

Is That Splice Really Good Enough?

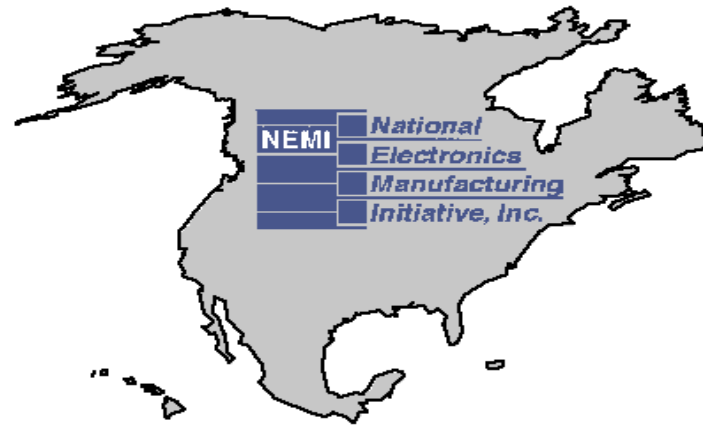
Improving Fiber Optic Splice Loss Measurement



Presented on Behalf of the Project Members

by Peter Arrowsmith

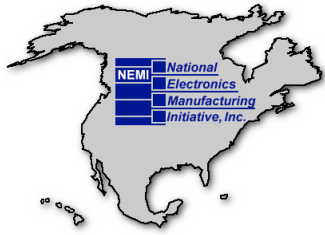
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Optoelectronics TIG

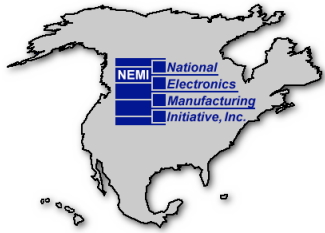
Fiber Optic Splice Improvement Project





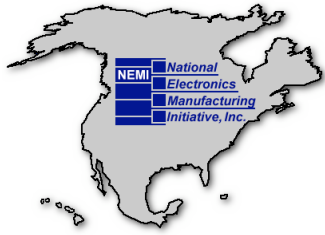
Acknowledgements

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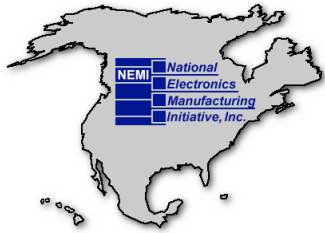
Improved Fiber Splicing Project

- Project Objective (from Statement of Work):
 - To develop and promote industry-wide test methods and splice quality criteria that will allow for systematic investigation of variability, comparison of equipment, improved yield and lower costs
- Project Benefits:
 - Promote the use of common metrics and measurement methods
 - Identify the sources of loss measurement variation for future improvement
 - Submit methods and guidelines for incorporation into OE standards, e.g. IPC-STD-0040
- Meeting Objectives:
 - Share technical results
 - Promote awareness of project activities
 - Attract companies to participate in follow-on OE projects



Areas of Interest & Priorities

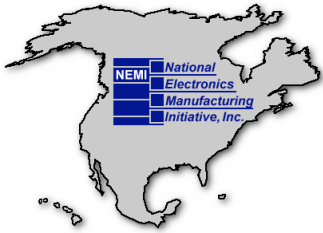
- Surveyed members to rank possible activities by expected benefit, likelihood of success and level of enthusiasm
- Survey included a wide range of topics relevant to the assembly of spliced optical modules
- Top Ranked Areas of Interest:
 - Review existing standards (Telcordia, TIA, IEC, IPC, etc)
 - Test method(s) for insertion loss (IL) of dissimilar splices (SMF-EDF, etc)
 - Splice acceptance metrics (measured & estimated IL, strength)
 - Estimated IL accuracy: compare methods, splicer vs measured, identify which loss mechanisms are included, potential improvement
 - Test method for strength (strain rates)
 - Test method for extinction ratio for PM fiber (fiber stressing for worst case vs non-stressed for repeatability, etc)
 - Splice reliability



Drivers: Why Loss Test Measurement?

- Different groups (fiber & equipment suppliers, OEMs, EMSs, Test Development, Manufacturing) often use different test methods
- Methods include: BFA, cut-back, add-on, inserted section, OTDR
- Test variables: measurement direction (e.g. SMF to EDF), 1310 vs. 1550 nm, use of fiber loops, integrating sphere, source stability, etc.
- Unknown measurement capability (R&R) and accuracy, poor correlation between measured and splicer estimated values
- Makes comparison of specs difficult for fiber batch, estimated values, splice & optical module loss budget requirements
- There are no standards for dissimilar fiber splice loss measurement
- Current standards do not address ultra low loss splices for optical module assembly (≤ 0.05 dB/splice loss budget for some applications)
- It is necessary to assess measurement capability at the limit of the test system, ideally $\leq 10\%$ of the smallest value to be measured

Connect With and Strengthen your Supply Chain

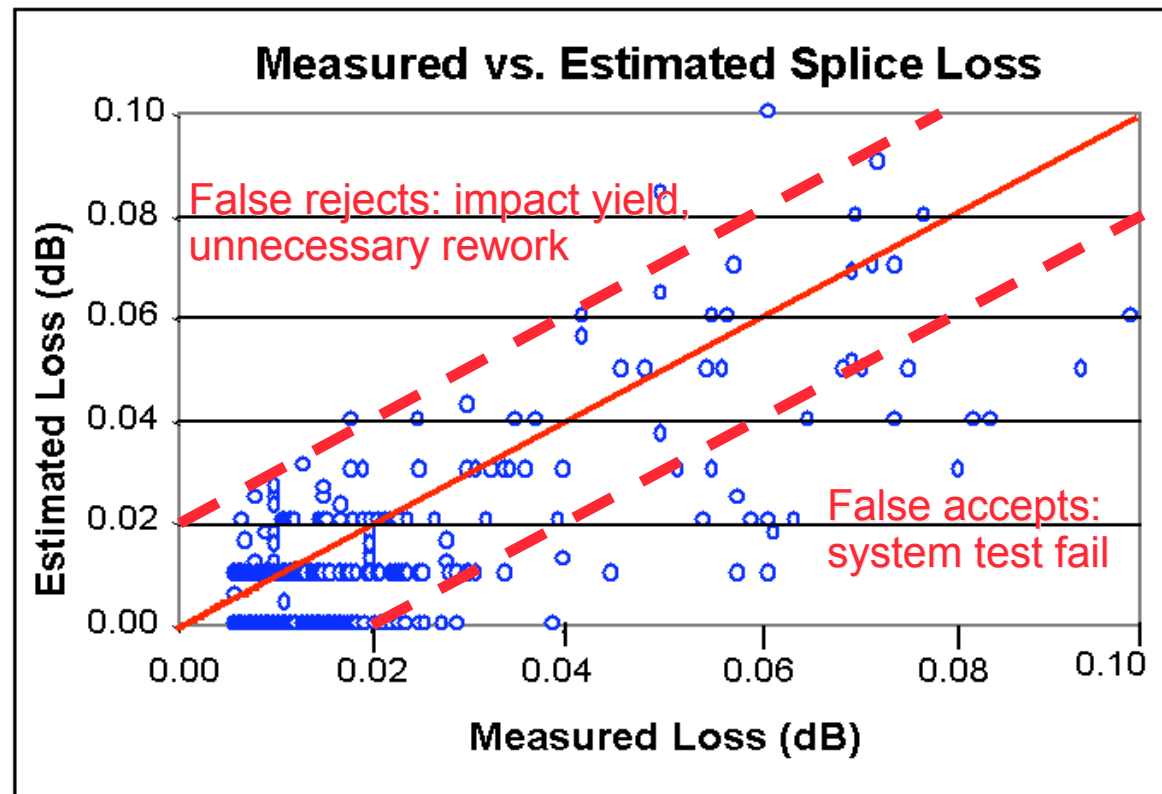


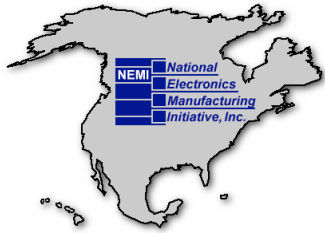
Correlation of Measured vs. Estimated Loss

- **Measured vs Estimated Loss**

- Low loss splicing for module assembly requires more accurate loss estimation
- Active splicing is used to ensure accuracy, but requires optical I/O access
- What are the failure modes for the outliers?
- Can the estimation be improved (software/hardware)?

