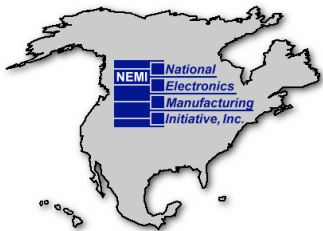




Improving Fiber Optic Splice Loss Measurement

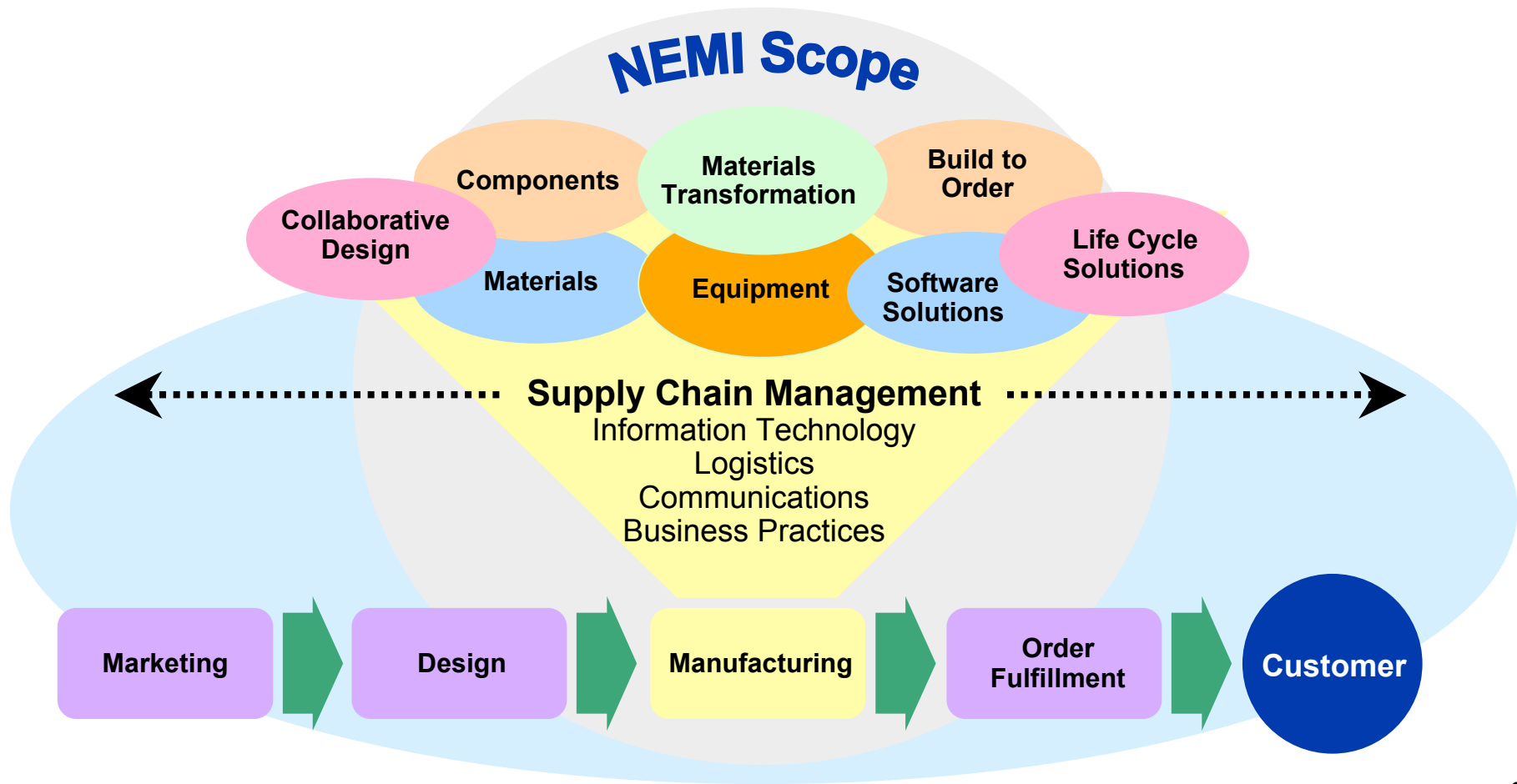


***Presented on Behalf of the Project
Members
by Peter Arrowsmith & Denis Gignac
10-7-2003***

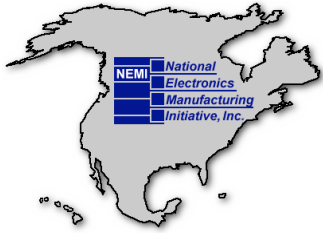


NEMI Mission

Assure Leadership of the Global Electronics Manufacturing Supply Chain



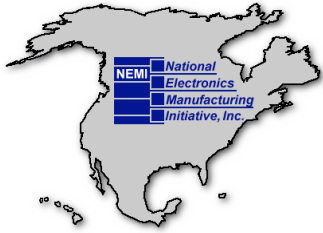
Connect with and Strengthen your Supply Chain



NEMI Mission Statement

NEMI is a North American based consortium whose mission is dedicated to providing leadership for the global electronics manufacturing supply chain for the benefit of its member companies and the industry.

Connect with and Strengthen your Supply Chain

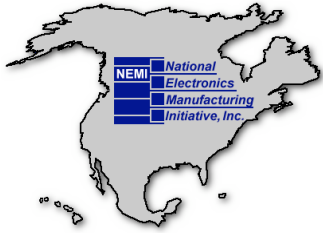


What Does NEMI Do?

Leverage the combined Power of Member Companies and their Partners to Provide Industry Leadership

- **NEMI Roadmaps the Global Needs of the Electronics Industry**
 - Evolution of existing technologies
 - Predictions on emerging/innovative technologies
- **NEMI Identifies Gaps (both business & technical) in the electronics Infrastructure**
- **NEMI Stimulates R&D Projects to fill these Gaps**
- **NEMI Establishes Regional Implementation Projects to Eliminate these Gaps**
- **NEMI Stimulates Global Standards to speed the Introduction of New Technology & Business Practices**
- **NEMI works with other organizations to insure that North American government policy recommendations are aligned with NEMI mission.**

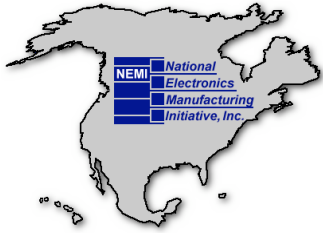
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NEMI & Standards

- **NEMI is not a formal standards body.**
- **However, many NEMI deployment projects can benefit from adoption of open industry standards.**
- **Our strategy then is to collaborate with other industry groups as required to develop the appropriate standards that will accelerate adoption of technology and business practices.**
- **This collaboration is driven by specific needs of NEMI projects and Technology Integration Groups (TIGs).**

