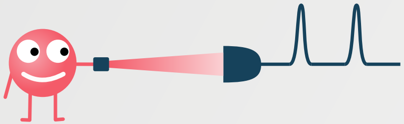
Counting Statistics of Actively Quenched SPADs Under Continuous Illumination



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We present stochastic approaches to model the counting behavior of actively quenched single-photon avalanche diodes (SPADs) subjected to continuous-wave constant illumination [1]. We present both analytical expressions and simulation algorithms predicting the distribution of the number of detections in a finite time window. We also present formulas for the mean detection rate. The approaches cover recovery time, afterpulsing, and twilight pulsing. We experimentally compare the theoretical predictions to measured data using commercially available silicon SPADs.

[1] I. Straka, J. Grygar, J. Hloušek, M. Ježek, J. Lightwave Technol. 2020 (early access). DOI: 10.1109/JLT.2020.2994654 https://github.com/ivo-s/SPAD-counting-model

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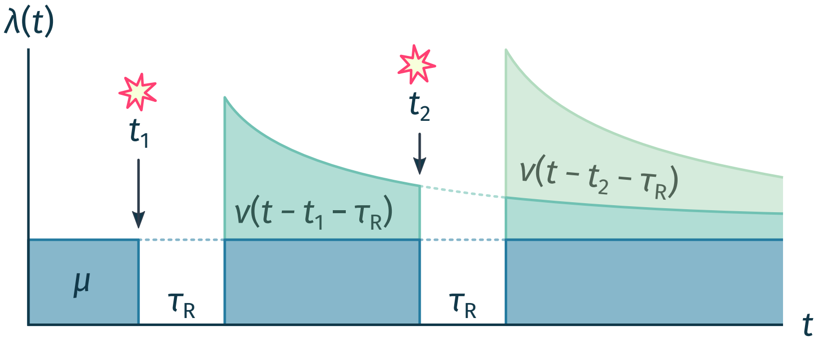
SPAD detection phenomena



SPAD counting as a self-exciting point process. The intensity λ in time consists of a constant intensity μ and afterpulsing contributions v triggered by the detections. (scale exaggerated)

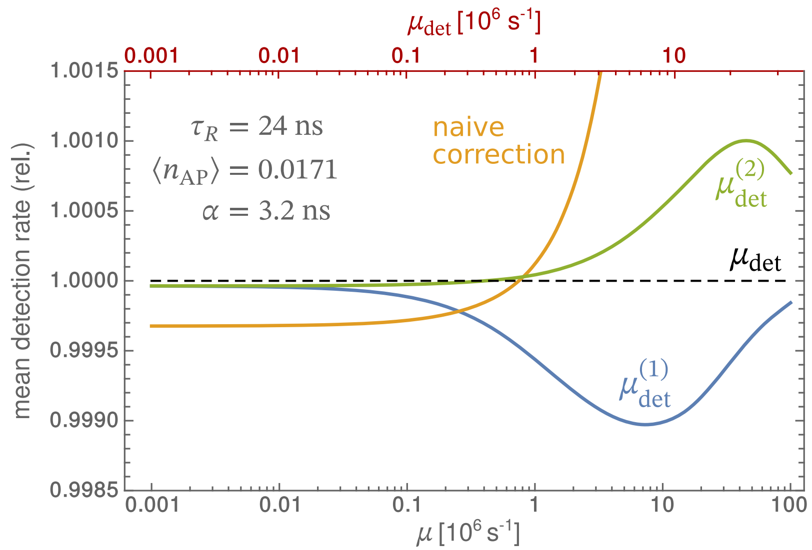
Relevant SPAD features:

oh no

τ_R	recovery time (not constant [1])
$v(t)$	afterpulsing intensity
α	twilight pulsing coefficient

parameters used to calculate the probability of detection that also depends on detection history. The process is numerically simulated.

Mean count rate



Assessment of mean rate accuracy as a function of incident rate [1]. The baseline is the point process model. Parameters (from top) are recovery time, mean afterpulses per detection, and the twilight coefficient.

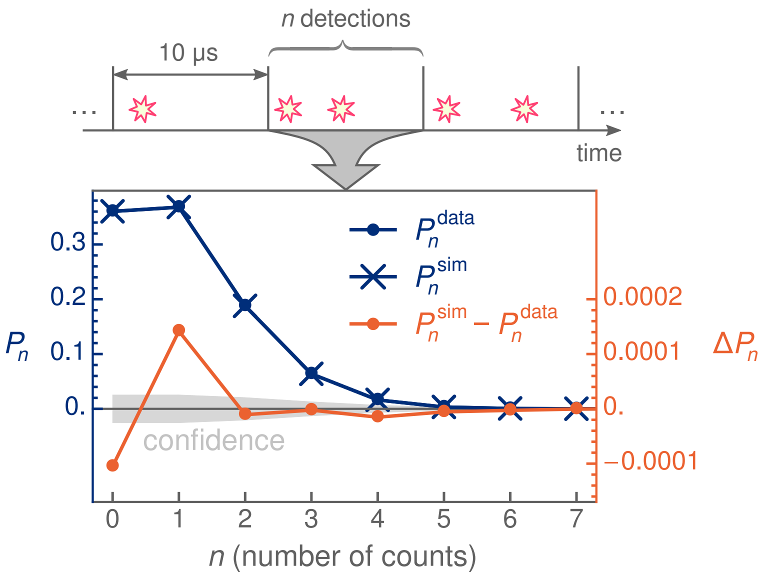
μ_{det} – full model given by an integral equation; solved numerically

$\mu_{\text{det}}^{(1)}$ – analytical approximation [1]

$$\mu_{\text{det}}^{(2)} = \frac{\mu}{1 - \widetilde{p}_a + \mu\tau_{\text{R}}}$$ (further approximation)

$\widetilde{p}_a$ – afterpulsing probability

Counting statistics: measured distributions



A sample measurement of the probability distribution of the number of counts in a 10-μs window.

Total variation distance: $\frac{1}{2}\sum_n |\Delta P_n|$

Measured tot. var. distances between data and models for three SPAD modules [1]:

rate	SPAD #1	SPAD #2	SPAD #3
10k	0.5×10^{-4}	0.5×10^{-4}	0.1×10^{-4}
100k	0.2×10^{-4}	1.4×10^{-4}	4.0×10^{-4}
1M	4.3×10^{-4}	1.8×10^{-4}	5.0×10^{-4}
5M	2.9×10^{-4}	2.3×10^{-4}	(4M) 83.6×10^{-4}