Application Note

AFBR-S4NxxPyy4M

Single-Photon Measurements

The Broadcom® AFBR-S4NxxPyy4M is a silicon photomultiplier (SiPM) series that is used for ultra-sensitive precision measurements of single photons. These SiPMs are based on NUV-MT technology with a SPAD pitch of 40 µm. The high sensitivity (63% at 420 nm) and high gain make the device a suitable sensor for low-photon flux down to single-photon measurements in the near ultraviolet (NUV) and visible (VIS) range of the electromagnetic spectrum. This application note provides the reader with more information on the performance of the Broadcom NUV SiPM for low-light and single-photon measurements.

Single-Photon Spectra (Finger Plots)

SiPMs, as arrays of single photon avalanche diodes (SPADs), provide a very well-defined signal per incident photon. The SiPM is operated in Geiger mode, meaning that a detected photon triggers a complete avalanche discharge of the SPAD. The result is a very well-defined charge output per detected photon, which corresponds to the overall stored charge in the SPAD and the corresponding quenching resistor. The high gain of the SiPM originates in this avalanche discharge and can be written as the overall released charge over the elementary charge *e*. The typical gain of SiPMs is in the order of 10^6. As a consequence of the Geiger-discharge, if more than one photon impinges onto the same SPAD simultaneously, the signal will look like a one-photon signal (1 p.e.). However, if another photon hits a neighboring SPAD on the SiPM, the SiPM signal will contain twice the charge of the one-photon signal. This characteristic of the SiPM allows for photon counting.

To access information on the number of detected photons, the charge of the signal must be measured. The following are the two most common approaches:

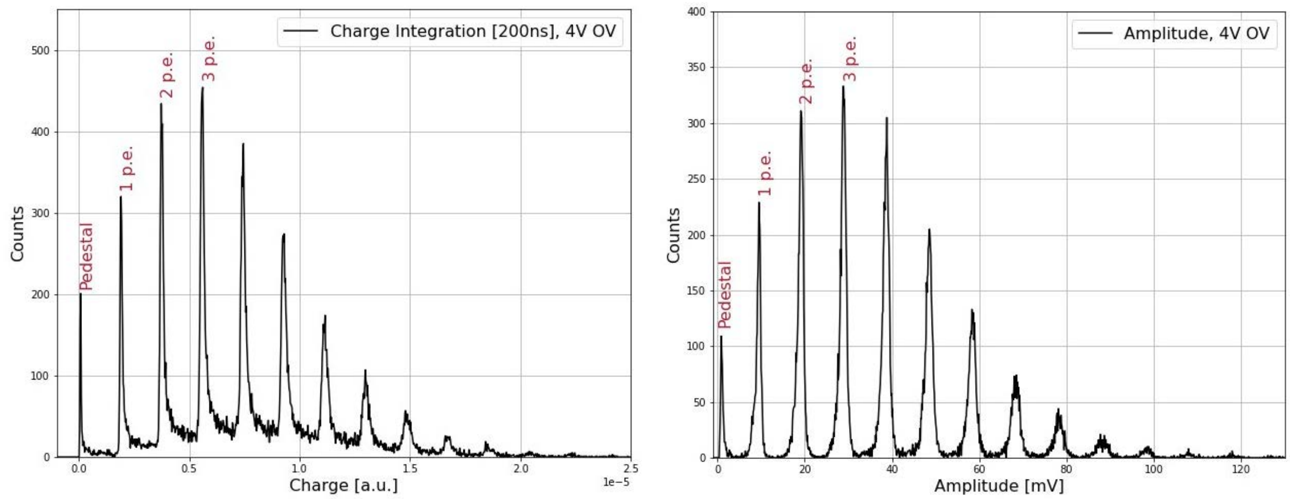
- Charge integration
- Amplitude measurement

Both methods have their advantages and disadvantages.

Beside the measurement method, further factors must be taken into account to obtain good separation between the individual peaks in a so-called finger plot, a histogram that displays the detected energy (like charge or amplitude). As examples, bandwidth limitations may help to reduce noise and increase the energy resolution. Also, a low-noise preamplifier is beneficial for low-photon flux measurements.

Figure 1 displays the charge histogram and amplitude histogram using a transimpedance amplifier (gain = 5000 V/A) and a 20-MHz bandwidth. The charge integration window was set to 200 ns. The SiPM was irradiated with an LED (420 nm) biased at 4V overvoltage.

