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Applications
Engineering Note

Considerations for Optical Fiber Termination

AEN 89, Revision 4

Introduction

Current telecommunications systems are transmitting greater amounts of information at faster and faster speeds. Optical fiber cables and high-precision connectors are integral and necessary components of these systems. After appropriate optical fiber cables have been selected for a system, the appropriate connector and termination method must be selected in order to meet system requirements such as insertion loss and return loss. This Applications Engineering Note explains how different optical fiber termination methods impact the optical performance of telecommunications systems.

Optical Fiber System Insertion Loss

Optical fiber cabling systems support various communications technologies that use digital as well as analog signaling. Gigabit Ethernet (GbE), which is typically a baseband local area networking (LAN) technology, uses digital signaling. Community access television (CATV), which is a broadband video application, often uses analog signaling. Regardless of signaling method, the communications hardware has a specification for maximum channel insertion loss measured in units of decibels (dB). Optical fiber channel insertion loss is the decrease in optical power that occurs when an active transmitter is linked to an active receiver via terminated, optical fiber cables and patch cords and may include splice points and optical couplers. In general, loss is the natural decay of a signal that propagates through a distance of any medium (i.e., optical fiber cabling, copper cabling or air) and is a function of propagation distance through the medium as well as through interfaces that impede the propagation of the signal (e.g., connectors, splices or couplers). The quality of optical fiber link terminations directly affects channel insertion loss. Poor quality terminations cause an increase in loss while high-performance terminations produce less loss. If the insertion loss of an optical fiber channel is less than the maximum channel insertion loss specification, then the system will not fail due to excessive insertion loss (provided the maximum channel length is not exceeded). The industry standard ANSI/TIA/EIA-568-C.3, "*Optical Fiber Cabling Component Standard"* specifies maximum connector insertion loss to be 0.75 dB. However, high performance connectors can be routinely installed with average insertion loss ≤ 0.4 dB.

Optical Fiber System Return Loss

Return loss is the power of the optical signal that returns towards the optical source against the direction of signal propagation. System contributors to return loss are Fresnel reflections (back reflected light due to interfaces at mated connectors and mechanical splices) and Rayleigh back scattering (scattered light due to intrinsic fiber properties).

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An Optical Time Domain Reflectometer (OTDR) measures and displays optical link attenuation as a function of time by converting the returned optical power from fiber length and components into a proportional electrical current. So, an OTDR indirectly measures and displays link attenuation by directly measuring link return loss. Figure 1 illustrates a typical OTDR display.

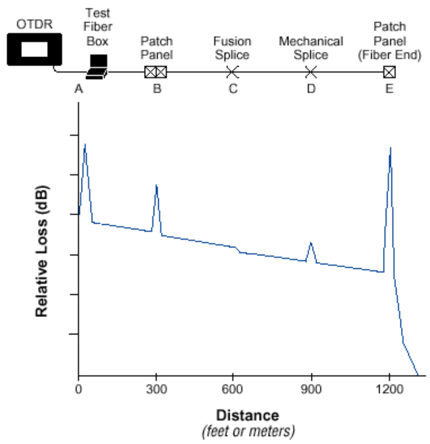

Figure 1 - OTDR Optical Link Trace

Communication systems can be impaired by an excessive amount of reflected optical power, which could alter the transmitted signal to an extent that is not interpreted at the same power level by the receiver. Analog signals (like CATV) are typically amplitude modulated and usually more affected by reflected light (e.g., a grainy television picture) than digital signals. Reflected optical power essentially raises the noise level, which effectively lowers the signal amplitude. An abrupt change in index of refraction occurring at mated connector pairs or a mechanical splice causes optical power to be reflected. For a mated connector pair, the largest contributor to change in index of refraction is the miniscule air gap between the end-faces of two coupled connectors. For this reason, connector ferrules and polishing procedures that result in physical contact (PC) of two fibers are recommended. Lower reflectance values result in higher system return loss values; the absolute value of either becomes larger as less light is reflected. Generally, components like connectors and mechanical splices are specified as reflectance, and system (cumulative effect of Fresnel reflections and Rayleigh scattering) sensitivity is specified as return loss. The industry standard TIA/EIA-568-C.3, Annex A prescribes the minimum return loss requirements for optical fiber connectors as follows:

- Multimode 20 dB
- Single-mode 26 dB
- Single-mode (CATV) 55 dB

Table 1 shows different levels of PC polishing that can be achieved with Corning Optical Communications' single-mode termination methods.

