LUNA
OPTOELECTRONICS

Luna's Avalanche Photodiodes

When an APD is the Right Choice

Avalanche Photodiodes (APDs) are, in the most basic terms, photodiodes with internal gain. For the same input signal of light, the APD output current will be amplified to a level up to a few hundred times higher than a PIN photodiode's. This higher output current is used to best advantage with faster, weaker signals when one considers the detector's electronics. Note that a photodetector requires an amplifier at its output to convert the photocurrent (transimpedance conversion) or photoelectrons (charge sensitive conversion) to a voltage that successive electronics stages can process. In high speed applications where the signal is characterized by

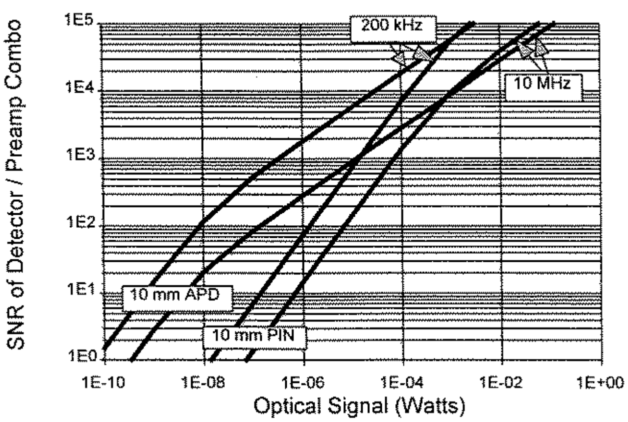


Figure 1: At low light levels and fast or frequent signal pulses, an APD is a better choice over a PIN diode for best signal-to-noise. This is true because the APD's internal gain can overcome preamplifier noise. Advanced Photonix offers the widest selection of APDs in any size.

short pulses, high repetition rates or modulation at high frequencies, one will need to choose a preamplifier with a high bandwidth. High bandwidth amplifiers are very fast, but contribute more noise. If your PIN diode is dominated by the noise of your preamplifier and you are not achieving the signal-to-noise ratio your application requires, an APD should be considered. By substituting an APD in this situation, your signal's amplitude will rise with APD gain At optimum gain, your APD/preamplifier will be roughly 10 to100 times more sensitive than a PIN/preamplifier for the same bandwidth of signals (**Figure 1**). Of course, this allows you the freedom to increase your signal bandwidth even more, which is often a goal for instrument designers and research scientists.

It often makes sense to substitute PMTs with APDs. Our large APDs come as large as photocathodes, without the bulk. Often a PMT's gain of 10^5 or 10^6 is overkill, because the signal, although weak, may only need a gain of 100 or so to overcome front end noise. Once the signal is

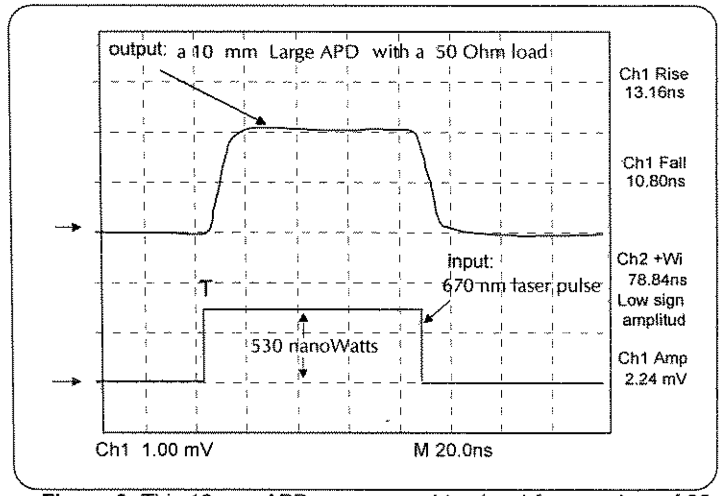


Figure 2: This 10 mm APD can respond to signal frequencies of 25 MHz and greater despite its large size. Notice the 12 ns risetime. Preamplifier noise is barely detectable due to the APD's gain of 200. For even faster response, select a standard size, high frequency APD.

