Technical Report

Optical network installation guide

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Abstract

This document is intended to serve as a guide for architecting and deploying fiber optic networks in a customer environment. This installation planning guide describes some basic fundamentals of fiber optic technology, considerations for deployment, and basic testing and troubleshooting procedures.

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Introduction

The purpose of this paper is to present a practical guide for the installation of an FC infrastructure as it relates to a Storage Area Network (SAN).This document includes the background information necessary for a successful installation.

This installation guide is designed for storage network installation technicians, administrators or architects who are already familiar with Data ONTAP® Administration, Active/Active configurations, and MetroCluster and are considering deployments for production environments.

General overview of SAN fiber network

Storage area networks (SANs) provide the data communication infrastructure for advanced storage systems. While general-purpose networks, such as LANs, enable communication between servers, a SAN utilizes multiple paths to connect servers and storage systems. SAN technology offers many advantages including cost effectiveness, advanced management features, resilient solutions for fast backup and restoration, business continuance, and data security. In order to take full advantage of its capabilities, a SAN is designed differently than and maintained separately from general-purpose networks.

In SANs, FC has become the industry's de facto fast-switching-system standard for connecting client computers and servers to highly scalable volumes of data. An FC network provides connectivity among heterogeneous devices and supports multiple interconnect topologies and the simultaneous use of various transport protocols (IP, SCSI, iSCSI).

FC network solutions operating at data rates of 1 Gbps and 2 Gbps have been widely deployed in SANs, with 4 Gbps now becoming more common. Already 8 Gbps FC—the newest industry- approved standard—is being used in high-end deployments. The FC standard specifies multimode fiber and single-mode fiber as the primary media types. The fiber type recommended depends on the desired distance and data rate. The primary application is for data center SANs over multimode fiber operating at 850 nm, such as laser-optimized 50/125 µm multimode fiber. Links between buildings may require single-mode fiber.

Typical fiber optic network topologies for SAN

Fiber applications can support the following logical topologies:

- **Point-to-point logical** topologies are still common in today's customer premises installations. Two devices requiring direct communication are directly linked by the fibers, normally a fiber pair (one to transmit, one to receive) (Figure 1(a)).
- **Logical star topology**: This is a collection of point-to-point topology links, all of which have a common device that is in control of the communications system (Figure 1(b)). Common star applications include a switch, such as Ethernet, or an FC switch.
- **Logical ring topology**: In this topology, each device is connected to its adjacent devices in a ring (Figure 1(c)). Devices are connected in single or dual (counter rotating) rings. With counter-rotating rings (most common), two rings transmit in opposite directions. If one device fails, one ring will automatically loop back on the other, allowing the remaining devices to function normally. This requires two fiber pairs per device rather than the one pair used in a simple ring. FDDI networks typically utilize a counter-rotating ring topology for the backbone and a single ring for the horizontal.
- **Logical bus topology** is utilized by data communication networks and is supported by the IEEE 802.3 Standard. All devices share a common line (Figure 1(d)). Transmission occurs in both directions on the common line rather than in one direction, as on a ring.
- **Logical mesh topology** logically links every device in the network to every other device in the network. If any one device or transmission port should fail, the data can be rerouted on another

device. This logical topology is typically implemented on networks of switches and routers (Figure 2) where each device is responsible for routing traffic and there is a need to provide high reliability.

Figure 1) Logical network topologies.

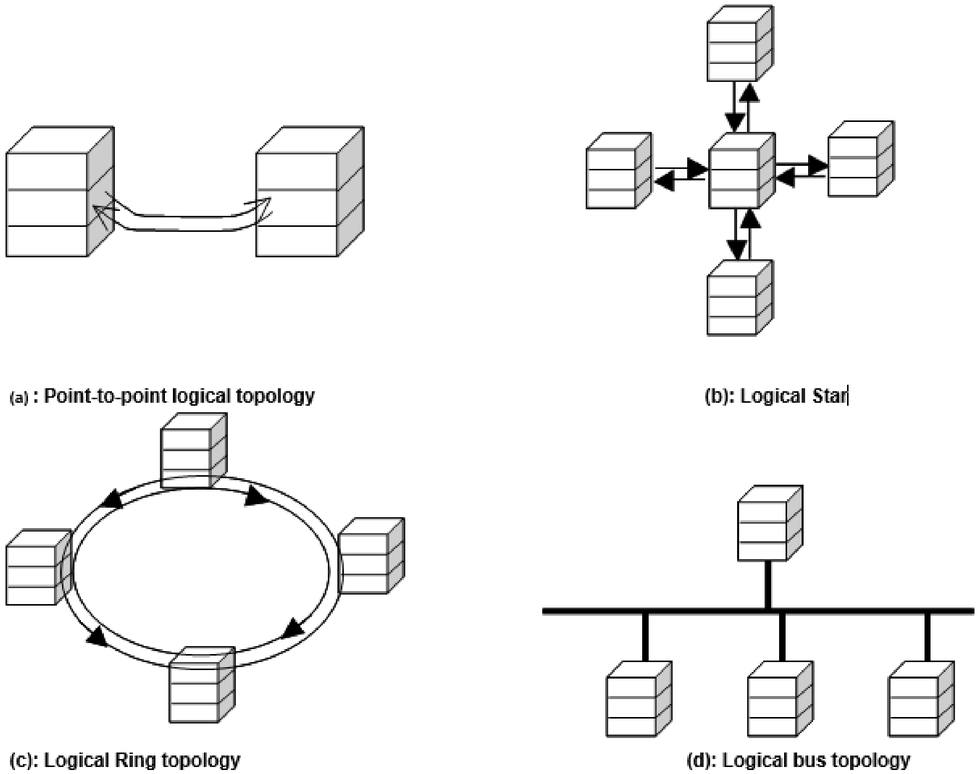
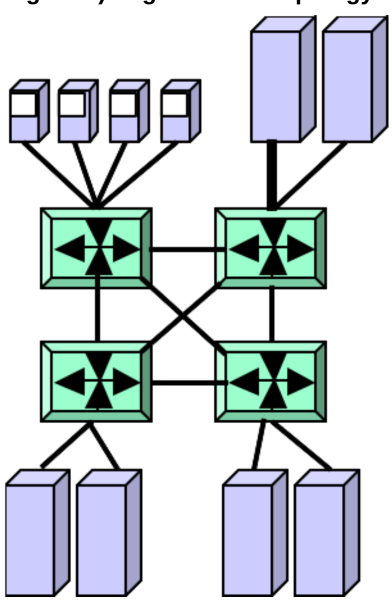


Figure 2) Logical mesh topology.



All of the logical topologies discussed above can be easily implemented with a physical star cabling scheme as recommended by the TIA/EIA-568-B, Commercial Building Telecommunications Cabling

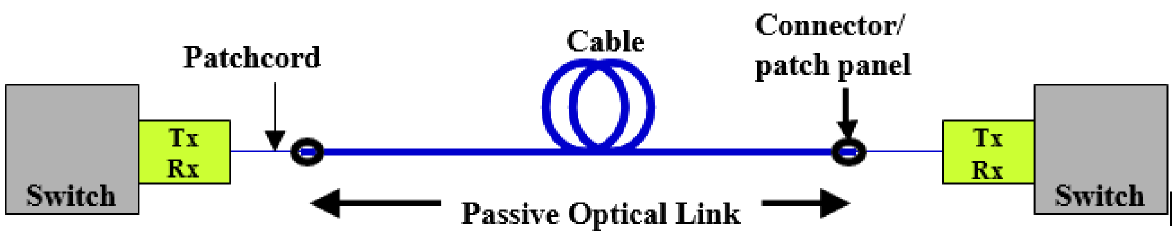
Standard. While the use of data networks that utilize a bus or ring topology may still exist, physical star cabling has become the method of choice for physical cabling systems in the enterprise environment.

It is common in Wide Area Networks (WANs) to find a physical ring topology deployed with redundant fiber paths. A key advantage of the ring physical topology is the improved device survivability in the event of cable cut.

Parts of a fiber optic link

The three determining factors for the selection of fiber type and end optical transceivers (Tx/Rx) for a fiber optic link are: fiber link distance, application and data rate. Multimode fiber (MMF) is the primary transmission medium for premises applications, as the associated optical transceivers are usually more economical than those for single mode systems. Links between buildings and campuses usually require single mode fiber (SMF). Analysis of a specific system design will result in the selection of the suitable fiber type and optical transceivers, after which detailed consideration of the optical parameters for both fiber and system is necessary (Figure 3).

Figure 3) Fiber optic link.



The geometrical properties and fiber core construction of single-mode and multi-mode fiber differ greatly, such that each fiber type has different optical-performance attributes that lend themselves to different communications network applications. The diameter of the core of MMF is more than five times greater in diameter than that of SMF, giving MMF distinct advantages such as low loss connection and simpler fiber-to-fiber and fiber-to-transceiver alignment. Consequently, MMF is best suited to premises and LAN to premises and LAN applications.

Transmitters To better understand the characteristics of MMF and SMF, one needs to consider the different transmitters used in optical transceivers. There are four main types of optical transmitters that can be used in transceivers. These four main types use either light emitting diodes (LEDs) or lasers as light sources and they differ greatly in cost, optical characteristics and performance. LEDs emit an incoherent, large spot size of light suitable for coupling into large core MMF. LEDs' wide spectral width limits their data rates to 655 Mb/s. For systems operating at > 655 Mb/s, lasers must be used. The typical output power for an LED source is -12 dBm. Lasers emit a narrow spot of light, allowing efficient coupling into SMF, and have much narrower spectral wavelength than LEDs allowing them to be modulated at much higher data rates. The three main types of lasers used in transceivers are:

- **Fabry-Perot (FP) lasers** are edge-emitting devices and exhibit multimode spectrum. They are commonly used for 1300/1310nm applications for both SM and MM fiber.
- **Distributed feedback (DFB) lasers** are more expensive than FP lasers and are spectrally single mode, offering longer reach performance over SMF. These lasers are available in 1310nm and 1550nm.
- **Vertical-cavity surface-emitting laser** (VCSEL) is a relatively new type of semiconductor laser. Its light is emitted from the surface of the semiconductor. The 850nm version of this laser has been in production for several years and has been adopted in about 95% of the Gigabit Ethernet and FC applications. VCSELs have become the transmitter of choice for short reach premises applications over MMF at data rates as high as 10 Gbps. Their low power and large active area make them inappropriate for SMF.

All types of transmitter sources used in premises applications are directly modulated (DM). They are called directly modulated because the source itself turns on and off. This is in contrast with external modulated (EM) lasers used in Long haul applications. The cost-to-performance ratio of DM sources is suitable for most premises applications.

