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Introduction to Fiber Optics

The equipment, tools and cabling
that comprise a fiber optic link, how they work
and their advantages over traditional copper.

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October 8, 2009

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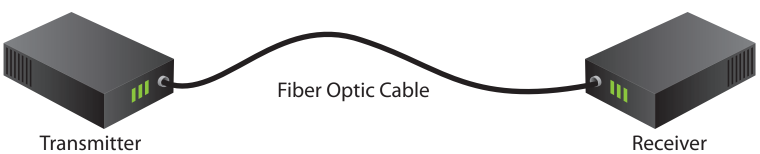
Introduction

Our current "age of technology" is the result of many brilliant inventions and discoveries, but it is our ability to transmit information, and the media we use to do it, that is perhaps most responsible for its evolution. Progressing from the copper wire of a century ago to today's fiber optic cable, our increasing ability to transmit more information, more quickly and over longer distances has expanded the boundaries of our technological development in all areas.

Today's low-loss glass fiber optic cable offers almost unlimited bandwidth and unique advantages over all previously developed transmission media. The basic point-to-point fiber optic transmission system consists of three basic elements: the optical transmitter, the fiber optic cable and the optical receiver.

Figure 1 - Basic Fiber Optic Transmission System



The Optical Transmitter

The transmitter converts an electrical analog or digital signal into a corresponding optical signal. The source of the optical signal can be either a light emitting diode, a VCSEL, or a solid state laser diode. The most popular wave-lengths of operation for optical transmitters are 850, 1310 or 1550 nanometers.

Most Fiberlink® and Pure Digital Fiberlink® transmission equipment manufactured by Communications Specialties operates at wavelengths of 850 or 1310nm.

The Fiber Optic Cable

The cable consists of one or more glass fibers, which act as waveguides for the optical signal (light). Fiber optic cable is similar to electrical cable in its construction, but provides special protection for the optical fiber within. For systems requiring transmission over distances of many kilometers, or where two or more fiber optic cables must be joined together, an optical splice is commonly used.

The Optical Receiver

The receiver converts the optical signal back into a replica of the original electrical signal. The detector of the optical signal is either a PIN-type photodiode or avalanche-type photodiode.

Fiberlink® and Pure Digital Fiberlink® receiving equipment use PIN-type photodiodes.

Advantages of Fiber Optic Systems

Fiber optic transmission systems – a fiber optic transmitter and receiver, connected by fiber optic cable – offer a wide range of benefits not offered by traditional copper wire or coaxial cable. These include:

1. The ability to carry much more information and deliver it with greater fidelity than either twisted pair wire or coaxial cable.

2. Fiber optic cable can support much higher data rates, and at greater distances, than coaxial cable, making it ideal for transmission of serial digital data.

3. The fiber is totally immune to virtually all kinds of interference, including lightning, and will not conduct electricity. It can therefore come in direct contact with high voltage electrical equipment and power lines. It will also not create ground loops of any kind.

4. As the basic fiber is made of glass, it will not corrode and is unaffected by most chemicals. It can be buried directly in most kinds of soil or exposed to most corrosive atmospheres in chemical plants without significant concern.

5. Since the only signal in the fiber is light, there is no possibility of a spark from a broken fiber. Even in the most explosive of atmospheres, there is no fire hazard, and no danger of electrical shock to personnel repairing broken fibers.

6. Fiber optic cables are virtually unaffected by outdoor atmospheric conditions, allowing them to be lashed directly to telephone poles or existing electrical cables without concern for extraneous signal pickup.

7. A fiber optic cable, even one that contains many fibers, is usually much smaller and lighter in weight than a wire or coaxial cable with similar information carrying capacity. It is easier to handle and install, and uses less duct space. (It can frequently be installed without ducts.)

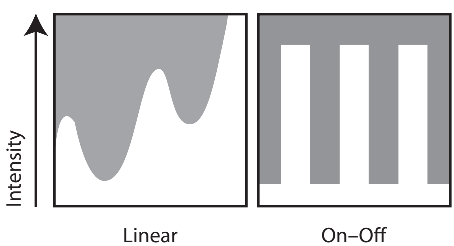
8. Fiber optic cable is ideal for secure communications systems because it is very difficult to tap but very easy to monitor. In addition, there is absolutely no electrical radiation from a fiber.

How are fiber optic cables able to provide all of these advantages? This guide will provide an overview of fiber optic technology - with sections devoted to each of the three system components - transmitters, receivers, and the fiber cable itself. An appreciation of the underlying technology will provide a useful framework for understanding the reasons behind its many benefits.

