Contribution of the Pico Event Timer to satellite laser station performance improvement

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ABSTRACT

To contribute to future laser ranging we have developed the Pico Event Timer (PET), consisting of two, or more, Event Timing Modules, Clock Generator Module, Input Trigger Module, Control Unit, Range Gate Generator, Microprocessor Module and the Software Package. The Pico Event Timer is designed and constructed entirely for the purpose of millimetre precision laser ranging to Satellites and the Moon. Timing Modules provide the picosecond event timing, Clock Generator Module supplies the precise clock frequency for timing, the Gate Generator Module maintains the smart arming and gating of the entire timing system. The Microprocessor Module equipped with a powerful operating system dedicated for parallel processing provides a real time control of the device, evaluates in a real time the gating epochs, identifies the measurements pairs and controls the data flow between the PET device and the host computer. The PET has been employed at five laser ranging stations for millimetre precision, two wavelength satellite laser ranging and for calibration reference purposes.

Keywords: satellite laser ranging, calibration, systematic error, picosecond timing

1. INTRODUCTION

Satellite laser ranging is an attractive measuring technique widely applied in geodesy, geophysics, global ecology and other disciplines. The ranging accuracy has increased from meters in early seventies to one centimetre in late nineties. However, the data users community requires the accuracy increase to a millimetre level. The ranging accuracy is limited by the ranging machine errors, the atmospheric propagation correction error, target error and by the orbit modelling and data aggregation errors. All of these contributors consist of both random and systematic components [3]. One of the main contributors to the ranging machine error budget is the timing system. The timing system provides two main parameters: the time of flight of the optical signal and the epoch of the measurement usually referred to the laser signal emission. The time of flight is used to evaluate the range corresponding to the epoch. The parameters of the interest of the timing systemare: time resolution, timing jitter, timing linearity, temporal stability and temperature dependence. The goal of millimetre ranging accuracy puts extreme and strict requirements on following parameters: the timing jitter well below 4picoseconds, timing non-linearity, temporal stability and temperature dependence of the order of units of picoseconds. Additionally, new measuring devices and techniques are needed to ensure the field operational systems performance. These facts led to the PET development and applications.

2. PRESENT STATUS

The performance of the timing systems used by the worldwide laser stations is summarized in Table1. In general, two time interval measurement principles can be employed: time interval (counter) principle and event timing principle. The counter devices, the commercial general purpose instruments manufactured by Hewlett Packard or Stanford Research Inst. are used on numerous stations for their simplicity, availability and affordable price. The timing jitter of the counter based system may be decreased by implementation of several units and appropriate data averaging (cluster concept).

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TIME INTERVAL UNITS PARAMETERS

	Year	Res. [ps]	Jitter [ps]	Stability [ps/K]	Stability [ps/h]	Type	Stops	Reference
HP5370B	'82	20	26			C	1	Hewlett Packard catalogue
SR620	'88	4	22	5-10	3	C	1	Stanford Research Inst. catalogue
MRCS	'98	2	10	2	1	E	3	Proc. of 10th Int. SLR Workshop, Shanghai, 1996
ALLIED Sig.	'98	2	3-4		0.5	E	4	Proc. of 10th Int. SLR Workshop, Shanghai, 1996
Cluster	'97	4	12	5-10	<3	C	1	Proc. of 10th Int. SLR Workshop, Shanghai, 1996
P-PET	'98	1.2	7	0.3	<1	E	1	EurOpto, London 1997
PET4/WLRS	'99	1.2	7	0.3	<1	E	3	Proc. of 12th Int. SLR Workshop, Deggendorf , 1998
PET4/TIGO	'99	1.2	3.5	<0.3	<0.5	E	3	EurOpto, Munich 1999

Table 1: Time Interval Units employed for Satellite Laser Ranging, status 1998/99, type C = time interval/Counter principle, E = Event timing principle

3. SYSTEM DESIGN

The block scheme of the PET, operating on an event timing principle, we did developed, is on Figure 1. Four identical Event Timing Modules (Dassault Electronique)[1] are employed, which provides the timing for the laser fire event (Start) and three timing signals from three independent echo signal detectors (Stops 1,2 and 3). The main parameters of the Event Timing Modules are: number of bits 64, the least significant bit 1.2 picosecond, timing jitter < 2.5 psec RMS, timing non-linearity bellow 2.5 psec oven an entire range, master clock frequency 200MHz. The precise master clock signal 200MHz is generated in the Clock Generator Module from he 10 MHz clock signal provided by the local time base. The Event Timing and Clock Generator Modules are space qualified. The entire PET needs no field adjustment and device calibration.

