CHAPTER 6

OPTICAL SOURCES AND FIBER OPTIC TRANSMITTERS

LEARNING OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

1. Explain the principal properties of an optical source and fiber optic transmitter.
2. Discuss the optical emission properties of semiconductor light-emitting diodes (LEDs) and laser diodes (LDs).
3. Describe the operational differences between surface-emitting LEDs (SLEDs), edge-emitting LEDs (ELEDs), superluminescent diodes (SLDs), and laser diodes.
4. Describe typical fiber optic transmitter packages.

INTRODUCTION TO OPTICAL SOURCES AND FIBER OPTIC TRANSMITTERS

Chapter 1 taught you that a fiber optic data link has three basic functions. One function is that a fiber optic data link must convert an electrical signal to an optical signal permitting the transfer of data along an optical fiber. The fiber optic device responsible for that signal conversion is a fiber optic transmitter.

A fiber optic transmitter is a hybrid device. It converts electrical signals into optical signals and launches the optical signals into an optical fiber. A fiber optic transmitter consists of an interface circuit, a source drive circuit, and an optical source. The interface circuit accepts the incoming electrical signal and processes it to make it compatible with the source drive circuit. The source drive circuit intensity modulates the optical source by varying the current through the source.

An optical source converts electrical energy (current) into optical energy (light). Light emitted by an optical source is launched, or coupled, into an optical fiber for transmission. Fiber optic data link performance depends on the amount of optical power (light) launched into the optical fiber. This chapter attempts to provide an understanding of light-generating mechanisms within the main types of optical sources used in fiber optics.

OPTICAL SOURCE PROPERTIES

The development of efficient semiconductor optical sources, along with low-loss optical fibers, led to substantial improvements in fiber optic communications. Semiconductor optical sources have the physical characteristics and performance properties necessary for successful implementations of fiber optic systems. It is desirable that optical sources:

- Be compatible in size to low-loss optical fibers by having a small light-emitting area capable of launching light into fiber
- Launch sufficient optical power into the optical fiber to overcome fiber attenuation and connection losses allowing for signal detection at the receiver
- Emit light at wavelengths that minimize optical fiber loss and dispersion. Optical sources should have a narrow spectral width to minimize dispersion
- Allow for direct modulation of optical output power
- Maintain stable operation in changing environmental conditions (such as temperature)
- Cost less and be more reliable than electrical devices, permitting fiber optic communication systems to compete with conventional systems

Semiconductor optical sources suitable for fiber optic systems range from inexpensive light-emitting diodes (LEDs) to more expensive semiconductor lasers. Semiconductor LEDs and laser diodes (LDs) are the principal light sources used in fiber optics.

OPERATING WAVELENGTH

Fiber optic communication systems operate in the 850-nm, the 1300-nm, and the 1550-nm wavelength windows. Semiconductor sources are designed to operate at wavelengths that minimize optical fiber absorption and maximize system bandwidth. By designing an optical source to operate at specific wavelengths, absorption from impurities in the optical fiber, such as hydroxyl ions (OH^-), can be minimized. Maximizing system bandwidth involves designing optical fibers and sources that minimize chromatic and intermodal dispersion at the intended operational wavelength.

Initially, the material properties of semiconductor optical sources provided for optical emission in the 850-nm wavelength region. An 850-nm operational wavelength avoids fiber absorption loss from OH^- impurities near the 900-nm wavelength. Light sources for 850-nm systems were originally semiconductor LEDs and lasers. Currently, most 850-nm systems use LEDs as a light source. LEDs operating at 850-nm provide sufficient optical power for short-distance, low-bandwidth systems. However, multimode fiber dispersion, the relatively high fiber attenuation, and the LED's relatively low optical output power prevent the use of these devices in longer-distance, higher bandwidth systems.

The first development allowing the operational wavelength to move from 850 nm to 1300 nm was the introduction of multimode graded-index fibers. Multimode graded-index fibers have substantially lower intermodal dispersion than multimode step-index fibers. Systems operating at 850 nm cannot take full advantage of the fiber's low intermodal dispersion because of high chromatic dispersion at 850 nm. However, the use of multimode graded-index fibers allow 850-nm LEDs to operate satisfactorily in short-distance, higher bandwidth systems.

Following the enhancements in multimode fiber design, next generation LEDs were designed to provide optical emission in the 1300-nm region. Multimode graded-index fiber systems using these LEDs can operate over longer distances and at higher bandwidths than 850-nm systems. Longer distances and higher bandwidths are possible because fiber material losses and dispersion are significantly reduced at the 1300-nm region.

