FIBER OPTIC TESTING ENHANCEMENT FOR COST REDUCTION FOLLOW-ON

Improvement to FO Testing for significant manpower and schedule reduction benefits

Final Project Update
3/30/2023

Presented by:
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FIBER OPTIC TESTING ENHANCEMENT FOR COST REDUCTION FOLLOW-ON

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Final Project Overview

This project will investigate the potential for Fiber Optic Testing Enhancement for Cost Reduction by evaluating the commercial practice of using on an Optical Time Domain Reflectometer (OTDR) to replace the Optical Loss Test Set (OLTS) and Optical Return Loss Meter (ORLM) in performance of MIL-STD-2042-6 required testing for shipboard installations. In addition, the OTDR test results will provide enhanced data that are not currently captured resulting in reduced time for system acceptance and identification of potential faults for expedited troubleshooting and repair during construction. Laboratory testing focusing on MM fiber will be conducted at NSWCDD.

This is a follow-on project proposal to NSRP ASE Subcontract Agreement No. 2016-416 and will be used to validate the laboratory findings from the previous FO test enhancement project completed May 15, 2017.

Extended POP: 9/16/2019 – 9/30/2022.

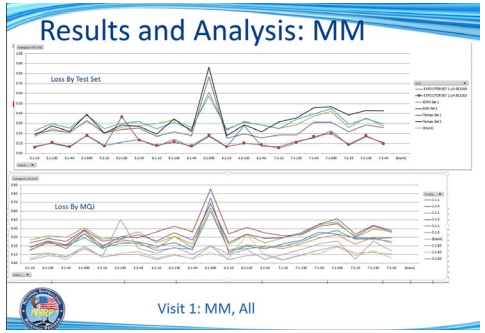
FIBER OPTIC TESTING ENHANCEMENT FOR COST REDUCTION

Improvement to FO Testing for significant manpower and schedule reduction benefits

Team: KITCO Fiber Optics | HII-NNS | NSWCDD | EXFO North America

Project Goals: Reduce Fiber Optic testing, troubleshooting and training requirements

Project will validate the potential for Cost Reduction by evaluating the commercial practice of using on an Optical Time Domain Reflectometer (OTDR) to replace the Optical Loss Test Set (OLTS) and Optical Return Loss Meter (ORLM) in performance of required testing for shipboard installations.



Project will Validate Laboratory Testing onboard New Construction VCS platform

- Validate forecasted Labor Savings
- Test various FO links using proposed equipment
- Test same links with current equipment
- Compare and analyze results for reliability and repeatability

Project Benefits and ROI

- Labor Savings estimated at 43,446 labor hours across all platforms
- Labor dollar savings of $2,172,300 (43,446hrs @ $50/hr) are estimated.
- Schedule Reduction for testing requirements.

•Reduced training requirements.
•Reduced FO test equipment required.

Original Completed Project Testing Results were promising

- Single mode results show good overall comparison agreement
- Multimode results showed predictable results when accounting for launch condition considerations

Labor Savings estimated at 43,446 labor hours across all platforms

Labor dollar savings of $2,172,300 (43,446hrs @ $50/hr) are estimated.

Reduced FO test equipment required.

Reduced training requirements.

Final Project Schedule

2019 -2020	19-Dec	20-Jan	20-Feb	20-Mar	20-Apr	20-May	20-Jun	20-Jul	20-Aug	20-Sep	20-Oct	20-Nov	20-Dec
1) Kick-Off Meeting and Project Plan Development													
2) Procurement of Test Equipment and Materials													
3) Testing of FO Circuit Leads onboard SSN-794													
4) Testing Result Comparison Analysis													
5) Project Suspended													

2021	21-Jan	21-Feb	Mar-21	Apr-21	May-21	Jun-21	Jul-21	Aug-21	Sep-21	Oct-21	Nov-21	Dec-21
5) Project Suspended												
6) Restart Project												
7) Procurement of Test Equipment and Materials												
8) Testing of FO Circuit Leads onboard SSN-796												
9) Project Delay												

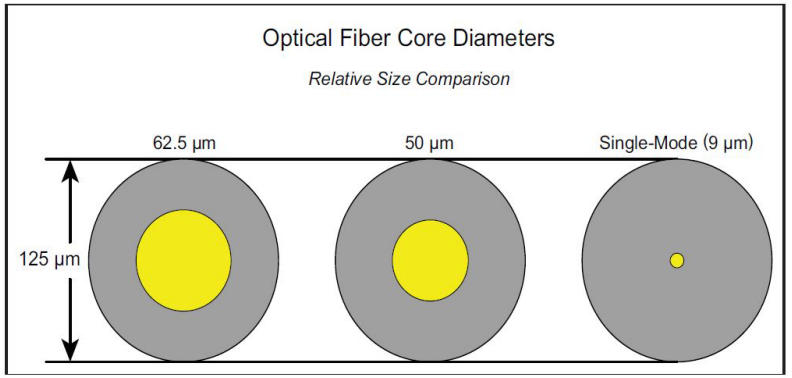
2022	Jan-22	Feb-22	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Aug-22	Sep-22
10) Project Delay									
11) Project Testing - NSWCDD and KITCO									
12) Project Data Analysis									
13) Project Final Report									

