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Field Testing Multimode 10 Gb/s (and beyond) Fiber Permanent Links

Best Practices to Minimize Costs
by Ensuring Measurement Repeatability,
Reproducibility and Accuracy

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The performance and reliability of the cabling infrastructure within the data center and in premises applications are of paramount importance. For new high-speed optical networks, it is critical for all network stakeholders to have an accurate knowledge of the performance of the permanent links deployed in the network. It is also very important to assure that links deployed by customers present a warrantable solution when measured against 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., 100GBASE-SX) in 2002, the 3.56 dB total channel insertion loss (IL) for 50/125 micron multimode fiber has been reduced to 2.6 dB for 10GBASE-SR, and more recently to 1.9 dB for 40GBASE-SR4 (or 100GBASE-SR10). Consequently, for 40GBASE-SR4, a maximum connector loss of 1.0 dB is required for a 150m channel containing multiple connector interfaces and high-bandwidth OM4 fiber.

Current multimode structured cabling systems built around LC and MTP connector systems typically have very little insertion loss. For example, to reliably measure the loss of a 30 meter OM3 permanent link to the TIA and IEC standards requirements, where we expect a total loss to be a little over 1.6 dB, would require measurement system repeatability and reproducibility to be a small fraction of 1.6 dB (less than 0.2 dB based on multiple standard deviations of measurement error). Permanent links built with low-loss multimode fiber (MMF) and these connector systems to support higher speed protocols require compliance with tight customer and industry specifications and hence very accurate/capable insertion-loss measurement processes.

In the factory, the most widely accepted method of measuring the insertion loss of connectors is the one-jumper reference patch cord method (as specified in FOTP 171 [3]). In this method, a single well-controlled nearly ideal patch cord is used as the test interface and the performance for each and every connector is measured. Since each connector is measured using a nearly ideal patch cord, there is a high degree of internal measurement repeatability and reproducibility between multiple suppliers of connectivity, and across many customers when such connectivity is deployed in permanent links.

In the cabling industry, the predominant method for field-testing of fiber optic links is the use of 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 permanent link testing (with LC connectors), with the potential to produce false fail result (link indicates fail, but truly passing) and false pass (link indicates pass, but truly failing). False fail results impact the customer's ability to deploy links in a timely fashion and can divert connectivity supplier monies wrongly (material and labor hours). False pass results can present link reliability issues and potential warranty claims against connectivity suppliers.

This raises several important questions: "What is the most accurate and capable measurement technique for higher speed multimode links?" and "What are the best industry practices to assure that remediation of links due to measurement errors (and hence costs) are kept to a minimum?"

In this paper, the various components of error that degrade the higher speed multimode permanent link measurement integrity are identified and discussed in the context of cost reduction through best practice.

The Importance of Permanent Link Testing

Permanent Link

ISO/IEC and TIA standards define the Permanent Link as the permanent fiber cabling infrastructure over which the active equipment must communicate. This does not include equipment patch cords to connect the active network devices in equipment distribution areas or the patch cords in cross connect patch areas (see Figure 1).

ISO/IEC and TIA standards define Permanent Link testing to verify the performance of the fixed (permanent) segments of installed cabling as accurately as possible. Completion of this testing provides assurance that permanent links that pass standards-based (or application-based) limits can reliably be configured into a passing Channel by adding good quality patch cords.

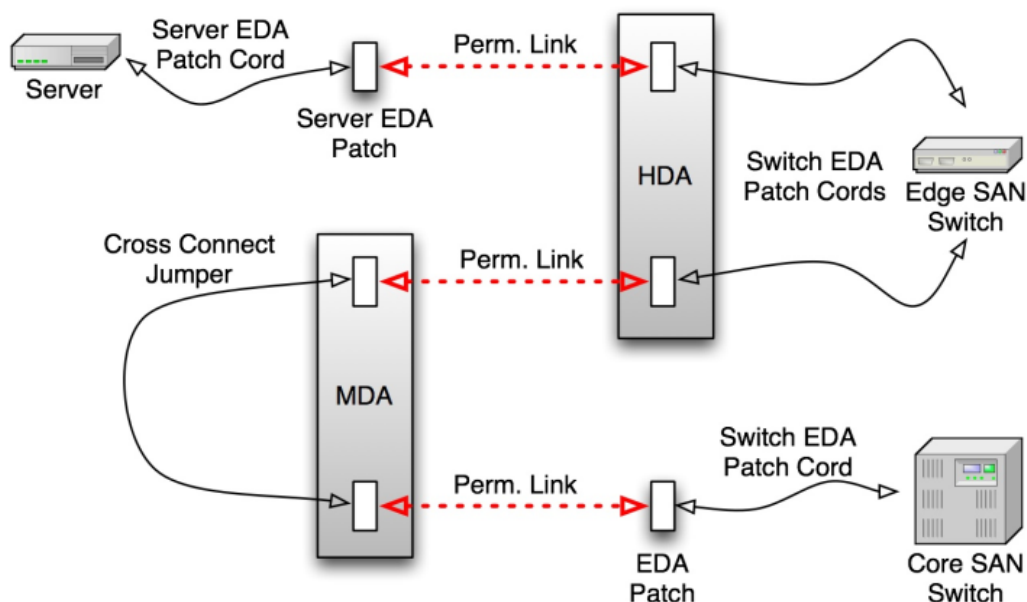


Figure 1. Example Permanent Link.

Channel

ISO/IEC and TIA standards define the Channel as the completed fiber structured cabling over which the active equipment must communicate. This end-to-end link includes equipment patch cords to connect the active network devices in equipment distribution areas (typically switch to switch or switch to host), and the patch cords in the cross connect patch (optional and located in the horizontal distribution area [hda] and/or main distribution area [MDA], see Figure 2).

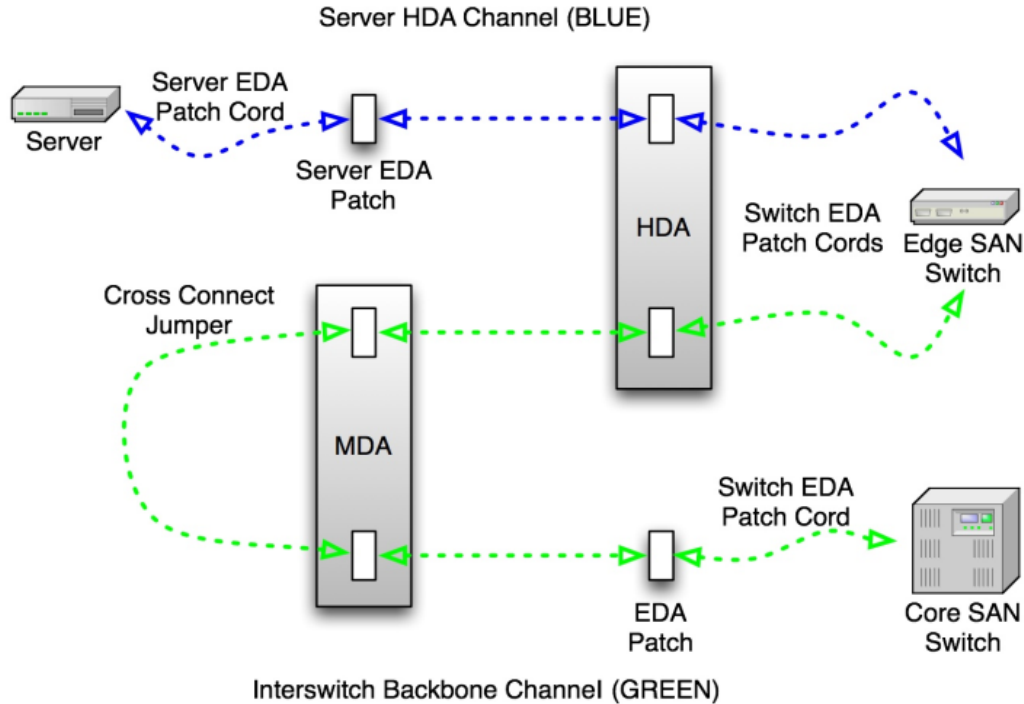


Figure 2. Example Fiber Optic Channel.

Ultimately, network functionality and signal integrity rely on the performance of the Channel (the completed end-to-end link). Installation and test personnel do not typically measure end-to-end loss of the complete Channel with all equipment distribution area (EDA) cords and cross connect cables in place.

EDA cords and cross connect cables are generally installed after the “permanent” cabling installation has been completed and tested, and then are subject to Moves, Adds and Changes (MACs) throughout the cabling system’s lifetime. It is therefore compulsory to certify that the permanent link (PL) cabling infrastructure meets performance level defined by standards and/or applications (generally whichever is more strict) to assure adequate system headroom when MACs are performed by IT personnel at a later date.

No standards address application-based channel test limits other than the extension of the permanent link test limits (with the addition of the connector losses in patch cords). The application link power budget (Ethernet, Fibre Channel, etc.) does not include the connectors that are attached to equipment on either end of the link as insertion loss “milestones”. These are built into the link power budget as minimum transmitter power into (-dBm) the fiber and receiver minimum sensitivity in (Amps/Watt). So, strictly speaking, the number of connectors in the Channel is the total number of “mated pairs” of connectors (connector terminations into the receptacles of the transceivers are not “mated pairs”).

Typically, channel certification using Power Meter and Light Source (PMLS) methods is at the behest of network owners and/or specifiers and brings no real additional value beyond the initial permanent link testing, and is best deployed as a troubleshooting tool for channel functionality.

Directional and “Dual Window” Testing

For backbone cabling, it is recommended that PL testing be performed for all MMF links at both specified wavelengths. Multimode fibers should be tested in one direction at 850nm (the 10GBASE-SR operating window) and additionally at 1300nm both to account for fiber attenuation differences due to wavelength and to reveal potential issues associated with installation practice. Significant differences in link results between these windows can aid in troubleshooting direction in the case of failing links: link failures predominately at the 1st window may indicate problems with connector systems, while 2nd failures may indicate fiber macrobend sites in the installed cabling causing incremental added attenuation.

Some end users require bidirectional PL loss testing to meet special requirements dictated by equipment certification or data center site documents/standards. There are instances where bi-directional testing can reveal issues in the cable plant that could go unseen with unidirectional testing. The current implementation of Bend-Insensitive Multimode Fiber (BIMF) into “brownfield” datacenters that utilize non-BIMF in network segments and/or patch cords presents a situation where directional losses may be present (losses across connectors that are a function of direction). These losses can be significant in light of tight application power budgets and/or networks that deploy multiple hops of mated connectors.

If it is known that such mixed fiber environments are present, it is best practice to perform such bi-directional testing and examine the results in the context of application requirements. However, generally speaking, if all of the fiber in the channel is one type (e.g. - 50/125 Laser Optimized), then bi-directional testing is of little value and provides no new information about the loss performance of the permanent infrastructure beyond unidirectional testing.

