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CASE STUDY:

BUILDING A WINNING ESPORTS VENUE AT POINT PARK UNIVERSITY

PLUS:

+ How to Minimize Installed Cost of High-Speed Fiber Data Center Links
+ How to Deliver Universal Wireless with a Wireless-First Approach

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HOW TO MINIMIZE INSTALLED COST OF HIGH-SPEED FIBER DATA CENTER LINKS

By Robert Reid

The performance and reliability of cabling infrastructure supporting critical applications within the data center are of paramount importance. For new high-speed optical networks, such as 100 Gb/s Ethernet and 128 Gb/s Fibre Channel, it is critical for network stakeholders to have accurate knowledge of the optical fiber cable plant performance against the application standards. It is also very important to ensure that customer-deployed links present a warrantable solution that is compatible with cabling standards.

As the performance requirements for networks have advanced, the specifications on the constituent components (i.e., connectors deployed in permanent links) have become more stringent. Since the standardization of 1 Gb/s Ethernet (i.e., 1000GBASE-SX) in 2002, the 3.56 dB total channel insertion loss (CIL) for 50/125 µm multimode optical fiber (MMF) has been reduced to 1.9 dB for 40GBASE-SR4 and 100GBASE-SR4. For these, a maximum total connector loss of 1.0 dB is required for a 150 m (≈492 ft) OM4 channel that may contain multiple connector interfaces.

Current plug-and-play multimode structured cabling systems built around LC and MPO connector systems have little insertion loss compared to the required cabling and component standards. Telecommunications Industry Association (TIA) 568 and the application standards, Ethernet and Fibre Channel, require that no mated connector pair exceed 0.75 dB insertion loss. State-of-the-art multimode LC connectors have average losses less than 0.1 dB, and many vendors offer ultra-performance MPO connectors that show no more than 0.25 dB insertion loss when mated against a reference connector.

In the factory, the most accepted method of measuring the insertion loss of connectors is the one-jumper reference patch cord method as specified in TIA FOTP-171. In this method, a single well-controlled, nearly ideal patch cord is the test interface. The installer measures performance for each connector. Since installers measure each connector using a nearly ideal patch cord, there is high internal measurement repeatability and reproducibility (R&R) between multiple suppliers of connectivity and across many customers when such connectivity exists in permanent links.

In North America, the predominant method for field-testing optical fiber links is the two-jumper reference method. This is a manifestation of legacy test equipment with SC connectors and has a significant impact on the efficacy of field-testing links with LC or MPO connectors. The potential to produce false fail results (i.e., link indicates fail but truly passing) and false passing results (i.e., link indicates pass but truly failing) scales directly with the capability of testing in the field. False fail results impact the customer's ability to deploy links in a timely fashion and can divert connectivity supplier monies incorrectly in terms of material and labor hours. False pass results can present link reliability issues and potential warranty claims against connectivity suppliers.

For example, to reliably measure the loss of a 30 m (≈98 ft) OM3 permanent link in the field to TIA and International Electrotechnical Commission (IEC) standards requirements, the expected total loss is a little over 1.6 dB, and the required measurement system R&R would be a small fraction of 1.6 dB (i.e., less than 0.2 dB based on multiple standard deviations of measurement error). Permanent links built with low-loss MMF and these connector systems to support higher speed protocols require compliance with tight customer and industry specifications and very accurate and capable insertion-loss measurement processes.

These requirements raise two important questions to examine:

- What is the most accurate and capable measurement technique for higher speed multimode links?
- What are the best industry practices to ensure that remediation of links due to measurement errors and costs are at a minimum?

APPLICATION STANDARDS LINK BUDGETS

Designers determine the overall power budget for an optical channel link during the development phase of the associated application standard, based on the magnitude of seven principal optical impairments (or power penalties), and the maximum channel reach. These penalties include inter-symbol interference (ISI), mode partition noise (MPN), modal noise (MN), relative intensity noise (RIN), reflection noise (RN), polarization noise (PN), and insertion loss.

Most of these optical impairments are small (<0.3dB) and not addressed. However, ISI and insertion loss contribute large optical penalties and, therefore, are the two primary impairments that limit channel performance or channel reach. The quality and practices for constructing the physical link strongly influence ISI and insertion loss.

When an optical pulse propagates through an optical fiber channel, its shape broadens in time due to the bandwidth limitation in the transmitter, optical fiber, and receiver. The optical pulse representing each data bit or "symbol" spreads in time and overlaps the adjacent symbols to the degree that the receiver cannot reliably distinguish between changes in the individual symbols and/or signal elements. The power penalty (i.e., ISI) affects the temporal characteristics of the signal pulses, resulting in signal dispersion and timing jitter at the receiver. Furthermore, ISI contributes the largest optical power penalty in high-speed MMF transmission systems.

