THE COMPLETE GUIDE TO

FIBER OPTIC CABLE SYSTEM INSTALLATION







ERIC R. PEARSON

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The Complete Guide to Fiber Optic Cable System Installation

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CHAPTER

1

The Basics of Fiber Optic Systems

CHAPTER OBJECTIVES

From this chapter, you will be able to:

1. Understand the basics of fiber optic transmission technology.
2. Understand how installation procedures can affect system performance.
3. Follow the instructions in Chapters 3–6.

INTRODUCTION

In this chapter, we present an overview of fiber optic systems. This overview consists of five elements:

- Identification of system components and their functions
- Structures of different types of components
- Advantages of different types of components
- Types of performance that system components must have
- Typical values of performance

FIBER OPTIC TRANSMISSION SYSTEMS: COMPONENTS AND FUNCTIONS

Installation of fiber optic transmission systems involves installation of three groups of products:

- Major system components
- Passive optical components
- Hardware

The four major system components (Figure 1–1), which are required in all systems, are the *fiber*, *cable*, connections, and end electronics (*optoelectronics*).

Functions of the Four Major Components

Fiber. The function of the fiber is to guide the light from one end of the system to the other. The light signal is modulated to carry information.

Cable. The function of the cable is to protect the fiber. Such protection is required to allow the fiber to be installed and handled during its lifetime (estimated

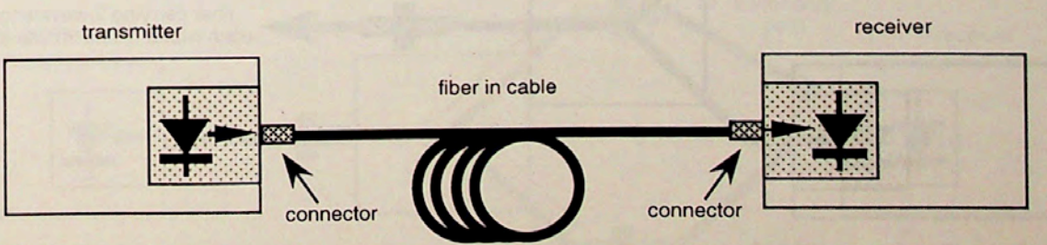


Figure 1–1 Four Major System Components

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at more than 20 years) without breakage and without unnecessary loss of signal strength. All types of fibers require some cable materials in order to enable the fiber to achieve its function.

Connection Mechanisms. The functions of the connection mechanisms are alignment and end protection. Fibers, most of which are roughly the size of a human hair, must be aligned at light sources, at receivers, and at fiber-to-fiber connections. Precision alignment is required to minimize loss of signal strength.

Fiber ends must be protected from mechanical damage and from contamination by dirt. Damage and contamination can result in increased loss of signal strength, which can, in turn, result in a degradation of signal quality.

End Electronics. The function of the optoelectronic devices is conversion. The electrical signals must be converted to optical signals at the transmitter; the optical signals must be converted to electrical signals at the receiver. We will examine each of these four major components in more detail later in this chapter.

Functions of the Six Passive Optical Components

Some, but not all, systems require passive optical components. *Passive components* are those without electrical to optical or optical to electrical signal conversion. Such components are couplers and splitters, wavelength division multiplexors/demultiplexors, optical rotary joints, optical fiber amplifiers, and optical switches. The main installation concern with passive components is signal strength loss through such components. This signal strength loss is due to both connector loss and internal loss.

Couplers. Couplers are devices that combine different optical signals on different paths into a single optical signal on a single fiber. Each of these different optical signals has a different wavelength of light[1] (Figure 1–2). Each wavelength carries a different data stream. Use of couplers increases the capacity of the fiber. Couplers can be used to transmit full-duplex signals over a single fiber (Figure 1–3).

Splitters. Splitters are devices that split a single optical signal into multiple optical signals. Splitters can be used to increase system reliability and to reduce

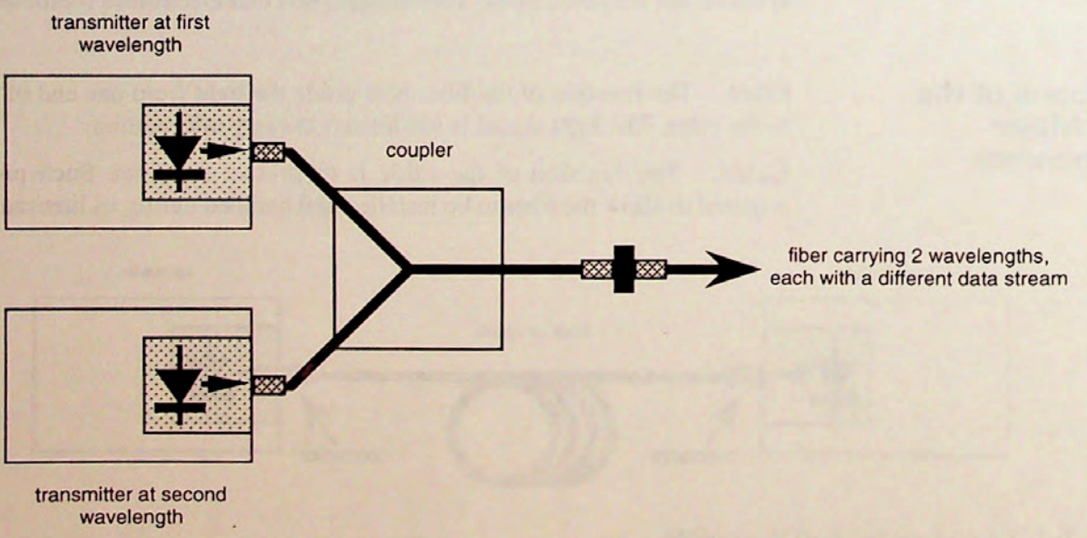


Figure 1–2 Transmission of Multiple Wavelengths on a Single Fiber with a Coupler

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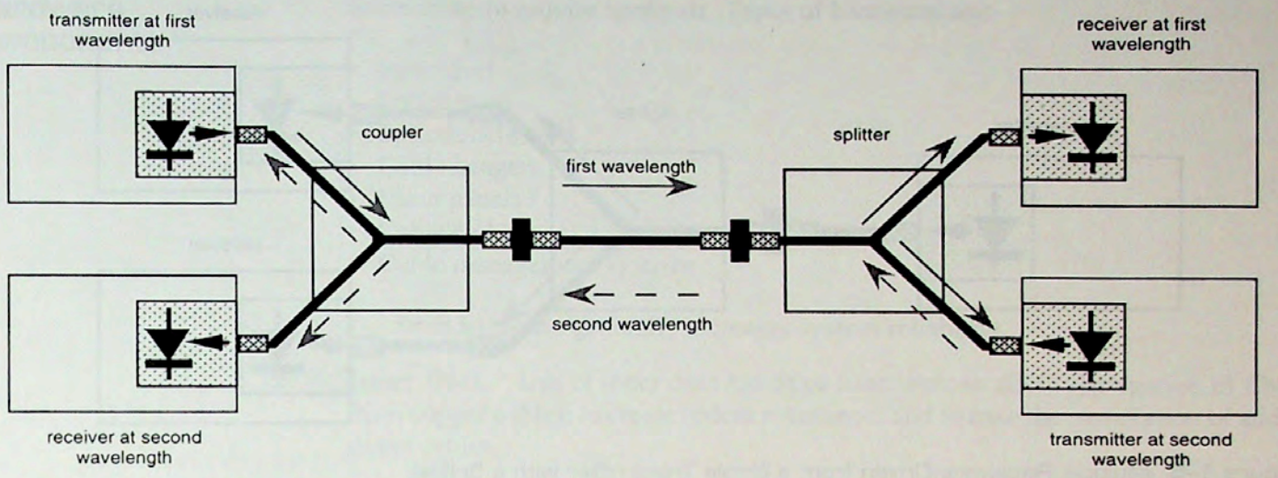


Figure 1–3 Bidirectional Transmission on a Single Fiber with a Coupler

system cost. The optical signal may consist of a single wavelength or of several wavelengths, each of which carries a unique signal. Increased system reliability results from the dividing, or sharing, of a single optical signal to redundant or multiple signal paths (Figure 1–4). Should one path be interrupted (a problem known as "back hoe fade"), a second path is immediately available. Applications of splitters to create redundant signal paths are mission-critical networks, such as those servicing NASA launches and those servicing the Federal Aviation Authority for control of airports.

Reduced system cost results from the delivery of a single information stream to multiple receiving sites (Figure 1–5). Cable TV systems use splitters to share the cost of relatively expensive laser transmitters with multiple, lower cost receivers.

Wavelength Division Multiplexors/Demultiplexors. Wavelength division multiplexors and demultiplexors are similar to couplers and splitters. The difference is that wavelength division demultiplexors direct each of the different colors to one of the outputs (Figure 1–6). In contrast, splitters split the light stream, delivering all colors to each of the outputs.

Optical Rotary Joints. Optical rotary joints serve the same function as do electrical rotary joints: optical rotary joints allow the transmission of an optical signal from a rotating structure to a stationary structure. Rotary joints are used on sensors that are towed behind ships and on rotating test equipment.

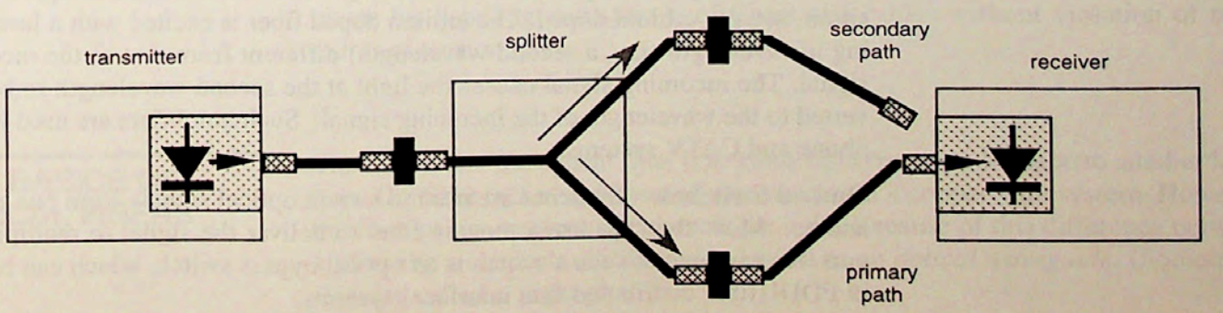


Figure 1–4 Redundant Optical Paths with a Splitter

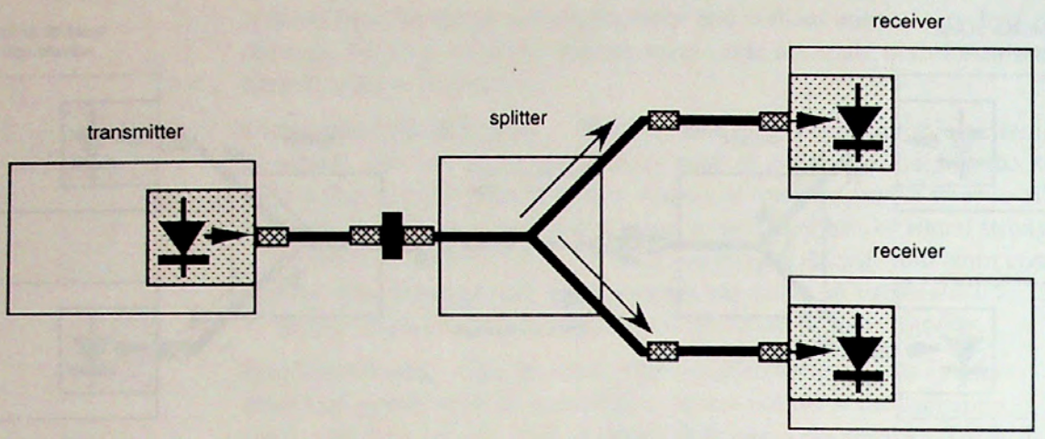


Figure 1–5 Multiple Receivers Driven from a Single Transmitter with a Splitter

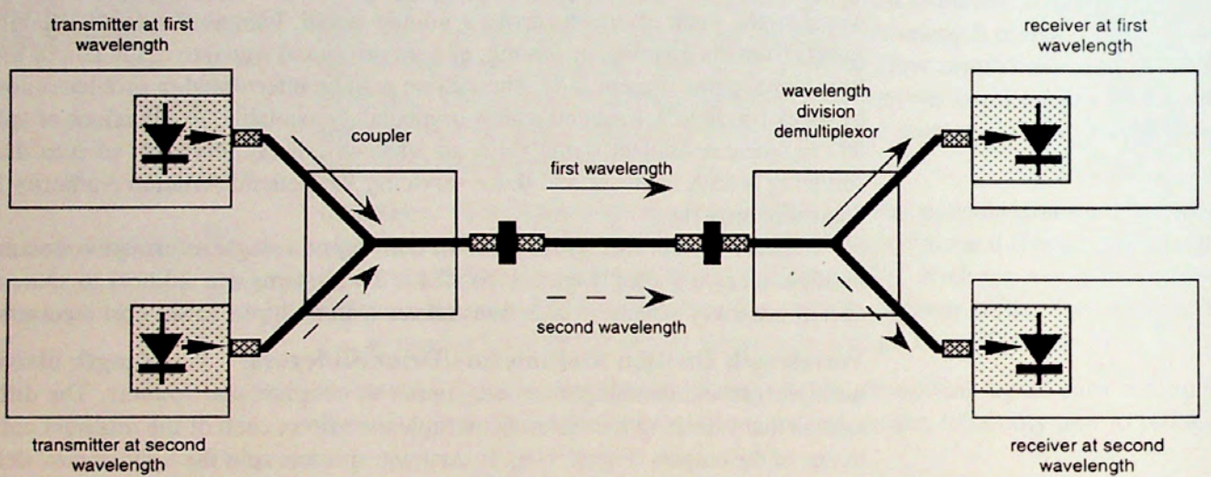


Figure 1–6 Function of a Wavelength Demultiplexor

Optical Amplifiers. Optical amplifiers allow for the amplification of an optical signal without requiring the optical signal to electrical signal to optical signal conversions. An optical amplifier contains a length of fiber that has a unique composition, usually erbium doped. The erbium doped fiber is excited with a laser having a wavelength (i.e., a second wavelength) different from that of the incoming signal. The incoming signal causes the light at the second wavelength to be converted to the wavelength of the incoming signal. Such amplifiers are used in telephone and CATV systems.

Optical Switches. Switches are used to switch optical signals from one path to another. Most switches use a moving fiber to deliver the signal to multiple outputs. An example of such a switch is an optical bypass switch, which can be used in FDDI (fiber distributed data interface) systems.

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Hardware Components

Some systems require hardware. Types of hardware are:

- Inner duct
- Splice trays
- Splice enclosures
- Cable hangers
- Patch panels
- Cable end boxes
- Cable management systems

Such hardware generally increases system reliability.

Inner Duct. Use of inner duct has three functions: to allow segregation of fiber from copper cables; to create rodent resistance; and to ease the installation of additional cables.

Splice Trays and Splice Enclosures. Splice trays protect splices. Splice enclosures protect splice trays and splices from environmental and mechanical damage. Splice enclosures can have one shell or two shells. With two shells, the space between the shells can be filled with a reenter able water-blocking compound to prevent moisture damage to the splices.

Cable Hangers. Cable hangers grip cables without causing damage to the fibers. Such hangers need to be chosen for a specific cable, since the gripping force must be both high enough to grip the cable and low enough to avoid causing either excess loss of signal strength or fiber breakage.

Patch Panels. Patch panels serve the same functions in fiber as in copper systems, with one significant difference: in copper systems, the copper segments are installed on the back of the patch panel, with short jumpers on the front of the panel connecting the segments. In fiber systems, the input segments are often installed on the back of the patch panel, with the output segments on the front. The short jumper is eliminated to achieve three goals: reduced installation cost, reduced maintenance cost, and reduced optical power loss.

Cable Enclosures. Cable enclosures, or end boxes, protect the ends of the cable. The ends require protection because the fibers are exposed there. (This is true for loose tube and premise cable designs. Break out cable designs do not require enclosures, since the cable protects the fiber and the buffer tube.) Cable enclosures may include integral patch panels or splice trays.

Cable Management Systems. Cable management systems provide mechanisms for handling and storage of fibers and cables without violation of bend radius or tension limits.

THE BASICS OF OPTICAL FIBERS

The function of the optical fiber is to guide light from one location to another location. The fiber is the equivalent of a conductor in a copper wire system. However, the fiber guides rather than conducts the light. Because of this difference between a fiber and a conductor, fiber is also known as an *optical waveguide*. (Sometimes it is also called a "light pipe.")

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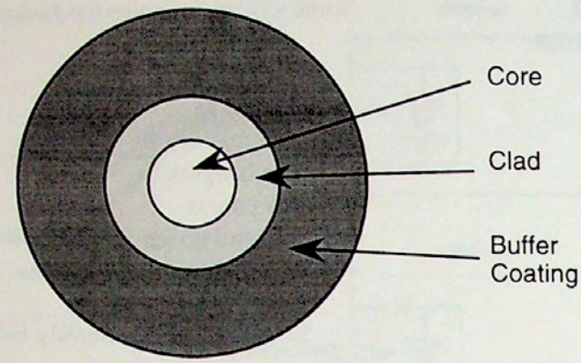


Figure 1–7 The Three Regions in an Optical Fiber

The Three Regions of the Fiber Structure

The structure of an optical fiber has at least two, but usually three, regions:

- Core
- Clad (or cladding)
- Coating (or buffer coating) (Figure 1–7)

The *core* is the central region in which most of the light energy travels, similar to the central region of a water pipe. The *clad* is the region that surrounds the core. The clad causes the light to travel along the fiber by preventing the light from leaking out of or escaping from the core (Figure 1–8).

The clad serves two additional functions. First, the clad insulates and protects the core from the environment. Second, the clad increases the size of the fiber. By increasing the size, the clad increases the strength of the fiber and makes the fiber easier to handle and use. Fiber core and clad diameters depend on the materials of the fiber.

Some, but not all, fibers have a third region, called the *buffer coating* or *coating*. The function of the buffer coating is to allow the fiber to retain its intrinsic high strength. The buffer coating achieves its function by protecting the fiber from both chemical and mechanical damage.

The Three Fiber Performance Mechanisms

In order to install fiber optic systems successfully, you must understand how the optical fiber functions. The optical fiber has three key performance mechanisms:

- Total internal reflection
- Reduction in signal intensity
- Pulse spreading

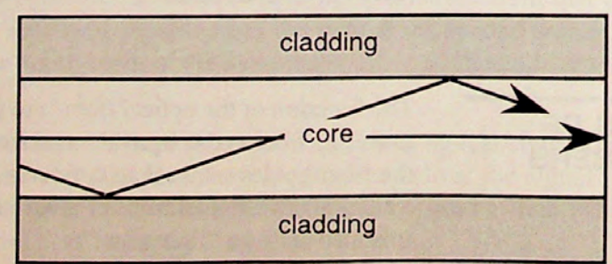


Figure 1–8 The Paths Taken by Light in an Optical Fiber Core

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Total Internal Reflection. Light travels in straight lines. Yet, with an optical fiber, we can move light in paths that are not straight, just as we move water in water pipes that are not straight. Why, then, does light travel along a fiber? The answer is in everyone's experience.

Imagine that you are standing at the edge of a lake; as you look at the surface of the water at a distance from you, you see the sky reflected in the water. However, as you look closer and closer to your feet, you stop seeing the sky and instead see into the water. This change from reflection, from which you see the sky, to refraction, from which you see into the water, occurs at a certain angle to the surface of the water. We will call this angle the *critical angle*. (This angle is also called the "acceptance angle.") On one side of this critical angle, you see a reflection of the sky. On the other side of this critical angle, you see into the water. This critical angle occurs because air and water have a different optical property. This optical property is the speed at which light travels in these two materials. While we could use the term "speed of light," scientists have found it more convenient to use the term *index of refraction* (IR or η), which is a measure of the speed of light in a material.

$$\eta = (\text{speed of light in vacuum/speed of light in material})$$

In glass optical fibers, the index of refraction ranges from 1.46 to 1.51 (Table 1–1). The index of refraction is used to calibrate an optical time domain reflectometer (OTDR) so that the OTDR can provide accurate length measurements. (Note that the industry uses the core-clad diameter ratio to denote the size of the fiber [e.g. 50/125]).

Optical fibers work on the same principle as light reflecting or refracting at the air-water surface. At the cylindrical core-clad surface, the index of refraction changes. When a ray of light enters the end of a fiber, the light strikes the boundary between the core and the clad at an angle equal to or less than the critical angle

		Wavelength (in nm) of Fiber			
Supplier	**Product**	**850**	**1300**	**1310**	**1550**
Corning Inc.	SMF-28			1.4675	1.4681
	SMF-21			1.4680	1.4680
	SMF-DF			1.4718	1.4711
	Titan			1.4675	1.4681
AT&T				1.4660	1.4670
	2136E			1.4670	1.4670
	215E			1.4670	1.4670
Corning Inc.	50/125	1.4897	1.4856		
	62.5/125	1.5014	1.4966		
	85/125	1.4748	1.4692		
	100/140	1.4805	1.4748		
AT&T	50/125	1.4860	1.4810		
	62.5/125	1.4960	1.4910		
Plasma	50/125	1.4810	1.4773		
	62.5/125	1.4850	1.4910		
Spectran	50/125	1.4860	1.4810		
	62.5/125	1.4960	1.4910		

Table 1–1 Indices of Refraction for Commonly Used Fibers (Data courtesy of Northern Lights Cable, Inc., N. Bennington, VT)

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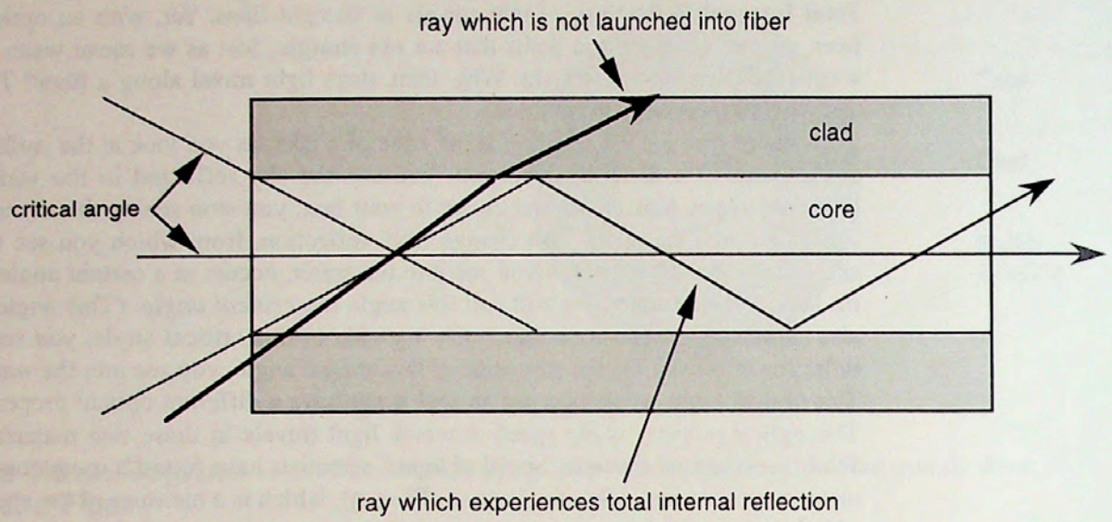


Figure 1–9 Different Paths Are Taken by Rays Within and Without the Critical Angle

or at an angle greater than the critical angle. If the angle is less than the critical angle, the light will be reflected, just as the image of the sky is reflected on the surface of the water. If the angle is greater than the critical angle, the light passes into and through the clad of fiber, just as the light from sky passes into the water of a lake (Figure 1–9).

