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Fiber Optic System Testing Tutorial

AEN 135, Revision 4

This Applications Engineering Note (AEN 135) explains and recommends standard measurement methods for characterizing optical fiber system performance. This note also provides background information on system link configurations, test equipment and system component considerations that influence overall system performance.

System Configuration

Fiber optic systems include both passive components and active electronics. Passive components consist of all the links and connections that unite communication devices on the overall network. System performance is typically evaluated on an individual link basis between any two given nodes of the network. A fiber optic link is usually terminated on one or both ends by adapters, or "patch panels" that physically serve to connect the transmit and receive ports on a network communications channel. Patchcords or equipment jumpers are used to bridge the network electronic ports to the fiber optic link contained between patch panels (also known as "cross-connects"). **Figure 1** below symbolically depicts the fiber optic link over which testing is typically carried out.

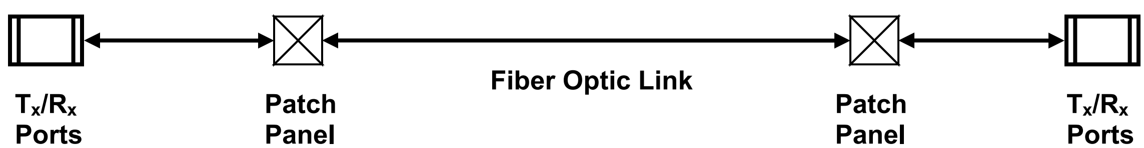

Figure 1: Fiber Optic Link Schematic

System Performance

System performance pertains to any measurable specification that characterizes a given communication network's capabilities. In the context of fiber optic testing, this term is usually applied without deference to any specific set of network electronics. In other words, when a fiber optic link's performance is evaluated, it is only the passive components that are evaluated. The assumption is that whatever network electronics are eventually connected to the fiber optic link will support the required network application and/or protocol (as determined by the network owner or customer). The decision of which network applications and/or protocols need to be supported by the passive fiber optic network should be made during the network planning stages of the design (prior to the actual installation). Additionally, the correct fiber type should also be determined during these initial planning stages. Please consult AE Note 75 ("Multimode Optical Fiber Selection & Specification") for more information. When a fiber optic system is successfully tested and determined to meet the customer's specific requirements and relevant industry standards, the system performance and individual links can be said to be "certified" to that relevant specification or

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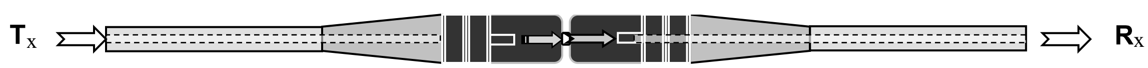
standard.

Insertion Loss (Connector, Splice & Link)

The passive fiber optic link may include the following components: 1) fiber optic cable, 2) fiber optic connectors, 3) fiber optic adapters, 4) fiber optic splices and 5) fiber optic “hardware” (housings and connector panels). It is only items one through four for which system performance can be determined using conventional test equipment. Connectors and adapters deserve particular attention in that they cannot be tested individually. When characterizing “connector” loss it must be realized that a measurable connector “insertion loss” value can only occur when two connectors are inserted into a fiber optic adapter (also known as a “sleeve” or “bulkhead”) forming a connection or connector pair. To borrow an analogy from another field, “it takes two to tango”. When measuring insertion loss, we are interested in how much light is lost when a signal crosses or passes through components between a transmitter and receiver (**Figure 2**). This is analogous to quantifying the amount of water that leaks through a coupling connecting two sections of pipe together. This can apply across a single connection or across an entire link. Discrete connector loss evaluation, however, is not a recommended practice nor a requirement for determining overall link performance. In other words, we are only interested in how much water leaks out of the plumbing from source (transmitter) to tap (receiver).

