Fiber Cable Basics

Fiber-optic communication is a method of transmitting information from one place to another by sending light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. First developed in the 1970s, fiber-optic communication systems have revolutionized the telecommunications industry and played a major role in the advent of the Information Age. Because of its advantages over electrical transmission, the use of optical fiber has largely replaced copper wire communications in core networks in the developed world.

The process of communicating using fiber-optics involves the following basic steps: Creating the optical signal using a transmitter, relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak, and receiving the optical signal and converting it into an electrical signal. The complete fiber optic link is represented in Figure 1 below.

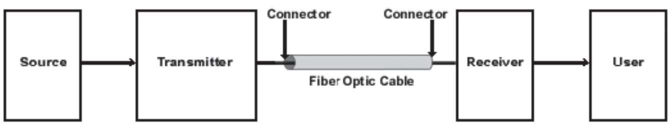


Figure 1: Model of "simple" fiber optic data link

We will look first at the cable, and then the transceivers (which act as both transmitter and receiver on each end of the fiber cable).

Fiber Optic Cable

A fiber optic cable is a cylindrical pipe. It may be made out of glass or plastic or a combination of glass and plastic. It is fabricated in such a way that this pipe can guide light from one end of it to the other.

Basically, a fiber optic cable is composed of two concentric layers termed the core and the cladding. These are shown on the right side of Figure 2. The core and cladding have different indices of refraction with the core having n1 and the cladding n2. Light is piped through the core. A fiber optic cable has an additional coating around the cladding called the jacket. Core, cladding and jacket are all shown in the three dimensional view on the left side of Figure 2. The jacket usually consists of one or more layers of polymer. Its role is to protect the core and cladding from shocks that might affect their optical or physical properties. It acts as a shock absorber. The jacket also provides protection from abrasions, solvents and other contaminants. The jacket does not have any optical properties that might affect the propagation of light within the fiber optic cable.

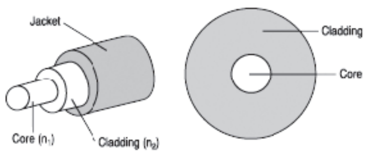


Figure 2: Fiber Optic Cable, 3 dimensional view and basic cross section

Light is guided down the core of the cable because the core and cladding have different indices of refraction with the index of the core, n1, always being greater than the index of the cladding, n2. Figure 3 shows how this is employed to effect the propagation of light down the fiber optic cable and confine it to the core.

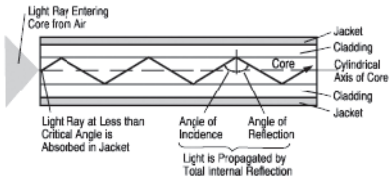


Figure 3: Propagation of a light ray down a fiber optic cable

As illustrated a light ray is injected into the fiber optic cable on the right. If the light ray is injected and strikes the core-to-cladding interface at an angle greater than an entity called the critical angle then it is reflected back into the core. Since the angle of incidence is always equal to the angle of reflection the reflected light will again be reflected. The light ray will then continue this bouncing path down the length of the fiber optic cable. If the light ray strikes the core-to-cladding interface at an angle less than the critical angle then it passes into the cladding where it is attenuated very rapidly with propagation distance.

When it comes to mode of propagation, fiber optic cable can be one of two types, multi-mode or single-mode. These provide different performance with respect to both attenuation and time dispersion.

Multimode

Multimode fiber optic links are the most popular in industrial and customer premise environments because they generally have the lowest cost cabling and transceivers. However, they have limited lengths of up to 4 or 5 km. To form a multimode link you must use multimode cable (either 50 or 62.5 µm core diameter) and multimode transceivers. With multimode fiber the light travels multiple paths down the cable and actually bounces side to side. Because of the nature of multimode fiber the distance it can go is limited primarily by a phenomenon called modal dispersion or multimode distortion.

