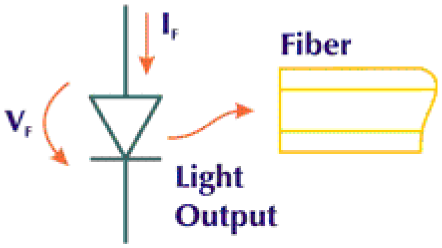
Laser Diodes

Figure 1 - Laser Diodes Convert an Electrical Signal to Light



Light emitters are a key element in any fiber optic system. This component converts the electrical signal into a corresponding light signal that can be injected into the fiber. The light emitter is an important element because it is often the most costly element in the system, and its characteristics often strongly influence the final performance limits of a given link. Laser Diodes are complex semiconductors that convert an electrical current into light. The conversion process is fairly efficient in that it generates little heat compared to incandescent lights. Five inherent properties make lasers attractive for use in fiber optics.

1. They are small.
2. They possess high radiance (i.e., They emit lots of light in a small area).
3. The emitting area is small, comparable to the dimensions of optical fibers.
4. They have a very long life, offering high reliability.
5. They can be modulated (turned off and on) at high speeds.

Table 1 offers a quick comparison of some of the characteristics for lasers and LEDs. These characteristics are discussed in greater detail throughout this article and in the article on light-emitting diodes.

Table 1 **- Comparison of LEDs and Lasers**

Characteristic	LEDs	Lasers
Output Power	Linearly proportional to drive current	Proportional to current above the threshold
Current	Drive Current: 50 to 100 mA Peak	Threshold Current: 5 to 40 mA
Coupled Power	Moderate	High
Speed	Slower	Faster
Output Pattern	Higher	Lower
Bandwidth	Moderate	High
Wavelengths Available	0.66 to 1.65 µm	0.78 to 1.65 µm

Spectral Width	Wider (40-190 nm FWHM)	Narrower (0.00001 nm to 10 nm FWHM)
Fiber Type	Multimode Only	SM, MM
Ease of Use	Easier	Harder
Lifetime	Longer	Long
Cost	Low ($5-$300)	High ($100-$10,000)

Laser diodes are typically constructed of GaAlAs (gallium aluminum arsenide) for short-wavelength devices. Long-wavelength devices generally incorporate InGaAsP (indium gallium arsenide phosphide).

Laser Diode Performance Characteristics

Several key characteristics lasers determine their usefulness in a given application. These are: **Peak Wavelength**:

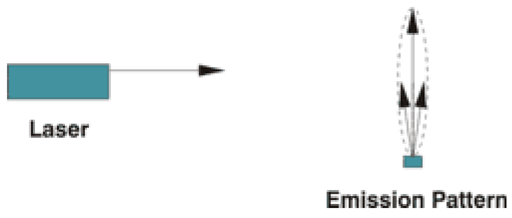
This is the wavelength at which the source emits the most power. It should be matched to the wavelengths that are transmitted with the least attenuation through optical fiber. The most common peak wavelengths are 1310, 1550, and 1625 nm. **Spectral Width**:

Ideally, all the light emitted from a laser would be at the peak wavelength, but in practice the light is emitted in a range of wavelengths centered at the peak wavelength. This range is called the spectral width of the source. **Emission Pattern**:

The pattern of emitted light affects the amount of light that can be coupled into the optical fiber. The size of the emitting region should be similar to the diameter of the fiber core. Figure 2 illustrates the emission pattern of a laser. **Power**:

The best results are usually achieved by coupling as much of a source's power into the fiber as possible. The key requirement is that the output power of the source be strong enough to provide sufficient power to the detector at the receiving end, considering fiber attenuation, coupling losses and other system constraints. In general, lasers are more powerful than LEDs.

Figure 2 - Laser Emission Pattern



Speed: A source should turn on and off fast enough to meet thebandwidth limits of the system. The speed is given according to a source's rise or fall time, the time required to go from 10% to 90% of peak power. Lasers have faster rise and fall times than LEDs. Linearity is another important characteristic to light sources for some applications. Linearity represents the degree to which the optical output is directly proportional to the electrical current input. Most light sources give little or no attention to linearity, making them usable only for digital applications. Analogapplications require close attention to linearity. Nonlinearity in lasers causes harmonic distortion in the analog signal that is transmitted over an analog fiber optic link. Lasers are temperature sensitive; the lasing threshold will change with the temperature. Figure 3 shows the typical behavior of a laser diode. As operating temperature changes, several effects can occur. First, the threshold current changes. The threshold current is always lower at lower temperatures and vice versa. The second change that can be important is the slope efficiency.