Final Project Summary

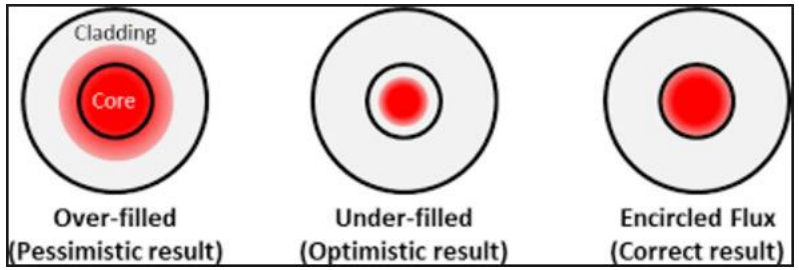
- Project testing was originally scheduled to start at NNS in the Spring of 2020.
- Due to the impacts of the COVID pandemic, the original project test window onboard SSN-794 was not able to be met.
- Project was paused approximately 1 year in order to realign project testing to SSN-796.
- At the time we transitioned project focus from SSN-794 to SSN-796, we were unaware that the Fiber Optic system of interest had transitioned from a shipyard system to GFE.
- After more delays, in October 2021 the project team was informed that because the FO system had transitioned to GFE, NNS no longer had tasking to complete the splicing and the issue would need to be resolved with the Navy.
- With such continued challenges the project team determined that a reduced scope project and change of venue would provide the best value to move forward.
- Project scope was reduced to focus on MM testing only with primary intent to validate launch condition compliance to Navy Coupled Power Ratio (CPR) and High Order Mode Power (HOMP) requirements as well as to validate test result agreement between the Navy approved OLTS and the proposed OTDR technology.

Technical Background – Fiber Launch Condition

- Measuring the loss for MM links has traditionally posed challenges especially in terms of reproducibility between test instruments.
- Tighter CPR/HOMP requirements (Navy adopted), which improve measurement uniformity, and create a more overfilled launch condition, generally result in more "conservative" link loss readings and provide a more confident Pass/Fail validation for installation quality of the shipboard fiber optic cable plant.
- Commercial Standards bodies have adopted Encircled Flux (EF) as the preferred test measurement launch condition.

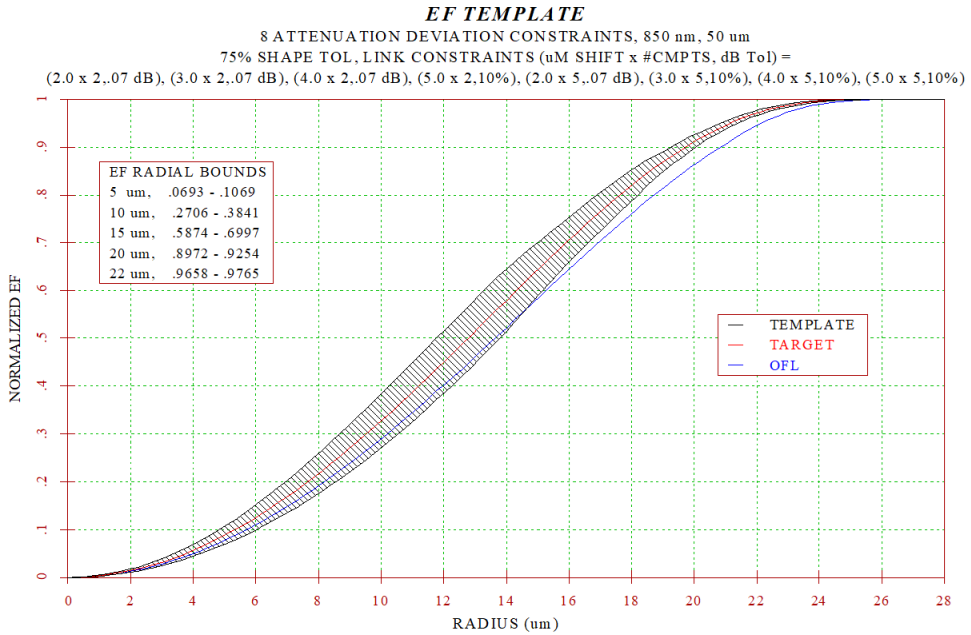


Source Launching Conditions	Source Type	Input Beam	Fiber	Output Beam
Overfilled (LED)				
Slightly under-filled (ideal conditions)				
Under-filled (VCSEL)				