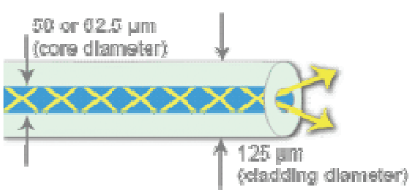


Figure 4 - Multimode Cable - Transmission

Singlemode and Long Haul

Singlemode fiber optic links are less popular because of their higher cost (both cabling and transceivers) but they can operate over extended distances up to 120 km or more. To form a singlemode link you must use singlemode cable (8, 9 or 10 µm core diameter; 9 µm is most common) and singlemode transceivers. With singlemode fiber the light travels in a single path down the cable. This is more efficient and allows for the extended distances. Singlemode fiber is not affected by modal dispersion so its distance is limited mostly by the power and sensitivity of the transceivers being used.

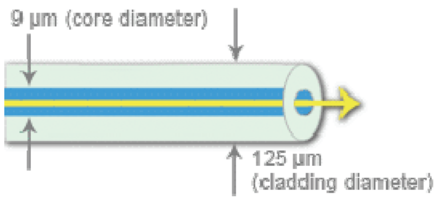


Figure 5 – Singlemode Cable - Transmission

Transceivers (Transmitters/Receivers) and Connectors

The Transmitter component of Figure 1 serves two functions. First, it must be a source of the light coupled into the fiber optic cable. Secondly, it must modulate this light so as to represent the binary data that it is receiving from the Source. With the first of these functions it is merely a light emitter or a source of light. With the second of these functions it is a valve, generally operating by varying the intensity of the light that it is emitting and coupling into the fiber.

The Receiver component of Figure 1 again serves two functions. First, it must sense or detect the light coupled out of the fiber optic cable then convert the light into an electrical signal. Secondly, it must demodulate this light to determine the identity of the binary data that it represents. In total, it must detect light and then measure the relevant Information bearing light wave parameters in the premises fiber optic data link context intensity in order to retrieve the Source's binary data.

Transceiver is the industry term for the transmitter/receiver unit as a pair. When manufacturers refer to a fiber optic “port,” they are typically referring to both transmit and receive connection required for a duplex fiber optic link. Thus a switch with 2 fiber ports will have 2 complimentary pairs of transmit and receive connections, or 2 “transceivers.”

Optical fibers are connected to terminal equipment by optical fiber connectors. These connectors are usually of a standard type such as SC, ST, or LC (the 3 types featured in Ultra Electronics, NSPI’s switches).

Fibers are terminated in connectors so that the fiber end is held at the end face precisely and securely. The end face is where light (and subsequently the fiber optic signal) enters and leaves the optic core. A fiber-optic connector is basically a rigid cylindrical barrel surrounded by a sleeve that holds the barrel in its mating socket. The mating mechanism can be "push and click", "turn and latch" ("bayonet"), or screw-in (threaded).

Regardless of what type of connection, it is essential that the connector used is matched to the type of fiber (MM or SM) it will terminate, that the connector is installed per manufacturer specifications, and that the end face of the connection remains clean at all times.

Ultra Electronics offers two distinct types of transceivers; 1x9 (SC or ST connectors) and SFP (LC connectors).

1x9 Transceivers with SC or ST Connectors

These are offered on the fiber optic fast Ethernet (100 Mbps) ports. The “1x9” refers to the industry-standard pin-out of 1 row by 9 pins. Ultra Electronics offers these transceivers with dual ST or SC style connectors. They are available as Multimode, Singlemode, or Singlemode Long Haul. Other variations are available as special order.

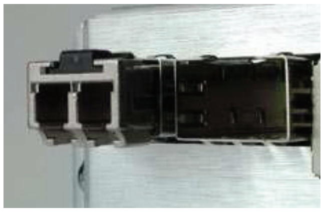
1x9 Transceiver with SC Connectors

1x9 Transceivers with ST Connectors

SFP (Small Form Pluggable) Transceivers (aka Mini-Gbic) with LC Connectors

These are offered on the fiber optic gigabit Ethernet (1000 Mbps) ports. These transceivers plug into a cage assembly that is already in place in the Ultra switch. They are more compact than the more traditional 1x9 style transceivers. Ultra offers these transceivers with dual LC connectors. They are available as Multimode, Singlemode, or Singlemode Long Haul. Other variations such as CDWM (Coarse Wavelength Division Multiplexing) are available as special order.

