High Stability InGaAs/InP Single-Photon Detector with Gigahertz Sinusoidal Gating

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More and more applications require the detection of near-infrared single photons with very high throughput. Some examples are quantum cryptography (Quantum Key Distribution, QKD), Optical Time Domain Reflectometry (OTDR), eye-safe laser ranging (Light Detection And Ranging, LIDAR). InGaAs/InP Single-Photon Avalanche Diodes (SPADs) are among the best single-photon detectors for the NIR range (up to 1.7 µm) not only for their good performance, but also for their easier implementation in practical and reliable systems compared to other solutions that require cryogenic cooling. Yet their main bottleneck is the afterpulsing effect, i.e. avalanches triggered by released carriers that were trapped during previous avalanches. This sets the main limitation to the maximum count rate, because in standard gated-mode operation long (tens of microseconds) hold-off time is required after each avalanche.

Techniques based on high frequency (> 1 GHz) sinusoidal gating can dramatically reduce the afterpulsing contribution [1][2]. The main disadvantage is their lower flexibility compared to square-wave detection modules: for example the gating frequency is usually fixed, thus limiting the synchronization with laser sources.

We proposed a more flexible architecture [3] where the gating frequency can be selected in a wide range (800 – 1500 MHz) without any change in the circuit. Instead of using filters to remove the gate capacitive feedthrough at the avalanche readout node, it employs a differential configuration, where the SPAD and a "dummy" device (not sensitive to photons) are gated through two antiphase sinusoidal signals, which cancel each other out. The obtained results are very good: at 1.3 GHz gate frequency, afterpulsing is very low (~ 1.5 %), dynamic range is high (maximum count rate of 650 Mcount/s), photon detection efficiency is high (> 30 % at 1550 nm with laser synchronous with the peak), noise is low (per-gate dark count rate is $2.2 \cdot 10^{-5}$) and timing jitter is low (< 70 ps).

However, the setup employed to characterize this approach was suitable just for an initial experimental phase: it was cumbersome and it suffered from drifts that impaired the effectiveness of the gate suppression. This forces to use a higher detection threshold, with a trade-off between performance and stability of the system. Therefore, we have developed a feedback loop that, by continuously monitoring the output, changes the phase and the amplitude of the "dummy" path signal in order to effectively cancel the feedthrough. Furthermore, we are developing a very compact detection system: the main components, such as frequency generator, amplifiers, phase shifters and attenuators, readout path, have been integrated into a single compact board (7.5 × 5 cm). We will present the preliminary experimental results obtained with this new system, which is suitable for many practical applications where cryogenically-cooled detectors cannot be employed.

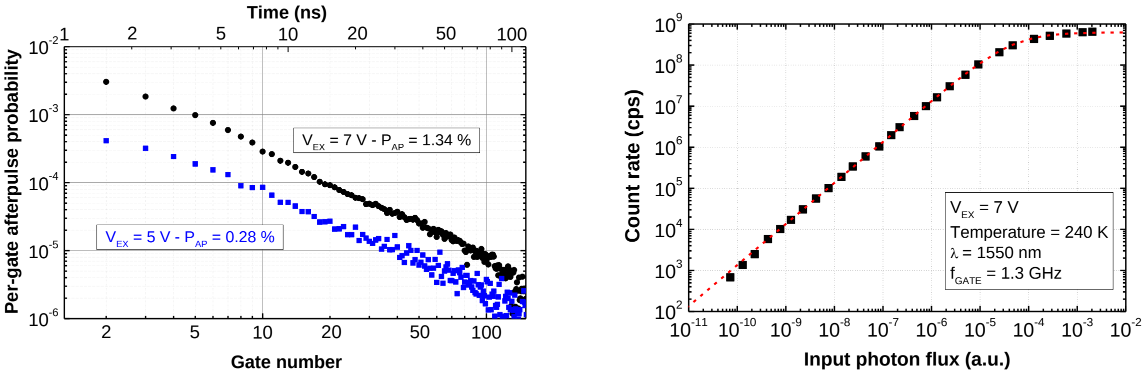

Fig. 1. Left: afterpulsing probability for each gate that follow the initial one where the avalanche occurred. The integrated afterpulsing probability is reported in the legend. Right: measured count rate at various incoming photon flux. Experimental points are in good agreement with the theoretical behavior of a single-photon detector with a count-off time of one gate.

References

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