Digital Range-bias Correction at SLR Station Riga-1884

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Abstract. A method and technical tools for correction of range-bias caused by variation of photo-multiplier (PM) output pulses in amplitude and shape are considered. The method is based on preliminary estimation of a relationship between certain integral parameter of PM pulses and corresponding range-bias. This integral parameter is measured for each PM pulse in parallel with measurement of basic time interval under real ranging conditions and used further for range-bias correction by data post-processing. Application of this method at the SLR-station Riga-1884 allows to reduce the range-bias many-fold. In particular, the RMS error has been reduced from 14.2 to 3.1 cm for satellite GFO-1 ranging.

Key words: Satellite Laser Ranging. Range-bias. Error correction.

1. Introduction

As known, in the course of satellite laser ranging an energy of returned laser pulses is varied in a wide range. This is caused by various factors, like energy losses during laser pulse passage through the Earth's atmosphere. If a photo-multiplier (PM) is used as a receiver of returned laser pulses, the pulses at PM output likewise are varied both in amplitude and shape. To detect uniquely a time instant of laser pulse returning, some discriminator of PM pulses is needed. In the simplest case of detecting this instant by an amplitude discriminator (as PM pulse crossing certain constant level), PM pulse variation increases error of measuring the distance to satellite (range-bias), and particularly:

- increases single-shot random error;
- introduces some distance-depended error which is caused by variation of returned laser pulse power depending on the angle of satellite observation;
- introduces some systematic error depended on the atmospheric conditions, mean of distance to different satellites, etc.

Particular value of the resulting range-bias depends on the PM construction, its sizes, system of dynodes, parameters of preamplifier, etc. At SLR station Riga-1884 the resulting range-bias reached 30 till 90 cm when various PM (FEU-135, FEU-79, FEU-128, FEU-164, and R5600P) were used.

Conventionally Constant Fraction Discriminators (CFD) are used to select the amplitude-independent component of PM pulses. However, specific of CFD operation gives no way to solve the problem sufficiently. To examine CFD possibilities for such application in more detail, we carried out following experiment.

During the measurement of the fixed distance (calibration mode), the energy of returned laser pulses at PM input has been changed deliberately by neutral optical filter with circular variable density. By this means we simulated possible real conditions of ranging the different satellites. Amplitude of the corresponding pulses at PM output was periodically varied from 0.2 to 2.5 V approximately. Further these PM pulses were discriminated by CFD "TENNELEC TC-454" and used directly as Stop-pulses for time interval measurement. This experiment clearly showed (Fig.1) that results of time interval measurement (corresponded to the fixed distance) are varied in a wide range (± 4 nsec approximately) in line with variation of laser pulse energy. In other words, CFD is not capable to reduce sufficiently both the systematic and random components of range-bias as well.

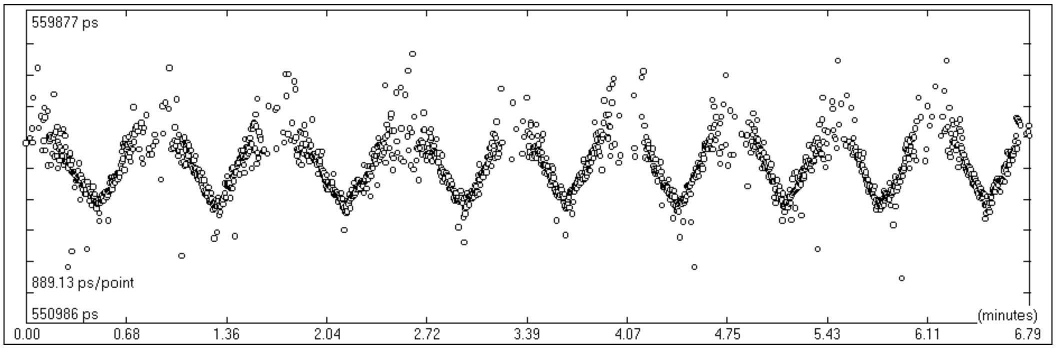

Figure 1. Results of CFD testing

Taking into account the mentioned limitations of CFD, we have applied additionally a method of range-bias reducing called further **Digital Range-bias Correction** (DRC). Briefly DRC includes following operations:

- defining of some integral parameter τ_{Sj} which reflects current parameters of PM pulses and, within certain limits, is correlated with range-bias;
- measuring this parameter τ_{Sj} for every pulse at PM output in parallel with corresponding basic time interval T_j;
- identification of the relationship between the values of integral parameter τ_S and actual range-bias Δ_T in the form of corrective function $\Delta_T(\tau_S)$;
- range-bias correction as such by post-processing the data obtained under real ranging conditions in accordance with expression: $T_j^* = T_j - \Delta_T(\tau_{Sj})$.

This method, its implementation and preliminary results of application at SLR station Riga-1884 is considered below in more detail.

2. Defining and measuring the integral parameter of PM pulses.

In our case the integral parameter τ_S of PM pulses has been chosen empirically with regard to simplicity of its measurement and sufficient correlation with range-bias values. In particular, it is determined by the width of triangle-shaped pulse obtained by special PM pulse conversion (Fig.2).

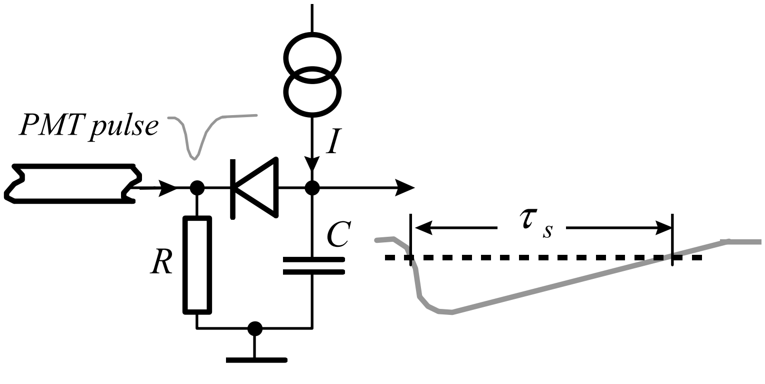

Figure 2. Schematic diagram of determining the parameter τ_S

The capacitor C is rapidly charged by PM pulse to certain negative level and simultaneously slowly discharged to initial level by small constant current. Timing constant RC of charging is much greater than PM pulse width. Correspondingly the width τ_S of the converted by this way PM pulse reflects approximately the value of its area. Therefore this parameter is arbitrarily called below the pulse area (while it is expressed in nanoseconds).

Note that real implementation of the PM pulse converter is not so simple as shown in order that it precise operates in a wide dynamic range. For example, a high performance preamplifier is needed to well match PM output with converter input. Additionally PM pulses at the converter input should be previously selected from common PM pulse flow by fast switch to protect the conversion process against distortions.

The PM pulse area is measured in parallel with basic time interval corresponded to the ranging delay. To do this, we used the special feature of our Selective Time Interval Counter (SETIC) [1] to measure continuously several time intervals in every ranging cycle (Fig.3).

