NEMI National Electronics Manufacturing Initiative, Inc.

Is That Splice Really Good Enough?

Improving Fiber Optic Splice Loss Measurement

Presented on Behalf of the Project Members

by Peter Arrowsmith

Board Assembly TIG

Fiber Optic Splice Improvement Project

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- Aurora:
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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-040.
- Meeting Objectives:
  - Share technical results
  - Promote awareness of project activities
  - Attract optoelectronics OEM participation

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

Current & Planned Activities

- Reviewing relevant standards from Telcordia, TIA, IEC, JIS
- Identify gaps relative to product (plant) splicing (loss <0.05 dB)
- Participants measuring SMF28-SMF28 loss using current test methods
- Compare in-line, unterminated fiber (cut-back/BFA) and OTDR loss measurement methods
- Developed Gage R&R method to assess measurement error
- Extend GR&R to SMF-EDF splicing (common batch of Er)
- Identify causes of measurement variation
- Work with IPC, TIA to improve existing & develop new standards
- Follow-on activities are decided by members
- Weekly conference calls
- Last face-to-face meeting: OFC Atlanta, March 27
- Project completion 3-4Q 2003, depending on scope & interest

Status of Project and Presentation Synopsis

1. Standards review. Request to IEC to distribute IEC 61073-3/1073-3 (splices) and 1073-1 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 to group (single fiber batch from Sumitomo)	Complete
7. SMF-EDF splice loss DOE	20% complete
8. Draft splice loss standard for SMF-EDF	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 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)	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)
(CO = condition for objective)	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 <0.01 dB 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	3.6.2 Better than 0.01 dB for loss <0.5dB	Min. reportable loss of non-reflective "event" (splice) ≤0.10 dB

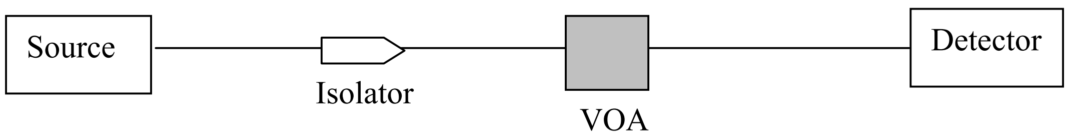
Table 2. Standards Specifications for Insertion Loss Test Methods and Equipment

Standards Review – Key Findings

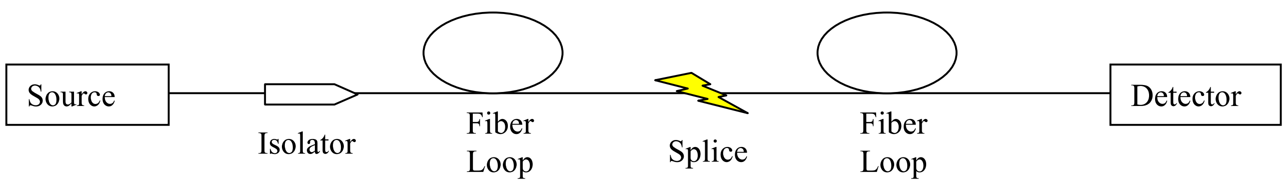
- Many of the standards that cover splicing are 6 or more years old and therefore do not cover newer fibers (80/165 μm, NZ-DS, LEAF) or fiber combinations such as dissimilar splicing (EDF-SMF, etc).
- For standards purposes, it is not clear whether a splice should be considered a fiber or a passive component
- 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

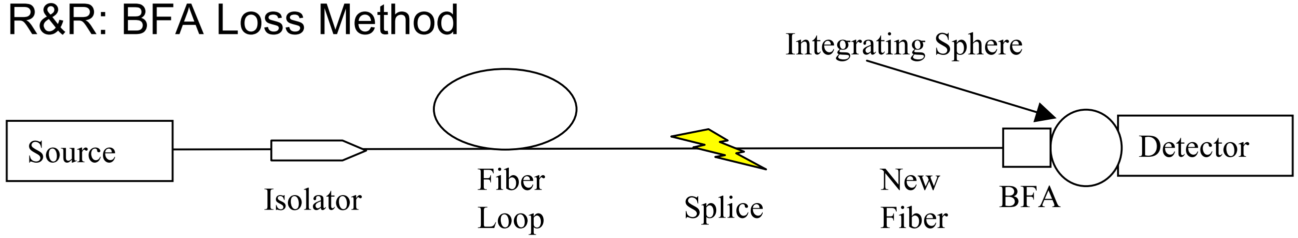
1. Stability: In-Line or BFA Methods (linearity requires VOA)