SFP Transceiver out of cage



SFP Transceiver inserted in cage

Selecting the Proper Components for a Fiber Optic Network Link

There are 4 primary considerations when selecting the proper components for a fiber optic link:

1. The length of the fiber link from end to end
2. The bandwidth (i.e. 100mbps or 1Gbps) required based on the applications and information that will be sent over the link
3. The estimated amount of total attenuation over the link (a factor of fiber optic cable properties and the amount and quality of the splice/connector points along the fiber from end to end).
4. The power budget of the transceiver pairs being used to generate and accept the fiber optic signal.

Using the Reference Tables at the end of this note as guidelines (and using attenuation characteristics for the specific fiber optic cable installed or proposed for use), a user can develop an acceptable link-loss budget and select the proper transceivers for their system. Please note that type of connector has no influence on the loss along a system.

Example

An industrial user has a series of Ethernet devices operational at Location A. They are building a new facility 8km away. At this distance they are certainly going to have to plan on using single mode fiber. They want to transmit (or plan to transmit) at Gigabit speeds. The SM fiber that they have decided to use attenuates at a rate of .3dB/km. There will be 3 splices along the route and then connectors at each end.

Cable attenuation = 8km x .3dB/km = 2.4dB

Splice loss = 3 splices x .2dB/splice = .6dB

Connector loss = 2 connectors x 1dB/connector = 2dB

Total loss along physical link = 5dB
Safety factor of 25% = 1.25dB
Total loss budget = 6.25dB

Looking at the Gigabit fiber transceiver performance specifications, we can see that the single mode Gigabit fiber transceiver has a worse-case power budget of 11dB so this should work satisfactorily in this proposed fiber link.

Troubleshooting Fiber Optic Links

If installed correctly, fiber optic links can provide years of worry free connectivity for users, but like all communications systems, there are times when some troubleshooting may be required. There is expensive cable test equipment such as power source/meters and OTDRs available on the market from a number of manufacturers which are optimal for testing and verifying physical links. For most users, the economy of owning equipment like this does not make sense, so the following are some quick and easy steps to try before calling in a vendor to test your system.

1. Make sure that all of your connectors are clean. Even a little bit of dust, dirt or grease on a connector face can significantly degrade a fiber signal. This includes the main fiber optic link as well as any patch cables that you may be using. When cleaning, it is important to use lint free swabs or wipes, preferably of a clean room quality. These can be used dry or wet (with 99% isopropyl alcohol solutions).
   - Make certain that you are not cleaning an active fiber as the laser can cause permanent damage to your eyes should you look into the end face.
   - Additionally, it is not necessary to scrub the end face, rather to just gently wipe it clean and then recheck the link. If additional cleaning is required simply repeat this process.
2. Ensure that the cable type you are using matches the transceiver type. That is, MM cable requires MM transceivers.
3. Ensure that the patch cords that you are using match the link fiber cable. Again MM needs to be used with MM. Additionally, it is important that 62.5um is used with 62.5um and 50um with 50um. This is a very common and easy to make mistake. If the fiber cores are not aligned correctly significant attenuation will occur.
4. Make sure that all connectors are plugged completely into their proper ports. Again if end faces are lined up correctly with transceivers and/or mated fiber ends, the system may fail due to excess attenuation.
5. Make sure that the transmit cable at the near end is the receive cable at the far end. Their needs to be a crossover for a fiber link to work correctly. Be sure to factor in all patch cords that may be used.