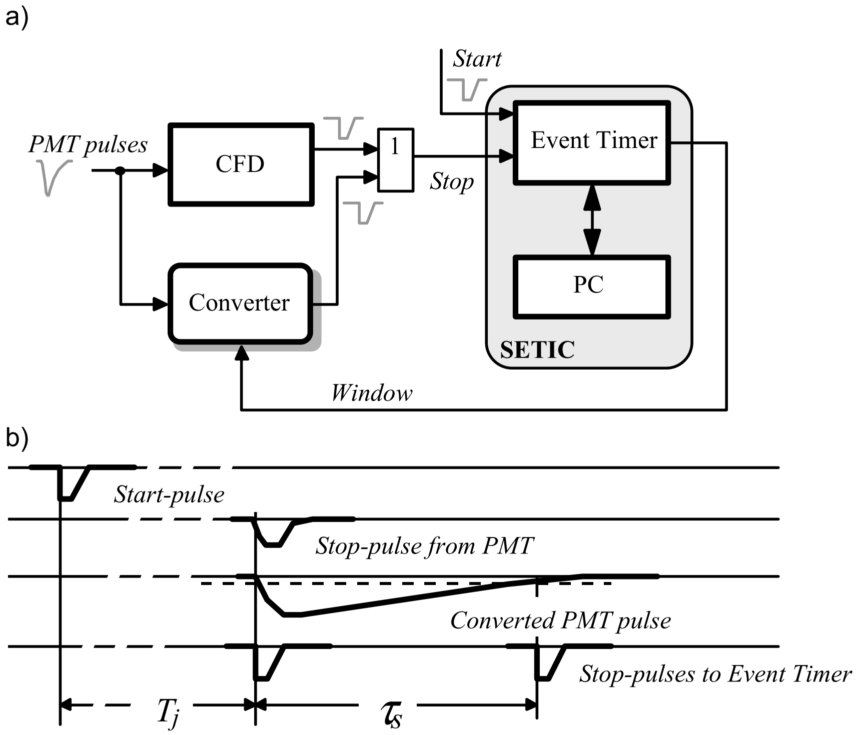

Figure 3. Schematic block diagram a) and time diagram b) showing the principle of parallel measurements

Hardware for measurement of PM pulse area has been designed as a stand-alone device fully compatible with SETIC.

As a whole in this manner we can measure the area of PM pulses with LSB resolution about 9 bits in the range of their amplitude variation from 0.2 to 2.5 V. That covers practically full range of PM pulse amplitudes for different satellites observed at our SLR station.

3. Evaluation of the corrective function

Evaluation of the corrective function $\Delta_T(\tau_S)$ is the key procedure of DRC method, which appreciably defines the end result of its application. This procedure is performed at two stages: initial data creating and corrective function calculation.

The initial data are created in calibration mode (measurements of the fixed distance) under conditions when energy of returned laser pulses is smoothly varied in a wide range by neutral optical filter with circular variable density. Continuous measurement the same constant distance has resulted in two curves (Fig.4): the estimates $\{T_j\}$ of basic time intervals (upper diagram) and estimates $\{\tau_{Sj}\}$ of PM pulse area (lower diagram), both versus the same real time.

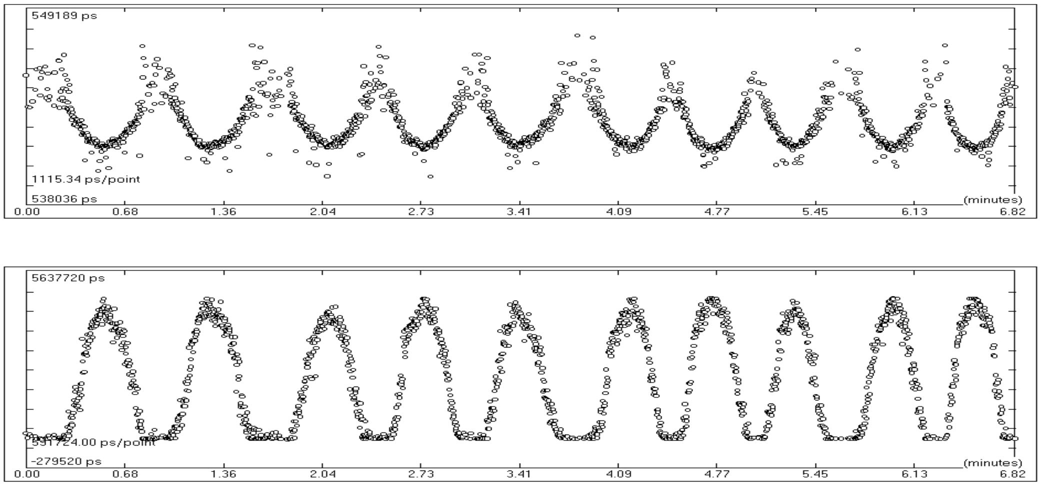

Figure 4. An example of initial data representation

Ordered set of pairs $<T_j;\ \tau_{Sj}>$ determines some digital many-valued function $T_j(\tau_{Sj})$ where values $\{\tau_{Sj}\}$ are determined in the full range of their possible variation under real conditions of satellite ranging (Fig.5).