Tier II OTDR Testing - Value Proposition for Troubleshooting Links

Many individuals responsible for performing link testing have questioned whether they should perform Optical Time Domain Reflectometer (OTDR) testing for data center cabling as specified in ANSI/TIA-568-C. A subset of these individuals also question if this type of testing can supplant traditional Power Meter and Light Source (PMLS) testing.

Industry standards require Tier I PMLS testing as the minimum regimen for a compliant installation. Tier II OTDR testing (i.e., extended testing) is not a substitute for PMLS testing but is complementary, and although highly recommended is ultimately performed at the discretion of the network owner and system designer. OTDR testing does not replace Tier I PMLS testing as the only type of testing required by domestic and international standards bodies for the commissioning testing for permanent links.

Together, PMLS and OTDR testing provide both the absolute loss measurements in comparison with the loss budget, and individual measurement of events on a fiber link. When measuring a simple, short data center link using PMLS, only total loss for the link is obtained (not component level loss information). By contrast, in addition to link loss, OTDR testing reveals component insertion loss and reflectivity of connectors, splices and other fiber attenuation discontinuities in the link.

The combined results of Tier I and Tier II testing are beneficial in that they can be used to validate individual component specifications. For links that marginally fail, the typical issue that people performing link testing run

into is the decision of which connector to remediate (retest and/or cut off, re-terminate and retest). The information to make these types of decisions cannot be gleaned from PMLS tests alone, but can be obtained from OTDR tests.

Specifically, for field installed connector systems deployed in permanent links, the decision to re-terminate connectors after a link fails Tier I PMLS testing can be a decision that brings added cost beyond that of the scrap parts, extra consumable materials and the labor to perform the re-termination and re-test. Since PMLS testing yields only link loss and not component loss, it occasionally becomes a “guessing game” on marginally failing links as to which connector is causing the link test failure. A portion of the time, compliant connectors will be cut-off and re-terminated, thus not fixing the root cause issue for the failing link. This effect is exacerbated by installer “First Pass Yield” (the yield in percent of individual single fiber connectors terminated successfully), by presenting more opportunities for these type of errors.

If we consider a situation in which a comparison is made between installations where only Tier I testing is performed on links to one where both Tier I and Tier II link testing are used, we can build a cost model for the incremental additional difference in cost per link for these two installation test methods. Considered in this model, is the original labor and materials to perform the termination and testing and the incremental materials and labor associated with remediation (or multiple remediations) as a function of installer first pass yield (expected range as labeled Figure 3) and the generation of connectors “cut off in error”.

We can use output of this statistical/probabilistic model to understand the simple payback period for Tier II OTDR testing gear required. This includes the following inputs with the aim of quantifying savings due to streamlining the troubleshooting process:

- **Installer Experience Level** - In the model this is quantified as 'LOW' (First Pass individual connector yield @ 80%) vs. 'HIGH' (First Pass individual connector yield @ 98%)
- **Labor Rate** - Assumed as being the same crew that does the installation, testing, troubleshooting and remediation and varying between “low” (\$50/hour) and “high” (\$100/hour)
- **Avg. Number of Links per Job** - For the sake of this analysis we will assume that 250 links are being installed and commissioned for use (4 connectors/ link x 250 links) = 1000 field install connectors
- **Connector Cost** - Here we assume that the connectors used are single-use mechanical cam-style connectors with a buy cost of \$10 each

Figure 4 indicates the potential “recovered cost” of labor and materials when using Tier II testing as a troubleshooting method for permanent link qualification. Here we can see that on a 250-link job, up to \$6,000 might be left unrecovered if only Tier I link testing is used under conditions when experience level is low and the labor rate is high. In general these situations are most prevalent where contractors are unfamiliar with a new fiber connector solution, where there is significant variance among the skill sets in an installation crew, and/or where the work environment is not optimal (i.e., lack of heat/illumination, no defined work areas, contamination, lack of access to permanent link fiber, etc.). Contaminated and/or poor work environments are common in many “Greenfield” installations where other infrastructure construction is occurring at the same time (such as dry walling, plumbing, and electrical installation).

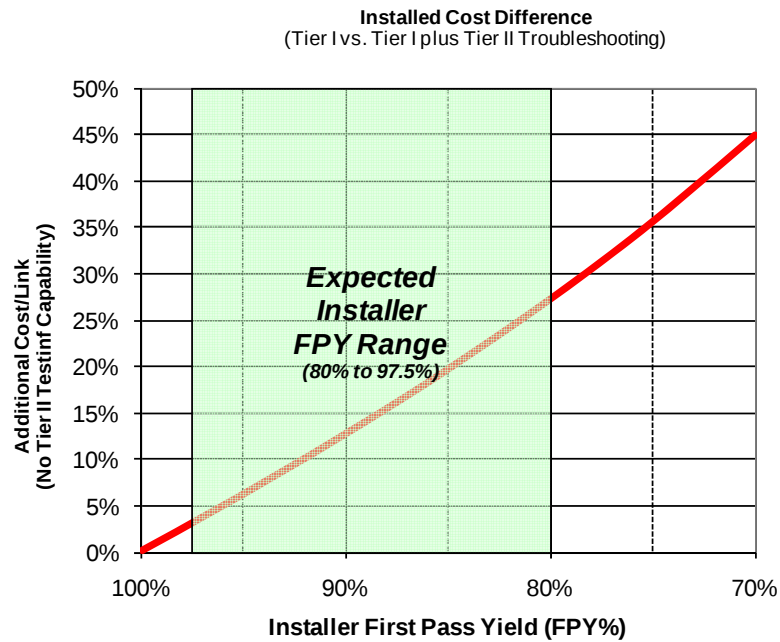


Figure 3. Plot of “Additional Cost” Per Link as a Function of Installer First Pass Yield.

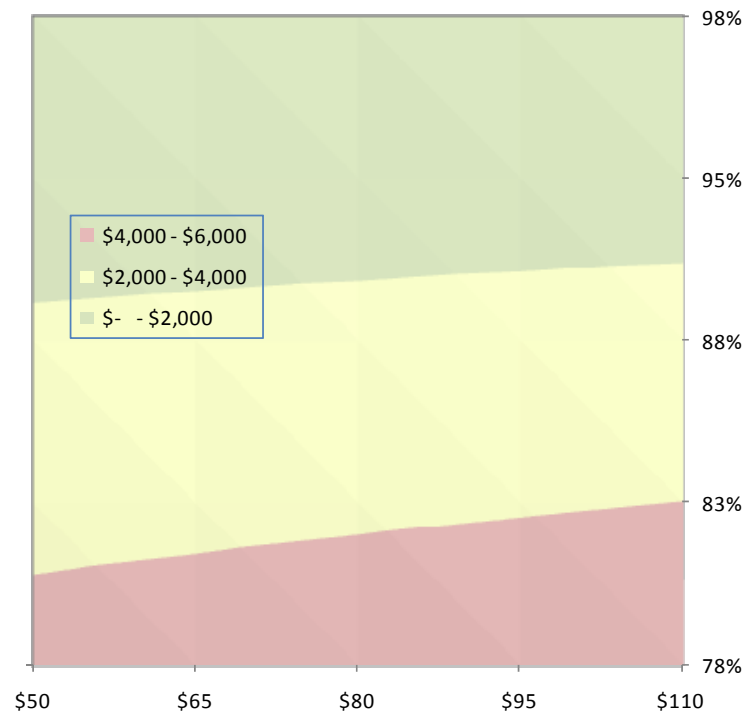


Figure 4. Plot of “Recovered Cost” as a Function of Installer FPY% (vertical axis) and Labor Rate (horizontal axis).

By contrast, if costs are recovered using Tier I and Tier II testing to more accurately determine which connectors to re-terminate, the simple payback of an OTDR (say, valued at \$20,000) would occur after a very few 250-link jobs. The converse case would be the minimization of “recovered cost” when installer experience is high, as “recovered cost” becomes independent of labor rate as installer first pass yield approaches 100% (i.e., links are not present to remediate).

Power Budgets and Requirements

Electrical noise is a very real threat to reliable, productive processing or manufacturing operations.

Application Standards Link Budgets

The overall power budget for an optical channel link is determined during the development phase of the associated application standard, and is based on the magnitude of seven principal optical impairments (or power penalties), as well as 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 (IL).

Typically, most of these optical impairments are small (<0.3 dB) and will not be considered here. However, ISI and IL do contribute large optical penalties and therefore, are the two primary impairments that limit channel performance (or channel reach), and are strongly influenced by the quality and practices used in the construction of the physical link.

When an optical pulse propagates through a fiber channel, its shape will broaden in time due to bandwidth limitation in the transmitter, fiber and receiver. The optical pulse representing each data bit or “symbol” will spread in time and overlap the adjacent symbols to the degree that the receiver cannot reliably distinguish between changes in the individual symbols or signal elements. The power penalty due to this effect is called ISI. ISI therefore affects the temporal characteristics of the signal pulses, which results in signal dispersion and timing jitter at the receiver. ISI typically 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 8Gb/s Fiber Channel (FC-4) specifies the minimum fiber bandwidth (or maximum dispersion) necessary to comply with the system ISI requirements and ensure error free system performance. The fiber bandwidth is specified in terms of Effective Modal Bandwidth (EMB), and high-speed systems (>10 Gb/s) must achieve a minimum EMB of 2000MHz·km for laser optimized OM3 MMF, and 4700MHz·km for OM4 MMF.

Insertion Loss is the second critical parameter that determines the performance of a channel link. There are two sources of IL: loss at the connector-to-connector interfaces, and loss or attenuation within the fiber itself due to the absorption and scattering of light as it propagates. For high-performance and reliable 10 Gb/s network operation, both of these loss sources should be minimized by selecting high quality, low IL connectors, patch cords, and cassettes plus high performance MMF. In Figure 5, we compare 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.

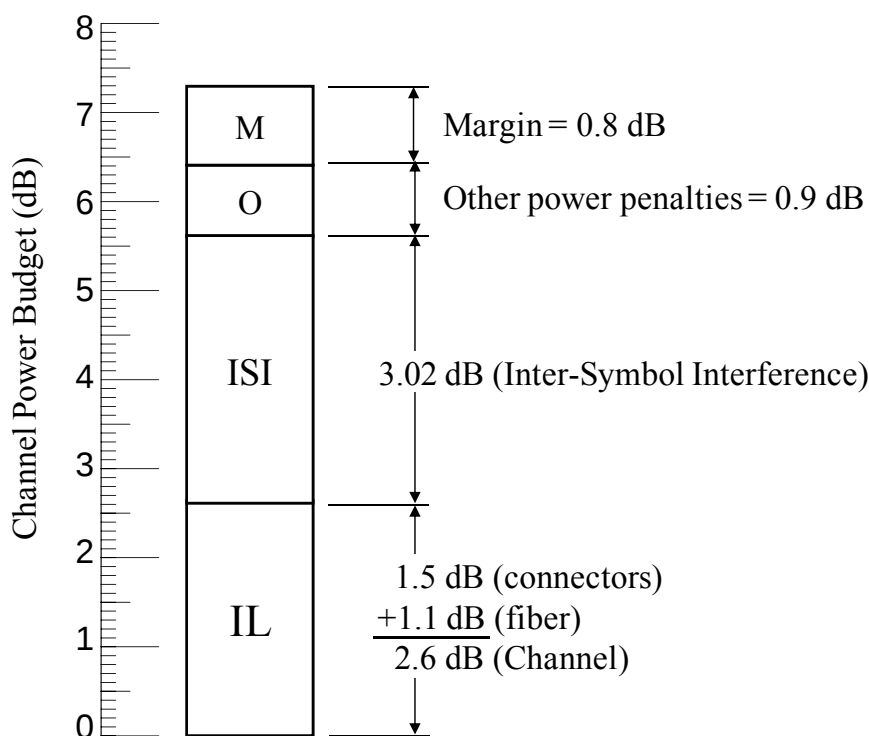


Figure 5. Optical Channel Budget for 10 Gb/s Ethernet (10GBASE-SR).