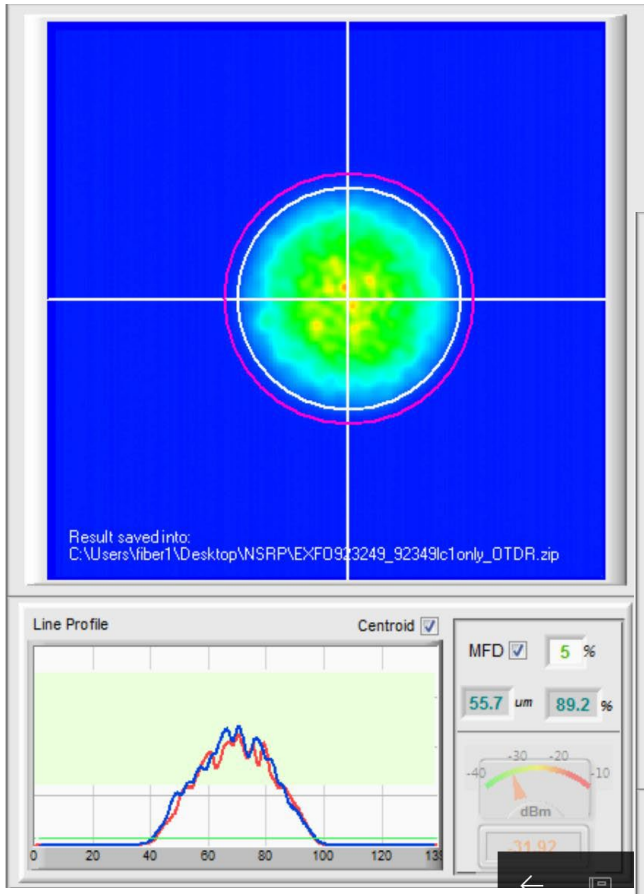
Technical Background

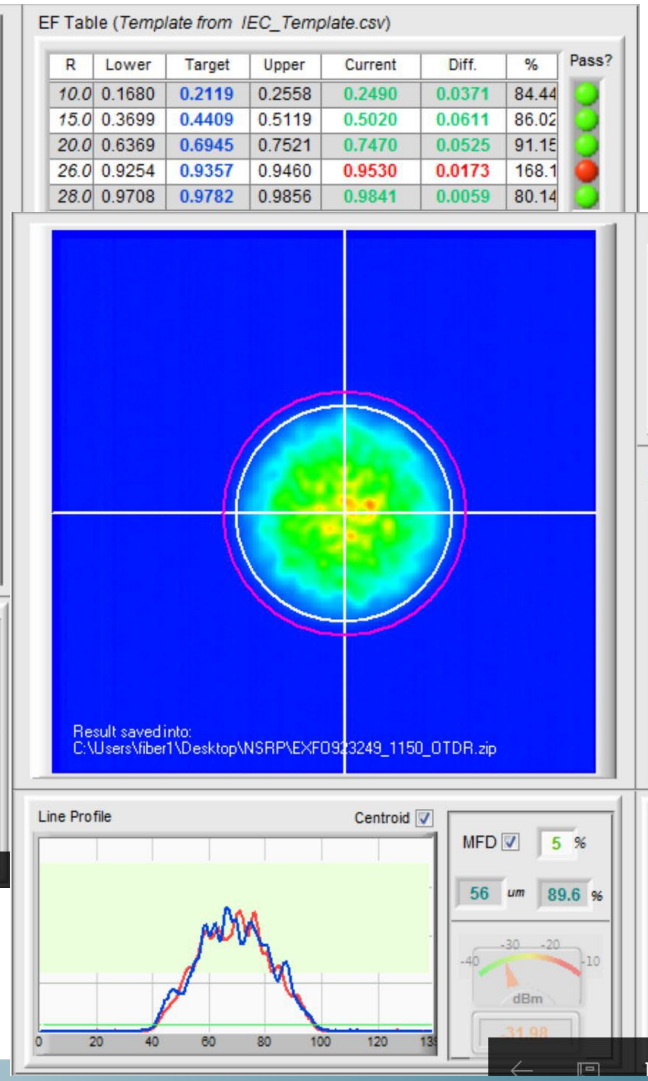
- Encircled Flux (EF) is a measurement of the intensity profile at the output of a MM fiber. A desired profile can be achieved by means of conditioning at the output of a light source using various techniques which allow for MM fibers with different characteristics (mainly core size and NA) to end up with a very similar desired launch profile.
- Coupled Power Ratio (CPR) measures the ratio of light referenced thru a MM fiber, that will propagate thru a SM fiber when the two fibers are coupled together. This will effectively identify how "underfilled" a light source may transmit relative to a MM fiber.
- High Order Mode Power (HOMP) measures the relative amount of power travelling at the core cladding boundary (High Order Modes) that can be filtered out thru a mandrel wrap. The more loss the more Overfilled the source.
- CPR and HOMP when combined together can help characterize the balance between underfilled and overfilled light sources.



