SPAD Time Walk Compensation and Return Energy Dependent Ranging

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Abstract

The Single Photon Avalanche Diode (SPAD), used above its break voltage to detect single and multiphotons with picosecond accuracy, introduces time walk effects when return energy exceeds the single photon level; when received energy is increased - to 1000 photons and more - the measured epoch time is shifted 240 ps or more towards earlier epochs, introducing range errors of up to 40 mm, when measuring distances to satellites.

As already published previously, we use the correlation between small changes (≈20 ps) of the avalanche rise time and the corresponding time walk to compensate automatically this time walk effect. The actually used versions of these circuits reduce the time walk effect to below ±10 ps, for a dynamical range from single photon up to more than 1000 photons. The SPAD chip - cooled via 3-stage Peltier elements - and the electronics are temperature stabilized, the stability is within ±5 ps from -20° to +35° Celsius.

In addition, measuring time differences between compensated and uncompensated SPAD output with an ultra-high accuracy event timer (P-PET: Portable Picosecond Event Timer) allows a direct return signal strength determination; using this to select returns with specific photon numbers, a significant improvement of single shot RMS can be achieved.

1. Introduction

The automatic time walk compensation scheme has been described already in previous papers (Kirchner, Koidl: 1995, 1996); the circuits have been improved during the last years to compensate the time walk over a dynamic range of 1 - 2000 photons (fig.1); the remaining ±10 ps maximum is within the capability of our measurement chain.

The circuit transfers the 0-20 ps rise time differences into 0-240 ps time shifts; in spite of this 1:10 transformation, the overall jitter of the system is even improved, especially in the critical range of a few photons (fig. 2); the unavoidable random fluctuations of return signals from satellites had caused here additional jitter due to the time walk effects, which is now eliminated due to the compensation circuits.

The upper limit of about 2000 photons is mainly due to the limited contrast ratios of the Nd:YAG laser systems; due to leakage in pulse selection systems (Graz: 1:500 ratio specified), the SPAD begins to see already the leaking pre-pulses of the full mode-locked train, thus detecting single-photon events before any high photon burst arrive; these pre-pulses are also detectable within the strong returns from low satellites, and are used in Graz for automatic offset pointing to reduce return signal strength (Kirchner, Koidl 1996)

2. Temperature Stabilization

The SPAD chip, mounted on 3-stage Peltier elements, is cooled to -60°C to decrease the noise down to about 50 kHz; the built-in temperature sensor allows to close the temperature control loop to stabilize the chip temperature at –60 °C ± 0.2 °C.

The ultra-fast comparator chips, used for discrimination and time walk compensation, also show drifts of about 7 ps/°C; therefore all electronic circuits are kept now at constant temperature, thus ensuring that all critical adjustments of the time walk compensation circuit remain constant over a range from -20°C to +35°C; this allows mounting of the whole SPAD detection package directly on the SLR telescope.

Using this time walk compensation, the SLR system in Graz operates routinely up to multiphoton returns, achieving 100% return rates, which is desirable for many obvious reasons (e.g. maximum possible return numbers, better Normal Point Precision; easier tracking, shorter acquisition times etc.); it is also desirable for our present and future multi-color rangings. To keep return energy in the range allowed by the time walk compensation circuit, our automatic tracking program identifies all valid returns and checks also for presence and percentage of pre-pulses (due to leakage of the pulse selector), which are indicating higher return signal levels; the automatic tracking routines perform online offset pointing in such a case, thus keeping return energy - reliably and independent from any observer action - within the tolerable limits for the automatic time walk compensation circuits (Kirchner, Koidl 1996).

3. Return Signal Energy Selection

The time walk compensated SPAD delivers the compensated and the uncompensated output; measuring the delay between these two pulses (0 to 240 ps) gives a direct indication of the return signal strength, or number of photons, for each return pulse (Fig. 1); to reduce the single shot RMS, this information can then be used to select returns of specified energy ranges only.