Insertion Loss: Connector Pair

$\mathbf{P_{In}} \ \mathbf{>} \ \mathbf{P_{Out}}$ **{** $P_{Out} < P_{In}$, I.L > 0.0 dB**}**



*Adapters omitted for clarity.

Insertion Loss: Single Connector

$\mathbf{P_{In}} \ \mathbf{=} \ \mathbf{P_{Out}}$ **{** $P_{Out} = P_{In}$, I.L = 0.0 dB**}**

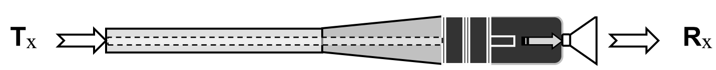


Figure 2: Measuring Insertion Loss*

When a fiber optic connector is plugged directly into an electronics port (“transceiver”) it is generally considered that optical loss is **not** occurring at this junction. The reason for this is simple- light is not crossing or passing through a component in which light can leak out of the channel. At the transmitter end, all the light that enters the connector is, for all intents and purposes, the maximum amount of power that can and will exist in the channel, and at the receiver end all of the light that exits the connector is received by the detector. When patch panels are omitted at either one or both ends of the link, this means that the optical link or trunk is terminated directly into end equipment, thereby subtracting the contribution of that connector pair from the link loss measurement.

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Attenuation & Bandwidth (Optical Fiber & Cable)

Optical fiber performance is another system parameter that can be characterized in isolation from the rest of the system, and it is here that the terms attenuation and bandwidth find their way into discussions on system performance. Attenuation is the amount of optical power loss (dB) that occurs per unit of distance (km) in optical fiber. Attenuation is also a specification that is included in the fiber manufacturer's data or specifications sheet. It is measured by the optical fiber (and cable) manufacturer but can also be field-tested and verified. However, individual fiber attenuation is not a requirement for evaluating overall system performance because it is implicitly included in any "end-to-end" insertion loss measurement that is carried out across the fiber optic link.

Bandwidth is the information carrying capacity of an optical fiber and is also determined and specified by the optical fiber manufacturer. However, bandwidth testing is not practically performed in the field (nor is it required/recommended). Please consult AE Note 81 ("Multimode Optical Fiber Bandwidth Characterization") for more information. Single-mode dispersion is likewise not field-characterized, but rather manufacturer specified.

Return Loss (Optical Channel)

In addition to insertion loss, overall system performance can also be field-characterized according to return loss. Return loss (dB) is a measure of how much power is reflected back to the source from all reflective events in the fiber optic link relative to how much power was launched into the link. This includes discrete reflective events such as connector pairs, as well as the inherent backscatter of the optical fiber. Today's digital communications are usually immune to such reflections but return loss characterization may be required in analog systems (RF video communications) or in situations where field-polished connectors were installed. Return loss is often measured through the use of an optical time domain reflectometer (OTDR). Please consult AE note 33 ("OTDR Return Loss Measurement") for more information.

In summary, system performance can usually be characterized by end-to-end insertion loss measurements alone. Prevailing measurement methods include source-meter end-to-end loss measurements, as well as optical time domain reflectometer methods. The remaining sections of this document discuss these methods and best practices for accurate system certification.

System Link Loss Budget

Prior to commencing with the actual system test it is necessary to determine the link loss budget. The link loss budget ultimately determines whether the system was correctly installed. It is assumed that the link loss budget will be within the channel loss requirements for the specific network application or protocol to be implemented. *This should have already been determined in the network planning stages or is verified by the customer or network owner.* Determining the link loss budget is a relatively straightforward calculation that involves adding up all the loss limits found in the fiber optic link. If abiding by ANSI/EIA/TIA recommendations, this typically includes the insertion loss of two connector pairs (one at each end of the link) and the optical fiber attenuation, and any splice loss in between. Corning Optical Communications provides a budget calculator on-line at the following address:

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https://www.corning.com/optical-communications/worldwide/en/home/Resources/system-design-calculators/link-loss-budget-calculator.html