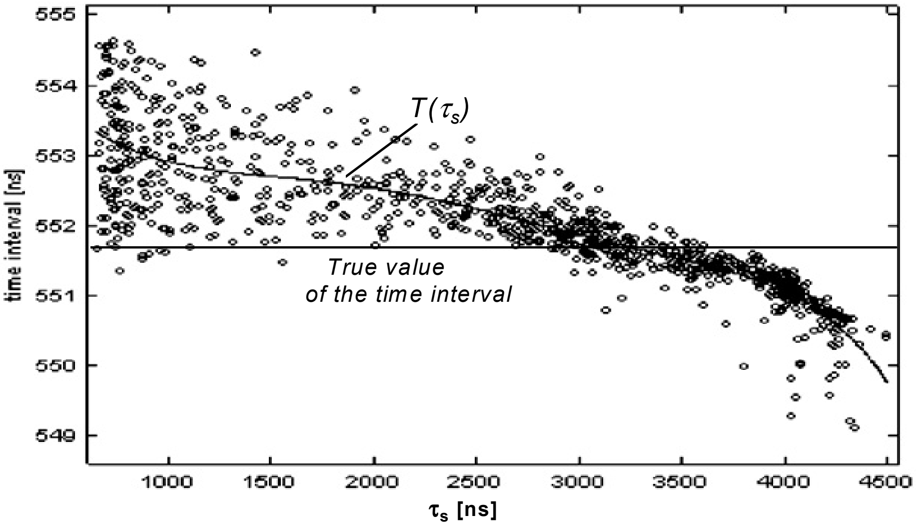

Figure 5. Experimentally obtained relationship between $\{\Delta_j\}$ and $\{\tau_j\}$, and calculated on this basis corrective function.

Desired one-valued function $T(\tau_S)$ is obtained from the initial data as a polynomial fit of the function $T_j(\tau_{Sj})$ using least-squares method. Previously some irregular points have been eliminated from initial data by special filtering algorithm based on Wavelet Transform. Finally the corrective function is calculated as $\Delta_T(\tau_S)=T(\tau_S)-T_0$, where T_0 is true (priori known) value of measured time interval corresponded to the fixed distance.

Evaluated by this means corrective function $\Delta_T(\tau_S)$ generalizes features of all input circuits (preamplifier, discriminator, etc.; not only PM) and further is used for digital correction of measurement results obtained under real conditions of satellite ranging. Note that the corrective function is not varied essentially under different operating conditions and can be used for any length of time.

4. DRC performance testing

As is followed from Fig.5, DRC eliminates a component of range-bias correlated with τ_{Sj}. This component is quite essential and can reach to tens of cm. Correspondingly, DRC is particularly advantageous for the cases when amplitude of PM pulses is varied in a wide range. Fig. 6 demonstrates DRC efficiency in the worst case of PM pulses amplitude quasi-uniform distribution in the full range (0.2 to 2.5 V), despite the fact that the real conditions are not so drastic.

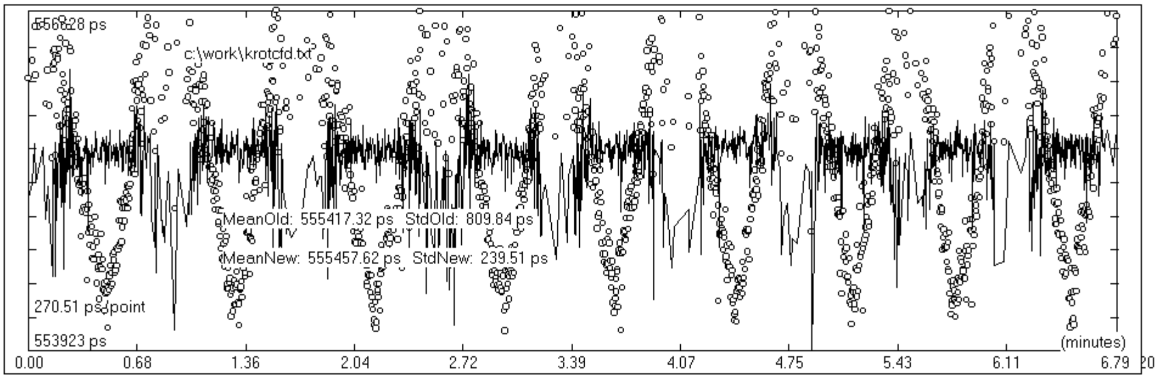

Figure 6. Results of initial data correction by DRC. (Circles show the samples before correction)

As shown, the RMS error of measurement results has been decreased after DRC from 810 down to 240 psec. It is important to note, that practically the same result (250-300 psec) has been obtained when CFD was replaced by a simple amplitude discriminator.