This has been tested for LAGEOS-1, LAGEOS-2, and ERS-2 (Fig.3); as we can expect from our relatively small SLR system, most Lageos returns are in the range between few and some 10 photons, while ERS-2 delivers also significant number of returns in the range above 100 photons.

Selecting the returns according to their energy, the single shot RMS can be reduced significantly for the high energy returns (Fig. 4); this is due to reduction of satellite signature contributions (Lageos) and also due to reduced contributions of the SPAD at higher photon levels (see also Fig. 2).

4. Limitations and Future Aspects

The accuracy and resolution required for these measurements (0-240 ps, <10 ps resolution), are not achievable with standard commercial TI counters; we used the P-PET: Produced by the Prague University (Hamal, Prochazka, 1998), using Dassault Event Timer modules; this unit has a 1.2 ps resolution, <7 ps RMS in TI mode, excellent linearity and stability.

Another limitation is the - relatively - small amount of high-energy returns for our small SLR system: While it is powerful enough to deliver up to 20000 returns per Lageos pass (10 Hz Laser), or an average of >2000 returns per ERS pass, the number of high energy returns is small; converting these selected returns into Normal Points, the formal NP precision (calculated with 1/SQRT(N)) for the selected returns never reaches that for the total return number (Fig. 5). However, for more powerful stations this might be an easy way to keep the returns at the desired high level (e.g. above 100 for Lageos), while still allowing 100% return rates, and offering the chance of reducing jitter contributions from satellite signature and from the SPAD.

Conclusion

The satellite laser ranging system, based on time walk compensated SPAD detector package, is capable of ranging to Lageos satellites with single shot jitter of 5 mm, and to low echo pulse spreading satellites, like ERS 1,2 with jitter of 3 mm, once the echo signal strength of the order of 100 photons per echo can be maintained. The time walk and temperature induced biases can be maintained on the one millimeter level.

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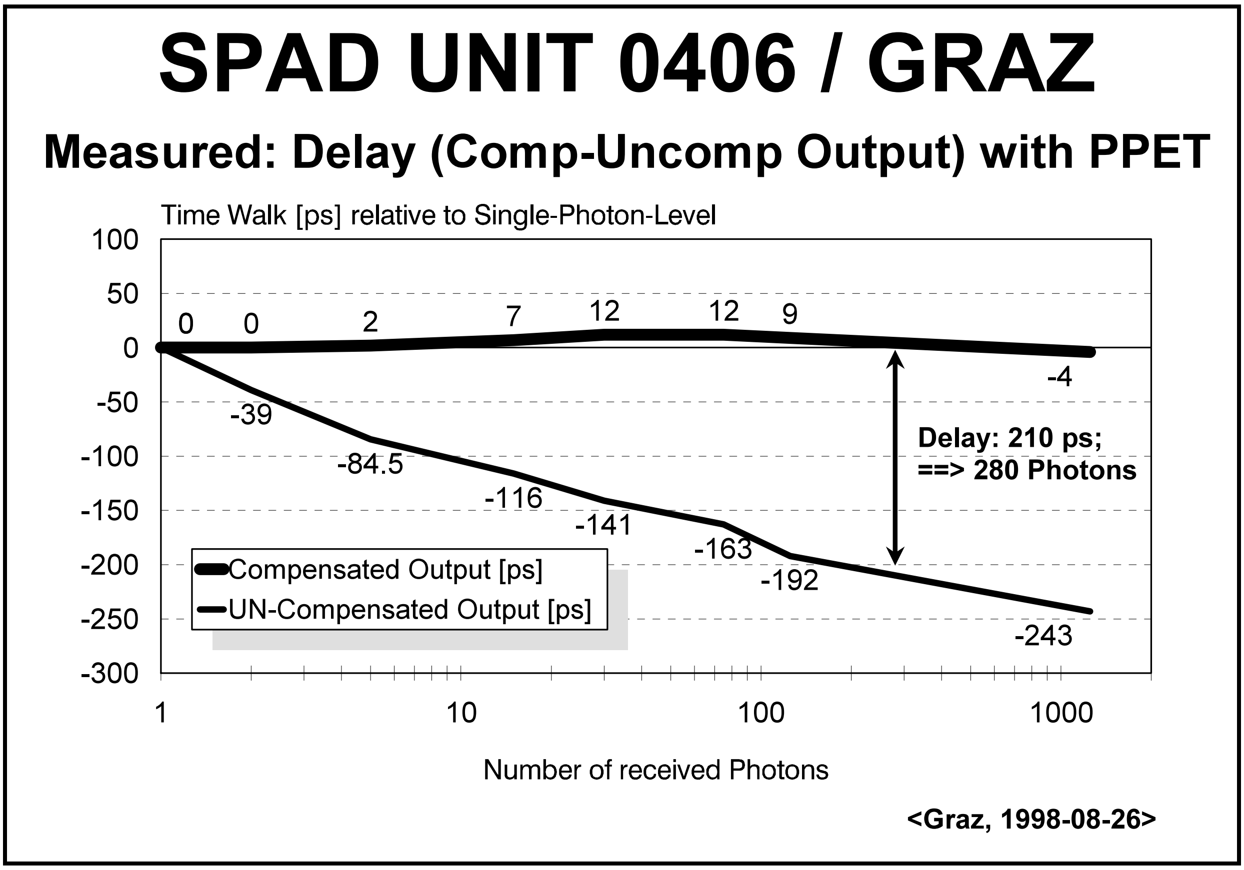