Advances in single mode fiber design and construction sped the development of semiconductor LEDs and LDs optimized for single mode fibers. Single mode fibers have very low dispersion values. However, existing LEDs were unable to focus and launch sufficient optical power into single mode fibers for long-haul, very high-bandwidth communication systems. New semiconductor LEDs and LDs capable of operating with single mode fibers at 1300 nm were developed to take advantage of single mode fiber's very low value of dispersion. Additionally, LEDs and LDs operating at 1550 nm were developed to take advantage of the fiber's lowest loss.

SEMICONDUCTOR LIGHT-EMITTING DIODES AND LASER DIODES

Semiconductor LEDs emit incoherent light. Spontaneous emission of light in semiconductor LEDs produces light waves that lack a fixed-phase relationship. Light waves that lack a fixed-phase relationship are referred to as incoherent light. Spontaneous emission of light is discussed in more detail later in this chapter. The use of LEDs in single mode systems is severely limited because they emit unfocused incoherent light. Even LEDs developed for single mode systems are unable to launch sufficient optical power into single mode fibers for many applications. LEDs are the preferred optical source for multimode systems because they can launch sufficient power at a lower cost than semiconductor LDs.

Semiconductor LDs emit coherent light. LDs produce light waves with a fixed-phase relationship (both spatial and temporal) between points on the electromagnetic wave. Light waves having a fixed-phase relationship are referred to as coherent light. Stimulated emission of light is discussed later in this chapter. Since semiconductor LDs emit more focused light than LEDs, they are able to launch optical power into both single mode and multimode optical fibers. However, LDs are usually used only in single mode fiber systems because they require more complex driver circuitry and cost more than LEDs.

Optical power produced by optical sources can range from microwatts (μW) for LEDs to tens of milliwatts (mW) for semiconductor LDs. However, it is not possible to effectively couple all the available optical power into the optical fiber for transmission.

The amount of optical power coupled into the fiber is the relevant optical power. It depends on the following factors:

- The angles over which the light is emitted
- The size of the source's light-emitting area relative to the fiber core size
- The alignment of the source and fiber
- The coupling characteristics of the fiber (such as the NA and the refractive index profile)

Typically, semiconductor lasers emit light spread out over an angle of 10 to 15 degrees. Semiconductor LEDs emit light spread out at even larger angles. Coupling losses of several decibels can easily occur when coupling light from an optical source to a fiber, especially with LEDs.

Source-to-fiber coupling efficiency is a measure of the relevant optical power. The coupling efficiency depends on the type of fiber that is attached to the optical source. Coupling efficiency also depends on the coupling technique. Source-to-fiber coupling involves centering a flat fiber-end face over the emitting region of the light source. If the fiber end face is directly placed over the source emitting region, it is referred to as butt coupling. If the source's output light pattern is larger than the fiber's acceptance pattern, source-to-fiber coupling efficiency may be improved by placing a small lens between the source and fiber. Lensing schemes improve coupling efficiency when coupling both LEDs and LDs to optical fibers.

SEMICONDUCTOR MATERIAL AND DEVICE OPERATING PRINCIPLES

Understanding optical emission in semiconductor lasers and LEDs requires knowledge of semiconductor material and device properties. Providing a complete description of semiconductor properties is beyond the scope of this introductory manual. In this chapter we only discuss the general properties of semiconductor LEDs and LDs.

Semiconductor sources are diodes, with all of the characteristics typical of diodes. However, their construction includes a special layer, called the active layer, which emits photons (light particles) when a current passes through the layer. The particular properties of the semiconductor are determined by the materials used and the layering of the materials within the semiconductor. Silicon (Si) and gallium arsenide (GaAs) are the two most common semiconductor materials used in electronic and electro-optic devices. In some cases other elements, such as aluminum (Al), indium (In) and phosphorus (P), are added to the base semiconductor material to modify the semiconductor properties. These elements are called dopants.

Current flowing through a semiconductor optical source causes it to produce light. An in-depth description of either of the two processes by which this occurs is beyond the scope of this module. However, we discuss elementary descriptions in the following paragraphs.

LEDs generally produce light through spontaneous emission when a current is passed through them. Spontaneous emission is the random generation of photons within the active layer of the LED. The emitted photons move in random directions. Only a certain percentage of the photons exit the semiconductor and are coupled into the fiber. Many of the photons are absorbed by the LED materials and the energy dissipated as heat. This process causes the light output from an LED to be incoherent, have a broad spectral width, and have a wide output pattern.