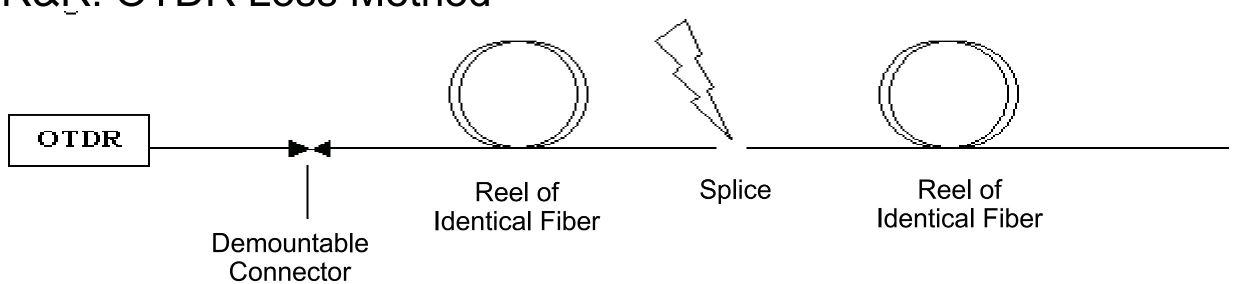
2. Gage R&R: In-Line Loss Method



3. Gage R&R: BFA Loss Method



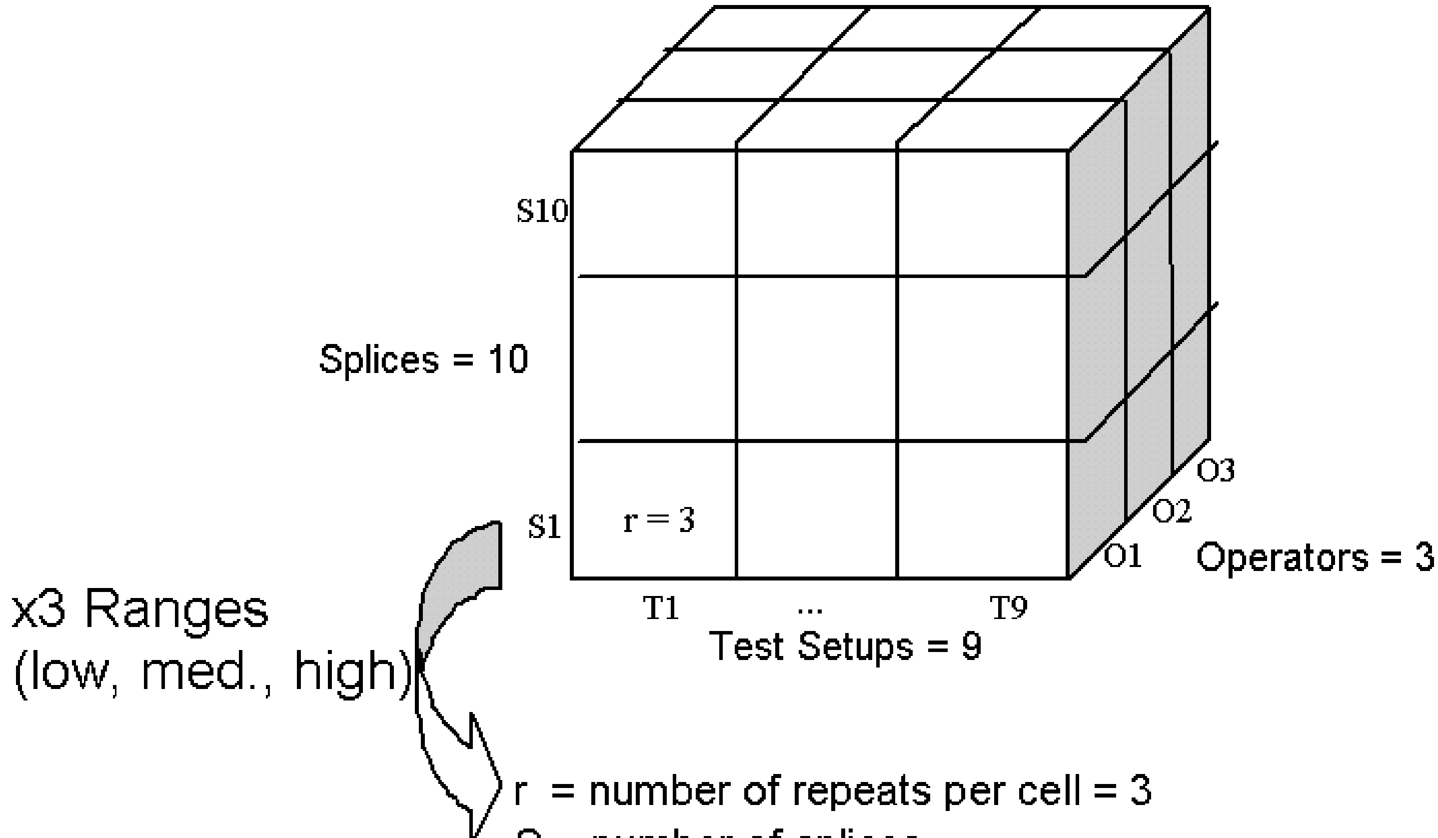
4. Gage R&R: OTDR Loss Method



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

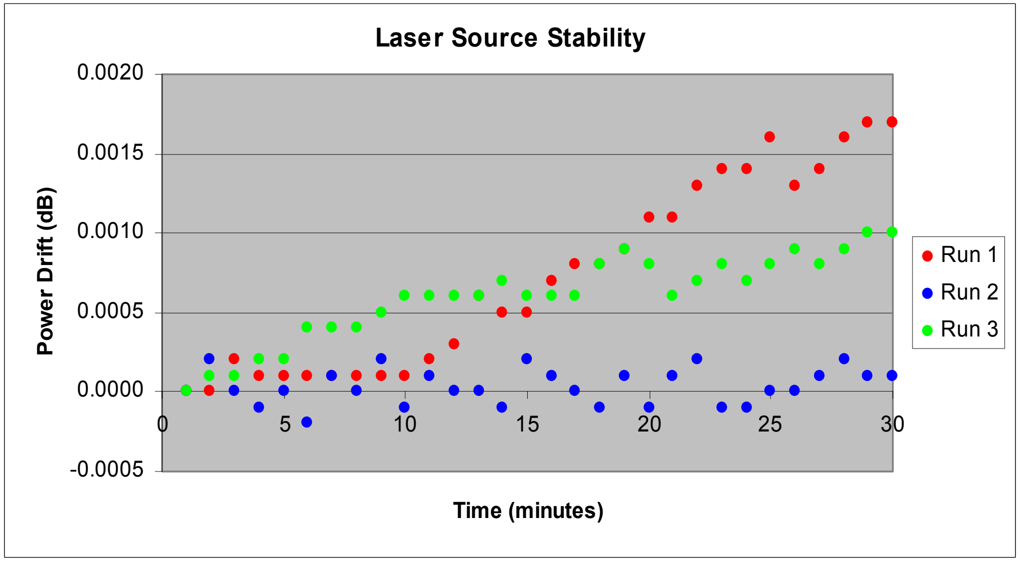
Splice Measurement Repeatability Gage R&R Study: Data Sets