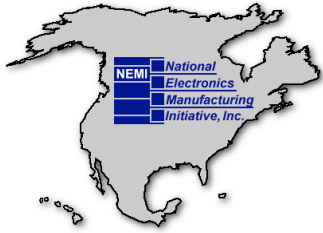
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Existing Cooperation on Standards

- **NEMI has worked with the following groups to develop and deploy standards:**
 - EIA/JEDEC (typically on Semiconductor Packaging)
 - IEEE (machine interface software)
 - IPC (Printed Wiring Board fabrication & assembly, data exchange)
 - RosettaNet (data exchange)
- **Typically we enter into a written agreement with organizations that spells out:**
 - Roles & Responsibilities
 - Recognition for standards developed
 - Ongoing support/updating

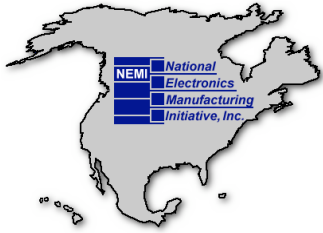
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Potential Cooperation

- **Based on work of NEMI's Optoelectronics projects, we recognize that we may need to work with other organizations to develop and deploy standards in these topics.**
- **NEMI is open to this possibility and welcomes the opportunity to establish new relationships to meet these needs.**

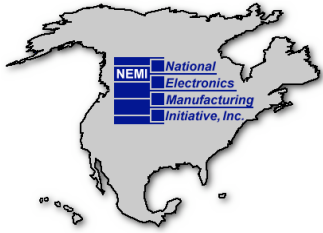
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Improved Fiber Splicing Project

- 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 critical cause(s) of splice variation for future yield improvement
 - Submit methods and guidelines for incorporation into OE standards, e.g. IPC-STD-0040.
- Meeting Objectives:
 - Raise IEC and TIA awareness of NEMI and OE projects
 - Share technical results
 - Promote liaison, leading to possible collaboration on standards development

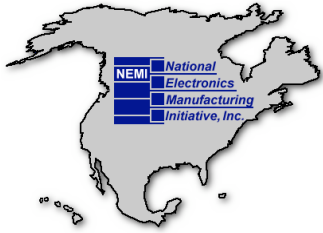
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Current Status of Project and Synopsis

- | | |
|--|--------------|
| 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. Distribution of EDF (Sumitomo & StockerYale) | Complete |
| 7. SMF-EDF splice loss repeatability, BFA method | Complete |
| 8. SMF-EDF splice round robin (directionality) | 50% complete |
| 9. Standards organization collaboration | In-progress |
| 10. Draft low loss/dissimilar splice standards | Planned |

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1. Standards Review

Goals

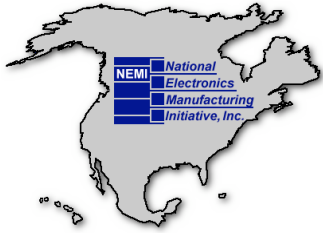
- Improve knowledge of existing specifications from Standards bodies
- Review all relevant specifications to see if product-level splicing requirements are addressed, vs. field/network splicing
- Compare standards to identify gaps, conflicts and overlaps

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

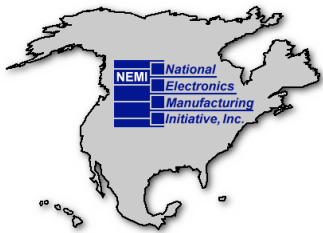
Note: Project members would like to thank TIA for providing CD copies of the TIA standards requested.

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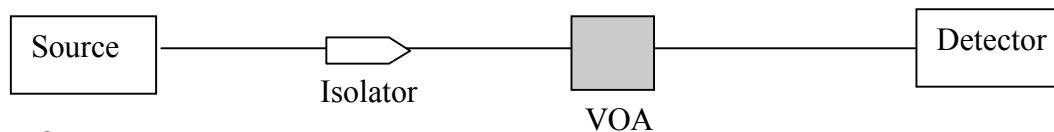
Standards Review – Key Findings

- Many of the standards that cover splicing are 6 or more years old and therefore do not cover newer fibers (80/165 μ m, NZ-DS, LEAF) or fiber combinations such as dissimilar splicing (EDF-SMF, 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

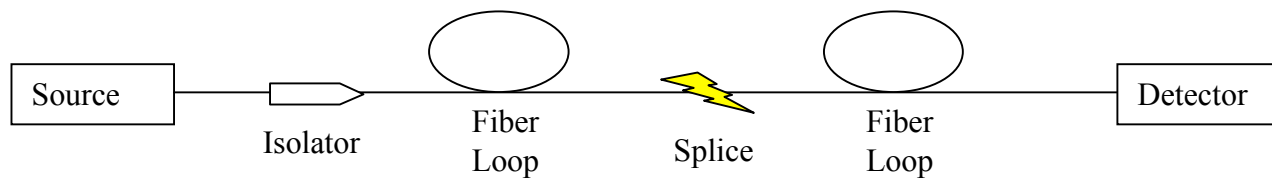


2. Member Splice Loss Test Methods

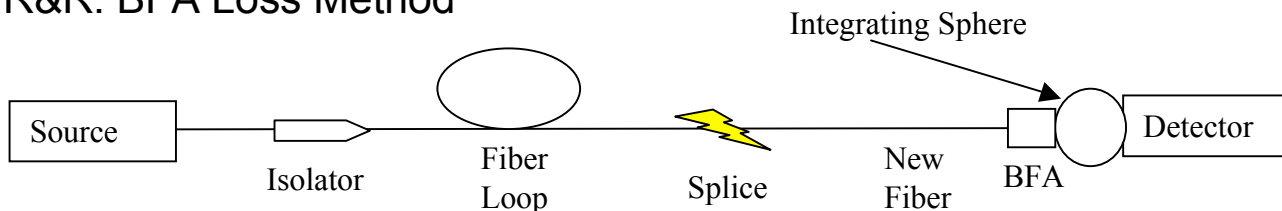
1. Stability: In-Line or BFA Methods (linearity requires VOA)