above this small amount of noise, an APD will preserve more of the input signal because of its much higher quantum efficiency for wavelengths ranging from about 250 nm to 1064 nm. This is usually true for signals on the order of 10 $fW/Hz^{1/2}$ or greater per square centimeter of APD active area. Furthermore, being solid state, an APD has a much larger dynamic range than PMTs, usually by at least 3 orders of magnitude without compromising output linearity. For example, a 20 ns pulse with amplitudes varying from 50 pW to say, 50 μW (**see Figure 2**) is more appropriate for an APD. The same would be true for pulses lasting 20 μs or longer, with amplitudes varying from about 1 pW to 1 μW (**see Figure 3**). A PMT would not be linear, and a PIN photodiode would not amplify the

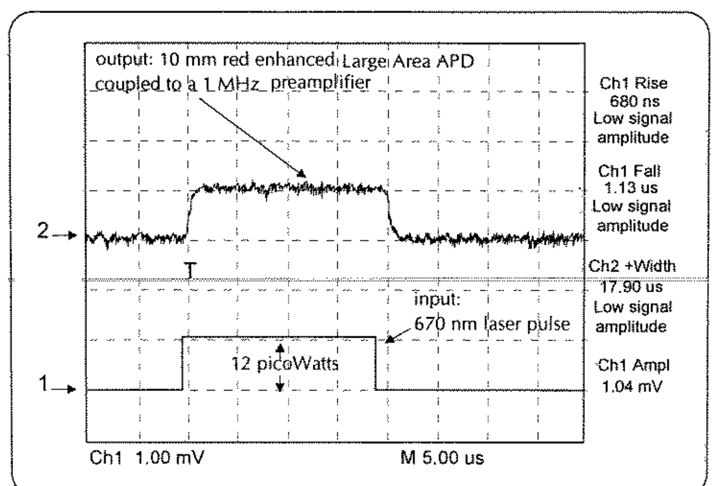


Figure 3: A 20 microsecond long, 12 pW signal is easily detected by one of our large area APDs coupled to a preamplifier. Bandwidth in this example is limited to ~1 MHz due to the relatively large 1 Megaohm feedback resistor chosen to display the signal on the scope.

signal above the preamplifier noise. APDs also benefit from a more rugged structure suitable for operation in harsh environments, far less power consumption than PMTs (no thirsty bleeder or voltage-divider network) and immunity to magnetic fields as high as several Tesla that dynode-based detectors can not withstand without losing severe amounts of gain.

Principle of Operation

A positive bias is applied to the detector's cathode. This voltage creates a strong electric field in the region of the junction, which is swept free of carriers. As the electric field increases, this "depletion", or "space charge" region expands. Photons, x-rays, or charged particles incident on the p side of the detector are converted to electron-hole pairs that get multiplied. This occurs when the electrons diffuse into the depletion region where they are accelerated in the high field, quickly achieving their saturation velocity. Near the junction, these carriers possess sufficient energy to ionize secondary electrons when they collide with atom sites. These secondary carriers accelerate and repeat this avalanche process. In

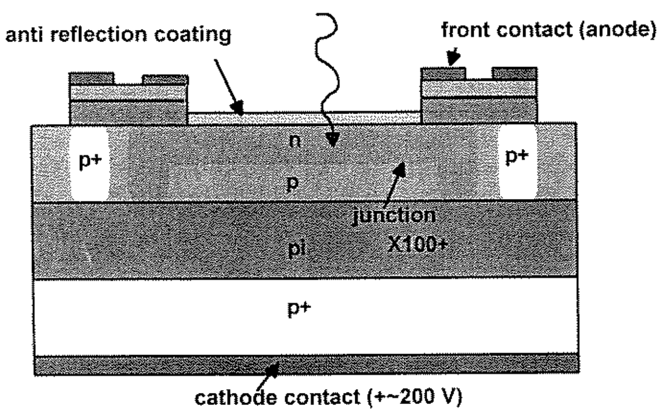


Figure 4. Structure of our High Frequency / Standard Size APDs.

this way the signal is multiplied, constituting the source of gain in APDs.

High Speed/Standard Size APDs

Luna Optoelectronics offers standard size APDs ranging in diameter from 300 μm to 1.5 mm. These APDs are amongst the fastest and most sensitive for their size available. Their structure is epiplanar, and they operate nominally at a gain of 100, attained at a bias of about 200 V (**Figure 4**). They are ideal for weak signal applications that require detector responses of about 1 ns or faster. This high speed is often warranted for data communications, telecommunications, and LIDAR (laser or light detection and ranging). The size selection is appropriate for fiber coupling applications, so please inquire about the possibility of pigtailing to these standard APDs.