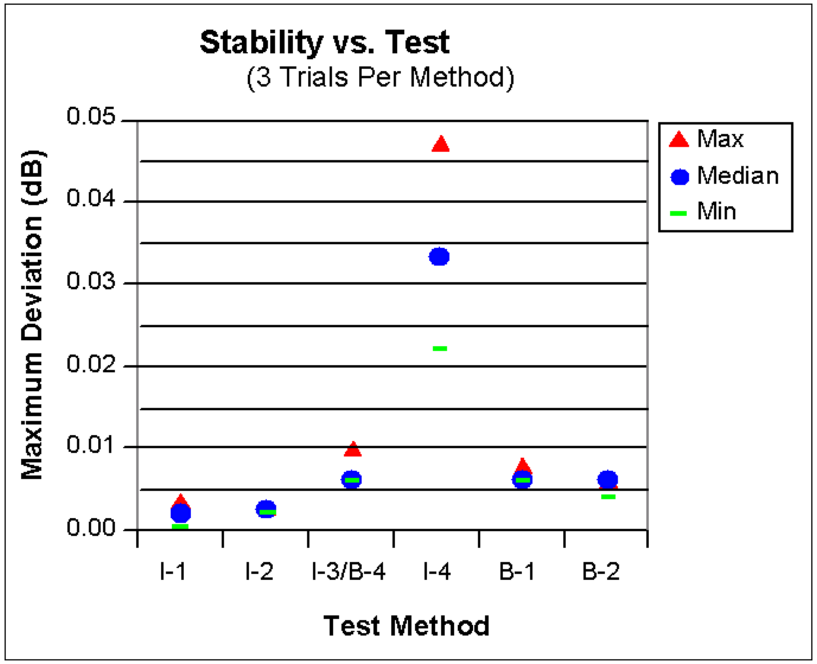


r = number of repeats per cell = 3
S = number of splices
O = number of operators/appraisers
N = total number of measurements per test method
= r x S x O = 3 x 10 x 3 = 90

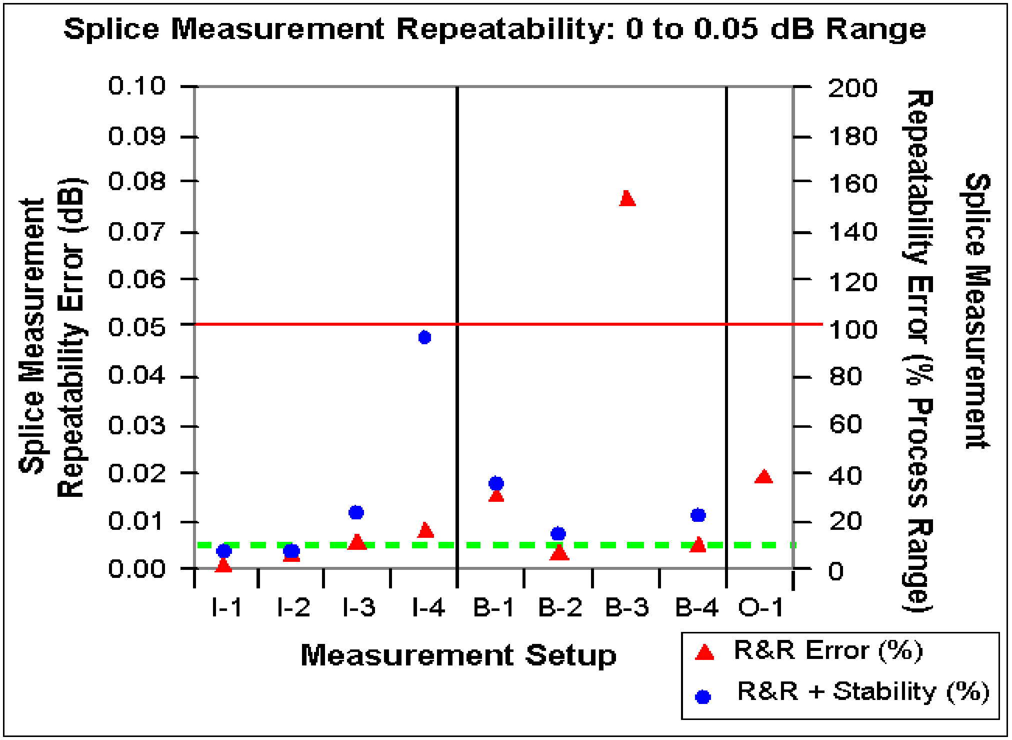
Splice Measurement Repeatability: Gage R&R Stability