Once light has entered a fiber within the critical angle, it is continuously reflected at the boundary of the core and clad, as long as the ray of light remains within the critical angle. We call this process *total internal reflection*. We use the term "internal reflection" because the reflection occurs inside the core. We use the term "total" because there is essentially no loss of signal strength at the reflection locations.

Just as we do not use the term "speed of light," we do not use the term "critical angle." Instead, we use the term *numerical aperture*, or *NA*, which is a measure of the critical angle. The NA is defined as:

numerical aperture (NA) = sine (critical angle)

Table 1–2 contains typical NAs for glass fibers.

Reduction in Signal Intensity. When light travels along a fiber, it becomes weaker. There are two mechanisms by which the signal becomes weaker:

- Loss of signal strength in the fiber (fiber attenuation)
- Connection loss[2]

Fiber Diameters, Core/Clad, in Microns	Most Common Numerical Aperture	Other Available Numerical Apertures
50/125	0.2 ± 0.02	0.23–0.25
62.5/125	0.29 ± 0.02	0.25–0.27
85/125	0.275 ± 0.015	
100/140	0.29 ± 0.02	0.25–0.27

Table 1–2 NA of All-Glass Fibers

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Attenuation is the reduction in signal strength along a fiber and is measured in units of *dB* (decibels). When we refer to fibers and cables, we use the term *attenuation rate* in units of dB/km, to describe the loss of signal strength per unit length.

This reduction occurs at a rate low enough to allow transmission to long distances. Optical fibers exhibit a linear decrease in the logarithm of the power with an increase in transmission distance (Figure 1–10).

While fiber attenuation can result from a number of mechanisms, Rayleigh scattering is the most important. This scattering occurs when light in a fiber core strikes an atom. Some of this scattered light strikes the core-clad boundary at an angle greater than the critical angle. When this happens, this light exits the core and is lost (Figure 1–11). Table 1–3 contains typical values of the attenuation rates of various types of cabled fibers. Note that the fibers listed are glass, except for the final one, which is plastic.

In addition to fiber attenuation, loss of signal strength can occur whenever there is a connection, such as a splice or connector. Some of this connection loss depends upon the connection. We will present such losses later in this chapter.

Note: *This loss of light signal strength is called attenuation. Attenuation limits the distance of transmission, resulting in a distance beyond which we cannot transmit without regeneration or amplification. If we exceed this distance, there will be insufficient signal strength to allow the receiving electronics to convert the optical signal to an electrical signal accurately. This is one of the two performance mechanisms that limit the distance of transmission of fiber optic systems.*

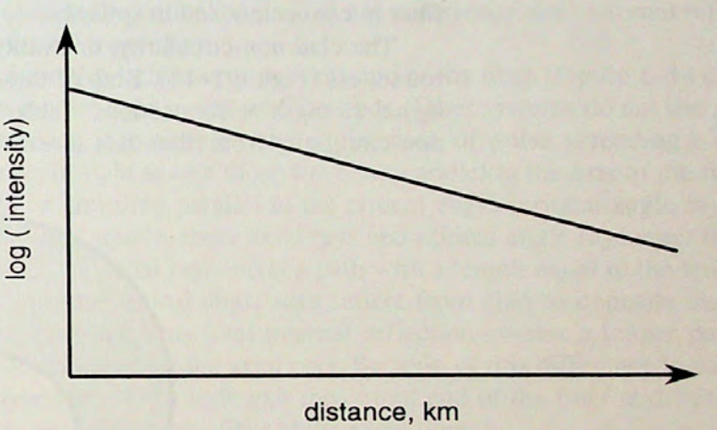


Figure 1–10 The Intensity of Light as It Travels Along a Fiber

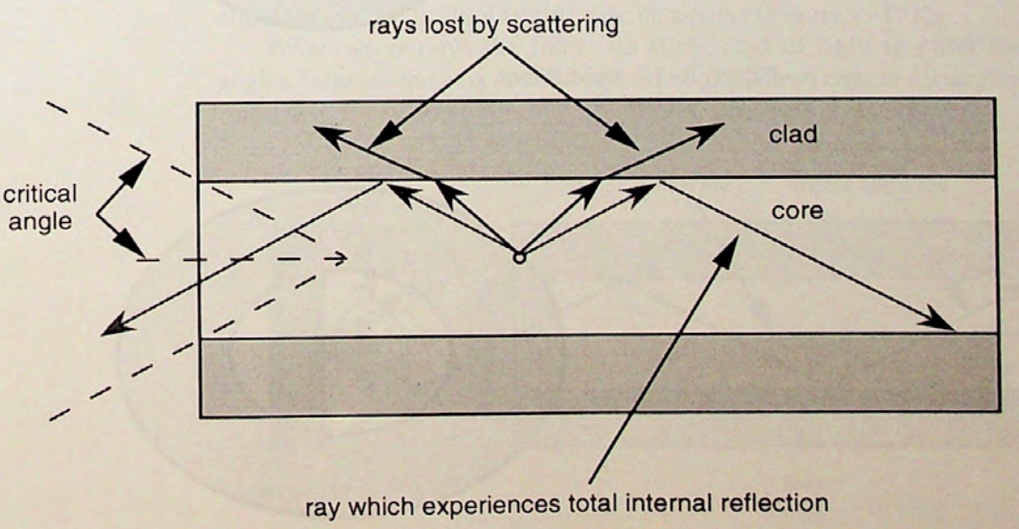


Figure 1–11 Light Lost Due to Scattering

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Fiber Type	Core Diameter (μm)	Wavelength (nm)	Attenuation Rate (dB/km)
singlemode	9	1550	0.25
singlemode	9	1310	0.5
multimode	50	1300	1.0
multimode	62.5	1300	1.5
multimode	50	850	3.0
multimode	62.5	850	4.0
multimode	960	660	125–250

Table 1–3 Attenuation Rates of Fibers when Cabled

However, some of this connection loss depends upon two fiber characteristics, core offset and clad non-circularity.

The core offset is the distance between the center of the core and the center of the clad (Figure 1–12). The amount of this offset affects the performance of the fiber in connectors and in splices.

The clad non-circularity, or ovality, is the deviation of the core from perfect roundness (Figure 1–13). Both of these conditions can result in excessive loss of signal strength at connections. Table 1–4 contains typical values for offset and non-circularity from fiber data sheets.

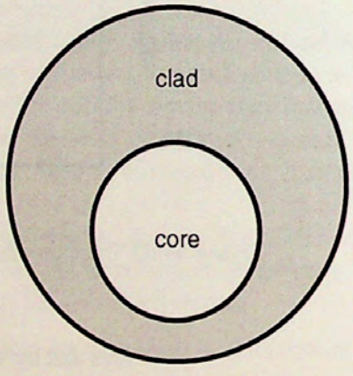


Figure 1–12 Core Offset

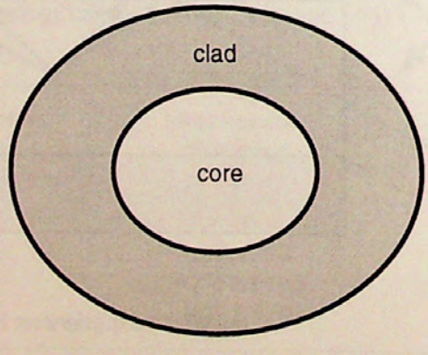


Figure 1–13 Clad Ovality

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Fiber Type	Core Offset	Clad Non-Circularity
singlemode	@1310 nm <1 μm	≤2%
singlemode	@1550 nm<1 μm	≤2%
multimode	<3 μm	≤2%

Table 1–4 Fiber Concentricity and Non-Circularity Values (Data courtesy of Corning, Inc.)

Pulse Spreading. The shape of a pulse of light[3] in an optical fiber changes as it travels along a fiber. Specifically, a pulse of light gets broader in time. We call this broadening "pulse spreading" or "pulse dispersion." Let us examine how and why such pulse spreading or pulse dispersion occurs.

Consider a light source that has rays emerging at all angles (Figure 1–14). These rays can be emitting at all angles, up to and beyond the critical angle. Since those rays outside the critical angle will not experience total internal reflection in the fiber, we can ignore them.

We position this light source near the end of the fiber (Figure 1–14). We place a filter between the light source and the fiber. (Fiber systems do not use such a filter. We introduce it to simplify the explanation of pulse spreading.) This filter blocks all rays of light except those traveling parallel to the axis of the fiber (axial rays) and those traveling parallel to the critical angle (critical angle rays). When we pulse the light source, these axial rays and critical angle rays enter the fiber at the same time. The axial rays travel a path with a length equal to the length of the fiber. However, the critical angle rays reflect from clad to opposite clad as they travel along the fiber. This total internal reflection creates a longer path for the critical angle rays than for the axial rays. Because of this difference in path length, these two types of rays of light exit the output end of the fiber at different times, even though they entered the fiber at the same time.

For any length of fiber, the first ray of light to arrive at the end will be the axial ray. The last ray to arrive will be the critical angle ray (Figure 1–15). The axial ray will be represented by a point at the leading (left) side of each pulse; the critical angle ray, by the trailing (right) side of a pulse (Figure 1–15).

When we remove the filter, we allow rays of light to enter the fiber at all angles between the axis and the critical angle. These rays at all angles arrive at the

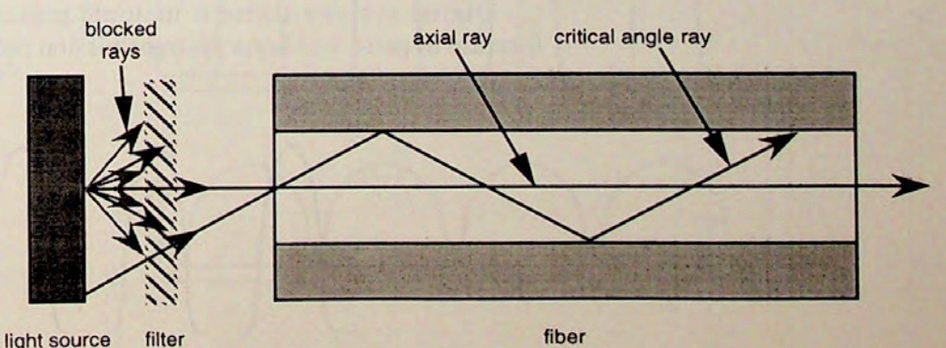


Figure 1–14 Axial Rays and Critical Angle Rays Travel Different Distances and Arrive at Different Times

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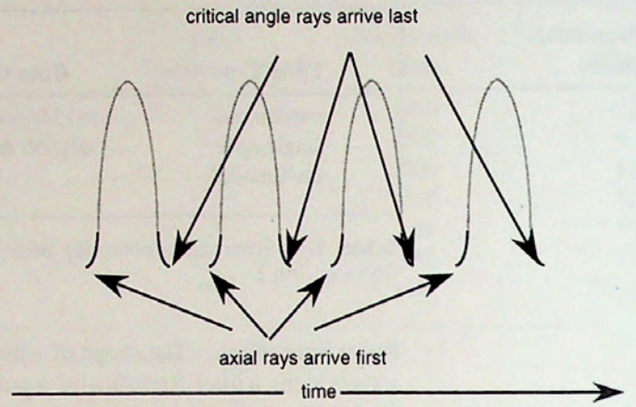


Figure 1–15 Arrival Times of Axial and Critical Angle Rays

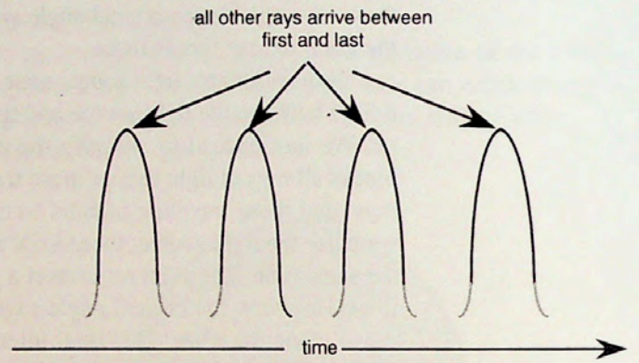


Figure 1–16 Arrival Times of All Rays

output end of the fiber at all times between the times of arrival of the axial and critical angle rays (Figure 1–16).

The difference between the time of arrival of the axial ray and the time of arrival of the critical angle ray is a measure of the pulse width. As the length of the fiber increases, the difference in the times of arrival of axial and critical angle rays also increases. Because this difference increases, the pulse width becomes larger (Figures 1–17 to 1–19).

Digital systems transmit multiple pulses, each of which experiences an increase in pulse width. As the transmission path becomes longer, the pulse width

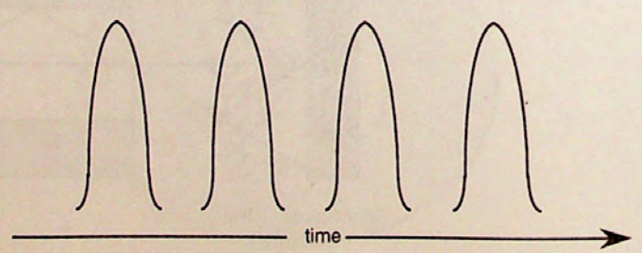


Figure 1–17 Pulse Width at Beginning of Fiber

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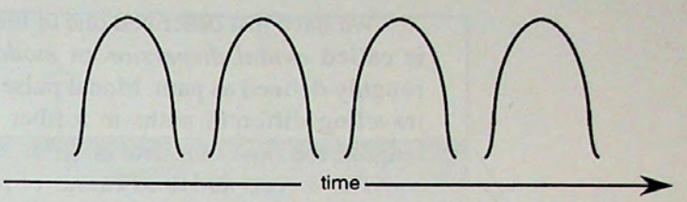


Figure 1–18 Pulse Width at Some Distance Beyond Beginning of Fiber

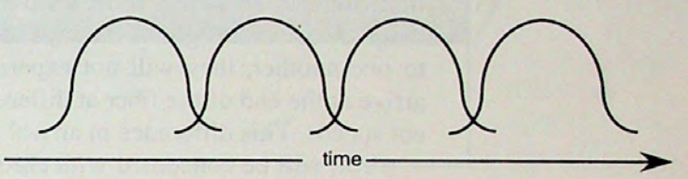


Figure 1–19 Pulse Width with Overlapping

becomes larger (Figure 1–18). As the pulse width becomes larger, the leading and trailing edges of successive pulses begin to overlap (Figure 1–19). When overlapping occurs, the receiving electronics add together the optical energy from the overlapping pulse regions, producing an output power waveform like that in Figure 1–20.

A digital system operates on the basic principle that a signal strength level below a certain level is a '0' and above that level is a '1.' The output power waveform in Figure 1–20 will be interpreted by the receiving electronics as a series of 1s. Note that the input signal in Figure 1–17 was a series of alternating 1s and 0s. Excessive pulse spreading results in loss of signal accuracy.

Although pulse spreading does limit the distance of transmission, the rate of pulse spreading in optical fibers is so low that high bandwidths or bit rates can be transmitted over large distances.

Note: *Pulse spreading limits the distance to which we can transmit without regeneration. If we exceed this distance, successive pulses will spread sufficiently to overlap. This overlapping results in an output signal different from the input signal (Figure 1–17). This is the second performance mechanism that limits the distance of transmission for fiber optic systems.*

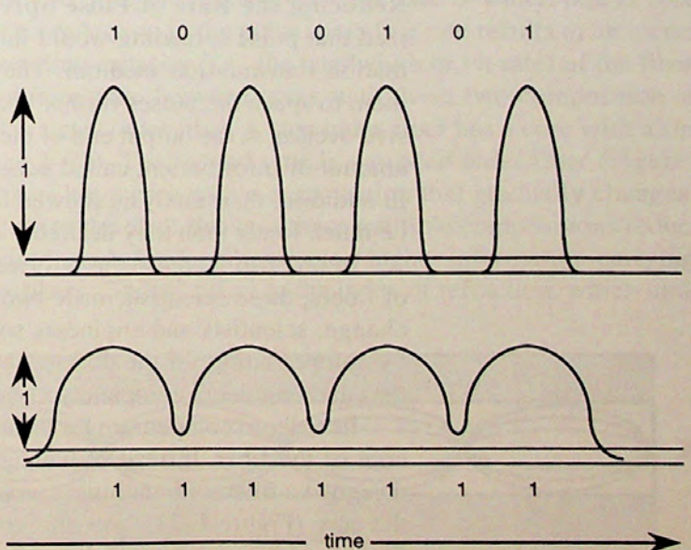


Figure 1–20 Output Pulse Intensity Waveform with Overlapping

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We have just described one of the three causes of pulse spreading. This cause is called *modal dispersion* or *modal pulse spreading*. The term *mode* can be roughly defined as path. Modal pulse spreading is a result of different rays of light traveling different paths in a fiber. Since these different paths have different lengths, the time of arrival of different rays will be different.

The second and third causes of pulse spreading are *chromatic dispersion* and *material dispersion*. You have all observed the cause of chromatic dispersion in high school physics: white light passing through a glass prism separates into its component colors because different colors of light travel at different speeds in materials. Chromatic dispersion is the pulse spreading that occurs because all light sources, including those used in fiber optic communication systems, emit a range of colors of light. If the rays of light emitted by these sources travel parallel to one another, they will not experience modal dispersion. However, they will arrive at the end of the fiber at different times because they are traveling at different speeds. This difference in arrival times will result in pulse spreading.

You will be concerned with chromatic dispersion. You will address this concern by using a test light source that has a wavelength, or color, and spectral width, or range of colors, which are close to those of the light source of the optoelectronics to be attached to the cable system.

The third cause of pulse spreading is material dispersion. Material dispersion is pulse spreading resulting from different rays of light traveling in different regions of the fiber. Imagine two rays of light that are traveling parallel paths and have the exact same color of light. These two rays of light can, and do, travel in different regions of the core of the fiber. Since they do, and since optical fibers do not have an exactly uniform chemical composition throughout the entire core (because they are non-crystalline, or amorphous, materials), these two rays travel at different speeds and arrive at different times. Again, this difference in time of arrival results in pulse spreading.

There are two changes in the shape of a pulse as it travels along a fiber: first, the strength of the pulse gets lower; and second, the pulse gets wider. Both of these changes limit the distance to which a fiber optic system can transmit.

Reducing the Rate of Pulse Spreading. Clever engineers and scientists realized that pulse spreading would limit the usefulness of optical fibers as an information transmission medium. They reasoned that pulse spreading would cause them to space the pulses further apart at the input end in order to eliminate excessive overlap at the output end of the fiber. This increase in spacing would limit the amount of information, called *bandwidth* or *bit rate*, which could be transmitted. In addition, their analysis showed that the maximum bandwidth or bit rate would be much lower than they desired.

In order to increase the information-carrying capacity (bandwidth or bit rate) of fibers, these scientists made two changes to the core of the fiber. With the first change, scientists and engineers sought to reduce the amount of pulse spreading by compensating for the differences in path lengths. In the second change, scientists and engineers completely eliminated modal pulse spreading.

In order to compensate for differences in path lengths, scientists redesigned the core of the fiber. Instead of having a constant composition in the core, scientists designed a fiber with multiple compositions. The first composition, in the center of the core (Figure 1–21), was chosen to have the lowest speed of light. Around the first composition is a second composition, in which the speed of light is higher than in the first. Around the second composition is a third composition, in which the

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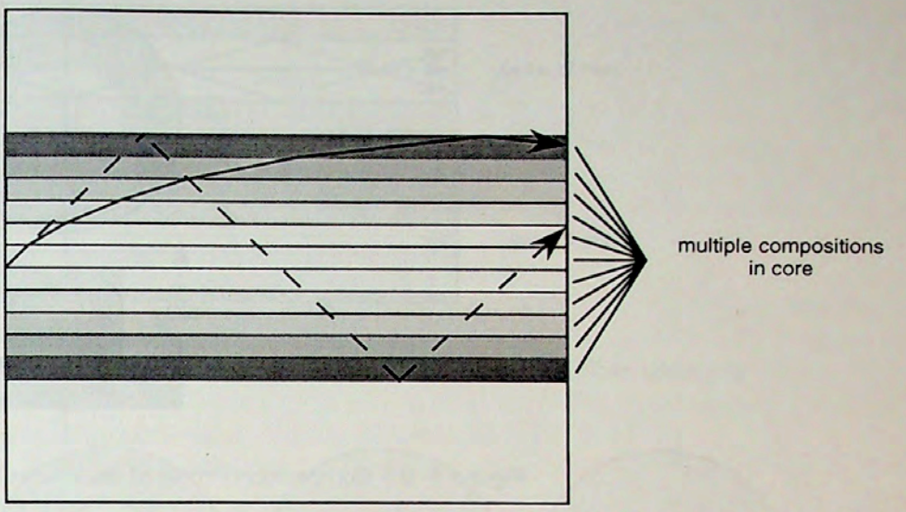


Figure 1–21 Path of Axial and Critical Angle Rays in Graded Index Core

speed of light is higher than in the second. This layering, or grading, of compositions is continued until the core has from 200 to 1,000 different compositions.

This grading of the core results in compensation: the farther away from the fiber axis a ray of light travels, the farther it goes. In addition, the farther away from the fiber axis a ray of light travels, the higher the average speed at which it travels. The longer distance of travel is offset, at least partially, by a higher average speed.

By grading the core in this manner, the scientists realized a second form of compensation: each time a ray of light crossed from a lower speed region to a higher speed region, the ray bends back towards the lower speed region (Figure 1–21). This bending creates a fiber path that appears to be curved (Figure 1–22), as compared to the straight path of light in fiber with a constant composition throughout the core (Figure 1–8). This second form of compensation results in the ray of light traveling a shorter distance than it would if the core had a single composition. These two compensations reduce the rate at which pulses spread in an optical fiber. This reduction in the pulse spreading rate results in an increase in the information handling capacity (i.e., the bandwidth or bit rate) of the fiber.