Fiber Transceiver Performance Specifications – Reference Tables

Ultra Electronics Fiber Transceivers Performance Specifications:

Ethernet Type	Mode	Data Rate (Mbps)	Signal Rate (MHz)	Wave-length (nm)	IEEE Standard
Fast Ethernet	Multi	100	125	1310	100BaseFX
Fast Ethernet	Single	100	125	1310	100BaseFX
Fast Ethernet	Single – long haul	100	125	1310	100BaseFX
Gigabit Ethernet	Multi	1000	1250	850	1000BaseSX
Gigabit Ethernet	Single	1000	1250	1310	1000BaseLX
Gigabit Ethernet	Single – long haul	1000	1250	1310	1000BaseLX
Gigabit Ethernet	Single – long haul	1000	1250	1550	1000BaseLH
Gigabit Ethernet	Single – long haul	1000	1250	1550	1000BaseLH

Ultra Electronics Fiber Transceivers Performance Specifications (continued):

Ethernet Type	Mode	Power Budget (Power - Sensitivity)		Transmitter Power*			Receiver Sensitivity*		
		Typical	Worst	Min. dB	Typ. dB	Max. dB	Min. dB	Typ. dB	Max. dB
Fast Ethernet	Multi	14 (-17 minus -31)	10 (-21 minus -31)	-21	-17	-14	--	-34	-31
Fast Ethernet	Single	20 (-11 minus -31)	16 (-15 minus -31)	-15	-11	-8	--	-36	-31
Fast Ethernet	Single-long haul	31 (-3 minus -34)	29 (-5 minus -34)	-5	-3	0	--	-36	-34
Gigabit Ethernet	Multi	12 (-6 minus -18)	9 (-9 minus -18)	-9	-6	-3	--	--	-18
Gigabit Ethernet	Single	14 (-6 minus -20)	11 (-9 minus -20)	-9	-6	-3	--	--	-20
Gigabit Ethernet	Single-long haul	22 (-1 minus -23)	19 (-4 minus -23)	-4	-1	2	--	--	-23
Gigabit Ethernet	Single-long haul	22 (-1 minus -23)	19 (-4 minus -23)	-4	-1	2	--	--	-23
Gigabit Ethernet	Single-long haul	25 (2 minus -23)	23 (0 minus -23)	0	2	5	--	--	-23

**Note: For transmitter power, the higher the number the better. The opposite is true for receiver sensitivity, the lower the number the better.*

Fiber Cable Parameters (typical)

Cable Size (core/cladding) (µm)	Mode	Wavelength (nm)	Connector Losses (dB per connection)	Splice Loses (db per splice)	Distance Losses (dB per km)	Multimode Modal Dispersion* (MHz x km)	Singlemode Dispersion (ps/nm x km)
62.5/125 µm	Multi	850 nm	1 dB	0.2 dB	3.3 dB	300	--
50/125 µm	Multi	850 nm	1 dB	0.2 dB	2.7 dB	700	--
62.5/125 µm	Multi	1310 nm	1 dB	0.2 dB	1 dB	500	--
50/125 µm	Multi	1310 nm	1 dB	0.2 dB	0.8 dB	800	--
9/125 µm	Single	1310 nm	1 dB	0.2 dB	0.5 dB	--	3.5
9/125 µm	Single	1550 nm	1 dB	0.2 dB	0.25 dB	--	19
8/125 µm	Single	1550 nm	1 dB	0.2 dB	0.2 dB	--	19

•Note: These are just guideline numbers. Refer to your cable specifications for more accurate values.

Calculating Fiber Optic Distances

There are two primary ways to calculate how far you can go with your fiber optic links. To be safe you should go by the shortest result from the two methods, if you use both such as you can with Multimode fiber. Also, you should design for up to a 25% safety margin to be conservative and allow for degradation of the signal and cable over time.