- Three stability runs per measurement system (except for one BFA)
- Source stability is not relevant for OTDR (μs 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
1-2	0.0026	5.3	0.0028	7.7
1-3	0.0054	10.9	0.0100	22.8
1-4	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)

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

3. Splicer Based Loss Estimation

Estimation techniques

1. PAS – Profile Alignment Systems

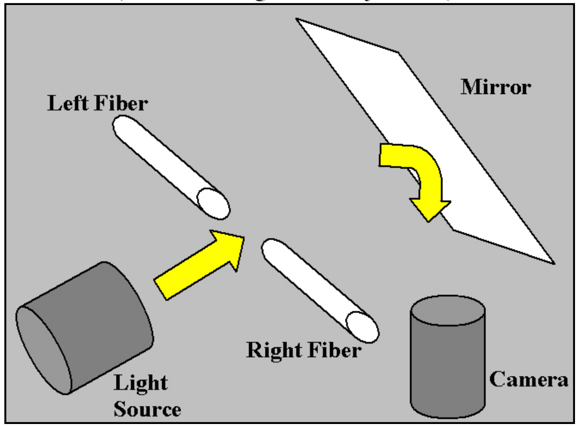
   A PAS system uses LEDs to illuminate the fibers. The light passes through the glass, reflects off a stationary mirror and onto a CCD camera via a microscope lens. Depending on the splicer, image analysis allows detection of the fiber core in the splice region and measurement of core offset, mismatch,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

2. 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.

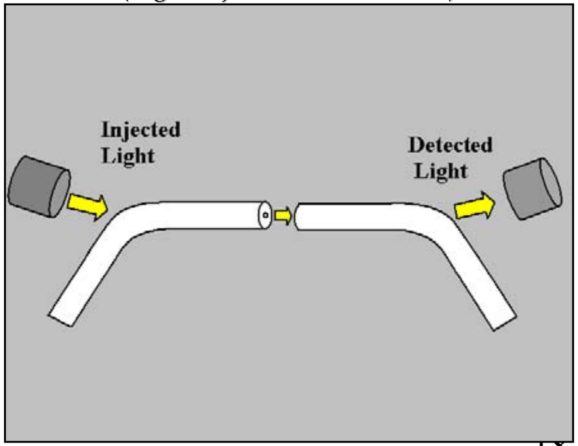
PAS

(Passive Alignment Systems)



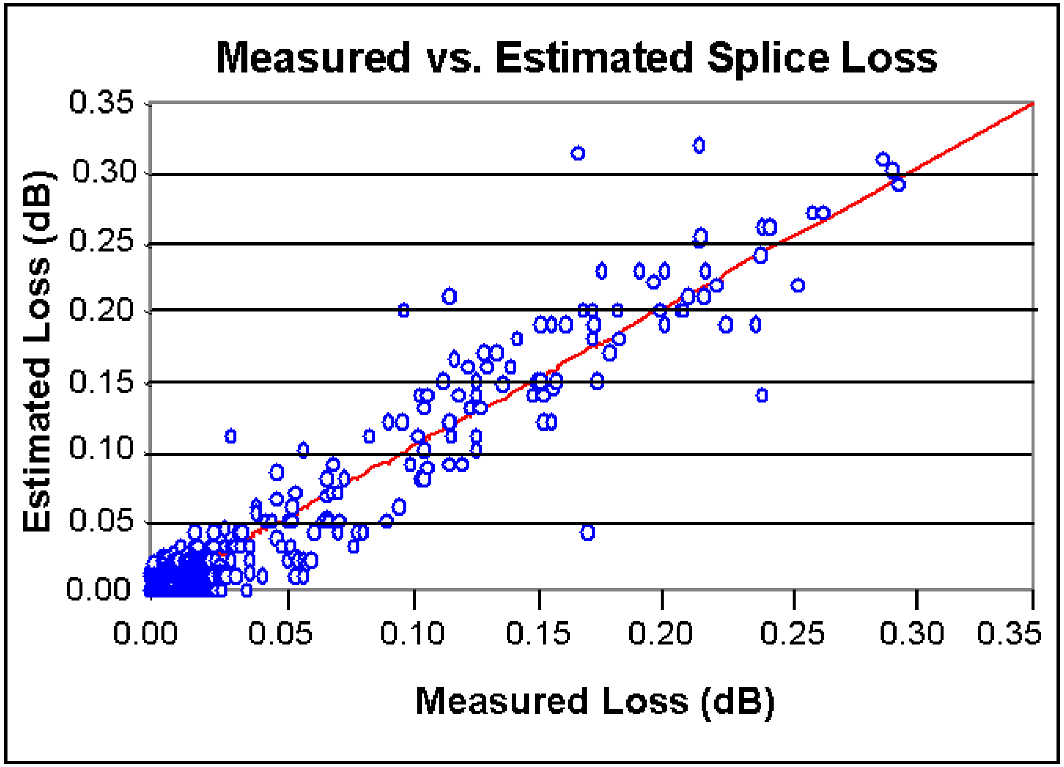
LID

(Light Injection & Detection)