The input signals are processed in the Input Circuits. The input signals are multiplexed using high frequency relays, signals from one of two input connectors may be connected to the timing device timing inputs. The input signals, fast timing NIM pulses, are discriminated and converted to the ECL signal levels, the presence of the input signal is signalized. The arming logic enables the signal path to the Timing Modules.

The Range Gate Generator generates signals with programmable delays with respect to the Start events. Two independent range gate and arming signals are generated: one within the range 0 to 500 nanoseconds for the real time calibration purposes and one within the range 2 milliseconds to 10 seconds for the satellite laser ranging. The actual range gate generator delay is computed and set in a real time, as soon as the epoch of the Start event is read and the corresponding range prediction is computed.

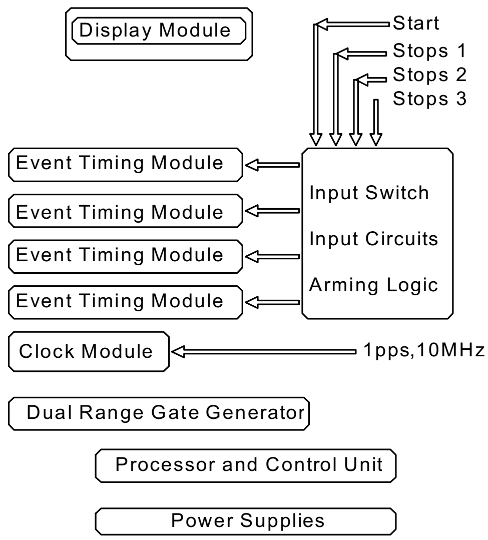

Figure 1 : Pico Event Timer block scheme

The Range Gate Generator and the Control Unit are based on the logical arrays, field programmable, if desirable. This construction ensured the device simplicity and flexibility. There is still a significant array capacity available for future system upgrades and modifications.

The Microprocessor Module is based on an eight bit microprocessor equipped with a powerful operating system dedicated for parallel processing provides a real time control of the device. It evaluates in a real time the range gating epochs, identifies the measurement pairs of Start and Stop signals and controls the data flow between the PET device and the host computer. The built-in computing power inside the PET allows to carry out a lot of data processing inside the PET and hence to reduce the volumes of data transferred to and from the host computer. The standard serial data link to a simple Personal Computer manages the operation of the PET at the measuring repetition rate of 100pulses per second, measuring with three independent detectors simultaneously with the real time calibration. This concept of the real time control of the PET contributed significantly to its application simplicity and to the possibility to create the user friendly user interface[2].

Special attention has been put to the PET design from the point of view radio-frequency interference influence and temperature and a heat flow control inside the device. The individual parts have separate grounds, independent shielding and independent power supplies. To separate internal grounds, the communication uses strictly opto-coupled data lines even on board-to-board level. The radio-frequency interference suppression is necessary to achieve minimum timing jitter on the picosecond level. The advanced temperature and heat flow control is inevitable for high temperature stability and long term stability of timing properties. The passive temperature control has been used entirely.

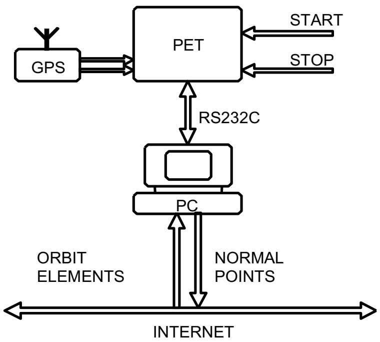

Figure 2 : Pico Event Timer integration to the satellite laser ranging system

The PET is designed to operate as a complete timing system for the satellite laser station acting as a time interval and epoch device and range gate generator, Figure 2. Optionally, PET can be connected to the satellite laser ranging system parallel to the existing timing system in a so-called Portable Calibration Standard configuration. In this configuration, the PET together with an independent control and software package can be used to identify the possible systematic error sources in the laser ranging system under test[4]. In both cases, just the Start and Stop(s) signals of the ranging systems are connected to PET, no additional timing synchronization signals are needed.