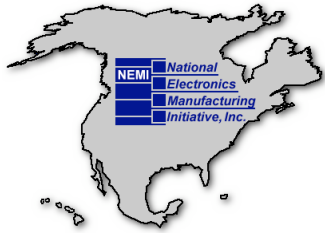
Figure shows Measured vs Estimated insertion loss for SMF-SMF splices on different 'PAS' style splicers





Current Status of Project and Synopsis

- | | |
|--|--------------|
| 1. Standards review. Request to IEC to distribute IEC 61073-3/1073-3 to group | 80% complete |
| 2. SMF-SMF gage R&R comparison of member's splice loss test methods | Complete |
| 3. Correlation of estimated vs. measured loss | 80% complete |
| 4. Loss estimator accuracy metrics, confidence limits | 50% complete |
| 5. Statistical comparison of actual loss distributions based on 1000 splice data sets, | 50% complete |
| 6. SMF-EDF splice loss repeatability, BFA method | Complete |
| 7. SMF-EDF splice round robin (directionality) | Complete |
| 8. Standards organization collaboration | In-progress |
| 9. Verify loss test methods for dissimilar fiber splices | In-progress |
| 10. Draft splice loss standard | Planned |



1. Standards Review

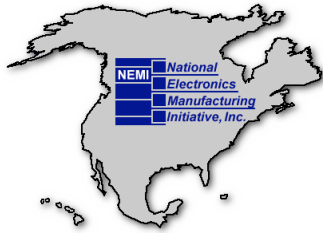
Goals

- Improve knowledge of existing specifications from Standards bodies
- Review all relevant specifications to see if product-level splicing requirements are addressed, vs. field/network splicing
- Compare standards to identify gaps, conflicts and overlaps

Actions Taken

- Identified the following bodies:
 - ITU-T, ETSI, JSA, Telcordia, TIA/EIA, IEC, BT, IPC & DOD Mil Stds
- Members split up workload and concurrently reviewed standards on-hand
- The following standards bodies have most relevant specifications:
 - Telcordia (TRs, GRs...), TIA (FOTPs...), IEC
- Approached IPC-PMA, Telcordia, TIA and IEC representatives to request additional standards, copies for use within project, and to develop partnerships
- TIA and IPC are enthusiastic to work with NEMI project on improved or new splice standards

Note: Project members would like to thank TIA for providing CD copies of the TIA standards requested.



Standards Review: Splicer & Splice Acceptance

	GR-765 Single Fiber SMF Splices and Splicing Systems	GR-1095 Multi-Fiber SM Splices and Splicing Systems	BT LN 469E Machines Joining for Single Fiber Fusion Splicers
Test fiber	≤ 0.4 μm core eccentricity. TIA fiber classes IVa & IVb	Nominal geometry error, diameter 125±0.3 μm, core-cladding concentricity ≤0.4 μm	>0.4 μm core eccentricity. Fiber per CW 1505 and CW 1504
Mean splice loss (R = required, O = objective)	R4-85 ≤0.10 dB for fiber with nominal geometry error	R4-104, R4-110 (module) ≤0.15 dB (passive ribbon splicing)	Mean not specified
	O4-86 ≤0.05 dB	O4-105 ≤0.10 dB (passive splicing) O4-111 (within module) Std. dev. ≤0.1 dB per joint	3.1 (O) Losses follow Weibull distrbn. (shape param 1.6 & characteristic value ≈ 0.05 dB)
Splice loss yield	R4-89 95% of splices, ≤0.10 dB	R4-107 95% of joints have loss ≤0.20 dB	3.1 (R) 95% ≤0.10 dB and 99.8% ≤0.15 dB (implies data set n>500)
	O4-90 95% of splices ≤0.05 dB	O4-108 95% of joints have loss ≤ 0.10 dB R4-109 (within module) 100% <0.40 dB	
Loss estimator accuracy (CR = condition for requirement) (CO = condition for objective)	CR4-55 Within ±0.10 dB for actual loss ≤0.40 dB. Within ±25% for actual loss >0.40 dB (n=10 splices). NB implies 100% of est. losses	CR4-62 For actual loss ≤ 0.40 dB, 90% of estimates within ±0.10 dB of actual loss, 100% within ±0.25 dB. For actual loss >0.40 dB, 90% of estimates within ±25% of actual loss, 100% within ±50%.	3.16 ±0.10 dB on fiber with known core offset ≥0.4 μm, with random orientation Mean difference between est. and actual losses ≤ 0.02 dB (n=100 splices)
	CO4-56 Within ±0.05 dB for actual loss ≤0.40 dB Within ±15% for actual loss >0.40 dB	CO4-64 For actual loss ≤0.40 dB, 90% of estimates within 0.05 dB of actual, 100% within 0.10 dB. For actual loss >0.40 dB, 90% of estimates within 15% of actual loss, 100% within 30%.	

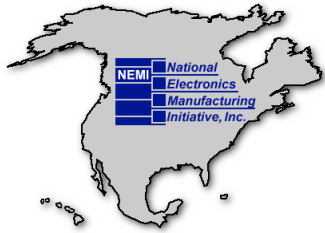
Table 1. Key Standards Requirements Relating to Fusion Splicer and Splice Acceptance



