AFBR-S4NxxPyy4M

SiPM Dynamic Range, Linearity, and Saturation

The SiPM dynamic depends on the number of SPADs per device, the photon detection efficiency, and the recovery time, and it determines the maximum number photons that can irradiate the SiPM before saturation is reached. Furthermore, the pulse lengths (time for which the SiPM is irradiated) are a crucial parameter. In general, two scenarios can be distinguished:

- Short illumination (a light pulse width less than the SiPM recharge time)
- Long illumination (a light pulse width much greater than the SiPM recharge time)

Even before saturation occurs, deviations from a linear detector response can be observed. The light flux for which a linear SiPM response can be obtained furthermore depends on the exact light spot profile. This is due to the stochastic nature of the photon distribution and the increase in the probability that two photons hit the same SPAD at higher light intensities.

The detector response curve can be given as follows:

$$N_{fired} = N_{SPADs}\left(1 - e^{-\frac{N_{photons} \times PDE}{N_{SPADs}}}\right)$$

Dynamic Range for Short Pulses (t < $\tau_{recovery}$)

For short light pulses (LED/laser), the dynamic range is mainly determined by the number of SPADs on the SiPM and the PDE at the given wavelengths of interest (PDE(λ)).

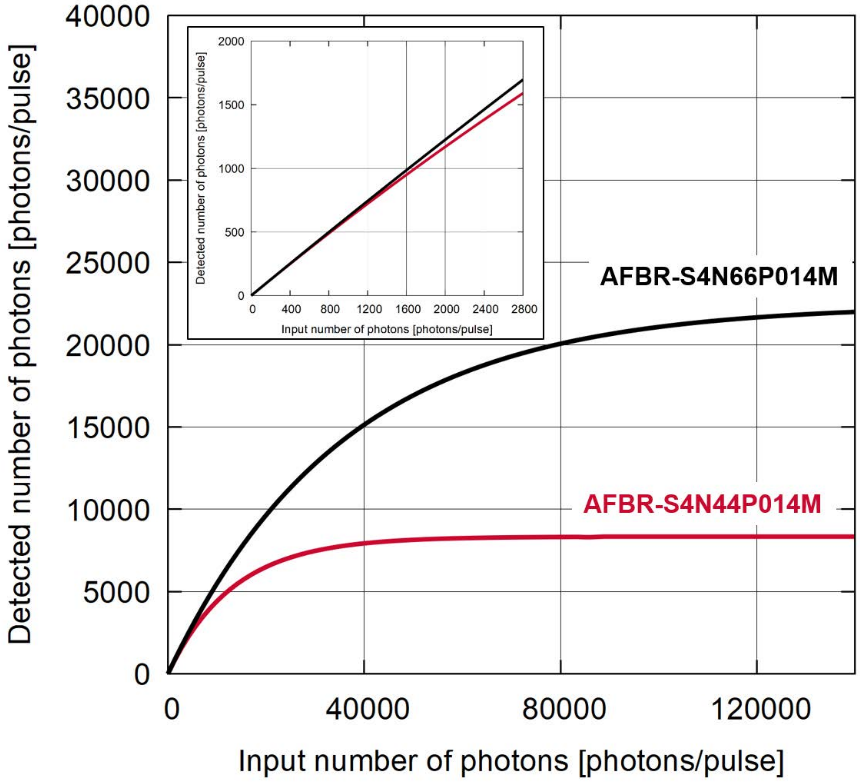
SiPM saturation occurs when no SPAD on the device is capable of detecting photons anymore (all SPADs firing). The number of incident photons at which saturation occurs can be approximated as follows:

$$\varphi_{photons} \approx \frac{Number\_of\_SPADs}{PDE(\lambda)}$$

In reality, however, deviations from a perfectly linear detector response already occur at lower incident light levels. The origin of these deviations lies in an inhomogeneous spot profile, which may lead to multiple photons impinging on a single SPAD, while no photon is detected at the neighboring cell. This effect is especially prominent for beam spot profiles with strong gradients from the spot center to the spot edge, like Gaussian profiles.

Figure 1 shows the saturation curves of two single-channel SiPMs in the Broadcom NUV-MT series with two different active areas. The number of SPADs increases with a larger device area.

Figure 1: SiPM Linearity for an AFBR-S4N44P014M (4x4 mm^2) and AFBR-S4N66P014M (6x6 mm^2)



Dynamic Range for Long Pulses (t >> $\tau_{recovery}$)

For pulses with a pulse length much more than the SiPM recovery time (t), an initially triggered SPAD may partially or fully recover within illumination. Therefore, the SiPM recovery time also plays a role in addition to the number of SPADs and the PDE.