Large Area/Ultra Sensitive APDs

If your signal is even more diffuse, and you can not use focusing optics or fibers, or you employ a large scintillator for gamma conversion, Luna Optoelectronics manufactures award-winning "beveled edge" Large Area APDs

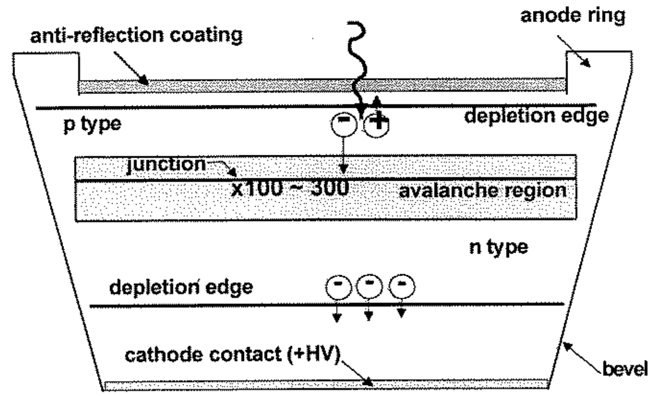


Figure 5. Structure of our Large Area / Ultra-Sensitive APDs.

(LAAPDs) in 5, 10, and 16 mm active diameters (**Figure 5**). These are considered to be a technological breakthrough, the largest commercially available, with the highest sensitivity per unit area. The LAAPD is a fast pulse detector of low light levels spanning the near UV, visible, and near IR spectra. It can also directly detect charged particles and x-rays (order them in the "open face" version), and when coupled to a scintillator, gamma-rays as well. The Large Area APD has found use in the following low light level/high speed applications:

- Fluorescence Measurements (Spectroscopy)
- Medical Diagnostics
- Light Detection and Ranging
- Reprographic Scanning
- Defect Scanning (Aerospace, Semiconductors)
- Medical Imaging
- Calorimetry and High Energy Physics

Dark current and noise resulting from the multiplication process are low per unit area when compared to APDs of other designs operated at the same gain due to proprietary doping techniques and ultrapure starting material. The Luna Optoelectronics LAAPD design lowers excess noise by creating a broad, shallow gradient to the electric field. The result is almost half the excess noise factor at a gain of 100 compared to APDs produced by other suppliers. LAAPDs are operated at a bias of about 2400 V, corresponding to a gain of 200. "Linear mode" operation, below the breakdown voltage, ensures high dynamic range and no dead time. These devices have ultra-high quantum efficiency enhanced for the UV, blue, and red spectra.

Operating Suggestions

Power Supplies

Whichever APD power supply you choose, be sure that it has the following basic features:

- adjustable from 0 to 300 V for standard / high frequency APDs or to 3 kV for large / ultra sensitive APDs;
- can supply about 10 μA of output current;
- voltage ripple of < .01%.

Depending on your application, you may prefer a benchtop, rack mounted power supply, or a miniaturized, low cost modular supply. Other features that you may consider for your power supply in either configuration include computer control of the APD voltage with an input

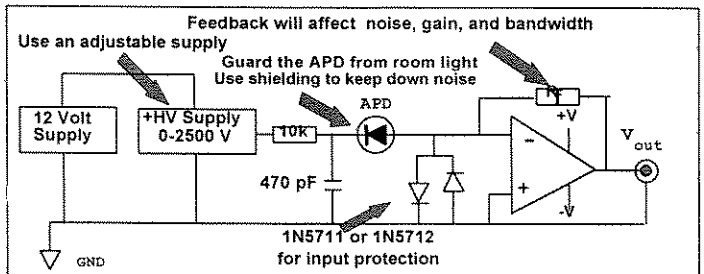
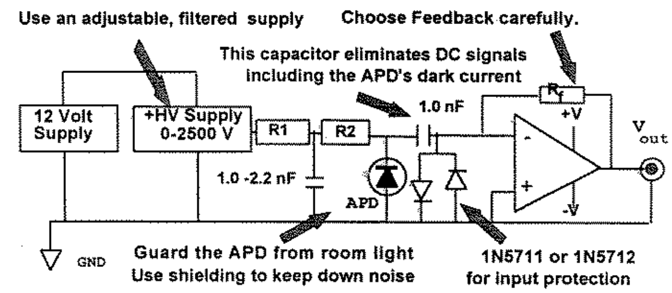


Figure 6. DC Coupled APD with Transimpedance Preamplifier for detecting light ranging from DC to fast pulses

analog signal. and a sensor that adjusts the APD voltage to compensate for fluctuations in the ambient temperature.