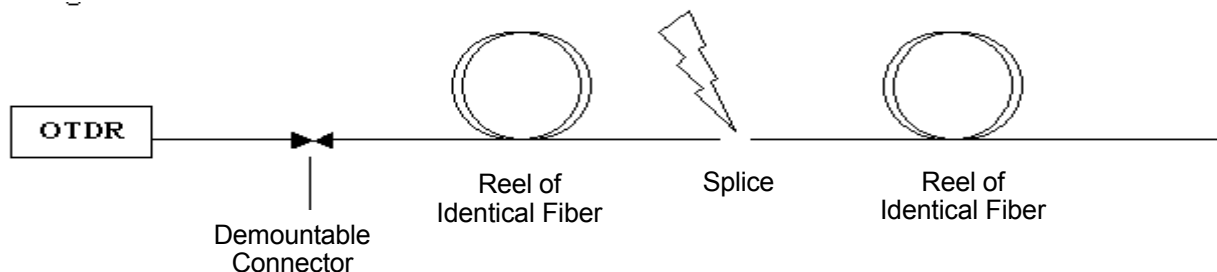
2. Gage R&R: In-Line Loss Method



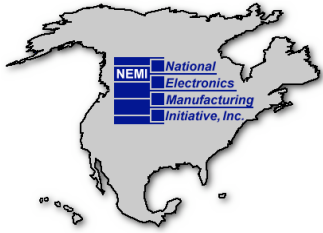
3. Gage R&R: BFA Loss Method



4. Gage R&R: OTDR Loss Method

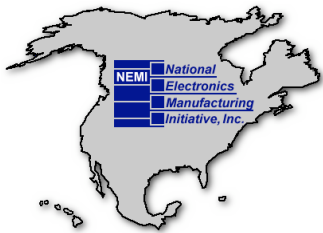


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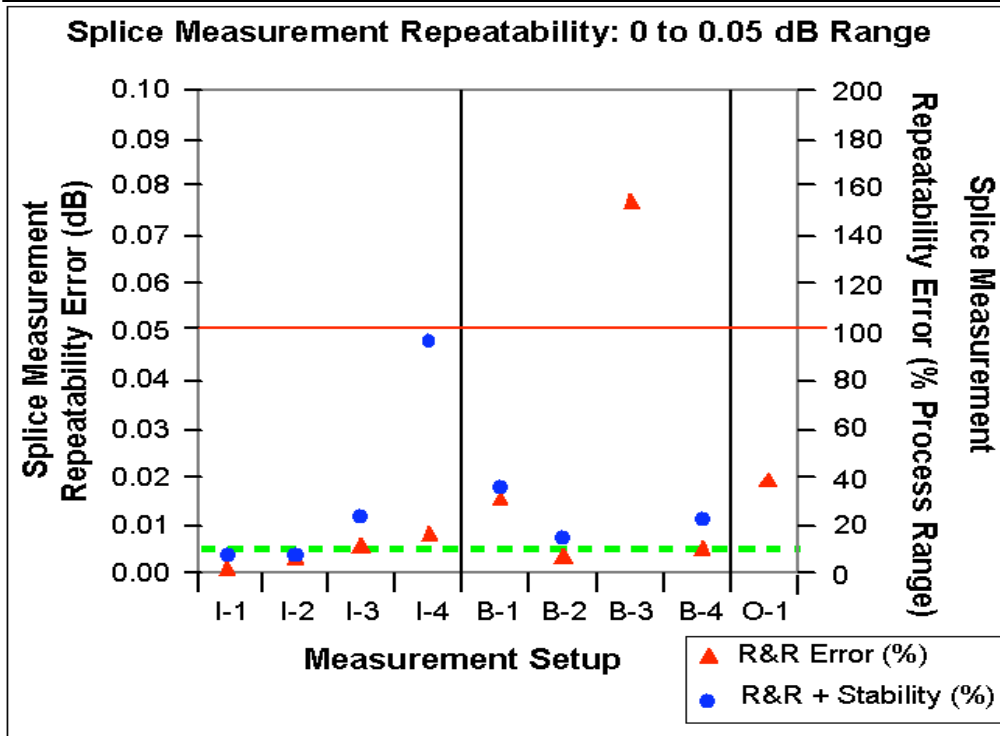


Gage R&R Test Method and Data Collection

- 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 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



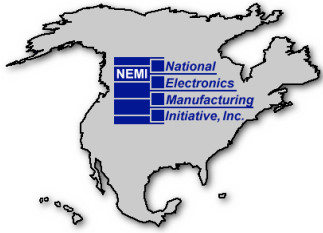
Splice Measurement Repeatability Gage R&R Study – Results



	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

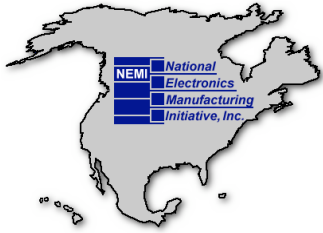
Table 4. Gage R&R Test Results (Two-sided Values)

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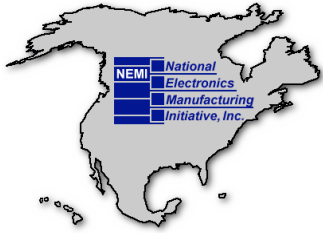
Splice Measurement Repeatability Gage R&R Study – Conclusions

- 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



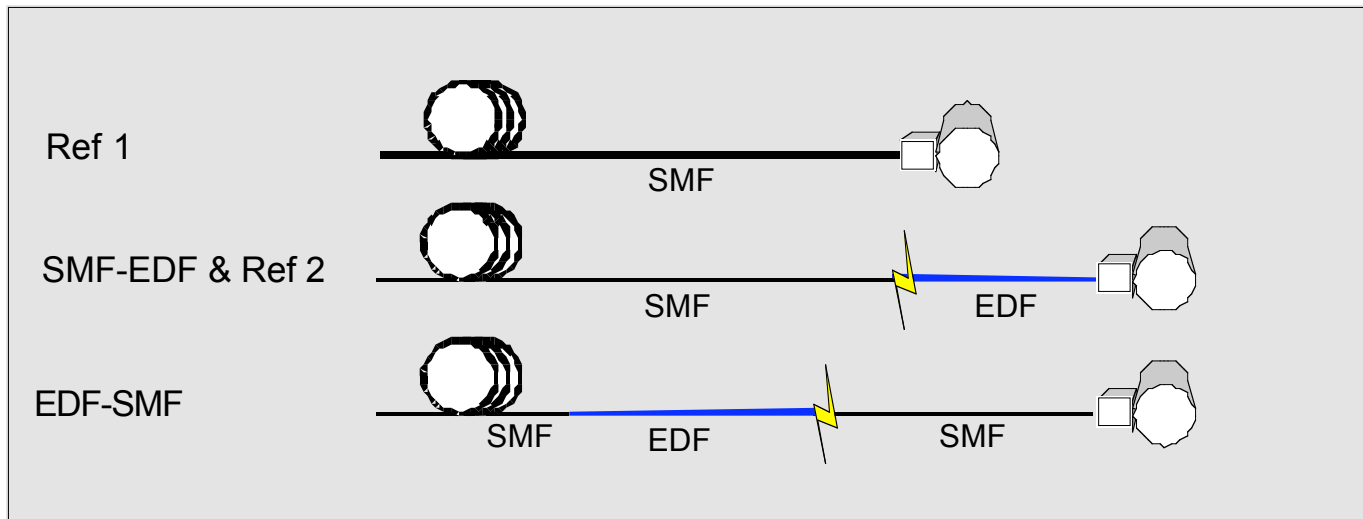
7. SMF-EDF Splice Loss Measurement

- Erbium doped fiber (EDF) is most important fiber type used in optical amplifiers, hence need for dissimilar fiber splicing (SMF-EDF)
- There are no standards for dissimilar splice loss measurement
- Fiber suppliers, OEMs, equipment & EMS companies use in-house methods... unknown measurement capability (R&R) and accuracy
- Makes comparison of specs difficult for fiber batch, splicer estimator values, splice & optical module loss requirements
- Different test methods: BFA, cut-back, inserted EDF section (average)
- Initial verification using two different EDF suppliers
- Test variables: measurement direction (“high” is SMF-EDF), 1310 vs. 1550 nm, use of fiber loops, integrating sphere, source stability, etc.
- Initially investigated directionality: “high” vs “low” using defined BFA method at 1310 nm. Exact set-up & equipment varied with user