Optical fiber transmitters are characterized by the wavelength at which they emit light. The nominal emission wavelength is called the center wavelength of the transmitter. LEDs with center wavelengths at 850 nm or 1300 nm have been in wide use for many years and the transmission specifications for multimode fiber are typically given at these two wavelengths. Laser transmitters for single-mode systems operate at center wavelengths of 1310 nm or 1550 nm; thus single-mode fibers carry specifications for transmission at these two wavelengths. VCSELs operate at a center wavelength of 850 nm over multimode fiber.

Receivers The receiver side of optical transceivers contains a photodetector that converts the optical signal into an electrical signal. For LAN and SAN applications PIN photodetectors are the most widely used. PIN photodetectors are simple and low cost devices. In long reach WAN/Metro/Long Haul applications, Avalanche Photodiodes (APDs) are widely used because of their higher sensitivity. The operating wavelength of the receiver should match that of the transmitter. A receiver designed for 1300 and 1550 nm operation is not suitable for use at 850 nm.

Data Rate The data rate is the maximum number of bits per second that can be transmitted and received with a bit error rate (BER) below a certain threshold. A typical BER threshold is one error in 1012 bit.

Dynamic Range Bit errors can occur when too much or too little light strikes the photodetector. The response of a photodetector is linear only within a certain range of power levels, called the dynamic range. Exceeding the linear response area (dynamic range) for a given photodetector causes the receiver to saturate leading to the degradation of the bit error rate. If optical power at the receiver is too high, an optical attenuator can be placed at the receiver in line with the optical fiber to reduce the amount of received light power.

Receiver sensitivity specifies the minimum power level required at the receiver for a certain BER to be maintained (say, BER of 10^{-12}). A typical value would be -17 dBm for 1 Gbps Ethernet operation at 850 nm.

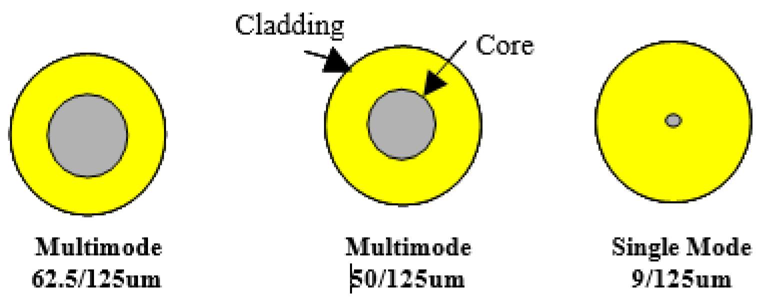
Operating Wavelength Operating wavelength is another important parameter in system design. Multimode fiber is optimized for operation in two wavelength windows: 850 nm and 1300 nm. The two key parameters affected by transmission wavelength are signal attenuation (or propagation loss) and transmission noise.

Legacy multimode fiber (62.5/125 µm) was optimized with respect to bandwidth at 1300nm to take advantage of the lower attenuation at 1300nm compared with that at 850nm. But, with the steady increase in data rates, multimode systems are now less likely to be attenuation-limited and more likely to be bandwidth-limited due to modal dispersion. VCSELs which operate at 850 nm have accelerated the development of laser-optimized 50/125 µm multimode fiber which can extend link distance at high data rates while still taking advantage of the overall lower system costs associated with multimode fiber.

Multimode Fibers In these fibers, numerous modes or light rays are carried simultaneously through the fiber core (waveguide). Modes exist because light will only propagate in the fiber core at several discrete angles within the cone of acceptance. MMFs have a much larger core diameter, compared to single-mode fiber, making them easier to couple light into than SMF. The disparity between arrival times of the different modes or light rays is known as modal dispersion, and causes signal noise at the receiving end of an MMF link. Multimode fiber may be categorized as step-index or graded-index fiber.

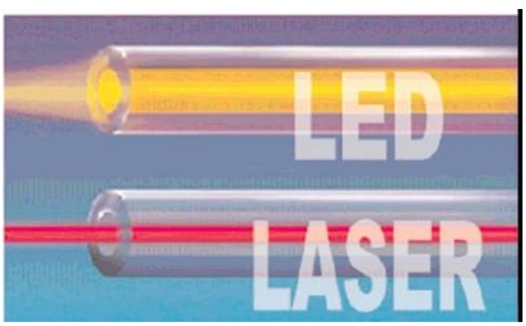
The standard types of multimode fiber in North America are 50/125 µm and 62.5/125µm optical fiber and are recognized by TIA/EIA-568-B.3 and IEC 11801. Mechanical, geometrical and optical characteristics for 62.5/125 µm, 50/125 µm are detailed in TIA/EIA 492AAAA and TIA/EIA-492AAAB, respectively. Figure 4 depicts the cross-section of the 3 types of optical fibers.

Figure 4) Relative core/cladding size of multimode and single mode fibers.



OM-1 conventional (FDDI grade) multimode fibers were widely used with LED-based transceivers. As data rates increased from Mb/s to Gbps, networks migrated from LED-optimized to laser-optimized multimode fibers that are compatible with high-speed VCSEL-based transceivers. Laser light couples into and propagates inside multimode fibers differently than single mode fibers. The diameter of the light from an LED source is larger than the diameter of the fiber core, leading to the so-called “overfill launch” condition (Figure 5). On the other hand, the diameter of a light beam from a laser source is smaller than the core of multimode fiber, thus only a few modes in the multimode fiber are excited (Figure 5). The small number of excited modes, combined with the inherently higher modulation speed of lasers, allows laser-based transceivers to achieve higher bandwidth with laser optimized multimode fibers.

Figure 5) LED vs. laser light launch into multimode fiber. [1]



Multiple measurement techniques have been developed to better quantify the bandwidth/reach performance of multimode fibers. The 4 key bandwidth measurement techniques for multimode fiber are:

- Overfill Launch (OFL): uses an LED–like launch to “overfill ” the core of an LED-optimized multimode fiber. This measurement gives a good indication of system performance running legacy protocols and using LED sources.
- Restricted Mode Launch (RML): This technique was developed to accommodate the transition to laser-optimized fibers. The launch condition of this measurement is similar to that of a high-speed VCSEL laser source and consists of launching a 23.5μm spot in the center of the multimode fiber.
- Differential Mode Delay (DMD): This fiber measurement characterizes the delay time of mode groups within a multimode fiber.
- Effective Modal bandwidth (EMD): This is the bandwidth as seen in a system using a commercially available laser of known launch power distribution and also a fiber of known RML or DMD.

The key types of multimode fibers are summarized in Table 1.

Table 1) Types of multimode fibers.

MMF type	Core/Clad diameter	Standard	Description
OM-1	62.5/125	Draft ISO/IEC11801 Edition 2 Fiber classification	Specifies minimum OFL bandwidth 850nm as 200MHz.km, OFL bandwidth 1300nm as 500MHz.km
OM-2	50/125	Draft ISO/IEC11801 Edition 2 Fiber classification	Specifies minimum OFL bandwidth 850nm as 500MHz.km, OFL bandwidth 1300nm as 500MHz.km
OM-3	50/125	Draft ISO/IEC11801 Edition 2 Fiber classification	Specifies minimum OFL bandwidth 850nm as 1500MHz.km, OFL bandwidth 1300nm as 500MHz.km & EMB 850nm 2000MHz.km

Note that some suppliers offer enhanced specifications for OM-1, OM-2 and OM-3 multimode fibers. These higher performance versions are referred to as “OM-1+”, “OM-2+” and “OM-3+”, respectively, but they are not standardized as per ISO/IEC 11801. As an example, the fiber bandwidth at 850nm for Corning’s OM-1+, OM-2+ and OM-3+ are 385, 850, and 4700 MHz.km, respectively.

Single Mode Fiber Dispersion unshifted single-mode fiber, having a low attenuation in the water peak region as specified in ITU-T G.652.D and TIA/EIA-492-CAAB, is designed for operation in the 1310 nm and 1550 nm regions; however, there is a tradeoff at each wavelength region. The attenuation at 1550 nm is generally lower than that at 1310 nm. The chromatic dispersion, however, is much higher at 1550 nm than at 1310 nm. For premises applications, TIA/EIA-568-B.1, Commercial Building Telecommunications Cabling Standard, and IEC 11801, Generic Cabling for Customer Premises, recommend the use of dispersion unshifted single mode fiber because premises communication standards are designed for operation at 1310 nm. The 10 Gbps Ethernet Standard specifies operation at 1310 nm and 1550 nm with dispersion unshifted single-mode fiber having a low water peak (Table 2).

Table 2) FC data rates/maximum reach for various Corning fibers.

Fibre type	Wavelength	Data rate	Max distance (m)
OM-1 (62.5/125um)	850 nm	1 Gbps	300
	850 nm	2 Gbps	150
	850 nm	4Gbps	70
	850 nm	10Gbps	33
OM-2 (50/125UM)	850 nm	1Gbps	500
	850 nm	2Gbps	300
	850 nm	4Gbps	150
	850 nm	10Gbps	82
OM-3 (50/125UM)	850 nm	1Gbps	860
	850 nm	2Gbps	500
	850 nm	4Gbps	270
	850 nm	10Gbps	82
OM-3+ (50/125UM)	850 nm	1Gbps	1130
	850 nm	2Gbps	650
	850 nm	4Gbps	350
	850 nm	10Gbps	550
	1300 nm	1Gbps	10,000

Fibre type	Wavelength	Data rate	Max distance (m)
OS1 Single Mode Fiber (9/125UM)	1300 nm	2Gbps	10,000
	1300 nm	4Gbps	10,000
	1300 nm	10Gbps	10,000

Termination of optical fibers

There are four basic ways to terminate optical fibers:

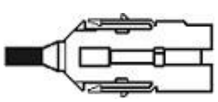
- Pigtail splicing
- Preterminated cable assemblies
- Field termination
- Preterminated hardware

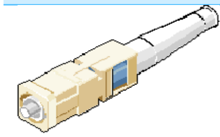
NetApp recommends the use of factory-terminated cable assemblies for the equipment jumpers, work area jumpers and patch cords because cable placement is straightforward and various short lengths are readily available. The use of factory-terminated cable assemblies minimizes the labor and time involved in installation and guarantees a higher quality of workmanship. Preterminated assemblies are available in all lengths and with all modern connector types.

