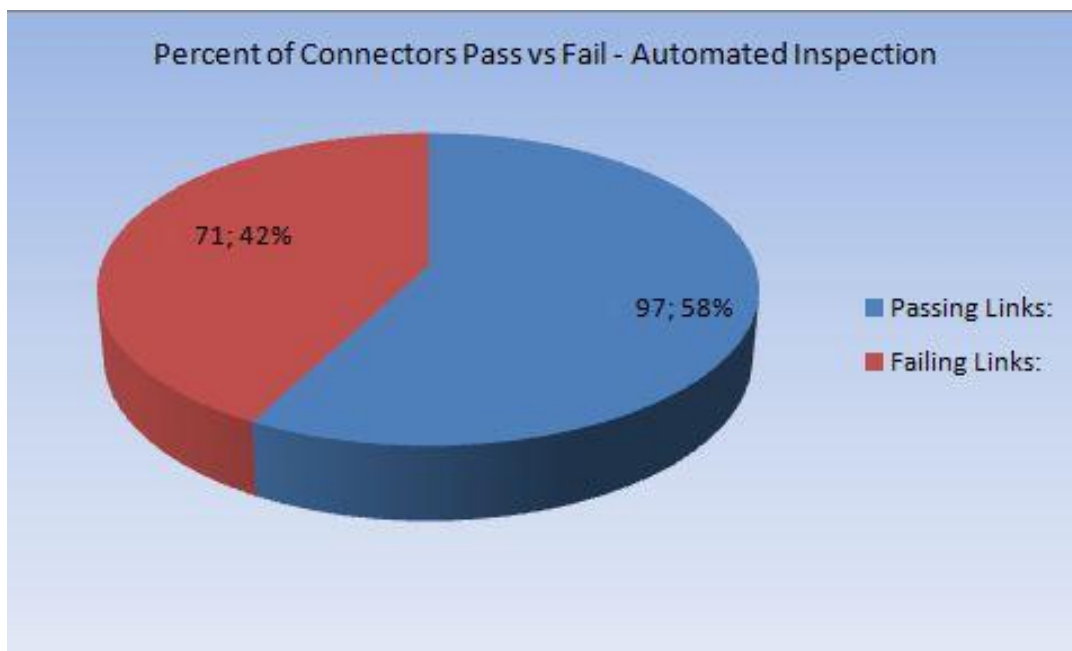


Figure 24 - Combined Visual Inspection Results - (Automated Inspection)

## 7.10. Combined Field Test Results Comparison

	Optical Testing	Technician Rated	Automation Rated
Pass	92%	88%	58%
Fail	8%	12%	42%

- Optical Performance expectation tends to drive Technician Visual Quality decision (92% to 88%). The test results and input from Technician interviews confirm that the technicians tended to rate end face quality based on the expected optical performance.
  - Initial Optical Performance results are not an indicator of workmanship quality which impacts Life-Cycle performance and Total Ownership Cost
- Project Findings Variation exists between Technicians using current method (human subjectivity, no eye exam requirement, quality, experience, training) The study proved there is significant variation between technicians due to several factors:
- ☐ The acceptance standard is very vague and leaves a lot of room for interpretation.
  - ☐ The operators who utilize the microscope do not receive vision tests and therefore there is an opportunity that each operator's vision may differ potentially providing different results between each operator.
  - ☐ The quality of the equipment varied between each operator. Experience, training and competency vary since there is only initial training required and no refresher or maintenance training is required.