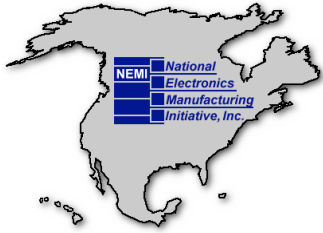


SMF-EDF Splice Loss Measurement: Option 1

- Perform 10 to 30 SMF-EDF splices and measurements in the “low” direction
- Same in the “high” direction
- 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)

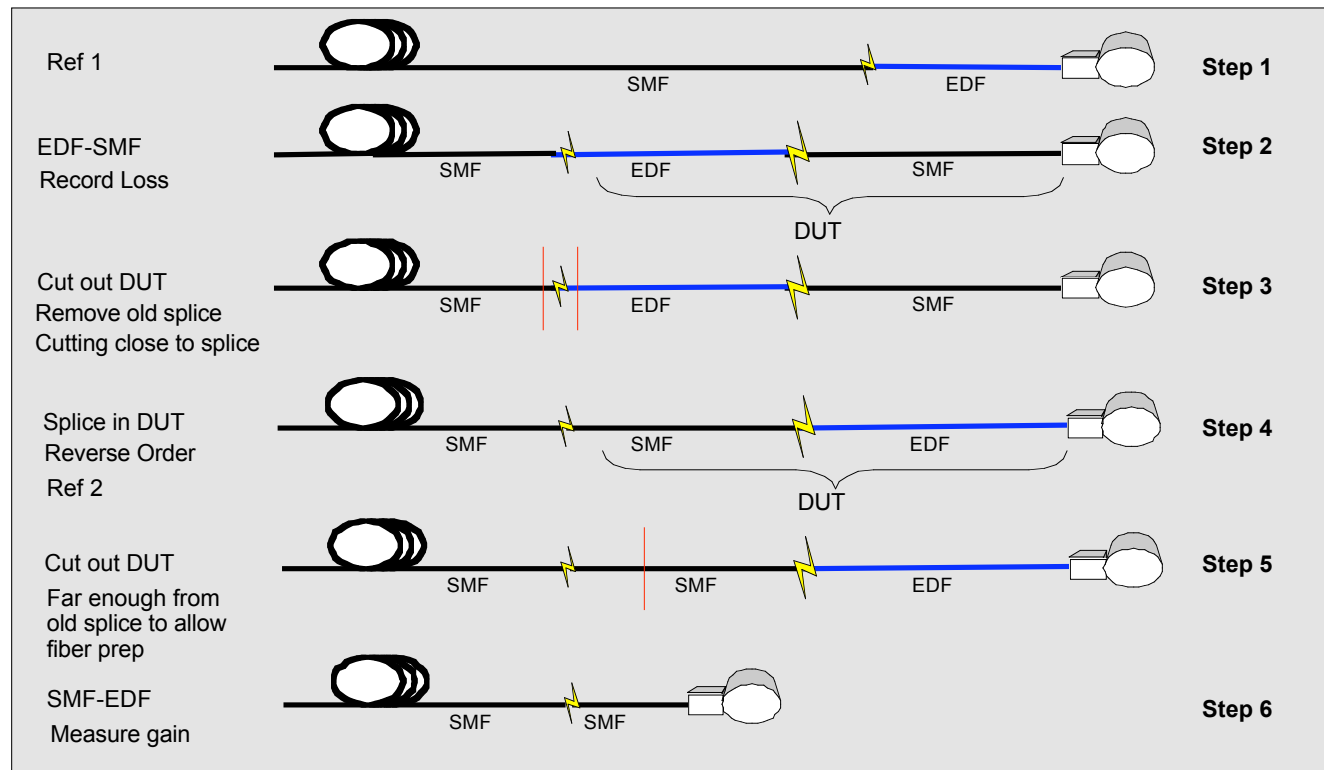


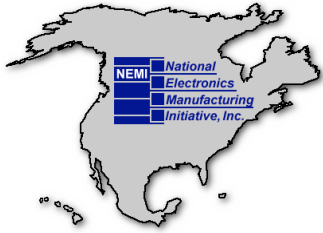
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SMF-EDF Splice Loss Measurement: Option 2

- Perform 10 to 30 SMF-EDF splices, and measure the same splices in both the “low” and “high” loss directions (randomize directions)
- Correct for EDF absorption 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



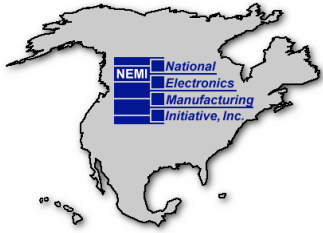


SMF-EDF Splice Directionality Results

Approximate chronological sequence. 3 largest Delta values highlighted

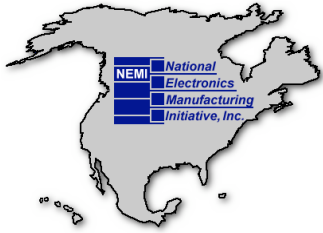
User	Method / Option	Fiber	Number of Samples	EDF-SMF Average Loss (dB)	Standard Deviation (dB)	SMF-EDF Average Loss (dB)	Standard Deviation (dB)	Average of the Two Directions (dB)	Delta = EDF-SMF Minus SMF-EDF (dB)
E	1	SEL	6	0.073	0.011	0.079	0.011	0.076	-0.006
D	1	SEL	30	0.198	0.028	0.279	0.022	0.239	-0.081
D	1	SEL	15	0.156	0.033	0.208	0.043	0.182	-0.052
B	2	SEL	10	0.130	0.023	0.120	0.023	0.125	0.010
F	1	SEL	10	0.133	0.018	0.348	0.020	0.241	-0.215
F	2	SEL	10	0.145	0.020	0.314	0.044	0.230	-0.169
D		SEL	10	0.159	0.033	0.219	0.052	0.189	-0.060
C		SEL	10	0.166	0.043	0.166	0.047	0.166	0.000
A	1	SEL	9	0.360	0.019	0.378	0.044	0.369	-0.018
A	1	SY	11	0.169	0.019	0.152	0.055	0.161	0.017
A	2	SEL	10	0.131	0.023	0.119	0.028	0.125	0.012
A	2	SY	10	0.178	0.017	0.179	0.013	0.179	-0.001
average				0.167		0.213			-0.047

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SMF-EDF Loss Measurement – Interim