Optic Transmitters

The basic optical transmitter converts electrical input signals into modulated light for transmission over an optical fiber. Depending on the nature of this signal, the resulting modulated light may be turned on and off or may be linearly varied in intensity between two predetermined levels.

Figure 2 - Basic Optical Modulation Methods



The most common devices used as the light source in optical transmitters are the light emitting diode (LED), the vertical cavity side emitting laser (VCSEL) and the laser diode (LD). In a fiber optic system, these devices are mounted in a package that enables an optical fiber to be placed in very close proximity to the light emitting region in order to couple as much light as possible into the fiber. In some cases, the emitter is even fitted with a tiny spherical lens to collect and focus "every last drop" of light onto the fiber and in other cases, a fiber is "pigtailed" directly onto the actual surface of the emitter.

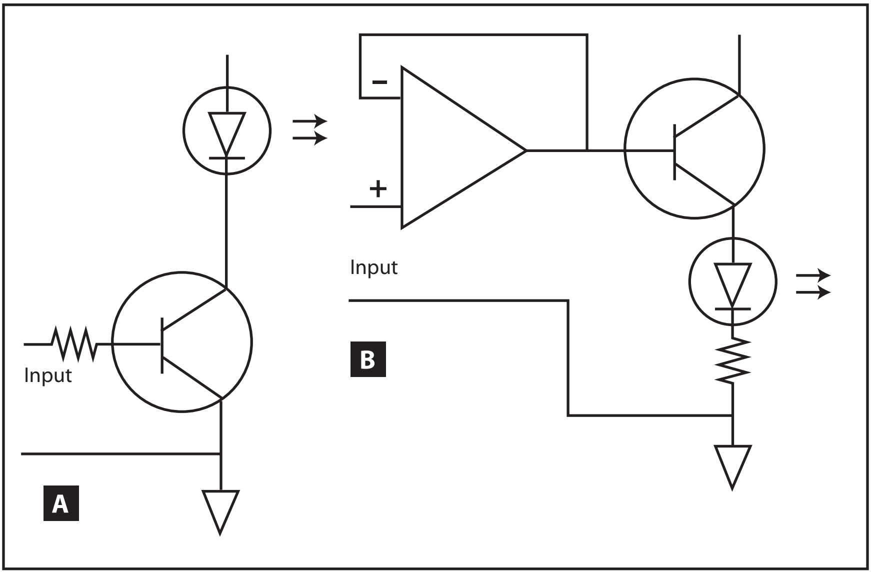
LEDs have relatively large emitting areas and as a result are not as good light sources as LDs. However, they are widely used for short to moderate transmission distances because they are much more economical, quite linear in terms of light output versus electrical current input and stable in terms of light output versus ambient operating temperature. LDs, on the other hand, have very small light emitting surfaces and can couple many times more power to the fiber than LEDs. LDs are also linear in terms of light output versus electrical current input, but unlike LEDs, they are not stable over wide operating temperature ranges and require more elaborate circuitry to achieve acceptable stability. In addition, their added cost makes them primarily useful for applications that require the transmission of signals over long distances.

LEDs, VCSELs and LDs operate in the infrared portion of the electromagnetic spectrum so that their light output is usually invisible to the human eye. Their operating wavelengths are chosen to be compatible with the lowest transmission loss wavelengths of glass fibers and highest sensitivity ranges of photodiodes. The most common wavelengths in use today are 850 nanometers, 1310 nanometers, and 1550 nanometers. Both LEDs and LDs are available in all three wavelengths. VCSELs, however, only operate at 850 nanometers.

LEDs and LDs, as previously stated, are modulated in one of two ways; on and off, or linearly. Figure 3 shows simplified circuitry to achieve either method with an LED or LD. As can be seen from Figure 3A, a transistor is used to switch the LED or LD on and off in step with an input digital signal. This signal can be converted from almost any digital format by the appropriate circuitry, into the correct base drive for the transistor. Overall speed is then determined by the circuitry and the inherent speed of the LED or LD. Used in this manner, speeds of several hundred megahertz are readily achieved for LEDs and thousands of megahertz for LDs. Temperature stabilization circuitry for the LD has been omitted from this example for simplicity. LEDs do not normally require any temperature stabilization.