The slope efficiency is the number of milliwatts or microwatts of light output per milliampere of increased drive current above threshold. Most lasers show a drop in slope efficiency as temperature increases. Thus, lasers require a method of stabilizing the threshold to achieve maximum performance. Often, a photodiode is used to monitor the light output on the rear facet of the laser. The current from the photodiode changes with variations in light output and provides feedback to adjust the laser drive current.

Figure 3 - Temperature Effects on Laser Optical Output Power

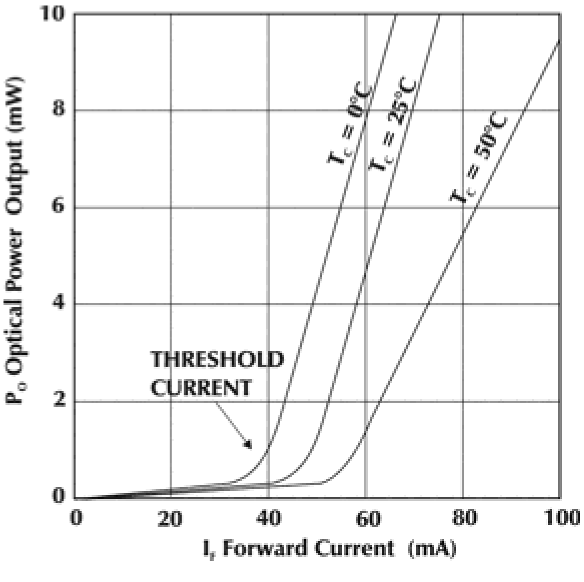


Figure 4 - Emitters Characteristics
a) LED   b) Laser

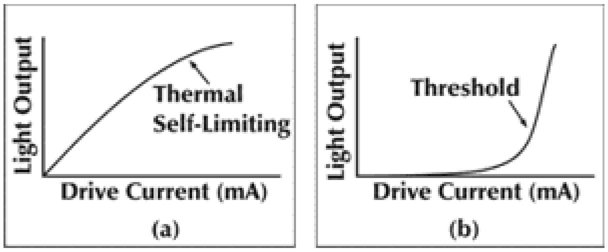
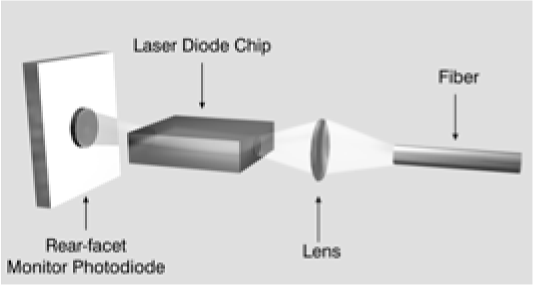


Figure 4a shows the behavior of an LED, and Figure 4b shows the behavior of a laser diode. The plots show the relative amount of light output versus electrical drive current. The LED outputs light that is approximately linear with the drive current. Nearly all LED's exhibit a "droop" in the curve as shown in Figure 4b. This nonlinearity in the LED limits its usefulness in analog applications. The droop can be caused by a number of factors in the LED semiconductor physics but is often largely due to self-heating of the LED chip. All LED's drop in efficiency as their operating temperature increases. Thus, as the LED is driven to higher currents, the LED chip gets hotter causing a drop in conversion efficiency and the droop apparent in Figure 4a. LED's are typically operated at currents to about 100 mA peak. Only specialized devices operate at higher current levels.