To meet the ISI channel requirement, each standard, such as 10 Gb/s Ethernet (IEEE 802.3ae) or 8 Gb/s Fibre Channel (FC-4), specifies the minimum optical fiber bandwidth (or maximum dispersion) necessary to comply with the system ISI requirements to ensure error-free system performance. Effective modal bandwidth (EMB) determines the optical fiber bandwidth and high-speed systems (>10 Gb/s) that must achieve a minimum EMB of 2000 MHz-km for laser-optimized OM3 MMF and 4700 MHz-km for OM4 MMF.

Insertion loss is the second critical parameter that determines a channel link's performance. The two sources of insertion loss are loss at the connector-to-connector interfaces and loss or attenuation within the optical fiber due to the absorption and scattering of

light as it propagates. For high-performance and reliable 10 Gb/s network operation, installers should minimize both loss sources by selecting high-quality, low-insertion-loss connectors, patch cords, cassettes, and high-performance MMF. Figure 1 compares the optical power penalties for a 10 Gb/s Ethernet channel link as specified in IEEE 802.3ae for 10GBASE-SR. The total power budget for
this channel link is 7.3 dB.

In theory, installers can trade off cable attenuation for connector insertion loss or ISI power penalties for insertion loss; however, they must do this with caution. Engineered links are those channels making tradeoffs of parameters.

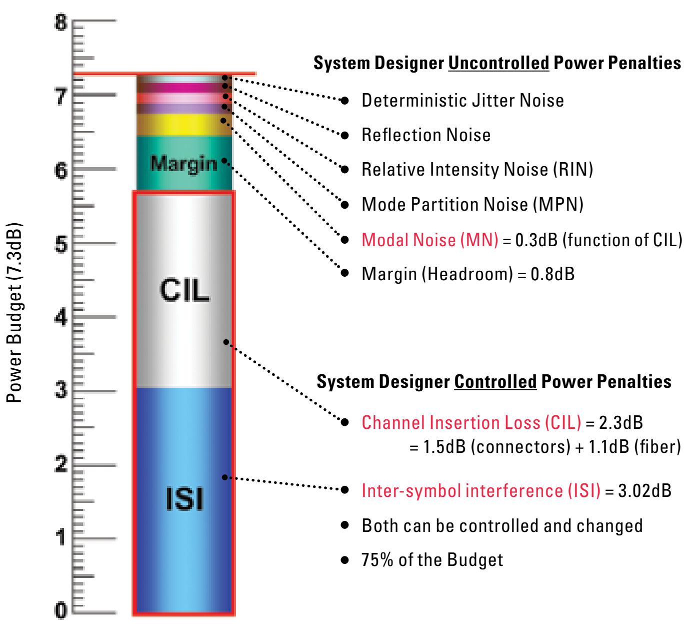


FIGURE 1: Optical channel budget for 10 Gb/s Ethernet (10GBASE-SR).

THE EMERGENCE OF COMPLEX ENGINEERED LINKS/CHANNELS

Customers design engineered channels for solid reasons:

- The reach of the standards-based solutions for Ethernet and Fibre Channel does not fulfill requirements.
- Customers like the flexibility and scalability of fiber structured cabling and, by default, will specify a central patching location (CPL) that functions as a cross-connect facility for "any-to-any" moves, adds, and changes (MACs). Certain customers propagate this model into cross-connect zones or pods, which results in a concatenated main cross-connect and zone cross-connect. This pushes the boundaries of the espoused standards and introduces the need for engineering channels to suit, based on the deployment of high-performance fiber and/or ultra-low-loss connector systems.
- The customer designs a migratable cable plant for higher speed optics at some point, and based on industry trends, more loss constrained channels.

The second bullet point describes the core focus. Customers expect to validate ultra-low-loss connectivity, built into an engineered channel, to the same performance limits as installers measure in the factory.

Figure 2 illustrates how the customer designed a full cross-connect into the channel to support port-mapping 40G core switches within a central patching location (i.e., full 12-fiber ribbon cable plant throughout, terminated with MPO connectors that reach out to distribution switches within the server pods).

