RLH Industries, Inc.

Calculating Fiber Loss & Distance

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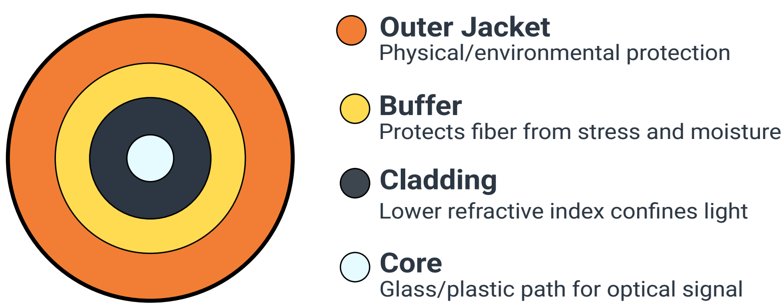
Introduction

Fiber Advantages

Fiber optic cabling has traditionally been associated with long-distance communications. Today, however, it is rapidly gaining market share in Local Area Networks (LANs), a market once dominated by copper cabling. As networks continue to grow and bandwidth requirements, LANs are increasingly connecting to Metropolitan Area Networks (MANs), and Fiber to the Premises (FTTx) deployments are becoming more common. At the same time, the cost of fiber has decreased, installation methods have improved, and a growing range of networking equipment now supports fiber connectivity. These advancements, combined with fiber's superior performance and reliability, have made it an increasingly popular choice for modern network infrastructure. Its growing adoption is driven by the following key advantages:

- **Distance:** Supports transmission distances of up to 120 km (75 miles) under ideal conditions, far exceeding the capabilities of copper cabling.
- **Electrical Isolation:** Provides complete electrical isolation, helping protect equipment from lightning strikes, ground potential differences, and other electrical faults.
- **Immunity to Electromagnetic Interference (EMI):** Fiber is immune to electromagnetic interference generated by high-voltage power lines, electric motors, radio transmitters, and other electrical equipment.
- **Bandwidth:** While Gigabit Ethernet operates at the same data rate over both copper and fiber, fiber's significantly greater bandwidth capacity enables technologies such as wavelength-division multiplexing (WDM), allowing multiple independent data channels to be transmitted simultaneously over a single fiber.
- **Security:** Fiber optic cables are much more difficult to tap than copper or wireless communications. Intercepting fiber traffic typically requires physical access to the cable and specialized equipment, making unauthorized monitoring easier to detect.
- **Lightweight:** Fiber optic cables are smaller and lighter than equivalent copper cables, making them easier to install and advantageous where cable weight is a concern.
- **Long Service Life:** Glass fiber is not susceptible to corrosion like copper conductors, providing excellent durability and long-term reliability in harsh environments.



Fiber Cable Structure

Fiber optic cable consists of three components:

- **Core:** The central, very small strand of high-quality glass or plastic through which light signals are transmitted.
- **Cladding:** A layer of high-quality glass surrounding the core with a slightly lower refractive index (typically 1–2% lower than the core). This difference in refractive index keeps the light confined within the core through total internal reflection.
- **Buffer and Outer Jacket:** Protective layers, typically made of plastic. The buffer protects the fiber from mechanical stress and moisture, while the outer jacket provides additional environmental and physical protection. Depending on the cable construction, strength members such as aramid (Kevlar®) fibers may also be included to improve tensile strength.

Light signals are coupled into the fiber using one of three common optical sources:

- Light Emitting Diode (LED)
- Vertical-Cavity Surface-Emitting Laser (VCSEL)
- Laser Diode

The choice of optical source depends on the fiber type, transmission distance, and required data rate.

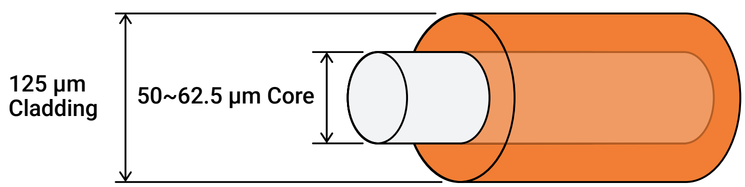
For applications requiring higher optical power, longer transmission distances, or higher bandwidth, laser-based transmitters are typically used. LEDs are generally found in lower-speed, shorter-distance multimode applications, while VCSELs are commonly used for high-speed multimode Ethernet. Laser diodes are primarily used with single-mode fiber for long-distance, high-performance communications.