We must differentiate between cores with these two composition structures. The first type[4] is a *step index* fiber. A step index fiber has a core with a single composition (Figure 1–23). The second type is a *graded index* fiber (Figure 1–24). A graded index fiber has a core with a composition that gradually changes from the center of the core to the clad. Because these multiple compositions reduce the rate of pulse spreading, graded index fibers have a higher information-carrying capacity than step index fibers. "Index" refers to the index of refraction, which undergoes an

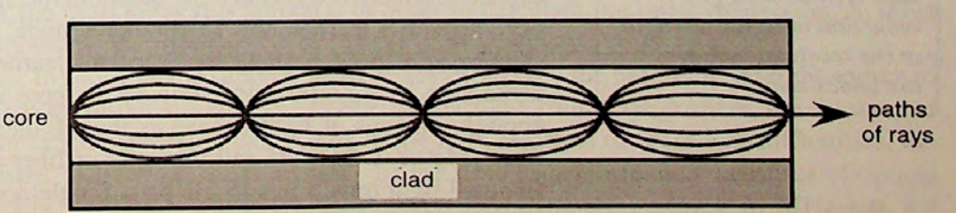


Figure 1–22 Curved Path of Ray in Graded Index Fiber

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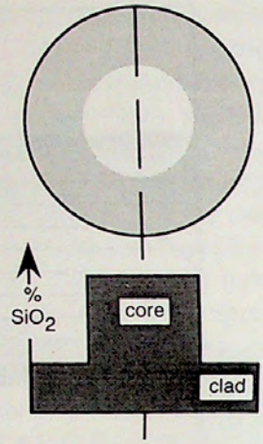


Figure 1–23 Composition Profile of Step Index Fiber

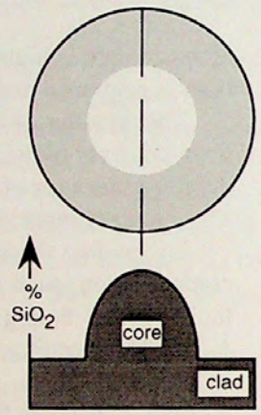


Figure 1–24 Composition Profile of Graded Index Fiber

abrupt change at the core-clad boundary of a step index fiber, but which changes gradually throughout the core of a graded index fiber. Both step index and graded index fibers (Figures 1–8 and 1–22) are called *multimode*, since light can travel multiple paths.

Although the change from step index fibers to graded index fibers resulted in a considerable reduction in the pulse spreading rate, all three dispersions (modal, chromatic, and material) were still active. Scientists wanted to increase the information-carrying capacity beyond the theoretical and practical limits of graded index fibers.

To learn how to achieve this additional increase in information-carrying capacity, scientists examined the quantum mechanics of light. From this examination, scientists learned how to eliminate modal pulse spreading, the largest cause of pulse spreading, completely. Scientists learned that they could eliminate modal dispersion by significantly reducing the core diameter. When the core is small enough, all rays of light behave as though they travel parallel to the axis of the fiber (Figure 1–25). We call this type of fiber a *singlemode* or *monomode* fiber, since all light travels in a single path. Singlemode fibers have significantly higher information-carrying capacities than do multimode fibers because the largest cause of pulse spreading, modal dispersion, does not occur.

Note: *Pulse spreading is not a concern during installation. Cable installation errors can result in a reduction in pulse spreading and an increase in information-carrying capacity. Because such errors result in a reduction in signal strength at the receiver, such errors are undesirable.*

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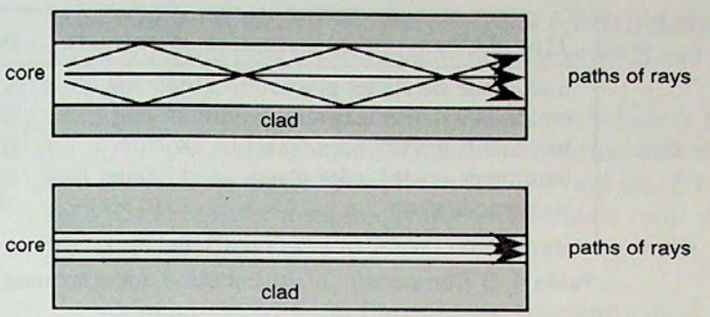


Figure 1–25 Comparison of Paths of Light in a Multimode Fiber (Top) and a Singlemode Fiber (Bottom)

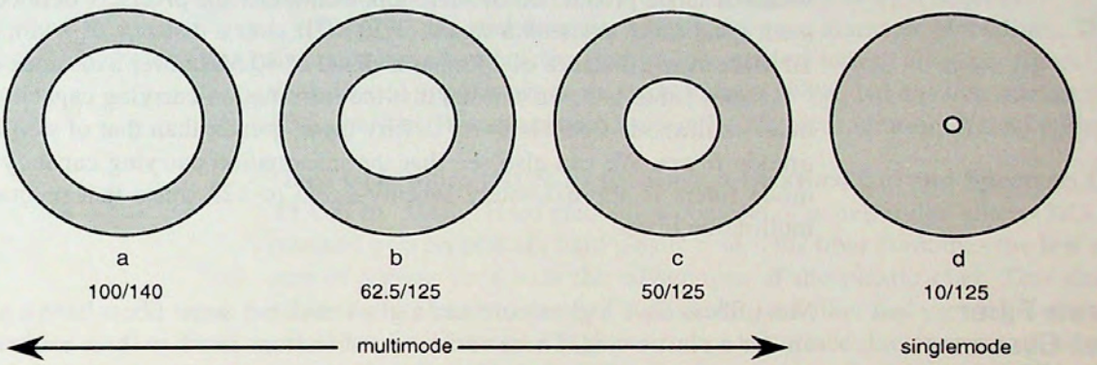


Figure 1–26 A Comparison of Core Diameters: Multimode and Singlemode Fibers, Drawn to Scale

This reduction in core size is significant: typical multimode core diameters are 50 µm, 62.5 µm, and 100 µm; typical singlemode core diameters range from 8 to 10 µm (Figure 1–26 a, b, c, and d respectively).

The core diameters of singlemode fibers are so small that some of the energy field travels in the clad. Because connections require alignment of the region in which the light travels, we need another term, the *mode field diameter*. The mode field diameter is the diameter within which most of the light energy travels. The mode field diameter is slightly larger than the core diameter, approximately 10 µm.

Pulse spreading rates are not our primary interest: information-carrying capacity is. The most commonly used information carrying capacity terms are "bandwidth" and "bit rate." It would make sense to use these two terms to characterize fibers. However, use of these terms is technically difficult because of two factors: link length and chromatic dispersion. In order to supply fiber with a desired bandwidth or bit rate, the supplier must know the length of the link(s). He or she must know this length(s) in order to calculate the pulse dispersion. In most situations, the supplier will not know such lengths.

In addition, the supplier usually does not know the nature of the light source to be used in the system. The nature of the light source determines the amount of chromatic dispersion that occurs in the link. Because of these two difficulties, the terms "bandwidth" and "bit rate" are not used as performance measures of optical fibers. Two other terms are used: *bandwidth-distance product*, in MHz-km, for multimode fibers, and *dispersion rate*, in picoseconds/nanometer/kilometer (ps/nm/km), for singlemode fibers.

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Type of Fiber	Wavelength	Bandwidth-Distance Product
multimode step index plastic	660 nm	5 MHz-km
multimode step index glass	850 nm	20 MHz-km
multimode graded index glass	850 nm	600 MHz-km
multimode graded index glass	1300 nm	1000–2500 MHz-km
singlemode glass	1310 nm	76,800–300,000 Mbps-km

Table 1–5 Comparison of Typical Bandwidth-Distance Products of Fibers

The bandwidth-distance product (BWDP) is the product of the length of the fiber or cable and the maximum bandwidth that the fiber or cable can transmit under specified measurement conditions.[5] Roughly speaking, a fiber with a bandwidth-distance product of 20 MHz-km, can, under the precisely defined measurement conditions, transmit a signal of 20 MHz over a distance of 1 km, a signal of 10 MHz over a distance of 2 km, or a signal of 40 MHz over a distance of 0.5 km.

From Table 1–5, we can see that the information-carrying capacity of graded index multimode fibers is thirty to fifty times greater than that of step index multimode fibers. We can also see that the information-carrying capacity of singlemode fibers is approximately seventy-seven to 128 times that of graded index multimode fibers.

The Three Fiber Material Systems and Four Fiber Types

Most fibers have a glass core and a glass clad, but some fibers have a plastic core and/or a plastic clad. These various combinations result in three material systems and four types of fibers: all glass, plastic clad silica (PCS), hard clad silica (HCS), and plastic optical fiber (POF).

All glass and PCS fibers have a coating or buffer coating (Figure 1–7). On all-glass fibers, this buffer coating protects the fiber from becoming weakened by abrasions of the clad or by interaction of the clad with gases and liquids in its environment. In other words, the buffer coating allows the fiber to retain its intrinsic high strength.

On PCS fibers, the buffer coating prevents the clad, which is a weak silicone rubber, from being mechanically removed from the core. If such removal occurs, the light will escape from the core and the attenuation of the fiber will increase.

A buffer coating is usually absent from a POF fiber and may, or may not, be present on a HCS fiber.

All-Glass Fibers. According to Kessler Marketing Intelligence, Newport, R.I., most fibers (88%) are all-glass (glass core and glass clad), singlemode fibers. These fibers are used because of their high information-carrying capacity (high bit rate or bandwidth, Table 1–5) and low attenuation rates (for long distances of transmission, Table 1–3). Singlemode fibers are used by telephone companies, CATV companies, and corporations as part of backbone networks.

Singlemode fibers are less expensive than multimode fibers. However, the optoelectronics and connectors for singlemode systems are more expensive than those for multimode systems. Almost all singlemode fibers have core diameters of 8–10 μm and a clad diameter of 125 μm.

Most of the remaining 12 percent are all-glass multimode fibers, which are used by corporations for LANs, backbone networks, video transmissions (RGB and CCTV), process control applications, and security applications. These fibers are used because of their moderate bandwidth-distance products, moderate attenuation

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rates, reduced optoelectronic and connector prices (relative to those of singlemode systems), lower fiber prices (relative to those of HCS and PCS fibers), compliance with standards, and upgradeability.

Most multimode fibers (Table 1–3) are graded index fibers with a clad diameter of 125 μm, although there is some use of fibers with clad diameters of 140 μm and above. Core diameters with the 125 μm clad are: 50 μ, 62.5 μ, and 85 μ. The 62.5 μm fiber is the most frequently used because most standards (such as FDDI, 802.3, Fiber Channel, and EIA/TIA-568A) have been or are being developed around this fiber.

Although the 62.5 μm fiber is most frequently used, the 50 μm fiber has the advantages of comparatively reduced attenuation rate, increased bandwidth-distance product, and reduced cost. However, the 50 μm fiber has a smaller core size and numerical aperture (NA), both of which contribute to reduced light power launched or coupled into the core from typical LED light sources.

The 140 μm clad diameter fiber has a core diameter of 100 μm. This fiber is the most expensive of the multimode, graded index, all-glass fibers. This fiber experienced popular use in the early to mid-1980s, but has lost market share to the 62.5 μm fiber. It is sometimes used in LANs incorporating optical splitters.

Hard Clad Silica (HCS, by the Ensign-Bickford Co. and Spectran Corp., and TECS, by 3M). Hard clad silica consists of a step index silica (SiO_2) core surrounded by a proprietary hard plastic clad. This fiber combines the low attenuation rate of a glass core with the advantages of the plastic clad. This clad has five advantages relative to those of a glass clad: the fiber has very high strength, a very small bend radius, and a high resistance to surface damage, which would weaken an all-glass fiber. This clad allows a connector to be crimped directly to the clad. In addition, this clad allows the fiber to be cleaved as though it were an all-glass fiber. This direct crimping and cleaving allows for fast, and low-cost, connector installation. The increased costs of this fiber and its connectors and reduced optical performance (increased attenuation rate—6 dB/km at 850 nm—and reduced bandwidth-distance product—17 MHz-km at 850 nm) have resulted in limited usage of HCS and TECS.

However, HCS is used when the environment favors the cleaving operation, and in connector-intensive situations, in which reduced labor cost offsets higher fiber and connector costs.

Plastic Clad Silica (PCS). PCS consists of a soft plastic clad of silicone rubber, placed around a step index silica (SiO_2) core. This fiber combines the low attenuation rate of a glass core with a soft plastic clad to which a connector can be crimped. The soft plastic clad can allow the core to be eccentric in the clad and in the connector, resulting in undesirably high connector losses. This product requires a buffer coating to protect the soft clad. This product was popular in the early 1980s, but now is rarely used in communication applications.

Plastic Optical Fibers (POF). All plastic fibers consist of a step index, plastic core surrounded by a plastic clad. The materials used in POFs are usually polymethmethacrylates, although styrenes, fluorocarbons, and polycarbonates can be used. POF optoelectronics have a visible wavelength of approximately 660 nm.

POFs have technical and economic advantages. The two technical advantages are an extremely large core (typically 960 μ) and ruggedness. POFs do not suffer from the problem of breakage, as do all-glass, HCS, and PCS fibers.

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The economic advantage of POFs is low cost. POF cables, fiber, connectors, connector installation, and LEDs all cost less than their glass fiber cousins. Low-cost, injection molded connectors can be crimped directly to the clad. Installation of such connectors takes less than two minutes, as opposed to 5 to 15 minutes for all-glass fiber connectors.

POF has five disadvantages. The first disadvantage is a high attenuation rate (Table 1–3), which limits the use of POF to short distance applications, typically less than 328 feet (though it is possible to use POF to 500 feet). This distance limitation suggests that POF is ideal for desktop to wiring closets, in which the typical distances are less than 328 feet. Low cost laser diodes may increase this limit to thousands of feet and bit rates to in excess of 100 Mbps.

The second disadvantage is low bandwidth-distance product (Table 1–5). The third, fourth, and fifth disadvantages are lack of knowledge on the part of the potential user, lack of support from those companies most likely to benefit from marketing of this product, and lack of standards, both for measurement and for product performance criteria. POF is likely to see increased usage in the next 10 years.

BASIC CABLE FACTS

The Ten Structural Elements and Functions

All structural elements of a fiber optic cable protect the fiber during installation and use. Many types of protection are required. The fiber, usually glass, cannot be subjected to excessive tension, bending, crushing, or to chemical or mechanical damage from the environment.

This protection comes from ten structural parts:

- Buffer tube
- Strength members
- Outer jacket
- Inner jacket
- Gel filling compound
- Water blocking compound
- Binding tape or yarn
- Armor
- Ribbon
- Fillers

Buffer Tube. The *buffer tube* is the first layer of plastic placed around a fiber by the cable manufacturer. There are two types of buffer tubes, *tight buffer tube* and *loose buffer tube*.

In the tight buffer tube, the inner diameter of the buffer tube is exactly the same as the outer diameter of the fiber (Figure 1–27). The tight buffer tube design has the unique advantage of allowing the ends of a broken fiber to remain

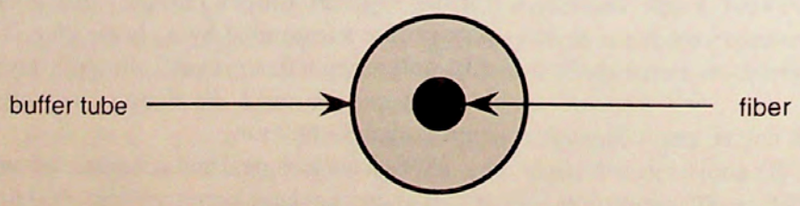


Figure 1–27 Cross Section of a Tight Buffer Tube

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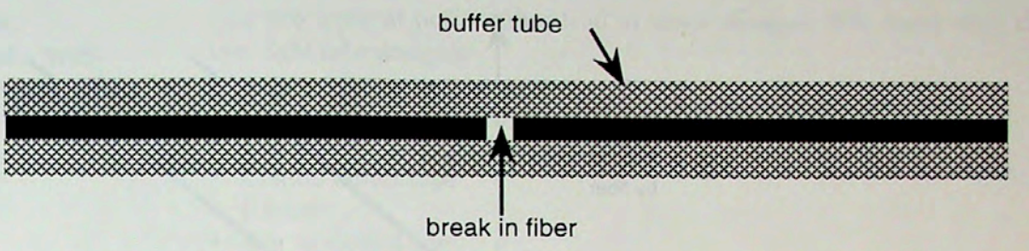


Figure 1–28 Broken Fiber in a Tight Buffer Tube

aligned and in contact (Figure 1–28). In this situation, a broken cable may not result in a lost signal. This advantage creates a highly reliable cable in severe environments. For this reason, tight tube designs are favored by the Army in field tactical applications, by the Navy for shipboard applications, and by the Air Force in aircraft applications.

A second advantage of tight tube designs is low labor cost for end preparation. The cost is low because there are no water blocking compounds to remove for splicing and connector installation. A third advantage is increased ruggedness: the buffer tube increases the overall diameter of the buffered fiber approximately 3.5 times.

In the loose buffer tube, the inner diameter of the plastic tube is much larger than the outer diameter of the fiber (Figure 1–29). In addition, the length of the fiber can be greater than the length of the tube. This difference between fiber length and buffer tube length results in the fiber having a helical path in the buffer tube. Loose buffer tubes can contain one or more fibers; tight buffer tubes contain only one fiber.

The loose tube design has two basic advantages: isolation from mechanical and environmental forces and ease of filling with water blocking materials. This isolation results from a mechanical dead zone (Figure 1–30). This mechanical dead zone isolates the fiber from mechanical and environmental forces.

The mechanical dead zone occurs because the fiber can both move from the center of the loose buffer tube to the inside edge when stress is applied to the cable, and straighten out from its normal helical path. Both of these features allow a fiber to be isolated from forces applied to a cable. Whenever a force is applied to a loose tube cable, there is a force level below which no force is applied to the fiber. If no force is applied to the fiber, it is impossible to break the fiber.

A second, generally accepted advantage of loose tube designs is good resistance to damage from moisture. Loose tube designs can be easily filled with water blocking materials.

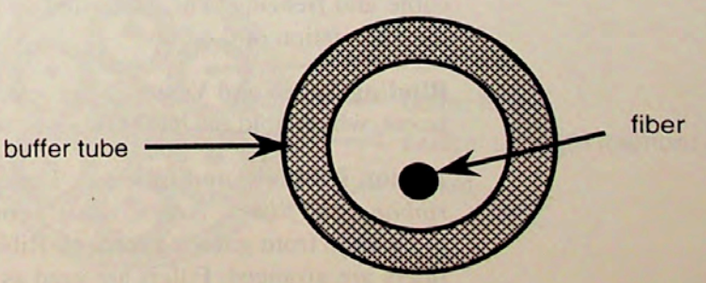


Figure 1–29 Cross Section of a Loose Buffer Tube

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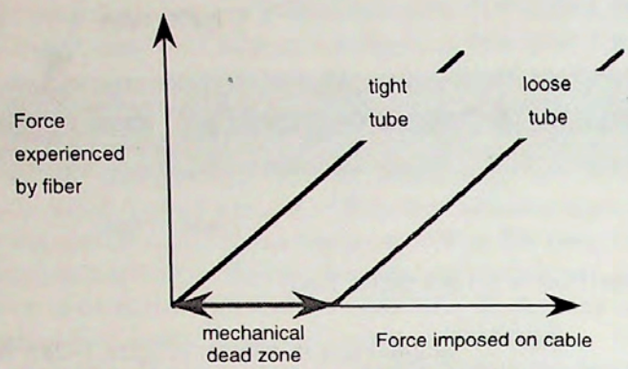


Figure 1–30 Mechanical Dead Zone in a Loose Buffer Tube

Strength Members. The second cable structural element is the *strength members*. Strength members are materials that restrict the elongation of the fiber when the cable is under load. Strength members are necessary in order to prevent fiber breakage, since fiber breaking loads are 2–10 pounds. The combination of a central strength member and buffer tubes is called a *cable core*.

Strength members can be metal wires, metal ropes, fiberglass-epoxy rods, flexible aramid yarns, such as Kevlar®, or flexible fiberglass rovings. Fiberglass epoxy rods and flexible aramid yarns are the most commonly used strength member materials. In the future, flexible fiberglass rovings will become more common because their use reduces the cost of the cable.

Outer Jacket. The third structural element is the outer jacket. The outer jacket is the outermost layer of the cable. This jacket protects the fiber and the cable from the environment and from the installation process.

Inner Jacket. The fourth structural element is the inner jacket, which is not included in all designs. The inner jacket separates subunits of fiber(s) from one another. The inner jacket can separate the cable core from other structural elements.

Gel Filling and Water Blocking Compounds. The fifth and sixth structural elements are the filling and blocking compounds. *Gel filling* and *water blocking* compounds provide protection against damage from water. The gel filling compounds fill the empty space in a loose buffer tube. This filling is necessary to prevent moisture from contacting fibers. Such contact can result in a reduction in the strength of the cable.

The water blocking compounds prevent water from traveling along the cable into the electronics. In addition, these compounds prevent water from entering a cable and freezing. The expansion of freezing water can result in an increase in the attenuation of the fiber.

Binding Tapes and Yarns. The seventh structural element is *binding tapes and yarns*, which hold the buffer tubes or sub cables together during jacket extrusion.

Armor, Ribbons, and Fillers. The eighth, ninth, and tenth elements are *armor*, *ribbons*, and *fillers*. Armor, usually corrugated stainless steel, provides resistance to damage from gnawing rodents. Ribbons are precision tapes on which multiple fibers are arranged. Fillers are used as a manufacturing convenience to allow for efficient use of cable processing equipment.

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Structures, Advantages, and Disadvantages of the Seven Cable Designs

The two types of buffer tubes lead to seven designs: five loose tube designs, and two tight tube designs:

- Loose tube, single fiber per tube
- Loose tube, multiple fiber per tube
- Central buffer tube
- Ribbon
- Star or slotted core
- (Tight-tube) premise
- (Tight-tube) break out

The five most commonly used designs are: break-out cable; premise cable; loose tube, multiple fiber per tube; central buffer tube; and ribbon.

Loose Tube, Single Fiber Per Tube. This design consists of a fiber surrounded by a loose buffer tube (Figure 1–31). Multiple buffer tubes are stranded around a central filler or strength member to form a cable core. This cable core is surrounded by binder tape or yarn and by a jacket.

The advantages of this design are the two basic advantages of the loose tube design: isolation of the fiber from mechanical and environmental forces and good resistance to damage from moisture. An additional advantage is the protection of each fiber by a separate buffer tube. The disadvantages are relatively high cost, large size, high shipping cost, and relatively large bend radii.

When used, this cable design is used in outdoor applications with fiber counts less than twelve. However, this design is rarely used in the United States.

Loose Tube, Multiple Fiber Per Tube. The loose buffer tube, multiple fiber per tube (*MFPT*) design consists of a number of fibers surrounded by a loose buffer tube (Figure 1–32). The most common numbers of fibers are six and twelve. Multiple buffer tubes are stranded around a central filler or strength member to form a cable core. The MFPT cable core is surrounded by binder tape or yarn and by a jacket.

The advantages of the MFPT design are the two basic advantages of the loose tube design. Additional advantages are low cable cost, ease of water blocking, wide temperature range of operation, and convenient mid-span access. Convenient mid-span access is important when a system requires access to some, but not all, of the fibers at some location between the ends. The separate buffer tubes allow access to the required fibers without risk of damage to all fibers in the cable.