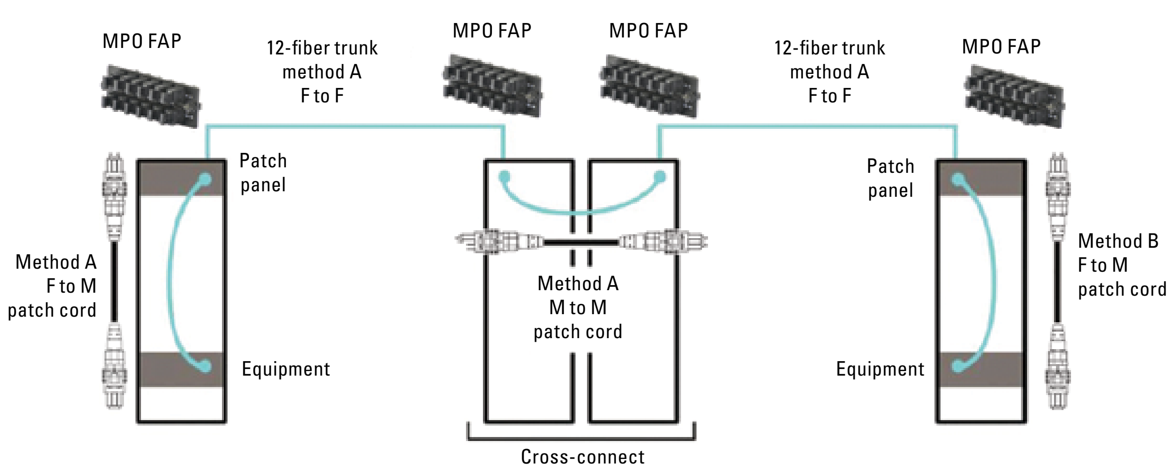


FIGURE 2: 40GBASE-SR4 engineered channel example.

This customer's longest channel for the end-to-end optics is 170 m (≈558 ft), which is outside of the capability of the 150 m (≈492 ft) OM4 according to the IEEE 802.3ba standard. See a plot of connector loss and optical fiber type versus reach for the 802.3ba standard in Figure 3.

As a result, the customer deploys ultra-low-loss MPO connectors to ensure channel integrity. These MPO connectors demonstrate a maximum insertion loss of 0.25 dB based on factory test results.

The design requires long trunk assemblies reaching out to the servers (150 m (≈492 ft) maximum) and shorter trunks to connect between the core and cross-connect area at 10 m (≈33 ft) maximum. The customer then wants to qualify the two trunks, when mated into MPO optical fiber adapter panels, as permanent infrastructure links to the manufacturer's ultra specifications (i.e., not TIA limits). Therefore, the long trunk (on the top) and the short trunk (on the bottom) in Figure 4 would yield the following engineered limits:

Server Side Trunk test limit =
2 x 0.25 dB + 0.15 km x 3.5 dB/km = 1.03dB

Core Side Trunk test limit =
2 x 0.25 dB + 0.01 km x 3.5 dB/km = 0.54 dB

If tested in the field against TIA/IEC guidelines, these links would yield:

Server Side Trunk test limit =
2 x 0.75 dB + 0.15 km x 3.5 dB/km = 2.03dB

Core Side Trunk test limit =
2 x 0.75 dB + 0.01 km x 3.5 dB/km = 1.54 dB

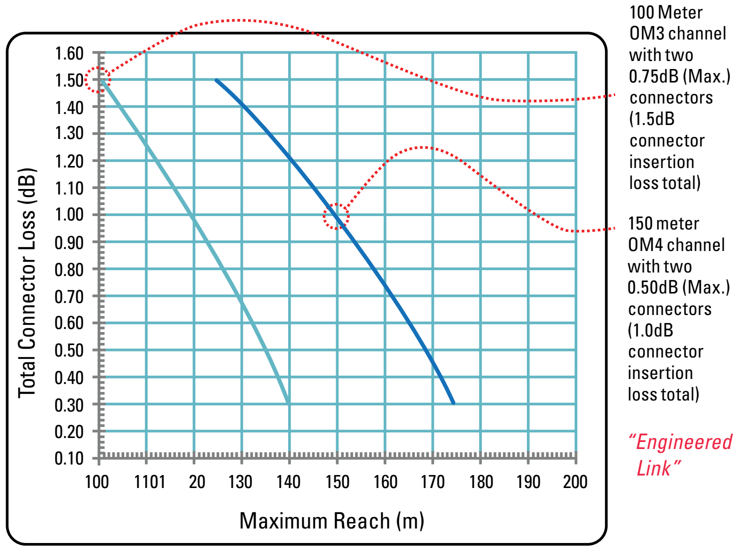


FIGURE 3: Extrapolation/interpolation from IEEE model for various connector insertion loss values.

THE REAL CAPABILITY OF FIELD TEST VERSUS FACTORY TEST

American National Standards Institute (ANSI)/Automotive Industry Measurement Systems Analysis defines Gage or Gauge Repeatability and Reproducibility (GR&R) as measurement capability. With light source power meter (LSPM) testing in the field, the gauge is the LSPM along with the reference cords that interface to the link under test.

Repeatability is the measurement variation obtained when one operator repeatedly measures the same item with the same test set.

Reproducibility is the variation due to different operators using the same test set to measure the same item.