Multimode Fiber

Multimode fiber (MMF) is the most common type of fiber optic cabling used for short-distance communications within buildings. It is widely specified by IEEE, ANSI, TIA, and ISO standards for Local Area Networks (LANs) and data center applications.

Typical multimode fiber core sizes:

- 50/125 µm – The current industry standard for new installations (OM2, OM3, OM4, and OM5)
- 62.5/125 µm – Common in legacy installations (OM1)
- Other core sizes, such as 100 µm, exist but are rarely used for Ethernet networking



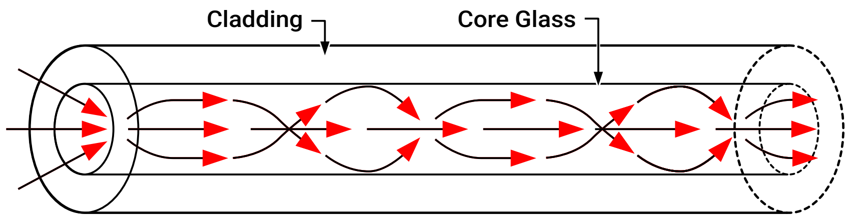
Multimode Fiber Cross-Section

Multimode Fiber Characteristics

- Multiple propagation paths (modes)
- Lower transceiver costs than single-mode systems
- Ideal for short- to medium-distance applications
- Available in high-bandwidth laser-optimized versions
- Commonly used for LANs, enterprise networks, and data centers

The term multimode refers to the fact that multiple light rays, or modes, propagate through the fiber core simultaneously. As light travels down the fiber, it reflects from the core-to-cladding boundary through the principle of total internal reflection. Because each mode follows a slightly different path, some light rays arrive at the receiver later than others, creating a phenomenon known as modal dispersion, which limits the maximum transmission distance and bandwidth. Two multimode fiber designs have historically been used:

- **Step-Index Fiber:** The refractive index changes abruptly between the core and cladding, causing light to follow highly reflective, zigzag paths. Step-index multimode fiber has relatively high modal dispersion and is rarely used for modern data communications.
- **Graded-Index Fiber:** The refractive index gradually decreases from the center of the core toward the cladding, causing light rays to follow smooth, curved paths that minimize differences in travel time. Nearly all multimode Ethernet fiber installed today uses graded-index construction.

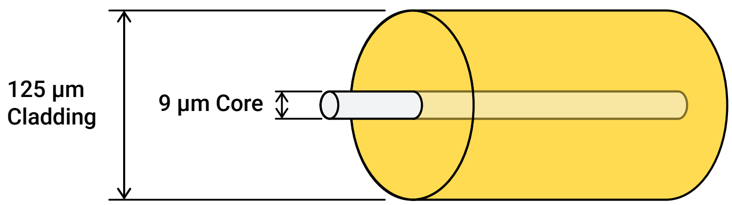


Multimode Fiber Diagram

Modern multimode networks typically use VCSEL (Vertical-Cavity Surface-Emitting Laser) transmitters operating at 850 nm. Laser-optimized multimode fibers such as OM3, OM4, and OM5 support Gigabit, 10 Gigabit, 40 Gigabit, and 100 Gigabit Ethernet over distances up to several hundred meters, depending on the Ethernet standard.

Single-Mode Fiber

For applications requiring greater transmission distances, higher bandwidth, or future scalability, single-mode fiber (SMF) is the preferred choice. Single-mode fiber has a much smaller core diameter than multimode fiber, typically 9 µm, with a standard 125 µm cladding diameter.

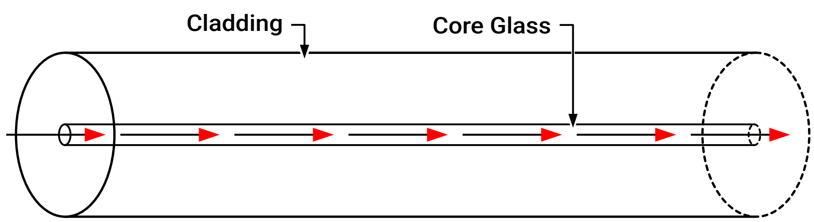


Single-Mode Fiber Cross-Section

Single-Mode Fiber Characteristics

- Single propagation mode
- Extremely long transmission distances
- Very high bandwidth capacity
- Low signal attenuation and minimal dispersion
- Primarily used for Metropolitan Area Networks (MANs), Wide Area Networks (WANs), campus backbones, telecommunications, and increasingly for enterprise networks and data centers

Unlike multimode fiber, single-mode fiber supports only a single propagation mode. Because there is only one optical path, modal dispersion is essentially eliminated, allowing signals to travel much greater distances while maintaining high data rates. Light remains confined within the core by total internal reflection, but the small core diameter permits only one propagation mode to exist.



