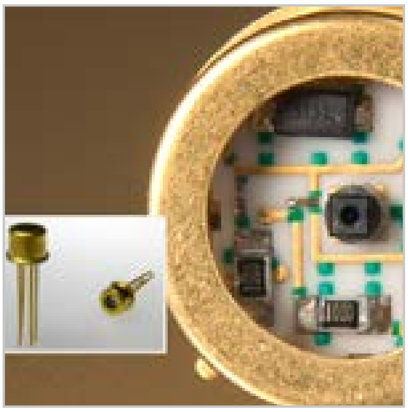
Detection of Minimal Light Quantities with Avalanche Photodiodes

Optical APD Receiver Modules



With APDs, charge carriers are accelerated in an electric field and form additional electron-hole pairs as a result of impact ionization. In this way, even an individual photon can trigger a significant photo-current, which can then be detected. Avalanche photodiodes are therefore superior to normal PIN diodes when it comes to applications involving detection of minimal light quantities.

Winfried Reeb - Dragan Grubisic

The use of avalanche photodiodes (APDs) represents the most efficient method of increasing sensitivity. The internal amplification of the APD can be increased until the signal-to-noise ratio (SNR) is limited by the shot noise. However, the capability of the entire detector system depends primarily on the electronic circuitry.

Signal Amplification

APDs are only required if the noise of the entire receiver is limited by the amplifier noise – that is, the noise component of the amplifier is greater than the noise of the detector. However, this only occurs at high speeds.

In this case, the transimpedance amplification is limited by the ›RC‹ time constant. The use of an APD with internal amplification improves the signal-to-noise ratio of an APD amplifier relatively compared to a module with PIN detector plus amplifier. Both the optimum amplification and the SNR of the receiver are higher the lower the excess noise [1]. At high bandwidths, this specific noise caused by the amplification is the dominant noise source. It is important, therefore, to keep the capacitance present at the amplifier as low as possible in order to reduce the total noise of the detector/amplifier module.

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The Optimum SNR

In practice, this is achieved by having all components in a receiver module being tightly packed on a ceramic substrate with low capacitance. This reduces the stray capacitance and thus the noise, which provides the best system bandwidth for the relevant application. In addition, this method enables extremely compact modules to be produced.

In simple terms, an APD receiver module involves a compromise between speed and noise. A typical receiver consists of the APD and a transimpedance amplifier (TIA). The TIA is a current-to-voltage converting amplifier that fixes the amplification using a feedback resistor. As the APD generates a current, the feedback resistor acts as the amplifier with the output voltage being equal to the APD current multiplied by the feedback resistance.

Interference Factors

As well as APD noise, Johnson noise from the feedback resistor is the main component of the total noise [2]. In contrast to the Johnson noise voltage, which increases as the resistance rises, the equivalent Johnson noise current falls. Increasing the amplification (feedback resistance) thus reduces the input noise density of the amplifier. However, the reduction in bandwidth now becomes an issue, as the product of amplification and bandwidth for the TIA is constant – that is, with higher amplification or greater resistance, both the bandwidth and the input noise density fall.

Optimum Signal Level

The diagram (**Figure 1**) shows the optimum relationship between noise and bandwidth, which is achieved using the APD amplifier units from Laser Components. Here, the noise is represented as a noise equivalent power (NEP), which is a value in watts equivalent to the system noise density. This is a good indicator of the lowest optical power value that can be detected by the receiver.

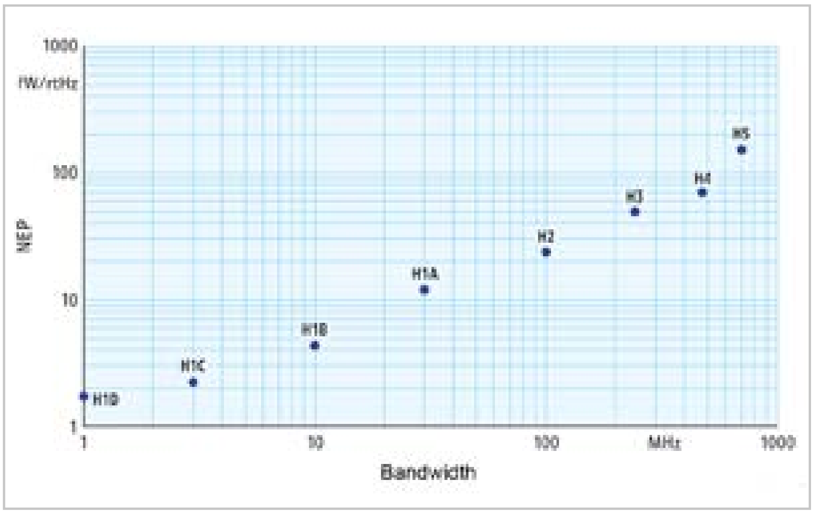

Figure 1: Optimally adjusted signal-to-noise ratios for actual APD receivers

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Choosing The Correct APD Receiver

For the user, it is important to be clear about the actual bandwidth requirements in the relevant application so that the most appropriate component can be selected and the associated NEP minimized. Various models are available in the market, each of them optimized for a different bandwidth.