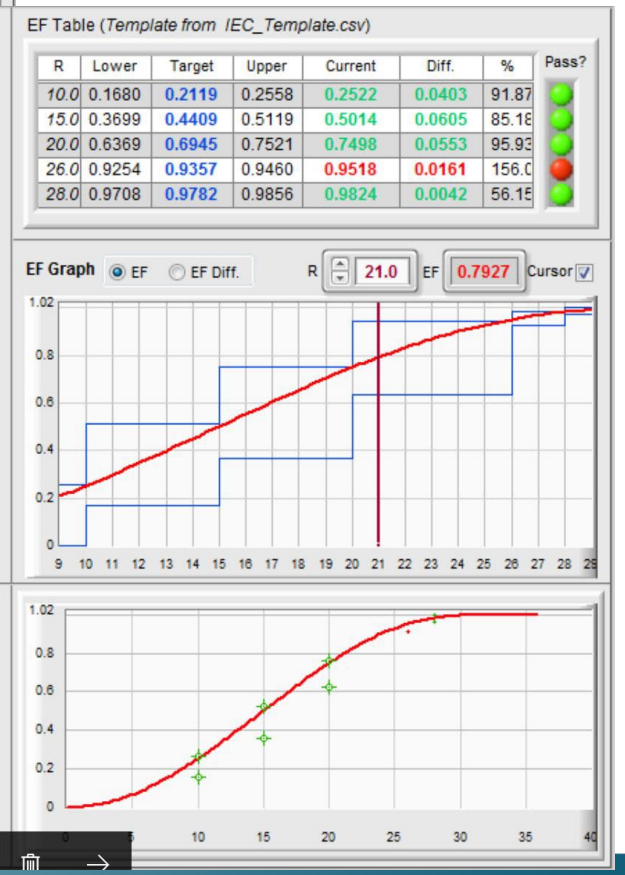
OTDR EF Measurements

EXFO OTDR w/EF Launch Cord Only





EXFO OTDR w/Launch Cord & MQJ



Final Project Summary … continued

- Projects Goals:
  1. Conduct experimentation to confirm the proposed test unit type provides the required precision and repeatability to replace the existing identified test units for conducting fiber optic tests during ship construction, system upgrades and fleet maintenance.
  2. Identify test unit specifications for future shipyard and fleet procurement.
  3. Identify roadmap for TWH approval and implementation process.
- Project testing performed at NSWCDD FO lab May 31 thru June 3.
- Test equipment launch condition characterization completed (EF, CPR and HOMP).
- Results =
  - MAX-945 Set 1 (Navy compliant/approved): More Overfilled than EF template; meets Navy CPR/HOMP
  - MAX-945 Set 2 (Navy compliant/approved): More Overfilled than EF template; meets Navy CPR/HOMP
  - OTDR Set 1: More Overfilled than EF template; More Overfilled than the MAX-945 units, Meets Navy CPR/HOMP for OLTS
  - OTDR Set 2: Meets EF template; More Overfilled than the MAX-945 units, Meets Navy CPR/HOMP for OLTS

OLTS	S/N	OTHER	TX-MQJ	Date	EF: 10	EF: 15	EF: 20	EF: 26	EF: 28	Comply: EF10	Comply: EF15	Comply: EF20	Comply: EF26	Comply: EF28	EF COMPLY RESULT	CPR Ref	CPR 4.2-1	CPR Comply Range = (-20.5 to -22.5)	HOMP	HOMP Comply Range = (0.3 to 0.8)
MAX:945: Set 1	1290718		1.3-1	6/2/2022	0.2184	0.4455	0.6884	0.9173	0.9658	PASS	PASS	PASS	FAIL	FAIL	FAIL	-20.82	-21.35	**Yes**	-0.55	**Yes**
MAX:945: Set 2	1290719		1.3-1	6/2/2022	0.2200	0.4479	0.6898	0.9163	0.9651	PASS	PASS	PASS	FAIL	FAIL	FAIL	-20.19	-21.26	**Yes**	-0.64	Yes
OTDR: Set 1 MAX-720C-NS2659	1290023	with Mode Conditioner	see left	6/2/2022	0.2451	0.4846	0.7175	0.9262	0.9703	PASS	PASS	PASS	PASS	FAIL	FAIL	-5.85	-20.60	**Yes**	-0.36	Yes
OTDR: Set 2 MAX-720C-NS2659	1286731	with Mode Conditioner	see left	6/2/2021	0.2510	0.4879	0.7226	0.9301	0.9721	PASS	PASS	PASS	PASS	PASS	PASS	-5.59	-20.50	**Yes**	-0.37	Yes

Final Project Summary … continued

- Testing of multiple fiber paths representing shipboard configurations conducted.
- Fiber path configurations made with fibers optic cables containing different light propagation characteristics (Numerical Aperture (NA) and Core Diameter (CD)) in order to validate test result alignment across different mode group variations.

Navy Approved MAX-945-NAV-M2042-KIT units

OTDR evaluation units with iOLM

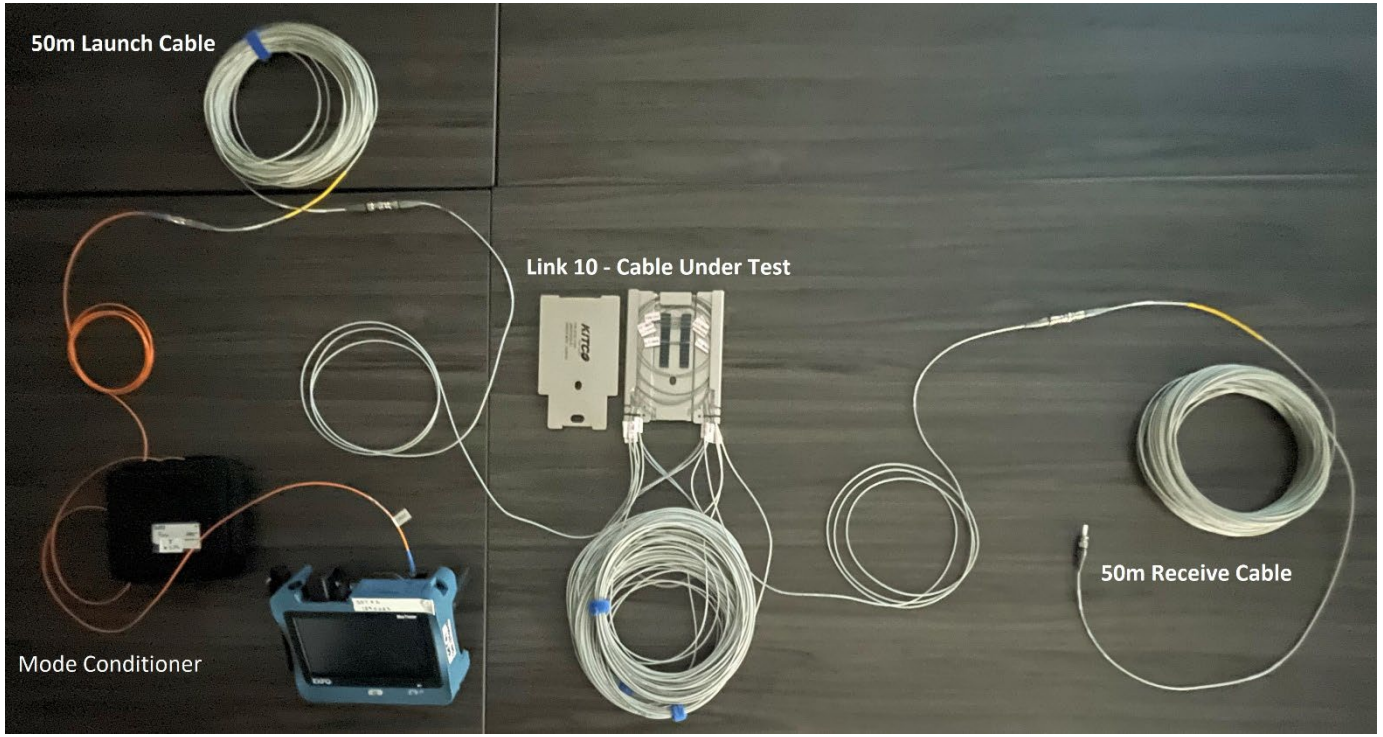
Final Project Status Summary … continued