Single-Mode Fiber Diagram

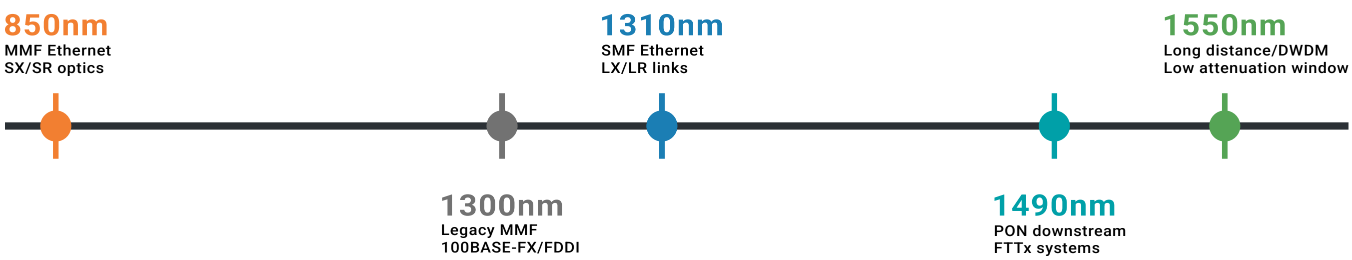
Single-mode fiber is designed for use with laser-based transmitters, typically operating at wavelengths of 1310 nm or 1550 nm, where fiber attenuation is lowest. These wavelengths enable transmission distances ranging from several kilometers to well over 100 km, depending on the optical transceivers and network design.

Historically, single-mode installations were significantly more expensive than multimode due to the cost of precision laser optics. Today, the cost of single-mode fiber cable is comparable to multimode cable, and the price of optical transceivers has decreased substantially. As a result, many new network backbones—and an increasing number of new enterprise installations—are choosing single-mode fiber to provide greater performance and long-term scalability.

Wavelengths

Ethernet and other fiber optic communication systems use several standardized optical wavelengths. The wavelength selected depends on the fiber type, Ethernet standard, transmission distance, and optical transceiver.

Common Ethernet Optical Wavelengths



Common Ethernet Optical Wavelengths

Wavelength selection depends on fiber type, Ethernet standard, reach, and transceiver specifications.

- **850 nm (Multimode):** The most common wavelength used with multimode fiber. It is the standard for 1000BASE-SX, 10GBASE-SR, 25GBASE-SR, 40GBASE-SR4, and 100GBASE-SR4 Ethernet. VCSEL transmitters operating at 850 nm provide a cost-effective solution for short-distance LAN and data center applications.
- **1300 nm (Multimode):** Historically used by 100BASE-FX Fast Ethernet, FDDI, ATM, and other legacy networking technologies. While still found in some installed systems, new Ethernet deployments rarely use 1300 nm over multimode fiber.
- **1310 nm (Single-Mode):** A standard wavelength for many single-mode Ethernet applications, including 1000BASE-LX, 10GBASE-LR, 25GBASE-LR, and numerous other IEEE Ethernet standards. It is commonly used for campus networks and metropolitan links requiring distances from several kilometers to tens of kilometers.
- **1490 nm (Single-Mode):** Commonly used in Passive Optical Networks (PON), including GPON and EPON systems, for downstream transmission. Although not typically used for standard Ethernet links, it is widely deployed in Fiber-to-the-Premises (FTTx) networks.
- **1550 nm (Single-Mode):** Used for long-distance Ethernet, Dense Wavelength Division Multiplexing (DWDM), and telecommunications networks. The 1550 nm window offers the lowest fiber attenuation and supports transmission distances exceeding 100 km with appropriate optics. It is also widely used for CATV optical distribution and high-capacity transport networks.

Modern optical systems may also employ Coarse Wavelength Division Multiplexing (CWDM) and Dense Wavelength Division Multiplexing (DWDM) technologies, which allow multiple optical wavelengths to be transmitted simultaneously over a single fiber pair, dramatically increasing available bandwidth without installing additional fiber.