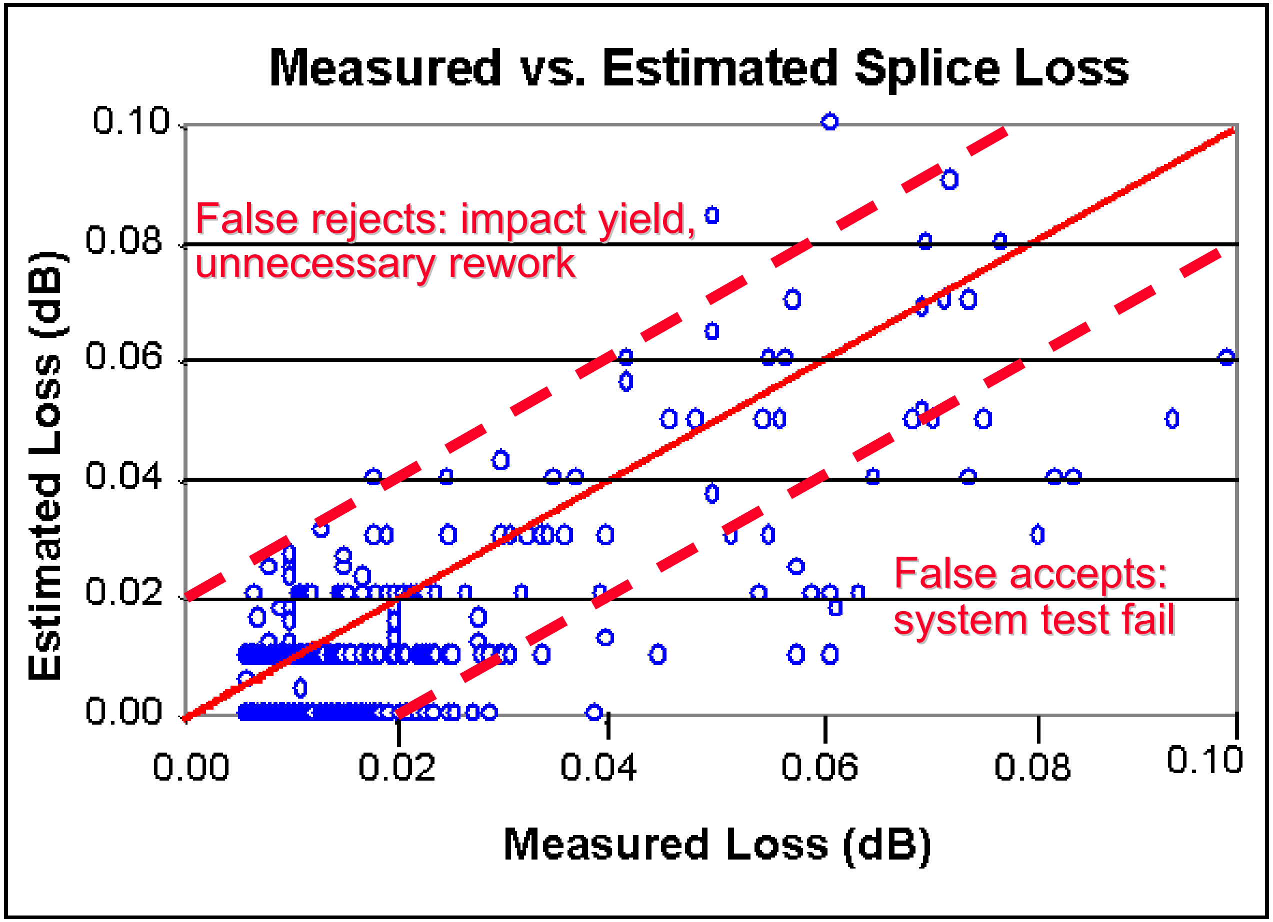


Correlation of Measured vs. Estimated Loss

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



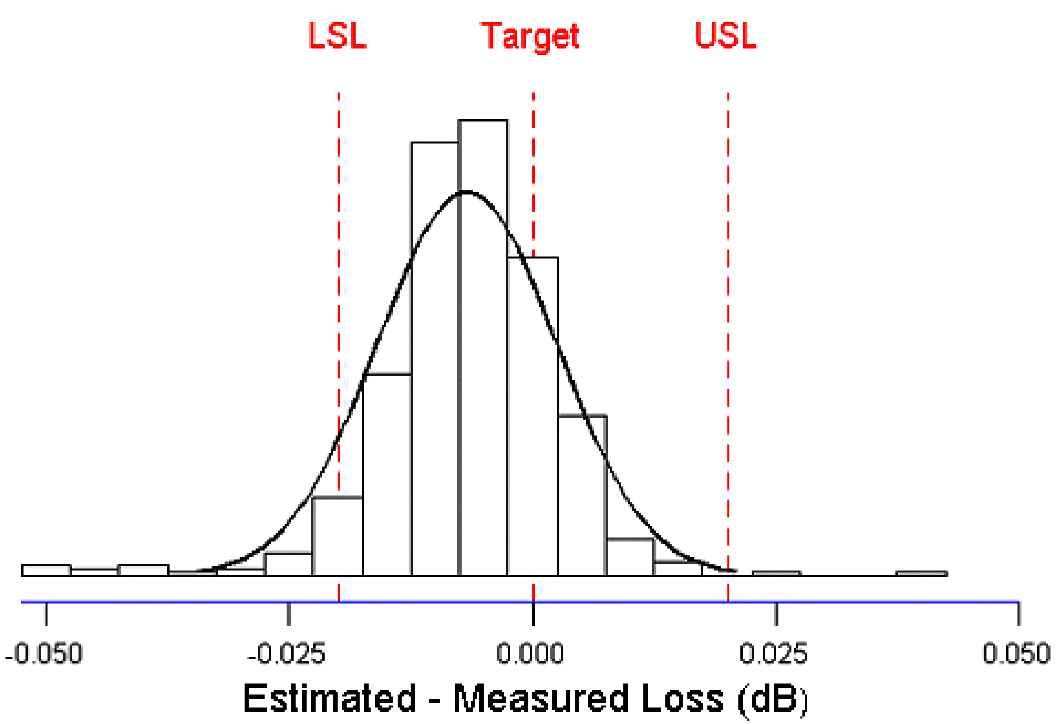
Measured vs Estimated Loss: Low Loss Range