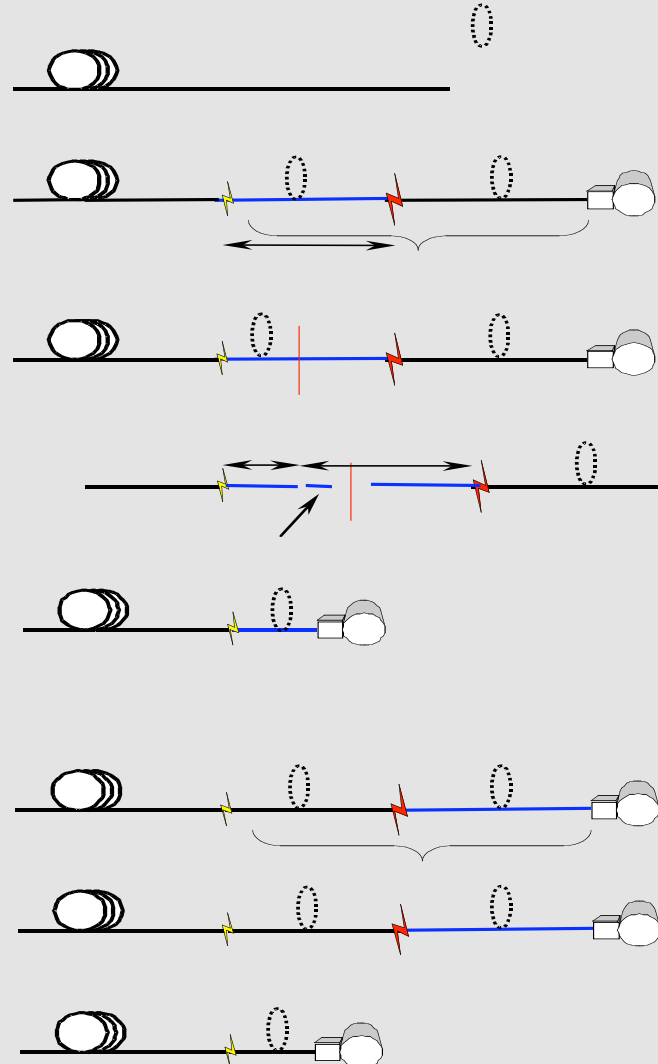
- Some users found significant directional difference, SMF-EDF direction has higher loss
- Average loss (both directions) for users with small and large deltas are within 2%, hence delta is not an artifact of measurement accuracy
- Sumitomo used with & without fiber loops (high order mode stripper) -- no significant difference
- Directionality impacts a proposed standard measurement method
- Cause may be with measurement set-up, fiber type(s) and/or splice
- Investigated further by round-robin measurements

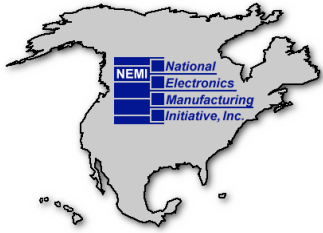


8. SMF-EDF Splice Repeatability: Site-to-Site Round Robin Method

- Site-to-site method allows each splice section to be measured in both directions (paired comparison) without destroying the original splice
- Three users each made at least 5 splice sections, measured all splices

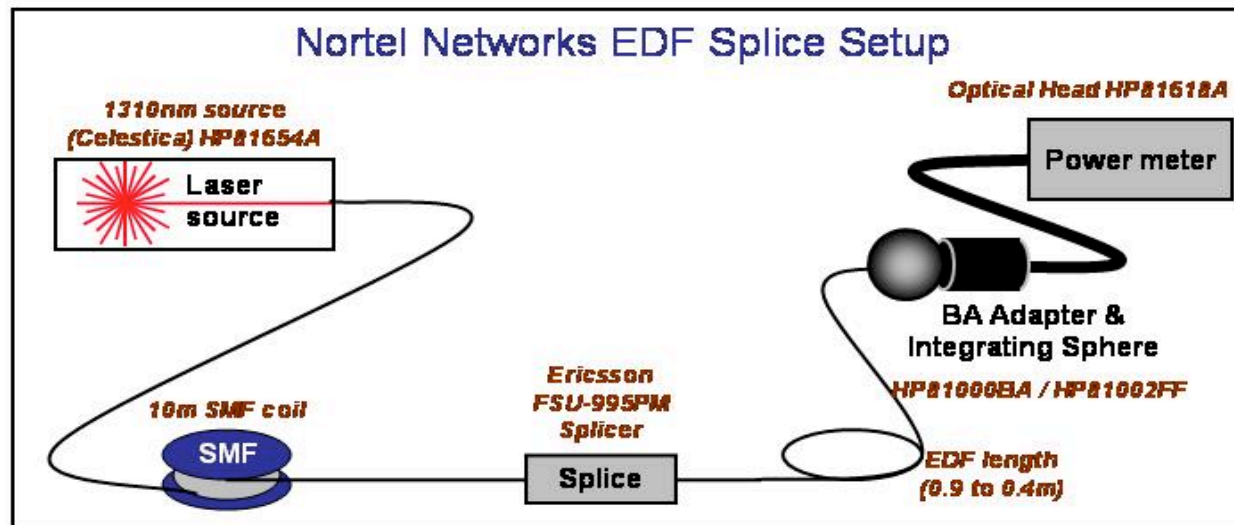
EDFSMFPrep SMFSplice inDUT,EDF-SMFdirection,Ref System,Measure EDFLeng

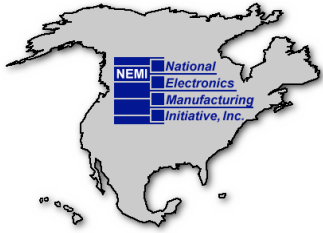




SMF-EDF Splice Round Robin (Interim)

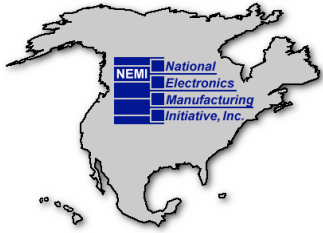
Fiber Combination	Spliced By	Meas. By	Integrating Sphere	No. Splices	Avg Loss EDF-SMF (dB)	Avg Loss SMF-EDF (dB)	Avg of Two Directions (dB)	Avg Delta (EDF-SMF) - (SMF-EDF)
Sumitomo SMF-Sumitomo EDF (1st set, short lengths)	F	F	N	10	0.141	0.284	0.213	-0.143
		F	N	3 (nos 1,3,7)	0.154	0.294	0.224	-0.140
		B	Y	3 (nos 1,3,7)	0.213	0.214	0.214	-0.001
Sumitomo SMF-Sumitomo EDF (2nd set, long lengths)	F	F	N	5	0.138	0.204	0.171	-0.066
		B	Y		0.165	0.158	0.162	0.007
		D	N					
Corning SMF28-Sumitomo EDF	B	B	Y	5	0.140	0.136	0.138	0.004
		B	N		0.097	0.188	0.143	-0.091
		D	N					
		F	N					
Corning SMF28-Sumitomo EDF	D	D	N	5	0.282	0.271	0.277	0.011
		B	Y		0.240	0.239	0.240	0.001
		F	N					