The maximum channel IL for 10GBASE-SR is 2.6 dB, which includes connector insertion loss, cable attenuation and splice loss. This IL budget allows for a maximum channel reach of 300m and a maximum connector IL of 1.5 dB. For next generation 40G and 100G Ethernet (40GBASE-SR4 and 100GBASE-SR10 respectively), the ISI penalty is larger and consequently, the maximum IL penalty allowed is smaller. Due to the larger ISI penalty, the maximum reach for 40G/100G Ethernet is reduced to 100m for OM3 MMF and 150m for OM4, with a maximum connector IL of 1.5 dB and 1.0 dB respectively.

In principle, one can tradeoff cable attenuation for connector IL, or EMB for IL; however, this must be done with caution. Channel links designed with parameter tradeoffs are referred to “engineered” links. As an example, consider a 10GBASE-SR channel link with an installed reach of 150m (half the maximum specified reach). The ISI for this channel would only be 1.5 dB as opposed to 3.02 dB. As a result, a larger connector IL of 2.5 dB can be tolerated. However, more connector loss can lead to increases in other power penalties such as modal noise. Alternatively, the ISI penalty can be reduced by increasing the fiber bandwidth (i.e., by using OM4 fiber).

Cabling Standards Link Budgets

The maximum reach and allowable cable attenuation for optical channel links are also specified in commercial cabling standards such as Telecommunications Industry Association (TIA-568-C.1) and the International Electrotechnical Commission (IEC 11801). These standards specify the supportable distances and channel attenuations for applications by fiber type. This assures that channel links comprising legacy fiber types, lower bandwidth fibers, or channels containing numerous connector interfaces or splices operate reliably.

Some test sets use these cable standards to verify channel link compliance. This method of verification can be illustrated by considering the following example. Let's assume we are verifying a 75m horizontal channel link supporting 850nm transmission over an OM3 cable. Let's also assume the channel contains two connector pairs and one splice. According to TIA and IEC standards, the maximum cable attenuation coefficient is 3.5 dB/km. We also find that the maximum mated pair connector loss is 0.75 dB and the maximum splice loss is 0.3 dB. From this we can calculate the maximum allowable cable attenuation for this link to be,

$$\begin{aligned} & (3.5 \text{ dB/km} \times 0.075 \text{ km}) \\ & + (0.75 \text{ dB} \times 2 \text{ Connector pairs}) \\ & + (0.3 \text{ dB} \times 1 \text{ Splice}) \\ & = 2.06 \text{ dB Cable Attenuation (dB)} \end{aligned}$$

Given this calculated maximum allowable attenuation, one can readily determine if the measured channel loss exceeds the industry allowable optical penalty as specified in TIA and IEC cabling standards.

Test Methods

Several Permanent Link (PL) test configurations exist as defined by standards and all are not created equal. The goal of any PL testing should be such that the contributions made by the tester referencing cables (and adapters) are fully excluded from the measurement results so that the unbiased capability of the PL is quantified.

The three standard methods of completing a link loss test for premises cabling are as follows:

- One Jumper Method (TIA-526-14-B Annex 'A')
- Two Jumper Method (TIA-526-14-B Annex 'C')
- Three Jumper Method (TIA-526-14-B Annex 'B')

Reference Grade Patch Cords

For all testing methods, "reference quality" patch cords and adapters must be used to ensure accurate, repeatable and reproducible measurements. A reference patch cord is that cord that contains connectors which have nominal optical and geometrical characteristics (Numerical Aperture and Core/Ferrule concentricity for example), such that when mated against other reference connectors produce "near zero" loss.

In essence, these reference connectors minimize the mean and standard deviation of insertion loss when mated against a large population of sample connectors. Use of such reference grade patch cords is a necessity to assure accuracy (in referencing) and gage repeatability (replication of link tests under same reference) and reproducibility (replication of test results across multiple test sets and references).

One Jumper Method – TIA-526-14-B (Annex 'A')

The one jumper method calculates the link loss as the loss of the two adapters and the link under test, Figure 6. This is the preferred method for qualifying the cable plant as outlined in ANSI/TIA-568-C. Here the power meter test lead must have the same connector type as the Link Under Test (LUT). This has been proven to be the most accurate and reproducible method of the three.

Key points:

- Preferred method with cabling vendors for testing permanent links
- Power meter test head must have same connector type as link under test
- Most accurate, repeatable and reproducible link measurement method
- Must use "reference quality" test cords and adapters for all connector mating surfaces [2]
- Similar to component insertion loss test (FOTP 171 [3]) used by connector and component manufacturers to qualify component insertion loss

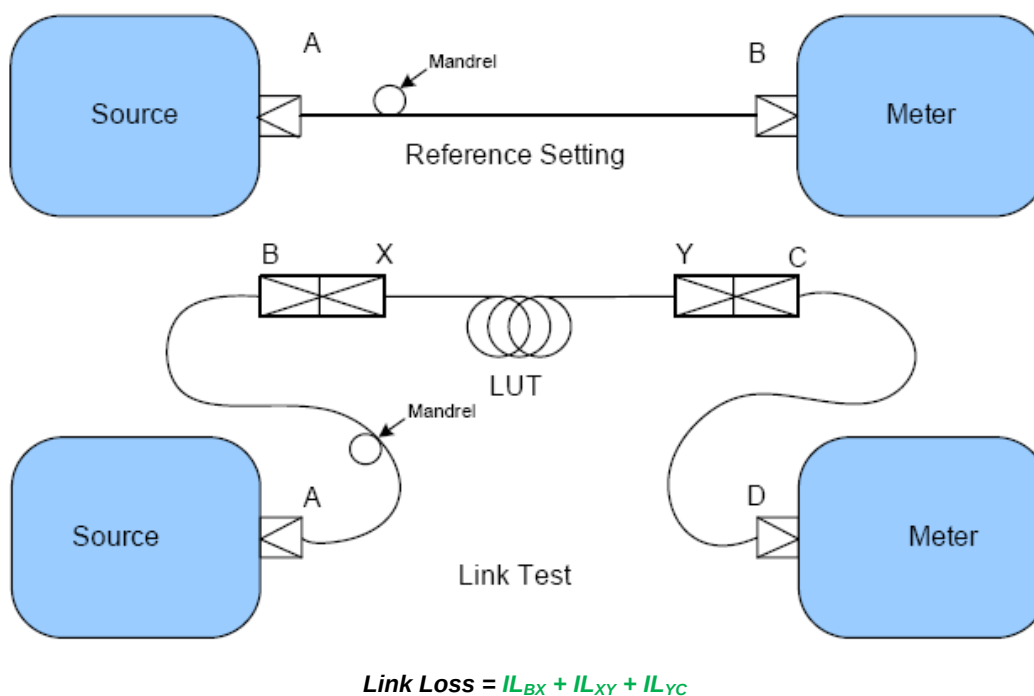


Figure 6. One Jumper Method.

Two Jumper Method – TIA-526-14-B (Annex 'C')

The two jumper method calculates the link loss as the loss of the adapter in the original reference setup subtracted from the sum of the two adapters and the link under test, see Figure 7. This method is preferred by contractors (even though it is not referenced in ISO/IEC 11801) because the power meter test lead does not have to have the same connector type as the LUT. This method also assumes that a majority of the loss is in the fiber cable itself and not the connectors.

This method is not recommended for MM 10 Gb/s data center links that have tight loss budgets (or for cable plant that will be repurposed to support 40G/100G Ethernet).

Key points:

- Power meter test head does not need to have the same connector type as link under test
- Must use "reference quality " test cords and adapters for all connector mating surfaces [2]
- Similar to component insertion loss test (FOTP 171 [3]) used by connector and component manufacturers to qualify component insertion loss
- High variability and measurement bias - Measurement bias and uncertainty (due to propagation of referencing error) can be substantial

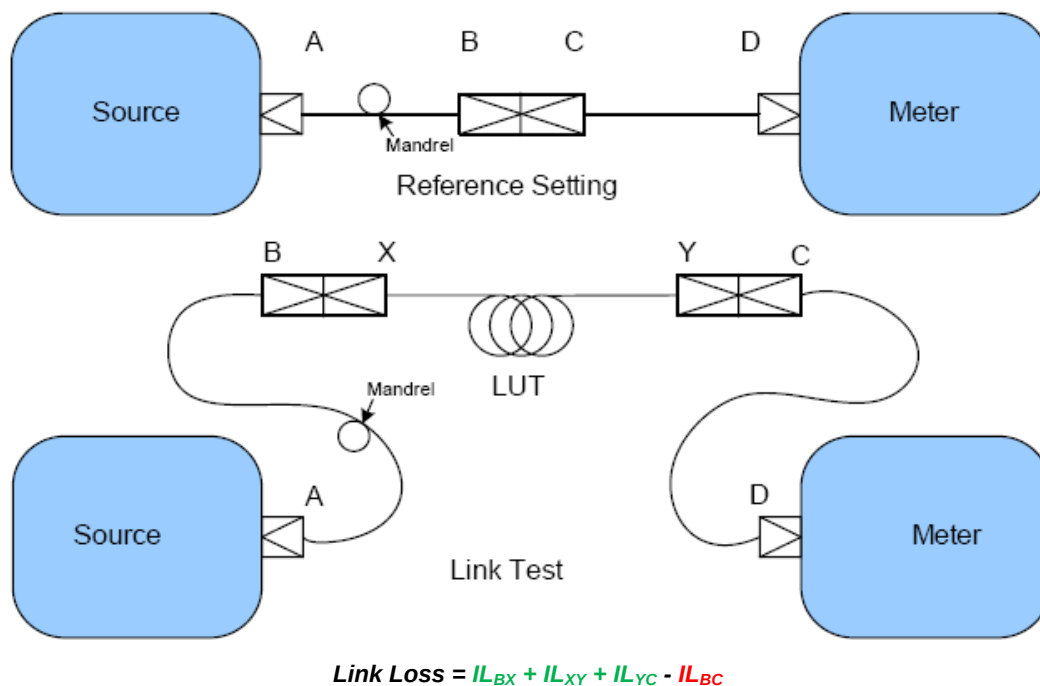


Figure 7. Two Jumper Method.