End-to-End Loss Measurements

Corning Optical Communications' recommendations for end-to-end insertion loss testing are derived from both industry standards, as well as generations of direct field experience and best practices. Corning Optical Communications has underwritten many of the industry standards in place today. Relevant standards include (but are not limited to) the following:

- ANSI/TIA-568, "Commercial Building Telecommunications Cabling Standard"
- ISO/IEC 11801, "Information technology – Generic cabling for customer premises
- IEC 61280-4-1, "Fibre-optic communication subsystem test procedures – Part 4-1: Installed cable plant – Multimode attenuation measurement"

The recommended measurement method for end-to-end link testing is the single-jumper (or "one-cord") reference method (with mandrel wrap for multimode). This test configuration is depicted below:

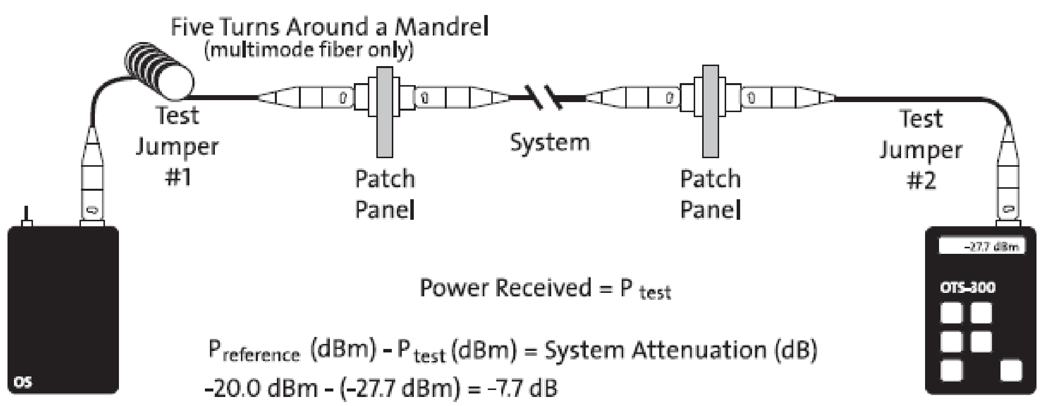

Figure 3: One-jumper End-to-end test

The test configuration depicted in **Figure 3** includes a test source on one end (which generates the light signal), and a test meter on the opposite end (which receives the light signal). In addition, it is interesting to note that two test jumpers are included in this configuration despite it being referred to as a "One-jumper End-to-end Test". The reason for this name is that only a single jumper (1 to 5 m long) is included in the initial reference of the test source to the test meter. Prior to commencing with an end-to-end test, it is important to communicate to the meter how much light is actually emanating from the source. This sets the base-line expectation for how much light (optical power) the meter should expect to see or receive. Reverting back to our plumbing analogy, if one wanted to determine how much water was leaking out of the network of pipes from one end to the other, one would have to first know how much water was flowing into one of the pipes. Because it is not practical (or mechanically feasible) to couple the output port of the source to the input port of the meter, a single patchcord is used to accomplish this.

The decibel (dB)

Once the reference jumper is connected between source and meter, a number should display on the meter that indicates the amount of power reaching the meter. This number initially will show up in terms of "dBm" (assuming the meter has not previously been referenced, or "zeroed out"). A dBm is an "absolute" power measurement that is another way of expressing the number of milliwatts of optical power reaching the meter. Mathematically, let's explore what this means in terms of the decibel (dB):

$$dB = 10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

The above equation simply expresses a "decibel" as the ratio or comparison between the power injected into the fiber optic link (P_{in}) and the power that exits the fiber optic link (P_{out}). This ratio is then converted to a logarithmic scale to facilitate data entry. For example, rather than speaking in terms of a 50% power drop across a given link, the loss is characterized as 3.00 dB. During the initial jumper referencing, the meter is actually reading P_{out} from the connector directly coupled to it and is not directly measuring the power coupled into the connector at the source. A value of 1 mw is therefore arbitrarily assigned to P_{in} (the actual value cannot be directly determined). This is what a dBm represents. Figure 2 provides some example numbers encountered during a typical jumper referencing.

