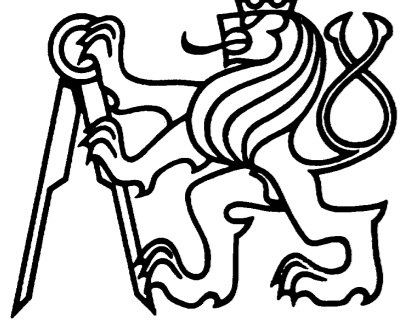


Dark Count Rate Reduction of the SPAD Detection Package for SLR



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Introduction

We are presenting recent achievements in development of the Single Photon Avalanche Detector (SPAD) packages optimized for satellite laser ranging purposes at high laser repetition rates. The commonly used SPAD detector packages are based on 200 μm diameter SPAD chips cooled down to -60°C to lower the effective dark count rate. The detection chips are operated in an active gating and quenching mode. The effective dark count rate of the entire SPAD package is typically 4 kHz for gate rate of 10 Hz. However for modern SLR systems operating typically at 1 kHz rates this effective dark count rate is increasing to 100 kHz and more. This increase is caused by the effect called after-pulsing, which is pronounced by lowered detection chip temperatures. Modifying the SPAD control circuit we succeeded to reduce the after-pulsing influence significantly. As a result the effective dark count rate of the new version of the SPAD detection package is kept well below 10 kHz for the gate rate of 1 kHz. The new SPAD control circuit maintains the reduction of effective dark count rates at higher gate rates by factor of 5 to 20. All the other detection and timing performance of the SPAD detector package remained unchanged in comparison to the previous version.

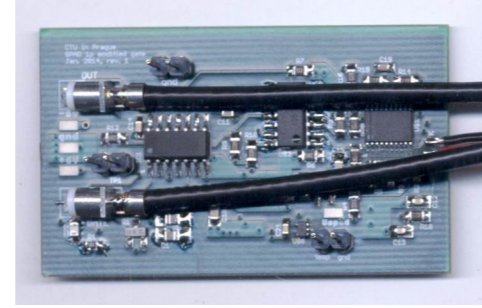


Fig. 1 left - Photograph of SPAD detector package installed in standard housing; right - the PCB of the active quenching and gating circuits.