Field-Installable Connector Polish Grades & Associated Single-Mode Reflectance	
Physical Contact	≤ -30 dB
Super Physical Contact (SPC)	≤ -40 dB
Ultra Physical Contact (UPC)	≤ -55 dB
Angled Physical Contact (APC)	≤ - 65 dB

Table 1- Single-Mode Connector Reflectance Values

Optical Fiber Termination Methods

Different optical fiber connector types are commercially available (e.g., SC, ST, LC, MTP). Also, different termination methods exist for each connector type. Common termination methods include no-epoxy-no-polish, epoxy and polish and pigtail splicing. The capabilities and limitations of each termination method affect mated connector pair insertion loss and reflectance. In reality, terminations must be measured for both insertion loss and reflectance. In practice, insertion loss is typically the only measurement taken for installed optical fiber links. The availability of quick mount connectors that are polished and measured for both insertion loss and reflectance at the time of manufacture considerably reduces testing time in the field.

No-epoxy-no-polish Connectors

No-epoxy-no-polish connectors do not require the use of epoxy or polishing in the field because the manufacturer completes those processes when the connector is made. High-quality connectors that conform to TIA/EIA-568-C.3 contain epoxy and require polishing. However, the epoxy injection and subsequent polishing of the ferrule end-face is performed in a factory setting where these processes can be precisely controlled and measured. To terminate an optical fiber cable in the field, the fiber (either tight-buffered or loose fan-out tube) is simply stripped, cleaved, inserted into the connector and mechanically secured. Figure 2 shows a no-epoxy-no-polish connector, which contains a factory-installed fiber stub and index-matching gel in the mechanical splice part.

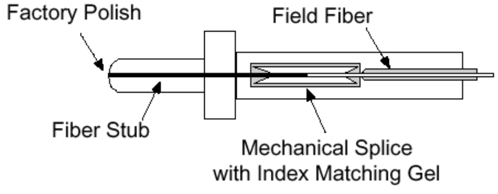

Figure 2 - UniCam Connector Cross Section

A primary advantage of no-epoxy-no-polish connectors is that the most important and tedious part of the termination process (polishing the fiber end-face) is accomplished in advance in a manufacturing environment rather than in the field in various setups and conditions. A direct correlation exists between polishing precision and the two primary measures of connector termination quality, which are insertion loss and reflectance. Corning Optical Communications' UniCam® connectors employ a no-epoxy-no-polish method and can be installed in less than 90 seconds with the optical performance characteristics shown in Table 2.

	Average Insertion Loss (dB)		**Reflectance (dB)**	
	MM	**SM**	**MM**	**SM**
***SC**	0.1	UPC 0.2 APC 0.3	≤ -26	SPC ≤ -40 UPC ≤ -55 APC ≤ -60*
***ST® Compatible**	0.1	0.2	≤ -26	SPC ≤ -40 UPC ≤ -55
***LC**	0.1	UPC 0.2 APC 0.3	≤ -26	SPC ≤ -40 UPC ≤ -55 APC ≤ -60*
MTP	0.1	0.25	≤ -20	≤ -55

Table 2 – Corning's' UniCam Connector Field-Installed Values

* Pretium Performance UniCam Connectors

Epoxy and Polish Connectors

Epoxy and polish connectors may be installed at a tier 1 manufacturer like Corning or a cable assembly house to make patch cords or field-installed to terminate backbone and distribution cables. Epoxy and polish fiber termination include the following steps: injecting the connector ferrule with epoxy, curing, scribing the protruding fiber(s) from the ferrule, and polishing the ferrule end-face. Figure 3 shows an epoxy and polish connector prior to being scribed and polished. The correct amount of epoxy must be injected into the ferrule and cured for the specified time and temperature before the ferrule end-face is scribed and polished. If air bubbles are present in the epoxy, micro-bending and increased loss may occur. The cured epoxy secures the fiber in the ferrule over the operating temperature, minimizing relative fiber movement.