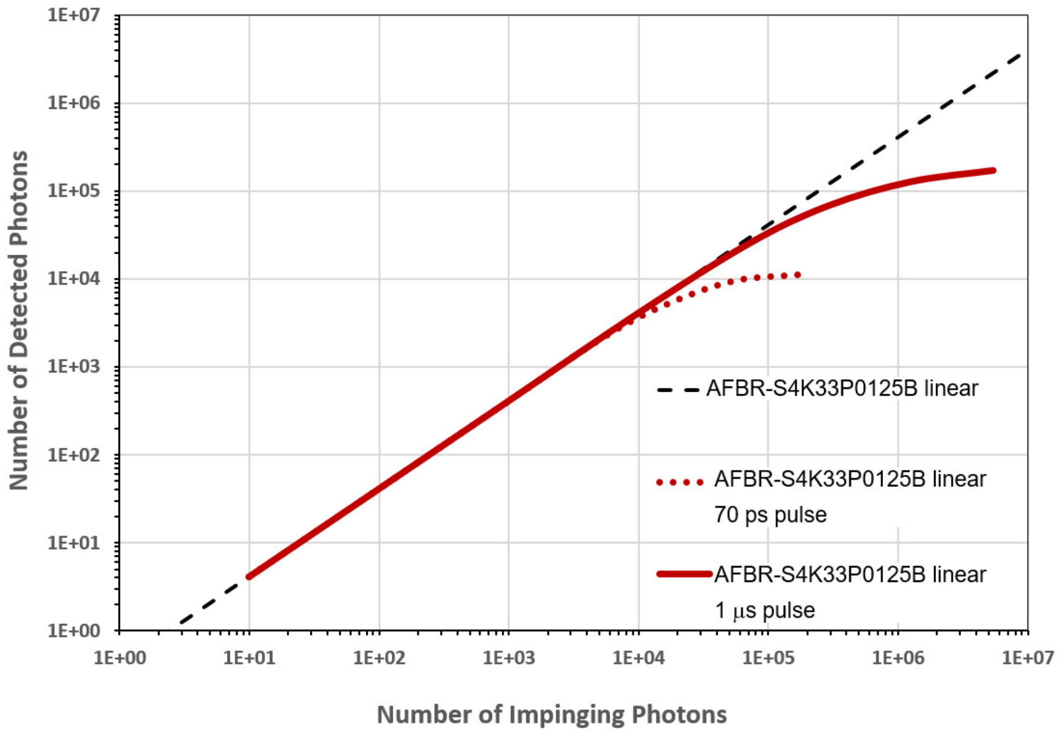
The equation that approximates the maximum number of incident photons that can be detected before SiPM saturations therefore changes to the following:

$$\phi_{photons} \approx \frac{Number\_of\_SPADs}{PDE(\lambda) \times \tau_{recovery}}$$

Note that according to this equation, the maximum number of photons is given in units of 1/s and must be multiplied by the pulse lengths to obtain a representative value for a specific application.

Figure 2 shows a comparison of a SiPM response linearity measurement on a Broadcom AFBR-S4K33P0125B for a 70-ps and 1-µs laser pulse. The calculated maximum number on impinging photons before saturations occurs is 3.87×10^{11} photons/s, which corresponds to 3.87×10^5 photons/µs and 3.1×10^4 photons for short pulses.

Figure 2: SiPM Linearity Measurement for Two Laser Pulse Widths



<u>Example: Dynamic Range of NUV-HD vs. NUV-MT (Both 4×4 mm^2 Active Area) for µs Pulses (At Peak PDE)</u>

- AFBR-S4N44C013 (NUV-HD) with a 30-µm SPAD pitch and 55% peak PDE: Approximately 3.0×10^5 photons/µs
- AFBR-S4N44P014M (NUV-MT) with a 40-µm SPAD pitch and 63% peak PDE: Approximately 1.7×10^5 photons/µs

Please note that the dynamic range of a SiPM is further reduced by the dark count rate (DCR) and correlated noise, which means afterpulsing and crosstalk. All three effects can cause a SPAD to be triggered without an actual signal photon impinging on the SPAD. Therefore, this cell is not available for signal detection.

NOTE: Choosing a SiPM with a low PDE to increase the dynamic range is not necessarily advised. A reduced PDE results in inferior accuracy on energy measurements due to increased statistical fluctuations. Customers must evaluate the device performance in their setup and for their specific applications.

PDE vs. Dynamic Range

As mentioned in the previous sections, the SiPM linearity deviations and saturations occur due to a lack of nonfired SPADs. Therefore, a higher PDE causes more SPADs to trigger for a given number of incident photons. As a consequence, the SiPM linearity depends on the applied overvoltage and the wavelengths of the incident light.

Figure 3 shows the SiPM saturation curves (for short laser pulses) of different wavelengths. For both plots, the y-axis is kept the same to allow better comparison between the AFBR-S4N66P014M and the AFBR-S4N44P014M. The x-axis of the AFBR-S4N66P014M, however, is twice the range.

Figure 3: SiPM Saturation of the AFBR-S4N66P014M (Left) and the AFBR-S4N44P014M (Right) for Different Wavelengths