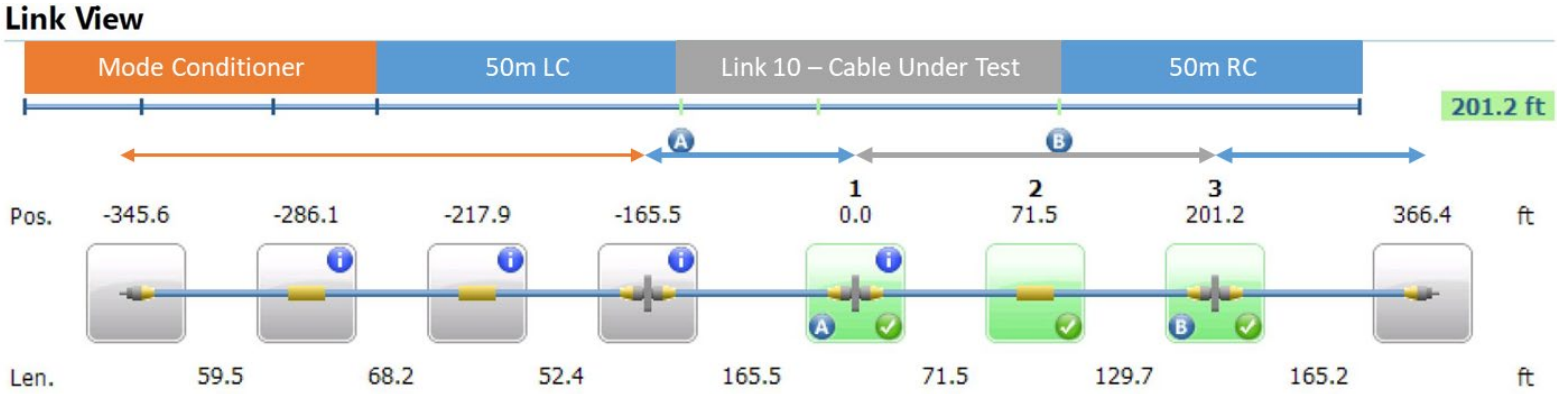
- Testing of multiple fiber paths representing shipboard configurations conducted.
- Fiber path configurations made with fibers optic cables containing different light propagation characteristics (Numerical Aperture (NA) and Core Diameter (CD)) in order to validate test result alignment across different mode group variations.

5 = CUT, Fiber Batch 1: K6W0014381, 62.2um - 62.7um, NA: 0.272
6 = CUT, Fiber Batch 2: K6W0002044. 64.2um - 64.3um, NA: 0.276
7 = CUT, Fiber Batch 3: K6Z0000700, 63.1um - 63.4um, NA: 0.269