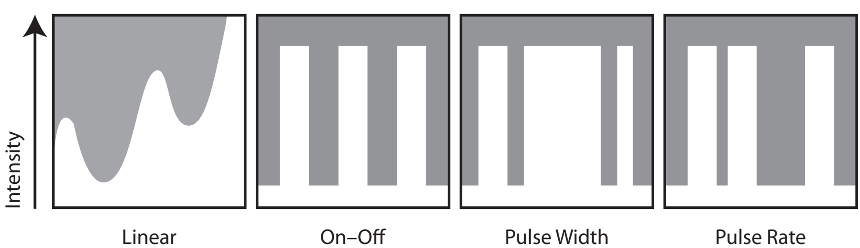
Linear modulation of an LED or LD is accomplished by the operational amplifier circuit of figure 3B. The inverting input is used to supply the modulating drive to the LED or LD while the non-inverting input supplies a DC bias reference. Once again, temperature stabilization circuitry for the LD has been omitted from this example for simplicity.

Figure 3 - Methods of Modulating LEDs or Laser Diodes



Digital on/off modulation of an LED or LD can take a number of forms. The simplest, as we have already seen, is light-on for a logic "1", and light-off for a logic "0". Two other common forms are *pulse width modulation* and *pulse rate modulation*. In the former, a constant stream of pulses is produced with one width signifying a logic "1" and another width, a logic "0". In the latter, the pulses are all of the same width but the pulse rate changes to differentiate between logic "1" and logic "0".

Figure 4 - Various Methods to Optically Transmit Analog Information



Analog modulation can also take a number of forms. The simplest is intensity modulation where the brightness of an LED is varied in direct step with the variations of the transmitted signal. In other methods, an RF carrier is first frequency modulated with another signal or, in some cases, several RF carriers are separately modulated with separate signals, then all are combined and transmitted as one complex wave-form. Figure 4 shows all of the above modulation methods as a function of light output.

The equivalent operating frequency of light, which is, after all, electro-magnetic radiation, is extremely high – on the order of 1,000,000 GHz. The output bandwidth of the light produced by LEDs and Laser diodes is quite wide. Unfortunately, today's technology does not allow this bandwidth to be selectively used in the way that conventional radio frequency transmissions are utilized. Rather, the entire optical bandwidth is turned on and off in the same way that early "spark transmitters" (in the infancy of radio), turned wide portions of the RF spectrum on and off. However, with time, researchers will overcome this obstacle and "coherent transmissions", as they are called, will become the direction in which the fiber optic field progresses.

The Optical Fiber - Launching the Light

Once the transmitter has converted the electrical input signal into whatever form of modulated light is desired, the light must be "launched" into the optical fiber.

As previously mentioned, there are two methods where by light is coupled into a fiber. One is by pigtailing. The other is by placing the fiber's tip in very close proximity to an LED or LD.

When the proximity type of coupling is employed, the amount of light that will enter the fiber is a function of one of four factors: the intensity of the LED or LD, the area of the light emitting surface, the acceptance angle of the fiber, and the losses due to reflections and scattering. Following is a short discussion on each:

Intensity

The intensity of an LED or LD is a function of its design and is usually specified in terms of total power output at a particular drive current. Sometimes, this figure is given as actual power that is delivered into a particular type of fiber. All other factors being equal, more power provided by an LED or LD translates to more power "launched" into the fiber.

Area

The amount of light "launched" into a fiber is a function of the area of the light emitting surface compared to the area of the light accepting core of the fiber. The smaller this ratio is, the more light that is "launched" into the fiber.

Acceptance Angle

The acceptance angle of a fiber is expressed in terms of numeric aperture. The numerical aperture (NA) is defined as the sine of one half of the acceptance angle of the fiber. Typical NA values are 0.1 to 0.4 which correspond to acceptance angles of 11 degrees to 46 degrees. Optical fibers will only transmit light that enters at an angle that is equal to or less than the acceptance angle for the particular fiber.

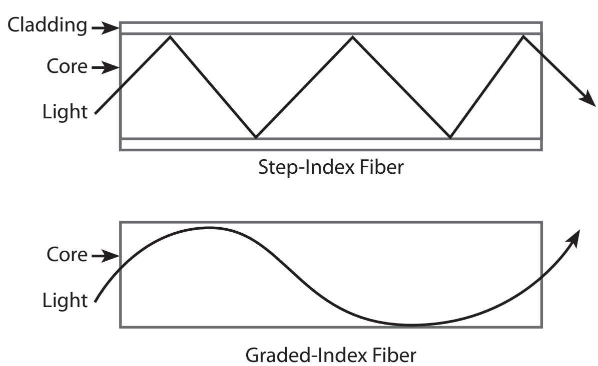
Other Losses

Other than opaque obstructions on the surface of a fiber, there is always a loss due to reflection from the entrance and exit surface of any fiber. This loss is called the Fresnell Loss and is equal to about 4% for each transition between air and glass. There are special coupling gels that can be applied between glass surfaces to reduce this loss when necessary.