Three Jumper Method – TIA-526-14-B (Annex 'B')

This method is for channel testing where user cords are part of the test, see Figure 8. This method calculates the link loss as the sum of the loss of the adapter on the transmit side, the loss of the link under test and the loss of the connector on the receive side, minus the sum of the connectors on the receive and transmit side of the link under test in the original reference setup. This method has the highest variability of all the methods discussed. This method is not recommended for MM 10 Gb/s data center links that have tight loss budgets (or for cable plant that will be repurposed to support 40G/100G Ethernet).

Key points:

- Defined in ANSI/TIA-568-C.0 for channel testing only. Found in IEC 14763-3 and used for channel and permanent link testing.
- Power meter test head does not need to have the same connector type as link under test
- Must use "reference quality" test cords and adapters for all connector mating surfaces [4]
- On average will slightly underestimate link loss (i.e., a false pass) (depending on loss of the sum of two mated reference pairs) if # connectors in budget = # deployed in link/channel
- Highest variability and measurement bias of all methods - Measurement bias and uncertainty (due to propagation of referencing error) can be substantial

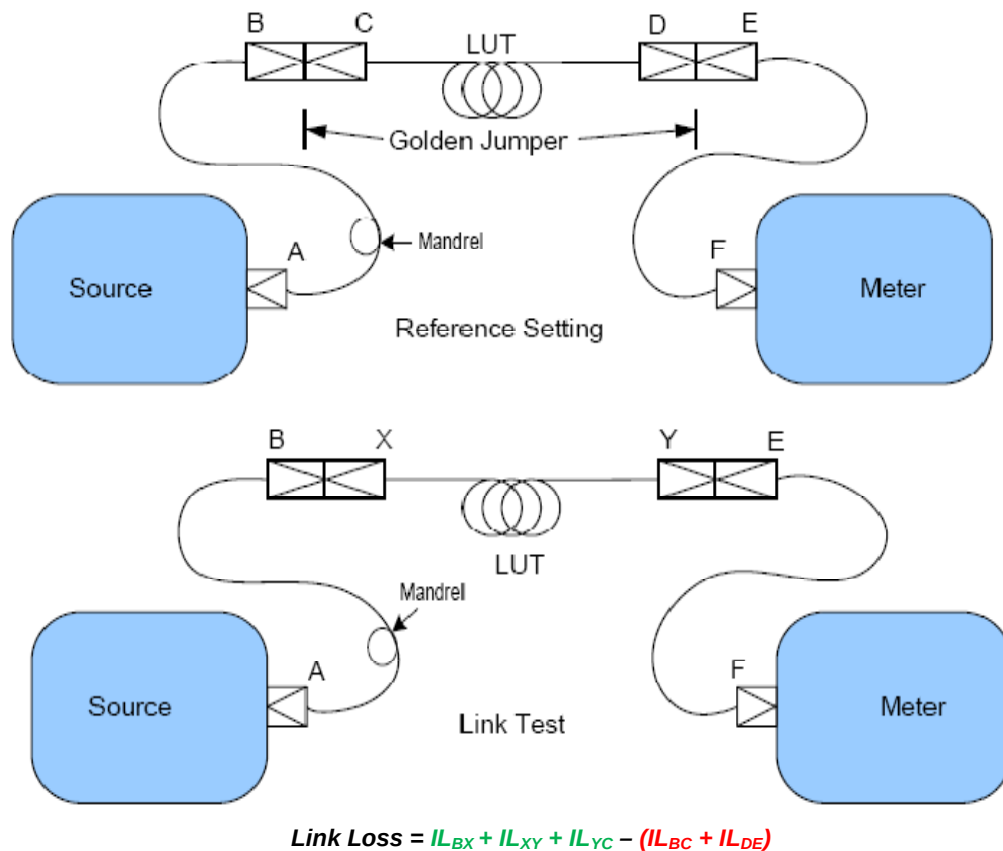


Figure 8. Three Jumper Method.

Test Method Discussion

Table 1 presents a summary 'scorecard' comparison of the three link measurement methods in terms of accuracy/capability and user concerns. This scorecard considers only an empirical ranking amongst the three techniques and offers some guidance with respect to technique applicability.

Table 1. Scorecard Comparison of Link Measurement Methods.

Characteristic	One Jumper Method	Two Jumper Method	'Golden' Jumper Method
Accuracy	✓✓✓✓	✓✓	✓
Repeatability & Reproducibility	✓✓✓✓	✓✓✓	✓
Ease of Use (Test time, etc)	✓✓✓	✓✓✓✓	✓✓✓
Consumables (# reference jumpers, adapters)	Low	Medium	High
Assumptions	Reference Jumpers (two connectors measured against reference connectors)	Reference Jumpers (two connectors measured against reference connectors). Offset due to non-zero insertion of reference pair must be small.	Reference Jumpers (two connectors measured against reference connectors). Offsets due to non-zero insertion of both reference pairs must be small
Applicability (where best suited)	When test equipment connector system matches perm. link connector system, tight loss budgets	Where media attenuation dominates compared to connectivity loss. Test equipment connectors can be different than perm. link connectors	When test equipment connectors are different than perm. link connectors, when connectivity content and/or link attenuation is high

Link Loss and Measurement Artifacts. The text box below compares the methods for calculating link loss across all three methods. Both one- and three-jumper methods have measurement "artifacts" (in red type) that cannot be effectively subtracted out and overall yield higher link measurement uncertainty. The actual link loss of interest is represented by the green type.

Fluke Networks and Panduit prefer to use the one-jumper reference measurement techniques in light of the tight optical loss budgets placed on 10G (and beyond) Links/Channels. Language within IEC 14763-3 (sec 9.1.1.4) indicates that measurement uncertainty/variability is increased unacceptably for other methods.

Panduit and Fluke Networks take the position that other methods are only appropriate where attenuation of the fiber significantly dominates loss generated by the connector systems (such as in long haul SM systems) or where connector-related uncertainties generated by incapable measurement techniques (such as three jumper methods) are a small portion of total connector insertion loss (systems with many connector hops) or systems that do not have very tight requirements on channel (e.g., legacy channels supporting 1G Ethernet).

Link Loss Method Comparison - Calculation Method and Measurement 'Artifacts'

One Jumper Method (TIA-526 Annex 'A')

$$\text{Link Loss} = IL_{BX} + IL_{XY} + IL_{YC}$$

Two Jumper Method (TIA-526 Annex 'C')

$$\text{Link Loss} = IL_{BX} + IL_{XY} + IL_{YC} - IL_{BC}$$

Three Jumper Method (TIA-526 Annex 'B')

$$\text{Link Loss} = IL_{BX} + IL_{XY} + IL_{YC} - (IL_{BC} + IL_{DE})$$

In support of this position, the Fiber Optic Association (FOA) performed an Ad-Hoc study comparing the capability of link loss measurement techniques aimed at quantifying the measurement variability for each of the three methods and establishing test application ground rules/baseline. In this study the following measurement protocol was used:

- Test links were built with various lengths and numbers of connectors
- Different contractors/testers were used to measure permanent links
- Reference cords were used for all three methods
- Best practices with respect to cleaning and inspection were adhered to

The resultant test and measurement variability (between methods) for the same test personnel, measuring the same links, using the three methods is summarized in Table 2. This work suggests that only the one-jumper method should be used for measuring “tight requirement” links/channels (customer imposed and/or standards imposed) and that:

- 5.15 sigmas of measurement error for multiple jumper methods > 1.0 dB and hence could consume the total link power budget or a significant fraction thereof
- multiple jumper methods are not recommended in simple links with tight budgets (where variability presented above is a significant fraction of the link budget specification)

Table 2. FOA Link Test Method Benchmark Analysis

Test Method	Standard Deviation
One Jumper	± 0.02 dB
Two Jumper	± 0.20 dB
Three Jumper (i.e., Golden Jumper)	± 0.24 dB

The one jumper method (TIA-526-14-B -Annex 'A'), although it is slightly more difficult to execute in the field than the three jumper method, yields the most accurate, repeatable, and reproducible test results. This method does not carry with it the referencing ‘artifacts’ that the other two methods have. However, the one jumper method does require that the receive test head match the link under test, which means that legacy testers (with ST or SC connector interfaces) will have to be upgraded or replaced to use the one jumper method.

“Reference Grade” Patch Cords. Reference-grade patch cords are required for accurate characterization of link loss in fiber-based permanent links. These cords are typically used as consumable items in the commissioning and qualification of links (after initial installation). Reference-grade patch cords minimize Total Installed Cost by providing excellent measurement capability in the face of tight application power loss budgets required for higher speed channels.

A reference patch cord is a cord that contains connectors which minimize the mean and standard deviation of insertion loss when mated against a large population of sample connectors. These reference connectors are then connectors that have nominal optical and geometrical characteristics (Numerical Aperture and Core/Ferrule concentricity for example), such that when mated against other reference connectors produce “near zero” loss. Use of such reference grade patch cords is a necessity to assure accuracy (in referencing) and gage repeatability (replication of link tests under same reference) and reproducibility (replication of test results across multiple test sets and references).

Such cords are called for in the context of standardized test methods for measuring fiber connectors and cable assemblies (TIA/EIA-455-171A as an example) and are defined in terms of geometry and optical performance in other standards (ISO/IEC 14763-3 and TIA/EIA-455-171A Annex 'A' as examples). From ISO/IEC 14763-3 we have Table 3:

Table 3. Non-SC Reference Connector Requirements.

Requirement	Cylindrical connector style		Rectangular connector styles	
	MMF	SMF	MMF	SMF
Eccentricity of core centre to ferrule outer diameter	$<1\ \mu\text{m}$	$<0,3\ \mu\text{m}$	na	na
True position of the fibre core	na	na	$<1\ \mu\text{m}$	$<0,3\ \mu\text{m}$
Exit angle	$\leq 0,2^\circ$	$\leq 0,2^\circ$	$\leq 0,2^\circ$	$\leq 0,2^\circ$
Accuracy of ferrule diameter	$\pm 0,5\ \mu\text{m}$	$\pm 0,5\ \mu\text{m}$	na	na
Attenuation between 2 reference connectors	$\leq 0,10\ \text{dB}$	$\leq 0,20\ \text{dB}$	$\leq 0,10\ \text{dB}$	$\leq 0,20\ \text{dB}$

Note: table reproduced from ISO/IEC 14763-3.

The longevity and durability of such cords is also discussed in standards (Telcordia GR 326 as an example) with the aim of providing guidance with respect to maintenance of working reference cords. Here it is generally left to the individuals performing testing to assess the integrity of the reference cords:

From Telcordia GR-326:

8.2.4.3.3 Replacement of Testing Parts

R8-108 [192] The manufacturer shall specify the maximum number of times that reference parts are used in finished goods testing.

R8-109 [193] The manufacturer shall have a method of determining how many times the reference parts have been used in finished goods testing.