Laser diodes are much more complex than LEDs. Laser is an acronym for light amplification by the stimulated emission of radiation. Laser diodes produce light through stimulated emission when a current is passed through them. Stimulated emission describes how light is produced in any type of laser. In the laser diode, photons, initially produced by spontaneous emission interact with the laser material to produce additional photons. This process occurs within the active area of the diode called the laser cavity. The process does not affect the original photon. The stimulated photon has many of the same properties (wavelength, direction, phase) as the original photon.

As with the LED, not all of the photons produced are emitted from the laser diode. Some of the photons are absorbed and the energy dissipated as heat. The emission process and the physical characteristics of the diode cause the light output to be coherent, have a narrow spectral width, and have a narrow output pattern.

It is important to note that in both LED and laser diodes all of the electrical energy is not converted into optical energy. A substantial portion is converted to heat. Different LED and laser diode structures convert differing amounts of electrical energy into optical energy.

LIGHT-EMITTING DIODES

A light-emitting diode (LED) is a semiconductor device that emits incoherent light, through spontaneous emission, when a current is passed through it. Typically LEDs for the 850-nm region are fabricated using GaAs and AlGaAs. LEDs for the 1300-nm and 1550-nm regions are fabricated using InGaAsP and InP.

The basic LED types used for fiber optic communication systems are the surface-emitting LED (SLED), the edge-emitting LED (ELED), and the superluminescent diode (SLD). LED performance differences help link designers decide which device is appropriate for the intended application. For short-distance (0 to 3 km), low-data-rate fiber optic systems, SLEDs and ELEDs are the preferred optical source. Typically, SLEDs operate efficiently for bit rates up to 250 megabits per second (Mb/s). Because SLEDs emit light over a wide area (wide far-field angle), they are almost exclusively used in multimode systems.

For medium-distance, medium-data-rate systems, ELEDs are preferred. ELEDs may be modulated at rates up to 400 Mb/s. ELEDs may be used for both single mode and multimode fiber systems. Both SLDs and ELEDs are used in long-distance, high-data-rate systems. SLDs are ELED-based diodes designed to operate in the superluminescence mode. A further discussion on superluminescence is provided later in this chapter. SLDs may be modulated at bit rates of over 400 Mb/s.

Surface-Emitting LEDs

The surface-emitting LED (shown in figure 6-1) is also known as the Burrus LED in honor of C. A. Burrus, its developer. In SLEDs, the size of the primary active region is limited to a small circular area of 20 μm to 50 μm in diameter. The active region is the portion of the LED where photons are emitted. The primary active region is below the surface of the semiconductor substrate perpendicular to the axis of the fiber. A well is etched into the substrate to allow direct coupling of the emitted light to the optical fiber. The etched well allows the optical fiber to come into close contact with the emitting surface. In addition, the epoxy resin that binds the optical fiber to the SLED reduces the refractive index mismatch, increasing coupling efficiency.

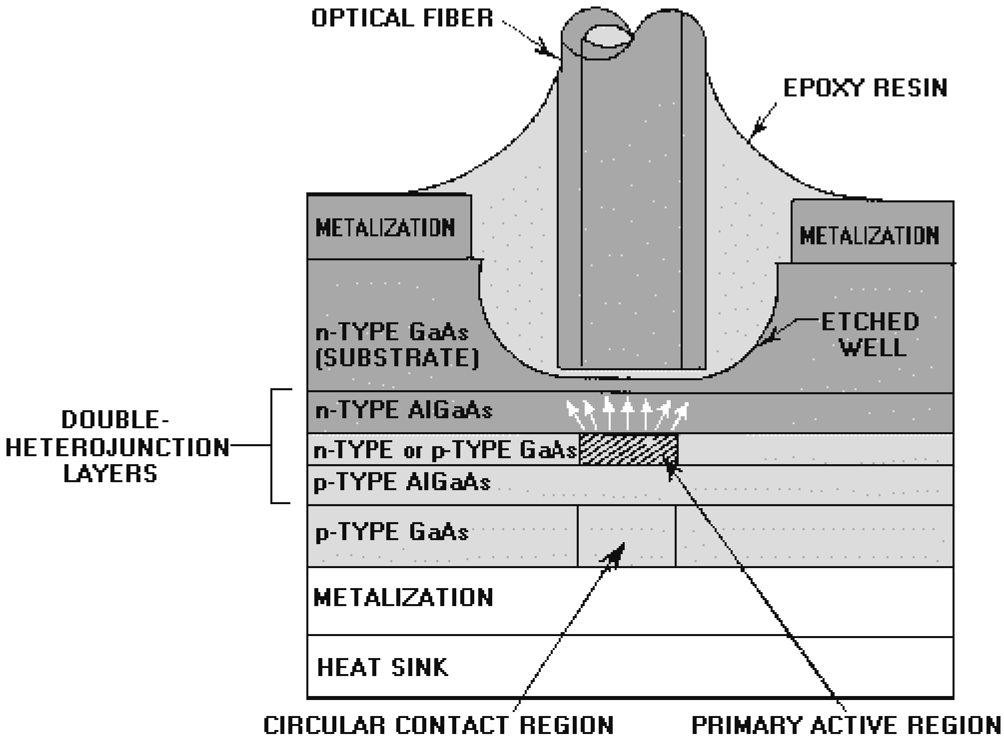

Figure 6-1.—Example of the SLED structure.