Laser Types

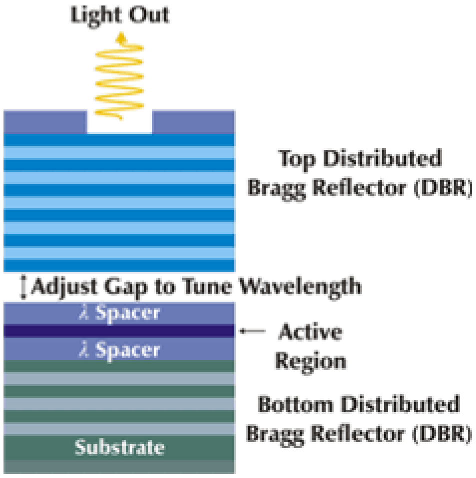
There are two basic types of laser diode structures: Fabry-Perot (FP) and distributed feedback (DFB). Of the two types of lasers, Fabry-Perot lasers are the most economical, but they are generally noisy, slower devices. DFB lasers are quieter devices (e.g., high signal-to-noise), have narrower spectral widths, and are usually faster devices. DFB lasers offer the highest performance levels and also the highest cost of the two types. They are nearly monochromatic (i.e. they emit a very pure single color of light.) while FP lasers emit light at a number of discrete wavelengths. DFB lasers tend to be used for the highest speed digital applications and for most analog applications because of their faster speed, lower noise, and superior linearity. Fabry-Perot lasers further break down into buried hetero (BH) and multi-quantum well (MQW) types. BH and related styles ruled for many years, but now MQW types are becoming very widespread. MQW lasers offer significant advantages over all former types of Fabry-Perot lasers. They offer lower threshold current, higher slope efficiency, lower noise, better linearity, and much greater stability over temperature. As a bonus, the performance margins of MQW lasers are so great, laser manufacturers get better yields, so laser cost is reduced. One disadvantage of MQW lasers is their tendency to be more susceptible to backreflections. See article "Laser Backreflection - The Bane of Good Performance" for more information.

Figure 5 - Laser Construction



VCSELs are a new laser structure that emits laser light vertically from its surface and has vertical laser cavity. Figure 6 illustrates the structure of a VCSEL.

Figure 6 - Basic VCSEL Structure



The VCSEL's principles of operation closely resembles those of conventional edge-emitting semiconductor lasers. The heart of the VCSEL is an electrically pumped gain region, also called the active region, emits light. Layers of varying semiconductor materials above and below the gain region create mirrors. Each mirror reflects a narrow range of wavelengths back into the cavity causing light emission at a single wavelength. VCSELs are typically multi-quantum well (MQW) devices with lasing occurring in layers only 20-30 atoms thick. Bragg-reflectors with as many as 120 mirror layers form the laser reflectors. There are many advantages to VCSELs. Their small size and high efficiency mirrors produce a low threshold current, below 1 mA. The transfer function allows stability over a wide temperature range, a feature that is unique to this type of laser diode. These features make the VCSEL ideal for applications that require an array of devices.

Backreflection

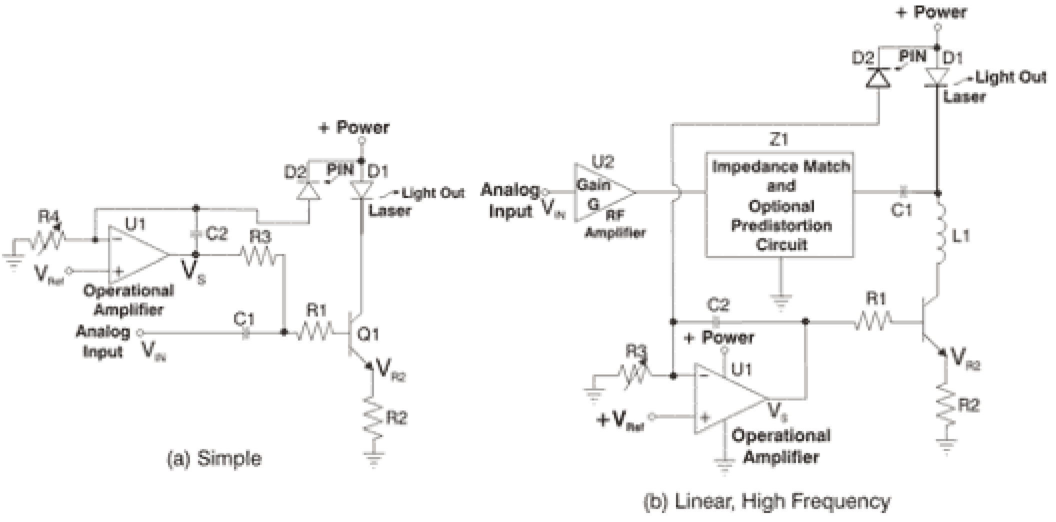
Actually, all lasers are susceptible to backreflections. Backreflections disturb the standing-wave oscillation in the laser cavity, and the net effect is an increase in the effective noise floor of the laser. A strong backreflection can cause some lasers to become wildly unstable and completely unusable in some applications. It can also generate nonlinearities, called kinks, in the laser response. Most analog applications and some digital ones cannot tolerate these degradations. The importance of controlling backreflection depends on the type of information being sent and the particular laser. Some lasers are very susceptible to backreflections due to the design of the laser chip itself. Most often the determining factor is how tightly the fiber is coupled to the laser chip. A low-power laser generally has weak coupling to the fiber. Perhaps only 5-10% of the laser power is coupled into the fiber. This means that only 5-10% of the backreflection would be coupled into the laser cavity, making the laser relatively immune to backreflections. On the other hand, a high-power laser may have 50-70% of the laser chip output coupled to the fiber. This also means that 50-70% of the backreflection will be coupled back into the laser cavity. This makes high-power lasers more susceptible to backreflections.