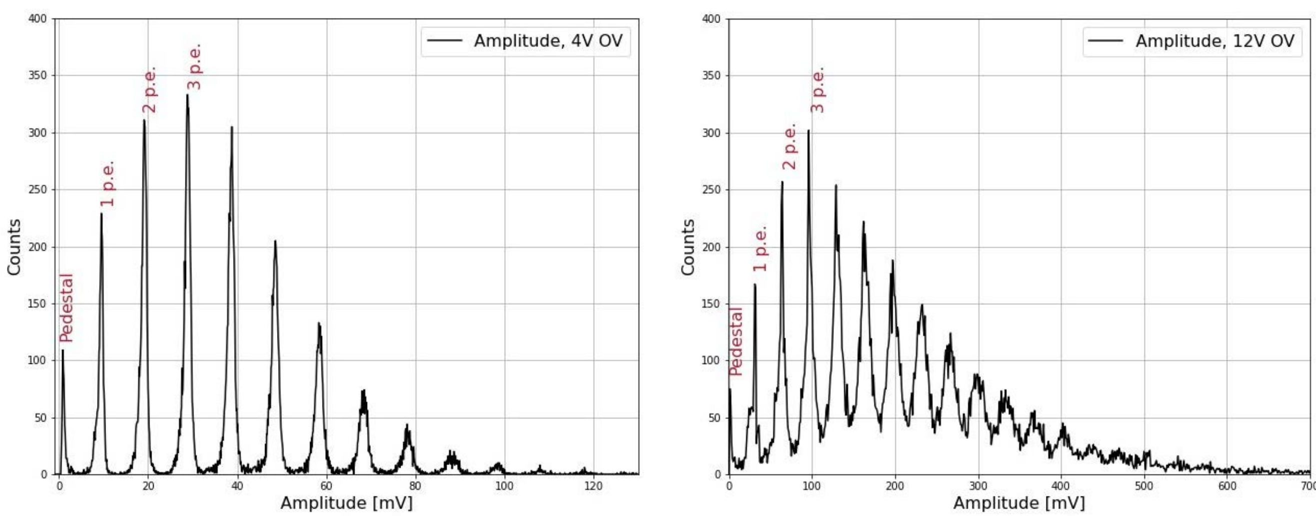
Figure 1: Charge Histogram (Left) and Amplitude Histogram (Right) of an AFBR-S4N44P014M from LED Irradiation (420 nm)



Single-Photon Spectra and Correlated Noise

For photon counting applications, low (correlated) noise is crucial. Therefore, it may be beneficial to operate the SiPM at low overvoltages. Especially in the NUV and for blue light, the PDE already reaches its saturation at low overvoltages, so that noise can be reduced without significantly reducing the sensitivity (refer to the “NUV-MT SiPM Performance Correlation” application note). Furthermore, for a larger SiPM (for example, with a 6x6 mm^2 active area), an amplitude measurement can be advantageous over charge integration (see Figure 1). The reason is that dark counts and afterpulses may add charge to the measurement. This becomes more influential with longer integration times. Figure 2 shows the amplitude histogram measured with an AFBR-S4N44P014M SiPM at 4V and 12V overvoltage. Both spectra were acquired under identical conditions with only different bias voltages applied to the SiPM.

Figure 2: Amplitude Histogram at 4V and 12V Overvoltage

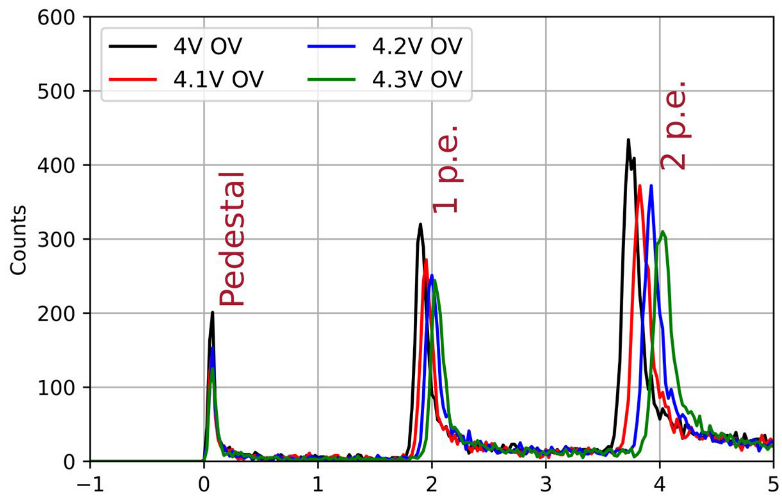


The increased noise causes the individual peaks to occur on top of a background distribution and can, in extreme scenarios, blur the resolution until individual peaks can no longer be resolved.

Temperature-Dependent Gain Drifts

The SiPM's breakdown voltage changes with temperature. The temperature coefficient for the Broadcom NUV-MT SiPM is 30 mV/°C. Consequently, external temperature drifts or count rate changes may lead to changing device temperatures. As a result, the change in breakdown voltage changes the applied overvoltage. This effect influences the resolution of charge/amplitude measurements. Figure 3 shows the pedestal, the 1 p.e. and 2 p.e. peaks (charge integration) at four different overvoltages. For the individual measurements, the overvoltage was consecutively increased by 100 mV (which corresponds to the breakdown voltage shift caused by an approximate temperature change of 3°C). It is evident that while the pedestal remains constant, the measured charge increases with higher overvoltage. The difference in peak position between 4V and 4.3V corresponds to an approximate temperature change of 10°C.

Figure 3: Pedestal, 1 P.E. and 2 P.E. Peaks at Four Different Overvoltages



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