# Calibration of Si-SPAD detectors using the double attenuator technique and a traceable low noise silicon photodiode


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We present the calibration results of a Si-SPAD detector using a low optical flux detector (LOFD) and the double attenuator technique. The calibration consists in determining the detection efficiency of the detector via these two approaches with independent traceability chains. The calibration was carried out at a wavelength of 770 nm and at different optical power levels from 90 fW to 1300 fW. The mean relative deviation of the detection efficiency determined using the LOFD and the double attenuator technique was < 0.2 %, thus within the combined standard uncertainty of the two measurements.


## 1 Introduction

In many quantum technology fields such as quantum communication, quantum information, etc, Silicon single-photon avalanche photodiodes (Si-SPADs) are the most frequently devices used for measuring the optical flux at single-photon levels. In all these fields, the detection efficiency is one of the key parameters that has to be accurately known for achieving reliable measurements [1]. At PTB, the detection efficiency of Si-SPADs is determined by means of the double attenuator technique [2]. However, an alternative way to determine the detection efficiency of a Si-SPAD is by direct comparison against a traceable low optical flux detector (LOFD). Both measurement procedures, each one with an independent traceability chain, were recently compared at PTB within the frame of the EMRP-Project “Single photon sources for quantum technologies” (SIQUTE).

## 2 Experimental setup and measurement procedure

The comparison was carried out using the low flux facility at PTB (see Fig. 1). In this case a strong attenuated laser at a wavelength of 770 nm is used as a light source. The laser beam is focused onto the active area of the detectors using a microscope objective.

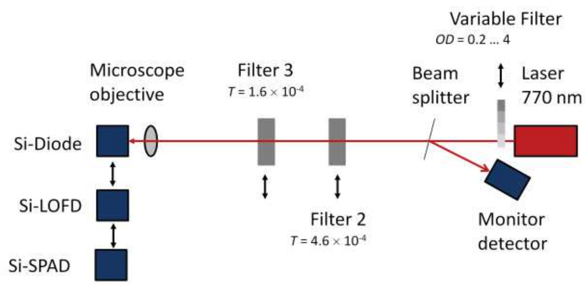


***Fig. 1*** *Schematic representation of the setup used for the calibration of the Si-SPAD detection efficiency.*

Filter 2 and 3 are used for the attenuation of the laser beam down to single-photon level. The detection efficiency of the SPAD detector is determined by comparing the photon rate measured with an analogue standard detector; e.g. the Si-diode or the LOFD, to the one measured with the SPAD detector under test. When the double attenuation technique is used, the optical flux impinging on the SPAD detector is determined by multiplying the transmission of the two filters with the optical flux originating from the laser. In this case, the filter transmission is measured *in situ* with a standard Si-Detector in a subsequent way; i.e. each filter is alternately moved into the beam path for its transmission measurement. This procedure is needed because the Si-Diode – in contrast to the the LOFD - is not able to measure the optical flux at fW power levels. Thus, when the LOFD is used, the filter 2 and 3 are placed into the beam simultaneously, since this detector is able to measure the optical flux at fW-level directly.

A simplified schema of the LOFD, built and calibrated at CMI, is shown in Fig. 2. Unlike a traditional optical flux detector composed of a


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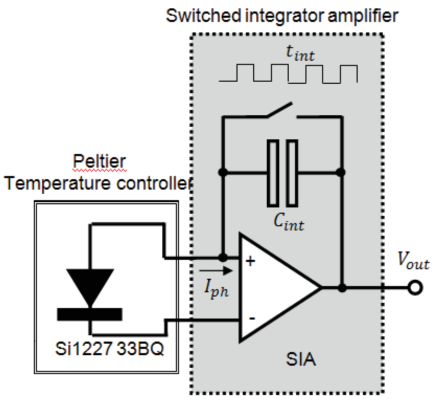


***Fig. 2** Simplified scheme of the low optical flux detector (LOFD).*

photodiode and a trans-impedance amplifier, the LOFD uses a switched integrator amplifier (SIA) [3] for converting the photocurrent to voltage. In this way, it is able to achieve a current-voltage conversion factor of $10^{12}$; i.e. sub-pA photocurrent levels can be measured with a standard uncertainty less than 0.2 %.

## 3 Results

Figure 3 shows the detection efficiency of a Si-SPAD detector (PerkinElmer AQR 16) determined with double attenuator technique and the LOFD. The intrinsic detection efficiency at low power levels (86 fW), corresponding to 330 kphotons/s, measured using the double attenuator technique and the LOFD are $0.629 \pm 0.003$ and $0.630 \pm 0.002$, respectively. The drop of the detection efficiency at approx. 450 fW is mainly caused by the intrinsic influence of the detector dead time and the photon statistic (Poissonian photon statistic) of the attenuated laser. The maximal relative deviation between the detection efficiencies is 1.3 % for all measured optical flux levels. The mean relative deviation is < 0.2 %, while the combined standard uncertainty is $\leq 0.6$ % for both measurement procedures.

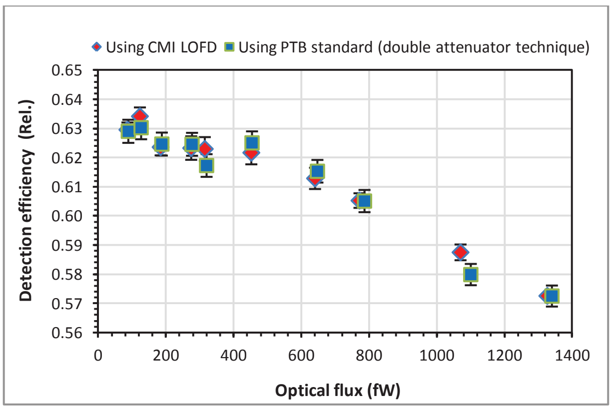


***Fig. 3** Detection efficiency of a Si-SPAD detector (PerkinElmer SPCM AQR 16) determined by using the PTB low flux measurement facility and the CMI low optical flux detector (LOFD).*

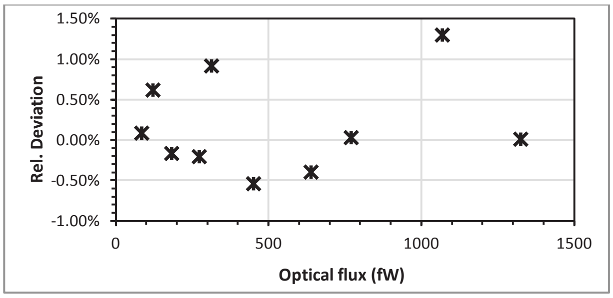


***Fig. 4** Deviation between the detection efficiency determined using the PTB´s low flux facility (double attenuator technique) and the LOFD.*

## 4 Conclusion

Two measurement procedures, with completely independent traceability chains, for the calibration of the Si-SPAD detection efficiency were presented. The calibration results are consistent for all optical flux levels measured between 86 fW and 1300 fW. The mean relative deviation of the detection efficiency determined with both procedures was less than 0.2 %, thus well within the combined standard uncertainty; $u_c(\eta_0) \leq 0.6$ %, achieved with both measurement procedures.


## 5 Acknowledgement

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## References


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