Fiber Standards

To better understand how fiber optic cabling is used in Ethernet networks, it is helpful to have a basic understanding of the standards developed by the Institute of Electrical and Electronics Engineers (IEEE). The IEEE is an international professional organization that develops widely adopted standards for networking technologies, including the IEEE 802.3 Ethernet family of standards.

IEEE Ethernet standards define the physical media, signaling methods, transmission distances, wavelengths, and performance requirements needed to ensure interoperability between networking equipment from different manufacturers.

The following table summarizes many of the most common IEEE fiber optic Ethernet standards, including the supported fiber type, operating wavelength, typical maximum distance, and intended application.

Standard	Data Rate	Fiber type	Max. Distance
10Base-FL	10	Multimode: 850 nm; 50/125µm or 62.5/125µm	2 km
100Base-FX	100	Multimode: 1300 nm; 50/125µm or 62.5/125µm	2 km
100Base-SX	100	Multimode: 850 nm; 50/125µm or 62.5/125µm*	300 m
100Base-LX	100	Single-mode: 1310nm, 1550nm, 9/125µm	10 km
1000Base-SX	1000	Multimode: 850 nm; 62.5/125µm	220 m
		Multimode; 850 nm; 50/125µm	550 m
1000Base-LX	1000	Multimode: 1300 nm; 50/125µm or 62.5/125µm**	550 m
		Single-mode: 1310 nm; 9/125µm	5 km
1000Base-LH***	1000	Single-mode: 1310 nm; 9/125µm	70 km
1000Base-ZX***	1000	Single-mode: 1550 nm; 9/125µm	120 km

- *TIA/EIA-785 Standard, not an IEEE standard
- **Launch conditioning patch cord required
- ***Not an IEEE standard but is used in the industry

Fiber Terminology

Before examining fiber optic link budget calculations, it is helpful to become familiar with several commonly used fiber optic terms and definitions. Understanding these concepts will make it easier to evaluate fiber performance, interpret product specifications, and design reliable optical communication systems.

- **Launch Power:** The optical output power emitted by a fiber optic transmitter and coupled into the fiber. Launch power is typically specified in dBm (decibels referenced to 1 milliwatt).
- **Receiver Sensitivity:** The minimum optical power required by a receiver to correctly detect and recover the transmitted signal while maintaining the specified bit error rate (BER). Receiver sensitivity is specified in dBm.
- **Receiver Saturation (Maximum Input Power):** The highest optical power level a receiver can tolerate while operating correctly. Optical power above this level may overload the receiver, resulting in increased bit errors or complete loss of communication. Receiver saturation is specified in dBm.
- **Optical Power Budget (Link Budget):** The maximum allowable optical loss between the transmitter and receiver.
- **Attenuation:** The reduction in optical signal power as light travels through the fiber. Attenuation is caused by absorption, scattering, connector losses, splice losses, bends, and other imperfections in the optical path. It is typically expressed as dB/km for fiber cable and dB for individual components.
- **Modal Dispersion (Intermodal Dispersion):** A phenomenon unique to multimode fiber in which multiple propagation modes travel different distances and arrive at the receiver at different times. This pulse spreading limits the maximum transmission distance and bandwidth of multimode fiber. Graded-index multimode fiber significantly reduces modal dispersion compared to step-index fiber.
- **Chromatic Dispersion:** A form of dispersion caused by different wavelengths of light traveling through the fiber at slightly different speeds. Chromatic dispersion primarily affects single-mode fiber over long distances and becomes increasingly important at higher data rates.
- **Insertion Loss:** The total optical power lost when a component, connector, or section of fiber is inserted into the optical path. Insertion loss is measured in dB and is commonly used to evaluate connectors, patch panels, splitters, and complete fiber links.

Calculating Fiber Loss and Distance

Single-Mode Fiber

Determining whether a fiber optic link will operate reliably requires calculating the optical link budget. A link budget compares the optical power available from the transmitter with the total optical loss between the transmitter and receiver. If the total link loss is less than the available optical power budget (including a safety margin), the link should operate reliably.

Because optical attenuation varies with both fiber type and operating wavelength, the expected loss depends on the specific fiber and transceivers being used. The most common Ethernet wavelengths are 850 nm (multimode), 1310 nm (single-mode), 1490 nm (PON applications), and 1550 nm (long-distance single-mode and DWDM applications).

Fiber attenuation is typically specified in dB/km by the cable manufacturer, while complete installed links are often verified by measuring the total insertion loss in dB using an optical loss test set (OLTS) or optical time-domain reflectometer (OTDR).