Edge-Emitting LEDs

The demand for optical sources for longer distance, higher bandwidth systems operating at longer wavelengths led to the development of edge-emitting LEDs. Figure 6-2 shows a typical ELED structure. It shows the different layers of semiconductor material used in the ELED. The primary active region of the ELED is a narrow stripe, which lies below the surface of the semiconductor substrate. The semiconductor substrate is cut or polished so that the stripe runs between the front and back of the device. The polished or cut surfaces at each end of the stripe are called facets.

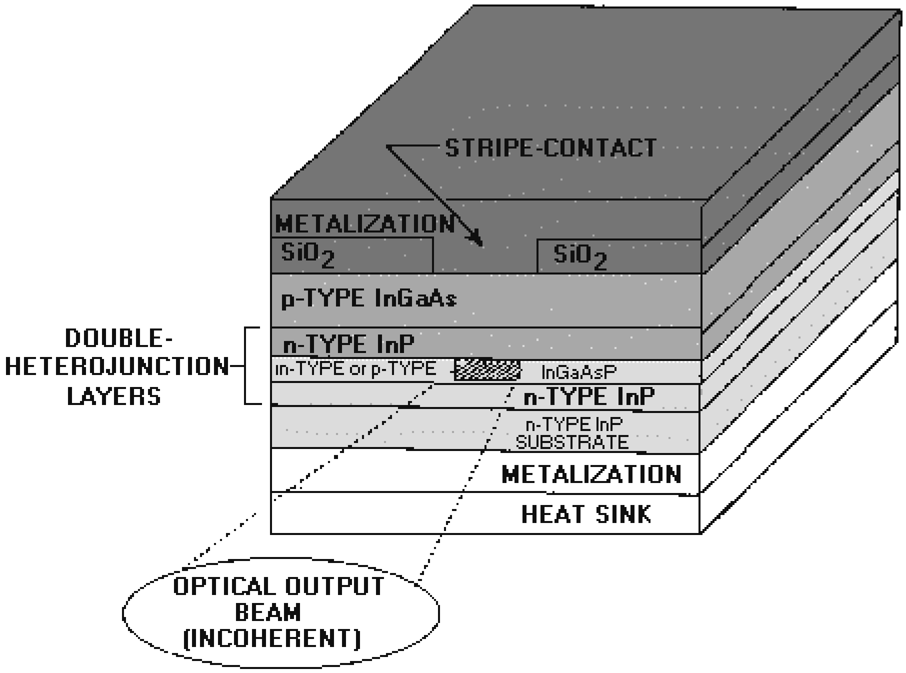

Figure 6-2.—Example of the ELED structure.

In an ELED the rear facet is highly reflective and the front facet is antireflection-coated. The rear facet reflects the light propagating toward the rear end-face back toward the front facet. By coating the front facet with antireflection material, the front facet reduces optical feedback and allows light emission. ELEDs emit light only through the front facet.

ELEDs emit light in a narrow emission angle allowing for better source-to-fiber coupling. They couple more power into small NA fibers than SLEDs. ELEDs can couple enough power into single mode fibers for some applications. ELEDs emit power over a narrower spectral range than SLEDs. However, ELEDs typically are more sensitive to temperature fluctuations than SLEDs.

LASER DIODES

A laser is a device that produces optical radiation by the process of stimulated emission. It is necessary to contain photons produced by stimulated emission within the laser active region. Figure 6-3 shows an optical cavity formed to contain the emitted photons by placing one reflecting mirror at each end of an amplifying medium. One mirror is made partially reflecting so that some radiation can escape from the cavity for coupling to an optical fiber.