NSWCDD does not object to using an automated inspection system with the proposed criteria to automatically determine a non-inclusive "No-Go" condition

- Quality of current inspection equipment varies widely impacting consistency. There is no requirement to standardize or calibrate the microscope at a time interval to assure it is providing consistent results. In most laboratory or similar environments, the operator is required to perform some type of validation before using the equipment. This is something that the technical warrant holder needs to investigate.
- The automated inspection profile is mathematically more critical than the Technicians who participated (88% vs 58%). Technicians passed 88% of the endfaces inspected where the FC2 with the proposed automated inspection profile passed only 58% of the same endfaces. The FC2 is more critical than the Technicians who participated in the field tests. We believe the automated inspection results are much closer to the intent on the Mil-Std-2042B guidance. As stated previously, the Technicians acknowledged that the optical performance expectations had an influence on how they rated the visual quality. Where they expected the connectors to pass optical testing they were more likely to pass a connector even where defects existed that would probably otherwise result in a Fail rating.

- The automated inspection method will significantly improve quality, consistency and repeatability; resulting in costing savings with enhanced system performance and lifecycle improvement. This was proven with the testing that was performed at the three different shipyard facilities. In every case, the automated inspection method provided endfaces that were of a higher quality which will enhance system performance and improve the lifecycle of the system.
- The current hardware utilized for field inspection cannot resolve scratches and defects to the precision desired by NSWCD. When identifying inspection criteria using an automated process the hardware should possess the capability to resolve defects at least to the level specified. During discussions surrounding the capability of the hardware the manufacture acknowledged that the device can not measure defects precisely. The commercial standards are vague on the precision requirements of the hardware. Those standards require that the device must have the “capability to identify” defects of certain sizes. They do not however require that the hardware possess the capability to precisely measure those defects. It is agreed that additional investigation in this area is prudent. The simple capability of the hardware to recognize certain defects means that there is still a level of subjectivity when using the current hardware. However, the level of uncertainty associated with the precise measuring of these defects is greatly reduced from that of the operator when using a handheld microscope only. It is possible that the FC2 could pass a connector that an experienced operator may otherwise fail. Many discussions between the project team and the Navy revolved around this issue. Investigation as to the hardware precision requirements in this area are ongoing.
  - ☐ NSWCD agrees that quality improvements would be realized
  - ☐ All defects that are visible to a human operator may not be identified
- NSWCD has no objection to the use of a video inspection system, in place of a hand held microscope, for a human operator to perform a visual quality check to determine acceptable quality based on M2042B criteria. The project results confirmed that the quality of the handheld microscopes used in the field varies greatly. This results in microscope equipment that will not allow an operator to detect certain defects that should be readily detectable. Therefore, it is quite possible that the operators are not able to see defects that; had they been detectable, would have resulted in the operator identifying a Fail condition. The use of certain video inspection equipment provides a much clearer image for the technician to grade the connector. NSWCD has agreed to approve video inspection system hardware that can be used in place of the hand held microscope where a fully manual inspection can take place. In that case, an automated inspection system will not be implemented at all. The technician will use the video inspection system manually in place of the hand held scope.

## 8. RESULTS / ACTIONS

- The project team has requested that NSWCD issue a letter which allows the utilization of Video Inspection equipment as an alternate to the hand held microscope for performing the end-face visual quality check. This letter will also provide guidance that allows shipyards to utilize the profile that was developed and proposed for this project as the “No-Go” automated acceptance criteria baseline until the “Go” criteria can be developed. This action is in process at the time of this report.
- NSWCD does not accept the proposed automated inspection criteria as equivalent to or as a replacement for the M2042B visual quality check. Therefore it is recommended that DSCR funding is provided to perform additional research to find acceptance criteria that meets or exceeds the Mil-Std-2042-5B requirements. Until an acceptance criteria is approved by NSWCD, this process still requires a human operator to perform a visual quality inspection per M2042B to Pass (GO) the connector.

- ☐ Use this quantitative criteria to determine if current automated inspection equipment has the necessary capabilities to perform automated inspections at the desired level of the Navy.
- ☐ Review NASA-STD-8735.5 (2/1998), NAVAIR 805 and other international standards to determine if there is criteria that more aligns with NSWCDD.

REFERENCES:

1. Mil-Std-2042B - Fiber Optic Cable Topology Installation Standard Methods for Naval Ships