Because the decibel scale is logarithmic, relatively large percentage changes in optical power correspond to modest changes in dB.

- 3 dB ≈ 50% power loss
- 10 dB = 90% power loss
- 20 dB = 99% power loss
- 30 dB = 99.9% power loss

Factors Affecting Fiber Link Loss

Fiber Attenuation

As light travels through the fiber, optical power gradually decreases due to absorption, Rayleigh scattering, and other material characteristics. Fiber attenuation depends on both the fiber type and the operating wavelength. Typical attenuation values are:

- Multimode (850 nm): approximately 3.0 dB/km
- Multimode (1300 nm): approximately 1.0 dB/km
- Single-mode (1310 nm): approximately 0.35 dB/km
- Single-mode (1550 nm): approximately 0.20 dB/km

Actual specifications should always be obtained from the fiber manufacturer.

Multimode - Modal Dispersion

Modal dispersion affects only multimode fiber. Because multiple propagation modes travel different distances through the fiber, pulses spread as they travel. As data rates increase, the maximum supported distance decreases. Modern laser-optimized fibers (OM3, OM4, and OM5) significantly reduce modal dispersion compared to earlier multimode fibers.

Chromatic Dispersion

Single-mode fiber does not suffer from modal dispersion, but it is affected by chromatic dispersion. Different wavelengths within a light pulse travel at slightly different speeds, causing pulse spreading over long distances. Chromatic dispersion becomes increasingly important at high data rates and over long fiber runs.

Splice Loss

Every fusion splice introduces a small amount of optical loss. Modern fusion splices typically have losses of 0.02 to 0.10 dB, while mechanical splices generally exhibit slightly higher losses. Although individual splice losses are small, they should always be included in the link budget.

Connector Loss

Each fiber connector contributes to insertion loss. Typical values are:

- LC: 0.15–0.30 dB
- SC: 0.20–0.30 dB
- ST: 0.25–0.50 dB

For conservative link budget calculations, many designers assume 0.5 dB per connector pair unless measured values are available. Dirty or damaged connectors are one of the most common causes of excessive optical loss and communication failures.

Passive Optical Components

Additional components such as patch panels, optical splitters, WDM multiplexers, attenuators, and optical switches introduce insertion loss and must be included in the total link budget.

Safety Margin (Design Margin)

A design margin of 2 to 3 dB is commonly reserved to account for fiber aging, future maintenance, additional patch connections, environmental changes, manufacturing tolerances, and measurement uncertainty. Including a safety margin helps ensure reliable long-term operation.

Determining Link Performance

To evaluate a fiber optic link, calculate the total expected optical loss by summing:

- Fiber attenuation
- Connector losses
- Splice losses
- Losses from passive optical components
- Design (safety) margin

The total calculated loss must be less than the optical power budget specified by the transmitter and receiver.

After installation, every fiber link should be tested and documented using an Optical Loss Test Set (OLTS) or Optical Time-Domain Reflectometer (OTDR) to verify that the measured insertion loss meets the design requirements and that the link will operate reliably under normal conditions.

Fiber Loss Table

The values below represent typical design values for modern fiber optic installations. Actual performance depends on the cable manufacturer, connector quality, installation practices, and operating wavelength. Always refer to the manufacturer's specifications when performing link budget calculations.

Wavelength / Fiber Type	Typical Fiber	Typical Attenuation (dB/km)	Typical Fusion Splice Loss (dB)	Typical Connector Loss (dB)	Typical Modal Bandwidth*
850 nm Multimode	OM2 (50/125 µm)	3	0.05	0.25	500 MHz·km
850 nm Multimode	OM3 (50/125 µm)	3	0.05	0.25	2000 MHz·km (EMB)
850 nm Multimode	OM4 (50/125 µm)	3	0.05	0.25	4700 MHz·km (EMB)
850 nm Multimode	OM5 (50/125 µm)	3	0.05	0.25	4700 MHz·km (EMB)
850 nm Multimode	OM1 (62.5/125 µm)	3.5	0.05	0.25	200 MHz·km
1300 nm Multimode	OM1 (62.5/125 µm)	1.5	0.05	0.25	500 MHz·km
1300 nm Multimode	OM2 (50/125 µm)	1	0.05	0.25	500 MHz·km
1310 nm Multimode	OS1/OS2 (9/125 µm)	.035	0.05	0.25	N/A
1550 nm Multimode	OS1/OS2 (9/125 µm)	.2	0.05	0.25	N/A

* Multimode bandwidth values are minimum standards. Modern Ethernet standards generally specify supported distances by fiber class (OM1–OM5) rather than bandwidth alone.