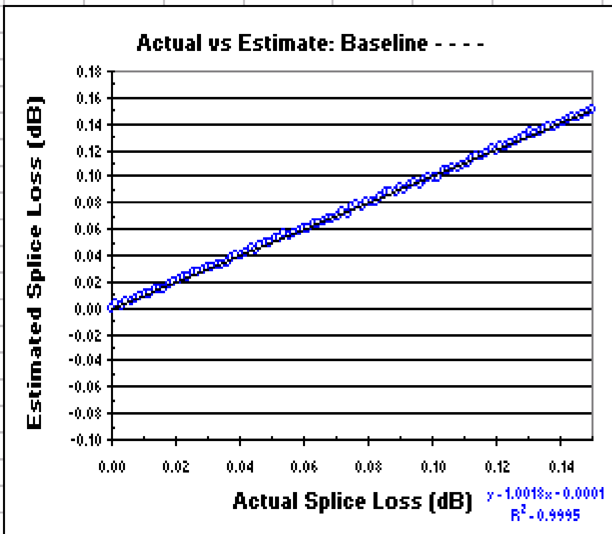
- Actual splice loss measurement often not possible for component pig-tail splicing
- LID unsuitable for some jackets, diam. >250 µm
- Product splice yield may depend on estimated loss
- Accuracy of estimator insufficient for low loss splicing <0.05 dB, even for SMF28-SMF26
- Compare estimators for different splicers, based on metrics, e.g. deltas & confidence limits

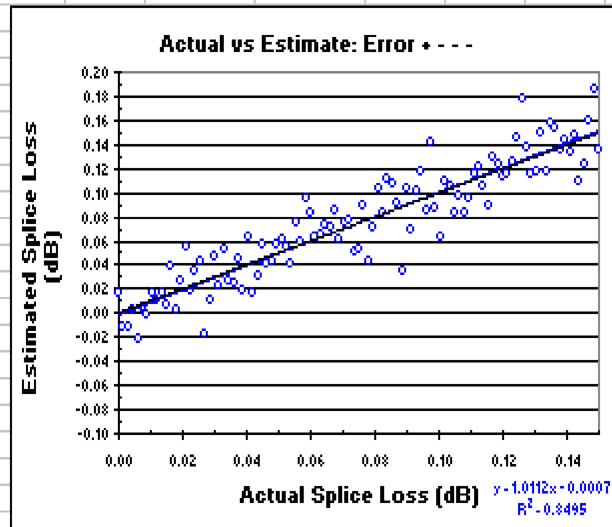
4. Splice Loss Delta Results – Comparison of Estimator Error Using Cpk

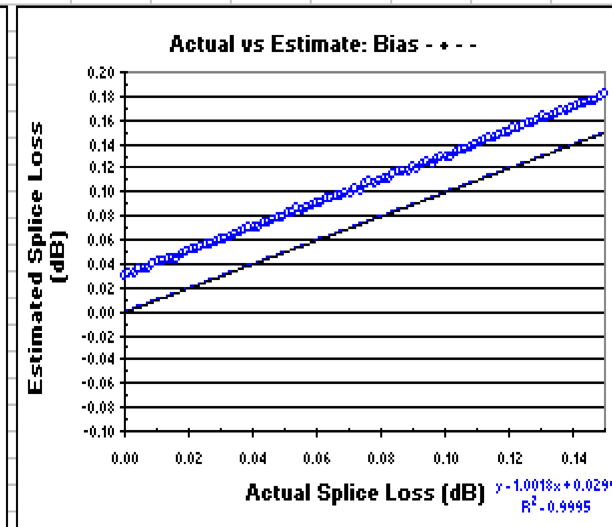
Estimator / Splicer	Loss Range	Sample Size	Mean	StDev	Mean + 3 Std. Dev.	Mean - 3 Std. Dev.	Cpk
1	Low	10	-0.001	0.006	0.019	-0.020	1.00
2	Low/Med	474	-0.007	0.009	0.021	-0.034	0.48
3	Low/Med	21	0.002	0.015	0.046	-0.042	0.40
4	Low/Med	38	-0.005	0.018	0.050	-0.059	0.28
5	Low/Med	20	-0.011	0.019	0.046	-0.068	0.16
6	Low/Med	33	0.011	0.023	0.081	-0.059	0.13
7	Low/Med	20	0.013	0.030	0.102	-0.077	0.08