40GBASE-SR4 & 100GBASE-SR4 CABLING

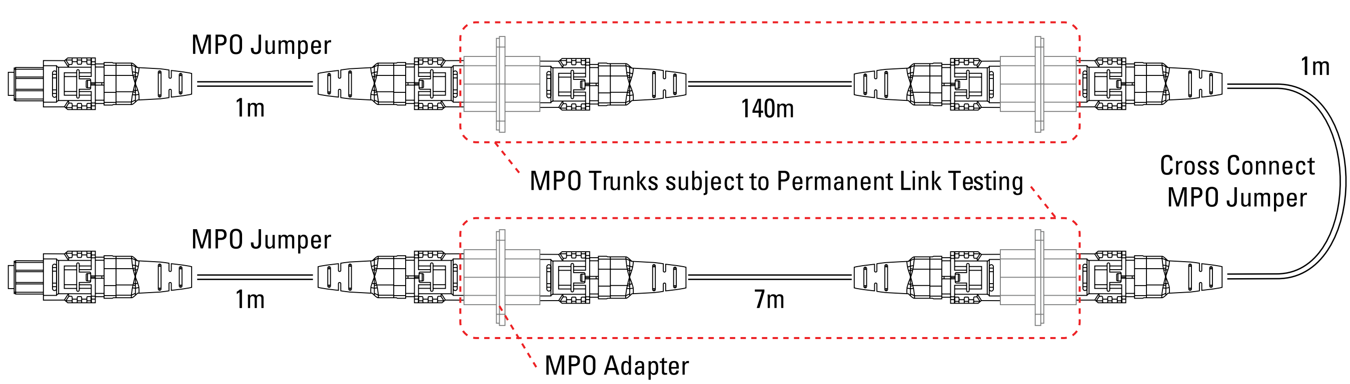


FIGURE 4: Parallel optics cross-connect cable plant.

The total variance (TV) of the actual link measurement is the sum of three components:

- Product Variation (PV) present in the link
- Appraiser Variation (AV) due to different test technicians (reproducibility)
- Equipment Variance (EV) of LSPM error (repeatability)

Such that: $TV = PV + AV + EV$

To estimate these components of variation, operators perform a standard Gauge R&R study (GR&R) using the following format:

- Fixed number of parts (12 optical fibers labeled 'A' through 'L')
- Fixed number of operators (three technicians labeled '1' through '3')
- Operators measure each part a fixed number of times (three to five times)

Operators perform this analysis on standard LSPM test sets to determine how much of the total variation is assignable to technician practice and test set uncertainty. The hope is that the sum of AV and EV will be a small fraction of the tolerance (i.e., test limits) that operators are measuring. Industry experts peg this ratio (i.e., capability ratio) at a maximum of 0.3, which is 30 percent of the tolerance range.

False fail results impact the customer's ability to deploy links in a timely fashion and can divert connectivity supplier monies incorrectly in terms of material and labor hours.

For a test limit of 1.0 dB, operators look for the sum of AV and EV to be less than 0.3 dB. ANSI equates this to 5.15 sigma or a standard deviation of measurement error of 0.06 dB. Figure 5 shows an example from a GR&R analysis on a typical LSPM.

Moreover, Figure 5 shows a GR&R study performed on a dozen connectorized optical fibers (A through L) that three technicians measured three to five times. The technicians deployed three LSPM test sets and multiple reference-grade cords in this study. The sequence of measurements was randomized among parts, technicians,

VARIABILITY CHART FOR INSERTION LOSS

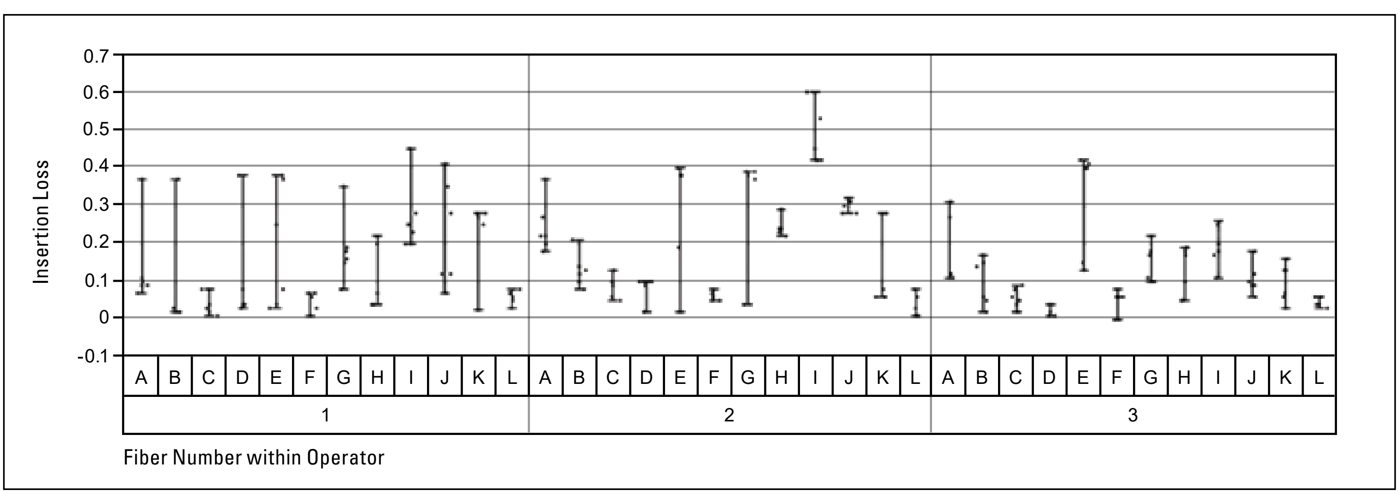


FIGURE 5: Sample output from a GR&R analysis on a typical LSPM.