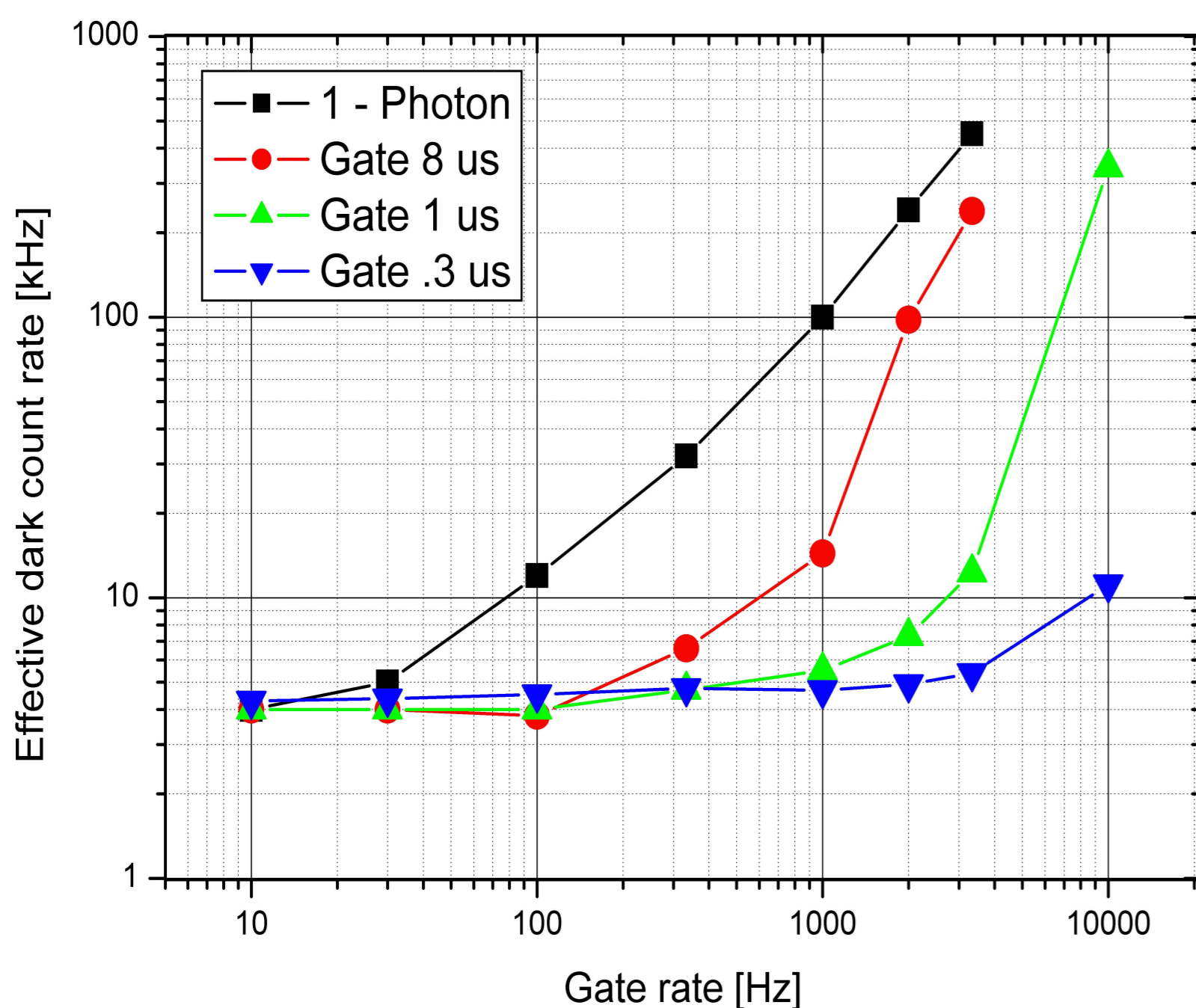


Fig. 2 The dependency of the effective dark count rate on repetition rate of detector gate

New SPAD Circuit Design

Research and development of the Single Photon Avalanche Diodes (SPADs) based on silicon were started in our labs at the Czech Technical University in Prague in 1984. The chip manufacturing technology tuning resulted in a process, internally called K14, which permits the creation of SPAD structures with a diameter 20 to 200 micrometers with timing resolution reaching 50 picoseconds FWHM and an acceptable dark count rate.

The SPADs are operated in Active Quenching and Gating Circuits. Various versions of active quenching and gating circuits have been optimized for various applications.

The newly developed circuitry contains modified classical circuit which is biasing the diode above its break down after receiving gate on signal. In classical design the diode biased voltage was hold constant above break until the diode break was occurred. After the detection of the break down the bias voltage is decrease under the break down voltage and the avalanche is quenched. The diode break can be caused by detection of photon of interests, detection of "noise" photons or thermal break. In another words in classical design the SPAD is always quench after the diode break is occurred, which is giving the strong rise of after-pulsing effect with increasing of the gating repetition rate.

In SLR application the photon of interests are received usually in a narrow time window from 0.3 up to 8 μs . Taking in to account the fact that the 200 μm SPAD has an effective dark count rate of 10 kHz for gating rate 100 Hz one can conclude that the mean gate on time is 12.5 times longer than maximum considered gate length used in SLR. This fact motivated us to come up with new circuitry design where the diode is quenched after occurring of the diode break or with the end of the gating window.

This new gating scheme of the SPAD leads to a dramatic limitation of an effective dark count rate with the increasing gating rate, see fig. 2. The dark count rate improvement by factor of ~ 6 times for gate length of 8 μs and gating rate 1 kHz. For shorter gate lengths the improvement is even more significant.

