State report of current developments for picosecond precision Time-Tagging systems

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Abstract

Since 2011, the Eventech team has demonstrated high competence in event timing, producing the fully CE certified A033-ET time-tagging system with 2.5(ps) precision recognized as a standard for SLR by NASA and used in more than half of the SLR stations in the world. The Eventech continue development of existing product introducing the performance improvement.

Moreover, Eventech proposed time-tagging technology has been accepted by ESA for space application, the closest mission is the 2024 HERA asteroid mission. It includes a centimeter-resolution PALT planetary altimeter, the main electronic unit of which is a precision time interval meter.

Except the time-tagging systems development for space, Eventech propose multi-channel time-tagging system improving the possible functionality not only for LSR, but providing another application opportunities such as wind LIDAR, and three-dimensional scanning systems, gravity field measurement, quantum communications, laser communications (T2L2), Internet of Space (IoS), etc.

1. Introduction

Time and time interval measurements are in high demand in many scientific and engineering fields. Among the time measurements, measurements of time intervals (TI) are most in-demand. Often called Time of Flight (ToF), the TI measurements are crucial in magnetic resonance angiography (MRA), Satellite Laser Ranging, mass spectrometry, 3D imaging, and many others.

Eventech company has succeeded in creating precise time measurement devices for terrestrial and space applications, and currently are expanding the technologies application possibilities.

Eve Timer A033-ET (Fig.1) is Eventech's bestseller device, frequently mentioned during IWLR22 event as 'Riga Event Timer'. It is acknowledged by NASA as a standard timing device for SLR and is used in more than a half of SLR stations over the world. A033-ET is a computer-based instrument that measures the time of events, combining high accuracy, high measurement rate and a reasonable price in one device. When integrated into a larger system, the A033-ET timer enables the system to indirectly measure distance, speed, position, etc.

Fig. 1 Event Timer A033-ET in RACK

The ET-device offers two inputs (A and B) to measure events on these inputs alternately with 50 ns dead time. Devices parameters are described below:

- 2,5 ps single-shot RMS precision;
- 50 ns dead time;
- 2 inputs;
- Best in class price/performance ratio;
- Parallel/USB/Ethernet interfaces;
- TRL9.

1.1. A033-ET precision characteristics

Single-shot RMS precision (Fig.2) is the main parameter specifying the practicable A033-ET precision. For the A033-ET it is defined as the standard deviation of total error in measurement of time intervals between events. Typically, the A033-ET supports single-shot RMS precision for interval transformation in the range of 3-4 ps. In some cases, the precision **may be a little better or a little worse depending on the hardware unique features.**

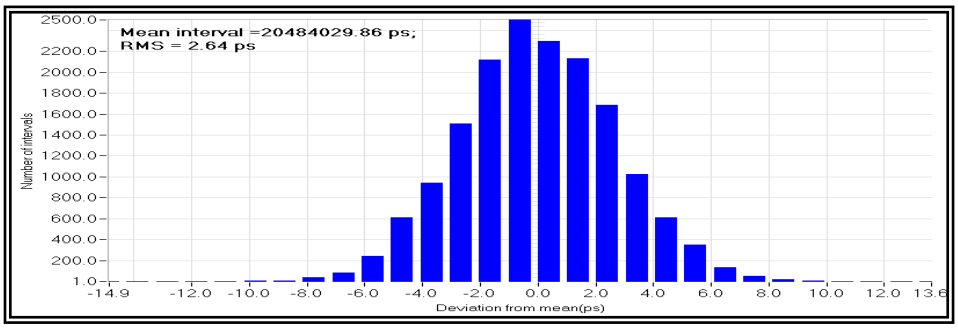

Fig. 2 Histogram of errors in measurement of high-stable time intervals

Temperature stability (Fig. 3): The best RMS precision is after calibration. It changes in a range ± 5% under variation of temperature ± 2.5 ºC.

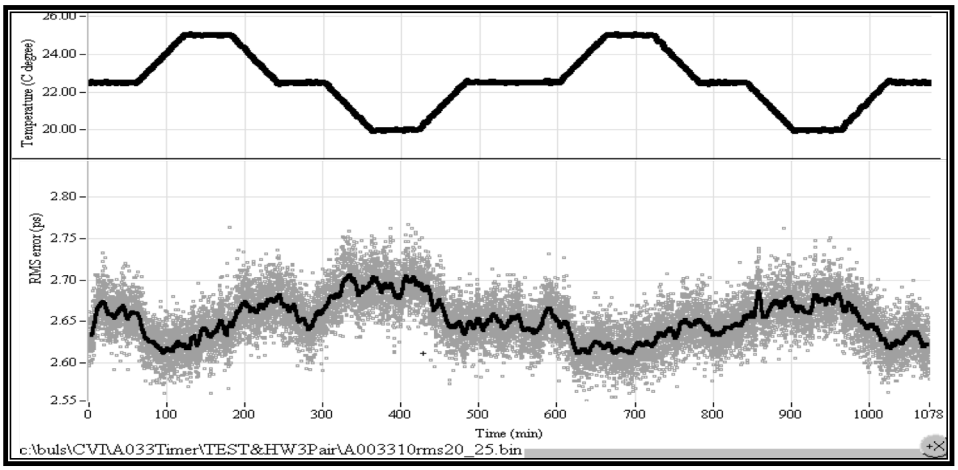

Fig. 3 Temperature stability curve

Interval non-linearity error (Fig.4) is a systematic error in measurement of time interval between adjacent events that depends on the value of this interval. Typically, the A033-ET interval nonlinearity error does not exceeds ±0.5 ps for time intervals greater than 100 ns. For smaller time intervals such errors can be a little greater (especially for time intervals that are near to the 50 ns dead time).