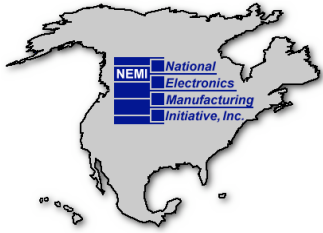
SMF-EDF Splice Directionality: Sorted by Delta with Integration Sphere Usage

User	Method / Option	Fiber	Integrating Sphere	Number of Samples	EDF-SMF Average Loss (dB)	Standard Deviation (dB)	SMF-EDF Average Loss (dB)	Standard Deviation (dB)	Average of the Two Directions (dB)	Delta = EDF-SMF Minus SMF-EDF (dB)
F	1	SEL	N	10	0.133	0.018	0.348	0.020	0.241	-0.215
F	2	SEL	N	10	0.145	0.020	0.314	0.044	0.230	-0.169
D	1	SEL	N	30	0.198	0.028	0.279	0.022	0.239	-0.081
D		SEL	N	10	0.159	0.033	0.219	0.052	0.189	-0.060
D	1	SEL	N	15	0.156	0.033	0.208	0.043	0.182	-0.052
A	1	SEL	Y	9	0.360	0.019	0.378	0.044	0.369	-0.018
E	1	SEL	Y	6	0.073	0.011	0.079	0.011	0.076	-0.006
A	2	SY	Y	10	0.178	0.017	0.179	0.013	0.179	-0.001
C		SEL	Y	10	0.166	0.043	0.166	0.047	0.166	0.000
B	2	SEL	Y	10	0.130	0.023	0.120	0.023	0.125	0.010
A	2	SEL	Y	10	0.131	0.023	0.119	0.028	0.125	0.012
A	1	SY	Y	11	0.169	0.019	0.152	0.055	0.161	0.017



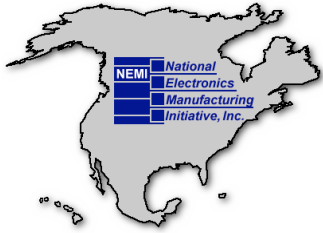
SMF-EDF Splice Loss -- Initial Conclusions

- BFA/cut-back method at 1310 nm is capable for dissimilar splice loss measurement, with losses >0.1 dB (R&R data not shown)
- No published directionality data, but theory predicts no delta for fiber with Gaussian mode fields
- Hence directionality dependence was not expected and had to be investigated
- SMF-EDF direction shows highest loss, where there is a delta
- Round robin indicates directionality depends on measurement set-up
- Directionality correlates with use of integrating sphere
- Speculate larger NA of EDF (small MFD), causes poor coupling between BFA and detector
- Near field intensity distribution will be performed to confirm cause of directionality



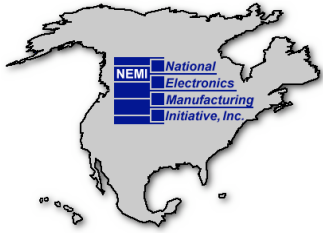
Future Project Activities

- Complete Gage R&R for SMF-EDF splicing... currently in-progress
- Complete investigation of loss measurement variability and additional test methods for dissimilar splices:
 - BFA/cut-back, as per TIA 455 (method used here)
 - inserted section (double splice)
 - incremental cut-back/extrapolation (relevant to attenuating fiber)
- Quantify splice estimator accuracy, based on metric, conf. limits
- Present project completion 4Q'03/1Q'04
- Possibly form follow-on project (with IPC, TIA and/or IEC) to develop loss measurement standard(s)
- Which organizations and how we go forward depend on levels of enthusiasm and support



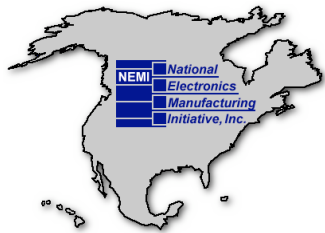
Possible Future Standards Development

- Low loss, high precision splice measurement for SMF, some possible options:
 - new standard, e.g. part of IPC STD-0400
 - based on TIA 455-34A, issue as amended standard, e.g. 34B
 - new TIA standard
- Dissimilar fiber splice loss measurement standard, useful attributes:
 - include several methods
 - measurement variables, some depend on method, e.g. direction
 - measurement repeatability assessment, e.g. gage R&R
 - fiber types and suppliers/batches, e.g. EDF, Truwave, LEAF
 - wavelength & power, relevant to strongly attenuating fiber



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- Vytran:
 - Eric Mies



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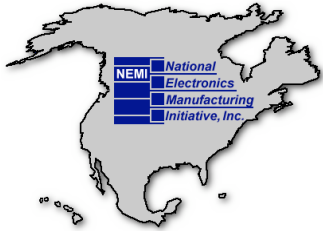
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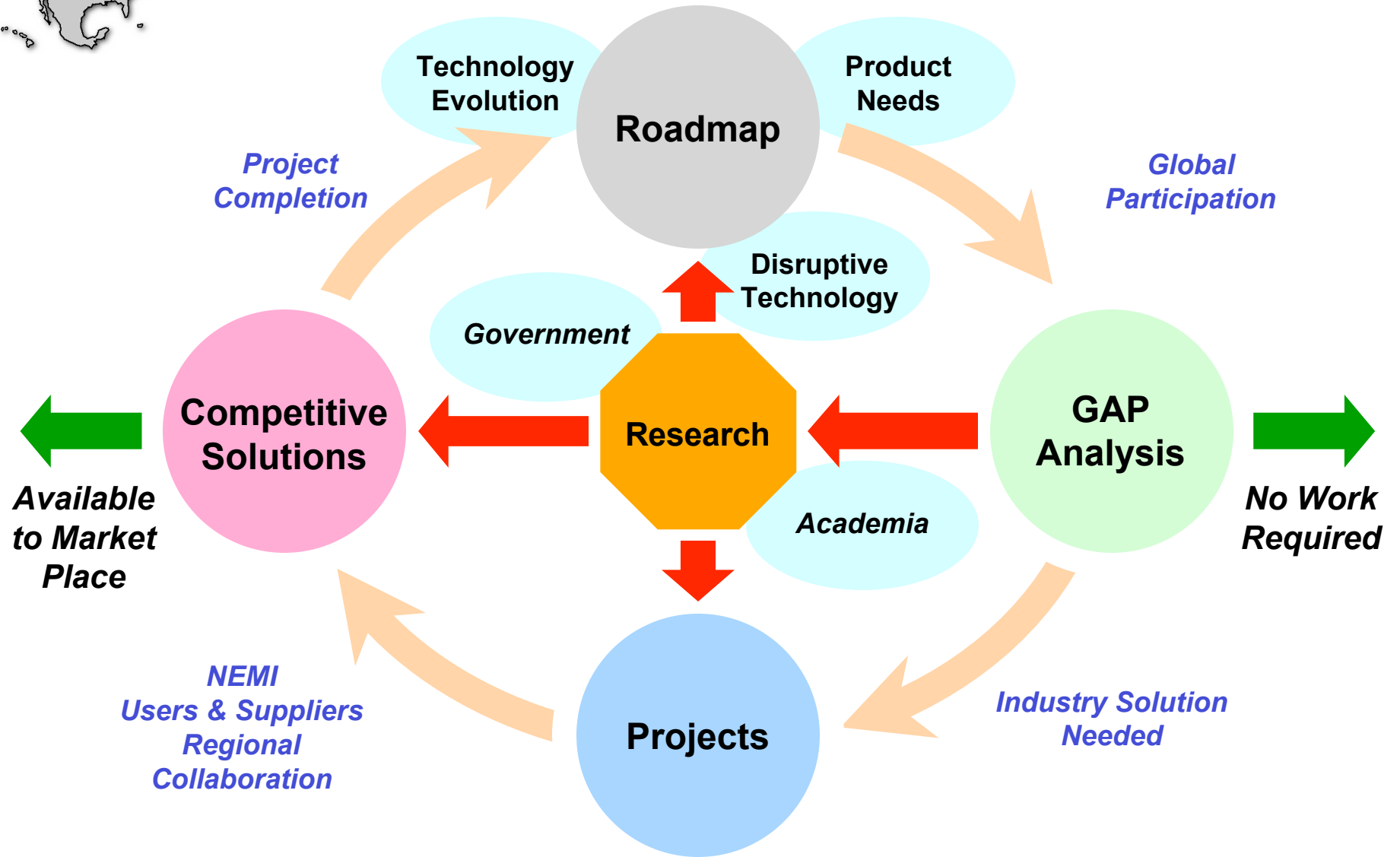
NEMI: David Godlewski, dgodlewski@nemi.org

