Inexpensive p-i-n photodiodes match fiber, source characteristics

by P. H. Wendland, R. M. Madden, and B. Kelly
United Detector Technology Inc., Santa Monica, Calif.

The receiver portion of any fiber-optic system requires a photodetector that responds strongly to both the peak output wavelength of the source and the low-loss spectral portion of the fiber cable used. Just as important is the match between the detector and its amplifier. On the whole, these needs in most emerging systems seem better served by p-i-n diodes than by either phototransistors or avalanche diodes.

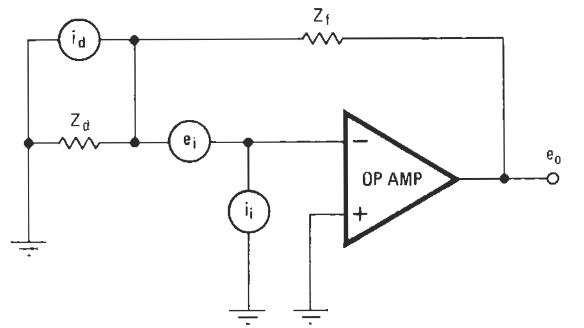
Silicon phototransistors are inexpensive—typically less than $1 each in large quantities. But their slow speed limits system bandwidth to less than a few megahertz, their poor linearity restricts their dynamic light-level range to about three decades and, worst of all, internal noise is an order of magnitude greater than in p-i-n photodetectors.

Getting gain

Avalanche photodiodes combine optical signal detection with internal amplification of photocurrent. But unfortunately, they also amplify noise—the avalanche mode creates it, and it reduces the internal signal-to-noise ratio.

However, the devices have their uses at the higher frequencies, because above 1 MHz system noise limitations are set by the preamplifier and not the detector. Also, though future devices may operate at voltages below 100 volts, today's units now need 200 to 300 V, so that a high-voltage power supply is required, and often a constant-temperature chamber as well.

All the same, avalanche photodiodes could prove useful in pulse-code-modulated systems, where the absolute level of the analog signal is not of major importance and the highly regulated power supply and a constant temperature chamber might therefore prove unnecessary. In amplitude-modulated communications systems, however, the effect of environmental and particularly temperature changes on avalanche diode gain would cause considerable problems.



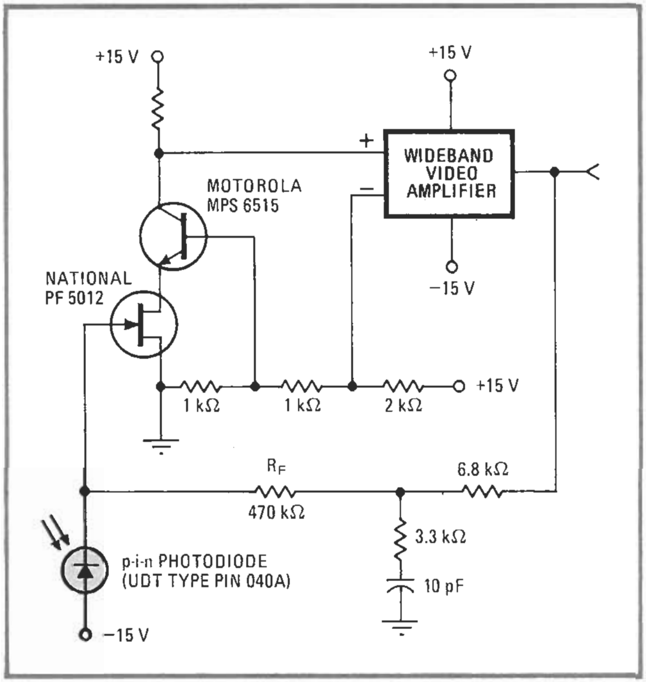
i_i = BIAS CURRENT
e_i = INPUT OFFSET VOLTAGE
i_d = PHOTODIODE CURRENT
Z_d = PHOTODIODE IMPEDANCE
Z_f = FEEDBACK IMPEDANCE

$$e_o = e_i \frac{(Z_f + Z_d)}{Z_d} + i_i Z_f + i_d Z_f$$

1. Team effort. Output current from a reverse-biased photodiode depends on its responsivity and the amount of light striking it. The output voltage of the combination is simply the product of the photodiode current and the feedback resistance.

High-performance p-i-n type silicon photodiodes have been in production for many years and cost less than $1 each. They exhibit nanosecond response times and can have a dynamic light-level range of 8 to 10 orders of magnitude at relatively low bias voltages. Their peak response between 850 and 950 nanometers matches well with the peak emissions of light-emitting diodes and the low-loss spectral regions of optical fibers.

These photodiodes are usually connected to a relatively low impedance to allow the photo-excited carriers to induce a photocurrent in the load circuit. (Photovol-



2. Typical circuit. The input field-effect transistor sets the overall noise performance of the photodetector-amplifier combination. Operating with 10-MHz optical-fiber links the circuit provides a signal-to-noise ratio of 5:1 for input power levels of 10 nW.

taic mode operation with open-circuited terminals is possible, but gives logarithmic outputs and a slow response.) Geared for systems of less than 10 MHz, 30-ns p-i-n photodiodes are commonly operated at bias voltages of about 15 V to reduce carrier drift time and lower diode capacitance without introducing an excessive dark current.

Operating a reverse biased p-i-n photodiode into a low-impedance operational amplifier (Fig. 1) provides maximum linear dynamic range and fastest response. The basic limitations of this circuit lie with the amplifier, not the detector. Present operational amplifier technology restricts the bandwidth to about 5 megahertz at input noise currents corresponding to light levels below 10 nanowatts.

A reverse-biased detector creates noise, however. There is the shot noise caused by detector dark current and signal current, the Johnson noise of the feedback resistor, and the input noise voltage of the amplifier. In wideband applications, the noise voltage of the amplifier, e_n, usually dominates. Its input noise voltage appears at the output, magnified by the ratio of the feedback resistance divided by the source impedance. At the higher frequencies, the capacitive reactance term of the source impedance predominates.

Critical components

Consequently, it's essential to minimize not only the input noise voltage of the preamplifier, but the input capacitance and noise bandwidth as well. Input capacitance has three components: amplifier input capacitance, detector capacitance and stray capacitance. The noise bandwidth is usually much larger than the signal bandwidth, and therefore it is essential that the amplifier bandwidth be made no greater than overall system constraints dictate.

Ideally, the preamplifier should raise the detector signal level to a magnitude that is easily manipulated by conventional analog or digital electronics without adding excessive noise or degrading the performance of the detector. The circuit shown in Fig. 2 typifies detector/preamplifier combinations available for use in fiber-optic systems.

The very low input impedance (10 to 50 ohms) of the transimpedance amplifier configuration is an ideal load line for the silicon p-i-n detector, assuring its linear operation and improving its frequency response. The amplifier, which acts as a current-to-voltage transducer, provides an output voltage equal to the photodiode current multiplied by the feedback resistance.