Standards Review: Splice Loss Test

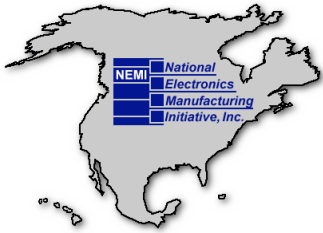
	GR-765 Single Fiber Single-Mode Optical Splices and Splicing Systems	GR-1095 Multi-Fiber Single-Mode Optical Splices and Splicing Systems	GR-198 Optical Loss Test Sets	TIA 455-34A Interconnection Device Insertion Loss Test	TIA 455-8 and 59 Measurement of splice or connector loss and reflection using an OTDR
Splice insertion loss test method (attenuation, transmittance)	5.1.4.1 In-line with selectable (optical switch) reference fibers, also OTDR per TIA 455-59.	5.1.4.1.1 In-line, measure continuous fiber, then break, splice and re-measure. Optical switch to select test or ref fibers. Also OTDR method.	Optical loss test sets (OLTS) used for outside plant optical network. Hand-held types with integrated optical source & power meter	1.1, 1.3, 5.1 & 5.2 SM splicing (test method B), procedures. In-line version and cut-back equivalent to "BFA". Recommends source monitoring.	OTDR , single fiber
Source wavelengths and spectral width	1310 and 1550 nm	5.1.4.1.4 1310 ± 20nm and 1550 ± 20nm spectral width ≤ 75 nm	R4-1 Dual λ capability. At 1310 nm: LED ≤140 nm, laser ≤5 nm. At 1550 nm: LED ≤150 nm, laser ≤5 nm	3.1.1 660, 850, 1310 & 1550 nm. Center wavelength ±30 nm, spectral width <140 nm for 1310 nm (LED or laser diode)	850, 1300, and 1550, ± 20 nm
Source stability	5.1.4.1.4 <0.01 dB over measurement period	5.1.4.1.4 <0.01dB over period required to make one set of measurements	R4-2 Within ±0.5 dBm over 8 hr period at (23±2°C)	3.1.3 "Greater" of ±0.02 dB over period of test or 10% of max attenuation	Not specified
Accuracy	Not specified	Not specified	R4-17 ≤±0.5 dBm at Pin -10 dBm Optionally -25dBm	Not specified	Calibrated to ≤ 0.05 dB
Detector range, response power (RP) and linearity	5.1.4.1.4 ≥60 dB below source power Linearity not specified	5.1.4.1.4 ≥60dB below the source power Linearity not specified	R 4-11 Min RP -55 dBm Max RP +1 dBm Linearity not specified	3.4 Must measure all power emitted from output fiber. Linearity within 5% of range of power	None specified
Resolution	Not specified	Not specified	Not specified	3.5.2 Better than 0.01 dB for loss <0.5dB	Min. reportable loss of non-reflective "event" (splice) ≤0.10 dB

Table 2. Standards Specifications for Insertion Loss Test Methods and Equipment



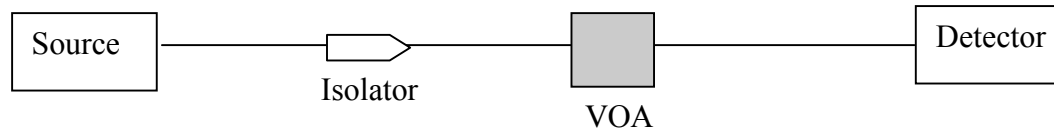
Standards Review – Key Findings

- Many of the standards that cover splicing are 6 or more years old and therefore do not cover newer fibers (80 μ m, NZ-DS, LEAF) or fiber combinations such as dissimilar splicing (SMF-EDF, etc).
- For standards purposes, it is not clear whether a splice should be considered a fiber or a passive component
- Most of the standards do not address splicing for optical module assembly
- Most specs consider splice losses of 0.1-0.4 dB to be acceptable
- Splice loss test requirements (source stability, measurement accuracy and repeatability, etc) are generally inadequate for low loss product splicing
- For today's products with SMF-SMF, low loss splices of 0.0-0.05 dB are routine, requiring measurement repeatability of ± 0.005 dB (10% of the range)
- A source stability of < 0.01 dB (Telcordia GR-765, 1095) is barely adequate
- Practical information on test set-ups and methods are generally omitted
- TIA 455-34A comes closest to meeting our needs for a loss measurement method

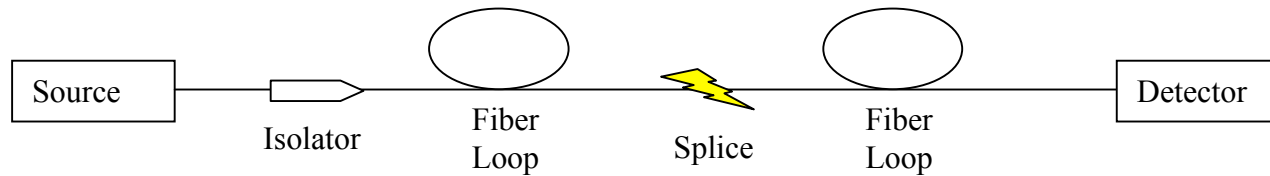


2. Member Splice Loss Test Methods

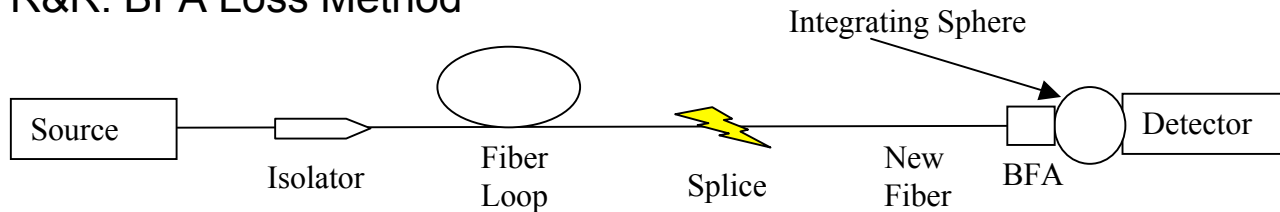
1. Stability: In-Line or BFA Methods (linearity requires VOA)



