An Overview of Fiber Optic Technology

The use of fiber optics in telecommunications and wide area networking has been common for many years, but more recently fiber optics have become increasingly prevalent in industrial data communications systems as well. High data rate capabilities, noise rejection and electrical isolation are just a few of the important characteristics that make fiber optic technology ideal for use in industrial and commercial systems.

Most often used for point-to-point connections, fiber optic links are being used to extend the distance limitations of RS-232, RS-422/485 and Ethernet systems while ensuring high data rates and minimizing electrical interference. Conventional electrical data signals are converted into a modulated light beam, introduced into the fiber and transported via a very small diameter glass or plastic fiber to a receiver that converts the light back into electrical signals. Fiber's ability to carry the light signal, with very low losses, is based on some fundamental physics associated with the refraction and reflection of light.

Fiber Optic Principles

Whenever a ray of light passes from one transparent medium to another, the light is affected by the interface between the two materials. This occurs because of the difference in speeds that the light can travel through different materials. Each material can be described in terms of its *refractive index*, which is the ratio of the speed of light in the material to its speed in free space. The relationship between these two refractive indices determines the *critical angle* of the interface between the two materials.

There are three actions that can happen when a ray of light hits an interface. Each action depends on the angle of incidence of the ray of light with the interface. If the angle of incidence is less than the critical angle, the light ray will refract, bending toward the material with the higher refractive index. If the angle of incidence is exactly equal to the critical angle the ray of light will travel along the surface of the interface. If the angle of incidence is greater than the critical angle, the ray of light will reflect.

The refractive index of vacuum is considered to be 1. Often, we consider the refractive index of air also to be 1 (although it is actually slightly higher). The refractive index of water is typically about 1.33. Glass has a refractive index in the range of 1.5, a value that can be manipulated by controlling the composition of the glass itself.

Fiber Optic Characteristics

Optical fibers allow data signals to propagate through them by ensuring that the light signal enters the fiber at an angle greater than the critical angle of the interface between two types of glass. As shown in Figure 1, optical fiber is actually made up of three parts. The center *core* is composed of very pure glass, with a refractive index of 1.5. Core dimensions are usually in the range of 50 to 125 um. The surrounding glass, called *cladding*, is a slightly less pure glass with a refractive index of 1.45. The diameter of the core and cladding together is in the range of 125 to 440 um. Surrounding the cladding is a protective layer of flexible silicone called the *sheath*.

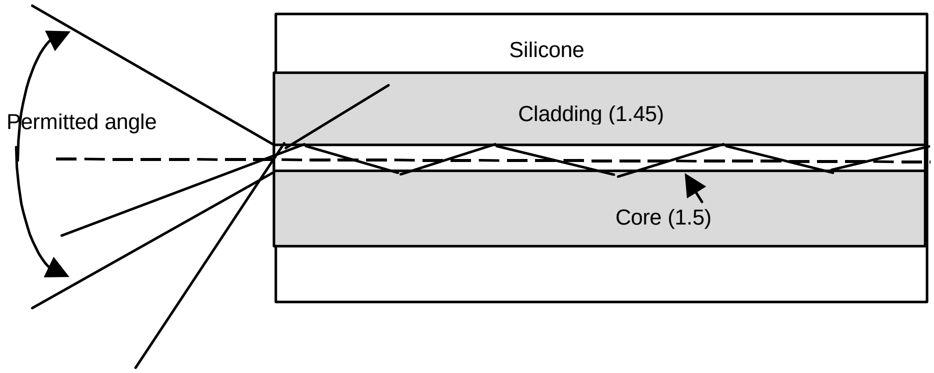

Figure 1. Light Traveling Through a Fiber

When light is introduced into the end of an optical fiber, any ray of light that hits the end of the fiber at an angle greater than the critical angle will propagate through the fiber. Each time it hits the interface between the core and the cladding it is reflected back into the fiber. The angle of acceptance for the fiber is determined by the critical angle of the interface. If this angle is rotated, a cone is generated. Any light falling on the end of the fiber within this cone of acceptance will travel through the fiber. Once the light is inside the fiber it 'bounces' through the core, reflecting inward each time it hits the interface.