Thank You
Fiber Splice Improvement Project

Connect with and Strengthen your Supply Chain

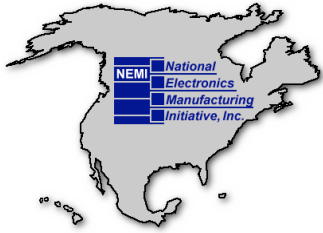


NEMI Roadmap Cycle

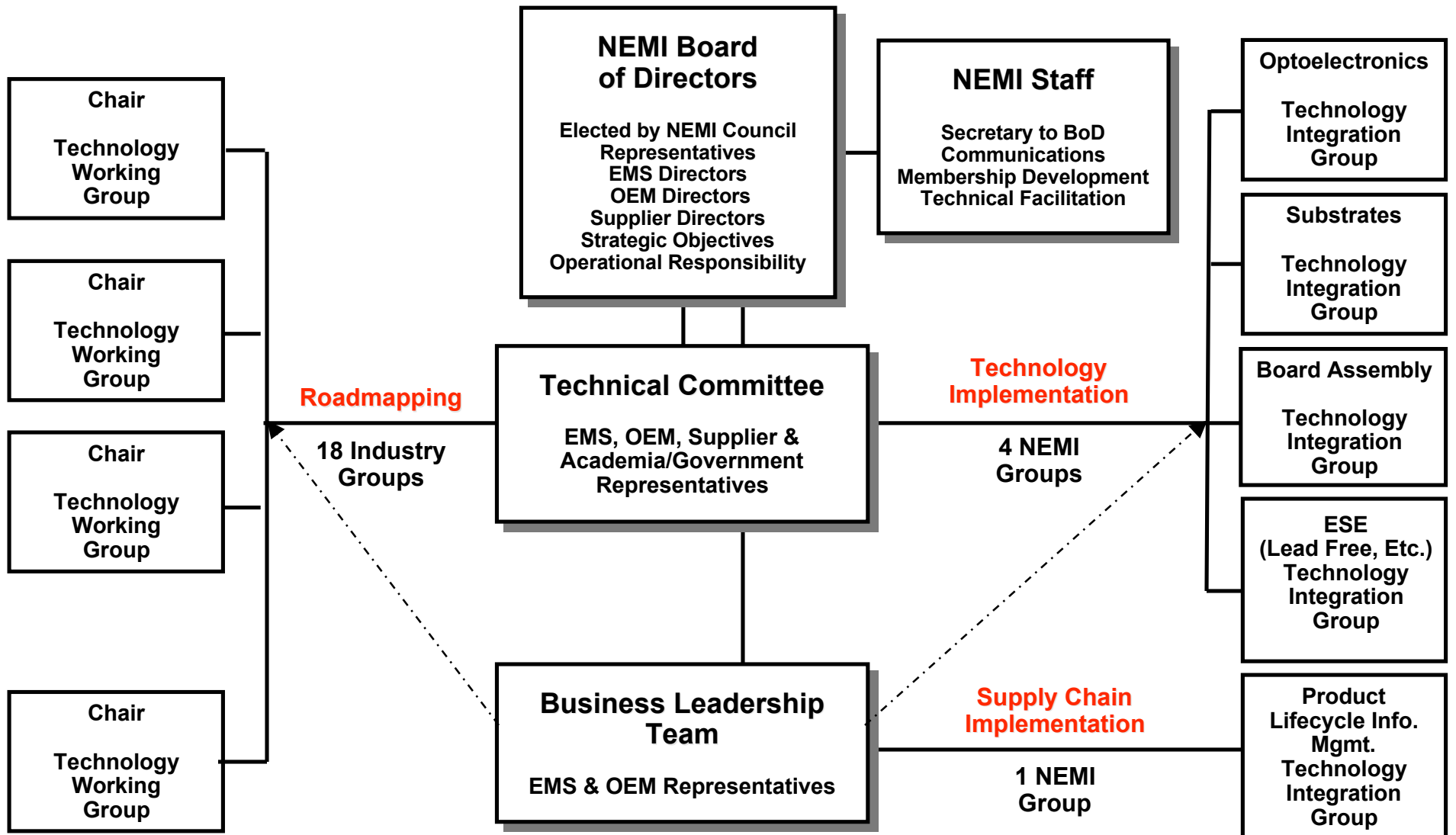


NEMI Implementation Cycle

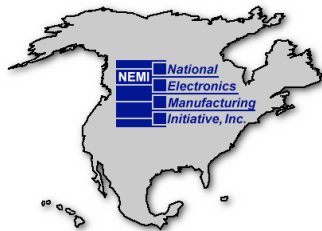
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NEMI Organization



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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 Jointing 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%.	