New Detector Package Properties

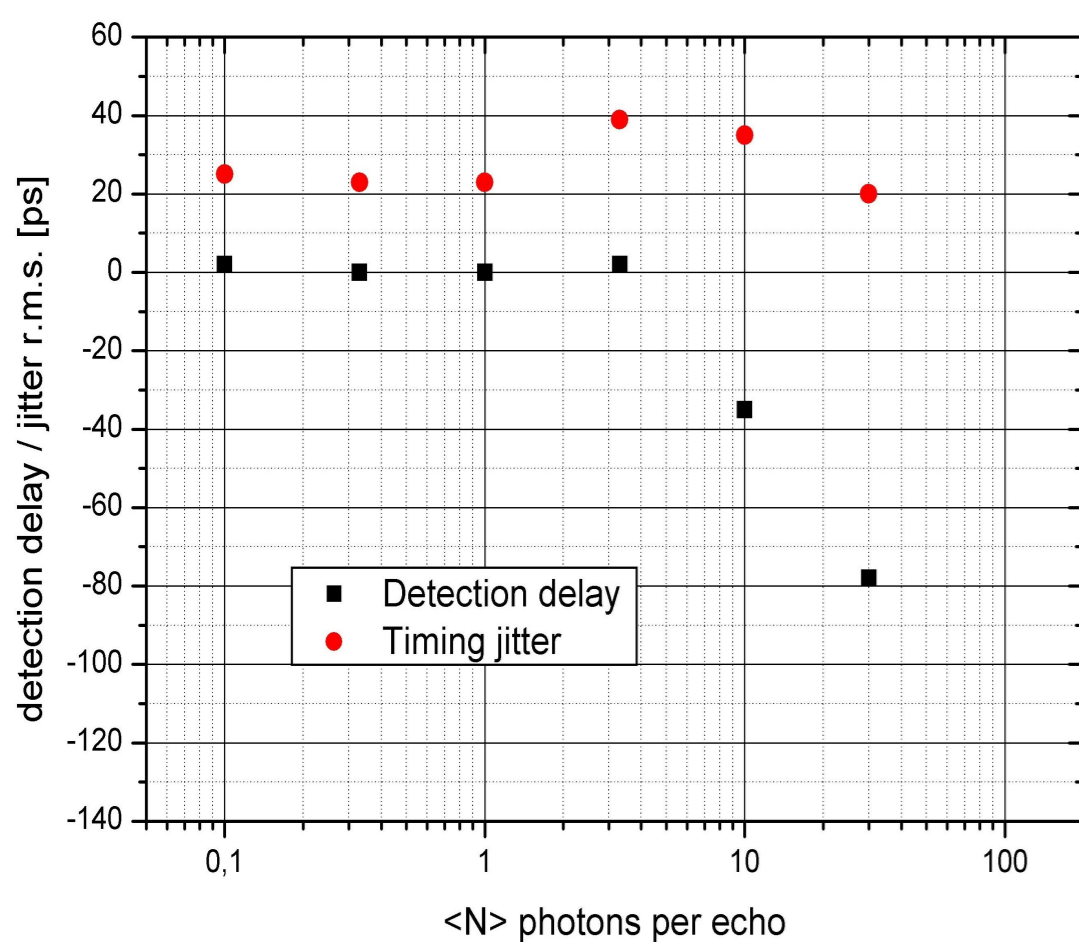


Fig. 3 The detection delay and over-all jitter dependency on a number of received photons.

- Operating principle: gated mode and active quenching
- Detector active area: 100 $\mu\text{m}/200 \mu\text{m}$
- Detection rms resolution: < 25 ps rms
- Quantum efficiency: > 30% @ 532 nm
- Detectable wavelength: 0.35 1.1 μm
- Effective Dark Count: < 20kHz @ gate 8us wide & 1kHz rep rat

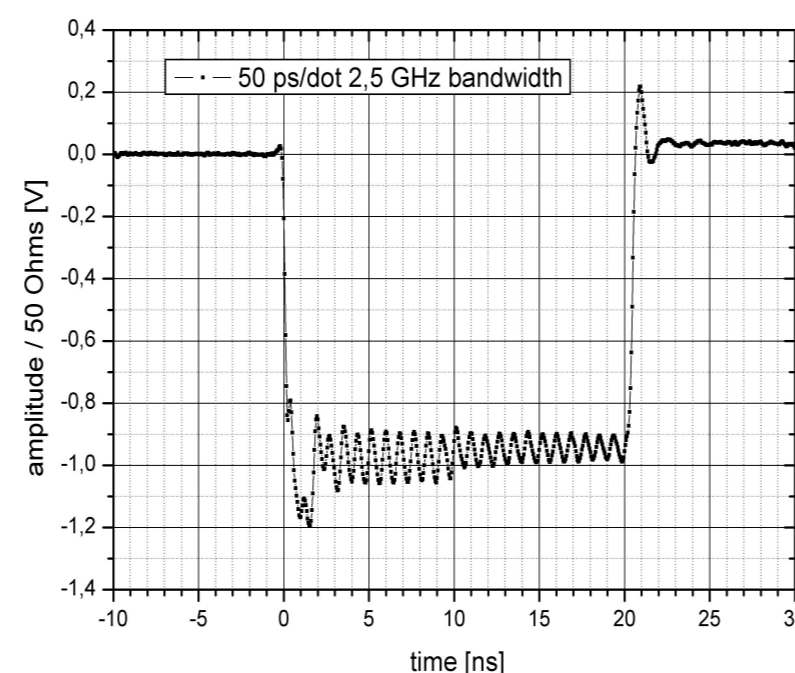


Fig. 4. The shape of the output detector pulse.