R8-110 [194] Reference cables shall be checked for wear.

R8-111 [195] The manufacturer shall specify how frequently the reference pieces are checked before the maximum number of insertions is reached.

Deciding when a reference cord is taken out of service can be best done by performing one jumper component insertion loss on all reference cord ends that interface to links under test with a 'master' cord that is purpose-built to qualify working reference cords (see best practices at the end of this paper for more information).

Sources (LED vs. Laser) – Implication on Mode Selective Losses (MSL)

Source launch conditions have proven to have a major influence on the accuracy and repeatability of optical fiber loss measurements. Because the light in graded-index multimode fiber propagates through various modes, the number of modes that are excited by the launch and the energy level in each mode affect the power measurements.

If the launch conditions are not controlled across sources, each instrument may provide a different measurement and test result, leading to uncertainty or questions regarding measurement veracity. The goal is to control the launch conditions such that test tools produce results that fall within a predictable and narrow range around the true loss value.

LEDs are the preferred light sources to test the link loss for multimode fiber links because they produce a cone of light that is evenly spread over the end-face of the fiber beyond the core, commonly called “overfilled” launch condition (see Figure 9).

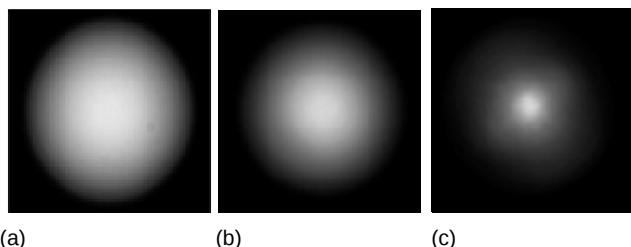


Figure 9. (a) “Overfilled” short length of fiber, fully excited by LED source. (b) “Equilibrium,” LED launch over a long length of fiber, resulting in “restricted” excitation. (c) “Restricted” VCSEL launch over a short or long length of fiber, resulting in “restricted” excitation

A laser light source including a VCSEL creates an “underfilled” launch condition. These sources shine a narrow cone of light in the center of the core. An “underfilled” launch condition may not properly detect problems in the fiber link and may consequently provide a more optimistic test result.

VCSELs have become the light source of choice for high-bandwidth network applications over multimode fiber because they meet the modulation capability to provide short pulses in rapid succession to support the associated data rate requirements. However, they are not well suited for loss testing because they may excite a different set of modes and produce a “restricted” launch condition.

The degree of overfill produces significant variations in the loss measurement. A comparison of the impact of “Restricted” vs. “Overfill” launch conditions on mated pair loss of a population of fiber connectors is shown in Figure 10 (same connectors measured with two different launch conditions).

In 10 Gigabit Ethernet transceivers that contain VCSEL sources (which result in a restricted launch condition), connector insertion loss is vastly reduced compared to the “overfilled” launch condition due to Mode Selective Losses (MSL) where higher order modes that are not present in a “restricted” launch are the main source of connector loss.

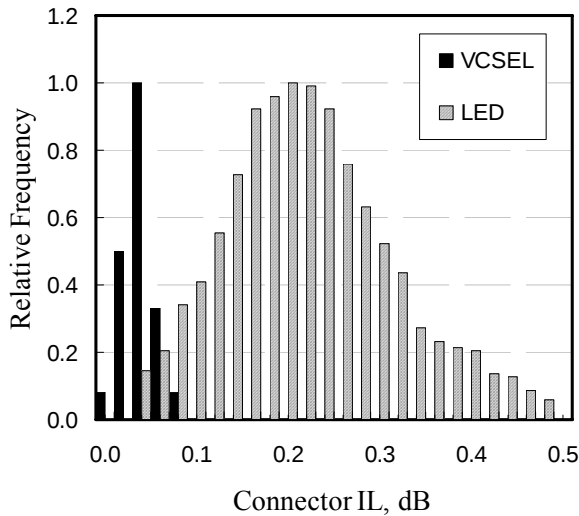


Figure 10. Comparison of the measured connector insertion loss for pre-terminated MTP cassettes using two different light sources. The two light sources result in different reference launch conditions, (1) a VCSEL restricted launch condition, and (2) an LED overfill launch condition.

Launch Conditions

To understand the impact of test launch conditions on measured channel insertion loss (IL), we must first consider how light propagates through an optical fiber. All optical fibers consist of an inner core rod surrounded by a cylindrical cladding layer, Figure 11. A key parameter that determines how light propagates (or is guided) through the core of the fiber is the difference in refractive index between the core center, $n(1)$ and cladding, $n(2)$. The refractive index is a parameter that describes the velocity of light through an optical medium. For light to be guided, the refractive index of the core must be greater than the refractive index of the cladding in order to meet the condition necessary for total internal reflection.

Due to the small core dimension, the wave nature of light, and wave interference effects, the optical power propagates through a multimode fiber along discrete optical paths called modes. The total number of modes supported by the fiber depends on the signal wavelength, fiber core diameter and the difference in core/cladding refractive indices. Typically, a MMF with a core diameter of 50 microns supports about 380 discrete modes for a single wavelength source of 850nm. Modes that occupy a spatial region close to the core center are referred to as low-order modes, whereas modes that traverse the outer regions of the core (close to the cladding) are referred to as high-order modes. To equalize the velocities of the modes and reduce dispersion effects, high bandwidth multimode fibers (MMF) such as OM3 and OM4, have graded index cores, $n(r)$, where the $n(r)$ decreases monotonically from $n(1)$ to $n(2)$ described by a mathematical power law i.e., refractive index profile (refer to Figure 11).

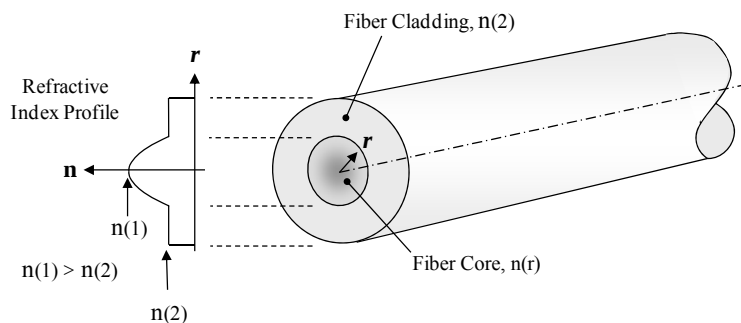


Figure 11. Multimode fiber is a cylindrical waveguide comprised of an inner core rod surrounded by a cylindrical cladding layer. The refractive index of the core decreases monotonically from $n(1)$ to $n(2)$ defined by a parabolic distribution law.

Although MMF will support many modes, only those modes that are physically compatible and spatially aligned with the launch signal are excited. Hence, not all modes are excited in an optical channel link nor do the modes carry the same amount of optical power. The power in the optical signal is split among a subset of available modes and the output power is the sum of the individual mode powers. If higher-order modes carry more optical power, then lateral fiber offsets at connector interfaces will result in high insertion loss. If only low-order modes are present, then small lateral offsets at connector interfaces contribute little IL. Consequently, the measured IL largely depends on the mode power distribution presented by the launch fiber. If the launch fiber has a fully populated mode distribution (i.e. overfilled launch condition), any difference in lateral offset between the fiber cores, will result in some of the light not being incident on the receiving fiber's core. This light will be lost into the cladding.

Alternatively, if the launch fiber only poses low-order modes confined within the inner region of the core (i.e. underfilled launch condition) the lateral misalignment may not result in optical loss since light still may be incident upon the receiving fiber's core region. Since the measured IL strongly depends on the mode power distribution, different light sources exhibiting different mode power distributions will result in different IL measurements as illustrated in Figure 10. Therefore, standard test methods must be employed to obtain reliable and reproducible measurements.

Overfilled and underfilled launch conditions correspond to how channels are both certified and operated. Channels are certified according to TIA/EIA-526-14B (OFSTP-14) which requires a nearly overfilled launch condition, while channels supporting transmission rates of 1 Gb/s and higher operate using VCSEL laser sources that generate underfilled launch conditions. Although insertion loss values realized during operation of multimode laser based systems are expected to be small, loss measurements made during the certification process on channels containing connector interfaces may include appreciable IL losses which may hinder channel certification.

Over the years, methods have been devised to define and control these launch conditions with the goal to produce repeatable and accurate loss test results. The standards established two independent metrics to characterize and control the launch conditions. They are the Coupled Power Ratio, and the recently released Encircled Flux standard, and are discussed in following sections.

Coupled Power Ratio

Coupled-power ratio (CPR), while now obsolete and replaced by Encircled Flux (EF), was an initial step in describing the Mode-Power Distribution (MPD) developed in a multimode fiber. It describes the proportion of total power in the fundamental mode of propagation normalized to the power carried in the fiber. CPR described and qualified the spatial power distributions present in emitters (primarily LEDs and VCSELs) when coupled to multimode fibers.

CPR values are defined in domestic and international standards and are used therein to establish launch condition controls necessary to reduce test set reproducibility (consistency across test sets) when measuring fiber permanent links.

“Optical Power Loss Measurements of Installed Multimode Fiber Cable Plant” (TIA/EIA-526-14A, Annex ‘A’) and “Implementation and Operation of Customer Premises Cabling - Part 3: Testing of Optical Fibre Cabling” (ISO/IEC 14763, Annex ‘A’) both define the method of test for CPR. CPR measurements are easily performed, yielding quick, quantitative results.

The first measurement (P0) is performed by connecting a reference grade MMF jumper (of the type used in the cable plant under test) to the output of the source to be used and connecting the other end to the detector, as shown in Figure 12. The second measurement (P1) is performed by disconnecting from the power meter (Input) and inserting a Single-mode CPR reference grade tail jumper between the MMF jumper and the power meter, as shown in Figure 13.

CPR is then calculated as the difference in the two power readings,

$$\text{CPR} = P_0 - P_1 \text{ (dB)}$$

High values of CPR indicate a full excitation of all modes in the fiber while lower CPR indicates more restrictive mode filling. TIA/EIA-526-14A identifies five categories of mode filling for 50/125µm at 850 nm and 1300 nm (as shown in Table 4).



Figure 12. First CPR Measurement.

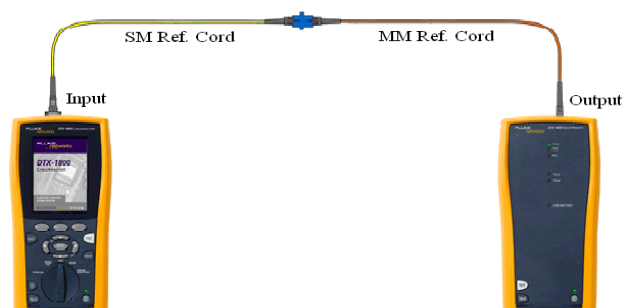


Figure 13. Second CPR Measurement.