One-Jumper Reference

Once the initial base-line value is established, it is not required to "zero out" the test jumper. "zeroing out" means to set or clear the meter display to zero. Alternatively, the base-line value could simply be written down and subtracted from any subsequent test measurements made. Fortunately, most conventional test sets today allow this number to be stored in memory and clear the display, essentially performing the subtraction for the technician. After the test source and meter have been connected together, and the reference button pressed, the test equipment has essentially been "referenced out". Following completion of this step, the system link can now be tested and the total insertion loss across the link determined. However, testing a fiber optic link between two patch panels usually necessitates adding a second jumper between the meter and one of the patch panels. Therefore, it is general practice to verify that this second test jumper is within specification prior to network connection. It is important to not disconnect or disturb the connection between the source and its respective patch cord, when connecting the second test jumper to the meter, as this could invalidate the initial reference value.

Two- and Three- Jumper References

The goal of performing two- or three- jumper references is to discount the contribution of either one or two connector pairs that are part of the test configuration, but that don't exist in the actual system channel (i.e. a one or zero patch panel configuration). In a two or three jumper reference, two or three jumpers are connected in series between the source and meter prior to the referencing out of the test set. Referencing the test set in this manner simply subtracts (or "pads") whatever arbitrary loss value happens to exist in that reference configuration over-and-above the value that would exist in a single-jumper reference. In a two-jumper reference, the two patchcords are disconnected, and the source and meter are

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connected to opposite ends of the link with their respective jumpers still attached. The procedure for a three-jumper reference is similar, except that the middle jumper is removed completely from the test configuration following the jumper referencing.

Jumper Reference Selection & Considerations

Fiber optic links that do not terminate in patch panels on either one or both ends do **not** invalidate the one-jumper reference test method. Interpretation of test results requires additional consideration, however. Recall that insertion loss only has meaning when evaluating how optical power is lost when crossing from one point to another in a fiber optic link (**Figure 2**). This could occur across a connector pair, a splice or entire length of fiber. For example, it is meaningless to quantify the contribution of a single connector to an insertion loss measurement, as insertion loss measures loss encountered across the connection. It is also misleading to attempt to subtract the contribution of a single connector from a link loss measurement during the initial jumper reference set-up.

When performing two- (or three-) jumper references, the implied intent is to subtract the contribution of the patch cord(s) used at one (or both) end(s) of the system. More specifically, the implied goal is to present link loss values that represent what the installed system electronics will eventually experience. The two- or three- jumper reference cannot duplicate this configuration exactly, because it references out insertion loss values that only apply during the test jumper configuration. When the jumpers are disconnected, the individual test jumper connectors mate up with different connectors (in the system link) that may or may not generate the same I.L. values that occurred during the test reference. Such an approach has the potential to arbitrarily affect test results.

For example, in a hypothetical two-jumper reference, only an additional 0.1 dB of loss might be referenced out, if the jumpers are exceptionally good. When the system link is tested, however, the test jumpers connect to different connectors that may cumulatively generate 1.6 dB of loss. If the 0.1 dB that was referenced out is included, the overall loss will show up as 1.5 on the meter (ignoring fiber loss- assume a short link). Technically, this is within TIA specifications (at 0.75 dB per connector pair). However, it is very likely that the customer will supply different jumpers that generate losses higher than the 0.1 dB observed during test. Most likely when the customer repeats the testing, it will be discovered that the link loss reading is higher than 1.5 dB now! Conversely, if exceptionally bad, or high, test jumpers are referenced out, the system test will be padded by an unrepresentative amount, increasing the likelihood of passing product that is not truly in conformance with either vendor specifications or industry standards.