Preamplifiers

A preamplifier at the output of the APD is essential to convert the signal to a voltage. Voltages are easier for successive electronics stages (amplifiers, ADCs, counters, comparators, and discriminators) to process. APDs by design exhibit their greatest advantage over PIN diodes when the signal frequency is very high (fast pulse repetition rate, and/or short pulse duration) because fast preamplifiers contribute noise that may limit the sensitivity of a weak signal. APDs strengthen these weak signals substantially so that fast preamplifiers are less likely to limit the sensitivity of the front end detection circuit. For most applications, a *transimpedance preamplifier* is preferred, converting the optical power incident on the APD (measured in watts) to a proportional voltage. Op-Amps such as the bipolar type Comlinear CLC 425, or the CMOS type OPA 655 from Burr Brown are highly regarded, because they are capable of processing very high signal frequencies with relatively low noise. Typical feedback resistances of 5 - 50 kΩ allow for transimpedance frequencies of 1 - 100 MHz, depending on the APD's capacitance. The total gain a DC to 20 MHz signal might experience in an APD/transimpedance circuit is on the order of one million volts per watt. DC coupling (**Figure 6**) will
provide detection of any steady-state portion of the signal,

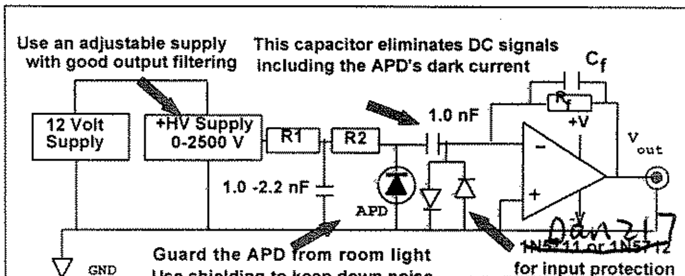


Suggested Values (please experiment)
$R_2 = 5R_1$ to $20R_1$ • $R_f = (R_2/5)$ to $(R_2/10)$

Figure 7. AC Coupled APD with Transimpedance Preamplifier eliminates DC signals and dark current

but at the cost of also passing along any ambient light and the dark current of the detector to the output of the preamplifier. AC coupling (**Figure 7**) removes these extraneous components from the output.

There are specialty applications that demand a conversion of APD electron charge to a voltage. These require a *charge sensitive preamplifier* (**Figure 8**) . Instances where this is desirable tend to be associated with high energy and nuclear physics experiments that involve the detection of x-rays or gamma rays (e.g., nuclear spectroscopy). Large APDs can directly detect x-rays below 20 keV with excellent counting efficiency. Each x-ray absorbed in the APD will create one electron-hole pair for every 3.62 eV



Suggested Values (please experiment)
$R_2 = 10R_1$ to $20R_1$ • $R_f = 2R_2$ to $10R_2$

Figure 8. AC Coupled APD with Charge Sensitive Preamplifier for detection of x-rays and gamma rays (with scintillators)

of x-ray energy. These primary electrons will experience a gain of 200 in the avalanche region. A charge sensitive preamplifier may then convert these electrons at the output of the APD to a voltage. The preamplifier voltage will be proportional to the x-ray energy in. For example, an ^{55}Fe x-ray (E = 5.9 keV) incident on one of our APDs will typically produce 9.6 Volts at the output of a charge sensitive preamplifier whose gain is 500 mV/ picoCoulomb. A ^{41}Ca x-ray (E=3.7 keV) will produce 6 Volts.