Types of Optical Fiber

There are two types of fiber constructions in use today: step index and graded index. As Figure 5 illustrates, light propagates through these different types of fiber in two different ways.

Figure 5 - Light Propagation Through Step and Graded Index Fibers



As shown in the drawing, step index fiber consists of a core of low-loss glass surrounded by a cladding of even lower refractive index glass. This difference in refractive index between the two types of glass causes light to continually "bounce" between the core/cladding interface along the entire length of the fiber. In graded index fiber, only one type of glass is used, but it is treated so that the index of refraction gradually decreases as the distance from the core increases. The result of this construction is that light continuously bends toward the center of the fiber much like a continuous lens.

Optical fiber is commonly characterized in terms of the core/cladding dimensions, which are given in microns. Currently, there are three popular sizes in general use although other sizes do exist for special applications. These are 50/125 and 62.5/125 multimode fiber and 8-10/125 single mode fiber. The 50 and 62.5 micron core fibers are usually driven by LEDs and VCSELs, and most commonly used for short and medium length point-to-point transmission systems. The 8-10 micron core fiber is driven by a laser diode and is most often used for long distance telecommunications purposes.

Losses in Optical Fiber

Other than the losses exhibited when coupling LEDs or LDs into a fiber, there are losses that occur as the light travels through the actual fiber. The core of an optical fiber is made of ultra-pure low-loss glass. Considering that light has to pass through thousands of meters or more of fiber core, the purity of the glass must be extremely high. To appreciate the purity of this glass, consider the glass in common windowpanes. We think of window panes as "clear," allowing light to pass freely through, but this is because they are only 1/16 to ¼ inch thick. In contrast to this clear appearance, the edges of a broken windowpane look green and almost opaque. In this case, the light is passing edgewise into the glass, through several inches. Just imagine how little light would be able to pass through a thousand feet of window glass!

Most general purpose optical fiber exhibits losses of 3 to 4 dB per km (a 60% to 75% loss per km) at a wavelength of 850nm. When the wavelength is changed to 1310nm, the loss drops to about 1 to 2 dB (50% to 60%) per km. At 1550nm, it is even lower. Premium fibers are available with loss figures of 3 dB (50%) per km at 850nm and 1 dB (20%) per km at 1310nm. Losses of 0.5 dB (10%) per km at 1550nm are not uncommon. These losses are primarily the result of random scattering of light and absorption by actual impurities within the glass.

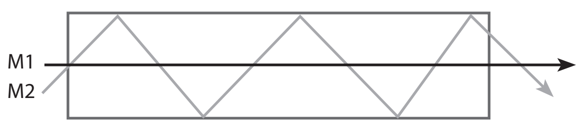
Another source of loss within the fiber is due to excessive bending, which causes some of the light to leave the core area of the fiber. The smaller the bend radius, the greater the loss. Because of this, bends along a fiber optic cable should have a turning radius of at least an inch.

Optical Fiber Bandwidth

All of the above attenuation factors result in simple attenuation that is independent of bandwidth. In other words, a 3 dB loss means that 50% of the light will be lost whether it is being modulated at 10Hz or 100 MHz. There is an actual bandwidth limitation of optical fiber however, and this is measured in MHz per km. The easiest way to understand why this loss occurs is to refer to Figure 6.

As Figure 6 illustrates, a ray of light that enters a fiber relatively straight or at a slight angle (M1) has a shorter path through the fiber than light which enters at an angle close to the maximum acceptance angle (M2). As a result, different rays (or modes) of light reach the end of fiber at different times, even though the original source is the same LED or LD. This produces a "smearing" effect or uncertainty as to where the start and end of the pulse occurs at the output end of the fiber - which in turn limits the maximum frequency that can be transmitted. In short, the less modes, the higher the bandwidth of the fiber.

Figure 6 - Different Light Path Lengths Determine the Bandwidth of a Fiber



The way that the number of modes is reduced is by making the core of the fiber as small as possible. Single mode fiber, with a core measuring only 8 to 10 microns in diameter, has a much higher bandwidth because it allows only a few modes of light to propagate along its core. Fibers with a wider core diameter, such as 50 and 62.5 microns, allow many more modes to propagate and are therefore referred to as "multimode" fibers.