LSPM sets, and reference cords. Whisker charts indicate the range of measurements for each technician measuring each optical fiber.

The differences among the operators when measuring the same optical fibers show discrepancies between the mean link loss and the variability of the link loss (Figure 6).

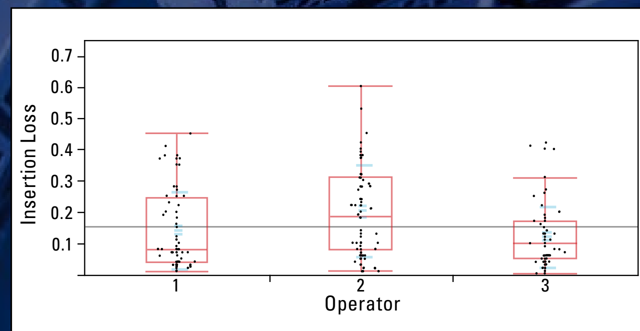
As shown in Figure 6, operator 2, when measuring the same optical fibers as operator 3, has almost twice as much link loss and about 50 percent more variation of link loss. The summary GR&R results shown in Figure 7 indicate a total measurement variation for the link loss (5.15 sigma) of 0.536 dB or approximately plus/minus 0.27 dB.

This is the total expected range of measurement error for a single link loss measurement. As a result, there are minimal measurement errors with the LSPM unit if the limits of the test are approximately 1.8 dB, which is 30 percent or less of the limit assigned to GR&R per the ANSI requirements.

CLASSIFYING ERRORS IN THE FIELD (FALSE POSITIVES AND FALSE NEGATIVES)

Both false fail and false pass relate to the ability of the measurement system to discriminate pass from fail. This discrimination is a result of test set capability (i.e., repeatability and reproducibility) and accuracy (i.e., bias due to referencing). Because of their importance, it is worth reiterating the meaning of false fail and false pass.

ONEWAY ANALYSIS OF INSERTION LOSS BY OPERATOR



Excluded Rows 2

Means and Standard Deviations

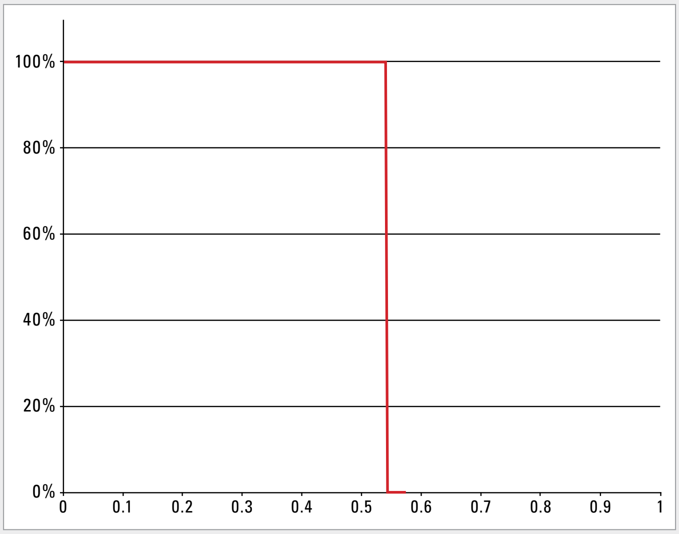
Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	72	0.139653	0.123066	0.01450	0.11073	0.16857
2	70	0.201000	0.146299	0.01749	0.16612	0.23588
3	72	0.119444	0.097820	0.01153	0.09646	0.14243

FIGURE 6: Operator measurement variability.

Measurement Source		(5.15*StdDev)	Tolerance	
Repeatability	(EV)	0.43588171	33.53	Equipment Variation
Reproducibility		0.31118821	23.94	Appraiser Variation
Operator		0.20651280	15.89	
Operator* Optical Fiber Number		0.23278867	17.91	
Gauge R&R	(R&R)	0.53556602	41.20	Measurement Variation
Part Variation	(PV)	0.42129141	32.41	Part Variation
Total Variation	(TV)	0.68140841	52.42	Total Variation
5.15 k				
78.5969 % Gauge R&R = 100* (RR/TV)				

FIGURE 7: Variability chart for insertion loss – GR&R.