The disadvantages of the MFPT design are high labor cost for end preparation (exposing and preparing fibers for splices or connection) and high cost for end

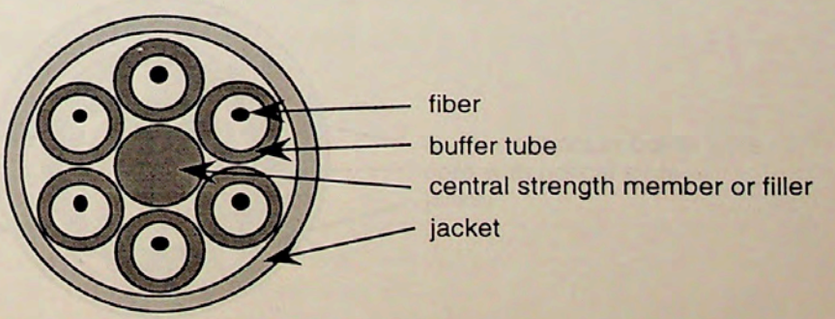


Figure 1–31 Cable Cross Section of Loose Tube, Single Fiber per Tube Design

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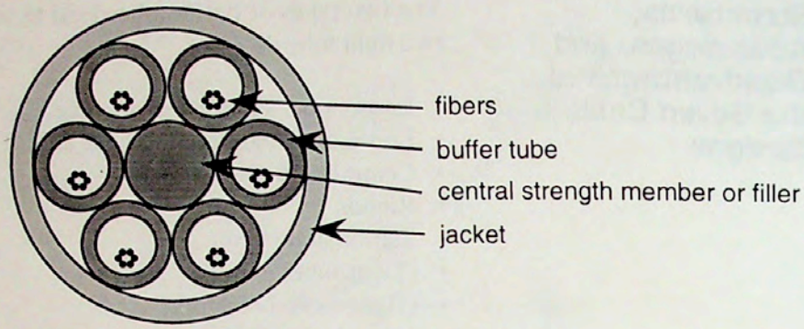


Figure 1–32 Cable Cross Section of Loose Tube, Multiple Fiber per Tube Design

hardware (wall or rack mounted boxes). The high labor cost for end preparation results from the difficulty of removing the heavy duty jacket and from the need to remove the water blocking grease and gel.

Rule of Thumb: *End preparation time for this design is 0.11 hour/fiber/end, or 2.6 man-hours per end for a 24-fiber cable and 5.2 man-hours per cable segment (for all dielectric designs).*

The high cost for end hardware is a result of the fibers being exposed during the end preparation process. These exposed fibers must be strengthened or protected by hardware. The MFPT design is most frequently found in outdoor applications with fiber counts greater than twelve.

Central Buffer Tube (CBT). The *central buffer tube* design consists of a single, centrally located loose buffer tube (Figure 1–33). The buffer tube encloses all the fibers, usually in multiple bundles, each of which contains twelve fibers. The bundles are held together by color-coded binder threads.

This buffer tube is surrounded by strength members and a jacket. The advantages of the CBT design are the basic advantages of the loose tube design. Additional advantages are low cost, small diameter, small bend radii, and relatively low shipping cost.

The disadvantages are inconvenient mid-span access, high labor cost for end preparation, and high cost for end hardware. Some of these designs use high strength piano wire as strength members. Such designs must be bonded and grounded. This cable design is most frequently found in outdoor applications with fiber counts greater than twelve.

Ribbon. The *ribbon* cable design is similar to the CBT design, with a different arrangement of the fibers. Four to twenty-four fibers are precisely arranged on a substrate to form a ribbon (Figure 1–34). The ribbons are stacked and may be

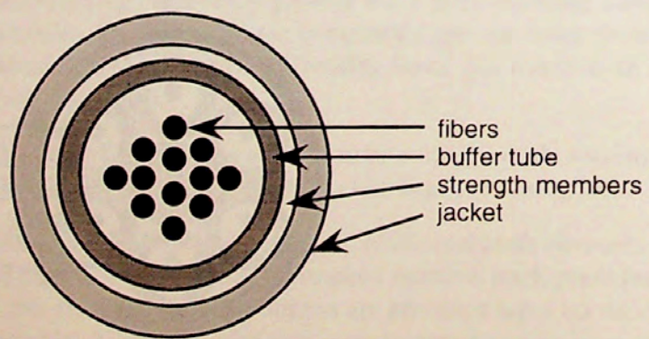


Figure 1–33 Cross Section of Central Buffer Tube Cable Design

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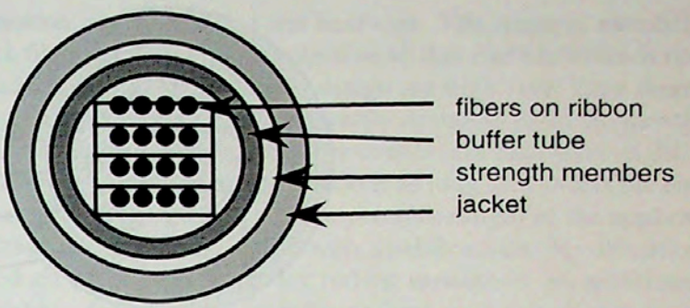


Figure 1–34 Cross Section of Ribbon Cable Design

twisted or buckled slightly. The stack of ribbons is enclosed in a centrally located buffer tube. The balance of the structure can be the same as that of the CBT design.

The advantages of the ribbon cable design are the advantages of the loose tube designs and the advantages of the central tube, multiple fiber per tube design. The major additional advantage is reduced splicing cost. This reduced cost results from the fiber alignment on ribbons, which allows for simultaneous splicing of up to twenty-four fibers.

The disadvantages of this design are the same as those for the central buffer tube design. In addition, there is a potential disadvantage of splice losses higher than those for the previous two designs (see Barbara Birrell and Sheila Cooper's "Practical Guidelines for Mass Mechanical Splicing," *Fiberoptic Product News*, April 1995, pp. 27–30). This increased splice loss is not significant in digital systems, but may be significant in high performance analog systems, like those of CATV companies. The final disadvantage is increased cable cost. This cable design is most frequently found in outdoor applications with fiber counts greater than twelve.

The Star or Slotted Core. The *star or slotted core* design consists of a core in which slots are formed (Figure 1–35). The slots take a helical path along the core. Fibers, or fibers in buffer tubes, are placed in the slots to form a cable core. The cable core is surrounded by a jacket.

The advantages of the slotted core, or star core, are the advantages of the loose tube designs, if the design is a loose tube. The disadvantages of this design are a limited number of suppliers and limited fiber counts. Typically, fiber counts are limited to twenty-four. This cable design is most frequently found in OPGW (optical power ground wire, used by power generating utilities) applications with fiber counts less than twenty-four. With the exception of the OPGW cable, this design is rarely used in the United States.

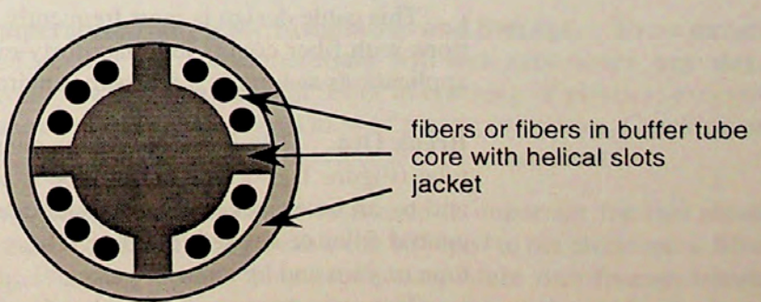


Figure 1–35 Cross Section of Star Core, or Slotted Core, Cable Design

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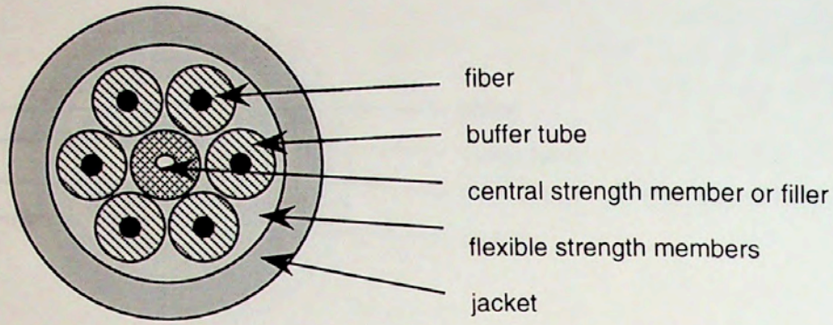


Figure 1–36 Cross Section of Premise Cable Design

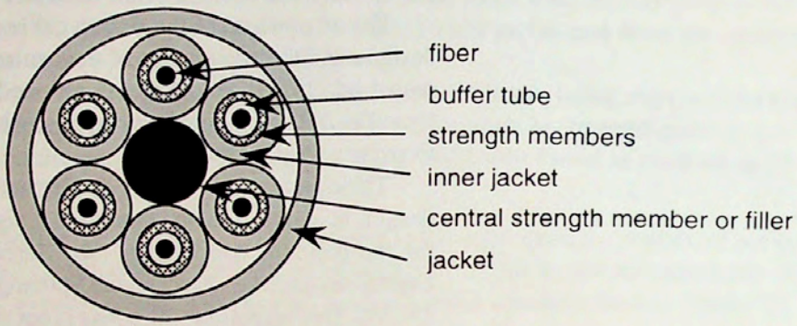


Figure 1–37 Cross Section of Break Out Cable Design

Premise. The *premise* design consists of multiple, tight buffer tubes stranded around a central strength member or filler (Figure 1–36). The buffer tubes are surrounded by flexible strength members, usually Kevlar®. The strength members are surrounded by a jacket.

The main advantage of the premise cable design is the unique advantage of tight tube designs, which is alignment of broken fiber ends. Additional advantages relative to the break out design are reduced end preparation labor cost, reduced cable cost, reduced diameter, reduced minimum bend radii, and reduced shipping cost.

The disadvantages of the premise design are that it is less rugged than the break out design and that it has high cost for end hardware. When the jacket is removed from this design, the tight buffer tubes are exposed. Because these buffer tubes can be damaged, they must be protected with the same type of hardware used to protect the ends of the loose tube cable designs.

This cable design is most frequently found in medium length, indoor applications with fiber counts less than forty-eight. This design can be used in outdoor applications as long as it meets the environmental requirements of the application.

Break Out. The *break out* design consists of fiber surrounded by a tight buffer tube (Figure 1–37). The buffer tube is surrounded by flexible strength members and by an inner jacket to form a sub cable. The sub cables are stranded around a central filler or strength member. These sub cables can be surrounded by binder tape or yarn and by an outer jacket.

The main advantage of the break out design is the unique advantage of tight tube designs. Additional advantages are rugged design, relatively low cost for labor

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of end preparation, and no cost for end hardware. The strength member and inner jacket of each fiber provide enough protection so that end hardware is not required.

The disadvantages of the break out design are high cost, large diameter, large bend radii, and high shipping cost. This cable design is most frequently found in short length, indoor applications with fiber counts less than forty-eight. The break out design can be used in outdoor applications as long as it meets the environmental requirements (water resistance and temperature range) of the application.

All of these designs are available with modifications. Modifications include an armor and an additional jacket for rodent resistance; an additional layer of strength members, for increased installation load or for increased long-term use load; and additional jackets for resistance to abrasion or to chemical attack.

The Five Most Important Installation Performance Characteristics

The five most important installation performance characteristics of the cable are:

- Maximum recommended installation load
- Minimum recommended long-term bend radius
- Minimum recommended short-term bend radius
- Installation and storage temperature ranges
- Moisture resistance

The Maximum Recommended Installation Load. This is the maximum load, in pounds force, that can be applied during installation. Exceeding this load can result in breakage of the fibers or a permanent increase in the attenuation. Typical ranges are 150–600 pounds.

Rule of Thumb: Most, but not all, fiber optic cables have a minimum recommended, long-term, bend radius equal to ten times the diameter of the cable.

The Minimum Recommended Long-Term Bend Radius. This is the minimum radius to which the cable can be bent for its lifetime without causing breakage of the fibers or a localized increase in attenuation. This performance characteristic must be observed during the installation process. This limitation requires proper installation of cable in all locations, including cable trays, cable boxes, splice enclosures, and patch panels.

Rule of Thumb: Most, but not all, fiber optic cables have a minimum recommended short-term bend radius equal to twenty times the diameter of the cable.

The Minimum Recommended Short-Term Bend Radius. This is the minimum radius to which the cable can be bent while under the maximum recommended installation load. Violation of this bend radius can result in breakage of the fibers, a localized increase in attenuation, or localized weakening of the fibers. Localized weakening can result in a reduction of the reliability of the cable.

This limitation requires selection of pulleys, slings, or sheaves with the proper diameter for installation. Pulley diameters may not fit in manholes.

The Temperature Ranges for Installation and Storage. These ranges must be observed so that the cable materials will not experience any degradation. Excessively low temperatures will result in cracking of plastics; excessively high temperatures will result in degradation of plastic properties. Cracking and degradation can result in exposure of the fiber to the environment.

Moisture Resistance. Moisture resistance is important for two reasons. First, moisture that can travel along a cable can be piped to the electronics. Moisture and electronics usually do not mix. Second, moisture that freezes inside a cable expands and causes an increase in the attenuation of the cable. Such an increase can shut down the transmission system.

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BASIC CONNECTION FACTS

The Three Functions of the Connection System

Fiber connections have three functions:

- Precise alignment
- Fiber retention
- End protection

Precise Alignment. Most fiber cores are smaller than the human hair. This extremely small size requires precise alignment to achieve efficient transfer of light at light sources, at light detectors, and at fiber-to-fiber connections.

Fiber Retention. Fiber retention prevents fibers from moving toward or away from one another. Such movement can result in excessively high signal intensity loss or damage to protruding fiber ends.

End Protection. End protection ensures reliability through preventing unnecessary damage. Such damage can also result in excessively high loss of signal strength.

Eight Causes of Signal Strength Loss in Connections

A connection can cause loss of light intensity in eight ways (Figure 1–38):

1. Radial offset or radial misalignment
2. Lateral separation or lateral misalignment
3. Angular mismatch or angular misalignment
4. NA mismatch
5. Core diameter mismatch
6. Lack of cleanliness
7. Lack of smooth surface
8. Surface, or Fresnel, reflection

Radial Offset or Radial Misalignment (Figure 1–38 a). If the axes of the cores of two connections are offset in the radial direction, light traveling from the core of the transmitting fiber will enter the clad of the receiving fiber. This light will be lost, since light experiences total internal reflection only when it travels in the core.

Lateral Separation or Lateral Misalignment (Figure 1–38 b). If the spacing between the ends of the two cores is excessive, light traveling at or near the critical angle will strike the clad of the receiving fiber and will be lost.

Angular Mismatch or Angular Misalignment (Figure 1–38 c). If the axes of two fibers are not coincident, light traveling from the transmitting fiber to the receiving fiber can be lost by two mechanisms. First, light traveling at the critical angle from the transmitting fiber will strike the clad of the receiving fiber. Second, light traveling at the critical angle (or the NA) can enter the core at an angle greater than the critical angle of the receiving fiber. This light would be lost because light that strikes a core at an angle greater than the critical angle does not experience total internal reflection at the boundary of the core and clad.

NA Mismatch (Figure 1–38 d). If the NA of the transmitting fiber is larger than that of the receiving fiber, light will be lost, because the receiving fiber cannot accept such light.

Core Diameter Mismatch (Figure 1–38 e). If the core diameter of the transmitting fiber is larger than that of the receiving fiber, some light will be lost, because it will strike the clad of the receiving fiber.

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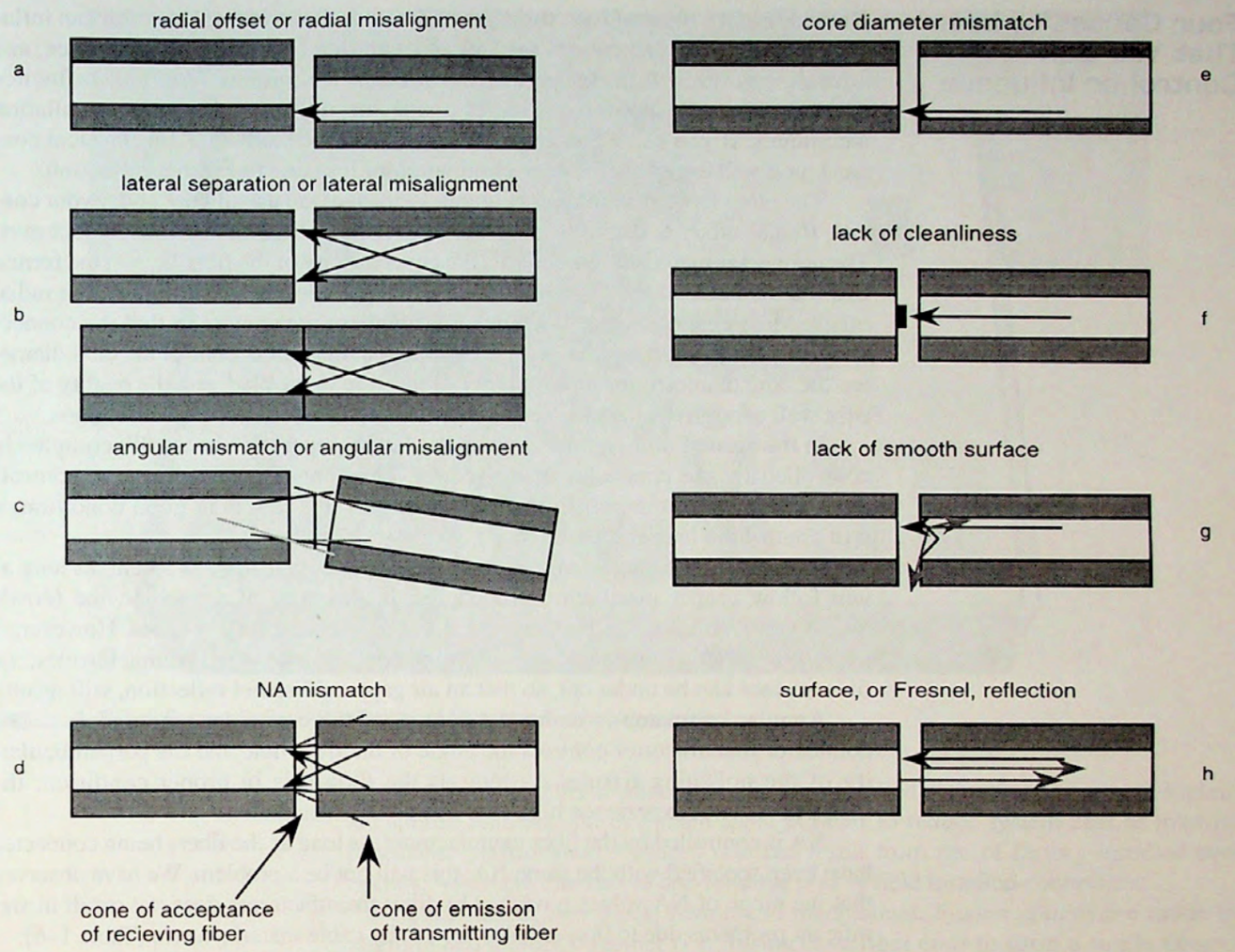


Figure 1–38 The Eight Causes of Loss in Connection Mechanisms

Lack of Cleanliness (Figure 1–38 f). Any dirt or particulate impurity on the surface of either the transmitting or receiving core will block some of the light. This problem is severe in singlemode fibers because their cores are much smaller (8–10 μm) than those of multimode fibers (50–100 μm).

Lack of Smooth Surface (Figure 1-38 g). If the surface of either the transmitting or receiving core is not smooth, the light will be refracted or reflected. In either case, the light can be redirected so that it strikes the clad of the receiving fiber or so that it enters the core at an angle greater than the critical angle. Such light will be lost. This problem is severe in singlemode fibers because of their small core diameters.

Surface, or Fresnel, Reflection (Figure 1–38 h). Whenever light travels through a surface, it might be partially reflected. If the surface has different indices of refraction on either side, as do air and fiber cores, light will experience a partial reflection. This light, which is reflected back into the fiber, represents a reduction in strength of the signal, and, therefore, a loss.

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Four Causes of Loss That You Can Control or Influence

Of these eight causes of loss, three are under your direct control and you can influence a fourth. You can control the lack of cleanliness, lack of smooth surface, and lateral separation through proper installation techniques. You can influence Fresnel reflection through choice of connector and through proper installation techniques. If you use a contact connector (usually called "PC" for physical contact), you will experience a near-elimination of loss due to Fresnel reflection.

The other five causes of loss (Figures 1–38, a–e) are usually not under your control. Radial offset is determined by the connector, splice, and fiber manufacturers. The connector manufacturer controls the concentricity of the fiber hole in the ferrule and the diameter of the fiber hole. These two parameters will influence the radial offset. Most connector manufacturers control these parameters so that the connectors meet their stated performance. The fiber manufacturers control the clad diameter, the core diameter, the concentricity of the core in the clad, and the ovality of the core well enough that connectors meet their stated performance specifications.

In the case of non-contact connectors, lateral separation is usually completely controlled by the connector manufacturer. The connector manufacturer controls the dimensions of the polishing tool. As long as this tool is in good condition, it will control the lateral separation.

In the case of contact connectors, lateral separation is not a problem, as long as you follow proper installation procedures. In this type of connector, the ferrule length is not critical. The low loss is a result of contact of the ferrules. However, if excessive polishing time and/or polishing pressure is used with ceramic ferrules, the fiber surface can be under cut, so that an air gap, and Fresnel reflection, will result.

Angular mismatch is under the control of the connector manufacturer. The connector manufacturer controls the angle of the fiber hole and the perpendicularity of the polishing fixture. As long as the fixture is in proper condition, the installer will not experience high loss due to this mechanism.

NA is controlled by the fiber manufacturer. As long as the fibers being connected have been specified with the same NA, this will not be a problem. We have observed that the range of NA values produced by fiber manufacturers does not result in significant problems due to proper NA selection by cable manufacturers (Table 1–6).

Core diameter mismatch is under the control of the fiber and cable manufacturers. Fortunately, fiber manufacturers control the core diameter tightly enough that core diameter mismatch is rarely a problem.

Splices

Types and Advantages. Connections can be splices or connectors. *Splices* are permanent or semi-permanent connections between fibers. Splices are used when rerouting of optical paths is not required or expected. Splices are used in two situations: mid-span splices, which connect two lengths of cable; and *pigtails*, at the ends of a main cable.

Average	0.2009
Standard Deviation	0.0026
Range	0.197-0.206
Number of fibers	60

Table 1–6 Average Loss and Range of NA of 50 μm Fibers
(Data courtesy of Pearson Technologies Inc.)

