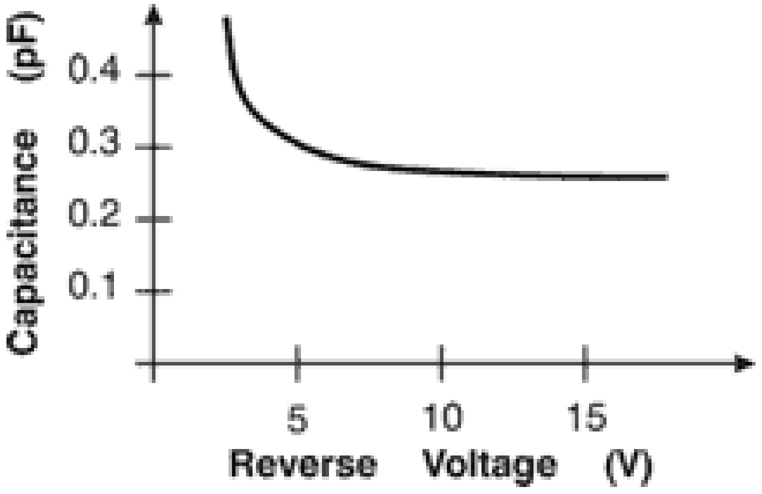
Fiber Optic Detectors

Detectors perform the opposite function of light emitters. They convert optical signals back into electrical impulses that are used by the receiving end of the fiber optic data, video, or audio link. The most common detector is the semiconductor photodiode, which produces current in response to incident light. Detectors operate based on the principle of the p-n junction. An incident photon striking the diode gives an electron in the valence band sufficient energy to move to the conduction band, creating a free electron and a hole. If the creation of these carriers occurs in a depleted region, the carriers will quickly separate and create a current. As they reach the edge of the depleted area, the electrical forces diminish and current ceases. While the p-n diodes are insufficient detectors for fiber optic systems, both PIN photodiodes and avalanche photodiode (APDs) are designed to compensate for the drawbacks of the p-n diode.

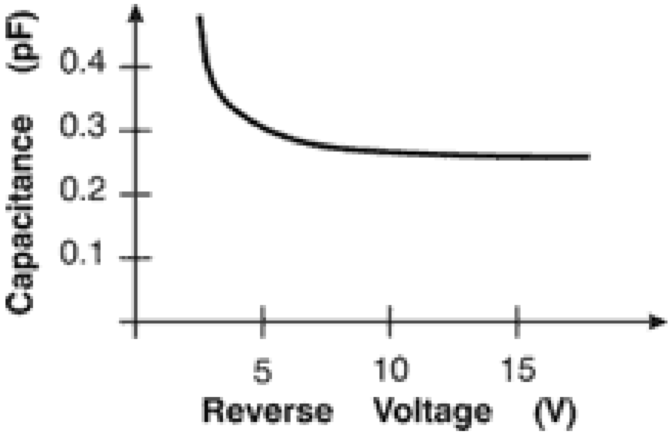
Important Detector Parameters

Figure 1— C-V Curve



- Responsivity: Ratio of current output to light input. High responsivity equals high receiver sensitivity.
- Quantum Efficiency: Ratio of primary electron-hole pairs created by incident photons to the photons incident on the detector material.
- Capacitance: Dependent upon the active area of the device and the reverse voltage across the device. This relationship is illustrated in Figure 1.
- Response Time: Time needed for the photodiode to respond to optical inputs and produce and external current.