Figure 1 illustrates how light rays travel through the fiber, reflecting off the interface. If the physical dimensions of the core are relatively large individual rays of light will enter at slightly different angles and will reflect at different angles. Since they travel different paths through the fiber, the distance they travel also varies. As a result they arrive at the receiver at different times. A pulse signal sent through the fiber will emerge wider than it was sent, deteriorating the quality of the signal. This is called *modal dispersion*. Another effect that causes deterioration of the signal is *chromatic dispersion*. Chromatic dispersion is caused by light rays of different wavelengths traveling at different speeds through the fiber. When a series of pulses is sent through the fiber, modal and chromatic dispersion can eventually cause the pulse to merge into one long pulse and the data signal is lost.

Another characteristic of optical fiber is attenuation. Although the glass used in the core of optical fiber is extremely pure, it is not perfect. As a result light can be absorbed within the cable. Other signal losses include bending and scattering losses as well as losses due to connections. Connection loses can be caused by misalignment of the ends of the fiber or end surfaces not properly polished.

Types of Fibers

Optical fibers are manufactured in three main types: *multi-mode step-index*, *multi-mode graded-index*, and *single-mode*. Multi-mode step-index fiber has the largest diameter core (typically 50 to 100 um). The larger distance between interfaces allows the light rays to travel the most distance when bouncing through the cable. Multi-mode fibers typically carry signals with wavelengths of 850 nm or 1300 nm. The diagram below shows how a narrow pulse introduced to the fiber becomes wider at the receiving end.

Multi-mode step-index fiber (a) is comparatively easy to splice and terminate due to the large diameter fiber. It is also relatively inexpensive to manufacture compared to other types. However, it tends to be too slow for most purposes and it not common in modern systems.

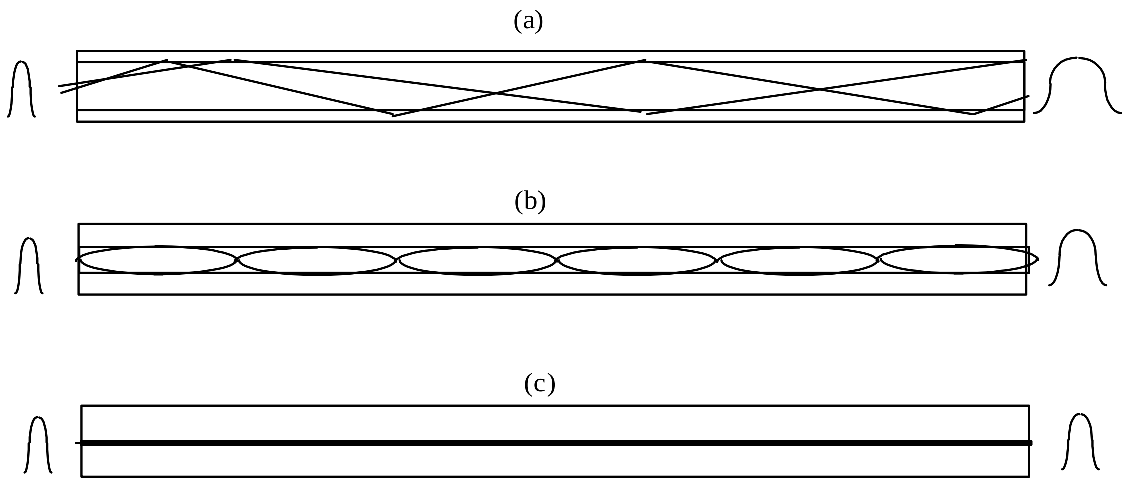

Figure 2. Step Index (a), Graded Index (b), and Single-mode (c)

Multi-mode graded-index fiber (b) is constructed in such a way that the refractive index between the core and cladding changes gradually. This causes the light rays to bend gradually, as well. The resulting pattern of reflections tends to be more uniform and dispersion is reduced. This provides improved performance for a moderate increase in cost. Graded-index fibers provide wider bandwidth than step-index fibers.