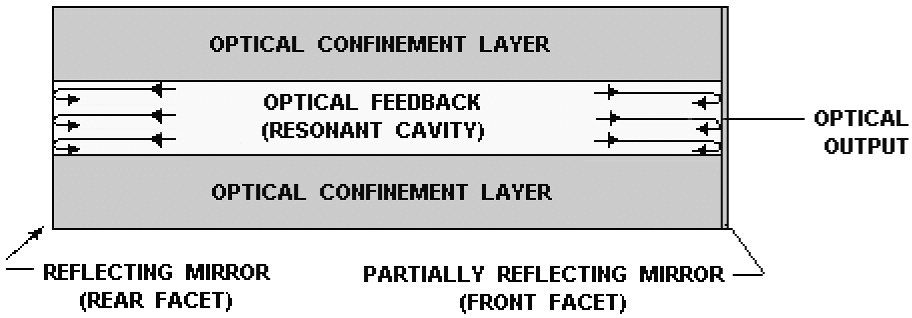

Figure 6-3.—Optical cavity for producing lasing.

Only a portion of the optical radiation is amplified. For a particular laser structure, there are only certain wavelengths that will be amplified by that laser. Amplification occurs when selected wavelengths, also called laser modes, reflect back and forth through the cavity. For lasing to occur, the optical gain of the selected modes must exceed the optical loss during one round-trip through the cavity. This process is referred to as optical feedback.

The lasing threshold is the lowest drive current level at which the output of the laser results primarily from stimulated emission rather than spontaneous emission. Figure 6-4 illustrates the transition from spontaneous emission to stimulated emission by plotting the relative optical output power and input drive current of a semiconductor laser diode. The lowest current at which stimulated emission exceeds spontaneous emission is the threshold current. Before the threshold current is reached, the optical output power increases only slightly with small increases in drive current. However, after the threshold current is reached, the optical output power increases significantly with small changes in drive currents.

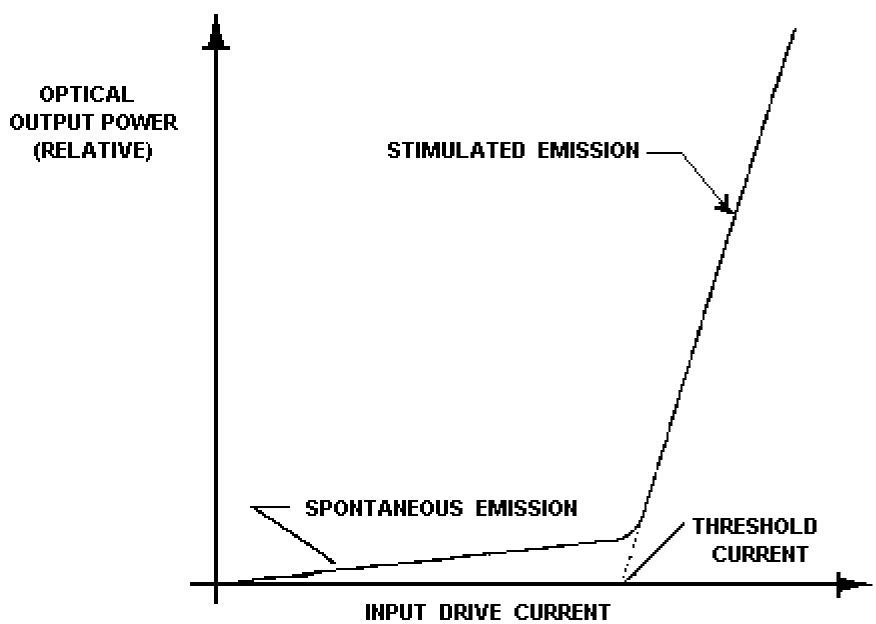

Figure 6-4.—The optical output power as a function of input drive current of a semiconductor laser diode.

Many types of materials including gas, liquid, and semiconductors can form the lasing medium. However, in this chapter we only discuss semiconductor laser diodes. Semiconductor laser diodes are the primary lasers used in fiber optics. A laser diode emits light that is highly monochromatic and very directional. This means that the LD's output has a narrow spectral width and small output beam angle.

A semiconductor LD's geometry is similar to an ELED with light-guiding regions surrounding the active region. Optical feedback is established by making the front facet partially reflective. This chapter provides no diagram detailing LD structures because they are similar to ELEDs in design. The rear facet is typically coated with a reflective layer so that all of the light striking the facet is reflected back into the active region. The front facet is typically left uncoated so that most of the light is emitted. By increasing the drive current, the diode becomes a laser.

At currents below the threshold current, LDs function as ELEDs. To optimize frequency response, laser diodes are often biased above this laser threshold. As a result, in an LD fiber optic system, light is modulated between a high power level and a lower power level, but never shut off. LDs typically can be modulated at frequencies up to over 2 gigahertz (GHz). Some lasers are capable of being modulated at frequencies over 20 GHz.