Figure 1: SPAD Time Walk Effects, and their almost complete elimination

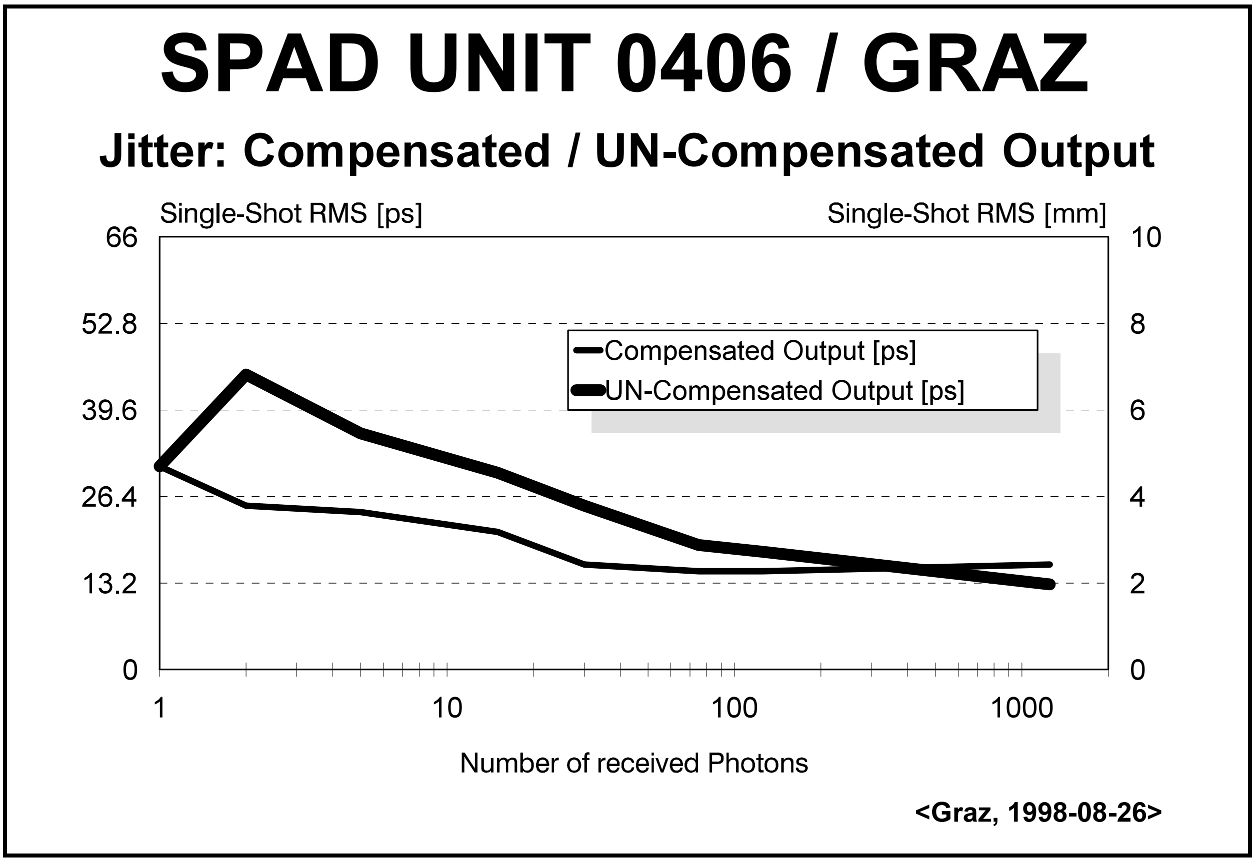