Optical Connectors The standardization and increased reliability of optical connectors have contributed to the increase in the use of fiber optic systems. Table 3 depicts some of the most commonly used connectors and lists their insertion loss, the primary consideration for connector performance, and repeatability. The LC connector is a small form-factor fiber optic connector that is fast becoming the connector of choice in many applications in LANs and WANs. The LC connector offers excellent packing density and its push-pull design with a latching mechanism resists fiber end face contact damage during unmating and remating cycles. The LC connector has been standardized as FOCIS 10 (Fiber Optic Connector Intermateability Standards) in EIA/TIA-604-10.

The SC connector is twice the size of the LC connector and has been standardized as FOCIS 3 (Fiber Optic Connector Intermateability Standards) in EIA/TIA-604-03.

Table 3) Commonly used types of optical connectors.

Connector	Fiber type	Insertion loss	Repeatability
FDDI 	MMF, SMF	0.2 - 0.7 dB	0.20 dB
LC 	MMF, SMF	0.15 dB (SMF) 0.10 dB (MMF)	0.20 dB
SC	MMF, SMF	0.20 - 0.45 dB	0.10 dB

Connector	Fiber type	Insertion loss	Repeatability
			
LC Duplex 	MMF, SMF	0.15 dB (SMF) 0.10 dB (MMF)	0.20 dB

Fiber optic connector cores are very small and even small dust particles can partially or completely obscure the core of a fiber. To prevent this, fiber optic connectors must be cleaned every time they are unmated and mated. It is also important to cover a fiber optic connector when it is not in use. Most connector manufacturers provide some sort of protection boot. Unprotected connector ends are most often damaged by impact, such as hitting the floor.

Field Termination: Field termination has become the most common method for terminating fiber optic cables in the LAN. Field termination is recommended throughout the network except for patch cords, equipment cords and cross-connect jumpers. Data centers typically use preterminated cable for horizontal and backbone applications to expedite installation. When selecting the proper termination for a given application, there are two specifications to consider: insertion loss and reflectance. Insertion loss is the attenuation of signal caused by the light going from one fiber to the other through the connector, while optical return loss, or reflectance, is the amount of light that is reflected back toward the source or transmitter from the connector mating.

Splicing Fiber-to fiber splicing in campus environments can often be avoided by installing a continuous length of cable. This is normally the most economical and convenient solution. However, because of the cable plant layout, length, raceway congestion or requirements to transition between non-listed and listed cable types at the building entrance point, splices may become necessary. Splicing methods for optical fibers fall into two main categories: (i) fusion splicing, and (ii) mechanical splicing. Fusion splicing consists of aligning and then using an electric arc to fuse together two stripped, cleaned and cleaved fibers. A mechanical splice is an optical device in which two or more optical fibers are aligned and held in place by a self-contained assembly approximately 50 mm in length. The alignment of the two fibers relies on the outer diameter of the fibers, thereby making the accuracy of core/cladding concentricity of the optic fibers critical to achieving low splice losses.

FC SFP transceivers

Optical transceivers interface a network device motherboard (for a switch, router or similar device) to a fiber optic or unshielded twisted pair networking cable. Optical transceivers are available in a number of form factors specified by multi-source agreement (MSA) between competing manufacturers. The small form-factor pluggable (SFP) optical transceiver was designed after the GBIC interface. SFP allows greater port density than the GBIC, which is why SFP is also known as mini-GBIC. SFPs use LC connectors. Figure 1Figure 6 shows pictures of an SFP module.

Figure 6) Side and front views of an SFP transceiver module.

Modern SFP transceivers support digital optical monitoring (DOM) functions according to the industry-standard SFF-8724 MSA, thus allowing the end user the ability to monitor real-time parameters of the SFP, such as optical output power, optical input power, temperature, laser bias current, and transceiver supply voltage.

SFP transceivers are available with a variety of transmitter and receiver types, allowing users to select the appropriate transceiver for each link to provide the required link reach over the available optical fiber type. Optical SFP transceivers are commonly available in four different categories—850nm, 1310nm, 1550nm, and WDM (both CWDM and DWDM)—and support multiple communication standards such as FC and Gigabit Ethernet. SFP transceivers are also available with a "copper" cable interface, allowing a host device designed primarily for optical fiber communications to also communicate over unshielded twisted pair networking cable. Commercially available SFP transceivers now have the capability for data rates up to 4.25 Gbps (4xFC).

There are four types of Small Form-factor Pluggables (SFPs) associated with the Fabric MetroCluster configuration. They are:

Short-Wavelength Laser (SWL) Short Wavelength Laser transceivers based on 850nm lasers are designed to transmit short distances. This is the most common type of media and is the default on the Brocade 200E.

Long Wavelength Laser (LWL) Long Wavelength Laser transceivers may be based on 1310nm lasers. They are used for long distance native FC links. Generally, these media types are used with single- mode fiber cable.

Extended Long Wavelength Laser (ELWM) Extended Long wavelength Laser transceivers may be based on 1550nm lasers. They are used to run native FC connections over even greater distance than LWL media can support. Generally these media types use single-mode fiber cable.

WDM Both coarse (CWDM) and dense (DWDM) SFP transceivers are commercially available for multi-wavelength channel transmission inside single mode fibers.

The type of SFP transceiver required is a function of the distance and the interconnect technology used. Table 4 summarizes the types and specifications for the SFP transceivers supported by the NetApp solution.

Table 4) SFP transceivers supported by NetApp.

SFP type (wavelength)	Max. distance	Speed	NetApp part #	Outside vendor/ part number	Min. power budget
SWL (850nm)	500m[1]	4Gbps[3]	X1563C-R5	Finisar/FTLF8524P2BNV	9 dB
LWL (1310nm)	10Km[2]	4Gbps[3]	X1670A-r5	Finisar/FTLF1424P2BCD	15dB
ELWL (1550nm)	80Km[2]	2Gbps[3]		Finisar/FTLF1519P1xTL	21dB
DWDM (1530-1560nm)	500Km	2Gbps[3]		Finisar/FWLF-1631-xx	28dB

Note: [1]Using 50/125 multimode cable. 300m when using 62.5/125 cable.

[2]Using 9/125 Single mode Cable.

[3]4Gbps speed is not supported yet. New 4Gbps LWL and ELWL SFPs are being qualified.

Fabric extension overview

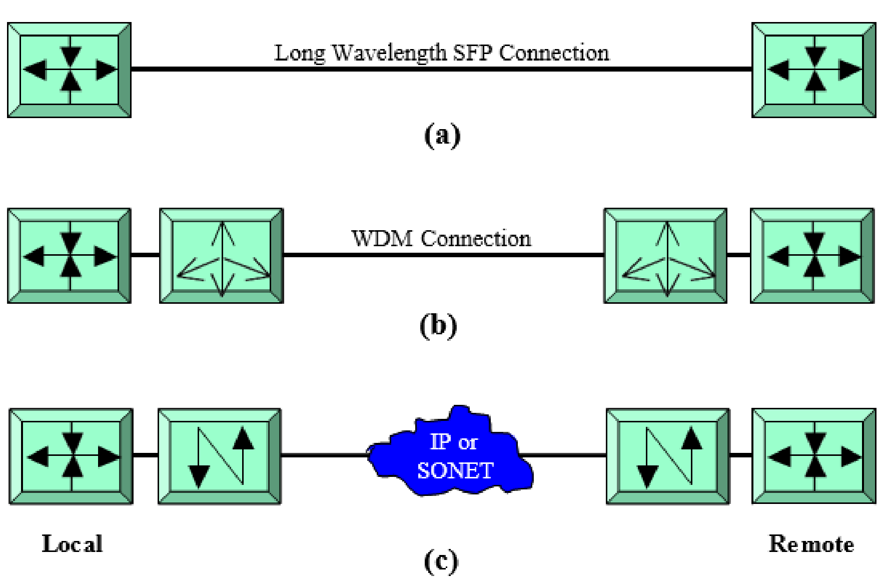
A fabric extension is an extended interswitch link connection between switches linking two sites. SAN extension enables a disaster-tolerant storage solution over long fiber distances and multiple sites and can be defined as:

- Any distance greater than:
  - 150m for 4Gbps FC
  - 300m for 2Gbps FC
  - 500m for 1Gbps FC
- Any distance between a pair of wavelength division multiplexing (WDM), Fibre Channel over IP (FC-IP), or FC-SONET products

Fabric extension can be implemented with any FC topology. Figure 7 illustrates three SAN extension examples:

1. FC using long wavelength, long reach transceiver
2. Wavelength Division Multiplexing (WDM) where multiple channels are transmitted over a single strand of fiber. Each channel uses a different color or wavelength transceiver. These channels are networked with a variety of wavelength-specific optical add/drop multiplexers (OADMs) that enable ring or point-to-point topologies.
3. Multi-protocol long-distance technology such as FC over Internet Protocol or over SONET. This configuration is not supported with MetroCluster.

Figure 7) Examples of SAN extension.



Factors affecting transmission and link distance over fiber link

Maximum transmission distance over fiber can be limited by either the available optical power budget or the degradation of the signal due to accumulated noise as the signal propagates through fiber. Limitation of maximum transmission distance due to power budget is treated in a later section. In this section, we focus on the effect of dispersion on the transmission of signal inside single-mode and multimode fiber.

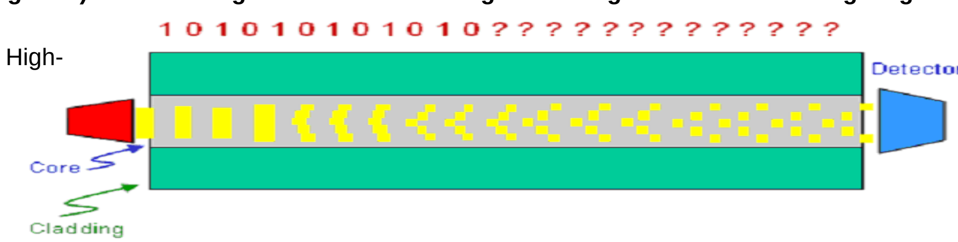
Modal dispersion in multimode fiber

As data Center and SAN applications grow rapidly and increase in speed from 1 to 4, 8, and 10 Gbps, transmission impairment in multimode fiber becomes a greater limiting parameter. One of the limiting parameters determining the performance of 1 and 10Gbps FC and Ethernet systems is Inter-Symbol Interference (ISI).

ISI is an impairment of data communications systems that limits the reach and bandwidth of the network. Ethernet and FC systems transmit information using digital transmission (1s and 0s). When the transmission laser is on, a digital "1" is transmitted, and when it is off, a digital "0" is represented. But if the laser pulses spread as they propagate down the fiber they may overlap into adjacent bit timeslots, confusing the detector at the receiving end of the fiber and resulting in bit errors and system failure. Increasing system speeds from 1 to 4, 8, 10 Gbps results in reduction of the system bit period by a factor of 4, 8, and 10, respectively, thus requiring that each bit remain completely within its assigned and much smaller bit period with no overlap into adjacent bit periods. By minimizing ISI, the reach of multimode-based systems can be increased.