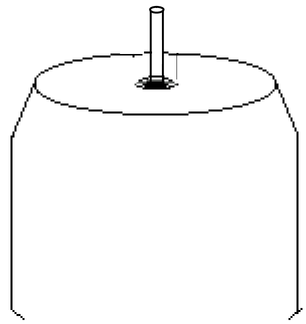

Figure 3 - Epoxy and Polish Connector

Connectors that do not contain epoxy or contain pre-loaded "glues" are adversely affected when subjected to extreme temperatures due to relative fiber movement decreasing optical performance. Epoxy-less connectors could also allow debris to settle inside the ferrule and decrease optical performance when mated and re-mated. An automatic polisher produces the most consistent polish, with single-mode reflectance to ≤ -65 dB. Hand polishing can also be performed, but this method can only consistently achieve reflectance ≤ -30 dB. Polished end-face quality directly impacts both insertion loss and reflectance. If installation and polishing steps are not precisely controlled increased insertion loss and reflectance will occur. Corning Optical Communications' anaerobic epoxy and polish connectors can be installed with the optical performance characteristics shown in Table 3. Corning Optical Communications' heat cure epoxy and polish connectors are shown in Table 4

	Average Insertion Loss (dB)		**Reflectance (dB)**	
	MM	**SM**	**MM**	**SM**
SC, FC, LC, & ST® Compatible	0.2	0.2	≤ -26	SPC ≤ -40

Table 3 - Corning's' *Anaerobic* Epoxy and Polish Connector Values.

	Average Insertion Loss (dB) MM	SM	Reflectance (dB) MM	SM
SC	0.2	0.2	≤ -20	PC ≤ -30 SPC ≤ -40 UPC ≤ -55* APC ≤ -65*
ST	0.2	0.2	≤ -20	PC ≤ -30 SPC ≤ -40 UPC ≤ -50*
LC	0.2	0.2	≤ -20	SPC ≤ -40 UPC≤ -55* APC ≤ -65*
MT-RJ	0.15	0.25	≤ -20	≤ -35
MTP	0.50	0.25	≤ -20	≤ -55*

Table 4 - Corning's' *Heat Cure* Epoxy and Polish Connector Values.

*Must be polished with an automatic polisher.

Pigtail Splicing
A pigtail is essentially a patch cord that has been cut into half. Therefore, one end contains a factory-terminated and measured connector and the other end is not terminated. Table 4 shows Corning Optical Communications' pigtail specifications.

	Average Insertion Loss (dB) MM	SM	Reflectance (dB) MM	SM
SC	0.35	0.15	≤ -20	UPC ≤ -58 APC ≤ -65
ST	0.35	0.15	≤ -20	UPC≤ -58
LC	0.35	0.15	≤ -20	UPC≤ -58 APC ≤ -65
MTP	0.5	0.5	≤ -20	≤ -65

Table 5 – Corning's Pigtail Connector Values

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Mechanical and fusion splice technology is used to field-terminate a cable with pigtails. Single-mode fibers are typically melted to the pigtail (fusion spliced) in order to minimize reflection. A single-fiber or mass fusion splicer is required to join the fibers together after being cleaned and cleaved. Cleave precision significantly impacts splice quality. If the cleave is good, single-fiber splicers with active fiber core alignment consistently produce low loss splices less than 0.1 dB. Multi-fiber splicers produce slightly higher splice loss due to mechanically aligning and joining as many as twelve fibers simultaneously. The rate at which cables can be spliced together is significantly faster using a mass fusion splicer. Like the UniCam termination method, insertion loss and reflectance values of factory pigtails are known because each one is optically measured. Reflectance from a low loss fusion splice is well below the measurement capability of typical optical test equipment (<-90 dB), so only pigtail insertion loss must be measured in the field. For typical pigtail lengths of less than three meters, system capacity should not decrease due to different single-mode fiber types being spliced together