Uncorrectable component of range-biases is caused mainly by a jitter of pulses at the CFD output. As expected, this jitter depends on the PM pulse area (see Fig.5). On average, the CFD jitter causes range-bias RMS about 3 cm.

5. Preliminary results of DRC application for satellite laser ranging

Considerable scattering of the PM pulse amplitudes under the real ranging conditions is illustrated for one passage of the satellite GFO-1 (Fig.7).

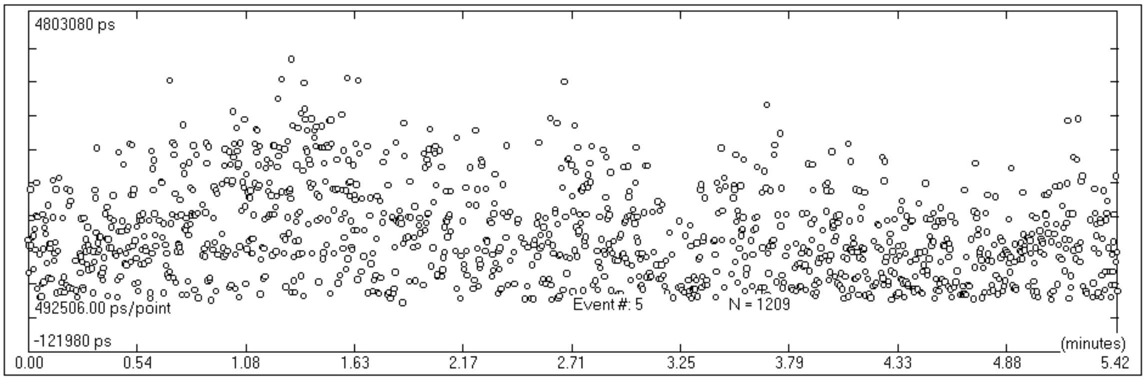

Figure 7. Scattering of the PM pulse areas for one passage of the GFO-1 satellite.

The area of PMT pulses is varied practically in the full range what corresponds to amplitude variation from 0.2 to 2.5 V approximately. Large scattering the PM pulse amplitudes is inherent also for the CHAMP and AJISAI satellites.

As already noted, DRC allows to minimize both random component and systematic component of range-biases caused by variation of PM pulse parameters. Table 1 demonstrates DRC efficiency for random error minimization (Full Rate) for some passes of different satellites.

Table 1.

Satellite Name	*RMS error before DRC [cm]*	*RMS error after DRC [cm]*	*Ratio*
CHAMP	11.67	3.21	3.64
CHAMP	12.65	3.22	3.93
CHAMP	14.20	3.01	4.72
ERS-2	7.22	2.76	2.62
ERS-2	4.59	2.96	1.55
ERS-2	3.94	2.84	1.39
GFO-1	12.46	3.15	3.96
TOPEX	7.33	4.05	1.81
TOPEX	13.16	4.75	2.77
TOPEX	7.76	4.37	1.78
TOPEX	6.84	4.58	1.49

As the data of Table 1 suggest, DRC is particularly attractive for satellite ranging where PMT pulse amplitudes are scattered in a wide range (as for CHAMP satellite). But in any other cases it allows to reduce RMS error practically to the same constant value independently from initial data scattering (except TOPEX satellite, where retro-reflector array parameters are specific). This value (about 3 cm) is limited mainly by the actual characteristic of our laser telescope system. With regard to that we use additionally special (adapted to the features of our SLR station) procedure of irregular samples elimination. After this procedure the RMS error has been approximately halved (reduced to 1.5-2 cm).