Pulse spreading (also called dispersion of the signal) causes ISI, and the primary cause of pulse spreading in multimode fiber is differential mode delay (DMD) or modal dispersion. Multimode fiber has hundreds of light pathways, or modes, in which light can travel through the fiber. If the speed of the light in each mode is equal, the fiber will have zero DMD. But imperfections in fiber manufacturing and design result in large differences in modal speed, causing some amount of DMD. If the laser transmits a "1" into a fiber with too high a DMD, the various modes of light representing this laser pulse will travel along the fiber at different speeds. As a result, some modes of light representing the binary "1" may spread into the adjacent bit periods, causing the system to fail, as illustrated in Figure 8. Using a fiber with low DMD, such as laser-optimized fiber, can dramatically improve system performance.

Figure 8) DMD causing ISI when transmitting data at high data rate over long length of multimode fiber.



Multimode fiber with graded refractive index profile (in which the refractive index of the core glass decreases slowly as a function of the radial distance from the center of the fiber) should in theory eliminate the modal dispersion. In practice, however, modal dispersion can be minimized but not eliminated, and it is the principal bandwidth-limiting factor in multimode fiber.

Dispersion in single-mode fiber

Single-mode fiber eliminated severe multimode fiber related dispersion and left only chromatic dispersion (CD) and polarization mode dispersion (PMD) to be dealt with.

Chromatic dispersion represents the fact that different colors or wavelengths travel at different speeds, even within the same mode. Chromatic dispersion is the result of material dispersion, waveguide dispersion, or profile dispersion. Since a pulse of light from the laser usually contains several wavelengths, these wavelengths tend to get spread out in time after traveling some distance in the fiber. The refractive index of fiber decreases as wavelength increases, so longer wavelengths travel faster. The net result is that the received pulse is wider than the transmitted one, or more precisely, is a superposition of the variously delayed pulses at the different wavelengths. PMD accounts for the pulse spreading due to the presence of multiple states of polarization of light.

Dispersion Power Penalty is a metric that is used to quantify the effect of dispersion on the transmission link. When an optical transmitter is connected to an optical receiver through a short length of fiber (back-to-back) and an optical attenuator, the attenuation can be increased to determine the receiver sensitivity. Usually the receiver sensitivity limit is defined at a given bit error rate (BER); usually a BER of 10-10 or 10-12 is used. Dispersion power penalty is the difference between the back-to-back sensitivity and the link sensitivity (with a specified distance of optical fiber between the transmitter and the receiver).

Back reflections in an optical link

All lasers are susceptible to back reflections. Back reflections disturb the laser cavity, resulting in an increase in the effective noise floor of the laser. A strong back reflection can cause some lasers to become unstable leading to major system degradation. The importance of controlling back reflection depends on the type of information being sent and the particular laser. Some lasers are very susceptible to back reflections due to the design of the laser chip itself. Most often the determining factor is how tightly the fiber is coupled to the laser chip. A low-power laser generally has weak coupling to the fiber. Perhaps only 5-10% of the laser power is coupled into the fiber. This means that only 5- 10% of the back reflection would be coupled into the laser cavity, making the laser relatively immune to back reflections. This is usually the case for multimode transceivers used in LAN/SAN applications.

Fiber bend

Since all fibers used in the LAN/SAN have the same glass cladding diameter of 125um, they all exhibit the same bending flexibility. Optical fiber bending diameters are limited by considerations for mechanical reliability before optical performance is affected. To ensure long-term mechanical integrity, TIA568 restricts the bend radius to no less than 30mm (1.8 inches) for 2 and 4-fiber cables.

From the optical performance standpoint, bending results in a significant level of optical attenuation in multimode fiber even at a low bend radius of less than 20mm (<1 inch).

Effective maximum fiber reach in a MetroCluster infrastructure

The maximum optical link length is the shorter of the following two distance limitations:

- Distance limitation due to optical power budget (Figure 9)
- Distance limitation due to the bandwidth limitation of the type of fiber used (expressed as Max Distance in Table 5).

Table 5) Optical cable parameters chart.

Cable type	Fibre type	Mode	Wavelength (nm)	Max. distance (m)	Attenuation (db/Km)	Splice loss (dB)	Connector pair loss (dB)
1Gbps							
OM2	50/125um	Multi	850	500	3	0.3	0.75

Cable type	Fibre type	Mode	Wavelength (nm)	Max. distance (m)	Attenuation (db/Km)	Splice loss (dB)	Connector pair loss (dB)
OM3	50/125um	Multi	850	860	3	0.3	0.75
OS1*	9/125um	Single	1310	2000	0.4	0.3	0.75
2Gbps							
OM2	50/125um	Multi	850	300	3	0.3	0.75
OM3	50/125um	Multi	850	500	3	0.3	0.75
OS1*	9/125um	Single	1310	2000	0.4	0.3	0.75
4G bps							
OM2	50/125um	Multi	850	150	3	0.3	0.75
OM3	50/125um	Multi	850	270	3	0.3	0.75
OS1*	9/125um	Single	1310	500	0.4	0.3	0.75
IB 1X 250 MB/sec							
OM2	50/125um	Multi	850	300	3.5	0.3	0.75
OM3	50/125um	Multi	850	500	3.5	0.3	0.75
Note: * single mode cable for ISLs only							

Table 5 summarizes “typical” data related to optical cabling for data communications available in documents published by various standards organizations. The focus is on data that is relevant to fiber deployments.

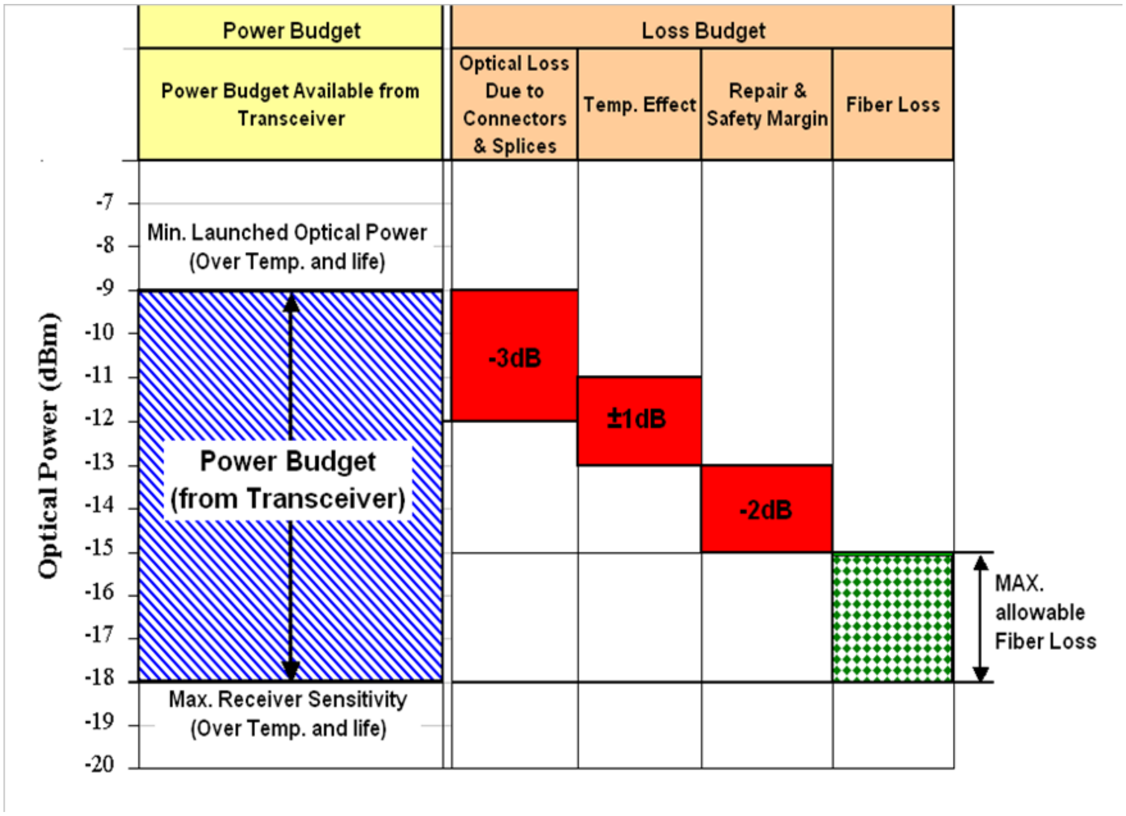
Power budget limitation

To design a fiber optic link, one needs to analyze the so-called “optical link loss budget” against the available optical power budget. Figure 9 illustrates the required optical calculations for designing a fiber link.

The link example considered here consists of 2Gbps (2xFC) SFP transceivers operating at 850nm, 300 meters of OM2 fiber, and 2 patch panels, as depicted in Figure 10.

The illustration in Figure 9 starts on the left side with the optical power budget available from the transmit and receive ports of the transceivers specified for the link. The difference between the minimum launch power and the worst-case sensitivity of the optical receiver constitutes the minimum available optical power budget. Worst-case optical launch power and receiver sensitivity are key parameters that are guaranteed by transceiver vendors over operating temperature range and over transceiver lifetime. In the example illustrated in Figure 9, a 2Gbps SFP transceiver operating at 850nm has a minimum launch

Figure 9) Illustration of key contributors to optical link loss budget.



power of –9dBm and a maximum receiver sensitivity of –18dBm, resulting is an available power budget of: -9 – (-18) = 9dB. This is the range shaded in blue diagonal lines in Figure 9.

The optical loss budget is shown by the solid-red blocks in Figure 9. One factor in the loss budget is the presence of connectors and/or splices. The optical path in our examples involves 3dB loss due to the presence of 4 optical connector pairs (source, destination, 2 patch panels) and no splices. Since each mated connector pair results in about 0.75dB loss (refer to Table 5), the total loss due to connectors is 4 x 0.75dB = 3dB.

Next, ±1dB is added to the optical link loss budget as a consideration for temperature effects on the fiber itself and the mated connectors.

The next factor in the Optical Link Loss Budget is the repair and safety margin for the addition of future patch panels or splices; in this case specified as -2dB.