Gammas will pass directly through the APD, so they are first converted to photons in the optical spectrum by mounting a scintillator crystal to the detector. Scintillators with emission spectra particularly suited to the ultra- high quantum efficiency of our large APDs include CsI, NaI, BGO, LSO, and a variety of plastics emitting in the blue, green, and red. The scintillator typically emits into the APD several tens of thousands of UV or visible photons for every MeV of gamma energy. PMTs on the other hand, have relatively poor quantum efficiency, and most of the scintillator emission is not detected.

Luna OptoelectronicsLarge APDs are particularly adept at resolving gammas of slightly different energies with scintillators, and their large sizes are an excellent match for the large faces of scintillators. The crystal exit plane and the detector active surface must be a good match in area to optimize detection efficiency and resolution. A charge sensitive preamplifier, and counting and discriminating electronics usually follow.

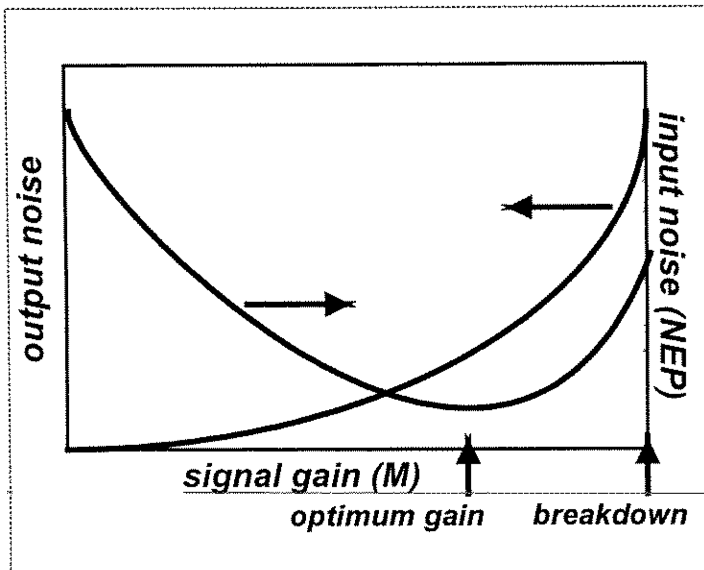


Figure 9. Although APD output noise increases with gain, its true sensitivity is measured by dividing the noise by the responsivity at a given gain (NEP). The result is an optimum gain where input power can be compared with the lowest input

Operating Considerations

APDs also produce noise, of course. The APD's output noise will increase as gain is increased. However, the noise relative to your signal actually decreases up to a certain APD gain (**Figure 9**). The output noise current of the APD based on a simplified version of the McIntyre mod is as follows:

$$i_{apd} = \sqrt{2qB[I_{ds} + M^2F(I_{db} + I_p)]}$$

where I_{ds} is the part of the dark current, mostly surface, that does not get multiplied; I_{db} is the component, mostly bulk, that does multiply; I_p is the primary photocurrent from the signal; M is the gain, and F, the excess noise factor. F is a measure of how much extra noise is introduced from the gain process. The large area / ultra sensitive APD selection from Luna Optoelectronics have the lowest F figures of any manufacturer. A universally accepted figure of merit to measure photodiode noise is Noise Equivalent Power (NEP):

$$NEP = i_{rms}/(M \times R_{M=1})$$

NEP from the APD alone will be at its lowest at typical operating gains of 100 for the standard size / high speed APDs, and a gain of 200 for the large area / ultra sensitive APDs. (**Figure 8**).

APD Modules

Now, the Large Area APDs are available with a integrated power supply, low noise transimpedanc preamplifier, and the large area APD of your choice, ideal for your initial evaluation. These modules feature AC coupling to eliminate both the detector's dark current, and the signal caused by any ambient light. As a result, there will be far less drift in your signal. A cooled version will soon be available, which cuts noise in half, lowers the APDs dark current dramatically, and stabilizes the signal with changes in ambient temperature. This cooled and temperature stabilized version will have DC to 20 MHz response. All Luna Optoelectronics modules are designed to maximize bandwidth and minimize noise.

For more information on our APDs and Large Area APD Modules, please contact our Sales Department at (805) 987 0146. We will be happy to entertain your applications questions as well, and discuss any custom project you may be considering. Our business hours are from 8:00 AM to 5:00 PM Pacific Time, Monday to Friday. You can also fax us at (805) 484 9935.