There are several important differences between LDs and LEDs. One is that LEDs usually lack reflective facets and in some cases are designed to suppress reflections back into the active region. Another is that lasers tend to operate at higher drive currents to produce light. A higher driver current results in more complicated drive circuits and more heat dissipation in the device.

LDs are also much more temperature sensitive than either SLEDs or ELEDs. Increases in the laser temperature significantly reduce laser output power. Increases in laser temperature beyond certain limits result in the loss of lasing. When lasers are used in many applications, the temperature of the laser must be controlled. Typically, electronic coolers, called thermo-electric (TE) coolers, are used to cool LDs in system applications.

SUPERLUMINESCENT DIODES

Superluminescence occurs when the spontaneous emissions of an ELED experience gain due to higher injected currents and reflections from facets. Superluminescent diodes (SLDs) are differentiated from both conventional LEDs and LDs. Although the output is not fully coherent, SLDs emit light that consists of amplified spontaneous emissions. The spectral width and beam angle of SLDs are narrower than that of conventional LEDs and wider than that of LDs.

An SLD is, in essence, a combination of a laser and an ELED. SLDs are similar in geometry to lasers but have no built-in optical feedback mechanism required by laser diodes for stimulated emission to achieve lasing. SLDs have structural features similar to those of ELEDs that suppress the lasing action by reducing the reflectivity of the facets. SLDs are essentially highly optimized ELEDs.

While SLDs operate like ELEDs at low current levels, their output power increases superlinearly and the spectral width narrows at high currents. Optical gain resulting from the higher injection currents causes the superlinear power increase and narrowing of the spectral width.

The advantages of SLDs over conventional LEDs include higher coupled power, narrower spectral width, and greater bandwidths. The disadvantages include nonlinear power-current characteristics, higher temperature sensitivity, and lower reliability.

FIBER OPTIC TRANSMITTERS

As stated previously, a fiber optic transmitter is a hybrid electro-optic device. It converts electrical signals into optical signals and launches the optical signals into an optical fiber. A fiber optic transmitter consists of an interface circuit, a source drive circuit, and an optical source. The interface circuit accepts the incoming electrical signal and processes it to make it compatible with the source drive circuit. The source drive circuit intensity modulates the optical source by varying the current through it. The optical signal is coupled into an optical fiber through the transmitter output interface.

Although semiconductor LEDs and LDs have many similarities, unique transmitter designs result from differences between LED and LD sources. Transmitter designs compensate for differences in optical output power, response time, linearity, and thermal behavior between LEDs and LDs to ensure proper system operation. Nonlinearities caused by junction heating in LEDs and mode instabilities in LDs necessitate the use of linearizing circuits within the transmitter in some cases.

Fiber optic transmitters using LDs require more complex circuitry than transmitters using LEDs. The basic requirement for digital systems is for drive circuitry to switch the optical output on and off at high speeds in response to logic voltage levels at the input of the source drive circuit. Because LDs are threshold devices, LDs are supplied with a bias just below the threshold in the off state. This bias is often referred to as prebias. One reason for prebiasing the LD is to reduce the turn-on delay in digital systems.

Most LD transmitters contain output power control circuitry to compensate for temperature sensitivity. This circuitry maintains the LD output at a constant average value by adjusting the bias current of the laser. In most cases LED transmitters do not contain output power control circuitry. LD and LED transmitters may also contain cooling devices to maintain the source at a relatively constant temperature. Most LD transmitters either have an internal thermo electric cooler or require a relatively controlled external temperature. Because LDs require more complex circuitry than LEDs, fiber optic transmitters using LDs are more expensive. For more information concerning fiber optic transmitters and their drive circuitry, refer to the reference material listed in appendix 2.

Transmitter output interfaces generally fall into two categories: optical connectors and optical fiber pigtails. Optical pigtails are attached to the transmitter optical source. This pigtail is generally routed out of the transmitter package as a coated fiber in a loose buffer tube or a single fiber cable. The pigtail is either soldered or epoxied to the transmitter package to provide fiber strain relief. The buffer tube or single fiber cable is also attached to the transmitter package to provide additional strain relief.

The transmitter output interface may consist of a fiber optical connector. The optical source may couple to the output optical connector through an intermediate optical fiber. One end of the optical fiber is attached to the source. The other end terminates in the transmitter optical output connector. The optical source may also couple to the output optical connector without an intermediate optical fiber. The optical source is placed within the transmitter package to launch power directly into the fiber of the mating optical connector. In some cases lenses are used to more efficiently couple light from the source into the mating optical connector.