Laser Driver Circuits

Analog Laser Drive Circuits

Figure 7 illustrates two common circuit configurations used to drive lasers for analog applications. The simpler of the two, shown in figure 7a, offers moderate linearity and good performance in frequencies up to 500 MHz. The analog signal path only involves C1, R1, Q1, R2, and D1, the laser diode. Q1 acts as a transconductant stage in which voltage flows in and current flows out. C1 passes only the AC portion of the analog input signal. R1, usually only a few tens of Ohms, squelches any possible oscillations in Q1. The AC portion of analog input voltage VIN appears at the base of Q1 and also at the emitter of Q1. VIN, the AC voltage at the emitter of Q1, imposes across R2 to create a modulation current VIN/R2. U1 supplies DC current to the laser through R3 and R1. U1 creates a servo loop that maintains a constant photodiode current through the rear facet monitor PIN diode.

Figure 7 - Analog Laser Drive Circuits



(a) Simple

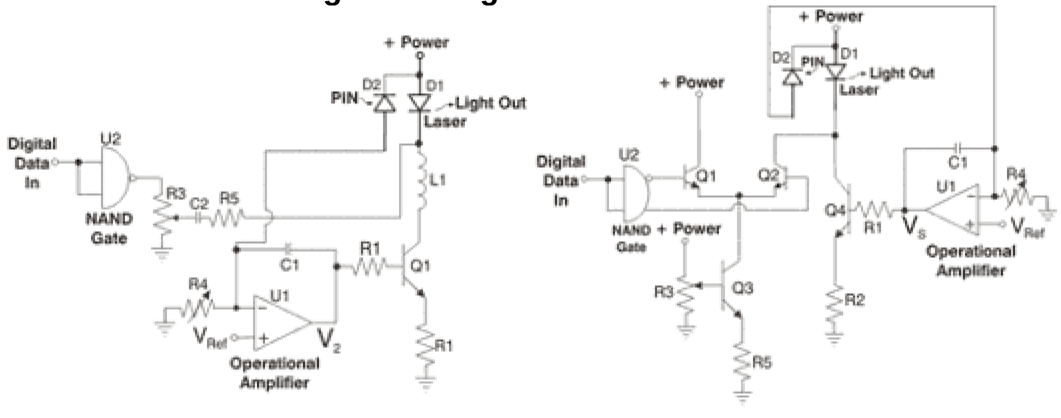
(b) Linear, High Frequency

The circuit illustrated in Figure 7a indirectly maintains constant laser optical output. The rear facet monitor PIN diode receives light from one end of the laser chip while the other end of the chip illuminates the optical fiber. While the light in the fiber correlates to light in the monitor PIN diode, it never matches exactly at all output and environmental conditions, an phenomenon called tracking error. Figure 7b shows a more advanced analog laser circuit, offering good to excellent linearity at very high frequencies (GHz). The signal path of this circuit only involves U2, Z1, C1, and the laser diode, D1. Amplifier U2 provides input matching, gain and isolates the laser from outside conditions. The block labeled Z1 can take on many functions. At a minimum, it interfaces the output of the amplifier U2, usually 50 or 75Ohms, to the laser that has an impedance ranging from 5 Ohms to 25 Ohms. As shown, sometimes the laser package incorporates this impedance matching.