4. INDOOR TESTS

The PET has been tested in a series of indoor experiments. In all the following experiments, the fixed delay formed by the cable has been measured between Start and Stop #2. The input signals, MIN levels, with the rise / fall times < 1 nanosecond have been used.

The timing jitter of the entire timing system when measuring intervals is demonstrated on Figure 3, the single shot jitter is 2.9 psec RMS in a cable delay test. Using a Titanium Sapphire laser at 1 psec @ 423 nm, C-SPAD detector operating at several hundreds photon echo signal level, the single shot timing jitter 6.7 picoseconds of an entire laser ranging chain has been achieved.

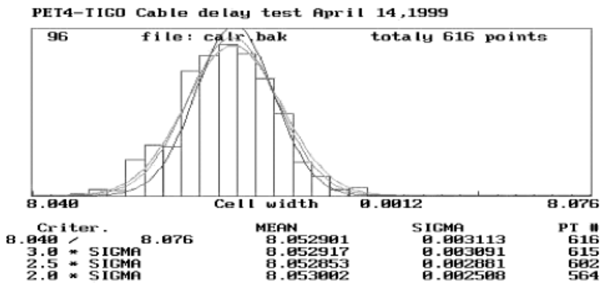

Figure 3: PET timing jitter, cable delay test, channel #2 timing jitter 2.9 picoseconds

The temperature dependence of the measured time interval is on Figure 4. Each circle represents an average of 1000 interval measurements. The time series starts with device power on, within 2.5 hours the device temperature increased by 14.7 Centigrade, while the measured time interval increased by one picosecond. The resulting temperature drift below 100 femtoseconds / K. For comparison to other systems see Table 1. The temporal stability is plotted on Figure 5, the value of ± 0.5 picosecond/hour has been achieved.

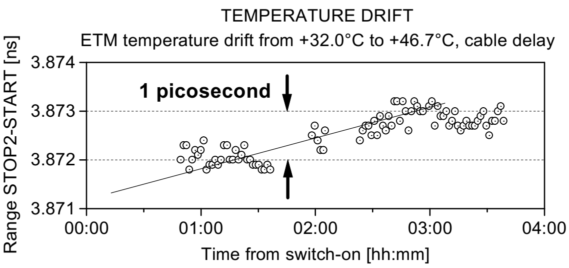

Figure 4: Temperature drift, cable delay test, channel #2, hours after power on, drift < 100 femtosecond/Kelvin

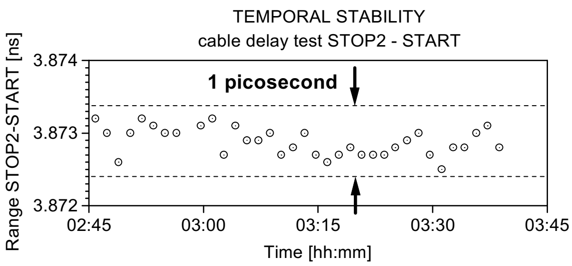

Figure 5: Temporal stability, channel #2, long term stability < ± 0.5 picosecond/hour

5. SATELLITE LASER RANGING

The PET has been used for timing in a satellite laser ranging at laser stations in Austria, Germany, United Kingdom and Switzerland. In Graz, Austria, using the second harmonic of YAG laser, 35 psec, C-SPAD detector, ranging to a ground target, the single shot timing jitter of an entire ranging chain 10-14 psec has been achieved. Ranging to the ERS-2 satellite, the timing jitter 19 psec has been achieved, see Figure 6. The availability of multiple stop channels of PET together with excellent temperature and long term stability permit to carry out a new class of measurements: satellite laser ranging on SPAD with software compensation of the time walk [5]. The preliminary experiments show the capability of millimeter laser ranging to satellites[6]. The multistop PET configuration is an attractive feature for the two-wavelength laser ranging systems, the first results of two wavelength satellite laser ranging using PET have been demonstrated at TIGO station, Wettzell, 1998. The PET has been used to trace the SR620 counter linearity error at the station RGO at the Herstmonceux Castle, UK, as well.