FIBER OPTIC TRANSMITTER PACKAGES

Fiber optic transmitters come in various sizes and shapes. The least complex fiber optic transmitters are typically packaged in transistor outline (TO) cans or hybrid microcircuit modules in dual inline packages (DIPs). These simple transmitters may require separate circuitry in the system equipment to provide an acceptable input signal to the transmitter. More complex fiber optic transmitters are available that have some or all of the signal conditioning circuitry integrated into the package. These transmitters typically are packaged in hybrid microcircuit modules in either DIP or butterfly lead packages, circuit cards, or complete stand-alone fiber optic converters. Stand-alone fiber optic converters and circuit cards generally contain sources in either TO cans or one of the hybrid microcircuit packages. For commercial applications, the most popular transmitter packages are the TO can and the DIP hybrid microcircuit.

FIBER OPTIC TRANSMITTER APPLICATIONS

Fiber optic transmitters can be classified into two categories: digital and analog. Digital transmitters produce two discrete optical power levels. These levels are essentially on and off with the exception that some light is emitted in the off state by some transmitters. Analog transmitters continuously vary the output optical power level as a function of the input electrical signal.

Digital Applications

Different types of fiber optic transmitters are used for different digital applications. For each specific application, the link data rate, transmission length, and operating environment influence the source type, center wavelength, spectral width, and package type chosen.

For low-data-rate applications, fiber optic transmitters generally use LEDs operating in either the 850-nm or 1300-nm window as their source. For the lowest data rates (0 to 20 megabits per second (Mbps)), sources tend to operate in the 850-nm window. For moderate data rates (50 to 200 Mbps), sources tend to operate in the 1300-nm window. Laser sources are almost never used in low-data-rate applications. Laser sources are only used when extremely high transmitter output powers are required in the application. The packages found in low-data-rate applications include all of the package types discussed earlier.

For high-data-rate applications, most fiber optic transmitters use laser diodes as sources. The sources typically operate in either the 1300-nm or 1550-nm windows. Most high-data-rate applications use LDs as the optical source and operate in the 1300-nm region. Almost all 1550-nm systems use an LD as the optical source. 1550-nm transmitters are usually only used in the extremely long distance high-data-rate applications (undersea links, etc.). High-data-rate transmitters are generally hybrid microcircuit modules or complete circuit cards. Almost all high-data-rate transmitters contain power control circuitry. Depending upon the application, high-data-rate transmitters may contain TE coolers.

Analog Applications

Different types of fiber optic transmitters are also used for different analog applications. For each specific application, analog signal type, transmission length, and operating environment influence the source type, center wavelength, spectral width, and package type chosen.

For low-frequency applications, analog fiber optic transmitters generally use LEDs operating in either the 850-nm or 1300-nm window. Typical low frequency applications are analog audio and single channel video systems. For these systems, sources tend to operate in the 850-nm window. For moderate frequency applications, sources tend to operate in the 1300-nm window. These types of systems include multi-channel analog audio and video systems as well as frequency modulated (FM) systems. Laser sources are almost never used in low- or moderate-frequency analog applications. The main reason for this is the added circuit complexity that laser sources require. Laser sources are only used if extremely high transmitter output powers are required in the application. Most low-frequency analog transmitters are hybrid microcircuit modules, circuit cards, or stand-alone boxes.

For high-frequency applications, analog fiber optic transmitters use laser diodes as sources. Typical high frequency applications are cable television trunk line and raw radar remoting applications. The LDs typically operate in either the 1300-nm or 1550-nm windows. 1550-nm transmitters are typically used in cable television trunk line applications. Other applications may use either 1300-nm or 1550-nm LDs. High frequency transmitters are predominately circuit cards, but some hybrid microcircuit modules are also used. All high frequency analog transmitters contain TE coolers as well as linearization and power control circuitry.

SUMMARY

Now that you have completed this chapter, let's review some of the new terms, concepts, and ideas that you have learned. You should have a thorough understanding of these principles before moving on to chapter 7.

A **FIBER OPTIC TRANSMITTER** is a hybrid electro-optic device. It converts electrical signals into optical signals and launches the optical signals into an optical fiber.

An **OPTICAL SOURCE** converts electrical energy (current) into optical energy (light).

The principal **LIGHT SOURCES** used in fiber optics are semiconductor light-emitting diodes (LEDs) and laser diodes (LDs).

SEMICONDUCTOR LD's emit coherent light. Light waves having a fixed-phase relationship are referred to as coherent light.

SEMICONDUCTOR LED'S emit incoherent light. Light waves that lack a fixed-phase relationship are referred to as incoherent light.