Recommended Practices

It is the recommendation of Corning Optical Communications that a single-jumper reference be used to certify any fiber optic system. Even in links where there is not a patch panel established at one or both ends, it is still desirable to evaluate the link connector that plugs directly into a system electronics port. If the measured value needs to be adjusted to more fully reflect the channel loss, it can simply be recommended that the customer subtract a representative connector pair loss value from the system results, where “representative” means a maximum (or typical) loss value associated with that particular type of connector. Plugging the system link connectors directly into the test equipment (and bypassing test jumpers altogether) is another possibility, but not recommended, because it fails to certify all

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link components.

Mandrel Wrapping

Although omitted in previous discussions for clarity of explanation, **Figure 3** depicts what is known as a "Mandrel Wrap" on the reference test jumper that is connected directly to the source. Both industry standards and Corning Optical Communications recommend the use of a mandrel wrap to ensure that a stable and consistent launch is established in the initial test configuration and jumper referencing for multimode system characterization. **Figure 4** below provides Corning Optical Communications' recommended mandrel diameters for relevant optical fiber types. Please refer to AE notes #68 "Improving Multimode Fiber Testing Accuracy with Mandrel Wrapping", and #131 "Multimode Fiber Considerations for Test Jumpers" for more detailed information on mandrel wrapping and test set launch conditions.

Fiber Core Size	**Mandrel Diameter for 3 mm (0.12 in) cable**	**Mandrel Diameter for 2 mm (0.08 in) cable**
50 µm (Standard OM2/OM3) at 850nm and 1300nm	22 mm (0.87 in)	N/A
50 µm (ClearCurve® multimode OM2/OM3) at 1300nm	N/A	22 mm (0.87 in)
62.5 µm at 850nm and 1300nm	17 mm (0.67 in)	

Figure 4: Mandrel Size Recommendations

Test Equipment Selection

Selecting the appropriate equipment for the system test is another important consideration. Corning Optical Communications supports the current test procedures of TIA/EIA-568-B.1 which advocates the One Reference Jumper Method specified by ANSI/TIA/EIA-526-14A, Method B for multimode systems and ANSI/TIA/EIA-526-7, Method A.1 for single-mode systems.

For **multimode systems**, this includes the following:

1) A "Category 1" light source (as defined by OFSTP-14), which is represented by most commercially available LED sources with an "overfilled launch" condition that is capable of producing the following wavelengths: 850 nm (±30) and 1300 nm (±20) with the following spectral widths, respectively: 30-60 nm and 100-140 nm.
2) An optical power meter capable of measuring relative or absolute optical power for the relevant system wavelength (either 850 nm or 1300 nm) and that is independent of the modal distribution.
3) Test jumpers with core diameters and numerical apertures that match those of the fiber in the link being measured. The jumpers should be 1 to 5 m long (max) and possess connectors compatible with the light source and system. A mandrel wrap (AEN 131) should be used on the jumper connected to the test source.
4) Other equipment required includes relevant jumper adapters for test referencing, cleaning materials (reagent-grade isopropyl alcohol, lint-free wipes, compressed air, cleaning wands, etc.), and a connector end-face scope to eliminate suspect jumpers from the test configuration.

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For **single-mode systems,** this includes the following:

1) An optical source with an operation wavelength (typ. 1310/1550 nm) matching that of the system. Typically, such test sources employ a Fabrey-Perot type laser.
2) An optical meter capable of measuring optical power over an absolute dynamic range at the wavelength(s) of light used in the test. The meter should be calibrated per industry standards.
3) Test jumpers with fiber that has a mode field diameter that matches that of the fiber in the link being measured. The jumpers should be 1 to 5 m long (max) and possess connectors compatible with the light source and system.
4) Other equipment as mentioned above.