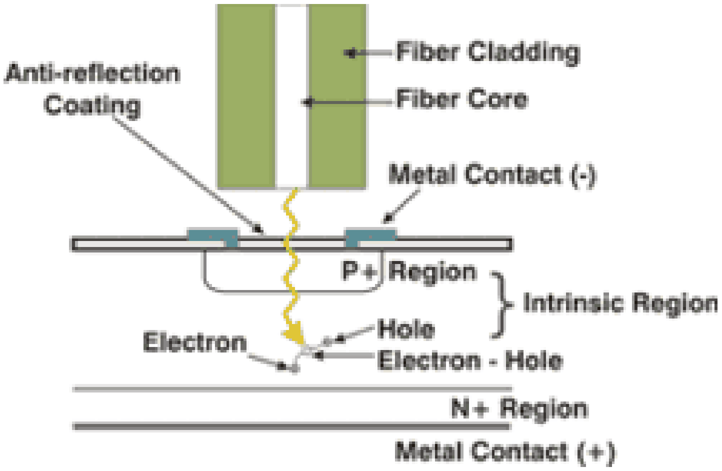
Figure 2 — Edge Effect



Response time can be affected by dark current, noise, linearity, backreflection, and edge effect (see Figure 2). Edge effect results from the fact that detectors only provide fast response in their center region. The outer region of the detector has a higher responsivity than the center region, which can cause problems when aligning the fiber to the detector. The higher responsivity may fool one into thinking they have aligned the fiber to the center region. Because response is much slower at the edge, this misalignment will reduce the response time of the detector.

PIN Photodiode

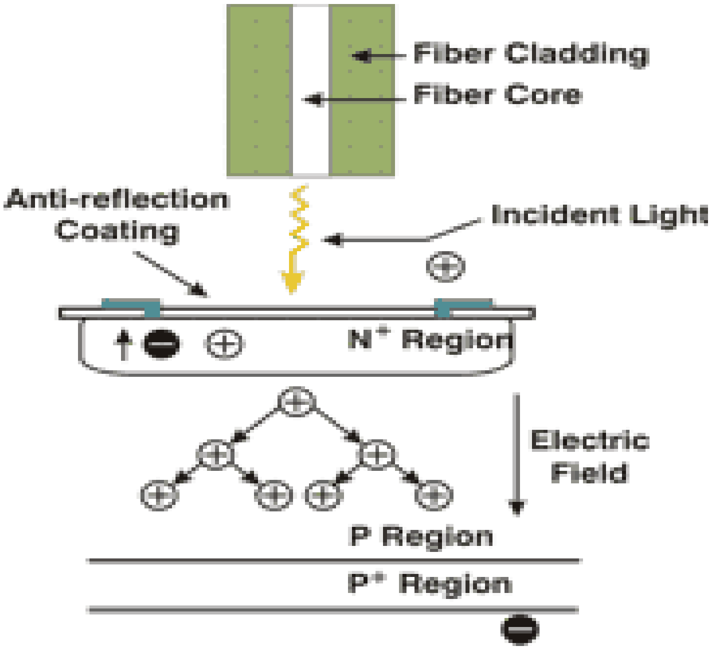
Figure 3 — PIN Photodiode



A p-n diode's deficiencies are related to the fact that the depletion area (active detection area) is small; many electron-hole pairs recombine before they can create a current in the external circuit. In the PIN photodiode, the depleted region is made as large as possible. A lightly doped intrinsic layer separates the more heavily doped p-types and n-types. The diode's name comes from the layering of these materials positive, intrinsic, negative — PIN. Figure 3 shows the cross-section and operation of a PIN photodiode.

Avalanche Photodiode (APD)

Figure 4 — APD



The avalanche photodiode (APD) operates as the primary carriers, the free electrons and holes created by absorbed photons, accelerate, gaining several electron Volts of kinetic energy. A collision of these fast carriers with neutral atoms causes the accelerated carriers to use some of their own energy to help the bound electrons break out of the valence shell. Free electron-hole pairs, called secondary carriers, appear. Collision ionization is the name for the process that creates these secondary carriers. As primary carriers create secondary carriers, the secondary carriers themselves accelerate and create new carriers. Collectively, this process is known as photomultiplication. Typical multiplication ranges in the tens and hundreds. For example, a multiplication factor of eighty means that, on average, eighty external electrons flow for every photon of light absorbed. APDs require high-voltage power supplies for their operation. The voltage can range from 30 or 70 Volts for InGaAs APDs to over 300 Volts for Si APDs. This adds circuit complexity. Also, APDs are very temperature sensitive, further complicating circuit requirements. In general, APDs are only useful for digital systems because they possess very poor linearity. Because of the added circuit complexity and the high voltages that the parts are subjected to, APDs are always less reliable than PIN detectors. This, added to the fact that at lower data rates, PIN detector-based receivers can almost match the performance of APD-based receivers, makes PIN detectors the first choice for most deployed low-speed systems. At multigigabit data rates, however, APDs rule supreme.