The **RELEVANT OPTICAL POWER** is the amount of optical power coupled into the fiber. It depends on the angle over which the light is emitted, the size of the source's light-emitting area relative to the fiber core size, the alignment of the source and fiber, and the coupling characteristics of the fiber (such as the NA and the refractive index profile).

SOURCE-TO-FIBER COUPLING EFFICIENCY is a measure of the relevant optical power.

SILICON (Si) and **GALLIUM ARSENIDE (GaAs)** are the two most common semiconductor materials used in electronic and electro-optic devices.

In a semiconductor device, **PHOTONS (LIGHT)** are emitted when current flows through the active area.

SPONTANEOUS EMISSION occurs when photons are emitted in a random manner. Spontaneous emission produces incoherent light.

STIMULATED EMISSION occurs when a photon interacts with the laser material to produce additional photons.

A **LIGHT-EMITTING DIODE (LED**) is a semiconductor device that emits incoherent light, through spontaneous emission, when a current is passed through it. The basic LED types used for fiber optic communication systems are the **SURFACE-EMITTING LED (SLED)**, the **EDGE-EMITTING LED (ELED)**, and **the SUPERLUMINESCENT DIODE (SLD)**.

In **SURFACE-EMITTING LED'S (SLEDs)**, the size of the primary active region is limited to a small circular area of 20 m to 50 m in diameter. The active region is the portion of the LED where photons are emitted. SLEDs usually emit more total power into the air gap at the fiber interface than an ELED, but they do not launch as much power into the fiber. SLEDS also tend to emit power over a wider spectral range than ELED.

EDGE-EMITTING LED'S (ELEDs) emit light in a narrow emission angle allowing for better source-to-fiber coupling. They couple more power into small NA fibers than SLEDs. The polished or cut surfaces at each end of the ELED active stripe are called FACETS.

SUPERLUMINESCENCE occurs when the spontaneous emissions of an ELED experience gain due to higher injected currents and reflections from facets.

SUPERLUMINESCENT DIODES (SLDs) are similar in geometry to lasers but have no built-in optical feedback mechanism required by laser diodes for stimulated emission to achieve lasing. Although the output is not fully coherent, superluminescent diodes (SLDs) emit light that consists of amplified spontaneous emissions. The spectral width and beam angle of SLDs are narrower than that of conventional LEDs and wider than that of LDs.

The **ADVANTAGES** of **SLDs** over conventional LEDs include higher coupled power, narrower spectral width, and greater bandwidths. The **DISADVANTAGES** include nonlinear power-current characteristics, higher temperature sensitivity, and lower reliability.

A **LASER** is a device that produces optical radiation using stimulated emission rather than spontaneous emission. Laser is an acronym for light amplification by the stimulated emission of radiation.

The **LASING THRESHOLD** is the lowest drive level at which the output of the laser results primarily from stimulated emission rather than spontaneous emission.

The **THRESHOLD CURRENT** is the lowest current at which stimulated emission exceeds spontaneous emission.

A **LASER DIODE** is a semiconductor diode that emits coherent light by lasing. The LD's output has a narrow spectral width and small output beam angle.

TRANSMITTER OUTPUT INTERFACES fall into two categories: optical connectors and optical fiber pigtails.

FIBER OPTIC TRANSMITTERS using LDs require more complex circuitry than transmitters using LEDs.

Because **LDs** are threshold devices, LDs are supplied with a bias just below the threshold in the off state. This bias is often referred to as a prebias.

The least complex **FIBER OPTIC TRANSMITTERS** are typically packaged in transistor outline (TO) cans or hybrid microcircuit modules in dual inline packages (DIPs).

More complex **FIBER OPTIC TRANSMITTERS** typically are packaged in hybrid microcircuit modules in either DIP or butterfly lead packages, circuit cards, or complete stand-alone fiber optic converters.

FIBER OPTIC TRANSMITTERS can be classified into two categories: digital and analog.

DIGITAL TRANSMITTERS modulate the fiber optic source between two discrete optical power levels. These levels are essentially on and off with the exception that some light is emitted in the off state by some transmitters.

ANALOG TRANSMITTERS continuously vary the output optical power level as a function of the input electrical signal.

For **LOW-DATA-RATE APPLICATIONS** (0 to 20 Mbps), fiber optic transmitters generally use LEDs operating in either the 850-nm or 1300-nm window.

For **MODERATE-DATA-RATE APPLICATIONS** (50 to 200 Mbps), fiber optic transmitters generally use LEDs operating in the 1300-nm window.

For **HIGH-DATA-RATE APPLICATIONS**, most fiber optic transmitters use laser diodes as sources.

LASER SOURCES are almost never used in low- or moderate-frequency analog applications because LED sources require much less complex circuitry.