For more detail on Corning Optical Communications' and Industry Standard recommendations for End-to-End testing and equipment, please consult the following AE Notes:

- AEN098, "Measurement Variability during Field Insertion Loss Testing."
- AEN100, "Insertion Loss of Multimode Optical Components - Variation across Wavelengths and Source Types"
- AEN104, "Standards Compliant Optical Test Equipment and Test Procedures."
- AEN109, "Link Attenuation Testing Tutorial w/ case study OptiTap Jumpers for FTTX"
- AEN116, "Multimode Cable Assemblies – Factory & Link Loss Testing."
- AEN131, "Multimode Fiber Considerations for Test Jumpers."

OTDR Measurements (Discrete Event & Trace Analysis)

The optical time domain reflectomer (OTDR) presents another method for analyzing fiber optic link attenuation and insertion loss. An OTDR sends short duration pulses of light down an optical fiber and measures the backscattered power as a function of propagation time delay or length along the optical fiber. An OTDR also allows discrete analysis and the individual determination of insertion loss for connector pairs, splices and other sources of attenuation in the fiber optic link. For a more complete explanation of how OTDR's are used and how they work, please consult AEN 134, "OTDR Testing Basics".

OTDR measurement methods are currently only advocated in IEC 61280-4-1 ("Fibre-optic communication subsystem test procedures – Part 4-1: Installed cable plant – Multimode attenuation measurement") for multimode systems. It is Corning Cable System's recommendation that OTDR testing should not be the primary measurement method for certifying overall fiber optic link loss, as it is not a direct measurement of the amount of optical power that exits a fiber optic link. Rather, it is an inferred measurement of this power based on a comparison between reflected power levels at opposing ends of the link. OTDR testing does not require jumper referencing in the traditional sense but does require the use of an "access jumper" on both ends of the link for proper trace analysis. Refer to **Figure 5** for a typical test configuration and representative trace.

OTDR testing should be used to corroborate previously determined test results (per a conventional source-meter test set) and/or to perform troubleshooting and subsequent discrete fiber optic component analysis.

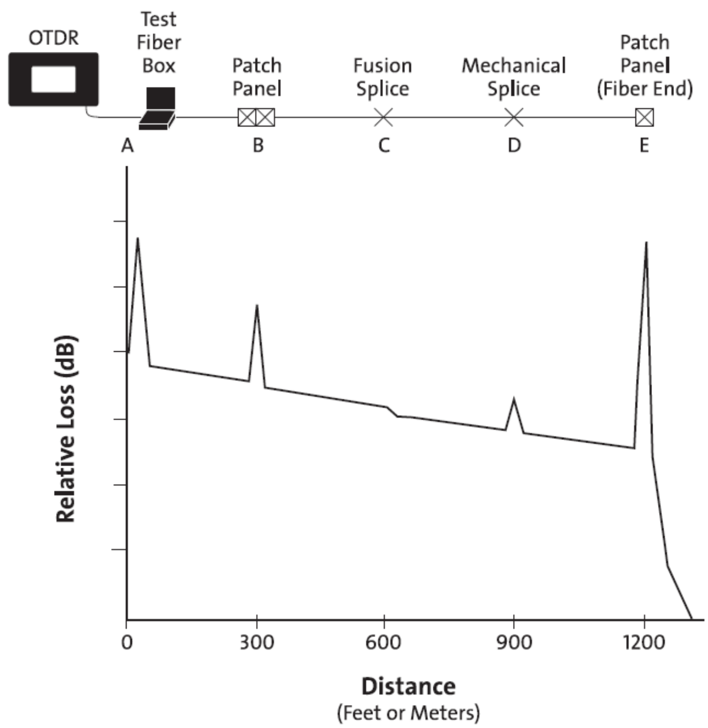

Figure 5: OTDR Test Configuration & Trace

Summary of Recommendations

Figure 6 below presents Corning Optical Communications' recommendations for testing any fiber optic link with required equipment (system-specific adapters not included):