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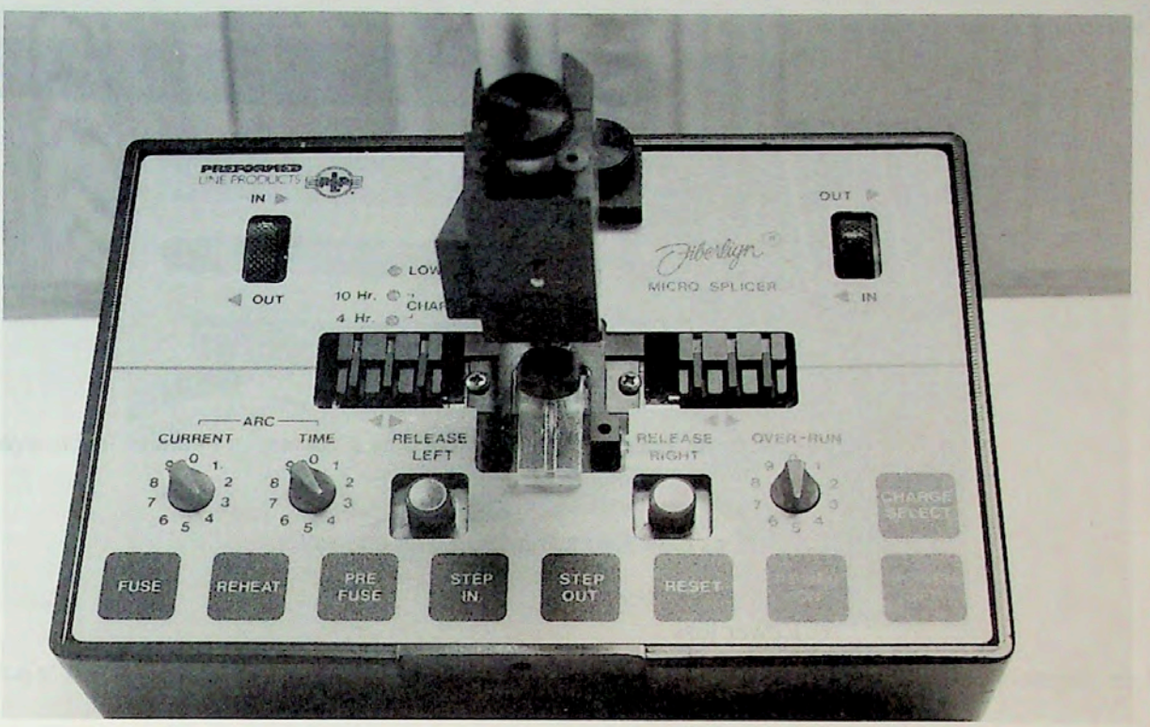


Figure 1–39 A Fusion Splicer (Courtesy of Pearson Technologies Inc.)

Pigtails are lengths of cable with a factory-installed connector on one end. Pigtails are spliced onto the end of a main cable in order to reduce system cost or improve reflectance performance. Reduced cost can result from use of factory-installed connectors, which are one-half to one-third the cost of field installed connectors.

Splices are of two types: fusion and mechanical. *Fusion splices* are made by aligning and melting together (i.e., fusing) two fiber ends to form a single fiber of increased length. The alignment and fusing are performed by a fusion splicer (Figure 1–39). Fusion splices are permanent, have a low consumable cost/splice, and, in general, have lower losses than do *mechanical splices*. However, the capital investment in equipment required to make fusion splices is significantly higher ($6,000–$36,000) than that for mechanical splices. In addition, fusion splices cannot be made in an atmosphere that contains explosive gasses. Typical fusion splice losses are less than 0.2 dB, with frequent values less than 0.1 dB.

Mechanical splices are made by inserting two ends of fibers into a piece of hardware that aligns the ends. This hardware is a consumable part, which results in a higher cost of consumables than for fusion splices. Mechanical splices have typical costs of $8–$24. Typical mechanical splice losses are in the range of 0.3–0.5 dB.

Mechanical splices (Figure 1–40) can be permanent or semi-permanent. Some permanent mechanical splices (from Norland Products Inc. and AT&T) require the use of an adhesive to permanently fix the fibers in the splice. Other permanent mechanical splices (from AMP and 3M) require the crimping of the splice to the fiber. Semi-permanent mechanical splices (from GTE, Advanced Components Applications Inc., and AMP) do not require the use of an adhesive, but use a mechanism to grip the fibers mechanically.

All mechanical splices use an index-matching gel or oil to reduce loss by reducing Fresnel reflections. This gel is installed in the splice by the manufacturer.

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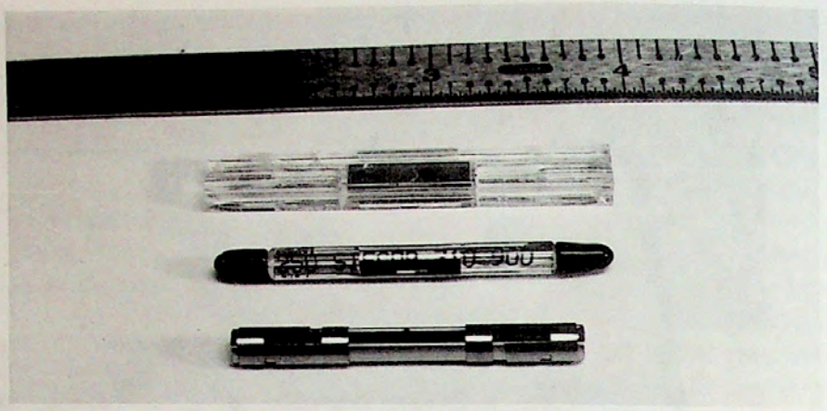


Figure 1–40 Types of Mechanical Splices (Courtesy of Pearson Technologies Inc.)

Splices have four advantages over connectors:

- Low reflectance
- Lower loss
- Better immunity to connection damage
- Lower maintenance cost

Hardware Required for Splice Protection. The installation of all splices requires exposing the fibers. These exposed fibers need to be protected from the environment. This protection is provided by splice covers (for fusion splices), splice trays, and splice enclosures.

Connectors

Advantages. In most cases, the choice between splices and connectors is clear cut. If there is a need to reroute the signal, connectors are the only choice, since the splice tray, splice case, and enclosure are not designed to allow for convenient or reliable rerouting, whereas connectors provide for rerouting of optical signals. Connectors have two additional advantages: low to moderate loss and ruggedness of the connection to the cable.

The Three-Part Connector System. Connectors are part of a three part system. The connector system includes the connector or plug, a receptacle, and an adapter (Figure 1–41). The connector aligns the fiber, holds the fiber and the cable, and protects the end of the fiber. The receptacle aligns the fiber to the source or detector and accepts the connector. The adapter, also called a feed through, a barrel, or a bulkhead, allows two connectors to be aligned to one another.

Connector Structural Elements and Functions. Regardless of the specific product or style, connectors have five basic structural elements:

- Ferrule
- Retaining nut
- Backshell
- Boot or heat shrink tubing
- Cap

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Some connectors also have a crimp ring or crimp sleeve (Figure 1–42), and the SC style has an outer housing (Figure 1–43).

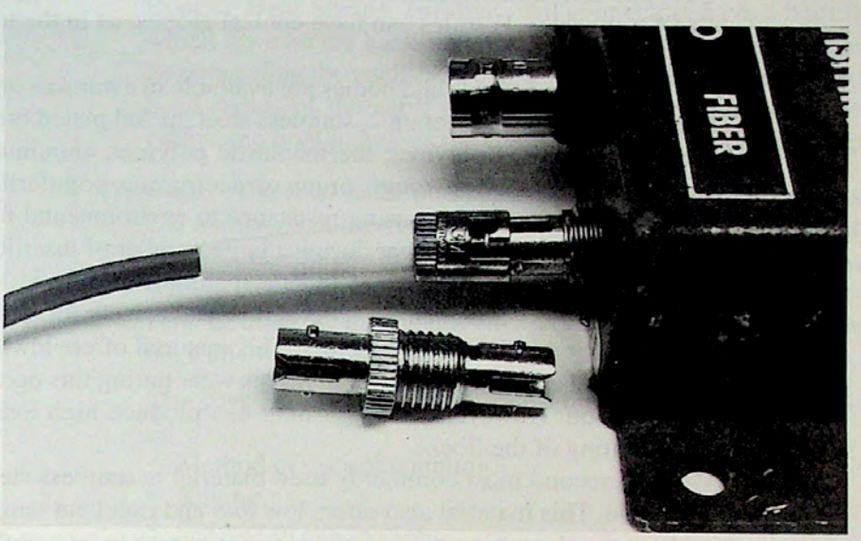


Figure 1–41 The Three Parts of the ST-Compatible Connector System (Courtesy of Pearson Technologies Inc.)

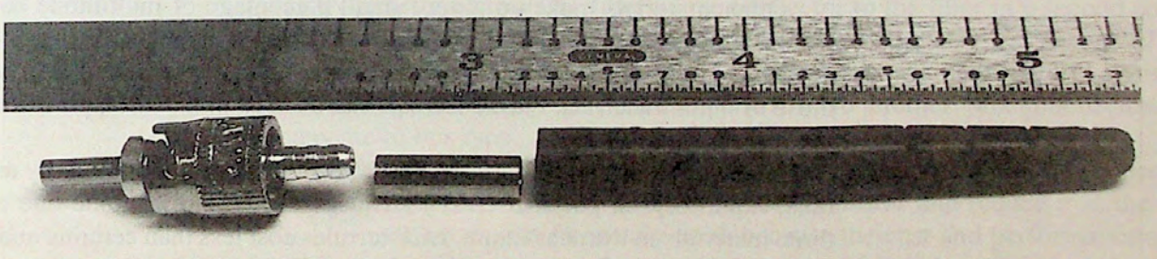


Figure 1–42 The Structure of the ST-Compatible Connector (Ferrule, Retaining Nut, Backshell, Crimp Sleeve, Boot) (Courtesy of Pearson Technologies Inc.)

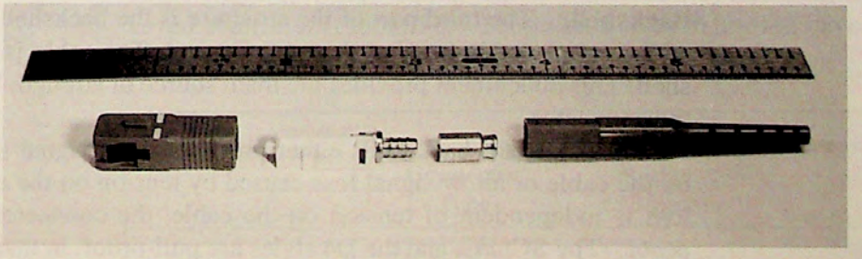


Figure 1–43 The Structure of the SC Connector (Housing, Ferrule, Retaining Nut, Backshell, Crimp Sleeve, Boot) (Courtesy of Pearson Technologies Inc.)

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Ferrule. The *ferrule*, or tip, is the most important part of the connector (Figure 1–42), because it precisely aligns the fiber. Ferrules can have straight tips as in the ST®, 905 SMA, FDDI, and FC styles. Ferrules can have stepped tips, as in the 906 SMA connector. Ferrules can have conical shapes, as in the biconic style and the AMP Optimate®.

Connector ferrules and bodies are available in a number of different materials. Ferrule materials are: ceramic, stainless steel, nickel plated brass, thermoset polymer, liquid crystal polymer, thermoplastic polymer, aluminum, and zinc. These materials are listed in rough order of decreasing popularity, decreasing cost, decreasing softness, decreasing resistance to environmental factors, and decreasing resistance to ferrule wear during a large number of insertion cycles.

The most commonly used ferrule material is ceramic. Ceramic materials, either zirconia or alumina, are used almost exclusively for singlemode connectors and in many multimode connectors. This material offers low loss. Polishing time is low because the ferrule material resists wear during this operation. Epoxy adhesion is good. However, over polishing can produce high loss connectors due to undercutting of the fiber.

The second most commonly used material is stainless steel, especially in the ST® style. This material also offers low loss and excellent temperature stability. In addition, undercutting of the fiber does not appear to be a problem.

Metal ferrule contact connectors can be repolished. Shallow scratches and damage of the fiber core can be polished out, lengthening the lifetime of these products. Ceramic ferrules, however, cannot be repaired by repolishing as frequently or as easily as can metal ferrules.

Other materials make up a very small percentage of multimode connectors. Plastic ferrules have the advantages of low cost, but also have higher losses than do metal and ceramic ferrules. In addition, the plastic ferrules wear faster than those of other materials. Plastic ferrules can be used in indoor applications requiring few insertion cycles.

While ceramic and stainless steel are now the two most commonly used materials, liquid crystal polymer (LCP) ferrules are likely to become one of the top three materials in the near future. LCP ferrules cost less than ceramic and stainless steel ferrules and have loss levels near those of ceramic ferrules.

Retaining Nut. The second part of the connector structure is the retaining nut, which provides the mechanism by which the connector is secured to a receptacle or an adapter (and thus, to another connector). Retaining nuts are either threaded (SMA, FC, D4) or bayonet (ST®, mini-BNC). The SC style has a push-on, push-off latching mechanism instead of a retaining nut.

Backshell. The third part of the structure is the backshell, which is the portion of the connector in back of the retaining nut. The cable is attached to the backshell. This attachment provides the main source of strength between the cable and the connector.

All connector backshells either prevent excess signal loss caused by tension on the cable or allow signal loss caused by tension on the cable. If the connector loss is independent of tension on the cable, the connector is considered "pull-proof." The SC, FC, and the D4 styles are pull-proof, in that their backshell structure eliminates separation of ferrules.

If the backshell design creates pull-proof performance, it can also create "wiggle proof" performance. Wiggle proof performance is achieved when the connector is immune to excess loss caused by a lateral pressure applied to the

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backshell. In a non–pull-proof design, lateral pressure on the backshell results in an increased signal loss.

Boot or Heat Shrink Tubing. All connectors have a boot or heat shrink tubing, which fits over the backshell. Both of these components serve a cosmetic function by concealing the backshell, cable, and strength members. The boot also limits the bend radius of the cable as the cable exits the backshell. By limiting the bend radius, the boot increases the cable's reliability through reducing breakage.

Cap. The final basic part is the dust cap. This cap prevents dust contamination and abrasions of the core, both of which can cause significant increases in loss.

In addition to the five basic parts, some connectors have a crimp ring or sleeve. The crimp ring fits around the backshell and traps the cable strength members. Connectors that do not have a crimp ring use other mechanisms for attaching the cable to the connector.

The Five Basic Features. Connectors can be grouped by five basic features:

- Method of optical coupling
- Keying
- Contact of fiber cores
- Style
- Technique of installation

Optical Coupling. *Optical coupling* refers to the manner in which light is efficiently transferred from the fiber in one connector to the fiber in a second connector. There are two methods of optical coupling: *butt coupling* and *expanded beam* or *lensed coupling*. In butt coupling, the connectors are mechanically positioned close enough for the light to pass from one fiber to another. Most connectors used today are of this type.

Expanded beam, or lensed coupling, requires a lens system in the connector to increase the size of the beam of light at one connector and reduce it at the other. Such connectors are not frequently used, because the cost and performance advantages envisioned by the manufacturers did not materialize. In addition, such connectors use index matching oil, which attracts dust; dust creates maintenance problems.

Keying. The second basic feature is *keying*, or lack thereof. Keying enables connectors to go through multiple cycles of connection and disconnection (an insertion cycle) with minimal variation in the signal strength loss across the connection. Unkeyed connectors can, and do, rotate relative to one another, resulting in a larger range of losses during multiple insertion cycles than that experienced by keyed connectors (Table 1–7). Most connectors in use are keyed.

Connector Type	Average Range (dB/pair)
Unkeyed	1.00
Keyed	0.31

Table 1–7 Comparison of Ranges of Loss for Keyed and Unkeyed Connectors (Data courtesy of Pearson Technologies Inc.)

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Connector Type	Average Loss (dB/pair)
Non-contact	0.97
Contact	0.40

Table 1–8 Comparison of Loss for Contact and Non-Contact Connectors (Data courtesy of Pearson Technologies Inc.)

Contact of Fibers. The third basic feature is contact of fibers, or lack thereof. Contact connectors have lower signal strength losses (Table 1–8) and lower reflectance values than non-contact connectors. Low reflectance is an important performance consideration for singlemode connectors. Because of this improved performance, contact connectors are more frequently used than non-contact connectors.

While contact connectors have improved performance, non-contact connectors can be more reliable than contact connectors in environments of high vibration, shock, or dirt. Such environmental factors can cause shattered or scratched fiber ends. In addition, contact connectors must be mated more carefully than non-contact connectors to avoid damage to the fiber ends. Most of the connectors designed and developed in the early 1980s were non-contact connectors. On the other hand, most of the connectors developed and marketed since 1985 are contact connectors.

Style. The fourth basic feature is the *style* of a connector. The style, or type, of a connector is the aggregate of design features that make a connector product unique. Connectors of the same style from different manufacturers are usually compatible. Connectors of different styles are not compatible, but can be connected with special adapters (available from AT&T and Storm Products). The style is an important factor since optoelectronics are not available for all styles of connectors. The ten non-proprietary styles are:

- ST®-compatible
- SMA 906
- SMA 905
- biconic
- mini-BNC
- FDDI
- ESCON
- SC
- FC, FC/PC
- D4

The *ST-compatible* design (ST is a trademark of AT&T) (Figure 1–42) is a keyed, contact connector with low average loss (0.3-0.5 dB/pair), and low cost. The ST-compatible is relatively easy to install. However, the ST-compatible is not pull-proof or wiggle proof. If the ferrule is stainless steel or liquid crystal polymer, the connector can be repolished to remove damage from the core of the fiber.

The ST-compatible style is presently the most commonly used connector style in both data communication and high performance (telephony and CATV) applications. This design is expected to continue to be commonly used into the late 1990s.

The *SMA 906* and *905* styles (Figure 1–44) are non-keyed, non-contact, with moderate average loss (1 dB/pair) and moderate cost. The SMA styles are somewhat more expensive to install than the ST and ST-compatible styles. The SMAs

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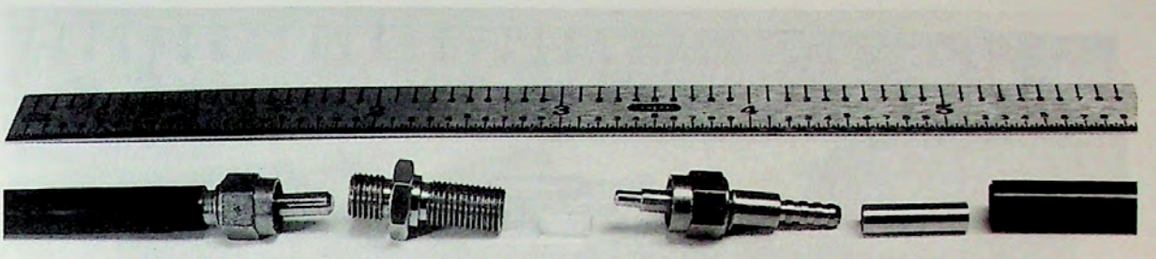


Figure 1–44 The 905 SMA Connector, Barrel with Alignment Sleeve, and 906 SMA Connector (Courtesy of Pearson Technologies Inc.)

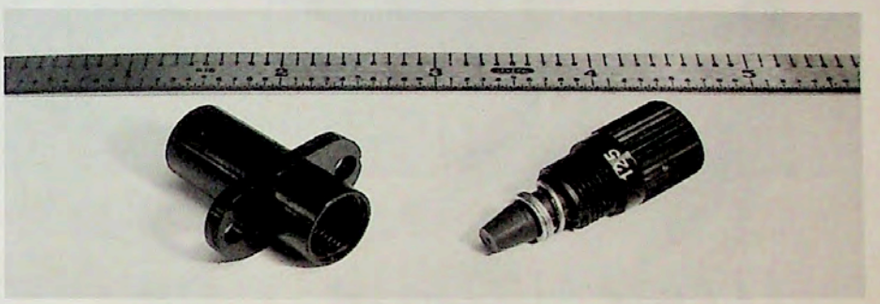


Figure 1–45 The Biconic Barrel and Connector (Courtesy of Pearson Technologies Inc.)

are pull-proof but not wiggle proof. These connectors cannot be repolished to remove damage from the core of the fiber, since the non-contact feature requires a fixed air gap. Repolishing increases the air gap and the loss. A unique feature of the SMA 906 connector is a precision alignment sleeve. This sleeve, which fits into the barrel, is removable, replaceable, and forgettable. Without this sleeve, the SMA 906 connector style exhibits very high loss.

Since they are unkeyed, the SMAs have noticeable loss variability, also called rotational sensitivity. The SMA style has experienced a significant decrease in usage since the 1986: many consider the SMAs a dinosaur. However, the non-contact feature of these styles favor their use in high shock and high vibration environments.

The *biconic* style (Figure 1–45) is non-keyed, non-contact, with moderate loss and relatively high cost. Pearson Technologies has found the biconic to be much more difficult to install than the ST or SMA styles.The biconic style was originally developed as a multimode connector for telephony applications. It has found some use in non-telephony multimode applications, but is expected to be used less in the future. It suffers from rotational sensitivity.

The *mini-BNC* style (Figure 1–46) is non-keyed, non-contact with moderate loss and moderate cost. It is relatively easy to install. However, the mini-BNC is not pull-proof or wiggle proof. This style is used on IBM Token Ring optoelectronics.

The *FDDI* style (Figure 1–47) is a two-fiber, fixed shroud, keyed, contact connector with moderate loss and moderate cost. It is pull-proof and wiggle proof. The ferrule of this connector has the same dimensions as the ST-compatible connectors. While the FDDI style (the official name is MIC or media interface connector) meets the specifications of the FDDI standards, this connector is not always used in FDDI systems. The ST-compatible style is often used instead.

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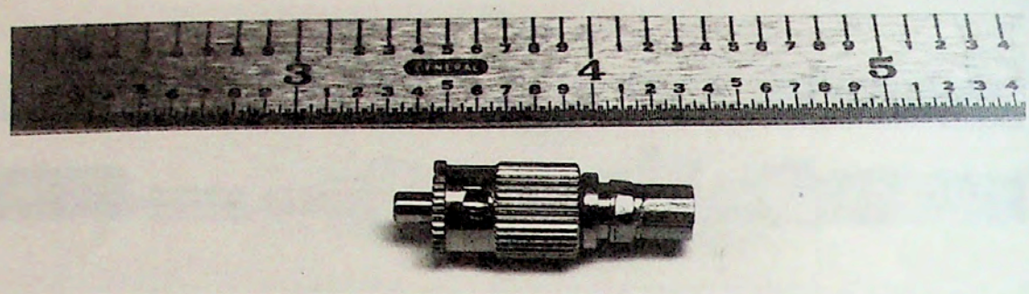


Figure 1–46 The Mini-BNC Connector (Courtesy of Pearson Technologies Inc.)