The maximum fiber length can now be determined by calculating the maximum allowable fiber loss, which is obtained by subtracting the total power loss (sum of all solid-red blocks) from the available power budget provided by the transceiver (block in blue diagonal lines). In our example, the maximum allowable fiber loss is (9dB – 6dB = 3dB), represented by the dotted green block in Figure 9 The maximum fiber length is then calculated by dividing up the allowable fiber loss by the fiber attenuation. As an example, the optical attenuation in OM2 fiber is 3dB/km as shown in Table 5. The maximum fiber link distance is then:

```
Lmax = (Max Allowable fiber loss) / (Fiber attenuation) = (3dB) / (3dB/km) = 1km.
```

So, the power-limited maximum link distance for our example is 1,000m. Now, one needs to check the distance limitation due to the type of fiber used.

The chart in Figure 9 can be easily applied to other link scenarios to determine the power-limited maximum link distance by applying the applicable values for the available power budget from the transceivers and the loss due to connectors and splices. The Appendix below also provides a practical worksheet for such calculation.

Figure 10) Link example.

Distance limitation due to modal dispersion

Contrary to popular belief, optical fiber does not provide unlimited bandwidth. Every type of fiber has a characteristic Bandwidth*Distance limitation which basically implies that the allowable fiber link length decreases as the data rate of the optical signal increases. This is true for single-mode fiber (SMF), but much more so for Multimode fiber (MMF), where effects such as modal noise conspire to limit the maximum Bandwidth•Distance (having a unit of MHz•km) attainable. Fiber Bandwidth•Distance limitation is also a function of the type and wavelength of the optical source used in the transmitter. The Maximum distance due to Fiber Bandwidth•Distance limitation is shown in Table 5 and is specified as 550m for our example of OM2 type multimode fiber at 2Gbps and at 850nm. So, the maximum guaranteed distance for our example is limited by the fiber bandwidth to 550m.

It must be noted that the typical parameters specified in Table 5 are conservative and specific installations may operate beyond the Max. distance specified in the table. While the analysis above provides a useful tool to design and assess an optical link based on nominal values, actual testing and characterization of the fiber link and its components by a qualified fiber technician are the most accurate ways to determine the real limitation of an optical link. This naturally implies that by physically measuring a channel's characteristics and finding that it is within the limits of the specification for the fiber in use, a longer distance than the specification's maximum could be achieved.

This decision is left up to the implementer, as the various standards take no official stance in support for distances beyond the stated maximums, other than to note the possibility of longer operating distances through the use of better than worst-case performing components. It is important to caution that maximum link distance is strongly dependent on the data rate running on the link; so careful re- evaluation must be conducted when upgrading a link to a higher data rate, such as migrating from 2 to 4Gbps.

Testing and verification of FC infrastructure

Testing of an installed fiber optic cabling system and documenting the test results are necessary tasks to ensure overall integrity and long-term performance of the network. Proper testing maximizes the system's lifetime, minimizes downtime and maintenance, and enables efficient system upgrades or reconfiguration. This chapter focuses on the testing, verification, and documentation of optical fiber cabling systems for new installation and system upgrades, with special emphasis on multimode fiber cabling for SANs.

This chapter covers the case of single-fiber connectors (such as LC or SC connectors) only and does not address multi-fiber connectors such as MP connectors.

Cable system testing

The TSB-1140 industry testing guidelines approved by the TR-442 standards body in February 2004, recommended changes to the way the installer and network owner had been certifying the cable plant. Basically there are two tiers of testing. Tier 1 is an end-to-end and segment-by-segment attenuation measurement based on using a loss/length certification tool that measures optical loss; Tier 2 involves using an Optical Time Domain Reflectometer (OTDR) that characterizes the fiber link. Performing both tiers of tests provides quantitative measures of the installed cable system and its components.

Attenuation, defined as optical power loss measured in decibels (dBs), is the primary field test parameter in fiber optic systems. The total network/system's attenuation includes the contributions of the cables, connectors, splices, and patch cords/jumpers, as well as tight fiber bends and excessive stresses on the fiber.

End-to-end attenuation testing

Background Attenuation, or optical power loss measured in dBs, of installed cable system is measured using the insertion loss method. The insertion loss method requires an optical source and optical power meter and consists of comparing the difference in two optical power values: the optical power launched into the cable system at the near end (P1), and the optical power of the signal exiting the far end (P2).

```
Loss (dB) = P2 (dBm) – P1 (dBm)
```

Where P1 = Input Power (dBm) and P2 = Output Power (dBm)

In premises applications, almost all the optical power levels are negative dBm values, meaning a power level less than 1mW. A typical LED has an output power of –20dBm, an 850nm VCSEL based SFP has an output power less than –3dBm.

Mandrel Wrapping TIA/EIA-568-B.1 recommends the use of mandrel wrapping when performing link attenuation testing on multimode fiber. Mandrel wrapping consists of wrapping a length of fiber (5 wraps) around a smooth, round mandrel (rod) as depicted in Figure 11. The bending caused by wrapping the fiber around the mandrel will strip out the high-order modes in the cladding. Along with the light in the core of a multimode fiber, there may be some high-order modes in the cladding due to the overfill launch condition. High-order modes traveling through sufficiently long fiber links leak into the cladding and are lost. But during the referencing step of a typical attenuation test, test jumpers that are only a few meters long are used. Over such a short distance, the higher order modes may reach the test meter, leading to higher optical power reading into the reference, giving the appearance of a higher- loss system during the actual system testing. A mandrel is used to prevent the higher order modes from invalidating the test results. Mandrel diameters recommended for various multimode fiber jackets are listed in Table 6.

Figure 11) Mandrel wrap.

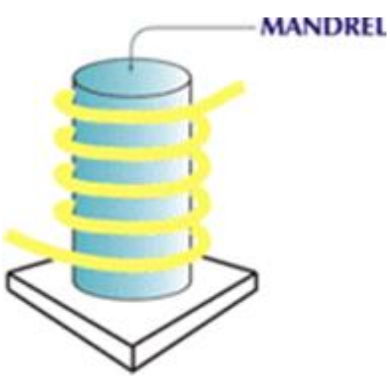


Table 6) Mandrel wrapping diameter with multimode fiber.

Jumper type (diameter)			
Mandrel Diameter vs. Fiber Type	2.0 mm Jacketed Cable, mm (in)	2.4 mm Jacketed Cable, mm (in)	3.0 mm Jacketed Cable, mm (in)
50 um	23 (0.9)	22.6 (0.9)	22 (0.9)
62.5 um	18 (0.7)	17.6 (0.7)	17 (0.7)

Equipment and accessories

- A stabilized light source provides a stabilized light of constant output power and known wavelength into the fiber for end-to-end attenuation testing. Light emitting diodes (LEDs) at 850nm and 1300nm are used for multimode testing, while 1310 and 1550nm lasers are used for testing single mode fibers. Vertical cavity surface emitting (VCSEL)-based light sources emitting at 850nm are used for high-date rate (>1 Gbps) multimode systems. (vendors: EXFO, Corning, Fluke, etc.)
- Optical power meter with a connector input matching that of the system. Most of the popular models can measure at the 850, 1300, and 1550nm wavelengths. Popular features include interchangeable connector adapters to easily test a variety of connectors, storage of multiple reference values, RF shielding to prevent errors caused by interference from electronic equipment like computers. (vendors: EXFO, Corning, Fluke, etc.)
- Wrapping mandrel with the appropriate diameter (vendors include Corning).
- Test fiber jumpers with the same fiber type as the system fiber. Factory-terminated jumpers are highly preferred.

Checks before field test

- Check that all test jumpers (end-to-end) and test fiber boxes (OTDRs) are of the same fiber core size and connector type as the cable system. For example, 50/125 < m test jumpers should be used when testing OM-2 (50/125 < m) fiber.
- Make sure that optical sources are stabilized and have center wavelengths within -/+20nm of the 850/1310nm multimode and 1310/1550nm single-mode nominal wavelengths. The TIA/EIA-526-14- A recommends that a multimode LED source should have spectral widths from 30 to 60nm at 850nm and 100 to 140nm at 1300nm.
- Check that the power meter is calibrated at each of the nominal wavelengths and traceable to the NIST calibration standard.
- Ensure that the power meter and the light source are set to the same wavelength.
- Ensure that all system connectors, adapters, and jumpers are cleaned properly before and during measurement (see section on Fiber Cleaning).

Procedure

End-to-end attenuation testing is performed by a simple three-step procedure in accordance with the following TIA/EIA specifications:

- Multimode fiber: OFSTP-14A
- Single-mode fiber: OFSTP-7A

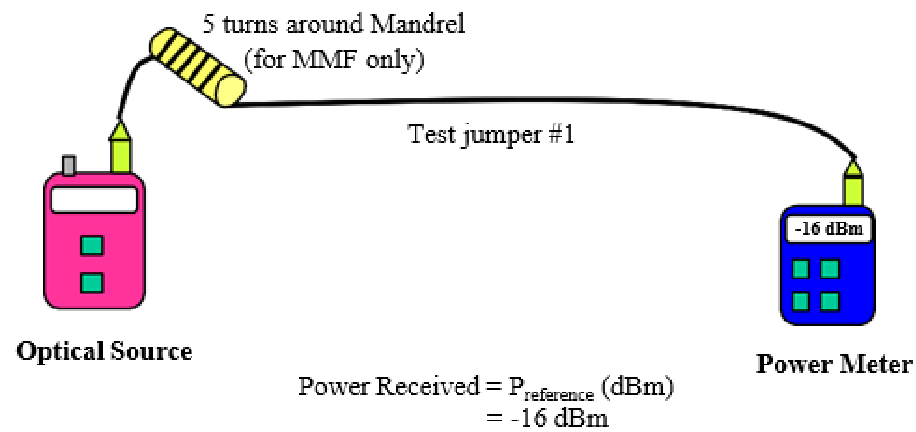
The procedure described is for patch panel to patch panel applications.

Step 1: Reference

A 1-jumper reference, as described below, is recommended because it leads to the most accurate results. A 2-jumper reference should only be used when the system begins at a patch panel and ends directly in end-equipment. A 3-jumper reference should only be used when the system begins and ends directly in the end equipment. Additional jumper referencing creates an inaccurate reference by eliminating potential loss events.

Connect a short test jumper between the optical source and the optical meter as shown in Figure 12. The mandrel wrapping ensures that the test results are representative of a system in operation. Record the reading as the reference power Preference in dBm. This is the power level of the light source coupled into the jumper. The jumper connection at the optical source must **not** be disconnected or adjusted after recording the reference value, Preference. Disturbing the jumper connection at the optical source may change the value and render the final test results inaccurate.

Figure 12) End-to-end attenuation test – Reference.