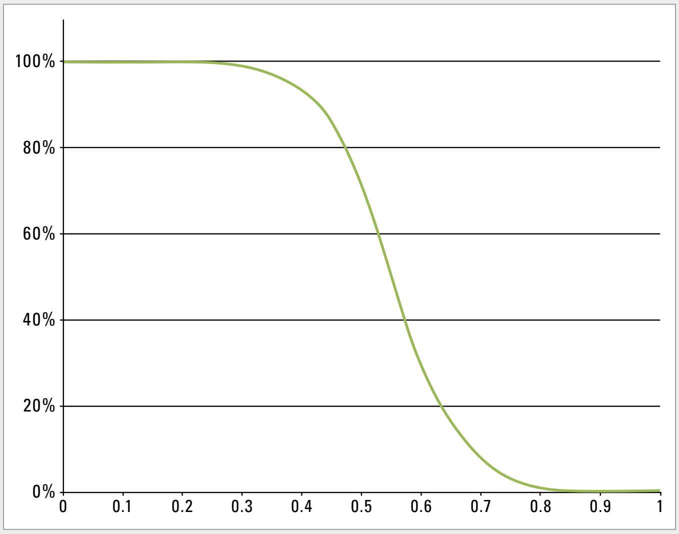
False pass results can present link reliability issues and potential warranty claims against connectivity suppliers.



Measurement system should reject any links above 0.54 dB and pass all links below 0.54 dB. It will not create any false fails or negatives in the process.

Such an idealized/perfect gauge is depicted in terms of probability of acceptance on the vertical axis and link loss on the horizontal axis.

This demonstrates no bias (or offset) because of poor referencing.



The green curve (based on the GR&R study from Fig. 7) is more indicative of a "real gauge" that is not "ideal."

The gauge capability depicted is related to the width of the transition from P(Accept)=100% to P(Accept)=0%, (approximately 0.6 dB).

.85 dB -.25 dB = 0.6 dB approximate width.

FIGURE 8:
Operating characteristic curves for light source/power meter.

False Fail

The link indicates fail, but it is truly passing. This impacts the customer's ability to deploy links in a timely manner. In this case, money is unnecessarily spent in remediating links that do not require it.

False Pass

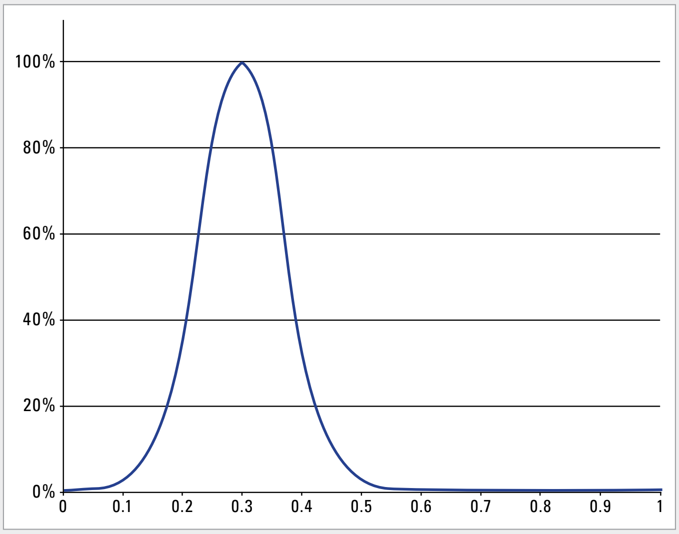
The link indicates pass, but it is truly failing. Link reliability issues and potential warranty claims against cabling suppliers, which is a "Day Two" issue, as tested good links may impinge on the signal integrity required. Figure 8 depicts a buildup of the 40G cabling scenario that demonstrates how false positives/negatives occur due to an incapable gauge and a distribution of link losses that is pushed near the limit of the test. This is not unrealistic for complex architectures and multiple connector "hops" with associated losses.

In a typical 10 m (≈33 ft) data center link with OM4 optical fiber and ultra-MPO connectors (insertion loss <0.25dB each), the customer's expectation for a passing link loss is 0.54 dB maximum, which is the red line in Figure 8.

The gauge in Figure 8 would err on the side of producing many false fails, good links that are deemed as fails. This effect would not occur if all the links produced were less than about 0.2 dB (i.e., no risk of measurement decision error). For marginally passing links between 0.54 dB and 1.6 dB link loss, there is an increased probability of false fails.