Digital Laser Drive Circuits

Figure 8 illustrates two common discrete component circuit configurations that function to drive lasers for digital applications. However, a wide variety of highly integrated ICs exist because of the high demand for digital laser drivers. The discrete component circuit configurations illustrate the most commonly used principles in commercially available laser driver ICs.

Figure 8 - Digital Laser Circuits



(a) Simple

(b) High-Speed

Figure 8a illustrates a simple circuit that is utilized at frequencies to several hundred megahertz. "Digital data in" takes a relatively simple path. The NAND gate, U2, buffers the signal and provides fast and consistent edges. Potentiometer, R3, adjusts the amplitude of the laser's oncoming digital signal, usually referred to as a modulation depth adjustment. Capacitor, C2, block any DC component, allowing the AC component of the "digital data in" to pass. Incidentally, nearly all digital laser drive circuits cannot handle a DC component in the "digital data in" signal, meaning that the "digital data in" signal must always have transitions present. Resistor, R5, provides impedance matching into the laser, and feeds directly into the cathode of the laser, D1. Inductor, L1, allows the AC component of the "digital data in" signal to reach the laser, as well as a DC signal. The rear facet monitor photodiode, D2, outputs a current proportional to the laser output. The current out of D2 goes to a servo loop, ensuring that the average optical output of D1 remains constant. U1 forms the heart of the servo loop. Capacitor, C1, configures U1 as an integrator. The +input of U1 remains at a positive voltage, VREF. The value of VREF usually lies midway between ground and +Power. Potentiometer, R4, adjusts the average optical output power of the laser D1 by sinking a current out of the -input of U1. This negative current causes the output of U1, referred to as V2, to increase. As V2 increases, transistor Q1 turns on. This causes an increasing current to flow through both L1 and D1. As the current through D1 increases, the average optical output of D1 increases, which causes the current from D2, the rear facet monitor photodiode, to increase. This continues until the current out of D2 matches the current being sinked by potentiometer, R4. R4, usually referred to as the "power adjust" in digital laser drive circuits, sets the rear facet monitor photodiode current. The average optical output power and the rear facet monitor photodiode current are nearly equal, differing only by tracking error. Three components in the circuit, C2, L1, and C1, function to limit the low-frequency, and thus limiting low data rate operations. Normally, a digital laser driver circuit should handle frequencies as low as 1/100th of the design data rate. Therefore, a laser driver designed to handle a 622 Mb/s data rate must also handle frequencies as low as 6.22 MHz. The more complex circuit shown in Figure 8b allows very high, multi-gigabit speeds. With only the omission of L1, the servo loop portion of the circuit matches the circuit in Figure 8a. L1 is replaced in this circuit by Q4 a very fast , low capacitance transistor. To not interfere with the modulation signal, Q4's collector will appear as a current source. Potentiometer, R4, sets the rear facet monitor photodiode current or average optical output power. The "digital data in" signal first goes through the NAND gate, U2, as in the first circuit. However, this circuit incorporates a NAND gate with the differential outputs of U2 to drive a transistor-based differential amplifier consisting of Q1 and Q2. Transistor Q3 forms a constant current source. The potentiometer, R3, sets the current flowing in the collector of Q3. The current flowing out of Q3 determines the amount of modulation current that is switched to the laser in response to 1's and 0's. The modulation current from the collector of Q3 oscillates between the +power line (by Q1) and the laser, D1, (by Q2), as the outputs of U2 switch back and forth. To avoid a circuit becoming slow, the digital laser circuit must avoid saturation. Q1, Q2 and Q3 all operate in a linear mode in circuit 8b allowing them to operate at very high speeds.

Packaging Characteristics

We have touched on the electrical and optical characteristics of laser diodes. Other factors that are important are the thermal and packaging characteristics. Laser diodes are available pigtailed to fiber or mounted in active device mounts (ADMs). Lasers with fiber pigtails require special handling precautions to prevent damage to the fiber. See Handling Fragile Optical Fibers and Fiber Pigtail Assemblies for more information. Lasers are very sensitive to backreflection, limiting their usefulness in the ADM add/drop multiplexer configurations. Some recent lasers mounted in ADMs incorporated a short length of single-mode fiber that provides the interface to the fiber optic connector. This technique not only enhances the launch stability, it also improves the backreflection problem.

Source: http://www.fiber-optics.info/articles/laser_diodes