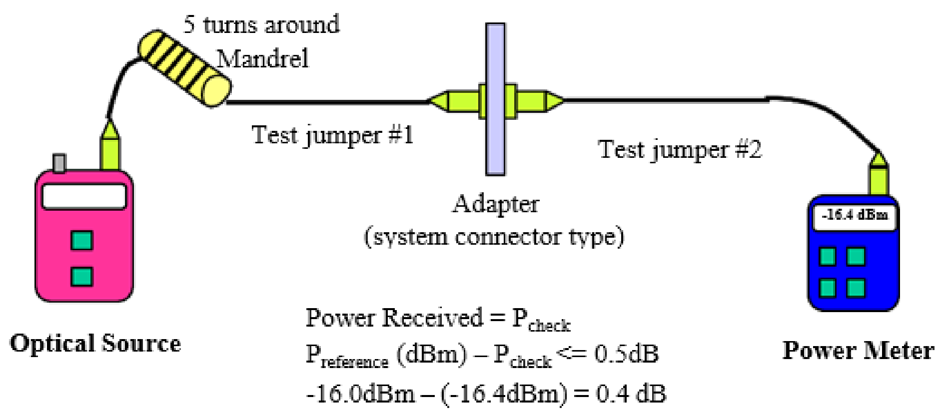


Step 2: Check

Disconnect test jumper #1 at the power meter and insert a second test jumper (test jumper #2), using an adapter, between the jumper used in Step 1 and the optical power meter (see Figure 13). Verify that the two test jumpers are good by ensuring that the power P`check` is within the appropriate connector loss, typically 0.5 dB of P`reference`. If this criterion is met, proceed to Step 3. Otherwise, clean all connectors except the source connection point and repeat Step 2. If the loss is still greater than 0.5 dB, replace test jumper #2 and repeat Step 2. If the loss is still greater than 0.5dB, then replace the adapter and repeat Step 2.

It is important to note that the 0.5 dB is typically used for factory-terminated test jumpers; and that the appropriate value is the guaranteed maximum pair loss for the specific type of connector used.

Figure 13) End-to-end attenuation test - Check.

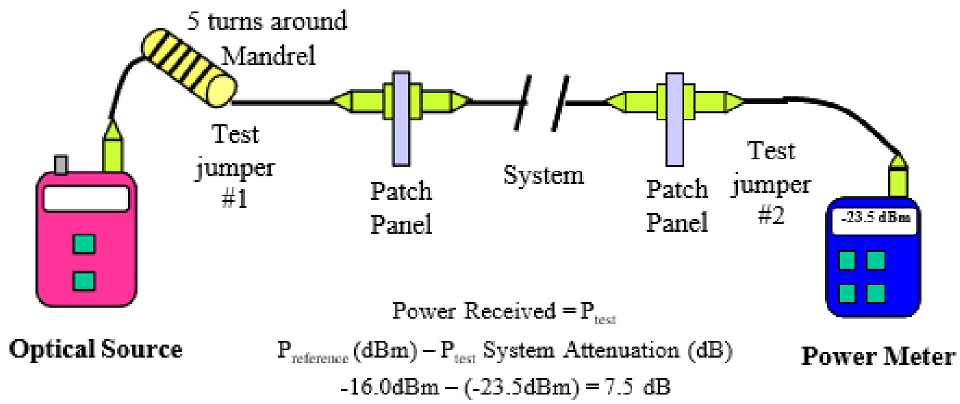


Step 3: Test

Disconnect the two jumpers at the adapter while leaving the two test jumpers attached to the optical source and optical meter. Attach the optical source/test jumper # 1 to one end of the system fiber to be tested and the power meter/test jumper #2 to the other end of the same fiber, as depicted in Figure 14.

Record the power level in dBm as Ptest and calculate the loss in dB. Repeat this step for each fiber to be tested.

Figure 14) End-to-end attenuation test – Test.



Application Guidelines By testing the attenuation of each segment from patch panel to patch panel, the loss of virtually any path can be determined by just adding the losses of the segments involved. This testing will ensure predictable system performance and allow routine maintenance checks.

It is highly recommended that you perform end-to-end attenuation tests at both specified wavelengths for every connector fiber in LAN and Data centers. Multimode fibers should be tested in one direction at 850 and 1300 nm, and single mode fibers should be tested in one direction at 1310 and 1550 nm to account for attenuation differences due to wavelength.

Acceptable link attenuation or system budget depends on link length, the number of splices, and the number of connector pairs. Maximum acceptable fiber attenuation values can be determined from the cable datasheet or the manufacturer's specifications. The attenuation value (dB/km) multiplied by length (km) will give you the maximum fiber attenuation (dB). If the link contains splices or connector pairs, add 0.3 dB per splice point and 0.75 dB per connector pair per TIA/EIA-568-B.3.

For example, the system in Figure 14 has 1.55 km of fiber, two connector pairs and two splices. If the fiber is 50/125 µm, the maximum fiber loss is 1.5 km multiplied by 3.5 dB/km @ 850 nm and 1.5 dB/km @ 1300 nm for values of 5.4 dB @ 850 nm and 2.3 dB @ 1300 nm. With a total connector loss of 1.5 dB and a total splice loss of 0.6 dB, the budget will be 7.5 dB @ 850 nm and 4.4 dB @ 1300 nm.

One needs to be aware that higher maximum losses for connector pairs and splices occur when multimode fibers of different core sizes or single-mode fibers of different mode field diameters are spliced or mated in a system. This loss will add to system loss and may prevent the system from operating.

OTDR testing

Background According to SB-1140, Tier 1 is required in all fiber optic cabling links and conforms to IA/EEIA-5526-14A and TIA/EIA-5526-7 (optical power loss measurements of installed multimode and single mode, respectively). Tier 2 testing with an OTDR is optional for LAN and data centers, but highly recommended, as a supplement to Tier 1. The OTDR trace is a graphical signature for each individual fiber link that provides insight into the quality of the installation and analyzes individual "events" such as cable, connectors, splices, and bends. An OTDR does not replace the need for a loss/length certification tool, but is used for additional valuation of the fiber link.

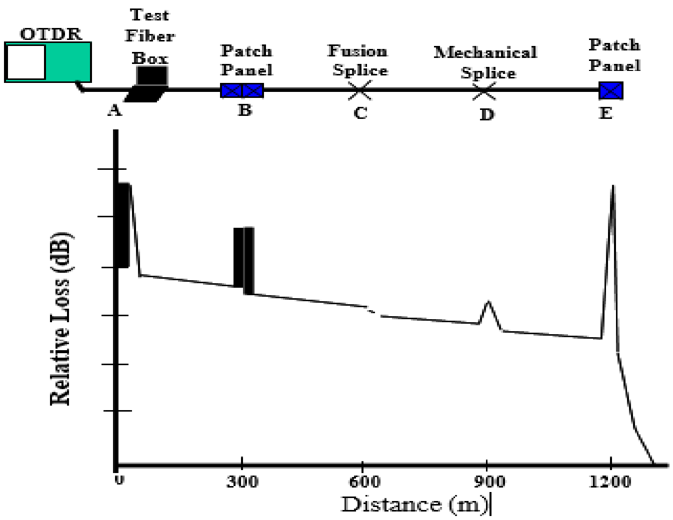
The OTDR provides detailed analysis of individual installed components with access to only one end of the fiber, making it is the most versatile installation and troubleshooting tool that can be used in a number of scenarios:

- Cable Acceptance – evaluates the integrity, overall length and fiber attenuation in dB/km for cables before and after installation.
- OTDR Signature Trace Documentation – provides useful documentation for cable system acceptance, network planning, and maintenance as the “as-built” fiber blueprint.
- Connector and Splice Loss – measures and documents field-installed connectors and midspan mechanical or fusion splices.
- Troubleshooting – provides a benchmark of initial system performance for comparisons over time and a powerful tool for identifying and locating cable problems or breaks by accessing only one end of the cable.

OTDR testing and trace analysis An OTDR works much like radar, sending pulses of laser light out through the fiber and then precisely measuring the time delay of the reflected pulses as they return. The OTDR presents this as loss and distance information in graphical format, providing a detailed overview of the entire cable length at once. **Error! Reference source not found.** shows an example of the information displayed by an OTDR:

- The OTDR plots distance in meters or feet on the horizontal scale and relative loss in dB on the vertical scale. The overall trace declines from left to right, indicating that the light is being attenuated by the fiber, connectors and splices as it travels down the length of cable.
- Linear sections represent continuous spans of cable.
- Slopes indicate distributed loss over a section of fiber (steeper slopes indicate higher fiber loss in dB/km).
- Vertical drops represent point losses at connectors (points A and B), splices (points C and D) and faults. The magnitude of the drop represents loss in dB.
- Spikes or humps indicate reflective events such as connectors (points A and B) or mechanical splices (point D) where the continuity of the glass is interrupted. The final spike on the trace indicates the end of the fiber (point E).
- Test fiber boxes are required to mitigate the effects of OTDR high-powered launches which may saturate the OTDR receiver due to reflections from the near end of the system fiber. This generates an inaccurate trace for the first several meters of the tested system. A minimum length of 100 m for multimode systems and 300 m for single-mode systems is required. Test fiber boxes must have the same fiber core diameter as the system fiber being tested.

Figure 15) OTDR trace.



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OTDR Equipment: The OTDR is the single most versatile fiber optic installation tool. Versatile OTDRs include:

- Dual 850/1300 nm multimode operation as well as the capability of supporting 1310/1550 nm single-mode operation in the same unit.
- Portable, battery-powered operation.
- A companion PC software package for analysis, comparison and printing of saved traces.

OTDRs are available from multiple vendors including Fluke, EXFO, JDSU, etc.

Summary of cable system testing

Table 7) Summary of cable system testing. [4]

Premises segment			
Test method	**Backbone cabling (LAN)**	**LAN & data center (horizontal cabling)**	**Equipment required**
End-to-end attenuation (required)	Dual wavelength insertion loss in one direction: * MM: 850 & 1300nm * SM: 1310 & 1550nm	850 or 1300nm (multimode)	*Optical meter *Optical source *2 test jumpers *One adapter *Wrapping mandrel
OTDR Test (optional Only for inside plant	OTDR inspection of each fiber >100m * MM: 850 and 1300nm * SM: 1310 and 1550nm Dual wavelength or bi-directional testing as required	Troubleshooting as required for links exceeding the budget limit	*OTDR *Test fiber box
Discrete connector and spice loss (optional only for outside and inside plant)	OTDR measurement for each field-terminated connector and each splice at 1 wavelength * MM: 850 and 1300nm * SM: 1310 and 1550nm	Troubleshooting as required for links exceeding the budget limit	*OTDR *Test fiber box

Documentation

Documenting test results quantifies system quality, identifies system faults, and establishes accountability when multiple vendors are involved. Maintaining an accessible documentation of the following test results and cable records is highly recommended. Moreover, formatting this documentation in accordance with the requirements stated in TIA/EIA-606, “Administration Standard for the Telecommunications Infrastructures of Commercial Buildings,” is beneficial.