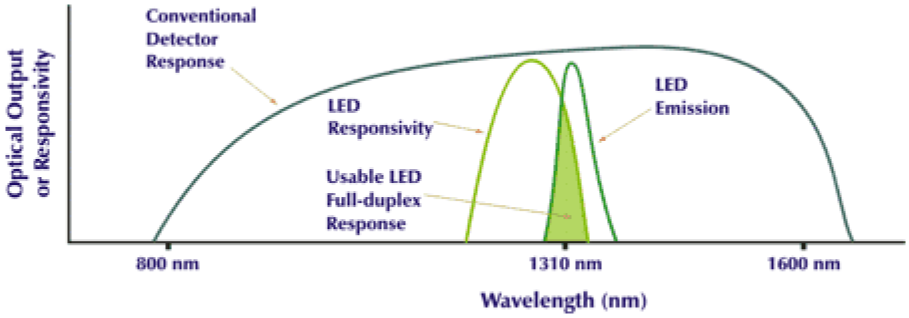
Table 1 — Comparison of PIN Photodiodes and APDs

Parameter	PIN Photodiodes	APDs
Construction Materials	Si, Ge, InGaAs	Si, Ge, InGaAs
Bandwidth	DC to 40+ GHz	DC to 40+ GHz
Wavelength	0.6 to 1.8 µm	0.6 to 1.8 µm
Conversion Efficiency	0.5 to 1.0 Amps/Watt	0.5 to 100 Amps/Watt
Support Circuitry Required	None	High Voltage, Temperature Stabilization
Cost (Fiber Ready)	\$1 to \$500	\$100to \$2,000

Light Emitters As Detectors

Light emitter such as LEDs and lasers, will also function as light detectors, allowing a unique technology to evolve, using light emitters as half-duplex fiber optic communication devices. This scheme involves using the LED or laser alternately as a light emitter, then as a light detector, which allows the transmission of information in either direction over the fiber. While all LEDs and lasers have the ability to act as detectors, a few perform this task much better than most. The key parameter to look for is very efficient coupling between the light emitter and the fiber. This allows good performance in both modes. It is also important that the LEDs have consistent spectral characteristics. While a good InGaAs detector may have a responsivity of 0.8 A/W at a wavelength of 1310 nm, an LED operating as a detector may provide a responsivity of 0.08 A/W at 1310 nm. The main reason for the much lower response is the fact that the LED operating as a detector has a relatively narrow spectral response spectrum that does not fully overlap with the LED emission spectrum. Figure 5 shows the spectral response of a typical InGaAs detector as well as the emission spectrum of an InGaAsP LED and the LEDs spectral response as a detector. It can be seen that a normal InGaAs detector has a very broad spectral response from 800 nm to beyond 1600 nm. Because the response is so wide, the detector responds to all photons emitted by the LED. The spectral emission of the LED is a relatively narrow spectrum, perhaps 60 nm wide, centered around 1310 nm. Notice that the spectral response of the same LED operating as a detector is shifted to the left. The center of the spectral response is centered at perhaps 1270 nm. The overall response as a detector is a bit wider than the emissions as an LED. However, note that the overlap between the LED emissions and the LED spectral response is rather low. This accounts for poor responsivity attributed to most LEDs operating as detectors. The problem becomes even worse when the emitting LED and the detecting LED are at different operating temperatures. This causes the individual spectral responses to drift with respect to each other. This will either increase or decrease the amount of overlap. The overwhelming concern when applying full-duplex LEDs is considering the different temperatures that the two ends will see. Laser diodes exhibit similar characteristics to the LED shown in Figure 5.

Figure 5 - Ping-Pong (Full-Duplex) LED



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