Figure 2: Jitter Reduction after Time Walk Compensation

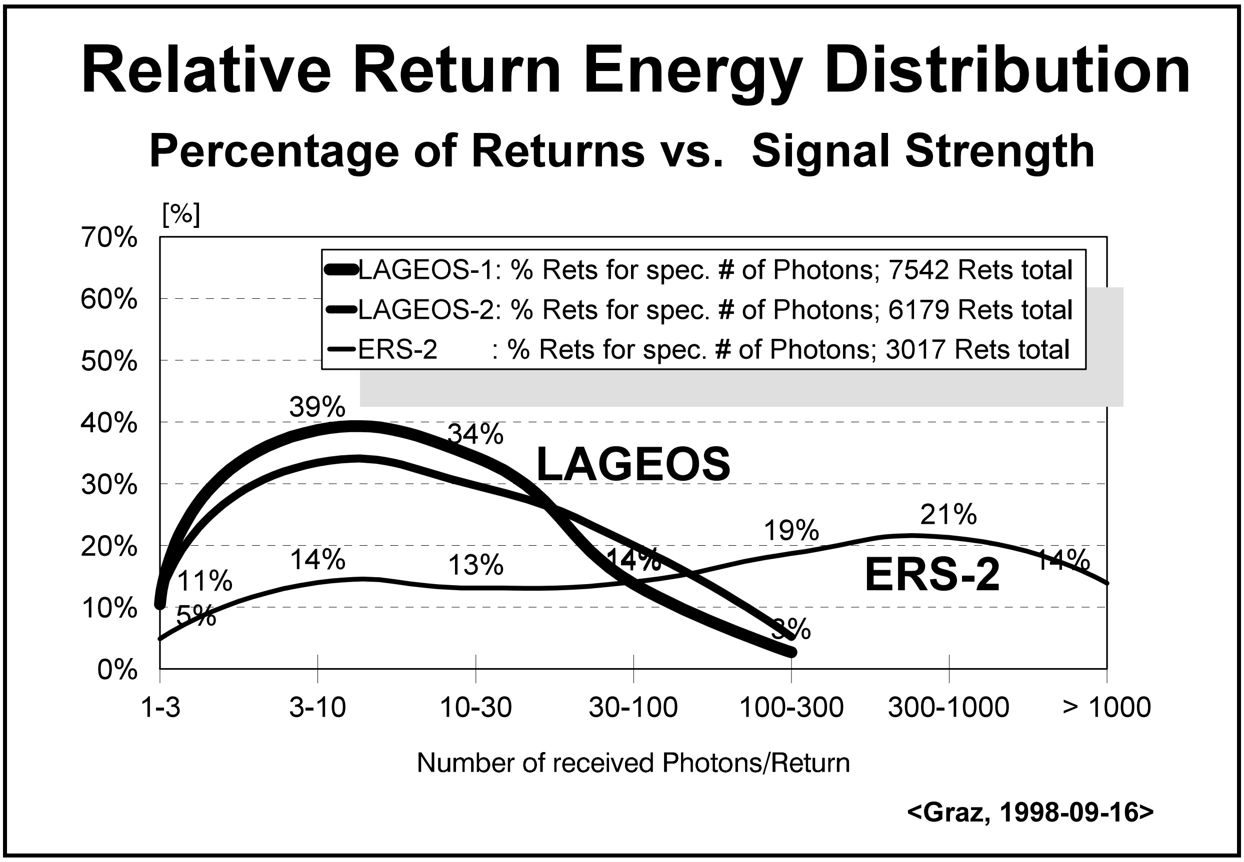

Figure 3: Distribution of Return Energy for Different Satellites