Table 4. TIA/EIA-526-14A Mode Filling Categories

	CPR Category				
	Over-Filled  Under-Filled				
Wavelength	1	2	3	4	5
850nm	20-24	16-19.9	11-15.9	6-10.9	0-5.9
1300nm	16-20	12-15.9	8-11.9	4-7.9	0-7.9

ISO/IEC identifies a fixed requirement for 50/125µm CPR at both wavelengths as follows. In the 850nm region the CPR shall be 20.5 +/- 0.5 dB and in the 1300nm region the CPR shall be 16.5 +/- 0.5 dB. A CPR of 1 would be indicative of a 50/125 fiber excited by a LED, while single digit CPRs would indicate excitation of such a fiber by a VCSEL source.

A newer multimode launch condition metric known as Encircled Flux (EF) improves upon the CPR metric by generating fiber mode distribution conditions that include upper and lower bounds on cumulative mode filling as a function of fiber core radius, with the goal of arriving at more reproducible (and realistic) loss readings.

Encircled Flux

The newest and current parameter used to characterize the mode power distribution is Encircled Flux (EF). EF is a measure of the fraction of the total power radiating from a multimode fiber's core as a function of radius. Since the complete mode power distribution at any radii can be specified, it is an ideal metric to quantitatively appraise power distribution at large radii.

In the process of defining the best or "target EF" to be used to measure IL, competing launch conditions were considered. For example, an overly inflated EF at a particular radius essentially underfills the fiber core and, although it may provide highly repeatable results, this launch condition may underestimate the IL and may not be able to discriminate the quality of connectors with high enough resolution.

Conversely, if the EF at a particular radius is too low, the fiber core will be overfilled and thus the IL will be overestimated. Furthermore, the repeatability of IL measurements in this latter case will be compromised. Finally, the tolerance limits on the ideal EF target should not be overly burdensome to readily realize both in the factory and in the field.

The target EF, as well as the upper and lower limits on light source and launch cord EF, have been determined through a combination of comprehensive theoretical modeling and experimental measurements executed in TIA TR-42.11.[1] The EF target plus tolerance was selected to constrain the measured loss variation to the larger value of ±10 % (in dB) or 0.08 dB. The EF target is defined for all the 4 combinations of operating wavelength (850 and 1300 nm) and nominal fiber core diameters (50 and 62.5 µm). The targets are only specified at 4 radial points for 50 µm fiber and 5 radial points for 62.5 µm fiber.

An example EF template for MMF with a core diameter of 50 μm and an 850 nm operating wavelength is provided in Figure 14. Although the shaded region appears continuous, the EF target and tolerance limits for 50 μm MMF are only quantified at 4 discrete radii denoted by horizontal black bars: 10, 15, 20 and 22 μm . Other templates are defined for other core diameters (62.5 μm) and/or operating wavelength (1300 nm).

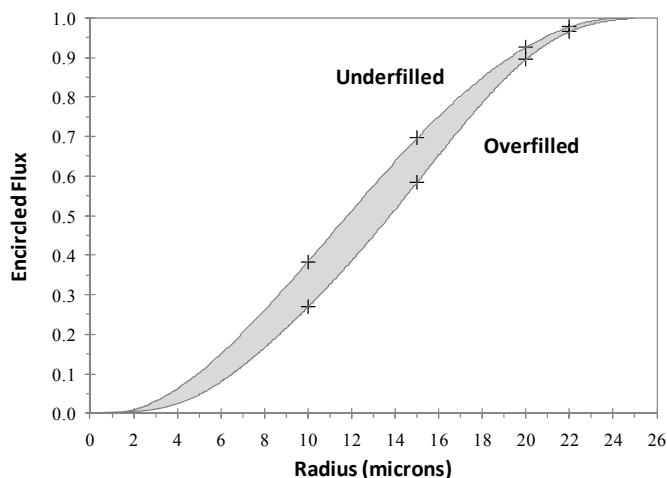


Figure 14. EF template (shaded region) for MMF with a 50 μm Core Diameter and an Operating Wavelength of 850 nm.

Types of Test Measurement Error

Propagation of Errors

The calculation of link loss is made with statistically independent power measurement results from a referencing measurement sequence and a test measurement sequence (each with associated uncertainty/error). In this case, the magnitude of the measurement 'artifact/bias' is related to the non-zero and uncertain nature of the loss of mated connector pair(s) in the reference chain (two jumper reference):

$$\text{Meas. Link Loss} = \text{Actual Link Loss} - \text{reference Bias}$$

Then the calculation itself will have error that is propagated through the calculation:

$$\text{Variance}_{\text{Meas. Link Loss}} = \text{Variance}_{\text{Actual Link Loss}} + \text{Variance}_{\text{reference Bias}}$$

Or in terms of standard deviations (s):

$$S^2_{\text{Meas. Link Loss}} = S^2_{\text{Actual Link Loss}} + S^2_{\text{reference Bias}}$$

In general, the uncertainty in the link loss value obtained as a result of this calculation is found using the propagation of errors formula above. If we use the case of a measuring a very short link with a single mated connector pair in the PL (like connector component insertion loss measurement) and we chose to measure this

link with two-jumper methods and non-reference grade patch cords of the grade in the PL, variance of the measured link loss is:

$$\text{Variance}(\text{Measured Link Loss}) = 2 * \text{Variance}(\text{Actual Link Loss})$$

Or in terms of standard deviations (s):

$$S\{\text{Measured Link Loss}\} = \sqrt{2} * S\{\text{Actual Link Loss}\}$$

This is so because the variance of the mated reference connectors in the two jumper method is equal to the variance of the IL of the connector under test. So, a two jumper reference (TIA-526-14B Annex 'C') will yield 41% more standard deviation in measurement than measurements done with no mated pairs in the reference. In general, the measured link loss standard deviation error of measurement (for the case above) will scale with the number of mated non-reference grade connector pairs (n) in the reference chain as:

$$S\{\text{Measured Link Loss}\} = \sqrt{n} * S\{\text{Actual Link Loss}\}$$

Multiple jumper referencing methods contain connectors with uncertain and variable amounts of insertion loss that propagate through the insertion loss calculation (subtraction propagation of error) and hence create additional variability. Multiple jumper referencing methods are therefore not best practice for measuring links with tight power budgets.

This is the value proposition for reference jumpers (in all cases) that serve to minimize error of measurement due to variability associated with measurement artifacts (bias).

False Fail / Pass

False fail - Link indicates fail but truly passing - This can impact the customer's ability to deploy links in a timely fashion. In this case, money is unnecessarily spent in remediating links that do not truly require as such.

False pass - Link indicates pass but truly failing - Presents link reliability issues and potential warranty claims against cabling suppliers. This is really a "Day Two" where links have been commissioned as good and begin to impinge on the signal integrity required by the communication protocol.

Both of these issues relate to the ability of the measurement system to discriminate PASS from FAIL. Such discrimination is a function of the capability (repeatability and reproducibility) and accuracy (bias due to referencing etc.) of the test set.

In a typical data center link of 30 meters of OM3 fiber terminated on each end with LC connectors, the standards (and customer) expectation of a passing link loss is roughly 1.6 dB max. A desirable measurement system will therefore reject any links above 1.6 dB and pass all links below 1.6 dB and therefore will not create any false fails or negatives in the process. Such a preferred gage is depicted in Figure 15, in terms of probability of acceptance on the vertical axis and link loss on the horizontal axis.

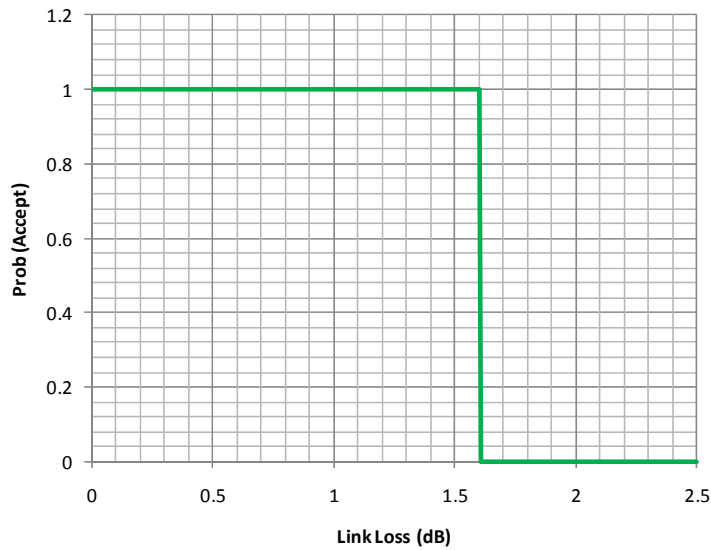


Figure 15. “Perfect” Test Set – No probability of False Errors (Fails will occur 100% of the time for link loss >1.6 dB and passes will occur 100% of the time for link loss <1.6 dB)

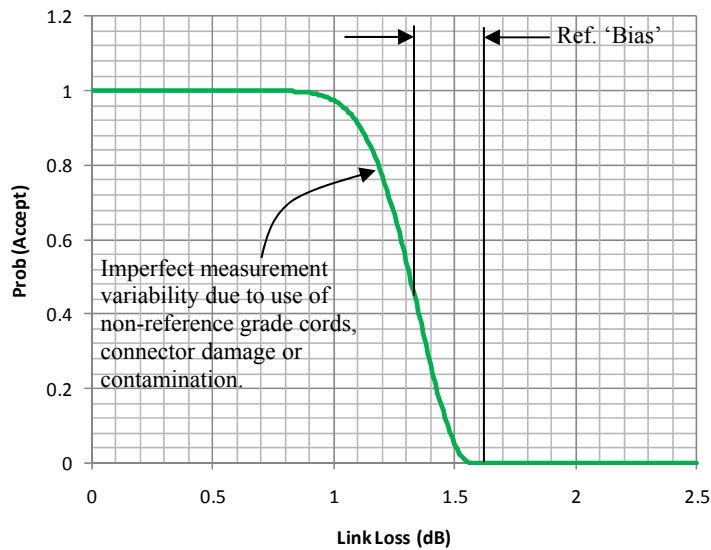


Figure 16. Referencing Bias with high Measurement Variability – Poor reference increasing probability of “False Fails” (Fails can occur even if link loss is <1.6 dB due to bias and or measurement practice)

Figure 16 is more indicative of a “real gauge” that has bias due to referencing and gauge capability that is non-ideal. The gauge capability for the gauge depicted is related to the width of the transition from $P(\text{Accept})=1$ to $P(\text{Accept})=0$; for the example in Figure 16 this is roughly 0.6 dB. The bias (due to poor referencing) is at the center of this transition and at approximately 1.3 dB (0.3 dB biased from actual).

The gauge portrayed in Figure 16 would tend to err on the side of producing many false fails (links that are really good but the measurement test set deems them as FAIL). This effect would obviously not come into play if all of the links produced were truly less than about 1.0 dB. But, for truly marginally passing links (between 1.0 dB and 1.6 dB link loss) there is increased probability of false fails.

Shifting the “Gauge Performance Curve” portrayed in the scenario above to the right would have the reverse effect and would tend to produce many false pass (again mitigated by the true level of link loss being measured by the gauge).