For Link Budget Calculations

- Attenuation values are typical specifications for modern telecommunications-grade fiber
- Fusion splice loss is typically 0.02–0.10 dB per splice. A design value of 0.05 dB per splice is commonly used
- Modern factory-polished connectors typically exhibit 0.15–0.30 dB insertion loss
- For conservative link budget calculations, 0.25 dB per connector is a reasonable design value
- Older installations or field-installed connectors may exhibit higher losses
- Actual installed link loss should always be verified using an Optical Loss Test Set (OLTS) or Optical Time-Domain Reflectometer (OTDR)

Estimating Signal Loss

The total optical loss of a fiber link is the sum of all losses introduced by the fiber and every component in the optical path.

Total Link Loss (dB) = Fiber Attenuation + Splice Loss + Connector Loss + Passive Component Loss + Design Margin

- Fiber Attenuation = Fiber attenuation (dB/km) × Fiber length (km)
- Fusion Splice Loss = Loss per splice × Number of splices
- Connector Loss = Loss per connector pair × Number of connector pairs
- Passive Component Loss = Loss introduced by splitters, WDM devices, attenuators, or other passive optical devices
- Design Margin = Typically 2–3 dB

Component	Calculation	Loss
Fiber attenuation	0.35 dB/km × 10 km	3.5 dB
Fusion splice	0.05 dB × 1 splice	0.05 dB
Connector loss	0.25 dB × 2 connector pairs	0.50 dB
Passive Comp. loss	0 x 0	0 dB
Design margin	3.00 dB	3.00 dB
Total Link Loss		**7.05 dB**

This example shows that the installed fiber link has an expected total optical loss of 7.05 dB. If more conservative design values are desired, higher connector or splice losses may be substituted.

Calculating Power Budget

Distance is calculated first by calculating the power budget. This is found by subtracting the receive sensitivity from the launch power. This information is found on the data sheet of the optics from the manufacturer. Example 1000mbps SFP data from manufacturer's data sheet:

Transmitter Section					
Parameter	**Symbol**	**Min.**	**Typical**	**Max.**	**Unit**
Data Rate	B	-	1250	-	Mb/s
Centre Wavelength	λc		1310	1360	nm
Output spectral Width	△λ(RMS)	-	-	4	nm
Average Output Power	Po	-9	-	-3	dBm
Extinction Ratio	EXT	9	-	-	dB
Rise time/Fall time(20%-80%)	Tr/Tf	-	-	260	ps
Total jitter	TJ	-	-	0.43	UI
Data Input Voltage-High	VIHS	Vcc-1.16	-	Vcc-0.89	V
Data Input Voltage -Low	VILS	Vcc-1.82	-	Vcc-1.48	V
Supply Current	ICC	-	70	200	mA
Output Optical Eye	Compliant with IEEE802.3z				

Receiver Section					
Parameter	**Symbol**	**Min.**	**Typical**	**Max.**	**Unit**
Receive Sensitivity	Pmin	-	-	-22	dBm
Maximum Input Power	Pmax	-3	-	-	dBm
LOS De-Assert	LOSD	-	-	-24	dBm
LOS Assert	LOSA	-35	-	-	dBm
LOS Hysteresis	-	.5	3	5	dB
Output High Voltage	VOH	Vcc-1.03	-	Vcc-0.89	V
Output Low Voltage	VOL	Vcc-1.82	-	Vcc-1.63	V
Operating Wavelength	λc	1470	1490	1510	nm
Supply Current	ICC	-	60	100	mA

This example highlights the minimum Transmitter launch power and Receiver sensitivity.

The optical power budget is the maximum amount of optical loss that can exist between the transmitter and receiver while still allowing the link to operate reliably.

The power budget is calculated by subtracting the receiver sensitivity from the minimum guaranteed transmitter launch power:

Optical Power Budget (dB) = Minimum Transmitter Launch Power (dBm) – Receiver Sensitivity (dBm)

Assume an Ethernet switch has a minimum transmitter launch power of **–9 dBm** and is connected to a media converter with a receiver sensitivity of **–22 dBm**.

Transmitter Launch Power		-9 dBm
Receiver Sensitivity	–	-22 dBm
Power Budget	=	**13 dB**

Why dBm Minus dBm Equals dB

At first glance, it may seem unusual that subtracting two values expressed in dBm results in a value expressed in dB.