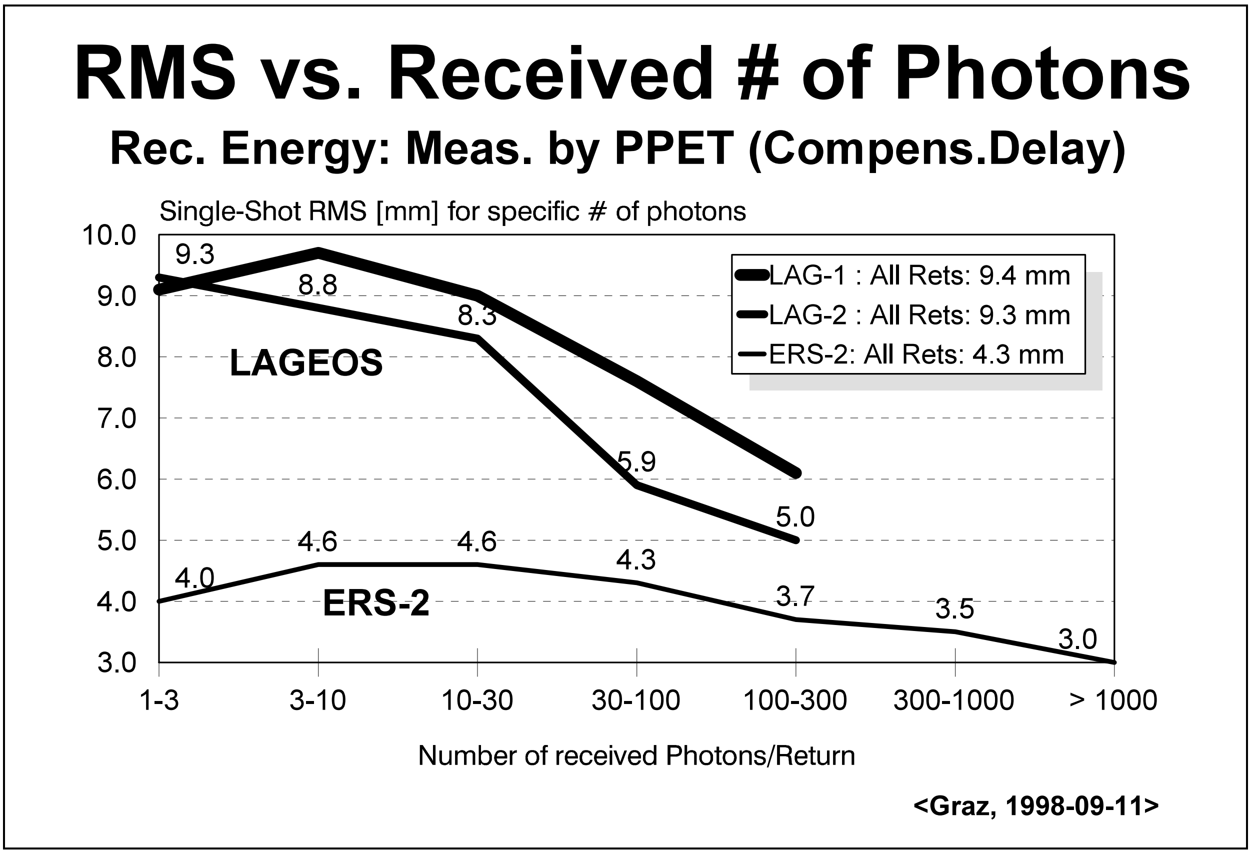

Figure 4: Reduction of Single Shot RMS by using Returns with Selected Energy only