Fiber Optic Link Testing Recommendations			
Test Method	**Backbone (Cabling Subsystem 2 or 3**)**	**Horizontal (Cabling Subsystem 1*)**	**Equipment Required**
End-to-End Attenuation (Required)	Unidirectional: ● MM: **850** or 1300 nm ● SM: 1310 & 1550 nm	Unidirectional: ● MM: **850** or 1300 nm ● SM: **1310** or 1550 nm	● (1) Optical Meter ● (1) Optical Source ● (2) Test Jumpers ● (1) Mandrel (MM)
OTDR Test (Optional for Inside Plant)	Unidirectional (trace only): ● MM: 850 or 1300 nm ● SM: 1310 & 1550 nm Bidirectional/dual wavelength as required.	Troubleshooting as required for links exceeding link loss budget.	● (1) OTDR ● (1) Test Fiber Box (or Access/Launch Jumper)
Discrete Connector & Splice Loss	As required per client/ customer contract.	Troubleshooting as required.	● (1) OTDR ● (1) Test Fiber Box

*As defined by ANSI/TIA-568-C.0, Cabling Subsystem 1 represents the cabling between the DA ("Distributor A"), also known as the HC ("Horizontal Cross-connect") and the EO (Equipment Outlet).
** As defined by ANSI/TIA-568-C.0, Cabling Subsystem 2 represents the cabling between the DB ("Distributor B"), also known as the IC ("Intermediate Cross-connect") and the DA; Cabling Subsystem 3 represents the cabling between the DC ("Distributor C"), also known as the MC ("Main Cross-connect") and the DB.

Figure 6: Corning Optical Communications Fiber Optic Link Testing Recommendations

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Although ANSI/TIA-568-C.0 and ISO/IEC 11801 both stipulate testing at both wavelengths in the backbone cable, please note in the above table that Corning Optical Communications only recommends single wavelength testing, in particular at 850 nm. The reason for this is that 850 nm is the predominant wavelength of relevance in prevailing VSCEL-based telecommunication networks that utilize multimode fiber. Testing at 1300 nm is optional if required by the customer or it is anticipated that the network electronics will utilize this wavelength. For more in-depth information on fiber optic testing and other related topics, the specific documents appended in the reference section of this document can be referenced.

References:

1) AEN 033: OTDR Return Loss Measurement
2) AEN 036: Optical Fiber Fault Location Procedure
3) AEN 040: Multimode Splice Loss
4) AEN 041: Multimode Gainers
5) AEN 050: “Ghost” Reflections on the Optical Time Domain Reflectometer (OTDR)
6) AEN 068: Improving Multimode Fiber Testing Accuracy with Mandrel Wrapping
7) AEN 075: Multimode Optical Fiber Selection & Specification
8) AEN 078: Field Test Procedure for Measuring Optical Power Loss of MTP (Pin-less) Links
9) AEN 081: Multimode Optical Fiber Bandwidth Characterization
10) AEN 098: Measurement Variability during Field Insertion Loss Testing
11) AEN 104: Standards Compliant Optical Test Equipment and Test Procedures
12) AEN 109: Link Attenuation Testing Tutorial w/ case study OptiTap Jumpers for FTTX
13) AEN 110: Considerations for Improved Bend Performance Optical Fibers
14) AEN 115: Plug & Play™ Link Loss Budget Determination
15) AEN 116: Multimode Cable Assemblies - Factory & Link Loss Testing
16) AEN 131: Multimode Fiber Considerations for Test Jumpers
17) AEN 134: OTDR Testing Basics
18) IEC 61280-4-1: Fiber optic communication subsystem test procedures – Part 4-1: Installed cable plant – Multimode attenuation measurement
19) ANSI/TIA-526-7 (OFSTP-7) Measurement of Optical Power Loss of Installed Single-mode Fiber Cable Plant
20) ANSI/TIA-526-14 (OFSTP-14) Optical Power Loss Measurements of Installed Multimode FIber Cable Plant
21) ANSI/TIA/EIA-568-B.1 Commercial Building Telecommunications Cabling Standard
22) ISO/IEC 11801 Information technology – Generic cabling for customer premises

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