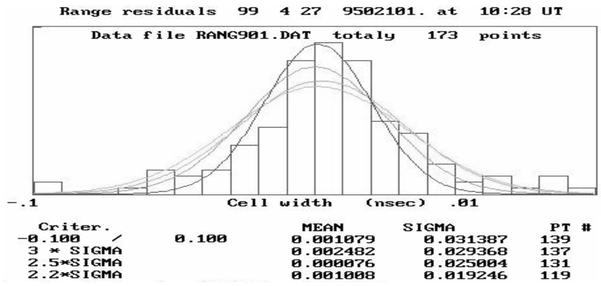

Figure 6 : Satellite laser ranging to the ERS-2, station Graz, Austria, single shot jitter 19 psec RMS

The ground based ranging machine error budget is shown in Table 2, the individual contrbutors are listed for the laser station, consisting of: 35 psec laser, C-SPAD stop detector with additional software time walk compensation, PET and echo signal strength corresponding to 100 photoelectrons. From the Table 2 the millimeter ranging capabilities of the PET based system may be seen, the single shot ranging precision has been demonstrated in the indoor experiment.

GROUND BASED RANGING MACHINE ERROR BUDGET

CONTRIBUTOR	RANDOM EFFECT		SYSTEMATIC EFFECT	
LASER PULSE	length, wave-front	1 psec		
START	trigger jitter	3 psec	uncorrected time walk	2 psec
STOP	trigger jitter	5 psec	uncorrected time walk	3 psec
TIMING SYSTEM	timing jitter	3 psec	temporal stability	1 psec
			non-linearity	3 psec
MOUNT		-	eccentricity	3 psec (0.5 mm)
CALIBRATION			survey	3 psec (0.5 mm)
Resulting r.m.s.	single shot precision	6.6 psec (1 mm)	accuracy	6.4 psec (1 mm)

Table 2: Ground based ranging machine error budget, the individual contributors are listed for the laser system consisting of: 35 psec laser, C-SPAD stop detector with additional software time walk compensation, echo signal strength corresponding to 100 photoelectrons, PET timing.

6. CONCLUSION

The timing resolution of the PET is 1.2 picosecond, the overall machine timing jitter is 2.9 picosecond, the temperature drift is bellow 100 femtoseconds/K and the temporal stability is better than ±500 femtoseconds/hour. Ranging to the ERS-2 satellite we obtained single shot overall jitter bellow 3 millimeters in range. The millimeter ranging capability of the PET based system has been demonstrated. The PET together with the software package has been operated at the satellite laser stations as the Portable Calibration Standard, as well. Running the PET in parallel to the standard laser ranging system, comparing the resulting ground target and satellite laser ranging data, the range and time biases have been evaluated. The ranging machine range bias of the order of units of picoseconds has been measured at the station Graz (+2psec) and TIGO (+8 psec). In all the field installations, the PET contributed significantly to station performance: ranging jitter reduction (typically down to 70% of the original value), temperature and temporal stability increase. The device is simply to implement, compact, rugged and friendly to operate from Personal Computer via basic serial interface. The device itself needs no field adjustment and calibration.

7. ACKNOWLEDGEMENTS

The co-operation and support of Dr. W. Schlüter and the Wettzell Observatory staff during R&D and field tests of two PET units has been highly appreciated.

8. REFERENCES

1. K.Hamal, I.Prochazka, *Picosecond event timer for millimeter laser ranging*, Annales Geophysicae Suppl.,Vol.16, 1998
2. U. Schreiber, K. H. Haufe, I.Prochazka, *Concept of a PET4/LabView – control system*, Proceedings of the 11th Workshop on Laser Ranging, Deggendorf, Germany, Sept. 1998
3. M.R.Pearlman, *Laser system characterization*, Proceedings of the 5th International Workshop on Laser Ranging Instrumentation, Herstmonceux Castle, Sept. 1984, edited by J.Gaignebet, GRGS-CERGA
4. I.Prochazka, K.Hamal, H.Kunimori, B.Greene, *Portable SLR calibration standard*, Proceedings of the 10th International Workshop on Laser Ranging Instrumentation, Shanghai, China, November, 1996
5. G.Kirchner, F.Koidl, I.Prochazka, K.Hamal, *SPAD time walk compensation and return energy dependent ranging,* Proceedings of the 11th Workshop on Laser Ranging, Deggendorf, Germany, Sept. 1998
6. I.Prochazka, K.Hamal, J.Blazej, *Millimetre ranging and echo signal strength monitoring with SPAD detectors,* Proceedings of the 11th Workshop on Laser Ranging, Deggendorf, Germany, Sept. 1998