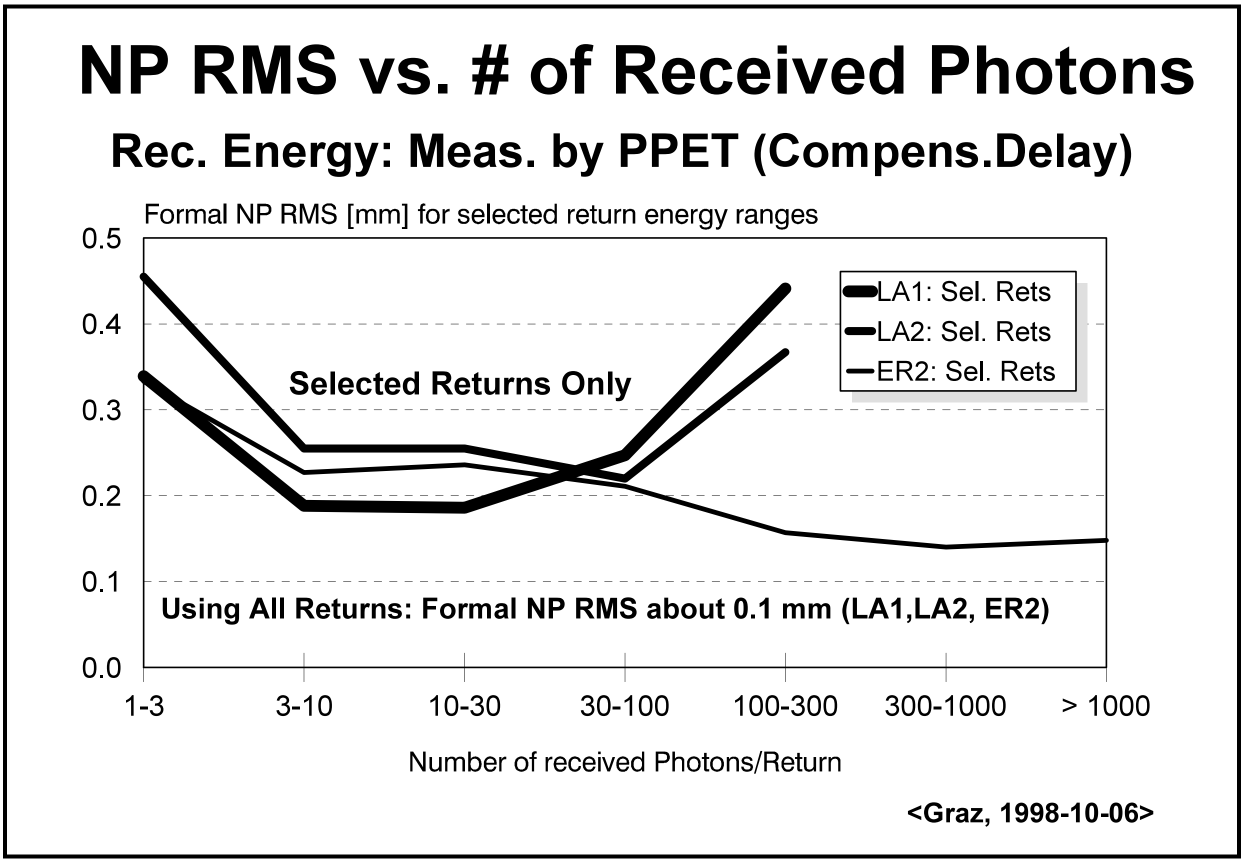

Figure 5: Formal NP RMS for energy-selected returns