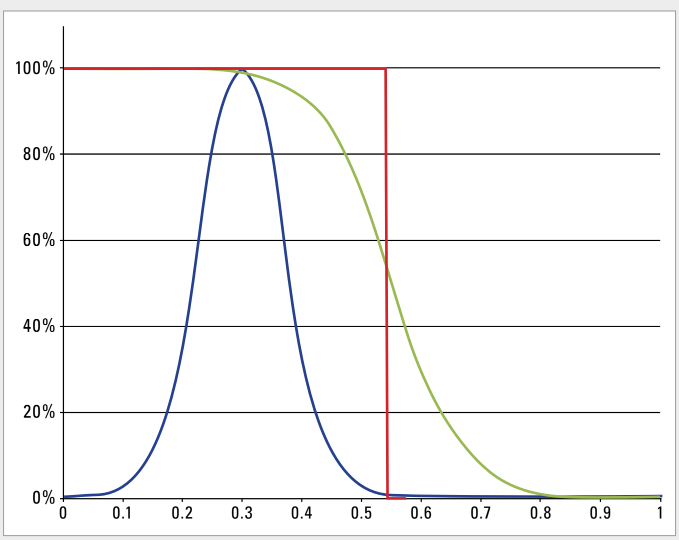
Shifting the gauge performance curve (green line) to the right would have the reverse effect and would produce many false passes, mitigated by the true level

FIGURE 8 CONTINUED.



Here an artificial distribution of link losses that represent the "real" results if large numbers of such links were measured as in a lab environment.

This indicates two mated pairs of ultra-MPO connectors in the channel and the short length of optical fiber (10 m) (≈33 ft) that would create a distribution that demonstrates an average link loss of 0.3 dB with approximately 0.4 dB of spread.



Combining all three lines illustrates the problem of poor measurement capability and links that demonstrate a significant number of fails near the test limit.

At the average "real" link loss just above 0.3 dB on the blue line, the probability of failing the link is almost 5 percent (green curve @ 95 percent pass probability).

Also, at 0.4 dB (real pass), the green line indicates about a 20 percent chance of a failing result with the LSPM test set.

Most importantly, adhere to good cleaning and inspection practices as outlined in connector component and test equipment manufacturers' guidelines. When in doubt, clean it.

of link loss from the gauge. This could happen if referencing is poor or "biased" downward by end contamination after referencing. It could also happen with reference cords getting bent during the reference that are straightened during link measurement.

MODIFIED ENGINEERED LIMITS—GUARDBANDING

When there is high measurement uncertainty (0.54 dB), consider new approaches to mitigating cost and effort in commissioning with tight test limits.

The assumption is that there is an understanding of the capability index of the LSPM. There is also an assumption that the manufacturer of the plug-and-play pre-terminated system components (e.g., trunks, harnesses, cassettes) has much better control over insertion loss measurements.

This includes advanced capabilities over monitoring the efficacy of the reference cords in use on the manufacturing floor and measurement process control of factory test sets. In addition, most quality manufacturers of optical assemblies perform testing, inspection, and packaging in clean rooms or at least laminar flow head facilities (Figure 9).

FIGURE 9: Field vs. factory test capability.

Expanding the test limits in a logical fashion with the knowledge of the test incapability can minimize the costs associated with commissioning such engineered links. The logical approach is to split the GR&R in half and guardband the test limits by this amount.

For this example, knowing that the GR&R is approximately 0.6 dB, operators would shift the limits of the LSPM test by 0.3 dB, yielding a new test limit at 0.84 dB (0.54 dB + 0.3 dB). This would shift the gauge performance curve previously generated (green curve) to the right by 0.3 dB (Figure 10).

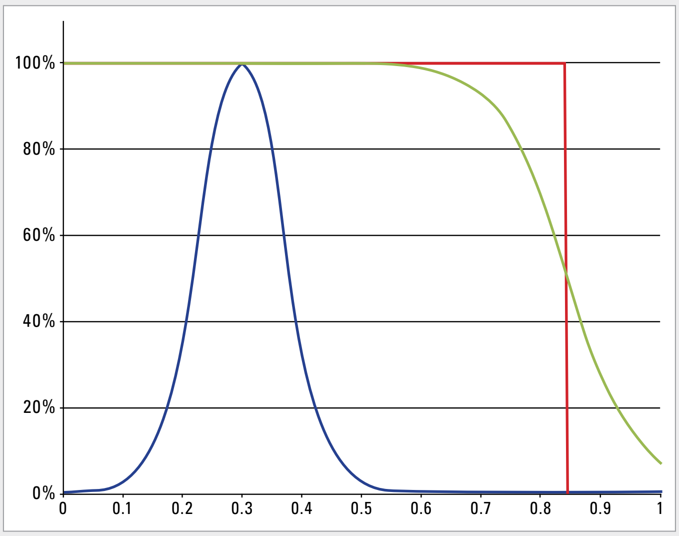


FIGURE 10: Guardbanded operating characteristic curve for light source/power meter.

If the average "real" link loss at just north of 0.3 dB on the blue line, the probability of rejecting (i.e., indicating a bad link) is almost 0% (green curve at 100% probability of a pass).

At just under 0.54 dB (real marginal pass), the green line indicates almost 0% chance of a mistakenly failed result with the modified limits.