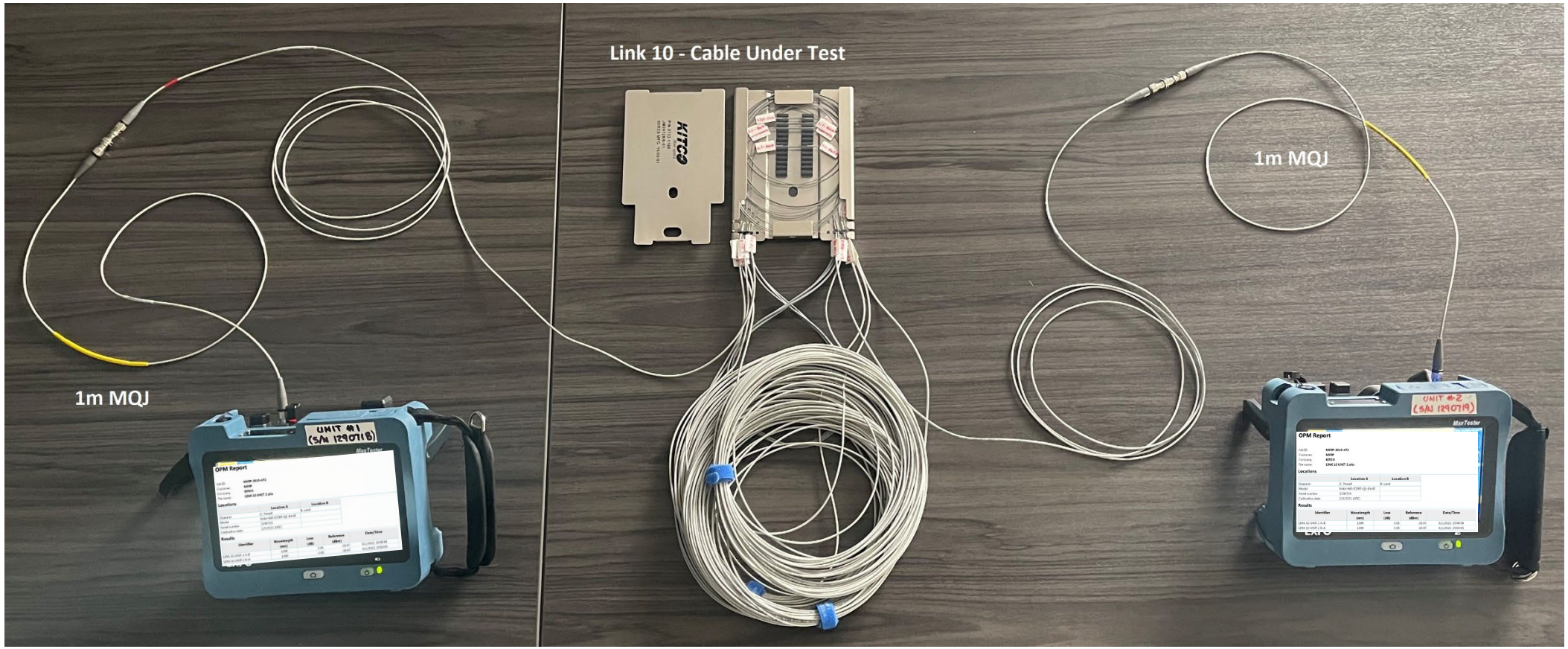
Link	Cable #1	Cable #2	Cable #3	Cable #4	Cable #5	Note:
1	5.1-10	5.1-40				
2	6.1-10	6.2-130				
3	7.1-10	7.1-500				
4	5.1-10	5.1-40	5.1-130			**Link 1 plus 5.1-130**
5	6.1-10	6.2-130	6.1-40			**Link 2 plus 6.1-40**
6	7.1-10	7.1-500	7.2-40			**Link 3 plus 7.2-40**
7	5.1-10	5.1-40	5.1-130	5.2-40		**Link 4 plus 5.2-40**
8	6.1-10	6.2-130	6.1-40	2.2-1		**Link 5 plus 2.2.-1**
9	7.1-10	7.1-500	7.2-40	7.2-10		**Link 6 plus 7.2-10**
10	5.3x-10a : FUSION	5.1-B60: Fusion splice	6.1-B60: Fusion splice	7.1-B60: Fusion splice	5.3x-10b : FUSION SPLICE	On Hand at NSWCDD

OTDR Test Set up – Link 10 example





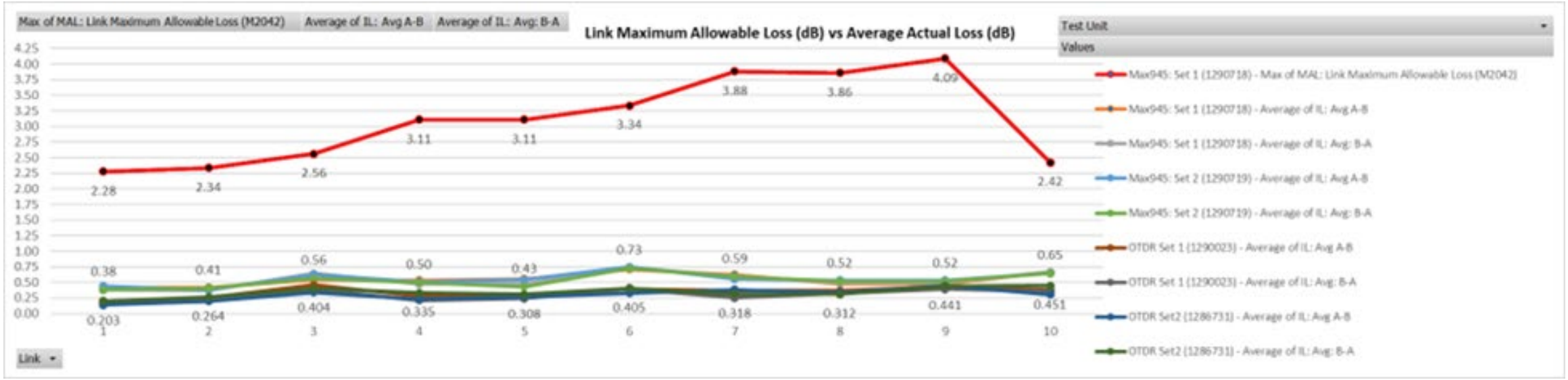
OLTS Test Set up – Link 10 example



Link	Unit	A to B	B to A
10	MAX-945-OLTS1	0.67	0.67
10	MAX-945-OLTS2	0.65	0.65
10	OTDR 1290023 MC+LC	0.38	0.36
10	OTDR 1286731 MC+LC	0.31	0.45