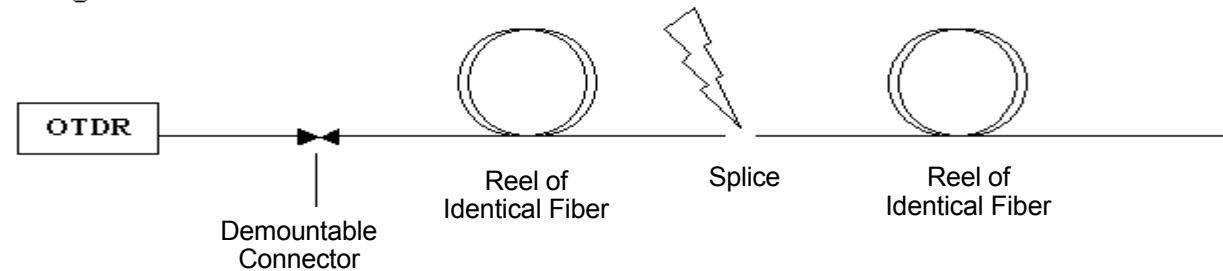
2. Gage R&R: In-Line Loss Method



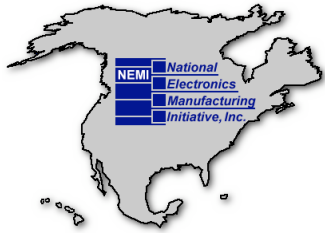
3. Gage R&R: BFA Loss Method



4. Gage R&R: OTDR Loss Method

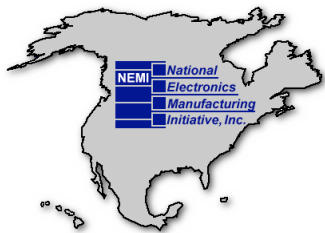


Connect With and Strengthen your Supply Chain



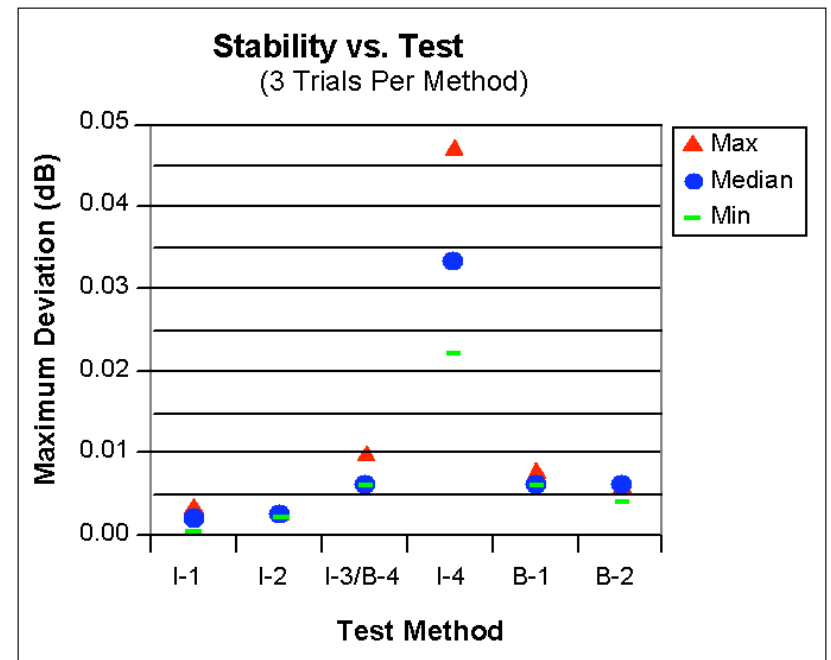
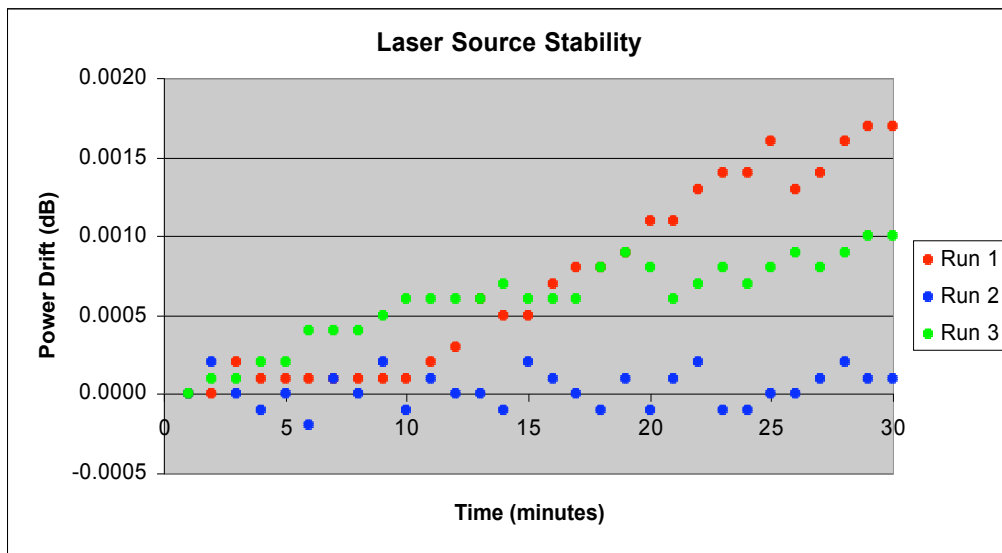
Gage R&R Test Method and Data Collection

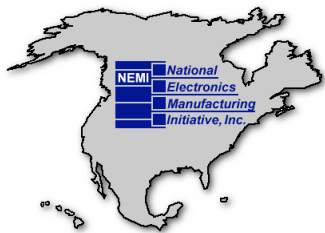
- Members submitted Gage R&R data using the In-line, BFA and OTDR methods
- Three loss ranges (0-0.05, 0.05-0.1, 0.1-0.15 dB), each measured by up to three operators
- Splicing and test equipment varied between members. Also variations in test setup, e.g. use of isolators, mode filters (fiber loops), coupling to detector & methodology
- Measurement repeatability as a percentage of the range is acceptable ($\leq 10\%$), marginal (10-30%) or unacceptable ($>30\%$)
- All used the same Gage R&R spreadsheet calculator
- Parameters recorded and used:
 - Measured loss (assumed to be actual loss)
 - Splicer estimated loss
 - Periodic source power & detector reading for stability monitoring (except OTDR method)
- Recorded only: cleave angles, splicer condition (arc time, power), env. conditions



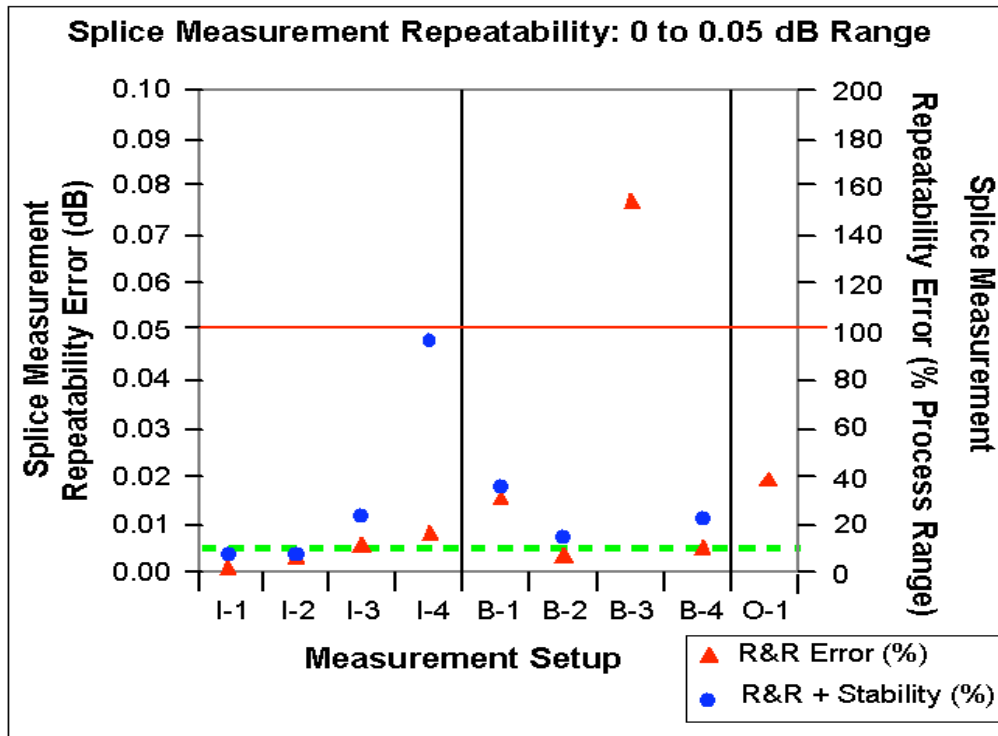
Splice Measurement Repeatability: Gage R&R Stability

- Three stability runs per measurement system (except for one BFA)
- Source stability is not relevant for OTDR (μ s to ns pulse)
- Time interval over which stability was monitored was the same as the splice process & measurement period
- The maximum drift deviation of the 3 runs was used to define the stability error





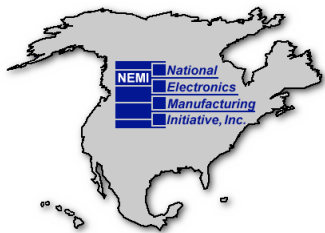
Splice Measurement Repeatability Gage R&R Study – Results