Typical bandwidth for common fibers range from a few MHz per km for very large core fibers, to hundreds of MHz per km for standard multimode fiber, to thousands of MHz per km for single mode fibers. And as the length of fiber increases, its bandwidth will decrease proportionally. For example, a fiber cable that can support 500MHz bandwidth at a distance of one kilometer will only be able to support 250 MHz at 2 kilometers and 100 MHz at 5 kilometers.

Because single mode fiber has such a high inherent bandwidth, the "bandwidth reduction as a function of length" factor is not a real issue of concern when using this type of fiber. However, it is a consideration when using multimode fiber, as its maximum bandwidth often falls within the range of the signals most often used in point-to-point transmission systems.

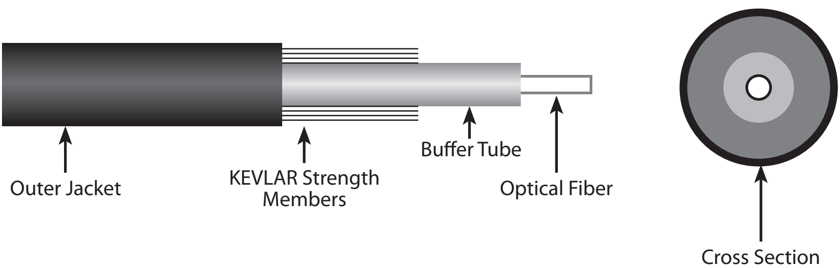
Fiber Optic Cable Construction

Fiber optic cable comes in all sizes and shapes. Like coaxial cable, its actual construction is a function of its intended application. It also has a similar "feel" and appearance.

The basic optical fiber is provided with a buffer coating which is mainly used for protection during the manufacturing process. This fiber is then enclosed in a central PVC loose tube which allows the fiber to flex and bend, particularly when going around corners or when being pulled through conduits.

Around the loose tube is a braided Kevlar yarn strength member which absorbs most of the strain put on the fiber during installation. Finally, a PVC outer jacket seals the cable and prevents moisture from entering. Basic optical fiber is ideal for most inter-building applications where extreme ruggedness is not required. In addition to the "basic" variety, it is also available for just about any application, including direct burial, armored, rodent resistant cable with steel outer jacket, and UL approved plenumgrade cable. Color-coded, multi-fiber cable is also available.

Figure 7 - Construction of a Typical fiber Optic Cable



Other Types of Fibers

Two additional types of fiber – very large core diameter silica fiber and fiber made completely of plastic – are normally not employed for data transmission.

Silica fiber is typically used in applications involving high-power lasers and sensors, such as medical laser surgery.

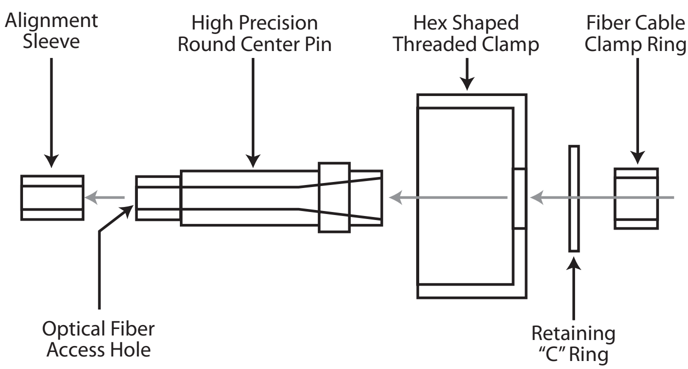
All-plastic fiber is useful for very short data links within equipment because it may be used with relatively inexpensive LEDs. An isolation system for use as part of a high voltage power supply would be a typical example of an application for plastic fiber.

Optical Connectors

Optical connectors are the means by which fiber optic cable is usually connected to peripheral equipment and to other fibers. These connectors are similar to their electrical counterparts in function and outward appearance but are actually high precision devices. In operation, the connector centers the small fiber so that its light gathering core lies directly over and in line with the light source (or other fiber) to tolerances of a few ten thousandths of an inch. Since the core size of common 50 micron fiber is only 0.002 inches, the need for such extreme tolerances is obvious.

There are many different types of optical connectors in use today. The SMA connector, which was first developed before the invention of single mode fiber, was the most popular type of connector until recently. Figure 8 shows an exploded view of the parts of this connector.