For example, the ›H1‹ series from LASER COMPONENTS has been developed for detection of minimal light quantities (**Figure 2**). The components are DC-coupled and have a 50 ohm output. A second amplifier level for signal inversion also ensures that a light pulse generates a positive voltage and an additional voltage amplification occurs. The amplifier level can also be used as a low pass filter to reduce high frequency noise. A temperature diode for measuring the APD temperature is additionally installed, thus enabling the user to vary the initial load to compensate for temperature-related changes in the receiver sensitivity. In addition, the circuit has an internal filter for reducing faults with the high voltage.

The bandwidth range of the H1 receivers extends up to 25 MHz and they are also available with different amplifier configurations. The ›A‹ to ›D‹ models use different feedback resistances, which provides the user with a choice of different sensitivities that can be matched to the bandwidth requirements of the specific application.

By contrast, AC-coupled APD receivers with bandwidths of up to 750 MHz are primarily used for rapid detection of minimal light quantities (**Figure 3**). The peak speed is only limited by the type of APD used. Developed for easy use in high speed digital electronics, the ›H2‹, ›H3‹, ›H4‹ and ›H5‹ series of receivers from LASER COMPONENTS have differential outputs.

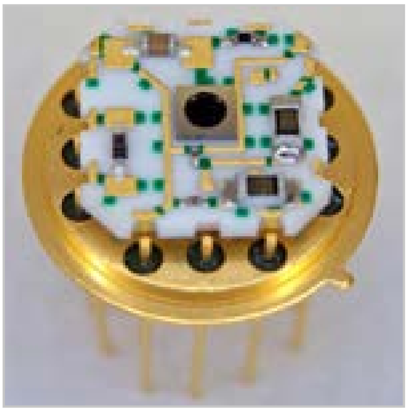

Figure 2:
DC-coupled APD receiver with no cover in a 12-pin TO-8 Housing for detection of minimal light quantities

Figure3:
AC-coupled APD receiver in a 5-pin TO-46 housing

The Right Detector For The Right Application

Hybrids and avalanche photodiodes from any one particular manufacturer can normally be freely combined as required. The two material combinations of major commercial relevance are silicon and InGaAs. Depending on their structure, Si-APDs are sensitive between 300 and 1100 nm, InGaAs between 900 and 1700 nm. The use of different detector structures enables the spectral sensitivity of APDs to be optimized for particular wavelengths (650, 905 or 1064 nm for Si-APDs and 1550 nm for InGaAs APDs). Further optimizations and selections allow the manufacture of extremely low noise APDs, which can be used to detect individual photons. This enables the user to choose the right detector for specific requirements.

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Medical applications such as optical coherence tomography (OCT) and fluorescence measurements normally require the low NEP of the H1 series. Advances in the utilization of near-infrared, broadband light sources in conjunction with APDs have paved the way for OCT imaging in highly dispersive tissue. These days, optical in vivo biopsy is one of the most challenging applications for OCT technology. High resolution and high penetration depth, as well as the potential for functional imaging enable OCT techniques to deliver a quality of optical biopsy that can be used to analyze tissue and cell functions or morphology.

The most recent application of very high speed APD receiver modules is range finding using lasers or laser scanners based on the ›time-of-flight‹ method. To achieve a range resolution in the millimeter range, very high measuring frequencies are necessary. For this reason, both commercial and military rangefinders, speed measuring instruments, LIDAR systems and ceilometers normally use the high bandwidths provided by the H2 to H5 series of APDs.

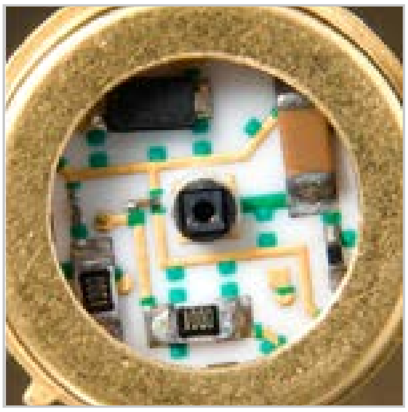

Figure 4:
DC-coupled APD receiver in TO-8 housing

Summary: The Right Product Is To Hand

The stray capacitance at the interface between the detector and amplifier has a negative influence on noise and on the bandwidth of the detector system. Detector/amplifier hybrids, with all components tightly packed on a ceramic substrate with low capacitance, help to obtain the best possible system performance. Certain compromises between noise and bandwidth need to be taken into account. LASER COMPONENTS supplies a range of APD hybrids for achieving optimum system performance for the relevant application.

Literature

1. http://en.wikipedia.org/wiki/avalanche_photodiode
2. http://en.wikipedia.org/wiki/johnson_noise

Winfried Reeb studied precision mechanics/optoelectronics at the Technical University in Aalen, Germany. Since 1994, he has been a production engineer at Laser Components and is responsible for sales of active components for laser technology and optoelectronics.

Dragan Grubisic is the Chief Executive of LASER COMPONENTS DG, the production location for high-tech avalanche photodiodes. Today, he benefits from his extensive experience in light detection and in the development and design of IR photodetectors, which he gained after completing his M.Sc.

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