A dBm value is an absolute measurement of optical power, referenced to 1 milliwatt (mW). In contrast, a dB value represents the ratio between two power levels and has no absolute reference.

When one dBm measurement is subtracted from another, the common 1 mW reference cancels out mathematically, leaving only the ratio between the two power levels. The result is expressed in decibels (dB) instead of (dBm), which represents the available optical loss or "power budget" between the transmitter and receiver.

This relationship is fundamental to fiber optic link budget calculations and is the reason transmitter output power, receiver sensitivity, and link losses can all be directly compared using decibel units.

Receiver Saturation and Optical Attenuators

In addition to ensuring enough optical power reaches the receiver, it is equally important to ensure that too much optical power is not received.

Every optical receiver has two important specifications:

- **Receiver Sensitivity:** The minimum optical power required for reliable operation
- **Receiver Saturation:** The highest optical power the receiver can accept while operating correctly

If the received optical power falls below the receiver sensitivity, the receiver may be unable to distinguish between logical ones and zeros, resulting in communication errors or complete loss of the link.

If the received optical power exceeds the receiver saturation level, the receiver's photodetector and amplifier circuitry can become overloaded. Although the fiber link may still establish a connection, excessive optical power can produce a high bit error rate (BER), intermittent communication problems, dropped packets, or complete loss of communication.

Receiver Saturation

Receiver saturation is most commonly encountered on short single-mode fiber links using long-range or high-power optical transceivers. Because single-mode fiber has very low attenuation, only a small amount of optical power is lost over short distances, allowing the received signal to remain stronger than the receiver is designed to handle.

A long-range optical transceiver is designed to operate over distances up to 40 km and has:

- **Maximum transmitter launch power:** +2 dBm
- **Receiver saturation:** –3 dBm

If the transceivers are connected by only 100 meters of single-mode fiber, the fiber loss is negligible (approximately 0.04 dB). The receiver may therefore see nearly +2 dBm, which exceeds its –3 dBm maximum input specification and may cause receiver saturation.

Optical Attenuators

An optical attenuator is a passive device installed in the fiber path to intentionally reduce the optical power reaching the receiver. Optical attenuators are commonly available with fixed attenuation values such as 3 dB, 5 dB, 10 dB, and 15 dB, as well as variable versions for testing and laboratory use.

For example, installing a 5 dB attenuator on the previous link would reduce the received power from approximately +2 dBm to approximately –3 dBm, bringing the received signal within the receiver's specified operating range.

When selecting an attenuator, the goal is to reduce the received optical power so that it remains:

- Above the receiver sensitivity, ensuring reliable communication
- Below the receiver saturation level, preventing receiver overload

Note: Receiver saturation typically causes communication errors rather than permanent damage. Standard Ethernet optical transceivers are designed to tolerate optical power somewhat above their saturation specification. Permanent damage is rare but can occur. You should avoid exposing optic receivers to high intensity light for prolonged periods of time. Calculate what size of an attenuator you need and use them when appropriate.

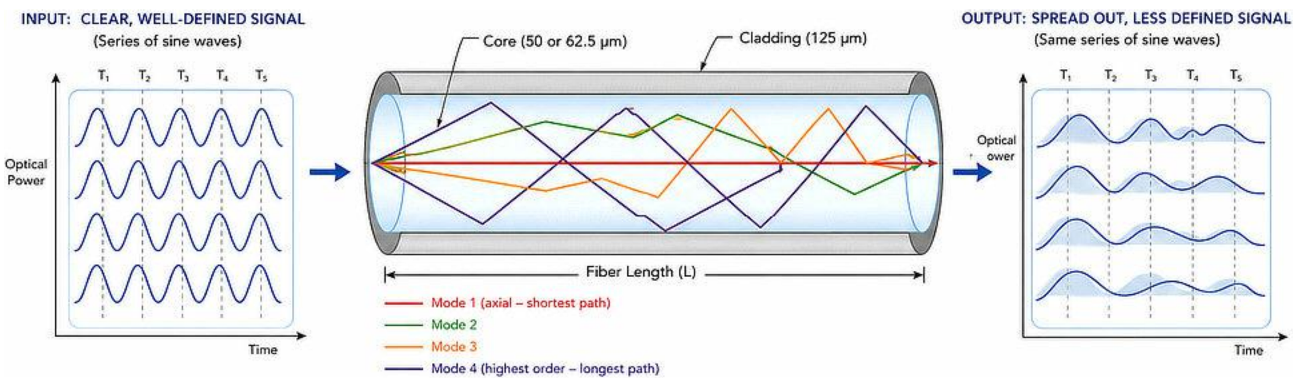
Putting all This Together, Will My Application Work?