For example, a pigtail containing ClearCurve® LBL fiber that is three meters long may be fusion spliced to a system with a SMF-28e+™ fiber. This system dispersion is practically unaffected by the addition of a three meter ClearCurve® LBL pigtail, which is further addressed in Corning Optical Communications' Applications Engineering Note 53. Another method of pigtail splicing is fusion splicing the field fiber directly to a connector.

The Corning Optical Communications' FuseLite® connector shown in Figure 4 is another example of a "pigtail" termination.

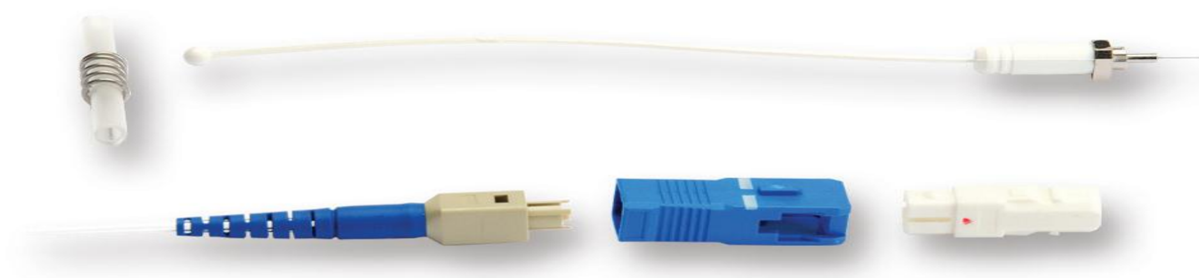

Figure 4: FuseLite Connector

The FuseLite is a no-epoxy-no-polish connector with a fusion splice (instead of a mechanical splice and index-matching gel) that further minimizes reflectance and insertion loss. The epoxy and polish process has been performed at the factory. The FuseLite is available in Multimode PC and Single-mode UPC and APC versions as shown in Table 5.

	Average Insertion Loss (dB)		**Reflectance (dB)**	
	MM	**SM**	**MM**	**SM**
SC, FC, LC	0.1	0.15	≤ -30	UPC ≤ -55 APC ≤ -65
ST® compatible	0.1	0.35	≤ -30	UPC ≤ -55 (No APC)

Table 6 - Corning’s' FuseLite Connector Field-Installed Values

Summary

Different networking technologies like Gigabit Ethernet, 10-Gigabit Ethernet and Fibre Channel specify optical fiber connector maximum insertion loss and minimum return loss. $0G and 100G require even better optical performance from connectors. Connector specifications must be respected so that the maximum channel insertion loss is not exceeded and the minimum channel return loss is met. Different methods exist for terminating optical fibers such as no-epoxy-no-polish, pigtail splicing, epoxy and polish and direct fusion splicing, all with varying amounts of insertion loss and reflectance. The epoxy-injection and subsequent polishing processes are the most critical steps during fiber termination that determines the magnitude of air gap (index of refraction change) at a connector interface. Factory-controlled manufacturing processes, such as those used by Corning Optical Communications, ensure consistent optical performance.

Field epoxy and polish procedures produce connector end-face conditions that vary among installation techniques. Most importantly, no-epoxy-no-polish connectors and pigtails not only are manufactured with precise and repeatable polishing processes, but insertion loss and reflectance are measured for each and every connector. To ensure that epoxy and polish connectors meet specified optical performances established by industry standards, both insertion loss and reflectance must be measured after the fiber is terminated. Connector insertion loss measurements are always necessary after installation, but connector reflectance measurements are typically impractical and can be avoided in the field. In conclusion, the proper optical fiber termination method should be chosen to ensure easy system installation as well as meet required insertion loss and reflectance values prescribed by either industry standards or link loss budget, or both.

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