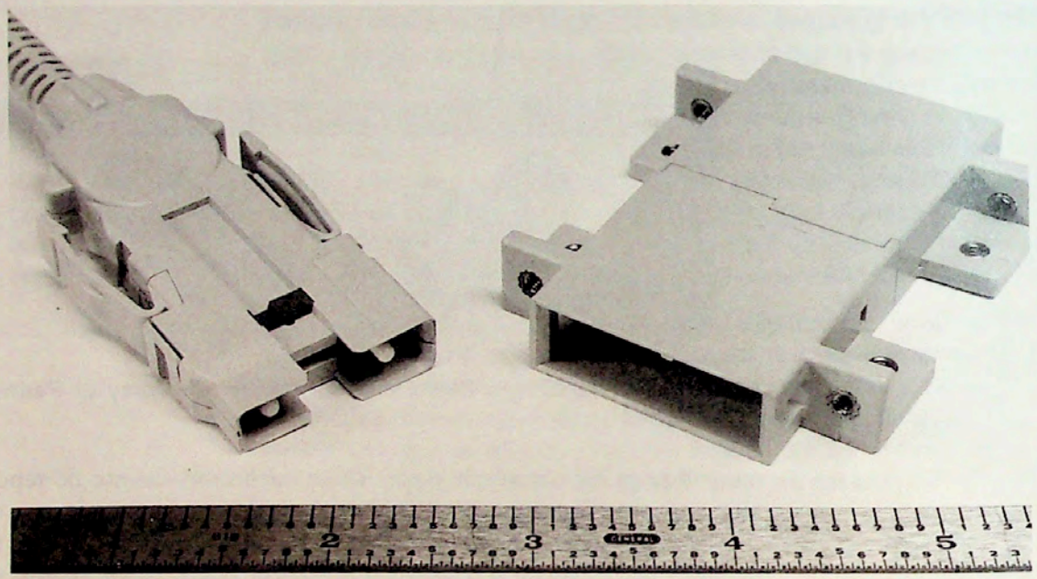


Figure 1–47 The FDDI Connector and Barrel (Courtesy of Pearson Technologies Inc.)

The *ESCON*™ connector style (Figure 1–48) is an IBM standard connector used in IBM's ESCON fiber system, which replaces the tag and bus communication system used in IBM computers. It is similar in style and dimensions to the FDDI MIC. This connector has a retractable shroud and is pull-proof and wiggle proof.

The *SC* style (Figure 1–43) is a keyed, contact connector, with low average loss (0.3 dB/pair) and a cost higher than that of the ST-compatible style. The SC style is slightly more difficult to install than the ST-compatible style, but is pull-proof and wiggle proof. The SC has a push-on, push-off insertion mechanism. This mechanism allows for reduced connector spacing and high density patch panels, which are preferred in telephony and other high fiber density applications. The SC is the style of choice in the EIA/TIA-568A building wiring standard and the Fiber Channel standard. Finally, multiple SCs can be clipped together to create duplex connectors. The forecasters at Kessler Marketing Intelligence expect the SC style to become the second most commonly used style by the year 2000.

The *FC*, *FC/PC* (Figure 1–49), and *D4* styles (Figure 1–50) are keyed, contact designs with low average losses (0.3 dB/pair) and relatively high costs. They are slightly more difficult to install than the ST-compatible designs and are pull-proof and wiggle proof. The FC/PC is the successor to the FC. The D4 has a unique feature: a key that can be tuned to the position of lowest loss and locked into that position.

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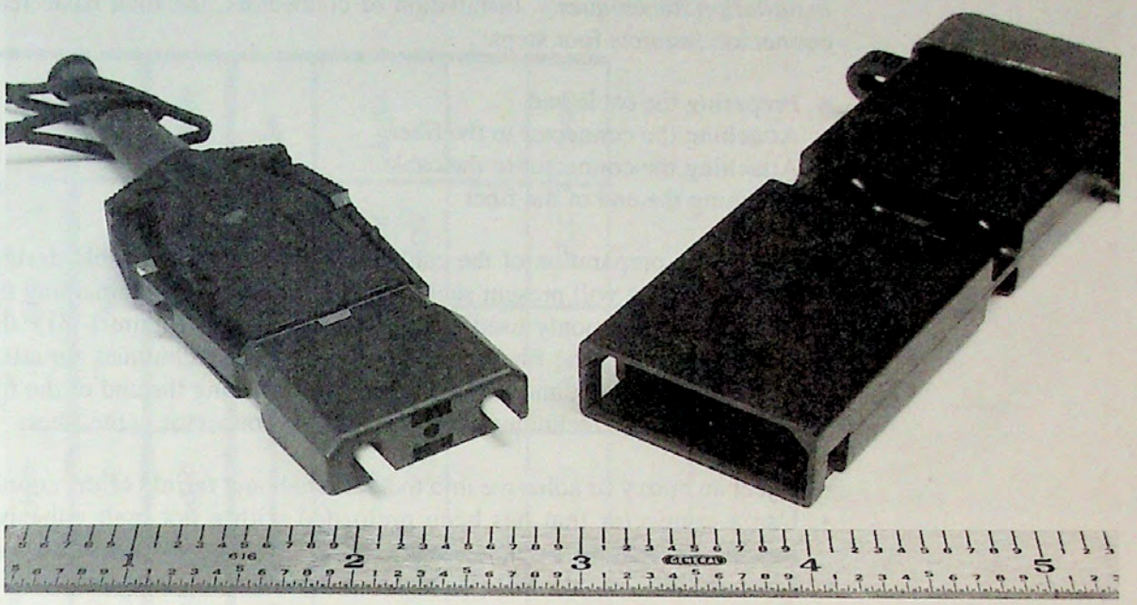


Figure 1–48 The ESCON Connector and Barrel (Courtesy of Pearson Technologies Inc.)

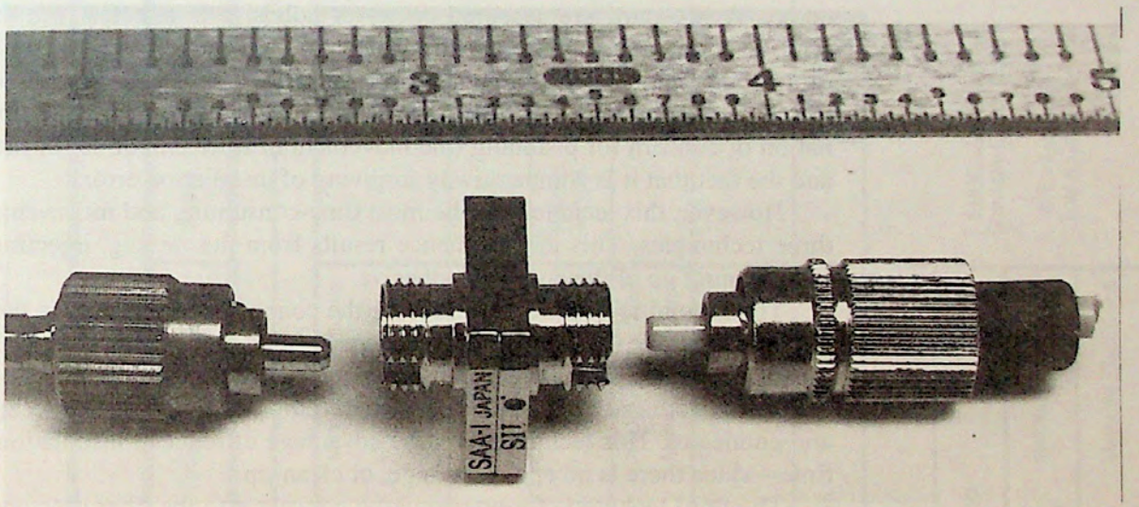


Figure 1–49 The FC/PC Connector and Barrel (Courtesy of Pearson Technologies Inc.)

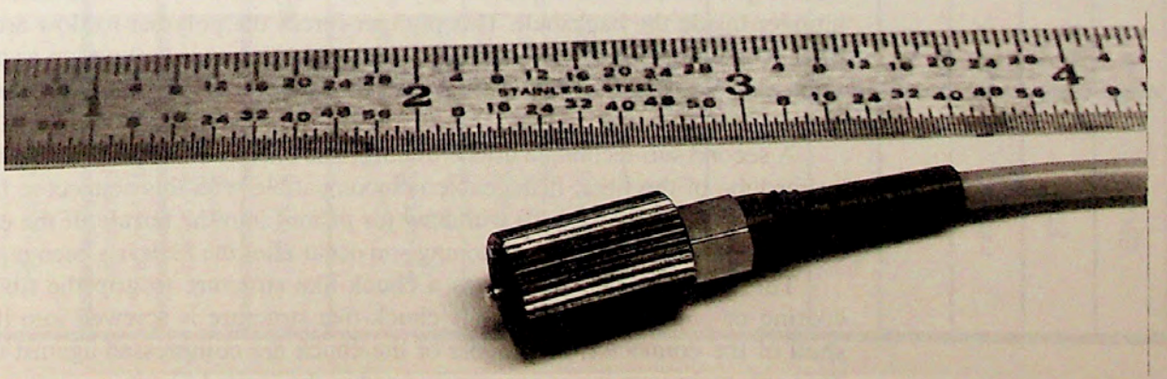


Figure 1–50 The D4 Connector (Courtesy of Pearson Technologies Inc.)

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Installation Techniques. Installation of connectors, the final basic feature of a connector, requires four steps:

- Preparing the cable end
- Attaching the connector to the fiber
- Attaching the connector to the cable
- Finishing the end of the fiber

Since the preparation of the cable ends depends on the cable design and not the connector, we will present such steps in Chapter 3. The remaining three steps result in eight commonly used installation techniques (Figure 1–51): three techniques for attaching the fiber to the connector, three techniques for attaching the cable to the connector, and two techniques for finishing the end of the fiber.

There are three techniques for attaching the connector to the fiber:

- Inject an epoxy or adhesive into the backshell and ferrule of the connector.
- Use a connector that has been preloaded with a hot melt adhesive, which requires preheating.
- Mechanically grip the fiber with part of the connector structure.

The most commonly used technique for attaching the connector to the fiber is epoxy. A two-part, premeasured epoxy or adhesive is injected into the ferrule (and, in some cases, the backshell). This epoxy is then allowed to cure, either at room temperature or in a temperature-controlled oven. The advantages of this technique are a strong and reliable bond between the ferrule and the fiber, elimination of concern for pistoning (the movement of fiber into or out of the ferrule), and the fact that it is comparatively forgiving of installation errors.

However, this technique is the most time-consuming and inconvenient of the three techniques. This inconvenience results from the mixing, injecting, curing, and cleaning up of the epoxy or adhesive.

The second technique for attaching the connector to the fiber is the use of a hot melt adhesive (or polymer), which is preloaded in the connector. This connector, pioneered by 3M, is preheated prior to insertion of the fiber and cable. When the hot melt adhesive cools, the adhesive develops a strong bond between the fiber and connector. This technique has the advantage of reduced installation cost and time—since there is no epoxy, syringe, or clean-up.

The third technique for attaching the connector to the fiber uses one of three sub-techniques to grip the fiber mechanically. The first sub-technique involves a ferrule preloaded with a proprietary polymer. This polymer is deformed by a plunger inside the backshell. This plunger forces the polymer to flow around the fiber. The plunger is locked in place, causing the polymer to function as an epoxy or an adhesive. Surface friction between the polymer and the fiber holds the fiber in place.

A second sub-technique uses crimping. The backshell is crimped directly to the buffer tube of the fiber. If the cable is incompatible with this connector, this technique may allow the fiber to withdraw (or piston) into the ferrule. If the cable and connector are incompatible, pistoning can occur after the fiber has been polished.

The third sub-technique uses a chuck-like structure to grip the fiber buffer coating or buffer tube. When this chuck-like structure is screwed into the backshell of the connector, the fingers of the chuck are compressed against the fiber. This sub-technique is not commonly used in the United States.

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method of fiber to connector bond	epoxy or adhesive			preload & preheat	mechanical gripping of fiber			
					polymer	crimp		chuck
method of cable to connector bond	crimp		epoxy or adhesive	epoxy or adhesive	crimp	crimp		crimp
method of end finishing	polish	cleave	polish	polish	polish	polish	cleave	cleave
STYLES	MANUFACTURERS							
ST® and compatibles	AT&T, Augat, GTE, 3M, AMP, Seiko, Siecor, ATC, Methode Electronics, MA/Com, Amphenol, Thomas & Betts		Molex	MA/Com, 3M	AMP	ATC, 3M	ATC, Siecor, EBOC	Leetec
SMA 906	AMP, Augat, GTE, Seiko, MA/Com, ATC, Amphenol					ATC		
SMA 905	AMP, ATC, Amphenol, MA/Com	Thomas & Betts	Molex			ATC	EBOC	Leetec
SC	Hirose, Molex, Augat, 3M, ATC, AMP, Methode Electronics			3M		ATC, 3M		
FC/PC	AMP, Seiko, Augat, MA/Com, Siecor, ATC, Hirose, Amphenol, 3M		Molex	3M				
BICONIC	AT&T, MA/Com, 3M		Methode Electronics					
D4	AMP, GTE, Seiko, ATC, MA/Com							
mini BNC	AMP, Sumitomo, Seiko, Hirose							
FDDI	AMP, Augat, Molex, Hirose, Methode Electronics							
ESCON	AT&T, AMP, Methode Electronics							

EBOC=Spectran Specialty Optics Co.

ATC=Automatic Tool & Connector

Figure 1-51 Eight Connector Installation Techniques

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There are three techniques for attaching the connector to the cable:

- Mechanically grip the cable strength members (crimping).
- Use epoxy or two-part adhesive, or adhesive, or hot melt adhesive on the cable strength members.
- Trap the cable strength members.

The most commonly used technique is crimping. In this technique, the cable strength members are trapped between the crimp sleeve and the backshell. This technique is simple, fast, and reliable. It does require a crimp tool with the appropriate crimp nest. Increased connector to cable strength can be achieved by adding epoxy or adhesive to the strength members.

The second technique is the use of adhesive or epoxy. In this technique, the cable strength members are inserted into the backshell and "glued" to the connector by the "glue" in the backshell. This technique is fast and reliable. However, it can be awkward, since the fiber and cable can slide out of the connector during handling prior to curing.

The third technique involves trapping the strength members between the two parts of the backshell. These parts usually have a threaded juncture, in which the strength members are trapped. These two parts of the backshell have a specific clearance, into which the strength members must fit. If the amount is insufficient, the 'joint' will be loose, and the cable may pull out of the connector. Clients of Pearson Technologies report that they completely avoid this potential problem by adding epoxy to the strength members. With the use of epoxy, this technique becomes similar to the second technique. If the amount of strength member is excessive, some strength member material will need to be removed, without leaving an insufficient amount.

There are two techniques of finishing the end of the fiber: polishing and cleaving. The first, and most commonly used, is polishing. Polishing requires abrading the fiber and tip of the ferrule with fine polishing papers, films, or pastes until the surface is flush with the ferrule and smooth. This polishing can be done by hand, on glass, hard plastic, or hard rubber plates, or by automatic machines, which use either films or diamond slurries or pastes.

There are two types of polishing: flat and radius polishing. Flat polishing can be performed on multimode fibers but is not usually performed on singlemode fibers. Radius polishing can be performed on contact type multimode connectors (i.e., ST®), and is performed on contact type singlemode connectors to achieve low reflectance.

Cleaving is performed on multimode connectors. It is a fast and simple procedure. However, the signal strength loss of the connector will be determined by the quality and condition of the cleaving tool. This tool can be expensive, needs periodic maintenance, and must be handled with care.

Cleaving is a preferred procedure in environments in which polishing cannot be successfully performed or is impractical. Cleaving is also preferable in environments in which the speed of the technique is needed, either for its low cost, high speed (restoration), or convenience (dirty environments).

The Four Most Important Connector Performances. Four optical performances are important during the installation of fiber optic connectors:

- Maximum loss/pair, dB/pair
- Average loss/pair, dB/pair
- Repeatability of loss, maximum change in dB/pair
- Reflectance (also known as return loss and back reflection)

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The *maximum loss/pair* (dB/pair) is the maximum loss you will experience when you install the connectors properly. This value will be value against which you accept or reject installed connectors.

Most connectors exhibit a typical loss/pair close to the *average loss/pair* stated by the connector manufacturer. This average loss/pair will be the value you expect to see most of the time. If you see losses consistently in excess of this value, you will suspect either errors in the installation procedure or in the test procedure.

Repeatability is the maximum change in loss/pair that can occur between successive measurements. Repeatability (roughly one-half the range) is important in maintenance and troubleshooting activities and in situations in which the optical power budget required by the system is close to the optical power budget available from the electronics.

Reflectance, which is also called *return loss* and *back reflection*, is the ratio of light intensity reflected from the connector back towards the light source to the intensity incident to the connector. It is a Fresnel reflection that occurs at any interface (such as that of a glass fiber core and air) at which the index of refraction changes (Figure 1–52). Reflectance causes signal errors and laser malfunctions. Reflectance needs to be measured for connectors in systems with singlemode fibers and laser diodes operating at high bit rates (400 Mbps). Reflectance is not a concern with most multimode systems.

In the ideal situation, fiber ends could be polished so that they were perfectly perpendicular to the fiber axis and perfectly smooth (Figure 1–52 a). This ideal

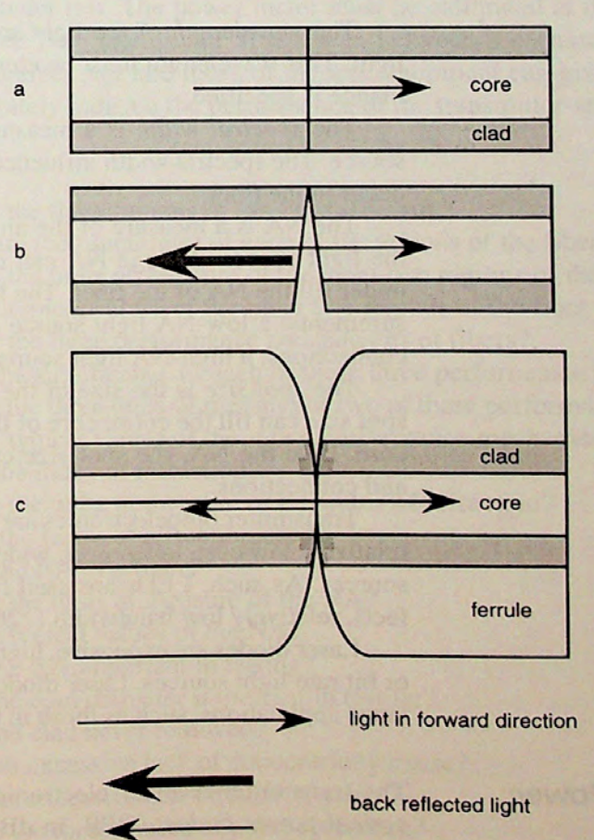


Figure 1–52 Reflectance: (a) with perfect cleaving (no reflectance), (b) with angle on fiber ends (high reflectance), (c) with radiussed ferrules (low reflectance)

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situation eliminates the air gaps that could result in high reflectance. However, achieving perfect perpendicularity is nearly impossible: most connector pairs will have a slight angle on one or both of the ferrules (Figure 1–52 b). To minimize reflectance, physical contact of ferrules with a radius on the tip (i.e., a radiussed tip) is most often used (Figure 1–52 c). Use of radiussed tips requires a high degree of surface smoothness to achieve low reflectance. This high degree of surface smoothness is achieved through multiple polishing steps with successively finer abrasives. Typical values of low reflectance connectors are <-30 dB, although values as low as -45 dB are advertised.

BASIC TRANSMITTER AND RECEIVER FACTS

Although transmission and receiving optoelectronics must be installed, such installation is straightforward. However, the testing and troubleshooting of installed cables, connectors, and splices requires an understanding of the characteristics of these optoelectronic devices.

Four Important Characteristics of Transmitters

Transmitting optoelectronics have four important characteristics:

- Wavelength, in nm
- Spectral width, in nm
- NA
- Spot size, in microns

The *wavelength* of the light source is a measure of the color of the emitted light. This wavelength must be close to the wavelength at which the fiber performance is specified.

The *spectral width* is a measure of the range of colors emitted by the light source. The spectral width influences the amount of chromatic dispersion that will occur in the fiber.

The NA is a measure of the angle in which most of the light is emitted from the light source. A large NA can overfill the NA of the fiber. A small NA will under fill the NA of the fiber. The NA of the light source can influence loss measurements: a low-NA light source can result in reduced losses in both fiber and connections; a high-NA light source can result in increased losses at connections.

The *spot size* is the size of the area from which the light is emitted. A large spot size can fill the entire core of the fiber. A small spot size will partially fill the core. Like the NA, the spot size can influence the loss measurements of fibers and connections.

Transmitter optoelectronics are based on LED or laser light sources. LEDs are relatively low cost, low power, wide spectral width, low bandwidth or bit rate light sources. As such, LEDs are used for relatively short distance (<7 km or 22,960 feet), relatively low bandwidth (<200 MHz) or bit rate (<200 Mbps) applications.

Laser diodes are expensive, high power, narrow spectral width, high bandwidth or bit rate light sources. Laser diodes are used for high bandwidth and/or long distance applications, such as those in telephone and cable TV applications.

The Optical Power Budget

The transmitter-receiver electronic pair have one important characteristic: the *optical power budget* (OPB, in dB). The optical power budget is the maximum loss in optical signal strength that the transmitter receiver pair can withstand while still functioning at the specified level of accuracy. The end to end power loss of all

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Wavelength (nm)	Type of Source	Fiber Core Diameter (μm)	Typical OPB (dB)	Spectral Width (nm)	Spot Size (μm)
850	LED	50	12		
	LED	62.5	16		
	LED	100	21		
	LED	any		30–50	150–250
1300	LED	any	16	60–190	50
1300	laser (singlemode)	9	25–45	0.5–5.0	2x10

Table 1–9 Typical Optical Performance Characteristics of Transmitter-Receiver Pairs

optical components in a fiber link (called the "link power budget" or "link loss") must be less than or equal to the optical power budget. Table 1–9 contains typical values for these optoelectronic characteristics.

Testing of Installed Systems

The testing of installed systems must simulate a transmitter-receiver pair. Ideally, this simulation requires using a testing light source with the same wavelength, spectral width, NA, and spot size as those in the transmitter-receiver pair. Ideally, the testing cables must have same core diameter, core offset, clad ovality, and NA as the cable under test. The power meter must be calibrated at the wavelength of the transmitter. Any significant differences between the characteristics of the transmitter-receiver pair and those of the test equipment can give test results that will not accurately indicate the performance of the transmitter-receiver pair.

REVIEW QUESTIONS

1. What are the three regions of the fiber structure?
2. What is/are the function(s) of each of the regions of the fiber structure?
3. What are the units of measure of the inner two regions of the fiber structure?
4. What are typical values of the inner two regions of the fiber structure?
5. What are the three performance mechanisms of fibers?
6. What is the significance of each of these three performance mechanisms?
7. What are the three units of measure of two of these performance mechanisms?
8. What are typical values of these two performance mechanisms?
9. What is the index of refraction?
10. What are the units of measure of the index of refraction?
11. When is the index of refraction used?
12. What is the NA of a fiber?
13. What are the units of measure of the NA?
14. What are typical values of the NA?
15. Why is the NA important in testing?
16. Why is the core diameter important in testing?
17. Why is the clad never removed?
18. What does excessive lack of concentricity cause?
19. What does excessive non-circularity cause?
20. What are the three causes of pulse spreading?
21. Describe the three causes of pulse spreading.
22. What type of fiber has three causes of pulse spreading?