	R&R (dB)	% R&R (%)	Stability (dB)	% R&R + Stability (%)
I-1	0.0012	2.4	0.0034	7.2
I-2	0.0026	5.3	0.0028	7.7
I-3	0.0054	10.9	0.0100	22.8
I-4	0.0080	16.1	0.0472	95.8
B-1	0.0154	30.7	0.008	34.6
B-2	0.0036	7.2	0.006	14.0
B-3	0.0769	153.8	---	---
B-4	0.0052	10.3	0.010	22.5
O-1	0.0190	38.1	---	38.1

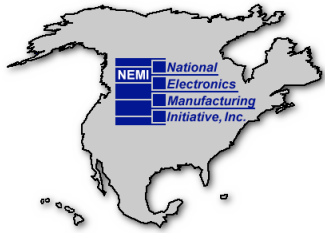
Table 4. Gage R&R Test Results (Two-sided Values)

Connect With and Strengthen your Supply Chain



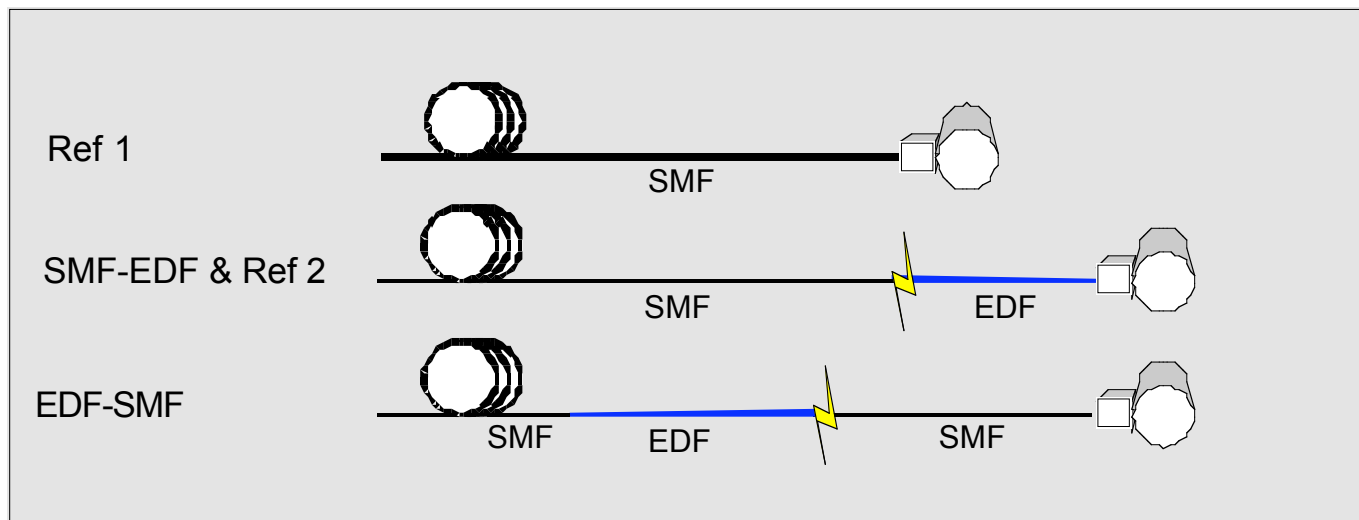
Splice Measurement Repeatability Gage R&R Study – Conclusions

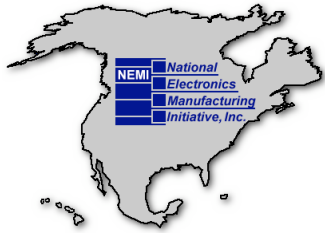
- Table shows variation within and across 4 In-line methods, 4 BFA and OTDR (users' current set-ups)
- Three test systems/processes are capable of meeting 10% R&R criterion
- Including source stability increases measurement error and only 2 of 9 methods pass 10% criterion
- Within each method there is a large range, e.g. the total process variation for the In-line is 2.4% to 16.1%
- Possibly the best In-line R&R results exceed the best BFA, but more study required using unbiased DOE, control of variables
- Variation in process, due to different splicers & arc parameters, is unknown (this is not expected to be large for SMF-SMF)
- Evident need for more specific standards that detail test methodologies for splice loss. Simply to say that the In-line method being used is not sufficient.
- Confirms need to develop and promote standardized test methods



6. Dissimilar Splice Loss Measurement: Option 1

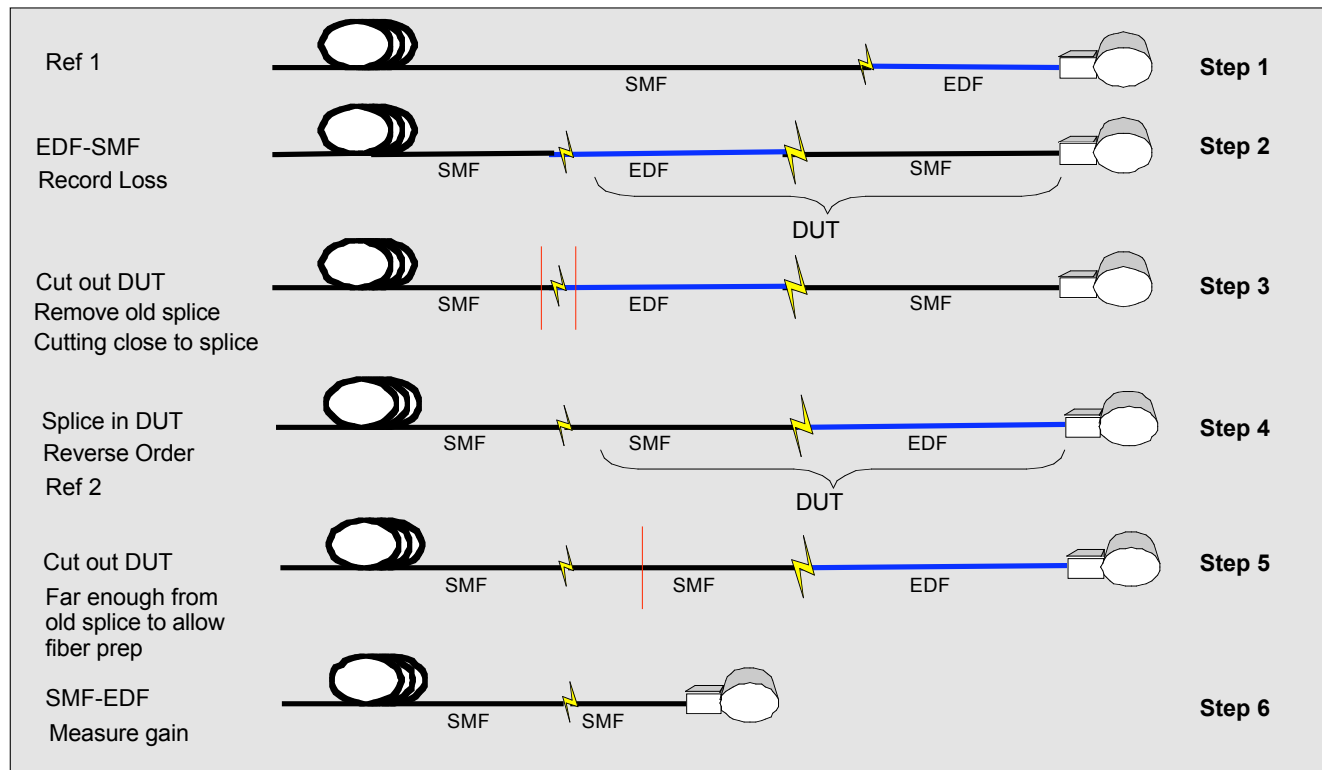
- Make 10 to 30 splices and measurement each splice in one direction, e.g. SMF \square EDF or EDF \square SMF
- Randomize measurement sequence
- Analyze data by comparing the means of the high & low groups for each user
- May not be possible to combine the data from all users, as values may vary depending on splicer parameters (optimization)