Negative Loss

Multiple jumper reference methods that add variability and propagate errors sometimes produce “negative loss”. These are link measurements that have poor reference practice leading to a low estimate of reference power such that when the device under test is inserted, the total power through the link being tested with the reference leads exceeds the power seen during the reference.

Figure 17 illustrates how such “negative loss” could happen in a simple example, using Method ‘A’ (two jumper referencing, only one fiber shown for clarity):

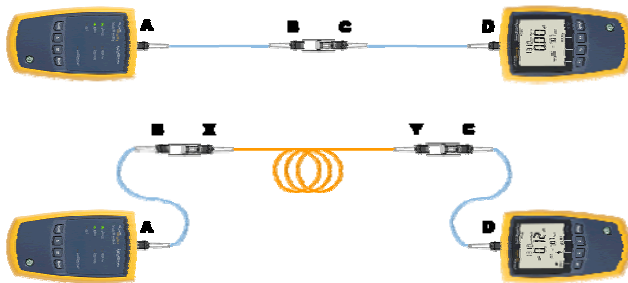


Figure 17. Example of “Negative Loss” Occurring in a Test Measurement

Reference:

Includes the loss of mated pair ‘BC’

Measurement:

Permanent link being tested is inserted between ‘B’ and ‘C’

Therefore the loss of the permanent link using 2 jumpers is:

$$\text{Link Loss} = IL_{BX} + IL_{XY} + IL_{YC} - IL_{BC}$$

Loss of permanent link connector ‘X’ mated against reference grade connector ‘B’
 Attenuation of fiber between connector ‘X’ and connector ‘Y’
 Loss of permanent link connector ‘Y’ mated against reference grade connector ‘C’
 Reference ‘Artifact’ Loss of ref. connector ‘B’ mated against ref. connector ‘C’

The following is a typical test summary for a 100ft. permanent link using the two jumper reference method:

Propagation Delay (ns)	149	
Length (ft)	100	PASS
Limit 16404		
	1310nm	1550nm
Results	PASS	PASS
Loss (dB)	-0.12	-0.08
Loss Limit (dB)	0.78	0.78
Loss Margin (dB)	0.90	0.86
Reference (dBm)	-7.07	-6.67

This particular set of results shows “negative loss” at both windows (negative loss circled in red). If the reference mated pair (‘BC’) has high loss (0.5 dB for example) and if we assume that loss is mainly a function of connector ‘C’ (which has loss related to lateral offset - fiber centering) and ‘B’ is a good reference connector, a poor reference is created that is “zeroed”, thereby setting an artificially low power baseline.

It is possible that connector ‘Y’ (one the connectors in the link being tested), when mated to connector ‘C’ exhibits significantly lower loss than the ‘reference’ mated pair ‘BC’ (i.e., the fiber in connector ‘Y’ may laterally offset in the same direction as connector ‘C’ and therefore provide better core alignment).

For this example, let’s say then that loss of YC=0.32 dB and assume that connector ‘X’ is of very good quality (say 0.06 dB). This would give a result of:

$$\text{Link Loss} = 0.06 + 0.001 + 0.32 - 0.5 = -0.12 \text{ (Gainer)}$$

It is practice when negative loss occurs to inspect and clean the reference connectors that interface with the link being tested, and then re-reference. Important to note is that the frequency of negative loss is related to both the method of test (more connectors in the reference increase probability of negative loss) and the quality of the reference leads (poor quality or degraded reference connectors increase the probability of negative loss).

Case Studies

Case Study #1: Reference Grade Jumpers

A large G500 account indicated that link failures for field installed 10G multimode fiber at one of their data centers were being uncovered during “audit testing” by a third party.

This “third party” contractor performing these tests was randomly selecting permanent links that had already been commissioned as “known good” by a different crew from the same contractor. These links contained two connector pairs and two fusion splices (in fiber trays). Small fiber count multimode premise distribution cable had been pulled into place and fusion spliced in the fiber trays to MMF pigtailed to form permanent link segments.

The Link Loss Budget for these links was set artificially low by the customer specification at around 0.8 dB (only allocated one connector @ 0.75 dB, no allocation for fusion splices and minimal contribution for fiber attenuation since these links were <50 meters in length).

The plot in Figure 18 indicates actual Fluke Networks test data for these links aligned in time along the horizontal axis (axis labeled 'Rows'). The horizontal axis indicates headroom (in dB) that is positive (passing) or negative (failing) about a headroom baseline of zero (green dashed line).

The arrows on the plot indicate significant lapses in time of the original testing (date and time stamping off of the Fluke Networks DTX 1800 Cable Analyzer units). It is practice to re-reference the meters after shift change, start up, etc. so these are indicative of re-referencing events. Interesting to note is the marked shift in average headroom after re-referencing. Poor referencing (low power) can lead to false high headroom values, 'negative loss' and increased headroom variability.

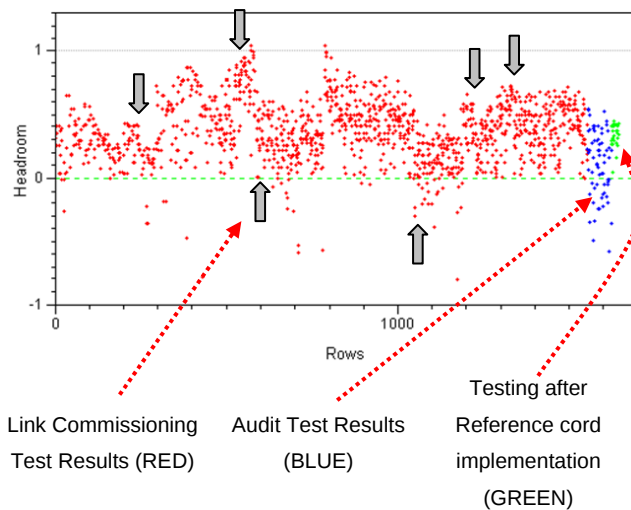


Figure 18. Plot of Headroom vs. Time

Figure 18 shows that only about 5% of the links failed the original link commissioning testing (RED) with negative headroom and that the average link result between the two test crews (for the same links, see below) yields significantly different results (>0.3 dB on average).

Figure 19 shows the following:

- Significant difference in average headroom between Audit and Commissioning permanent link tests
- Extremely poor reproducibility > 1 dB (based on 5.15 sigmas)
- Variability due to reproducibility (between test crews) and repeatability (within test crews) consumes the 0.8 dB power budget

The customer "blew the alarm" when the sampling done by the crew performing audit testing indicated that roughly 40-50% of the links were failing testing (BLUE) with negative headroom.

Mapping the measurements of links that were sampled by this crew against the original results for those same links, we would expect that for a capable and repeatable measurement process there would be strong correlation between these paired measurements. However, there is absolute lack of correlation between 1st measurements and the audit results (see Figure 20).

The blue line shown is the expected line that would indicate exact reproducibility of tests (samples would fall on this line). The scatter of points about this line is actual commissioning and audit test measurements plotted against each other.

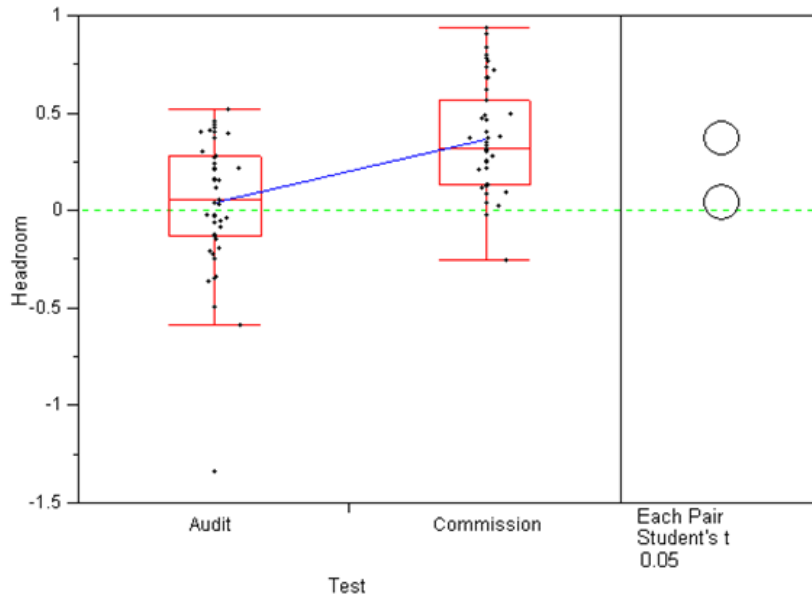


Figure 19. Box Whisker plot of Audit vs. Link Commissioning Test Results for Randomly Selected Links

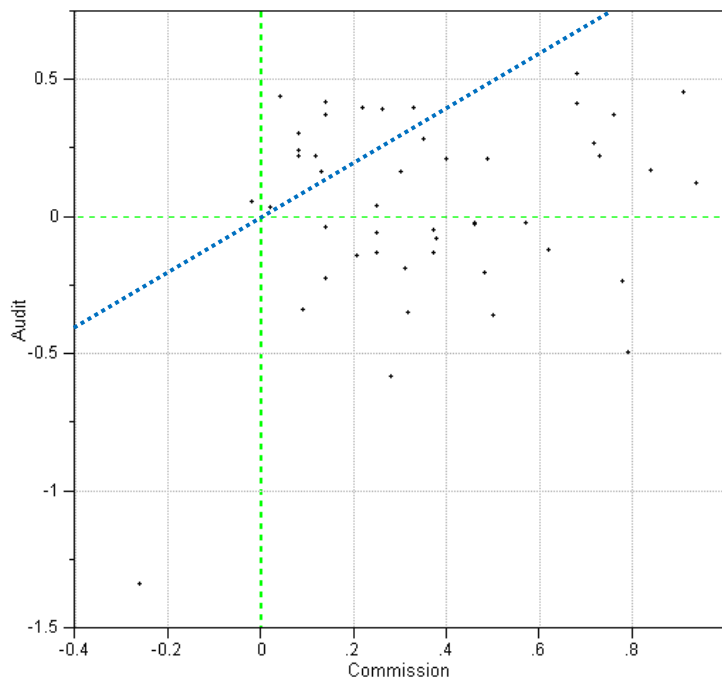


Figure 20. Plot Correlating First Commissioned Measurements against Audit Results

Expectation - Here the belief is that there will be a strong linear relationship between the audit and commissioning test results and the ability to reproduce (and predict) one from the other.

Result – Poor relationship exists between tests (random) and no ability to effectively predict one from the other.

All audited links were retested with the best practices outlined at the end of this document, with the main change being the use of reference grade test jumpers. As a result of this, all of the links that were audited passed headroom specifications and demonstrated about a quarter of the variability of both previous test efforts (shown in GREEN in Figure 18).

This customer has since adopted these test practices globally that have significantly mitigated issues with their own requirements to test beyond the standards requirements (as previously stated).