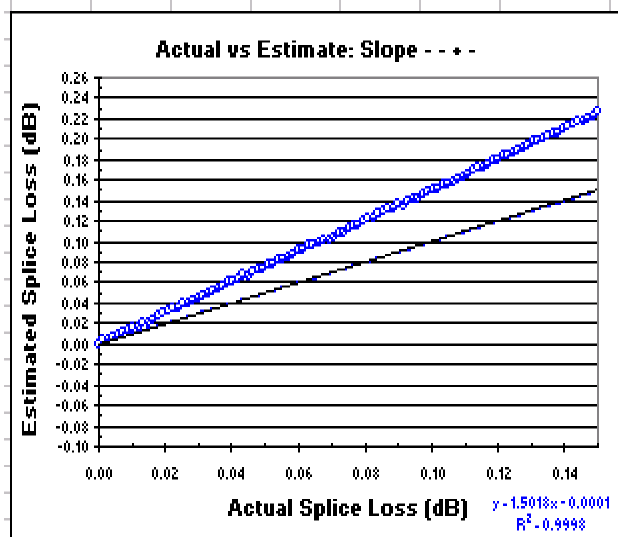


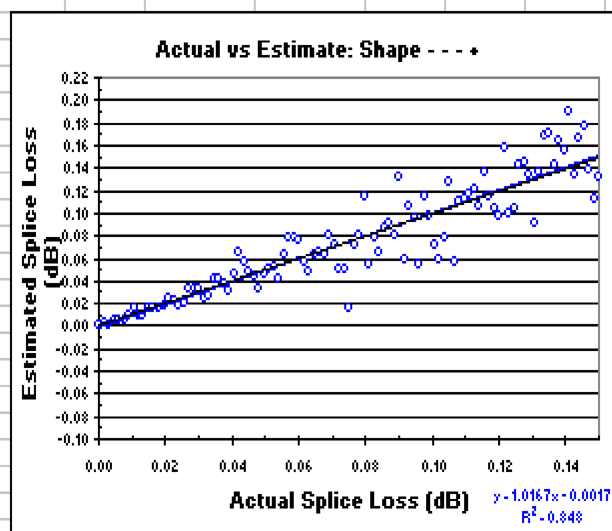
4. Splice Loss Metrics: Simulated Est. vs Actual Loss Distributions