In regard to the systematic component of range-biases, even at the first stage of experiments the DRC allowed to minimize it down to range -48/+28 mm as compared to the early existed range -160/+610 mm (Fig.8). It seems that this error can be minimized still further by finer adjustment of the measurement units.

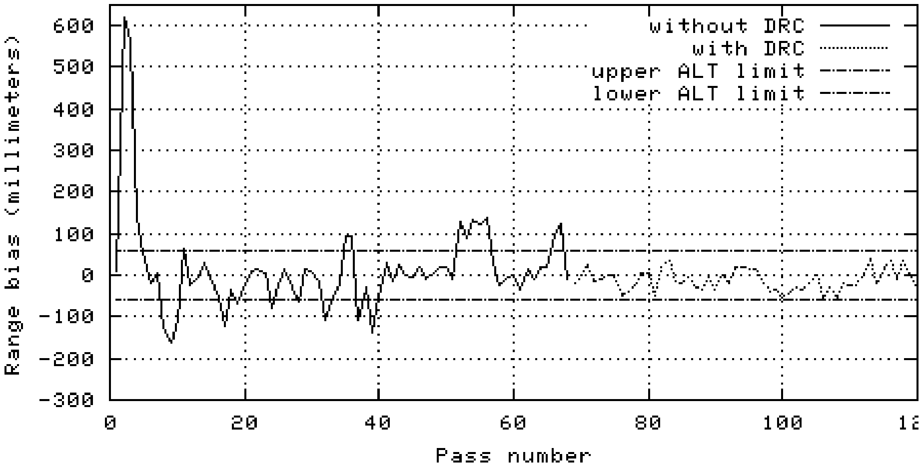

Figure 8. Systematic range-bias history for LAGEOS 1&2 before and after DRC application. Data was taken from Texas University Center of Space Research calculations for SLR station Riga-1884

6. Conclusions

1. Considered DRC method leads to the good results when conventional hardware tools of range-bias minimization (such as CFD) are inadequate. DRC can be usefully employed in combination with

different types of PM pulse discriminators to improve the end result of satellite ranging. It is not improbable that similar approach can be useful for the case of using other laser pulse receivers (such as SPAD [2-4]).

2. Development and application of DRC has allowed to radically perfect the main operating characteristics of our SLR station. In particular, we have reduced the random component of range-bias to the limit (1.5-2 cm) tolerated mainly by the features of our SLR station. At the same time the systematic component of range-bias has been essentially decreased.
3. Relative simplicity of DRC implementation within our SLR station is appreciably caused by the special features of measurement equipment being used (such as possibility to measure by SETIC several time intervals in every ranging cycle, high software-hardware integration).
4. Principally DRC is well suited for application in combination with simplest PM pulse discriminators. However, up to now there are some problems with using the amplitude discriminator if amplitude of PM pulses is small enough. Therefore we project to enhance the performance of the existing DRC implementation with the aim further to replace CFD by much simpler and cheaper technical solution.

REFERENCES

1. *Yu. Artyukh, V. Bespal'ko, K. Lapushka, A. Ribakov , V. Vedin.* Selective Time Interval Counter for SLR Applications. Proceedings of 11th international workshop on Laser Ranging. Vol.2. 510- 515. Deggendorf 1999.
2. *I. Prochazka, K. Hamal, J. Blazej.* Millimetre Ranging and Echo Signal Strength Monitoring with SPAD Detectors. Proceedings of 11th international workshop on Laser Ranging. Vol.2. 452 – 457 Deggendorf. 1999.
3. *G. Kirchner, F. Koidl, I. Prochazka, K. Hamal.* SPAD time walk compensation and return energy dependent ranging. Proceedings of 11th international workshop on Laser Ranging. Vol.2. 521- 525. Deggendorf 1999.
4. *G. Appleby, Ph. Gibbs.* Monitoring potential range biases in single-photon SLR systems. 9th international workshop on Laser Ranging Instrumentation. Vol.1. 92 – 102. Canberra .1994.
5. *J. Degnan.* Effects of detection threshold and signal strength on LAGEOS range bias. 9th international workshop on Laser Ranging Instrumentation. Vol.3. 920 – 926. Canberra 1994.