CASE STUDY—REAL FIELD DATA

Variability Among Test Technicians in the Field

A large bank in the Americas considered returning large quantities of pre-terminated assemblies (i.e., trunks, fan-outs, harnesses, and cords) based on onsite measurements of each component. This was a function of troubleshooting at the component level of various channels built on plug-and-play products. When link testing turned for the worse, installers set aside the channel components and measured for loss.

The plot is typical of data collected from LSPM test sets and indicates a huge disparity in the variability among technicians performing the field tests of fan-outs as shown in Figure 11.

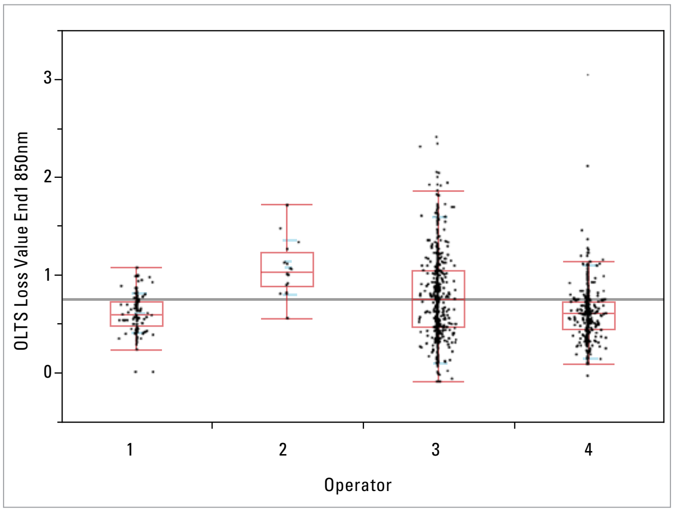


FIGURE 11: Box-Whisker chart of fan-out insertion loss versus operator measuring the same product.

Testing shows a significant difference in the skill level of individual operators performing field testing onsite. There was confusion about determining a good reference. Several of the operators involved had never learned the process of testing the reference cord using a single jumper reference and component test. For most, this was a practice that seemed unimportant to the job. Operators were also confused regarding reference check limits. Because of this engagement, key personnel were retrained in proper practice of using, maintaining, and qualifying reference cords to industry standards.

INCREASING THE EFFICACY OF THE FIELD TEST

To increase the effectiveness of field tests, consider the following:

1. Use TIA-526-14-B Annex "A" (i.e., one jumper method) as the default method of validating performance for data center links with MMF. The receiver end of the test equipment must be equipped with the same connector as present in the link under test.

2. Use Encircled Flux launch conditioning cords or mandrel wraps per test equipment manufacturer's guidelines to produce standards compliant launch conditions. This reduces the variability of tests, particularly between test sets.

3. Use reference grade launch jumpers in all cases. Ensure that mechanical and optical characteristics of these conform to standards. Reference-grade patch cords are required for accurate characterization of loss in permanent links. These cords are used as consumable items in the commissioning or qualification of links and minimize total installed cost by providing excellent measurement capability for tight application loss budgets.

4. Reference patch cords contain connectors that minimize the mean and standard deviation of insertion loss when mated with many standard connectors. These reference connectors have nominal optical and geometrical characteristics (e.g., numerical aperture and core/ferrule concentricity). They produce "near zero" loss when mated against other reference connectors and ensure accuracy in referencing and gauge repeatability (i.e., replication of link tests under the same reference) and reproducibility (i.e., replication of test results across multiple test sets and references).

    - Use TIA FOTP-171 (i.e., one jumper method) to qualify precision jumper connectors on a component basis instead of a fixed number of mating cycles.

    - Cord longevity and durability is discussed in Telcordia GR 326 standards, providing guidance on the maintenance of working with reference cords. It is the responsibility of the individuals performing testing to assess reference cord integrity.

    - Use TIA FOTP-171 to qualify reference cords on a "schedule" and when reference cords are in question. Deciding when to remove a reference cord from service can be determined by performing one jumper component insertion loss on all reference cord ends with a "master" cord that is purpose-built to qualify working reference cords. If possible, chart or log these to determine the state of measurement control.

In conclusion, it is a best practice to allocate the actual number of mated pairs of connectors in the channel into the test limit, regardless of the link measurement technique chosen. For loss challenged links (i.e., tight engineered links), assess the test limits against the GR&R of the test set. If the GR&R significantly infringes the capability to test to the limits, negotiate with the customer to modify limits upward by one-half of the GR&R. This is a good point to engage the structured cabling supplier to provide guidance and a technical bridge between the end customer and the system integrator or installer.

Most importantly, adhere to good cleaning and inspection practices as outlined in connector component and test equipment manufacturers' guidelines. When in doubt, clean it. This applies to anything that touches the link under test, including the test equipment reference cords and visual inspection equipment.

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