Case Study #2: Cleaning and Inspection Best Practices

A large government account indicated that they were encountering such a high failure rate of link failures for pre-terminated, cassette-based 10G multimode plug and play fiber product at their data center, that testing was halted until root case was found and rectified (50-60% failure rate of links before testing was stopped).

Raw test data from Fluke Networks DTX 1800 Cable Analyzer testers was examined by rack unit numbering against the failure rate of links. Racks were tested in sequence by the rack unit numbering sequence:

- KK01/SK02 Units tested first on 5/6/09 - 9.08am
- KK13/SK12 Units tested last on 5/13/09 - 9.01am
- Patching units between KK01/SK02 and KK13/SK12 tested in sequence

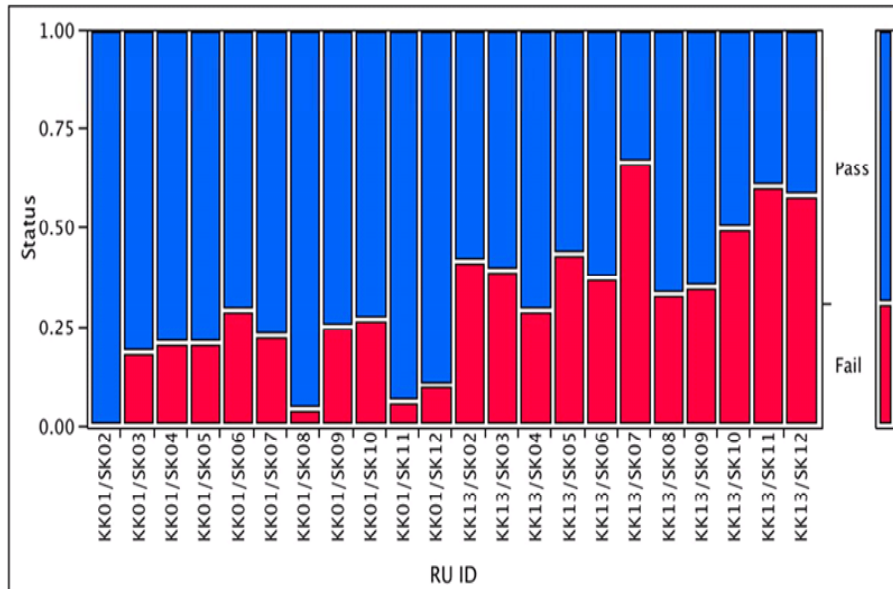


Figure 21. Plot Showing Link Fail Rate (% in red) and Link Pass Rate (% in blue) vs. Rack Location Code

Notes:

1. Scale "status" is link failure probability (1 = 100% failures)
2. Red is coded as percentage of link failures for a given link location
3. Blue is coded as percentage of link passes for a given link location
4. Testing sequence progress in time is left to right along the horizontal axis

Figure 21 shows dependence of link failure rate on time stamping data from Fluke Networks DTX 1800 (coding of link endpoint IDs matched to time stamp - time stamps line up with rack unit numbering sequence as shown in the plot). The plot indicates that the link failure rate went from 0% to roughly 50% of the fibers being tested over the space of the time of testing (the first 60-something fibers tested in sequence all passed).

It is highly unlikely that products could have been supplied that would produce such a linearly increasing failure rate. The conclusion here is that this is not 'nature' or related to natural variation of the product. We believe that there are systemic testing issues at play here (possibly damaged reference cords or the like).

All discrepant links were retested with the best practices outlined at the end of this document with the main change being inspection, cleaning and test of reference patch cords. As a result of this all of links that were that previously failed (as indicated in the plot) passed with significant headroom to the standard when retested.

This customer has since adopted these cleaning and inspection practices on reference patch cords and links under test, and this has had significant impact on their measurement capability and stability of measurements in particular.

Cost Implications

Costs involved in the installation of fiber structured cable systems can quickly escalate if best practices in preparation, installation, test/measurement, troubleshooting and remediation are not followed. There are many factors affecting Total Installed Cost (TCO) related to each process step involved in infrastructure installation.

Installation

The single largest contributor to the variability of TCO in the installation phase of PL installation is related to the efficacy of fiber connectorization in the field. The capability of the personnel performing the field terminations and the intrinsic insertion loss capability (and native distribution of insertion loss) of the chosen connector system are determining factors in "First Pass Yield" (FPY is the % of connectors that are "known good" after the first connectorization attempt).

FPY obviously affects the amount of re-test and remediation required and also the quantity of good connectors cut off in error in the case where Tier II testing is not available. Remediation requires new connector units to be on hand and hence proper estimating for such prior to the installation. Depending on the type and quantities of links and connector ends that are deemed discrepant, the cost of troubleshooting, remediation and test labor typically dominates over the costs associated with additional connector piece parts and consumable items.

Test/Measurement

Poor measurement capability of installed links can lead to bad decision making in the link commissioning process. As discussed earlier, the type of referencing used, quality of the reference leads deployed and the practices of cleaning and inspecting connector ends can directly impact link loss measurement integrity and hence TCO.

Standard quality jumpers when mixed with multiple jumper referencing methods (TIA-526-14-B Annex 'B' and Annex 'C') and poor test/measurement cleanliness are a recipe for false fails (links that fail but are truly passing) and false pass (links that pass but are truly failing). False fails immediately impact TCO as remediation and re-test are therefore required (this is usually absorbed by the contractor and hence may or may not be passed on to the customer). False pass, if severe enough, will cause link performance issues when the channels are in service (this costs both the customer in troubleshooting time and possibly the contractor who would have to return to remediate the links).

Conclusion / Best Practices

- a) Use precision or reference grade launch jumpers in all cases. Make sure that mechanical and optical characteristics of these conform to local standards.
- b) Use TIA-526-14-B Annex 'A' (one jumper method) as the default method of validating permanent link performance for data center links with multimode fiber. Test equipment (receive head) must be equipped with link under test connectors.
- c) Use FOTP 171 (one jumper method) to qualify precision jumper connectors on a component basis (instead of a fixed number of mating cycles).
- d) Verify IL of reference cords on a 'schedule' and when reference cords are in question.
- e) Use Encircled Flux launch conditioning cords (or mandrel wraps) per test equipment manufacturers' guidelines to produce standards compliant launch conditions.
- f) Bidirectional testing for simple channels/links does not add value and only increase probability of erroneous link failures when links/channels are near loss limits. Only perform such testing if end customer requires this, or if different fiber technologies are mixed in the links.
- g) Be sure to allocate the actual number of mated pairs of connectors present in link into the link power budget (measured against reference connectors), irrespective of link measurement technique chosen.
- h) Adhere to good cleaning and inspection practices as outlined in connector component and test equipment manufacturers' guidelines - "When in doubt, clean it".

Best Practice documentation regarding link test and measurement methods are available on the Fluke and Panduit web sites, and are listed below:

"Visual Inspection and Cleaning of MM and SM SCS Interconnect Components"

www.panduit.com/groups/MPM-OP/documents/BestPractice/109063.pdf

"Fiber Testing Best Practices"

<http://www.flukenetworks.com/inet/en-us/featuredTopics/Fiber+Test+Best+Practices.htm>

"Cleaning Fiber Optic Connectors and Ports"

<http://www.flukenetworks.com/fnet/en-us/supportAndDownloads/KB/Fiber-Testing/DTX-xFM2+Fiber+Adapters/Cleaning+fiber+optic+connectors+and+ports.htm>

“Reference Values You Can Expect with the DTX-MFM2, GFM2 and SFM2”

<http://www.flukenetworks.com/fnet/en-us/supportAndDownloads/KB/Fiber-Testing/DTX-xFM2+Fiber+Adapters/Reference+values+you+can+expect+with+the+DTX-MFM2+GFM2+and+SFM2.htm>

“Test Reference Cord Verification for SC to LC Patch Cords using the DTX-xFM”

<http://www.flukenetworks.com/fnet/en-us/supportAndDownloads/KB/Fiber-Testing/DTX-xFM+Fiber+Adapters/Test+reference+cord+verification+for+SC+to+LC+patch+cords+using+the+DTX-XFM.htm>

“ANSI/TIA-568-C Testing SC to SC (Duplex Multimode) DTX-MFM”

<http://www.flukenetworks.com/fnet/en-us/supportAndDownloads/KB/Fiber-Testing/DTX-xFM+Fiber+Adapters/ANSITIA-568-C+testing+SC+to+SC+Duplex+Multimode+DTX-MFM.htm>

“Permanent Link Testing of Multimode and Singlemode Fiber Optic Cabling Systems”

www.panduit.com/groups/MPM-OP/documents/BestPractice/110255.pdf

“Insertion Loss Performance Testing of 10 Gb/s Fiber Patch Cords for High-Speed Networks”

http://www.panduit.com/groups/MPM-OP/documents/TechnicalPaper/CMSCONT_034720.pdf

“Encircled Flux or EF - DTX xFM2 Series”

<http://www.flukenetworks.com/fnet/en-us/supportAndDownloads/KB/Fiber-Testing/DTX-xFM2+Fiber+Adapters/Encircled+Flux+or+EF+-+DTX+xFM2+Series.htm>

Referenced Standards

- ANSI/TIA 568-C “Generic Telecommunications Cabling for Customer Premises”
- EIA-455-171 (FOTP 171) “Attenuation by Substitution Measurement for Short-Length Multimode Graded-Index and Single-Mode Optical Fiber Cable Assemblies
- ISO/IEC 11801 “Information technology – Generic cabling for customer premises”
- ISO/IEC 14763-3 “Implementation and Operation of Customer Premises Cabling - Part 3: Testing of Optical Fibre Cabling”, 2006
- TIA-526-14-B “Optical Power Loss Measurements of Installed Multimode Fiber Cable Plant”
- TIA TSB-178 “Launch Conditions Guidelines for Measuring Attenuation of Installed Multimode Cabling”, 2008.

About Panduit

Panduit is a world-class developer and provider of leading-edge solutions that help customers optimize the physical infrastructure through simplification, increased agility and operational efficiency. Panduit's Unified Physical InfrastructureSM (UPI) based solutions give enterprises the capabilities to connect, manage and automate communications, computing, power, control and security systems for a smarter, unified business foundation. Panduit provides flexible, end-to-end solutions tailored by application and industry to drive performance, operational and financial advantages. Panduit's global manufacturing, logistics, and e-commerce capabilities along with a global network of distribution partners help customers reduce supply chain risk. Strong technology relationships with industry leading systems vendors and an engaged partner ecosystem of consultants, integrators and contractors together with its global staff and unmatched service and support make Panduit a valuable and trusted partner.

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About Fluke Networks

Fluke Networks provides innovative solutions for the installation and certification, testing, monitoring and analysis of copper, fiber and wireless networks used by enterprises and telecommunications carriers. The company's comprehensive line of Network SuperVisionTM Solutions provide network installers, owners, and maintainers with superior vision, combining speed, accuracy and ease of use to optimize network performance. Headquartered in Everett, Washington, the company distributes its products in more than 50 countries.

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