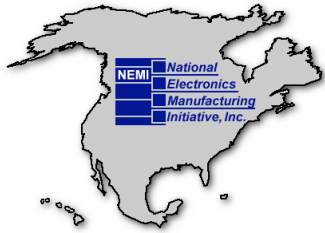




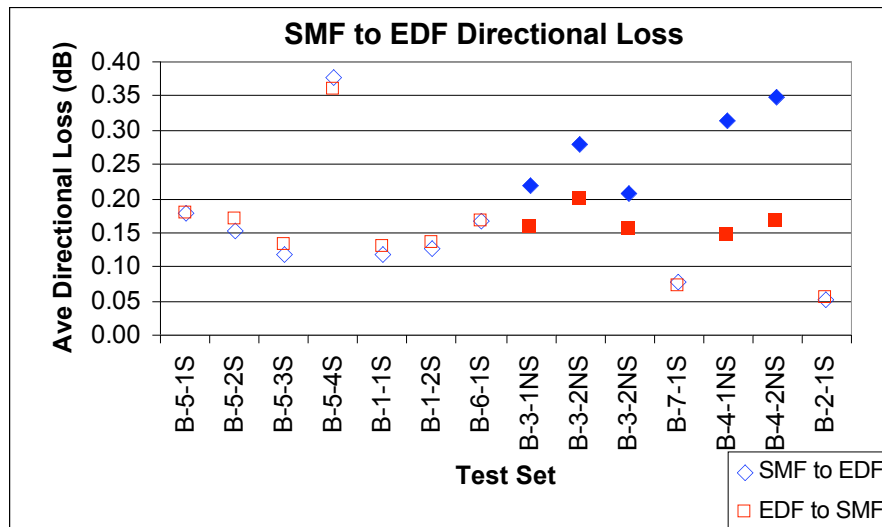
Dissimilar Splice Loss Measurement: Option 2

- Make 10 to 30 splices, and measure each splice in both directions (randomize directions)
- Correct for absorption, if significant (>0.01 dB/m). Measurements at 1310 nm
- Analyze data by performing paired comparison for each user. Compares the deltas in directions for each splice
- Should be possible to combine the data from all users, as well as analyzing each





SMF-EDF Splice Directionality Results



Loss data for SMF-EDF splices, measured in each direction at 1310 nm (using BFA methods 1 & 2). Set-ups B-3 and B-4 without an integrating sphere (NS) are shown as solid symbols.

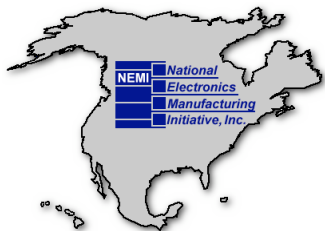
Sample Set	Integ. Sphere	Qty	SMF-EDF		EDF-SMF		Directionality (dB)
			Ave (dB)	StDev (dB)	Ave (dB)	StDev (dB)	
B-5-2S	Y	11	0.1519	0.0546	0.1691	0.0187	0.0172
B-5-3S	Y	10	0.1192	0.0281	0.1313	0.0226	0.0122
B-1-1S	Y	10	0.1186	0.0232	0.1298	0.0233	0.0112
B-1-2S	Y	10	0.1268	0.0250	0.1341	0.0253	0.0073
B-2-1S	Y	10	0.0508	0.0074	0.0545	0.0088	0.0037
B-6-1S	Y	10	0.1659	0.0470	0.1659	0.0425	0.0000
B-5-1S	Y	10	0.1786	0.0131	0.1783	0.0169	-0.0003
B-7-1S	Y	6	0.0788	0.0114	0.0732	0.0108	-0.0057
B-5-4S	Y	9	0.3778	0.0444	0.3600	0.0194	-0.0178
B-3-3NS	N	15	0.2080	0.0430	0.1560	0.0327	-0.0520
B-3-1NS	N	10	0.2193	0.0517	0.1590	0.0330	-0.0603
B-3-2NS	N	30	0.2790	0.0220	0.1983	0.0280	-0.0807
B-4-1NS	N	10	0.3142	0.0438	0.1454	0.0198	-0.1689
B-4-2NS	N	10	0.3478	0.0196	0.1655	0.0162	-0.1823

SMF-EDF splice loss data ranked by directionality (EDF - SMF minus SMF - EDF) showing dependence on use of integrating sphere, “S” with and “NS” without.