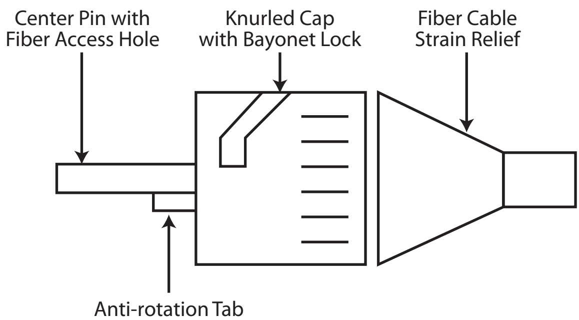
Figure 8 - Construction of SMA Connector



The most popular type of multimode connector in use today is the ST connector. Initially developed by AT&T for telecommunications purposes, this connector uses a twist lock type of design and provides lower overall losses than the SMA. A typical mated pair of ST connectors will exhibit less than 1 dB (20%) of loss and does not require alignment sleeves or other similar devices. The inclusion of an "anti-rotation tab" assures that every time the connectors are mated, the fibers always return to the same rotational position assuring constant, uniform performance.

ST connectors are available for both multimode and single mode fibers, the primary difference being the overall tolerances. Note that multimode ST connectors will only perform properly with multimode fibers. More expensive single mode ST connectors will perform properly with both single mode and multimode fibers. The installation procedure for the ST connector is very similar to that of the SMA and requires approximately the same amount of time.

Figure 9 - Major Features of the “Industry Standard” ST Connector



Optical Splices

While optical connectors can be used to connect fiber optic cables together, there are other methods that result in much lower loss splices. Two of the most common and popular are the mechanical splice and the fusion splice. Both are capable of splice losses in the range of 0.15 dB (3%) to 0.1 dB (2%).

In a mechanical splice, the ends of two pieces of fiber are cleaned and stripped, then carefully butted together and aligned using a mechanical assembly. A gel is used at the point of contact to reduce light reflection and keep the splice loss at a minimum. The ends of the fiber are held together by friction or compression, and the splice assembly features a locking mechanism so that the fibers remain aligned.

A fusion splice, by contrast, involves actually melting (fusing) together the ends of two pieces of fiber. The result is a continuous fiber without a break. Fusion splices require special expensive splicing equipment but can be performed very quickly, so the cost becomes reasonable if done in quantity. As fusion splices are fragile, mechanical devices are usually employed to protect them.

Optical Receivers

The basic optical receiver converts the modulated light coming from the optical fiber back into a replica of the original signal applied to the transmitter.

The detector of this modulated light is usually a photodiode of either the PIN or the Avalanche type. This detector is mounted in a connector similar to the one used for the LED, VCSEL or LD. Photodiodes usually have a large sensitive detecting area that can be several hundred microns in diameter. This relaxes the need for special precautions in centering the fiber in the receiving connector and makes the "alignment" concern much less critical than it is in optical transmitters.

Since the amount of light that exits a fiber is quite small, optical receivers usually employ high gain internal amplifiers. Because of this, for any given system, it is important only to use the size fiber specified as appropriate. Otherwise, overloading of the optical receiver may occur. If, for example, a transmitter/receiver pair designed for use with single mode fiber were used with multimode fiber, the large amount of light present at the output of the fiber (due to over-coupling at the light source) would overload the receiver and cause a severely distorted output signal.

Similarly, if a transmitter/receiver pair designed for use with multimode fiber were used with single mode fiber, not enough light would reach the receiver, resulting in either an excessively noisy output signal or no signal at all. The only time any sort of receiver "mismatching" might be considered is when there is so much excessive loss in the fiber that the extra 5 to 15 dB of light coupled into a multimode fiber by a single mode light source is the only chance to achieve proper operation. However, this is an extreme case and is not normally recommended.

As in the case of transmitters, optical receivers are available in both analog and digital versions. Both types usually employ an analog preamplifier stage, followed by either an analog or digital output stage (depending on the type of receiver). Figure 10 (next page) is a functional diagram of a simple analog optical receiver. The first stage is an operational amplifier connected as a current-to-voltage converter.

This stage takes the tiny current from the photodiode and converts it into a voltage, usually in the millivolt range. The next stage is a simple operational voltage amplifier. Here the signal is raised to the desired output level.

Figure 11 is a functional diagram of a simple digital optical receiver. As in the case of the analog receiver, the first stage is a current-to-voltage converter.

The output of this stage, however, is fed to a voltage comparator, which produces a clean, fast rise-time digital output signal. The trigger level adjustment, when present, is used to "touch up" the point on the analog signal where the comparator switches. This allows the symmetry of the recovered digital signal to be trimmed as accurately as desired.