Single-mode fibers (c) give the highest performance of the three types. Manufactured using a very small diameter fiber (typically 8 um), when light is introduced into the fiber reflections are kept to a minimum by the dimensions of the core. Light travels virtually straight through the core and pulses introduced at one end are reproduced at the other end with very little dispersion. Typically, single-mode fibers carry signals with wavelengths of 1320 nm or 1550 nm. Single-mode fiber is relatively expensive, however, and is more difficult to splice and terminate since the core must be aligned very accurately.

Single-mode fibers offer much lower attenuation than multi-mode fibers. At typical single-mode fiber will attenuate a 1310 nm signal less than 0.5 dB per kilometer. A typical multi-mode graded-index fiber will attenuate the same signal about 3 dB per kilometer. Single-mode fiber is most often used in applications with high bandwidth requirements over long distances. Some Ethernet fiber optic equipment can increase distances from two kilometers using multi-mode fiber to about 70 kilometers over single-mode fiber.

Fiber Optic Cable Construction

Even though optical fiber seems quite flexible, it is made of glass, which cannot withstand sharp bending or longitudinal stress. Therefore when fiber is placed inside complete cables special construction techniques are employed to allow the fiber to move freely within a tube. Usually fiber optic cables contain several fibers, a strong central strength member and one or more metal sheaths for mechanical protection. Some cables also include copper pairs for auxiliary applications.

Signal Sources and Detectors

To use fiber optic cables for communications, electrical signals must be converted to light, transmitted, received, and converted back from light to electrical signals. This requires optical sources and detectors that can operate at the data rates of the communications system.

Signal Sources

There are two main categories of optical signal sources:

- Light Emitting Diodes
- Infrared Laser Diodes

Light emitting diodes (LED) are the less expense, but lower performance device. These are used in lower-cost applications where lower data rates and/or shorter distances are required. Infrared laser diodes operate at much higher speeds, dissipate higher power levels and require temperature compensation or control to maintain specified performance levels. They are also more costly.

Signal Detectors

Signal detectors also fall into two main categories:

- PIN Photodiodes
- Avalanche Photodiodes

Similarly to sources, the two types provide much different cost/performance ratios. PIN photodiodes are more commonly used, especially in less stringent applications. Avalanche photodiodes on the other hand, are very sensitive and can be used where longer distances and higher data rates are involved.

B&B Electronics Fiber Optic Cables and Couplers

Cables

Some B&B Electronics fiber optic products use ST connectors while others use SC Duplex connectors.

Almost any multi-mode glass fiber can be used, including 50/125 um, 62.5/125 um, 100/140 um or 200 um fibers. Typically B&B Electronics products use graded index fibers operating with 820 nm wavelength signals. Simplex and duplex cables are available in standard 1 meter, 3 meter, 5 meter and 10 meter lengths. B&B will manufacture custom length cables with ST to ST, SC to SC and ST to SC terminations. Cable jackets are plenum rated.

Couplers

B&B Electronics offers fiber cable couplers for ST terminations and SC duplex terminations.

Splicing, Joining and Terminating Optical Fibers

In practical situations fiber optic cables exhibit signal power losses based on both the fiber and connections from the fiber to sensors or other fiber segments. Typically fiber losses run at about 10 dB per kilometer.

Whenever a fiber must be terminated the goal is to produce a perfectly transparent end to the fiber. The end should be square, clear and physically mated to the receiving optical device. In some cases cables are permanently joined by welding or gluing the ends of the fiber together. Others mechanically align the fibers and use a transparent gel to couple the signal at the interface.

