# Traceable Detection Efficiency Calibration of SPADs at the Sodium Fraunhofer Line for Secure Quantum Communication

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Secure free-space quantum communication during daylight is significantly limited by solar background radiation. To increase the signal-to-noise ratio (SNR), we can utilize the sodium Fraunhofer D1 line (589.6 nm), where the solar background is naturally reduced by about 20 dB. In such high-security links, reliable detector characterization is essential because any uncertainty in the detection efficiency directly impacts the Quantum Bit Error Rate (QBER) and creates security gaps that an eavesdropper could exploit without being detected. In this work, we present a high-precision, traceable calibration of single-photon detectors at 589.6 nm for daylight free-space Quantum Key Distribution.

As shown in Fig. 1, our experimental setup starts with a traceable Hamamatsu S1227 reference photodiode [1] working in the nanowatt range. To calibrate the femtowatt range single photon detectors, we use the double attenuator technique [2] to bridge the power gap between the reference and the detector under test (DUT). The setup utilizes a 589.6 nm CW laser and three Variable Optical Attenuators (VOAs). We integrated a 90:10 fiber coupler to create a monitoring arm, which allows us to normalize the photon flux during the calibration. To ensure traceability, the setup's stability and the 50:50 coupler's splitting ratio were precisely characterized. Our analysis includes the DUT's performance, including saturation corrections and the linearity of the reference diode.

Finally, a combined uncertainty budget was developed according to the GUM. The relative combined uncertainty starts at 0.5 % for high incident rates, remaining below 1.0 % for counts down to 300 ,000 counts/s, and reaching 1.5 % below 200 ,000 counts/s (Fig. 1, right). The main source of this uncertainty is the power-ratio determination in the reference arm at very low count rates.

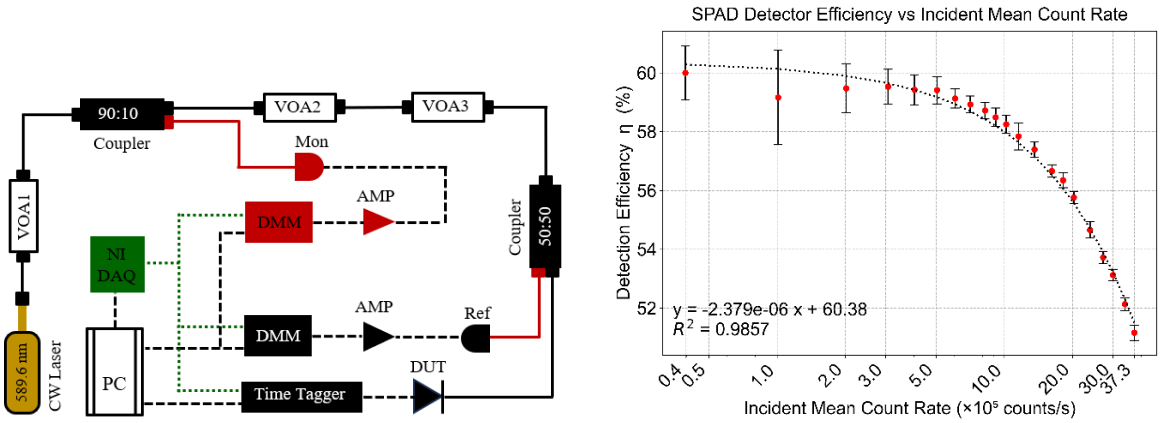


**Fig. 1:** *Schematic of the experimental setup for SPAD calibration (left) and the measured detection efficiency as a function of the incident mean count rate (right). Error bars represent the absolute combined uncertainty corresponding to a relative uncertainty between 0.5 % and 1.5 %.*

## References

[1] M. Durak and M. H. Aslan, Opt. Laser Technol, vol. 36, no. 3, pp. 223–227 (2004).

[2] M. López, H. Hofer, and S. Kück, J. Mod. Opt., vol. 62, no. 20, pp. 1732–1738 (2015).