Using the above examples of the example a 10km single mode cable having a total estimated power loss of 7.05db and the example fiber optic interface having a power budget of 13db we can determine that this link should work with a margin of error of 5.95db.

If you are using different optics on each end of the fiber, you will need to calculate the power budget in both directions as transmit power and receive sensitivity will differ based on the optics manufacturer

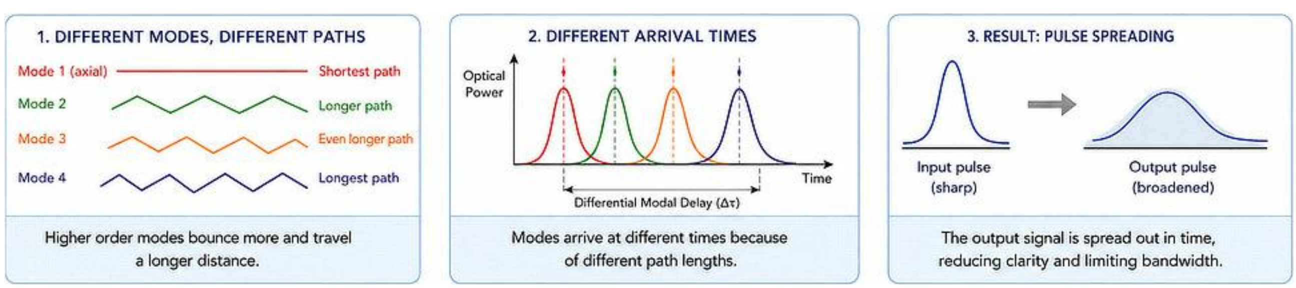
Understanding Modal Dispersion

In multimode fiber, light propagates along multiple paths, or modes. Because each mode follows a slightly different path length through the fiber core, some light rays arrive at the receiver sooner than others. This differential delay causes individual light pulses to gradually spread apart as they travel down the fiber, a phenomenon known as modal dispersion (or intermodal dispersion).



Modal Dispersion in Multimode Fiber

As this signal spreading increases over distance, it becomes more difficult for the receiver to distinguish one bit from the next. Eventually, adjacent bits begin to overlap, increasing the bit error rate (BER). Because of this, modal dispersion is one of the primary factors limiting the maximum transmission distance of multimode fiber.



Differential Modal Delay and Pulse Spreading

The effect of modal dispersion becomes significantly more severe as data rates increase. Because transmitted bits are much shorter in duration at higher speeds, less pulse spreading is required to cause signal overlap. A fiber link that easily supports 100 Mbps may not support 10 Gbps over the same distance.

Modal Bandwidth

Multimode fiber is specified by its modal bandwidth, expressed in MHz·km. This value indicates the amount of information the fiber can carry over a given distance before modal dispersion becomes excessive.

You can roughly estimate distance using this formula:

$$\text{Maximum Distance} \approx \frac{\text{Modal Bandwidth (Mhz.km)}}{\text{Signaling Rate (Mhz)}}$$

For example, consider OM1 (62.5/125 μm) fiber with a modal bandwidth of 200 MHz·km operating at 100BASE-FX, which has a signaling rate of 125 MBd:

Maximum Distance ≈ 200 ÷ 125 = 1.6 km

Likewise, for 10BASE-FL, which has a signaling rate of approximately 10 MBd:

Maximum Distance ≈ 200 ÷ 10 = 20 km

These calculations illustrate how lower data rates are less affected by modal dispersion than higher data rates.

Practical Considerations

Although the modal bandwidth equation is useful for understanding the effects of dispersion, modern Ethernet networks should always be designed using the maximum distances specified by the applicable IEEE 802.3 standard.

IEEE standards account for modal dispersion, attenuation, connector losses, transmitter characteristics, receiver performance, and other system factors. For this reason, the published maximum distances for Ethernet standards such as 100BASE-FX, 1000BASE-SX, 10GBASE-SR, and higher-speed variants should always take precedence over theoretical calculations.

In practice, the maximum supported fiber length is determined by whichever limit is reached first:

- The available optical power budget (attenuation), or
- The modal dispersion limit specified by the Ethernet standard

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