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23. What type of fiber has two causes of pulse spreading?
24. Why is the pulse spreading rate in an optical fiber dependent on the nature of the light source?
25. Describe the path of a ray of light in step index fibers.
26. Describe the path of a ray of light in graded index fibers.
27. Describe the path of a ray of light in singlemode fibers.
28. What is the practical significance of the difference between step index and graded index fibers?
29. What is the practical significance of the difference between multimode and singlemode fibers?
30. What are the two basic cable designs?
31. What are the differences in structure of these two basic designs?
32. What are the advantages of each of these two basic designs?
33. What are the seven cable designs?
34. Describe the structure of the seven cable designs.
35. Which designs are commonly used indoors?
36. Which designs are commonly used outdoors?
37. What is/are the advantages of each of the five most commonly designs?
38. What can happen if the long-term or short-term bend radii are violated?
39. What can happen if the maximum recommended installation load is exceeded?
40. Your cable has a diameter of 0.565″. What are the minimum recommended long-term and short-term bend radii?
41. What are the two types of connections?
42. Where are these two types of connections used?
43. What are the two types of splices?
44. What are the advantages and disadvantages of the two types of splices?
45. What three connector system parts must be compatible?
46. What are the two connector styles most commonly used in the United States?
47. What features are the same for these two connector styles?
48. What features are different for these two connector styles?
49. What are the four performance characteristics of connectors?
50. What are the units of measure and typical values for connectors?
51. What are the four important transmitter performance characteristics?
52. Why are each of these characteristics important?
53. What are typical values of these characteristics?
54. What is the most important transmitter-receiver pair performance characteristic?
55. Why is this characteristic important?
56. What is a typical value of this characteristic for a LED light source used with a 62.5 μm fiber at 850 nm?

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CHAPTER

6

How To Install Splices Properly

CHAPTER OBJECTIVES

From this chapter, you will be able to:

1. Set up and create low loss, high strength fusion splices.
2. Create fusion splices with unbuffered fiber and with pigtails.
3. Determine the optimum fusion splicing parameters.
4. Troubleshoot the splicing process.
5. Set up and create low loss mechanical splices.
6. Properly install splices in splice trays and enclosures.

INTRODUCTION

Splicing is the preferred method for making permanent connections between two fibers. Splices can be mid-span splices or pigtail splices. Mid-span splicing is performed during initial installation of two long lengths of fiber and during repair of broken cables.

Pigtail splicing is the splicing of a short length of cable (often 1 to 2 meters long) with a connector on one end to a longer length of installed cable. Pigtail splicing is performed for performance and/or cost reasons. The splicing of a factory-installed singlemode pigtail is performed to achieve low reflectance, since achieving low reflectance from field installed singlemode connectors can be difficult.

Splicing of pigtails is performed to reduce installation costs, since the cost of field-installed connectors can be two to three times the cost of factory-installed connectors. Splicing of pigtails is performed when the total cost of a pigtail and the splicing is less than the cost of a field-installed connector.

The two types of splicing are fusion and mechanical. Both types require five major steps:

- Preparation of the ends of the cable
- Preparation of the ends of the fiber (stripping and cleaving)
- Splicing
- Testing of the loss of the splice with an OTDR
- Installation of the splice in an appropriate splice tray and splice enclosure

Both types of splicing require *cleaving*. Cleaving is the process by which you create a fiber end which is perpendicular to the axis of the fiber and smooth (a "good" cleave). For both fusion and mechanical splicing, low loss is achieved with a good cleave. The difference between cleaving for fusion splicing and cleaving for mechanical splicing is in the length of bare fiber from the end of the buffer coating or buffer tube to the cleaved end.

Both types of splices require installation of the splice in a protective structure. This structure includes a splice tray (Figure 6–1) and a splice enclosure. The splice tray will be designed for the specific type of splice to be installed. The splice enclosure can be an indoor enclosure (Figure 6–2) or an outdoor enclosure (Figure 6–3).

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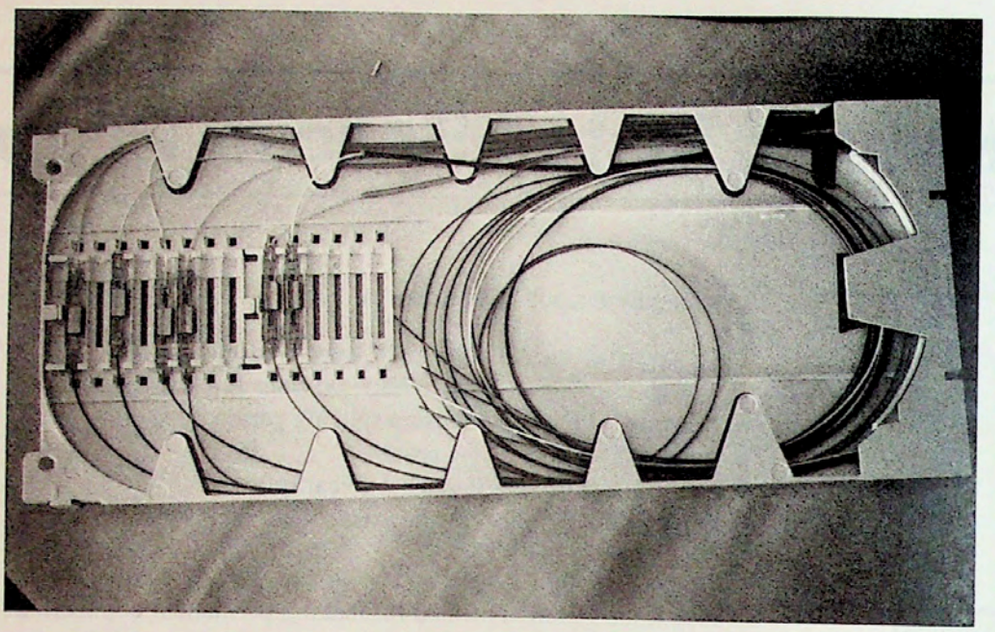


Figure 6–1 Mechanical Splices in Splice Tray (Courtesy of Pearson Technologies Inc.)

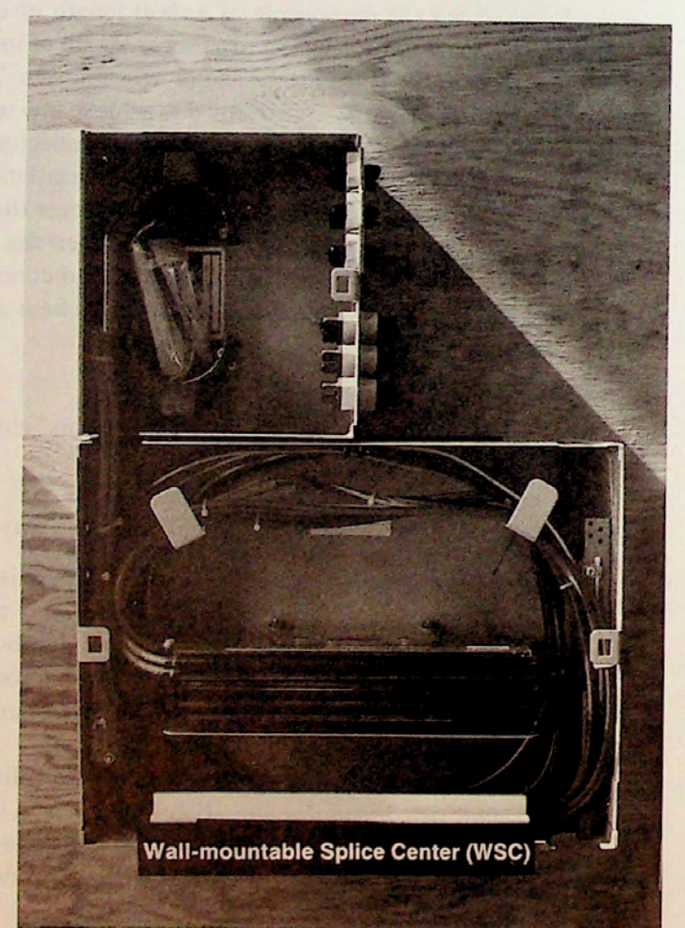


Figure 6–2 Indoor Splice Enclosure (Courtesy of Pearson Technologies Inc.)

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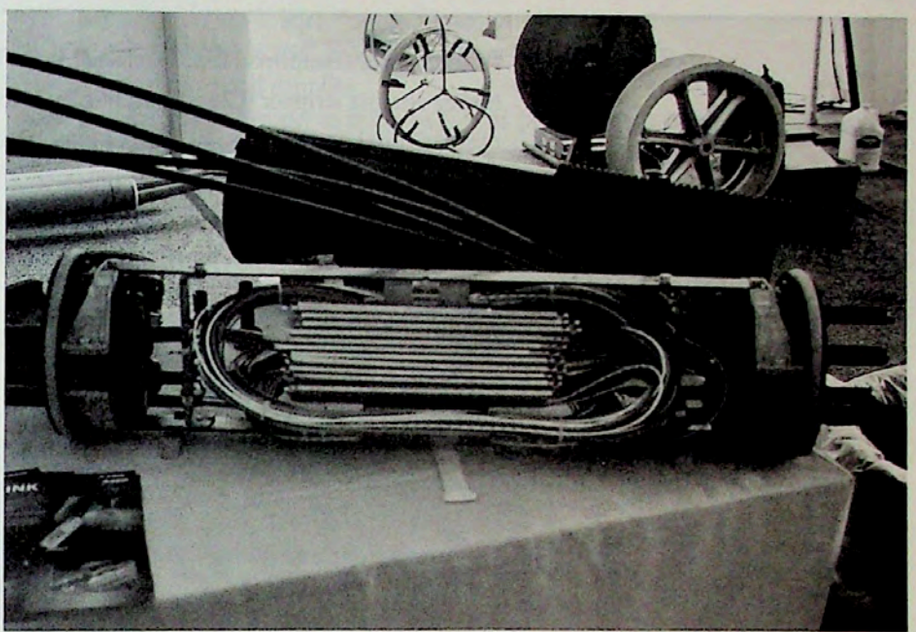


Figure 6–3 Internal Structure of Outdoor Splice Enclosure (Courtesy of Pearson Technologies Inc.)

FUSION SPLICING

In this section, we present two procedures for fusion splicing. The first procedure is a practice procedure. A splice made by this procedure will perform as a splice of a cable pigtail near the transmitter end of a multimode cable system.

The second procedure is for splicing at a long distance from the input, or transmitter, end of a multimode fiber. A splice made by this procedure will perform as a mid-span splice or a pigtail splice made at the receiver end of a fiber.

We have developed these procedures for use with the Fiberlign Micro Fusion Splicer from Preformed Line Products (Figure 6–4) and for the Fitel cleaver (Figure 6–5), which are both relatively inexpensive, but perform excellently. To use these procedures with other fusion splicers, you will need to change the values of parameters of arc current, arc time, and overrun of the splicer. The correct values of these parameters will be in the instruction manuals of other splicers. While we have developed the procedures in this chapter for multimode fibers, the same procedures can be used for singlemode fibers. (For singlemode fiber splicing, use a singlemode fiber with a wavelength and light source calibrated at 1310 nm.) If you wish to practice a splicing technique for measurement at 1300 nm, use a 1300 nm light source and a power meter calibrated at 1300 nm.

TOOLS AND SUPPLIES REQUIRED

for Procedure 1, at least 15 feet of all-glass, multimode optical fiber

for Procedure 2, approximately 1,000 m of all glass, multimode optical fiber

two bare fiber adapters with same connector style as the power meter and light source

power meter with calibration at 850 nm

850 nm stabilized light source

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Scotch Magic™ tape
fusion splicer (Preformed Line Products MicroFusion Splicer, Model MS-1008F)
buffer coating stripper (Clauss part number NN200 or equivalent)
cleaver (Fitel part number VL-310 or equivalent)
lens grade compressed air
91–95 percent isopropyl alcohol
heat shrink splice covers (ACP International Part Number DH1)
heat gun

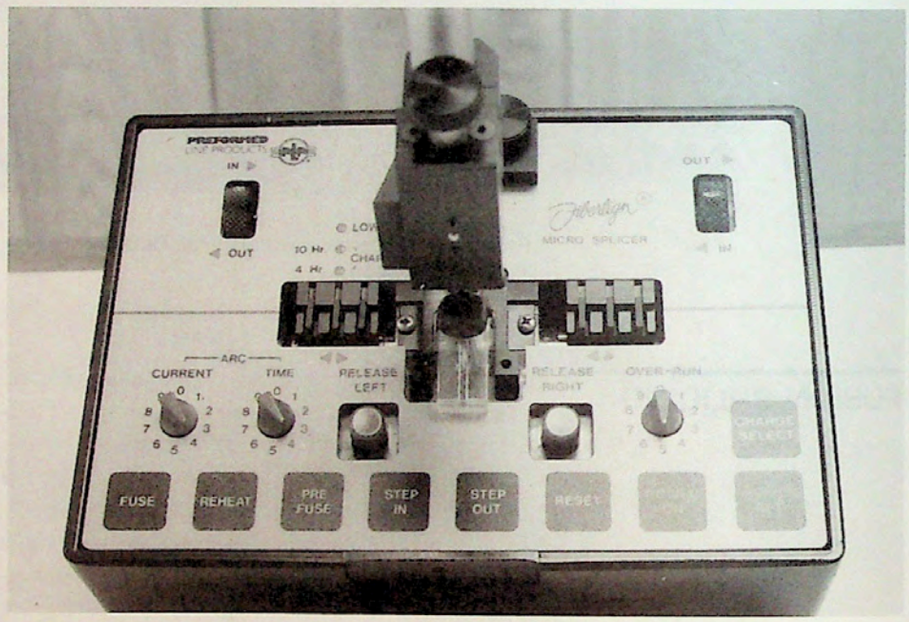


Figure 6–4 Fiberlign® Micro Fusion Splicer (Courtesy of Pearson Technologies Inc.)

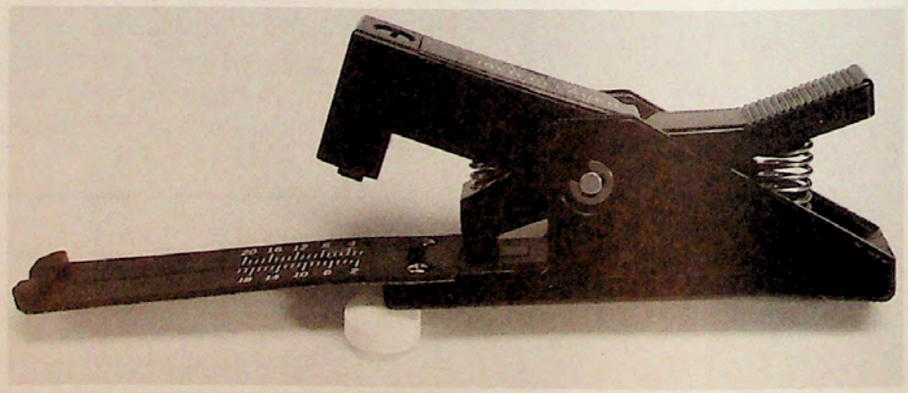


Figure 6–5 The Fitel Cleaver with Cleaving "Tail", Scribing Arm, Retaining Finger (Courtesy of Pearson Technologies Inc.)

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PROCEDURE 1: SPLICING SHORT LENGTHS OF FIBER

1. Obtain all tools and supplies.
2. Using the buffer stripper as in Steps 5–9 of Procedure 1, (Chapter 3), strip the buffer coating from one end of the fiber until 1.5 inches is bare.
3. Install the fiber in the cleaver: press down on the right end of the retaining finger (Figure 6–5) and slide the bare end of the fiber under the retaining finger until the buffer coating is at the 4 mm mark (Figure 6–6). Release the retaining finger onto the fiber.
4. With your thumb, press the fiber into the groove on the flexible tail of cleaver. Hold the fiber so that it is against one wall of the groove. Do not remove your thumb. Straighten the flexible tail of cleaver. The fiber will usually exhibit a slight bend. Press down on the right end of the retaining finger to allow the fiber to straighten out. Release the retaining finger onto the fiber. Gently push the scribing arm down until the scribing blade touches the fiber. Do not press the scribing arm down hard.
5. Press open the back end of the bare fiber adapter. Insert the bare fiber into the bare fiber adapter until it is flush with tip of the ferrule (Figure 6–7). Close the back end of the bare fiber adapter.

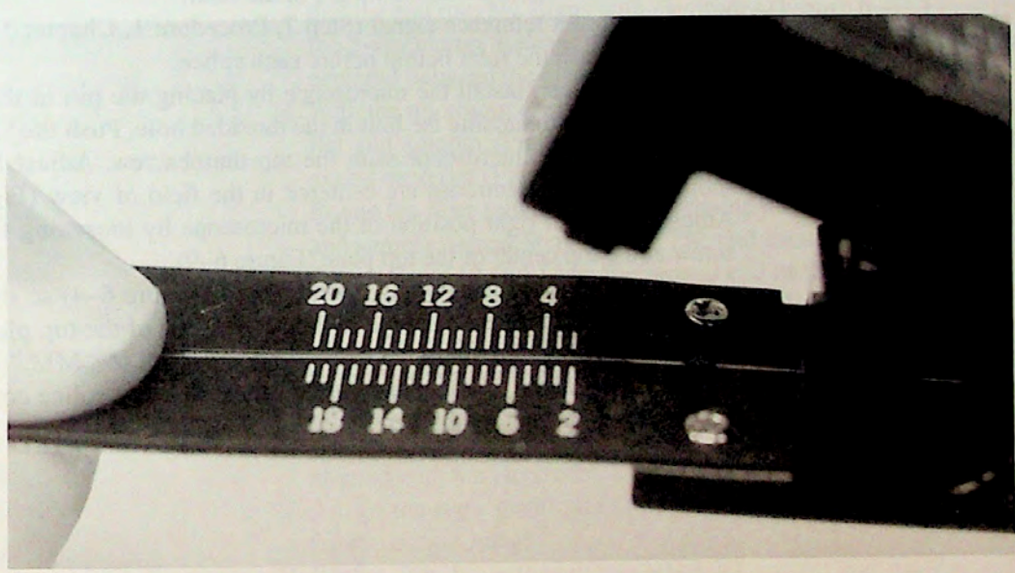


Figure 6–6 Fiber Properly Installed in Cleaver (Courtesy of Pearson Technologies Inc.)

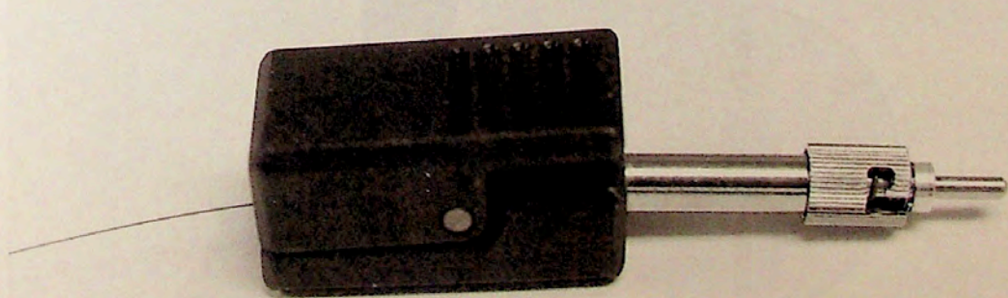


Figure 6–7 Fiber in Bare Fiber Adapter (Courtesy of Pearson Technologies Inc.)

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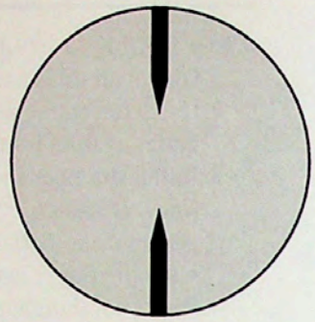


Figure 6–8 View when Microscope Properly Positioned

6. Insert the bare fiber adapter into the receptacle of the light source.
7. Tape down the fiber near the light source so that the fiber cannot be pulled from the bare fiber adapter accidently.
8. Repeat Steps 1–4 on the second end of the fiber.
9. Insert the bare fiber adapter into the power meter.
10. Tape down the fiber near the power meter. Check the fiber to ensure that there are no bend radii smaller than 2 inches in the fiber.
11. Set and record a reference signal (Step 7, Procedure 1, Chapter 5). Turn on the splicer. Push the reset button before each splice.
12. Set up the splicer. Install the microscope by placing the pin in the pin hole and by partially tightening the bolt in the threaded hole. Push the "power on" button. Focus the microscope with the top thumbscrew. Adjust the microscope so that the electrodes are centered in the field of view (Figure 6–8). Adjust the left to right position of the microscope by loosening the thumbscrew at the top center of the top plate (Figure 6–9).

    Adjust the coarse positioning thumb wheels (Figure 6–4) so that both 3-jaw clamp positioners are centered in the cut out area of the top plate (Figure 6–4). Set the recessed singlemode/multimode switch to "MM." Break the fiber near the middle. If you plan to use a heat shrinkable splice cover, install this cover on one end of the fiber.

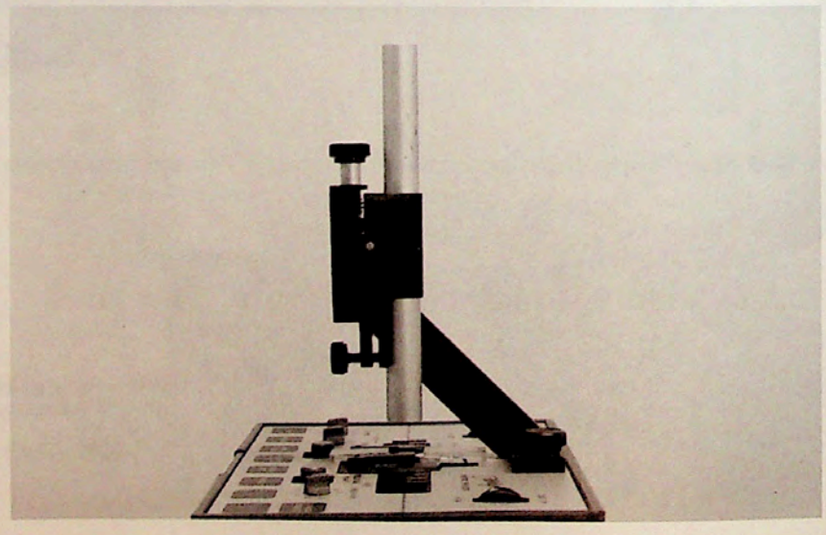


Figure 6–9 Microscope Position Adjustment Screws (Courtesy of Pearson Technologies Inc.)