Test results

- End-to-End Attenuation Data
- OTDR Signature Traces
- Certificate of Compliance for Connector and Splice Loss

Cable records

- Cable Specifications –minimum optical and mechanical performance guaranteed for the cable.
- Cable Route Diagram – should include:
  - Fiber routing and location information
  - Fiber connectivity information
  - Splice point locations
  - Patch panel locations
  - Cable lengths
  - Cable part numbers

Safety, handling, and cleaning procedures

Laser safety procedures

Transceiver Modules are equipped with a Class 1 Laser, which emits invisible radiation. Laser output from fiber optic products can and will damage eyesight under certain conditions. The following guidelines should be observed.

- Read the product datasheet and the laser safety label before powering the product. Note the operating wavelength, optical output power, and safety classification.
- Connect a fiber to the output of the device before power is applied.
- Never stare into open optical ports or the end of a fiber to see if light is coming out. Most fiber optic laser wavelengths (850, 1310, and 1550 nm) are invisible to the naked eye.
- Never look into the end of a fiber on a powered device with any sort of magnifying device. This includes microscopes, eye loupes, and magnifying glasses. This may cause a permanent, irreversible burn on your retina. Always double check that power is disconnected before using such devices.

Working with SFP transceiver modules

Use these guidelines when working with SFP modules:

- SFP modules are static sensitive. Wear an ESD-preventive wrist strap that is connected to the chassis in order to prevent ESD damage.
- SFP modules are dust-sensitive. Always store the devices with appropriate plugs installed in the optical bores.
- Do not remove and insert an SFP module more often than is necessary. Repeated removals and insertions of a SFP module will shorten its useful life.

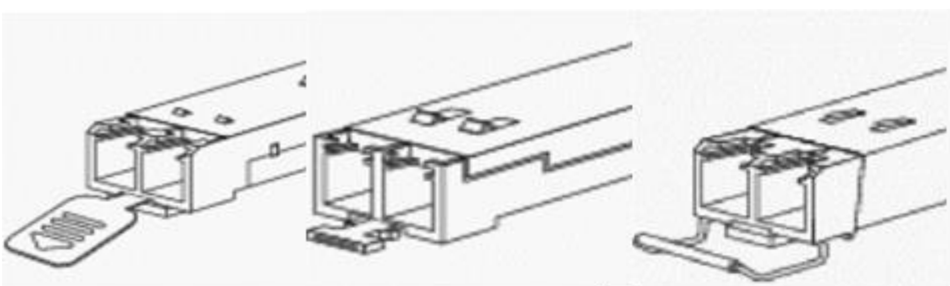
- For optical SFP transceivers, before the dust plugs are removed and any optical connection is made, it is important to always observe these guidelines:
- Keep the protective dust plugs on the unplugged fiber-optic cable connectors and the transceiver optical bores until a connection is made.
- Inspect and clean the LC connector end-faces just before making any connections.
- Grasp the LC connector housing to plug or unplug a fiber-optic cable. Do not pull the fiber-optic cable to disconnect the LC connector.

Required Tools for SFP module installation and removal The following tools are recommended for SFP module insertion and removal:

- Wrist strap to prevent ESD occurrences.
- Antistatic mat to set the transceiver on.
- Fiber-optic end-face cleaning tools and inspection equipment

SFP module installation procedure SFP Transceivers are hot-swappable input/output (I/O) devices that plug into FC ports. Use only SFP modules that are recommended by NetApp. SFP Transceiver modules can have three types of latching devices to secure an SFP transceiver in a port socket: (a) Mylar tab latch, (b) actuator button latch, and (c) bale-clasp latch. These are depicted in Figure 16. You need to determine which type of latch your SFP transceiver has before starting the installation procedure.

Figure 16) 3 types of latching devices for SFP transceiver modules (from Left to Right): (a) Mylar tab latch, (b) actuator button latch, and (c) bale-clasp latch.



Steps for the installation of SFP transceiver modules are:

1. Attach an ESD-preventive wrist strap to your wrist and to the ESD ground connector or a metal surface on the equipment chassis.
2. Remove the SFP Transceiver Module from its protective packaging. Verify that you have the correct model of transceiver for your application by checking the label on the SFP module. The optical bore dust plugs should not be removed until Step 5.
3. Find the send (TX) and receive (RX) markings that identify the top-side of the SFP transceiver.
4. Position the SFP transceiver in front of the socket opening and insert the SFP transceiver module into the socket until the module connector snaps into place in the socket connector.
5. Remove the dust plugs from the network interface cable LC connectors. Save the dust plugs for future use.
6. Remove the dust plugs from the SFP transceiver optical bores and immediately attach the network interface cable LC connector to the SFP transceiver.
7. Observe the port status LED: The LED turns green when the SFP transceiver and the target device have an established link. If the LED remains off or red, the user needs to refer to the Troubleshooting section of the hardware guide.

SFP module removal procedure: To remove the SFP transceiver:

1. Attach an ESD-preventive wrist strap to your wrist and to the ESD ground connector or a metal surface on the equipment chassis.
2. Disconnect the network fiber-optic cable from the SFP Transceiver Module connector and immediately reinstall the dust plugs in the SFP transceiver optical bores and the fiber-optic cable LC connectors.
3. Release and remove the SFP Transceiver Module from the socket connector.
4. If the SFP transceiver has a Mylar tab latch, pull the tab in a slightly downward direction until the transceiver disengages from the socket connector, and then pull the SFP transceiver straight out. Do not twist or pull the Mylar tab because you could detach it from the SFP transceiver.
5. If the SFP transceiver has an Actuator button latch, press the actuator button on the front of the SFP transceiver until the latch mechanism releases the SFP transceiver from the socket connector. Grasp the actuator and carefully pull the SFP transceiver straight from the module slot.
6. If the SFP transceiver has a Bale-clasp latch, pull the bale out and down to eject the SFP transceiver from the socket connector. If the bale-clasp latch is obstructed, use a small flat-blade screwdriver to open the bale-clasp latch. Grasp the SFP transceiver and carefully remove it from the socket.
7. Place the removed SFP transceiver in an antistatic bag or other protective environment.

Care and handling of optical patch cords, bulkheads and receptacles

A number of events can damage fiber optic connectors, bulkheads and receptacles. Unprotected connector and receptacle ends can experience damage by impact, airborne dust particles, or excess humidity or moisture. The increased optical output power of modern lasers also has the potential to damage a connector. Just a few milliwatts at 850nm will do permanent damage to a retina.

The user is reminded to always:

- Turn off any laser sources before you inspect fiber connectors, receptacles, or bulkheads.
- Make sure that the cable is disconnected at both ends or that the card or pluggable receiver is removed from the chassis.
- Wear the appropriate safety glasses when required in your area.
- Inspect the connectors or adapters before you clean.
- Inspect and clean the connectors before you make a connection.
- Use the connector housing to plug or unplug a fiber.
- Keep a protective cap on unplugged fiber connectors.
- Store unused protective caps in a resealable container in order to prevent the possibility of the transfer of dust to the fiber.

Additionally, the user is warned to:

- Never clean an optical connector attached to a fiber that is carrying light. Note that typical cleaning materials, such as tissues saturated with alcohol, will combust almost instantaneously when exposed to optical power levels of +15 dBm or higher, thus destroying the connector’s ability to carry light with low loss.
- Never wet clean without a way to ensure that it does not leave residue on the endface.
- Never look into a fiber or connect a fiber to a fiberscope while the system lasers are on.
- Never clean bulkheads or receptacle devices without a way to inspect them.
- Never touch products without being properly grounded.
- Never use unfiltered handheld magnifiers or focusing optics to inspect fiber connectors.
- Never touch the end face of the fiber connectors or the clean area of a tissue, swab, or cleaning fabric.
- Never reuse any tissue, swab or cleaning cassette reel.

- Never touch the dispensing tip of an alcohol bottle or any portion of a tissue or swab where alcohol was applied.
- Never use alcohol around an open flame or spark.

Cleaning of patch cords

It is recommended that dry cleaning be attempted first. Then if patch cord connectors are still contaminated upon inspection, a second dry cleaning may be applied. One should resort to wet cleaning only if the second dry cleaning attempt is determined to not be effective in eliminating contamination.

Dry cleaning Dry cleaning of optical patch cords can be performed in a number of ways: (i) the use of cartridge cleaning tools such OPTIPOP and CLETOP or pocket style cleaners like CARDCLEANER, (ii) the use of lint-free wipes, and (iii) the use of lint-free swabs.

In this section, we detail the use of lint-free wipes. 99% isopropyl alcohol is also required.

1. Make sure that the laser is turned off before you begin the inspection. Remove the protective endcap and store it in a small resealable container.
2. Inspect the connector with a fiberscope.
3. Fold the wipe into a square about 4 layers thick.
4. Moisten one section of the wipe with one drop of 99% alcohol. Be sure that a portion of the wipe remains dry.
5. Lightly wipe the ferrule tip in the alcohol moistened portion of the wipe with a figure “8” motion. Immediately repeat the figure “8” motion on the dry section of wipe to remove any residual alcohol. Do not scrub the fiber against the wipe as doing so may cause scratches.
6. Properly dispose of the wipe. Never reuse a wipe.
7. Inspect the connector again with a fiberscope.
8. Repeat the process as necessary.

Cleaning of bulkheads and receptacles

Receptacles refer to packaged devices with optical ports, such as SFP transceivers. Many receptacle devices use lens-based systems, which are less sensitive to contamination as opposed to fiber, but can be damaged if cleaned improperly. If you inspect a receptacle device and are not able to focus on the endface cladding, then you have a lensed device and should not attempt to clean it. Some general guidelines for cleaning bulkheads and receptacles:

- Wet cleaning is not recommended for bulkheads and receptacles. Damage to equipment can occur.
- Make sure you plug in a clean mating connector in order to avoid cross contaminating the receptacle side. Ground in contamination is much harder to remove than loose debris.
- Remember, inspect first and clean only if necessary!
- The use of swabs for cleaning is not always effective. It might be better to leave an optical port alone unless contamination is observed blocking the core. Contaminants can be pushed onto the endface in the process of inserting the swab.
- Do not clean bulkheads or receptacles without a way to inspect them afterwards. Cleaning can actually leave the endface in worse condition.

Dry-cleaning procedure for bulkheads and receptacles: This technique requires the use of lint-free swabs.