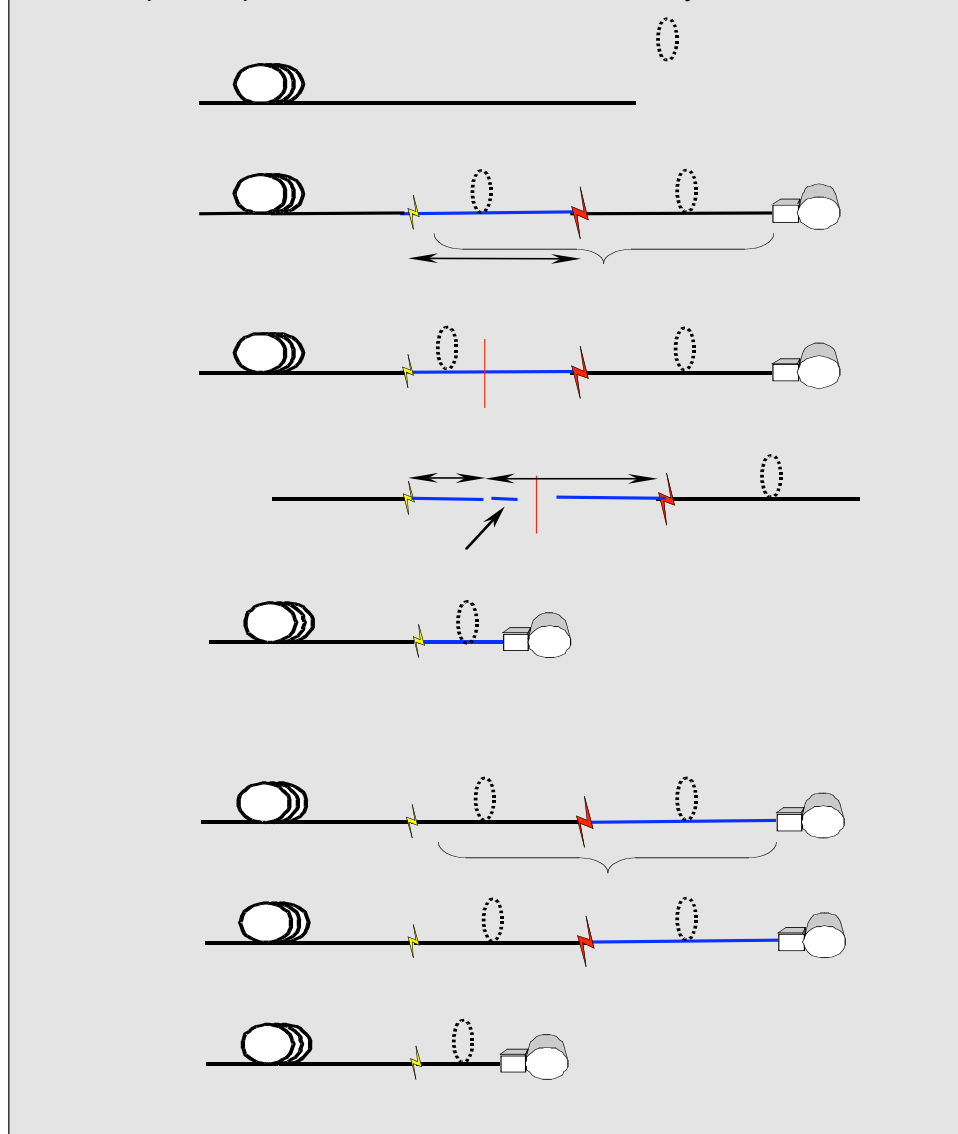
SMF-EDF Loss Measurement

- Some users found significant directional difference, SMF-EDF direction has higher loss
- Average loss (both directions) similar for users with small and large deltas
- One set-up used with & without fiber loops (high order mode stripper) -- no significant difference
- Directionality impacts any proposed standard measurement method
- Cause may be with measurement set-up, fiber type(s) and/or splice
- Investigated further by round-robin measurements
- Three users each made at least 5 splice sections, measured all splices
- Site-to-site method allows each splice section to be measured in both directions (paired comparison) without destroying the original splice



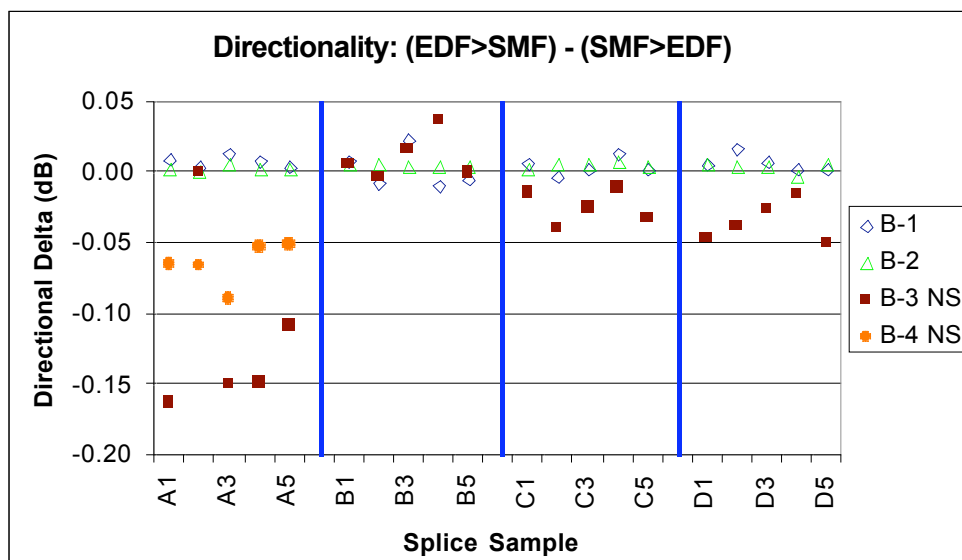
7. SMF-EDF Splice Repeatability: Site-to-Site Round Robin Method

EDFSMFPrep SMFSplice inDUT,EDF-SMFdirection,Ref System,Measure EDFleng

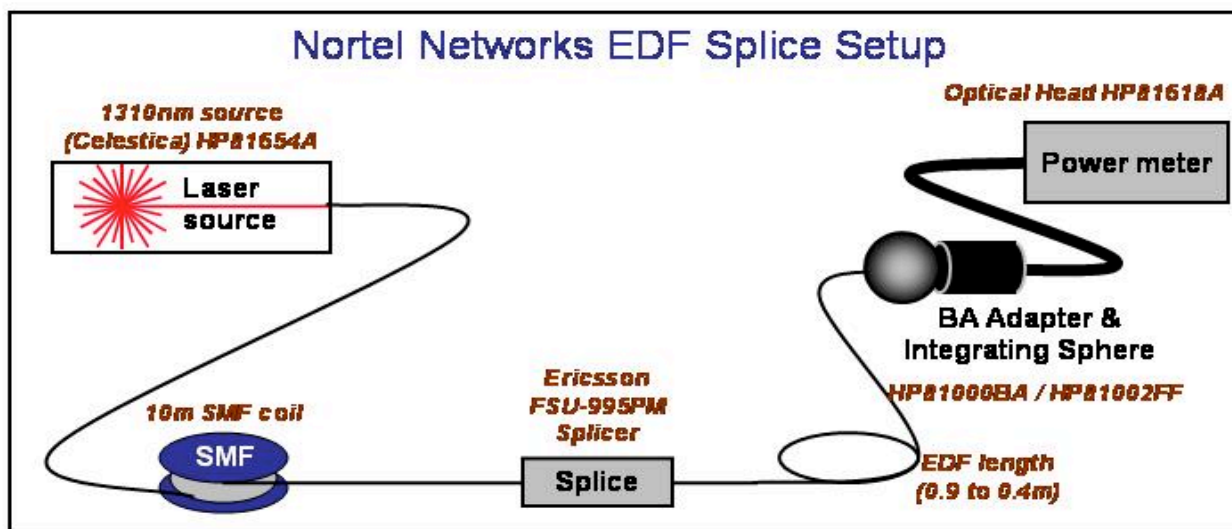


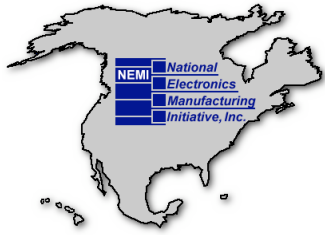


SMF-EDF Splice Round Robin Results



Round-robin directional data for SMF-EDF splices at 1310 nm (using BFA site-to-site method). A to D are fiber combinations and B-1 to B-4 are user test setups. The largest directionality is found for user set-ups B-3 & B-4, both without an integrating sphere.





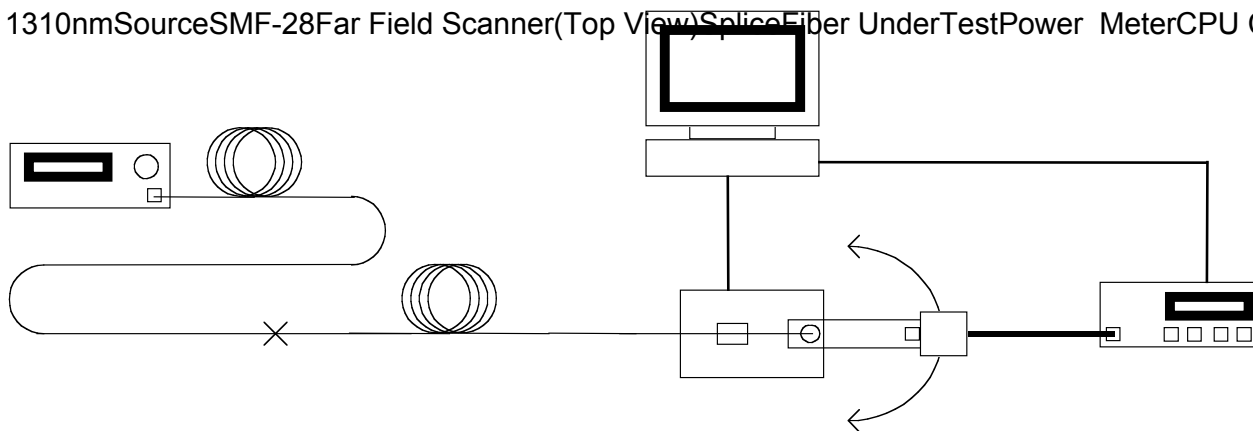
SMF-EDF Splice Loss -- Interim Conclusions