Figure 10 - Basic Analog Fiber Optic Receiver

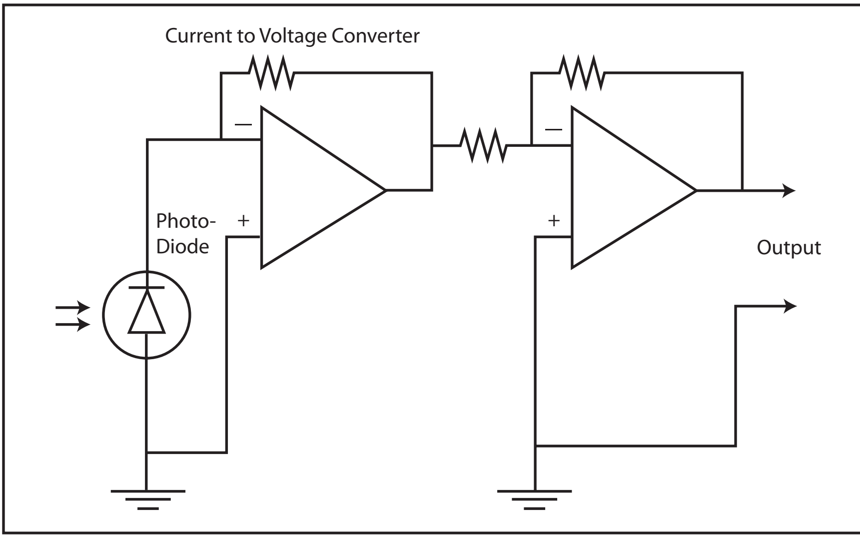
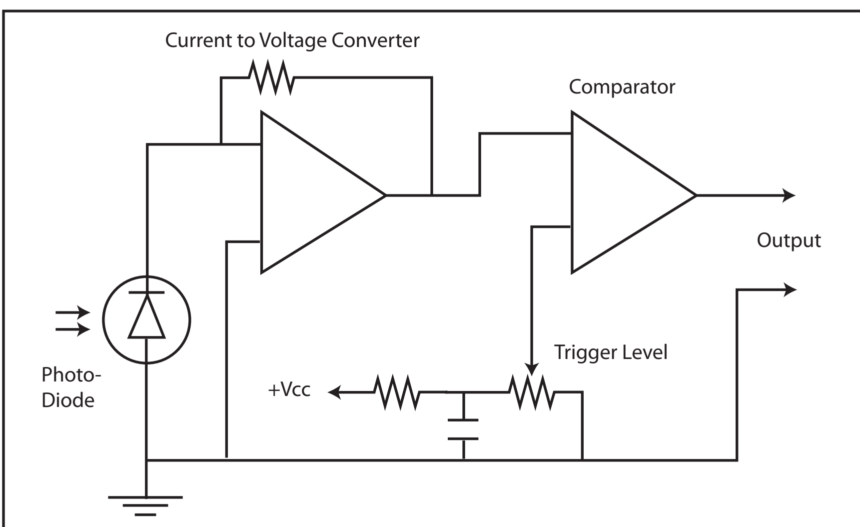


Figure 11 - Basic Digital Fiber Optic Receiver



Additional stages are often added to both analog and digital receivers to provide drivers for coaxial cables, protocol converters or a host of other functions in efforts to reproduce the original signal as accurately as possible. It is important to note that while fiber optic cable is immune to all forms of interference, the electronic receiver is not. Because of this, normal precautions, such as shielding and grounding, should be taken when using fiber optic electronic components.

Designing a Fiber Optic System

When designing a fiber optic system, there are many factors that must be considered – all of which contribute to the final goal of ensuring that enough light reaches the receiver. Without the right amount of light, the entire system will not operate properly. Figure 12 identifies many of these factors and considerations.

The following step-by-step procedure should be followed when designing any system.

1. Determine the correct optical transmitter and receiver combination based upon the signal to be transmitted (Analog, Digital, Audio, Video, RS-232, RS-422, RS-485, etc.).