1. Make sure that the laser is turned off before you start the inspection. Remove the protective endcap and store it in a resealable container.
2. Inspect the fiber connector in the adapter or bulkhead with a fiberscope probe. If the adapter is dirty, select the appropriate lint-free swab according to the connector ferrule size.

3. Inspect the connector in the adapter again with a fiberscope probe.
4. Insert the clean lint-free swab into the adapter.
5. Turn the swab several complete revolutions in the same direction.
6. Properly dispose of the swab. Never reuse a swab.
7. Repeat the cleaning process as necessary.

- **Wet-cleaning procedure for bulkheads and receptacles**: If the dry-cleaning procedure did not remove the dirt from the fiber endface, then use 99% isopropyl alcohol and lint-free swabs to perform wet cleaning.
- Make sure that the laser is turned off before you start the inspection. Remove the protective endcap and store it in a resealable container.
- Inspect the fiber connector in the adapter or bulkhead with a fiberscope probe. If the adapter is dirty, select the appropriate lint-free swab according to the connector ferrule size.
- Place one drop of 99% alcohol to lightly moisten a new lint-free swab, but without oversaturating the swab. A dry lint-free swab should be made available for drying immediately after the cleaning. Ensure that the drying swab stays clean.
- Lightly press and turn the dampened swab to clean the ferrule face.
- Immediately after you clean, lightly press and turn a dry swab to dry any alcohol that remains on the ferrule face. Never reuse a swab.
- Inspect the connector again.

Note that the use of isopropyl alcohol is not without concerns. If not removed completely from the connector or adapter, residual liquid alcohol acts as a transport mechanism for loose dirt on the endface. If the alcohol is allowed to evaporate slowly off the ferrule, it can leave residual material on the cladding and fiber core.

Troubleshooting

The three key elements for efficient troubleshooting and service restoration in the case of system error or failure troubleshooting are:

Documentation Initial test results and cable records are necessary for contrasting current test results with the original documentation. This will quickly and clearly identify changes and potential trouble spots.

Test Equipment Initial attenuation test results using a simple power meter can isolate faults, eliminate unnecessary service calls, and minimize downtime. Faulty patch cords can be replaced. If the problem is with the cable plant, an OTDR can be used to pinpoint its exact fault location.

Troubleshooting Plan A simple but effective flow chart or procedure should be used to quickly isolate a fault to either a network transmitter, receiver, patch cord or cable segment. The first step requires only a power meter, test jumper and the “as-built” documentation.

Test equipment for troubleshooting

An optical power meter is used to perform the first step in troubleshooting. A compact, no-frills power meter designed for measuring only dBm power levels is suitable for maintenance purposes.

Once a fault is isolated to the installed cable link, an OTDR’s single-ended testing capability is efficient in pinpointing the fault within the cable. However, the OTDR’s dead-zone limits its usefulness in cases where a fault is near an endpoint or within the connecting hardware. In such situations, a visual fault locator (VFL) can nicely complement an OTDR. VFL uses visible red laser source (wavelength ~ 650 nm) to locate faults or points of high loss near endpoints such as tight bends or crimps, faulty connectors, poor splices, damaged components and fiber breaks.

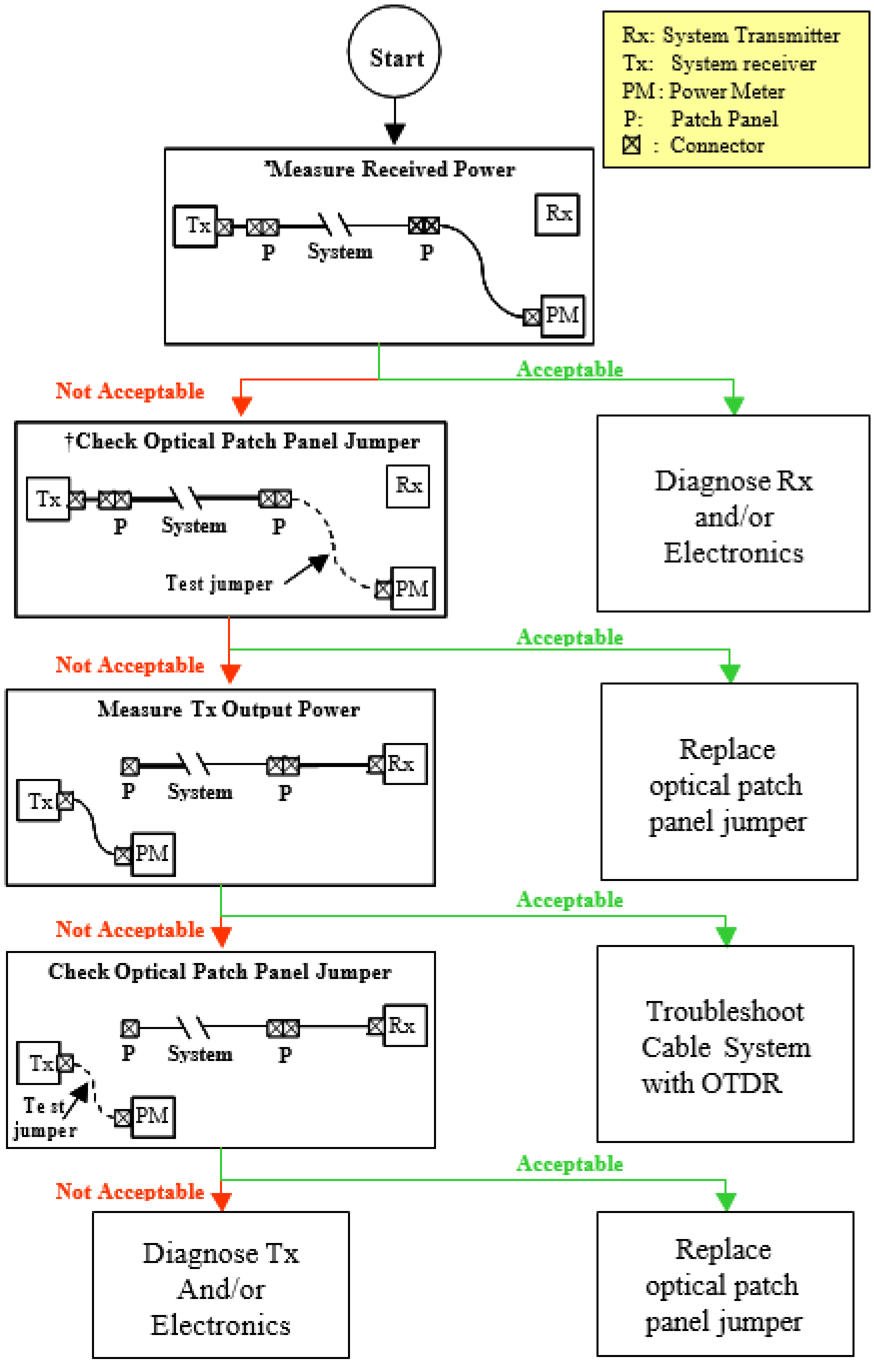
Fiber talk sets provide simple point-to-point communication over the installed cable during installation, testing, maintenance and restoration. Unlike two-way radios, they do not create error-causing RF interference that can disturb test equipment.

Additionally, endface inspection can be a useful troubleshooting capability. With a 250x or higher 400x camera (or camera attachment to an OTDR mainframe), one can view and correct for marginal or faulty polishes or unclean fiber endfaces that might have reduced system headroom.

Fiber link troubleshooting

The troubleshooting diagram in **Error! Reference source not found.** steps through the sequence for isolating and locating faults. First, the received optical power is measured and compared to the receiver sensitivity specification. If the received power is normal, the receiving electronics should be diagnosed to identify the problem. However, if the received power level is low, the transmitter output power should be tested next. A low transmitter output indicates a problem with the transmitter output or electronics. In these cases, you may need to remove the transceiver and plug in another vendor-recommended transceiver or contact the vendor for support. If the transmitter output is normal and the received power is low, excessive loss is occurring in the cable plant. A power meter and a test jumper are then used to confirm whether the fault is with the system jumper. If the system jumpers have acceptable loss, then the fault probably lies within the terminated cable plant itself. Losses in the cable plant are most often caused by damaged connectors and cut or damaged cable.

Figure 17) Troubleshooting diagram [4].



* If all systems fail simultaneously, then (a) troubleshoot with OTDR for cable cut, or (b) check power for a power failure

Appendices

Power budget

Project:	Span:		
Transceiver Manufacturer:			
Transceiver Manufacturer P/N:			
Type of Fiber:			
Transmitter Wavelength:			nm
Bit Rate:			Gbps
A) Minimum Transmitter Output Power:			dBm
B) Worst Case (or Maximum) Receiver Sensitivity:			dBm
C) System Gain: (A - B) or manufacturer specified optical budget			dB
D) Losses Due to Connectors: (per manufacturer's specifications)			dB
E) Losses Due to Installation Splice:			dB
F) Safety Margin and Margin for future Repair Splices[*]:			dB
G) Margin for future WDM Upgrade (addition of optical Mux/Demux, Splitters, etc.):			dB
H) Maximum Allowable Optical Fiber Link Loss: (C-D-E-F-G)			dB
I) Fiber Attenuation (from Table 1 or fiber manufacturer):			dB/km
J) Maximum Allowable power-limited Fiber Span Length (1000*H/I)			m
K) Maximum Allowable Bandwidth-Limited Fiber Span Length (from Table1; Applies			m
L) Maximum Allowable Fiber Span Length (Minimum of J and K)			m

Note: If (L) is less than the fiber span required in your application, installation tests by a qualified technician is recommended to assess the possibility of extending the fiber span length based on measurement results and/or actual tests with MetroCluster equipment.

The presence of significant optical reflections will make link performance poorer than calculated values.

[*]: Safety margin includes power penalty due to dispersion penalty caused by signal propagation in fiber.

References

[1] Russell Ellis, "The Importance of minEMBc Laser Bandwidth Measured Multimode Fiber for High Performance Premises Networks", Corning White paper WP1150, October 2006

[2] M. Connaughto and M. E. Adcox, "Taking advantage of Multimode Fiber for Premises Applications," Electrical Contractor, May 1999

[3] "Why choose multimode fiber?", Communications News, March 2006

[4] Corning Cable Systems, Design Guide, 2005

Refer to the Interoperability Matrix Tool (IMT) on the NetApp Support site to validate that the exact product and feature versions described in this document are supported for your specific environment. The NetApp IMT defines the product components and versions that can be used to construct configurations that are supported by NetApp. Specific results depend on each customer's installation in accordance with published specifications.

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