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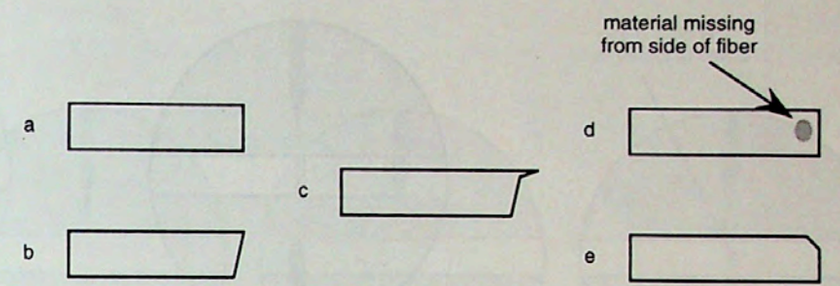


Figure 6–10 Good and Bad Cleaves

While pushing down both release buttons, blow off the "V-grooves" and the areas under the 3-jaw clamps with compressed air.

13. Using the buffer stripper, strip 1.5 inches of buffer coating from one end of the broken fiber.
14. Slide the fiber under the retaining finger of the cleaver until the buffer coating is at the 13 mm mark. Repeat Step 3 on first end of the broken fiber.
15. Push down the left release button of the splicer to lift the left 3-jaw clamp. Place the cleaved end into the central section of splicer (the splice area) so that the end roughly aligns with electrodes (Figure 6–8). Place the fiber under the 3-jaw clamp. Release the button for the 3-jaw clamp. The fiber should be centered between the electrodes (Figure 6–11).
16. With the microscope, examine the cleaved end of the fiber. The end should be flat and smooth (Figure 6–10 a), with no angle (Figures 6–8 and 6–10 b), excess material (Figure 6–10 c), or missing material (Figures 6–10 d and e). Rotate the fiber roughly 90° and examine the fiber again. If the end is not flat and smooth, repeat Steps 12–15. The end should be flat and smooth.
17. Repeat Steps 12 and 13 on the second end of the broken fiber.
18. Push down the right release button of the splicer to lift the right 3-jaw clamp. Place the cleaved end into the central section of the splicer so that the end roughly aligns with electrodes. Place the fiber under 3-jaw clamp. Release the button for the 3-jaw clamp.
19. Adjust the left positioner until the right image of the end of the fiber is aligned with the electrodes (Figure 6–11).
20. Adjust the right positioner until the left image is within one fiber diameter from the right image.
21. Repeat Step 16 on the left image.

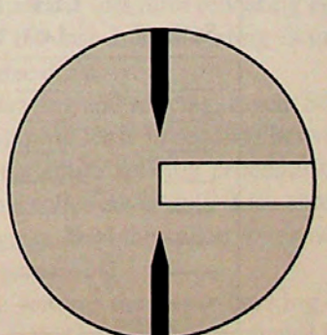


Figure 6–11 Alignment of First Fiber to Electrodes

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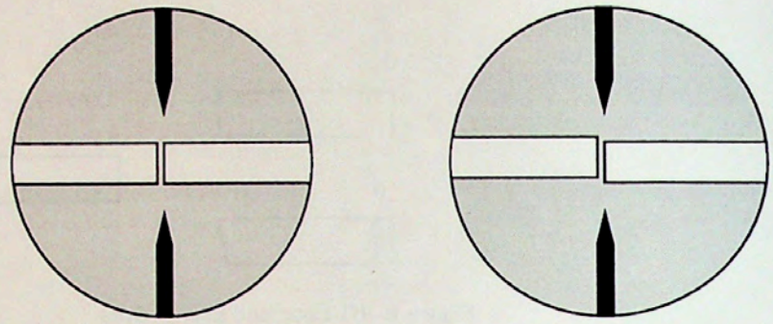


Figure 6–12 Acceptable and Unacceptable Alignment of Fiber Ends to One Another

22. Inspect the up down alignment of both fibers. The fibers should appear aligned with very little or no offset (Figure 6–12). If an offset appears, remove the fibers and wipe the stripped sections with lens grade tissue moistened with 91–95 percent isopropyl alcohol. With compressed air, blow off the V-grooves and the areas under both 3-jaw clamps. Reinstall both fibers according to Steps 14–22.
23. Set the controls according to Table 6–1. Enter the appearances of the cleaves in Table 6–2.
24. Press the reset button. Check the fibers under the microscope for cleanliness.
25. Press the PREFUSE button.

Control	Singlemode	Multimode
arc current	5	2
arc time	4	5
overrun	4	4
SM/MM switch	SM	MM

Table 6–1 Initial Settings for Fusion Splicer

	Cleave Appearance		Losses			
Splice #	Left	Right	Before	Initial	Reheat 1	Reheat 2
___	___	___	___	___	___	___
___	___	___	___	___	___	___
___	___	___	___	___	___	___
___	___	___	___	___	___	___
___	___	___	___	___	___	___
___	___	___	___	___	___	___
___	___	___	___	___	___	___
___	___	___	___	___	___	___

Table 6–2 Data Form for Splicing

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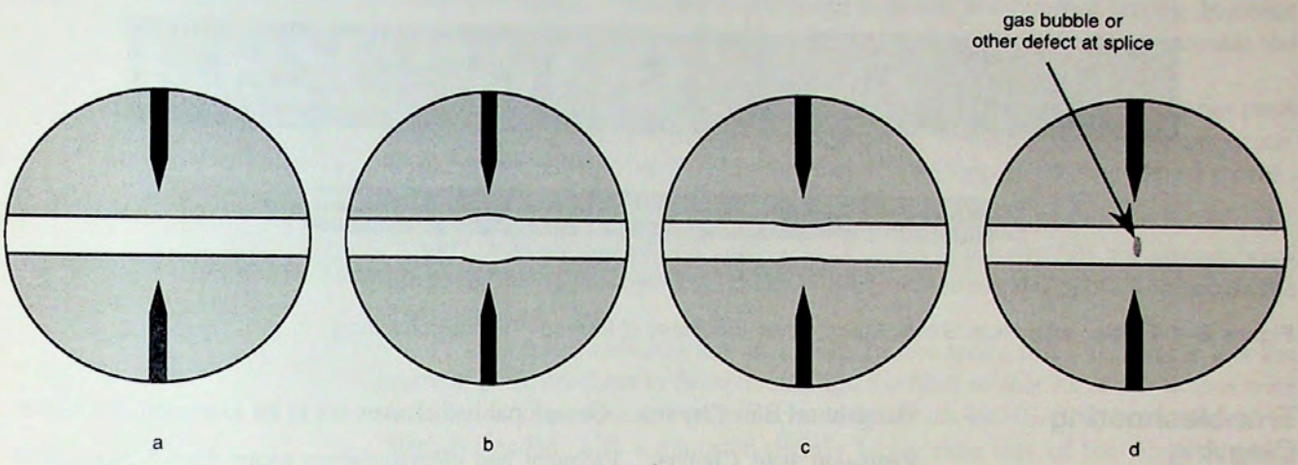


Figure 6–13 Proper and Improper Appearances of Fusion Splice

26. Push the STEP IN button repeatedly until the fiber ends just touch. If you push the STEP IN button too many times, push the STEP OUT button until you see an air gap between the fibers. Push the STEP IN button repeatedly until the fiber ends just touch.
27. Record the power meter reading in the column labeled "Before" (Table 6–2). Press the FUSE button to start the fusing process.
28. Inspect the fused fiber under the microscope. The fiber should be of uniform diameter (Figure 6–13 a), with no bulging (Figure 6–13 b), necking (Figure 6–13 c), or bubbling (Figure 6–13 d) in the area of the splice.
29. Measure and record the value on the power meter in the column labeled "Initial Loss"' (Table 6–2). If necessary, calculate the difference between the initial reading and the current reading to determine the splice loss.
30. If the splice is low loss (≤ 0.3 dB) and if the splice looks good (Step 28), remove the fiber by pressing both release buttons. Check the splice strength. Bend the bare fiber until it breaks. Compare the lengths of both of the broken ends. If the lengths of both ends are unequal, the splice is stronger than the virgin fiber. If the lengths of both ends are equal, the splice is weaker than the virgin fiber. If the ends are equal, increase the arc current by one setting and redo the splice (Steps 12–30).
31. If the splice loss is higher than the 0.3 dB, push the REHEAT button once. Measure and record the value on the power meter in the column labeled "Reheat 1" (Table 6–2). If the loss after reheating is still greater than 0.3 dB, repeat Steps 12–30. If the loss after reheating is unacceptable, increase the arc current setting by one digit.

32a. If you are practicing cleaving and splicing, repeat Steps 11–30 as many times as desired. However, allow at least 30 seconds between successive splices.

32b. If you are practicing the entire splicing procedure, install the splice cover. Slide the heat shrinkable splice cover until it is centered on the bare glass and covers all of the bare glass. Heat the splice cover with a heat gun until it has completely shrunk (Figure 6–14).

32c. Alternative procedure: remove the paper backing from an adhesive splice cover. Place the cover so that bare glass is centered in splice. Close the splice cover completely.

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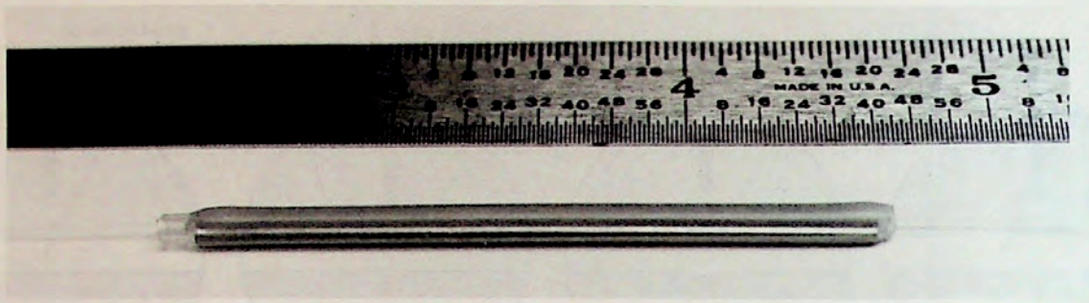


Figure 6–14 Fiber with Heat Shrink Splice Cover (Courtesy of Pearson Technologies Inc.)

Troubleshooting Cleaving

Occasional Bad Cleaves. Occasional bad cleaves are to be expected. Recleave.

Frequent Bad Cleaves. Frequent bad cleaves (when more than 5 percent of cleaves are visibly bad) indicate a problem with the cleaving technique or with the cleaver. To solve this problem, review three aspects of cleaving: how the fiber is held in the cleaver, straightness of the fiber before scribing, and how the fiber is bent during cleaving. The fiber must be held against one wall of the groove in the tail. The fiber must be straight before scribing. The fiber must be quickly bent, or snapped, so that the fiber is broken quickly.

If the problem persists after review of the procedure, the scribing blade may be worn or damaged. Replace this blade and recleave.

Troubleshooting Splicing

Offset Visible Prior to Splicing. Offset visible prior to splicing is usually due to contamination in the precision V-groove in the center of the splicer. Clean this groove with compressed air.

Infrequently, this offset may be due to buffer coating that was not removed from the fiber during stripping. Examine the bare fiber and remove any materials that remain on the fiber. Remove with an alcohol soaked lens-grade tissues.

Occasional High Loss. Occasional high loss is to be expected.

Consistent High Loss. Consistent high loss indicates a major deviation from optimum splicing conditions. Possible causes of this problem are a worn or damaged scribing blade in the cleaver or improper settings for the fiber being spliced (Table 6–1).

A worn or damaged scribing blade can create a cleave that looks good, but is actually not perpendicular to the axis of the fiber. Replace the scribing blade and attempt splicing. The lifetime of scribing blades depends on the cleaver and the care with which it is used. (During training, we have found the lifetime to be 1,000 cleaves.)

High loss from improper settings usually results in a splice with an improper visual appearance. This improper appearance is bulging, necking, or a "cold" or weak splice.

Gas Bubbles in Splice. Gas bubbles have two causes. The first cause is an end that is not perpendicular to the axis of the fiber. The second cause is gasses dissolved in the fiber. These gasses occasionally evolve during splicing.

Bulging in Splice. Bulging in the splice indicates an high overrun setting. Reduce the overrun control by one setting and resplice. If bulging persists, reduce the overrun control an additional setting until overrun disappears.

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Necking in Splice. Necking in the splice indicates low overrun setting. Increase the over-run control by one setting and resplice. If necking persists, increase the overrun control setting until necking disappears.

If necking persists, check the procedure you are following. If you do not push the RESET button before each splice (Step 24 of Procedure 1), necking can occur. If you do not position the fibers so that they touch (Step 26 of Procedure 1), necking can occur.

"Cold" or Weak Splice. A cold or weak splice is usually, but not always, visible under the microscope. This splice will have a clearly definable line across the diameter of the fiber.

A weak splice indicates low arc current or low splice time. To test for low arc current, place one fiber in the splicer. Align the fiber so that its end is in line with an imaginary line connecting the electrode tips. Push REHEAT. The end should be slightly beaded, with a diameter slightly larger than that of the fiber. Slightly larger means an increase of less than 10 percent in diameter.

If the fiber will not bead slightly with several increases in arc current, the electrodes may need cleaning or replacement. The battery may have lost its charge.

Well Defined Splice. A well defined splice has a clearly defined interface between the two fibers. A well defined splice is a weak splice. The best made splices are not distinguishable from unspliced fiber. See Weak Splice.

Fiber Ends Not Centered between Electrodes. Fiber ends not centered between electrodes indicates the need for alignment of the electrodes. See instruction manual for the alignment procedure.

PROCEDURE 2: SPLICING LONG LENGTHS OF FIBER

1. Unreel approximately 20 m of fiber from the outer end of a long length of fiber on a reel.
2. Unspool the inner end of the fiber from the reel. Attach this end to the light source according to Steps 1–7 of Procedure 1.
3. Prepare the outer end of the fiber reel and attach this end to the power meter according to Steps 8–10 of Procedure 1.
4. Repeat Step 11 of Procedure 1.
5. Break the fiber approximately 10 m from the power meter.
6. Repeat Steps 12–31 of Procedure 1.

Troubleshooting

See Troubleshooting of Procedure 1.

Question

Were the losses from Procedure 2 greater than or less than those from Procedure 1? In general, the losses from Procedure 2 will be less than those from Procedure 1. The reason for this reduction is differential modal attenuation.

Splicing Fiber to Tight Tube Cables

Tight buffer tube cables or tight tube pigtails can be spliced to fibers from loose buffer tube cables. These tight tube cables will be either a single fiber cable or a single fiber from a premise cable design. When splicing loose tube fibers to tight tube cables, the length from the end of the buffer tube to the cleave must be controlled to

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avoid misalignment. Misalignment can result from the large difference between the diameter of the buffer coating of the fiber (250 μm) and the diameter of the buffer tube of the cable (900 μm). The specific length of cleaved fiber will depend on the splicer. The 13 mm dimension can be used with 900 μm cables and the Preformed Line Products Fiberlign® Micro Splicer.

MECHANICAL SPLICING

In this section, we present the procedure for mechanical splicing. This procedure is designed around the Finger Splice from AMP Inc. With minor modifications, this procedure can be used with other mechanical splices. One of the modifications will be the length of the cleaved fiber. If you wish to practice singlemode fiber splicing, use a singlemode fiber with a light source and wavelength calibrated at 1310 nm. If you wish to practice a splicing technique for measurement at 1300 nm, use a 1300 nm light source and a power meter calibrated at 1300 nm.

TOOLS AND SUPPLIES REQUIRED

at least 15 feet of all-glass, 250 μm buffer coated multimode optical fiber

two bare fiber adapters with same connector style as the power meter and light source

power meter with calibration at 850 nm

850 nm stabilized light source

buffer coating stripper (Clauss part number NN200 or equivalent)

Scotch™ tape

cleaver (Fitel part number VL-310 or equivalent)

index matching gel (Fiber Instrument Sales part number F1-0001)

lens grade compressed air

91–95 percent isopropyl alcohol

AMP Finger Splice (part number 608119-1)

PROCEDURE 3: MECHANICAL SPLICING

1. Obtain all tools and supplies
2. Follow Steps 1–11 of Procedure 1 to obtain a reference signal.
3. Break the fiber in the middle.
4. Follow Steps 12 and 13 of Procedure 1, but place the end of the buffer coating at 6–7 mm, instead of 13 mm.
5. Clean the cleaved end by placing the end of the fiber against a clean piece of Scotch Magic™ tape.
6. Slide both clamping rings so that they are near the ends of the splice (Figure 6–15). If this is not the first use of this splice, insert this fiber end into index matching gel.
7. With your thumb, press down on one end of the clear plastic section in the center of the splice (the "nose," Figure 6–16).
8. While maintaining pressure on the nose, insert the fiber into the end of the splice opposite to your thumb.
9. While sliding the fiber into the splice, rotate the splice back and forth. Insert the fiber until it meets the limit stop inside the splice.

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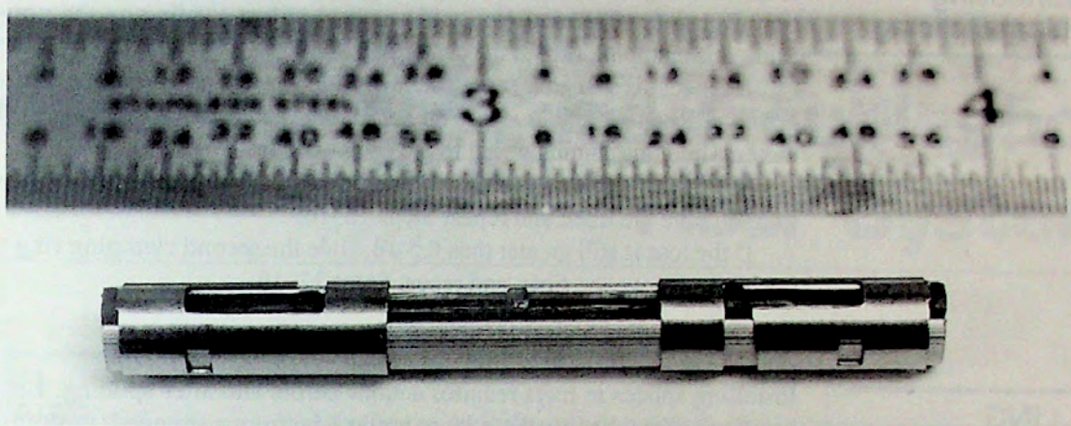


Figure 6–15 Mechanical Splice with Clamps at Ends (Open Position) (Courtesy of Pearson Technologies Inc.)

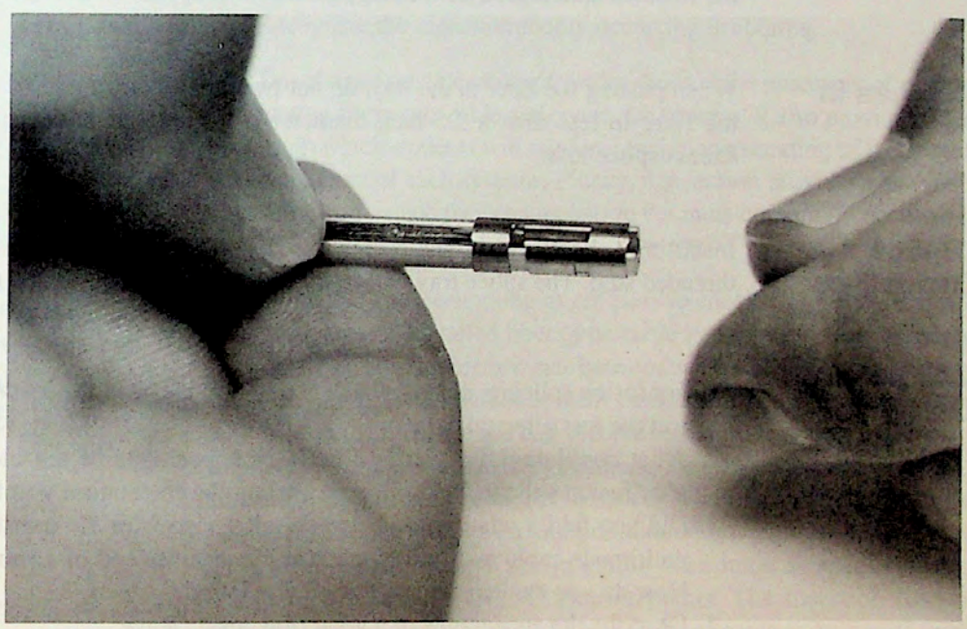


Figure 6–16 Proper Technique for Holding Splice for Insertion of First Fiber (Courtesy of Pearson Technologies Inc.)

10. Withdraw the fiber approximately 0.5 mm (0.020 inch).
11. Move the clamping ring toward the center of the splice until it will move no further. The fiber is fixed in the splice.
12. Repeat Steps 4 and 5 on the second end of the fiber.
13. Insert the second fiber end into the splice as in Step 8.
14. Place pressure on the fiber to keep it in the splice. Slide the second clamping ring towards the center of the splice until it will move no further.
15. Record the power meter reading and calculate the loss.
16. If the loss is less than 0.5 dB, remove both fibers and repeat the entire process. When repeating the process with this splice, dip the first fiber end in index matching gel. Dip just the end. If you put excessive gel on the sides of the fiber, the gel will prevent the two fiber ends from contact.

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Troubleshooting Mechanical Splicing

If the loss is greater than 0.5 dB, slide one of the clamping rings to the end position. Rotate the fiber until you achieve a lowest loss reading on the power meter. Slide this clamping ring to the center position.

If the loss is still greater than 0.5 dB, slide the second clamping ring to the end position. Rotate the fiber until you achieve the lowest loss reading on the power meter. Slide this clamping ring to the center position.

If the loss is still greater than 0.5 dB, slide one clamping ring to the end position, remove the fiber, and repeat Steps 12–16.

If the loss is still greater than 0.5 dB, slide the second clamping ring to the end position, remove the fiber, and repeat Steps 12–16.

INSTALLING SPLICES IN TRAYS AND ENCLOSURES

Installing splices in trays requires actions before and after splicing. Before splicing, the buffer tube (usually a loose buffer tube from a stranded, multiple fiber per tube cable) is placed in and fastened to the tray, with a service loop of fiber. The service loop is approximately 3 feet long, but can be longer to allow removal of the fiber for splicing. After splicing, the tray will appear as in Figure 3–11.

Installing Splices in Trays

When placing the fiber in the tray, do not twist the fiber. In addition, do not bend the fiber to less than a 2.5-inch diameter. Twisting and bending will result in excess splice loss.

Installing Splice Trays in Enclosures

Installing splice trays in enclosures is straightforward. Most enclosures have a threaded stud. The splice tray will fit on the stud (Figures 6–2 and 6–3).

REVIEW QUESTIONS

1. For fusion splicing, did you find a correlation between the loss before splicing and the loss after splicing?
2. What correlation did you find between appearance of the cleaves and loss after fusion splicing? How do you explain the correlation you found?
3. Did you find a relationship between splices made at the transmitter end of a multimode cable and splices made at the receiver end of a multimode cable? How do you explain the correlation you found?
4. Describe the appearance of a good (low loss) cleave.
5. Describe the appearance of a bad (high loss) cleave.
6. Describe the appearance of a fusion splice made with excessive overrun.
7. Describe the appearance of a fusion splice made with insufficient overrun.
8. How can you test a splice to determine that the splice was a cold splice?
9. What is the function of the prefuse step?
10. What is the function of a splice cover on a fusion splice?

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THE COMPLETE GUIDE TO

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ERIC R. PEARSON

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