2. Determine the operating power available (AC, DC, etc.).

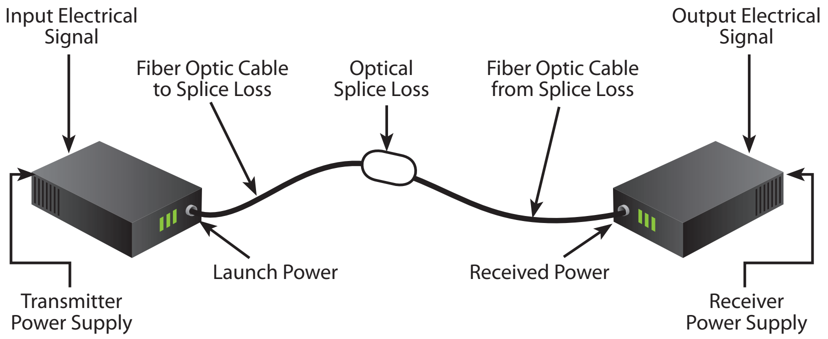
3. Determine the special modifications (if any) necessary (such as impedances, bandwidths, special connectors, special fiber size, etc.).

4. Calculate the total optical loss (in dB) in the system by adding the cable loss, splice loss, and connector loss. These parameters should be available from the manufacturer of the electronics and fiber.

5. Compare the loss figure obtained with the allowable optical loss budget of the receiver. Be certain to add a safety margin factor of at least 3 dB to the entire system.

6. Check that the fiber bandwidth is adequate to pass the signal desired.

Figure 12: Important Parameters to Consider when Specifying a Fiber Optic System



If the above calculations show that the fiber bandwidth you plan to use is inadequate for transmitting the required signal the necessary distance, it will be necessary either to select a different transmitter/receiver (wavelength) combination, or consider the use of a lower loss premium fiber.

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Everything you need to evaluate and decide on the perfect Scan Converter.

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A comprehensive overview of the technology, how it works and when to use this technology effectively.

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Easy explanations of Inverse 3:2 Pulldown, Anamorphic Scaling and Other Confusing Concepts.

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About Communications Specialties, Inc.

Communications Specialties, Inc. (CSI) is an award-winning, Long Island based company that manufactures and sells a variety of products for the distribution, conversion or transmission of television and computer video signals, including fiber optic transmission systems, scan converters and video scalers.

The company was founded in 1983 by veterans of the broadcast industry. Since then, CSI has managed to consistently design innovative products that are used worldwide by Fortune 500 Companies and Government Agencies in a variety of markets such as Broadcast, Professional A/V, Videoconferencing, Education, Home Theater, Security, ITS, Industrial Monitoring, Digital Signage, Government/Military and more!

The **Pure Digital Fiberlink®** line offers an extensive and affordable family of fiber optic transmission systems for the Professional A/V marketplace and includes several ground-breaking products for the transmission of high-resolution RGB signals. Systems for point-to-point and point-to-multipoint signal distribution make these products highly desirable for any Pro A/V applications.

Our premier product line, the **Scan Do®** family of computer to video scan converters, has redefined industry standards in computer video to NTSC/PAL technology with unsurpassed performance in its price range. All models support high resolutions and refresh rates and are VGA and Mac® compatible. The feature-rich and versatile Scan Do family offers the widest range of scan converters on the market.

The award-winning, **Deuce®** video scalers convert NTSC and PAL to high-resolution, non-interlaced video and offer a far superior and affordable alternative to line doubling and quadrupling. The new generation of Deuce products offer a wide range of non-interlaced resolutions and refresh rates for every application, from professional A/V installations to home theater, including a model designed especially for use with HDTV displays.

In addition, CSI manufactures a comprehensive selection of distribution amplifiers, VGA monitor, keyboard and mouse extenders and accessories for our entire product line.

Communications Specialties and its products have been the recipient of numerous industry awards. In 2005, the Pure Digital Fiberlink® 7220 Series for high-resolution RGB and Stereo Audio was honored as one of the AV industry's best technological innovations of the year by receiving a "rAVe Radical Product of the Year" award as "Best New Analog Signal Processing Product". The rAVe email newsletter is published by professional audiovisual industry veterans and is read industry-wide.

Among CSI's many other awards are AV Video Magazine's Platinum Award (given to Scan Do® Ultra and Deuce®) and the Video Systems' Vanguard Award (given to Deuce).

The company is headquartered in the United States on Long Island, New York, with Sales Offices in Florida, Indiana and Virginia. Research, development, design, engineering, manufacturing and customer support operations are performed at the New York headquarters. Other locations include Communications Specialties Pte Ltd (CSPL) - a wholly owned subsidiary office in Singapore that provides support to distributors in the Far East and Pacific Rim.

Our in-house sales department handles complete product-line sales directly to end-users as well as to an international network of representatives and resellers. All of our products are backed by an exceptional warranty.

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