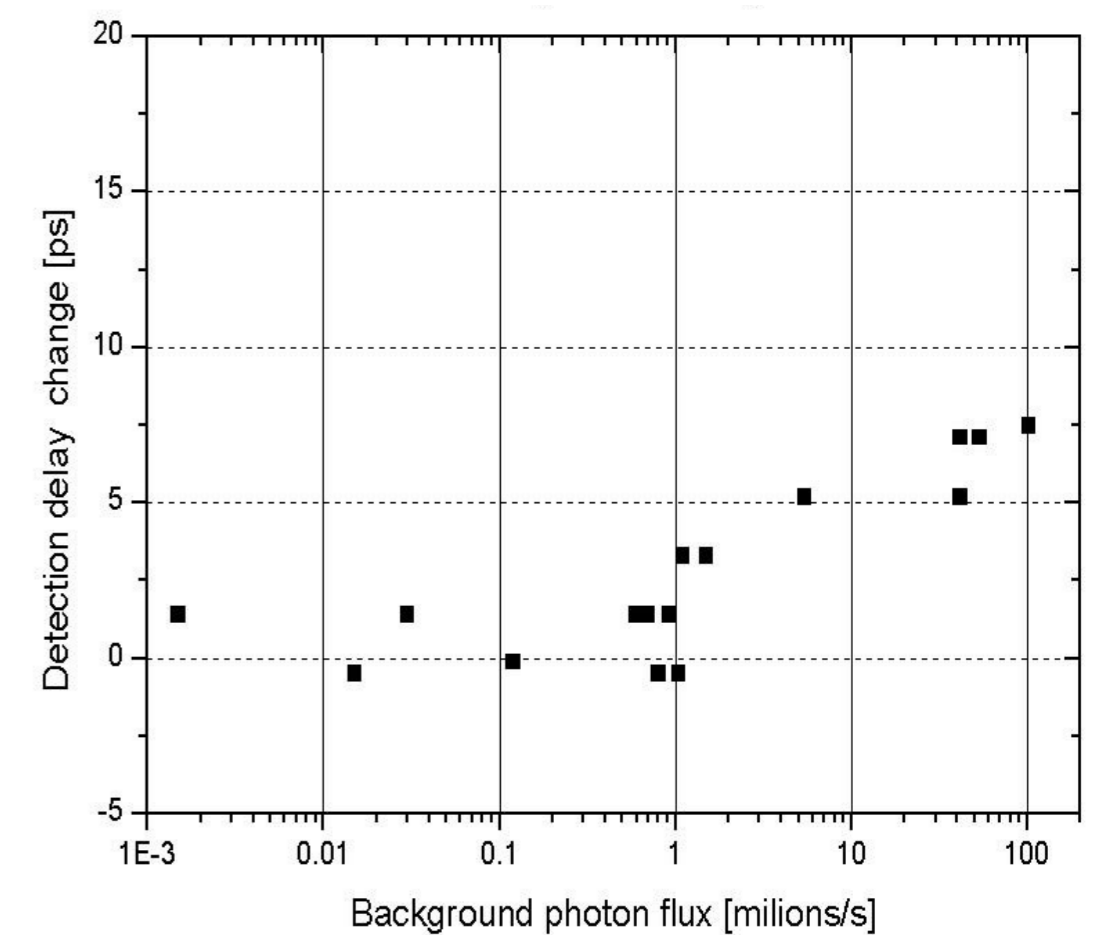


Fig. 5. The detection delay stability in presence of extremely high background photon flux.

Conclusion

The recent modernization of SLR network is putting the requirements on increasing the repetition rate of measurements. The recent detectors however are suffering with increasing dark count rate with increasing repetition rate, which is commonly called after-pulsing and is degrading signal to noise ration. This effect can be effectively reduced by new gating technique which is decreasing the bias voltage under the break with the end of the gate window. It is resulting in dark count rate decreases by factor of ~ 6 times for gate length 8 μs and gating rate 1 kHz. For shorter gate lengths the decrees is even more significant. All the other detection and timing performance of the SPAD detector package remained unchanged in comparison to the previous version.