Connectors

Early fiber optic connections involved cutting the fiber, epoxying a special connector, and polishing the end of the fiber. This operation required special tools and testing equipment to ensure a good connection. While this technique is still used, devices used to cut, align and join fibers have been improved and simplified. Connection losses vary, depending on the type of connection but typically range from 0.2 dB to 1 dB.

There are several standard connector types used to join or terminate fiber optic cables. These include:

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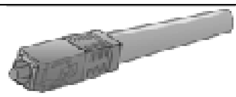
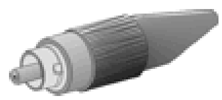
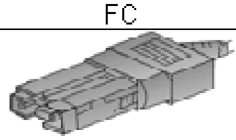
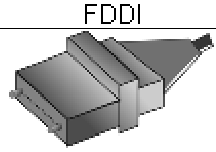
  SC	Used in data communications and telecommunications applications (also used with some B&B Electronics products)
 FC	Used in data communications and telecommunications applications
 FDDI	Used in some fiber optic networks
 MT Array  LC	Used where high density interconnections are required

Planning A Fiber Optic Link

The most important consideration in planning the fiber optic link is the *power budget* specification of the devices being connected. This value tells you the amount of loss in dB that can be present in the link between the two devices before the units fail to perform properly. This value will include line attenuation as well as connector loss.

Power Budget Example

For B&B Electronics' 9PFLST Port-Powered RS-232 Fiber Optic Modem the typical connector-to-connector power budget is 12.1 dB. Because 62.5/125 µm cable typically has a line attenuation of 3 dB per km at 820 nm, the 12.1 dB power budget translates into 2.5 miles (4 km). This assumes no extra connectors or splices in the link. Each extra connection would typically add 0.5 dB of loss, reducing the possible distance by 166 m (547 ft.) Your actual loss should be measured before assuming distances. When the 9PFLST is used without external power, the power available to the Fiber Optic transmitter may be less than the typical value. The link should be tested with the 9PFLST in place with a variable attenuator to check the optical power budget of the whole system.

Advantages of Fiber Optic Cables

Noise Immunity

Noise immunity is one of the most useful features of fiber optics in industrial applications. In environments where electromagnetic interference is prominent and unavoidable, fiber optics are unaffected. While cables are normally contained in protective sheaths and often run inside conduit, there is no need to physically isolate fiber optic cables from electrical cables. This makes cable routing simpler.

Electrical Isolation

The problem of ground loop noise and common mode potential differences is eliminated by the use of fiber optic cables. Field signals, generated by devices floating at high potentials, can be coupled to other equipment at much lower potentials without the risk of damage. This is particularly desirable in industrial applications.

Low Error Rates

When properly designed to provide adequate signal levels at the receiving end of the link, a fiber optic system provides very low bit error rates.

Safe for Use in Hazardous Areas

Fiber optic links can be used to couple signals into areas with potentially explosive atmospheres without a risk to delivering or storing sufficient energy to ignite an explosion. This makes fiber optic technology particularly useful when designing intrinsically safe systems.

Wide Bandwidth

Fiber optic cables can carry very wide bandwidth signals, well into the GHz range. Many individual, lower bandwidth signals can be multiplexed onto the same cable. In commercial systems fiber optic cable often carries a mixture of signal types, including voice, video and data all on the same fiber.

Low Signal Attenuation

Optical fibers do exhibit some attenuation due to absorption and scattering. However, this attenuation is relatively independent of frequency, a factor that is significant in copper cables.

Light Weight, Small Diameter

Because many signals can be multiplexed onto one fiber, cables tend to be smaller and lighter. This makes installation easier.

No Crosstalk

Since fibers do not pick up electromagnetic interference, signals on adjacent cables are not coupled together.

Inherent Signal Security

For applications where signal security is a concern, optical fiber is an excellent solution. Fiber optic cables do not generate electromagnetic fields that could be picked up by external sensors. It is also more difficult to 'steal' signals by spicing into optical fibers than it might be with conventional copper wiring.