Photon number resolving in avalanche photodiode photon counter

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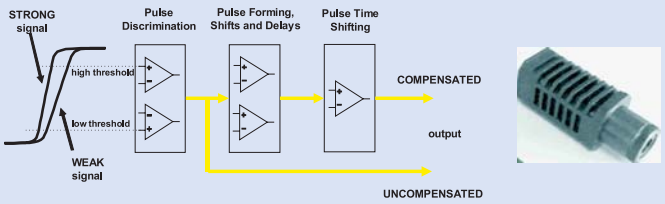
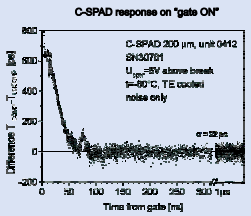
The solid state photodetectors based on silicon avalanche photodiode (SPAD) has been optimized for detection of echo signal in millimeter laser ranging measurements. The structures manufactured using a K14 process are 200 μm in diameter, they exhibit an excellent uniformity of detection delay, sensitivity and timing resolution. The avalanche process nonlinearity enhance the influence of starting conditions to avalanche grow of photodiode output signal. This is the reason why the internal delay of this type of detectors is depended on detected signal intensity, i.e. in case of weak signal depended on number of detected photons. The dependence is in the range of 0-200 ps for photon numbers 1-1000 photons. The active quenching and gating circuit with time walk compensation has been constructed to eliminate this effect (Kirchner et al, 1998). We have used the outputs of the compensation circuit to estimate the photon numbers detected on a shot by shot basis. The mutual time difference between the compensated and uncompensated output pulses corresponds to the photon number. Monitoring this time difference by the Pico Event Timer (P-PET) with picosecond timing resolution enabled us to monitor the echo signal strength fluctuation on a shot by shot basis in an indoor laser ranging experiments. The experimental results are presented.

Signal strength monitoring principle

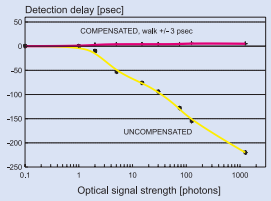


The block scheme of compensation circuit principle. It is realized (see Reference) as an extension of existing active gating and active quenching circuit to eliminate detection delay varying according to signal strength. The avalanche growth speed is dependent on initializing photon number.

Detector package with SPAD, active gating, active quenching and time walk compensation circuits build-in and focusing optics. (40x40x140 mm).



Uniformity of time position difference between C-SPAD outputs in high dynamical range time scale.



Effectivity of "time walk" compensation. Circuit is optimized for individual SPAD chip and individual laser pulse (width, shape, wavelength)

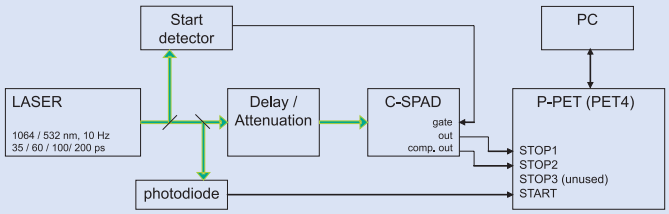
4 channels Portable Picosecond Event Timer

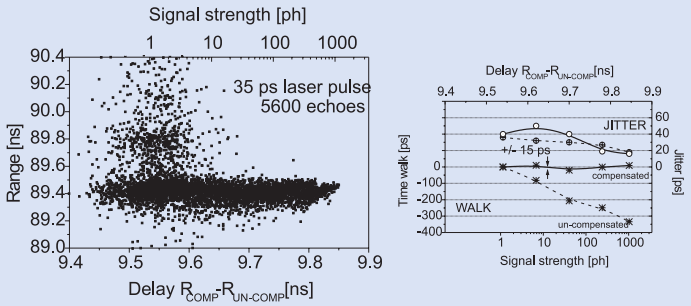
parameters:

• timing resolution	1.2 ps
• timing jitter	< 2.5 ps / channel
• non-linearity	< 2.5 ps / channel
• temporal stability	± 0.5 ps / h
• temperature drift	< 0.5 ps / K
• max rep. rate	100 Hz

P-PET 2003 version has 1 START channel and up to 3 independent STOP channels, it can cooperate with high repetition rate systems sampling from 2 MHz.

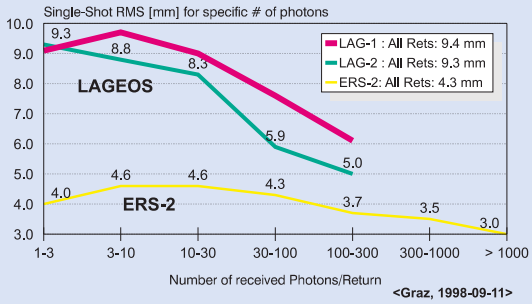
Photon number resolving





Experimental data from ranging experiment with fixed range using 35 ps laser pulse and optimized compensation circuit (experimental sample only, 15 ps jitter over all dynamical range). The correlation between signal strength and outputs mutual delay is labeled on graphs and it can be used for every shot signal strength determination in ranging experiments with uncertain range.

Laser ranging experiment



Photon number resolving application in satellite laser ranging, the single shot precision is increasing with increasing with photon number per echo.

Conclusion

We have presented the principle and performance of an all solid state photon counting detector package and its use for photon number resolving. The package detects optical signals in the range <0.001 - 2000> photons (i.e. >10^6) in the wavelength range 250 to 1100 nanometers. The timing resolution is 5 to 22 picoseconds FWHM for the input signal strength one thousand to a single photon, respectively. The built in compensation circuit maintains the detector delay dependence on the input signal strength flat within several picoseconds over the entire dynamical range. The entire detector package C-SPAD is compact, rugged and simple to operate within -20 ÷ 30 °C, no adjustment and tuning is required within 3 years of field operation. The detector dual outputs enables photon number estimate on a shot by shot basis.

Reference

KIRCHNER, G., KOIDL, F., BLAZEJ, J., HAMAL, K., PROCHAZKA, I., Time Walk Compensated SPAD: Multiple Photon Versus Single Photon Operation, Proc. SPIE Vol. 3218, p. 106-112, *Laser Radar Ranging and Atmospheric Lidar Techniques*, Dec 1997, ISBN 0-8194-2650-4