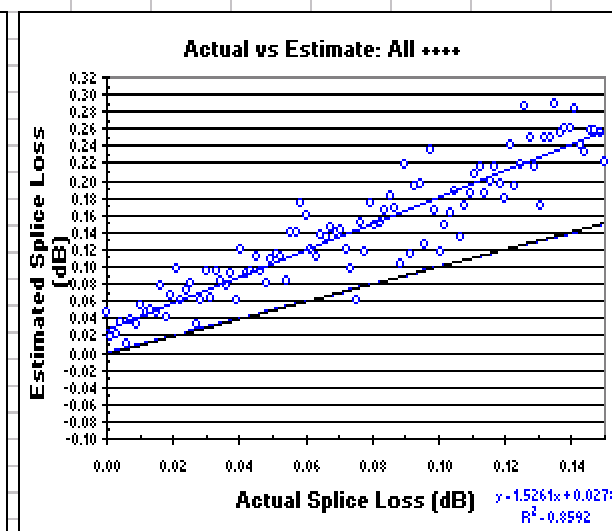






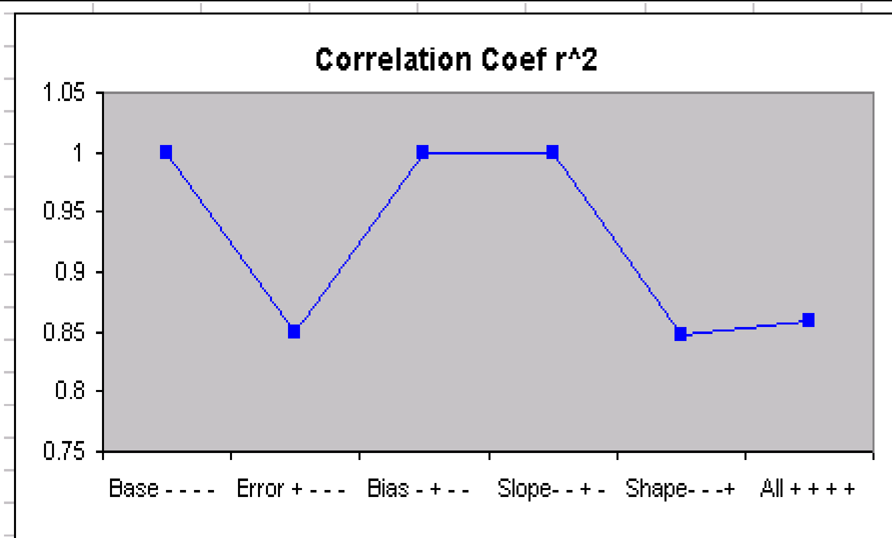


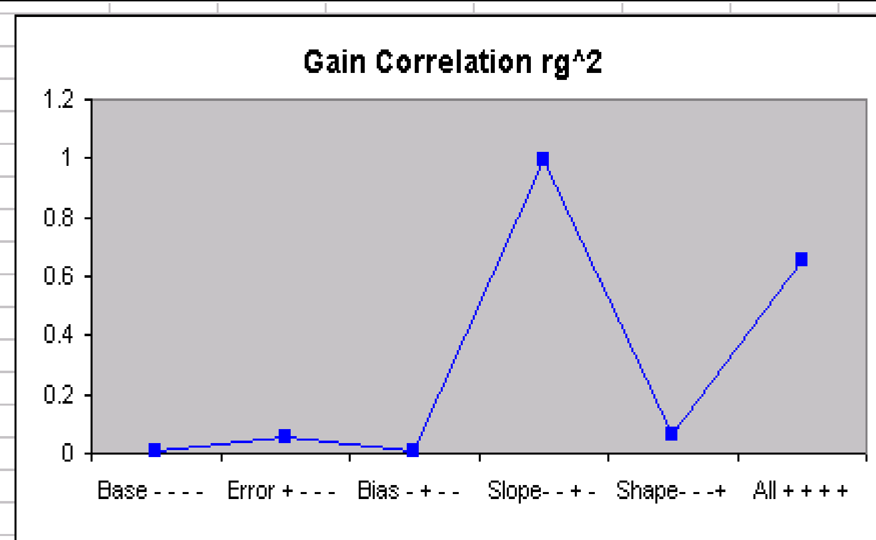


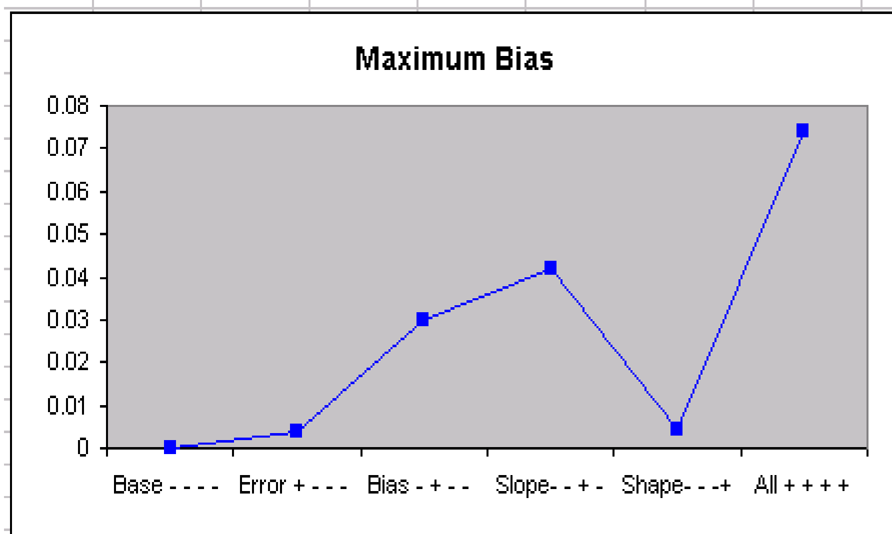


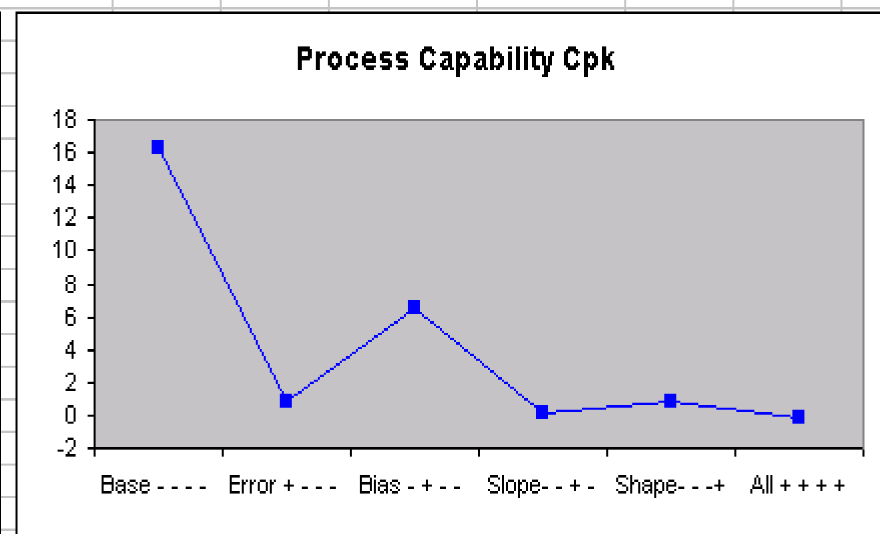
Connect With and Strengthen your Supply Chain

Statistical Metrics Comparison: TIA 455-B Methods & Cpk (Simulated Data)









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

Possible Future Activities

As a follow-on to the Gage R&R study, we will run refined survey to assess the benefit to, and enthusiasm of, members to:

- Quantify splice estimator accuracy, based on confidence limits
- Splice SMF at limits of MFD, core concentricity, eccentricity and batch-to-batch variation
- Investigate sources of loss variation (prep, splice, test, processes & equipment)
- Extend Gage R&R to SMF-EDF splicing… currently in-progress
- Form sub-project to develop low loss test standard for dissimilar fiber splicing with IPC/TIA
- Develop Design Guide for splice losses (loss budget predictor)
- Splice strength testing
- PM splicing, loss, etc

New Participants

- Project will accept new members by 3/4 majority vote
- Welcome additional members, particularly OEMs & equipment suppliers
- Contacts:

Chair: Peter Arrowsmith, parrowsm@celestica.com

Standards: Eric Mies, emies@vytran.com

Measurement: Rob Suurmann, rsuurman@celestica.com

NEMI: David Godlewski, dgodlewski@nemi.org

Thank You

Fiber Splice Improvement Project