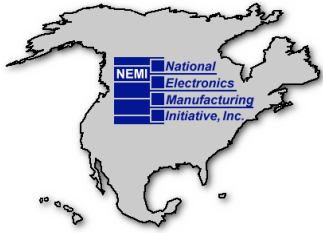
Table 1. Key Standards Requirements Relating to Fusion Splicer and Splice Acceptance



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



3. Splicer Based Loss Estimation

Estimation techniques

- PAS – Profile Alignment Systems

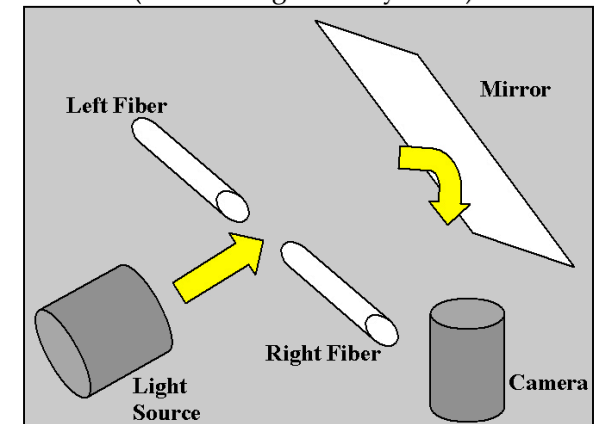
A PAS system uses LEDs to illuminate the fibers. The light passes through the glass, reflects off a stationary mirror and onto a CCD camera via a microscope lens. Depending on the splicer, image analysis allows detection of the fiber core in the splice region and measurement of core offset, mismatch, curve, and other defects. PAS is also used to align the fiber cores. (A.k.a. core direct monitoring, CDM)

- LID – Light Injection & Detection

A LID system measures the splice loss by injecting light, through the fiber cladding, into a fiber core. To achieve this it partially bends the fiber around a mandrel on one side of the splice point and injects light into the fiber. It uses the same process on the opposite side of the splice point to detect the light. The difference between the measurements (with and without splice) gives the estimated splice loss.

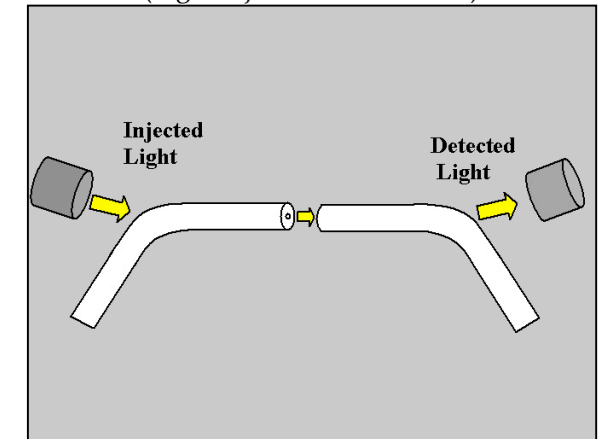
PAS

(Passive Alignment Systems)

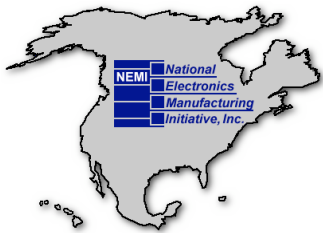


LID

(Light Injection & Detection)



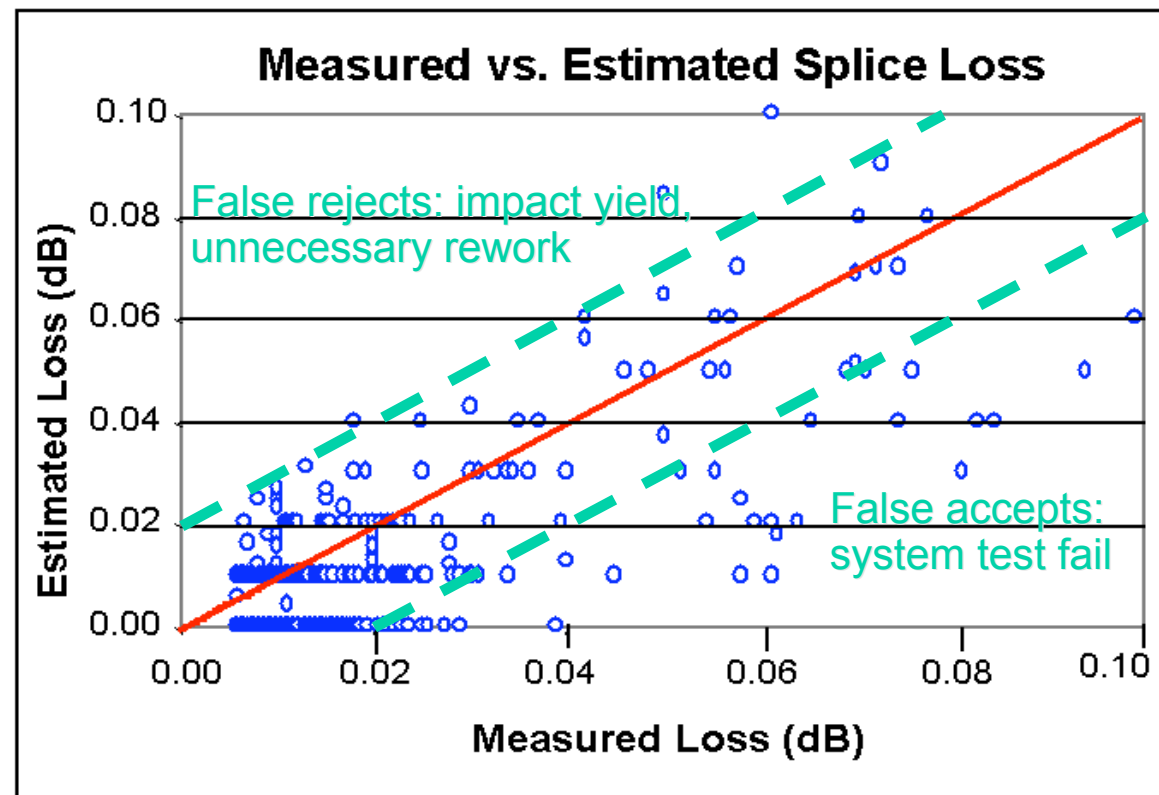
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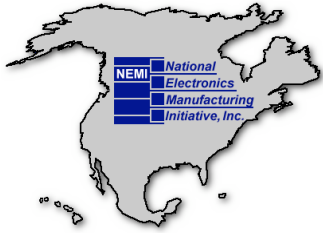


Correlation of Measured vs. Estimated Loss

- **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





Splice Loss Estimation – Conclusions

- Most users for this investigation used different splicers with PAS estimators
- Accuracy of estimator insufficient for low loss splicing <0.05 dB, even for SMF-SMF
- Compared statistical metrics from TIA 455-B with Cpk
- Cpk shows good discrimination for best case (low scatter, bias or slope)
- Control limits for Cpk are arbitrary, hence only relative Cpk can be compared
- The current PAS estimators would fail ($Cpk < 1.5$) with typical process control limits, e.g. 20% of the range, or ± 0.01 dB for the low loss range
- Different estimators may have poor response to attenuation splices, when “defects”, such as mode offset, are introduced