Method 1: Modal Dispersion for Multimode links only

Maximum Distance = modal Dispersion/Signal rate

Speed	Mode	Wavelength (nm)	Cable Diameter (µm)	Modal Dispersion*	Signal Rate (MHz)	Max. Distance Based on Modal Dispersion
Fast Ethernet	Multi	850 nm	62.5/125	300	125	2.4 km
Fast Ethernet	Multi	850 nm	50/125	700	125	5.6 km
Fast Ethernet	Multi	1310 nm	62.5/125	500	125	4 km
Fast Ethernet	Multi	1310 nm	50/125	800	125	6.4 km
Gigabit Ethernet	Multi	850 nm	62.5/125	300	1250	240 m
Gigabit Ethernet	Multi	850 nm	50/125	700	1250	560 m
Gigabit Ethernet	Multi	1310 nm	62.5/125	500	1250	400 m
Gigabit Ethernet	Multi	1310 nm	50/125	800	1250	640 m

Method 2: Based on Optical Budget

Power Budget = Transmitter Power – Receiver Sensitivity

Spare Optical Budget = Power Budget – Power Losses (splices and connectors)

Maximum Distance = Spare Optical Budget/Distance Losses

Speed	Mode	Cable Size	Wave-length	Power Budget (Worst case)	Typical Losses*	Spare Power	Distance Losses	Max. Distance
Fast Ethernet	Multi	62.5/125 µm	1310 nm	10 dB	6 dB	4 dB	1 dB	4 km
Fast Ethernet	Multi	50/125 µm	1310 nm	10 dB	6 dB	4 dB	0.8 dB	5 km
Fast Ethernet	Single	9/125 µm	1310 nm	16 dB	6 dB	10 dB	0.5 dB	20 km
Fast Ethernet	Long haul	9/125 µm	1310 nm	29 dB	6 dB	23 dB	0.5 dB	46 km
Gigabit Ethernet	Multi	62.5/125 µm	850 nm	9 dB	6 dB	3 dB	3.3 dB	0.9 km
Gigabit Ethernet	Multi	50/125 µm	850 nm	9 dB	6 dB	3 dB	2.7 dB	1.1 km
Gigabit Ethernet	Single	9/125 µm	1310 nm	11 dB	6 dB	5 dB	0.5 dB	10 km
Gigabit Ethernet	Long haul	9/125 µm	1310 nm	19 dB	6 dB	13 dB	0.5 dB	26 km
Gigabit Ethernet	Long haul	9/125 µm	1310 nm	19 dB	6 dB	13 dB	0.25 dB	52 km
Gigabit Ethernet	Long haul	9/125 µm	1310 nm	23 dB	6 dB	17 dB	0.2 dB	85 km

Note: Typical losses include 2 dB (two connectors), 3 dB (safety margin) & 0.4 (two splices) = 6 dB (rounded up)

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Fiber Optic Maximum Distance Summary

Speed	Mode	Cable Size	Wave-length	IEEE Recommended Distance	Max. Distance Based on Power Budget*	Max. Distance Based on Modal Dispersion*
Fast Ethernet	Multi	62.5/125 µm	1310 nm	2 km	4 km	4 km
Fast Ethernet	Multi	50/125 µm	1310 nm	2 km	5 km	6.4 km
Fast Ethernet	Single	9/125 µm	1310 nm	15 km	20 km	--
Fast Ethernet	Long haul	9/125 µm	1310 nm	--	46 km	--
Gigabit Ethernet	Multi	62.5/125 µm	850 nm	220 m	0.9 km	240 m
Gigabit Ethernet	Multi	50/125 µm	850 nm	550 m	1.1 km	560 m
Gigabit Ethernet	Single	9/125 µm	1310 nm	5 km	10 km	--
Gigabit Ethernet	Long haul	9/125 µm	1310 nm	--	26 km	--
Gigabit Ethernet	Long haul	9/125 µm	1310 nm	--	52 km	--
Gigabit Ethernet	Long haul	9/125 µm	1310 nm	70 km	85 km	--

**Note: These numbers are just guidelines and are highly dependent on your cable and transceiver specifications.*

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