**Photon number and timing resolution of a near-infrared continuous-wave source with a transition edge sensor**

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The slow recovery time, on the order of microseconds, of Transition Edge Sensors (TESlimits their number resolving and timing accuracy for high photon-flux detection. This is usually resolved by pulsing the light source or discarding overlapping signals, thereby limiting its applicability. In this work, we analyze the output signal when detecting a continuous wave source, and present a procedure to determine amplitude and timing of overlapping pulses. As a direct application, we measure the arrival-time difference distribution of a coherent source in a single spatial mode using a single detector.

The detection of a single photon by the TES produces a pulse with a fast rising edge of tens of nanoseconds, and a decay time of in the order of microseconds) [1]. The longer decay time is attributed to the rethermalisation of the detector with its cold bath through a weak thermal link [2].

Standard techniques for time-tagging a detection event depend on threshold crossing or constant fraction discrimination. These methods do not work when two pulses have a large overlap (see Figure 1), limiting the applicability of TES for high photon-flux detection.

In [3], Fowler et al. proposed a technique based on signal differentiations that works well for the high signal-to-noise ratio typical of the detection of high energy photons ( and X-rays).

For NIR photons the signal-to-noise ratios is lower, and the timing accurancy is affected by the bandwidth limitations necessary to reject false positives.

Our proposal consists in refining the results obtained by signal differentiation by fitting the signal with a model based on a linear superposition of single-photon traces. In the experimental demonstration, we modulate a laser diode (central wavelength 810 nm) to obtain 4 ns light pulses at a repetition rate of 100 kHz and average number of photons and record the TES signal using a digital oscilloscope. We select the traces corresponding to single photon detection and use them to create a model of the detector response.

We then switch the laser diode to continuous wave, record the signal as 10 s long traces, and select all the traces containing two photons. We apply a low-pass filter to the signal and estimate the time-tags by differentiation. When the individual photon detection events are sufficiently separated, we obtain two time-tags which are used to initialise a least-squares fit on the unfiltered trace.

For overlapping pulses we obtain a single initial time-tag. In this case, we fit the signal with a Monte-Carlo Markov Chain (see Figure 1), using the expected amplitude distribution as priors.

This methods resolves arrival-time differences of ~90 ns with an accuracy (fwhm) of ~60 ns. We obtain an arrival-time difference distribution that agrees well with our prediction (see Figure 2).

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| **Fig 1.** Bayesian-fitted (black) 2-photon signal (grey) composed of two laser diode pulse excitations (red, blue) separated by ~90ns, comparable to the rise time of a single photon pulse. | **Fig 2.** Arrival-time separation histogram of a continuously running LD. Bin size = 250~ns. Error bars indicate Poissonian standard deviation. Green line: Theoretical prediction. Due to the finite duration of our oscilloscope traces, the coincidence probability of two photons decreases with increasing separation. |

**References**

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