- BFA method at 1310 nm is capable for dissimilar splice loss measurement, with losses >0.1 dB (R&R data shown in paper)
- Limited published directionality data, but theory predicts no delta for fiber with pure Gaussian mode fields
- Hence directionality dependence is not expected and had to be investigated
- Round-robin indicates directionality may depend on measurement set-up
- Directionality correlates with lack of integrating sphere
- SMF \square EDF direction shows highest loss where there is a delta
- Measured far field intensity distribution at bare end of SMF-28 and EDF to investigate root cause (independent method)



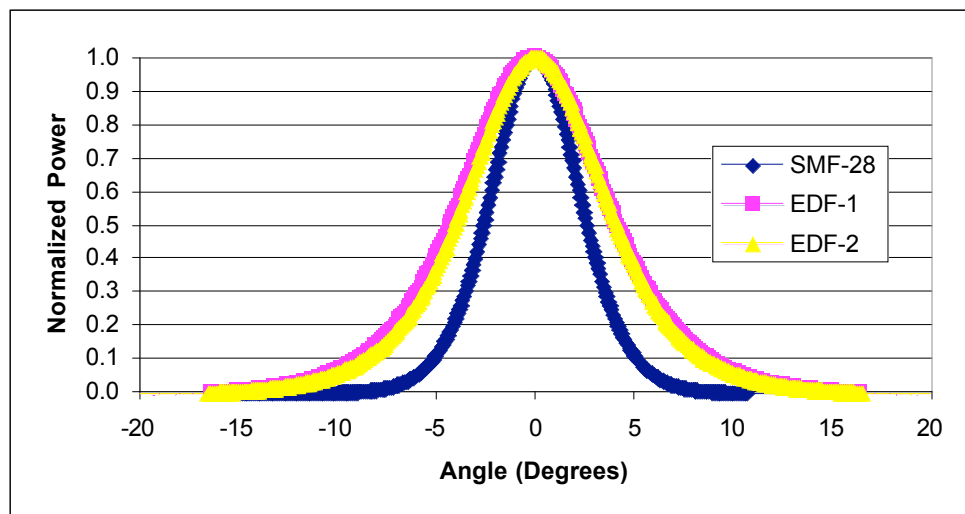
SMF-EDF Splice Directionality: Far Field Intensity Distribution

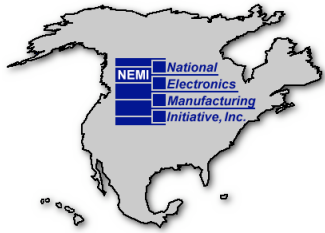
1310nmSourceSMF-28Far Field Scanner(Top View)SpliceFiber UnderTestPower MeterCPU Cc



The $1/e^2$ points of the intensity distribution give the numerical aperture (NA) of the fiber. The mode field diameter (MFD) is μ $1/NA$.

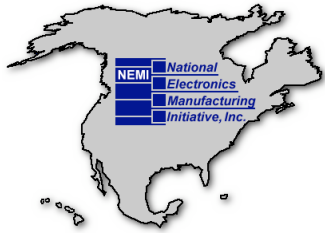
The EDF has smaller MFD and larger NA than SMF-28.



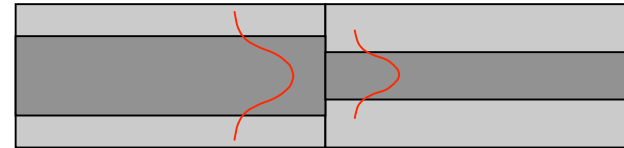
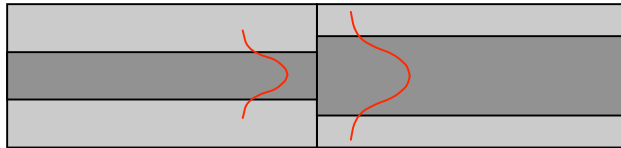


SMF-EDF Splice Loss -- Final Conclusions

- Light emitted from the EDF has a larger cone (NA) cf. SMF-28
- The integrating sphere collects a fraction of all the emitted light, independent of angle
- In the absence of the IS some of the light emitted at higher angles may not be coupled onto the detector, or be detected as efficiently
- Hence highest loss occurs when EDF is coupled to the detector
- Directionality is an artifact of the measurement set-up
- Users need to be aware of the issue and take corrective action
- For example, measure the EDF \square SMF direction, measure both directions and average, and/or use a large area detector/IS
- Even with a directional system, the sum (average) of the two directions gives the same/“correct” value for the splice loss (verified w/site-to-site)

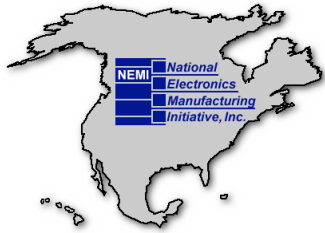


MFD Mismatch: The Water Bucket-Hose Analogy



**The “Hose and Bucket”
analogy does not hold
water!**





8. Standards Organization Liaison

IEC SC 84A fibers, SC 86B (Bruce LeFevre) fiber optic interconnecting devices and passive components

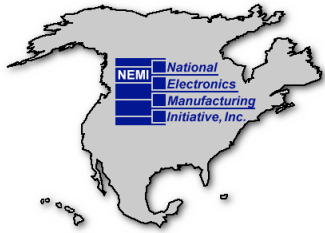
- WG1 (Al Cherin): fibers and associated measuring methods
- WG4 (Ton Bolhaar): stnd. test and measurement methods for f-o interconnecting devices & passive components
- WG6 (Philip Longhurst): stnds and specs for f-o interconnecting devices
- WG7 (Andre Girard): fiber optic passive components

TIA SC FO-4 (Chair, Steve Swanson) fiber optic components/sub-systems

- FO 4.2/4.4 test and measurement methods
- FO 4.3 (Tom Ball, Matt Brown): interconnecting devices and related components
- FO 4.8 (Andre Girard): passive f-o devices
- TIA has proposed NEMI representation on U.S. TAG

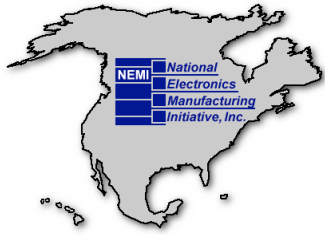
IPC STD 0040-302 fiber splicing & test (proposed)

Connect With and Strengthen your Supply Chain



Planned & Possible Follow-on Activities

- Verify test methods for dissimilar fiber splices, SMF28-X (X = EDF, LEAF, high NA)... currently in-progress (#9)
 - BFA/single cut-back, add-on and inserted section methods
- Write project report
- Project completion 1Q'04
- Form follow-on project (with IPC/TIA/IEC) to develop loss measurement standards
 - low loss SMF-SMF splicing and dissimilar fiber splices
- Splicer estimator accuracy metric, based on confidence limits
 - Splice SMF at limits of MFD, core concentricity, eccentricity and batch-to-batch variation, depending on member interest
- Low loss standard “splice” for accuracy assessment, with NIST



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Thank You
Fiber Splice Improvement Project

Connect With and Strengthen your Supply Chain