Final Project Status Summary … continued

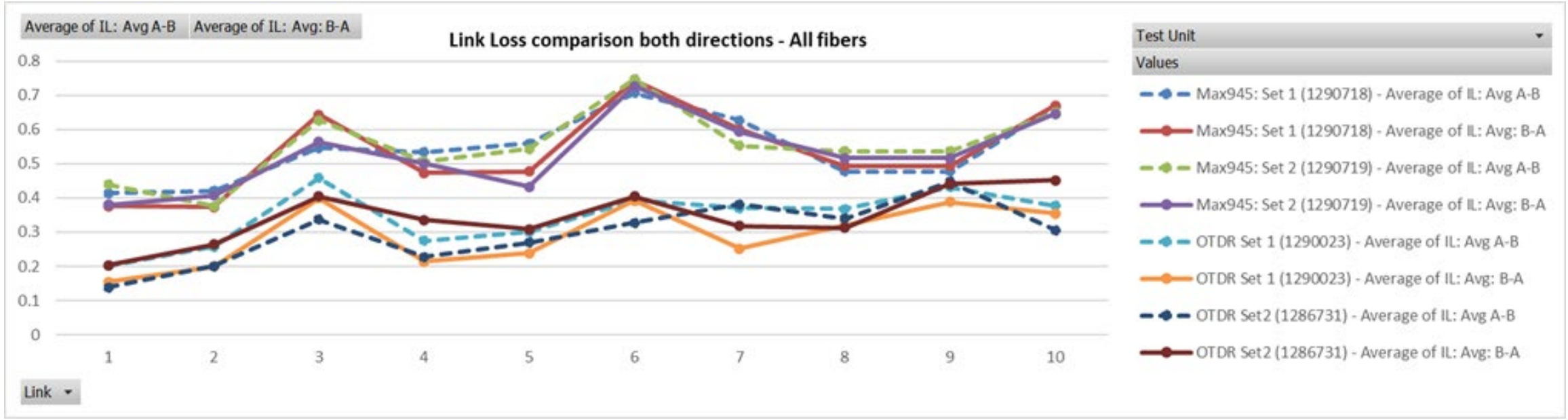
- Comparison Results:



- MIL-STD-2042 Maximum Allowable Loss (MAL) Link Budget value for each Link compared to the average loss values for the OLTS and OTDR.
- Links tested are of high quality and low loss. All Link loss values fall below 1dB.
- Published EF theory predicts that for loss values under 1dB, the measured attenuation difference will be within ±0.15dB.

Final Project Status Summary … continued

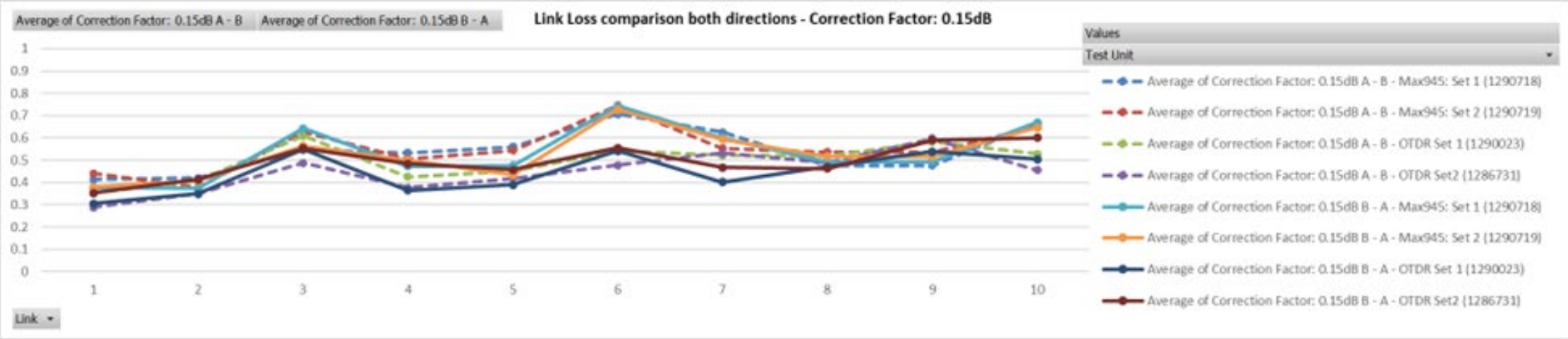
- Comparison Results:



- As a percentage of loss, the differences of measured loss are fairly significant.
- The differences range from 94% (6% less than measured by the OLTS) to 32% (68% less than measured by the OLTS). (Where 100% of the measured value would be the exact same value.)
- In dB the ranges were from -0.03dB to -0.36dB measured difference.
- In neither case are the values close enough to consider them comparable to one another as was the goal for this project.

Final Project Status Summary … continued

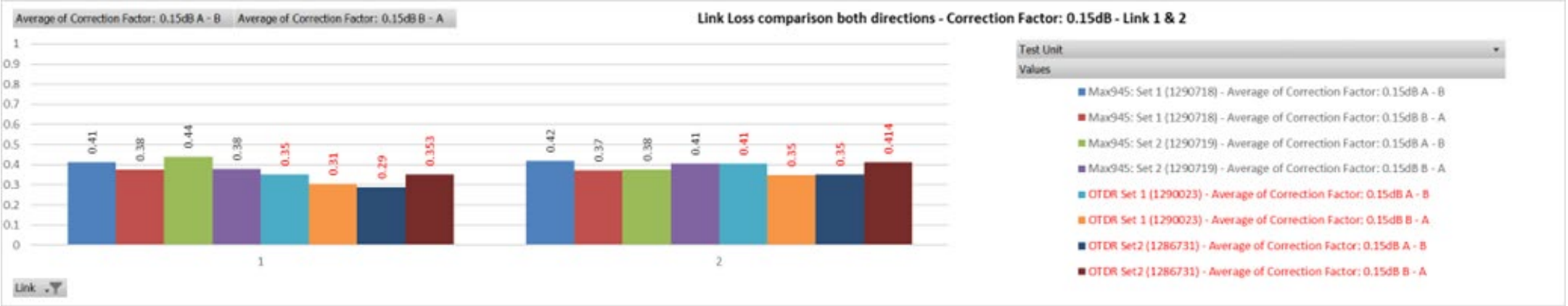
- Comparison Results:



- The figure above shows loss value alignment when a +0.15dB correction value is added to the measured OTDR loss value in both directions.
- For a measured OTDR Loss value of 0.20dB, a correction value of +0.15dB is added. The correction factor value is then plotted as 0.35dB and compared to the measured OLTS loss value.
- Although including a +0.15dB correction factor provides approved alignment, it is still not precise enough to recommend equivalence.

Final Project Status Summary … continued

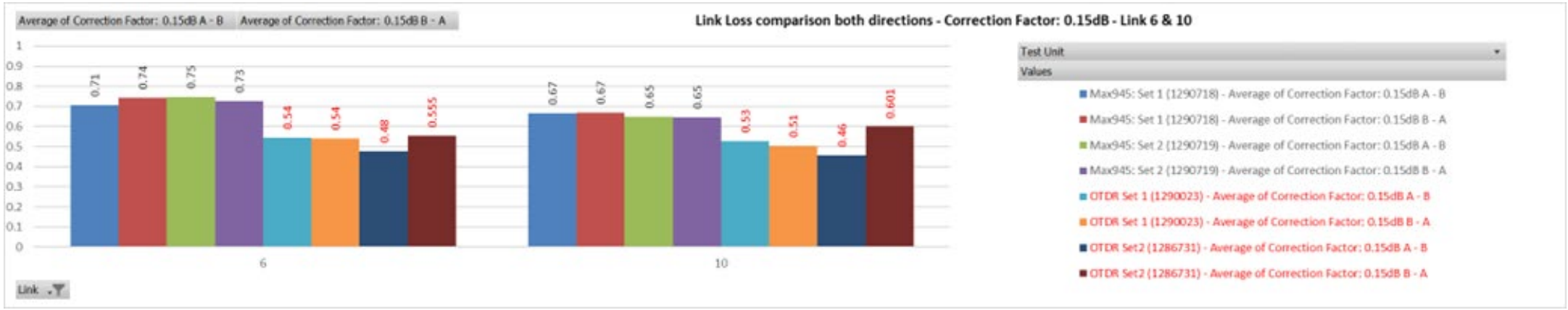
- Comparison Results:



- When including a +0.15dB correction factor, Links 1 & 2 appear to provide the closest alignment.
- Link 1 still shows a difference of -0.07dB when comparing the B to A measurement of both OLTS units to B to A measurement of OTDR unit 2.
- A corrective factor of +0.22dB would need to be applied for exact alignment. This falls outside of established EF Theory.
- Link 2 shows the closest alignment with the correction factor applied. There is still a -0.02dB difference between A to B measurements for the OLTS and OTDR.
- A correction factor difference of +0.02dB is still above the EF theory prediction.

Final Project Status Summary … continued

- Comparison Results:



- When including a +0.15dB correction factor, Links 6 & 10 appear to provide the largest misalignment of loss values.
- There remains a significant discrepancy between loss vales for both of these Links.
- The largest difference is in the A to B measurement for Link 6 resulting in a remaining loss value gap of -0.27dB. A correction factor of +0.42dB would need to be applied in order to have precise loss value alignment.
- Well outside of published EF Theory

Final Project Status Summary … continued

Possible Variation to EF Theory – Optical wavelength focus at 1300nm

- Optical wavelength for this project focuses on 1300nm as identified in MIL-STD-2042 (Methods 6C1, 6C2, 6E1) for multimode fiber testing.
- Light Emitting Diode (LED) transmitting sources operating at 1300nm have limited bandwidth and are generally recognized for data transmission below 655Mbps over multimode fiber.
- Vertical Cavity Surface-Emitting Lasers (VCSELs) operating at 850nm are generally recognized for data transmission up to 25Gbps for a single channel.
- Experimentation and focus for EF theory has been almost exclusively focused on 850nm window.
- Differences in published EF theory with a focus on 850nm transmission appear not to directly correlate to 1300nm experimentation. The difference in wavelengths is likely a critical reason the results for this project do not align with published EF theory.
- MQJ test cord length of 1m versus EF Theory based 2m to 5m Test Cords
- Potential for small variation in reference power that might contribute to EF Theory inconsistency.

Final Project Status Summary … continued

Conclusion:

- Although the launch condition of the Multimode OTDR was modified to align more closely with the Navy preferred launch condition, the testing results remained similar to the original project results for and do not provide the desired test result alignment required to recommend acceptance for using the OTDR in place of the OLTS for MM testing.
- At this time it cannot be recommended to accept the OTDR for equivalence to the OLTS for testing acceptance.
- Other benefits that the OTDR provides compared to the OLTS such as fault isolation to the component level and reduced manpower for testing may still be of interest in pursuing.

Areas for Possible Future Follow-on Efforts:

- Test measurement comparisons at 850nm
- Additional study related to MQJ test cord length from 1m to 2m

Questions???