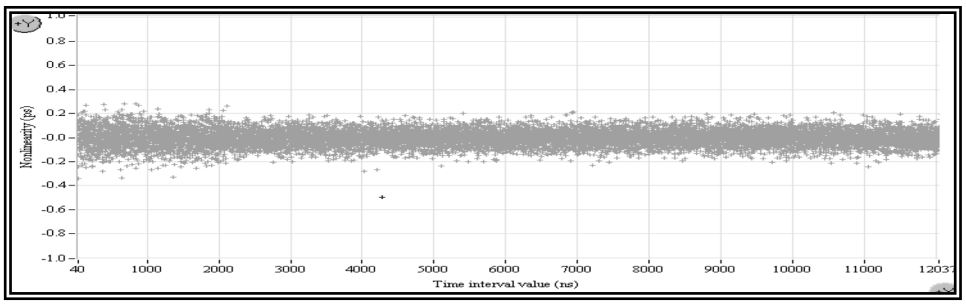

Fig. 4 Interval non-linearity error vs. time interval

1.2 New generation Event Timer EST-34

Many requests for repetition rate increase have been received from A033-ET device users. As a result, new version of event timer - Event Stream Timer EST-34, with better parameters as the current product, and with continuous repetition rate passes its final tests in the Eventech laboratory and will be available for customers in Q3 of 2023. It is going to be suggested as a replacement for event timer A033-ET.

2. Event Timer for Space

ESA's planetary defense mission **HERA** is designed to study two asteroids and evaluate the effectiveness of the kinetic impact on the asteroids' orbit. The mission equipment includes a **PALT** planetary altimeter developed by **Efacec** and **Eventech** (Fig. 5-6). Time interval meter for the altimeter is developed based on the **event timer**, which registers the moments of events relative to a discrete time scale. The result of the conversion is the event moment code (time-tag, time-stamp). The time interval is measured as the difference between the time-tag stop and start signals of the time interval (ESA Contract No. 4000125526).

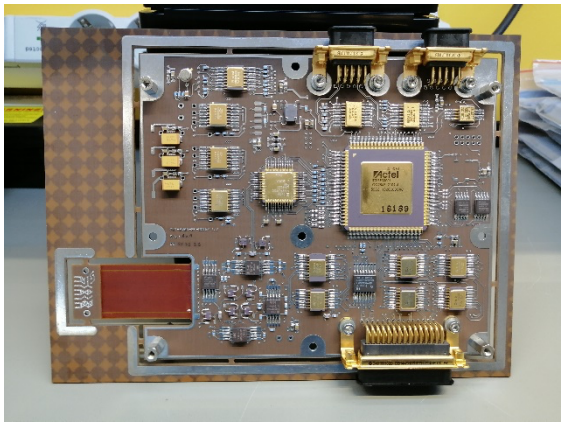

Fig. 5 PCB of Event Timer for PALT (front)

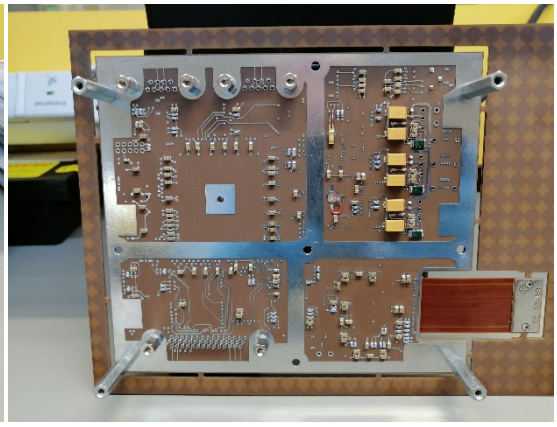

Fig. 6 PCB of Event Timer for PALT (back)

Parameters of the device are described in the table below.

Table 1 Technical parameters of the Event Timer for PALT

Parameter	Value
Precision (single-shot RMS resolution	7 – 8 ps
Input offset drift	0.4 ps/°C
Power consumption	3.5 W
Operating temperature range	-40 ÷ +60 °C
EPS	25 (Mevents/sec)
Rad Hard	100 krad
Form factor	One 8-layer PCB (150 x 130 mm)

3. Multi-channel picosecond time-tagging system

Currently, every SLR station in the ILRS network varies in systematic errors of laser range measurements. The next generation SLR stations will push current limits much further in accuracy and productivity, as one of the solutions suggesting multi-channel SLR systems. Currently, in the development stage, a multi-channel event timer could have a significant role in achieving this goal.

In a range of European regional development fund Eventech team applied for multi-channel picosecond time-tagging system with amplitude measurement for satellite laser ranging (Project no. 1.1.1.1/20/A/104) with following predicted parameters:

- Number of channels ≥ 5;
- Dead time < 30 ns;
- Single-shot RMS resolution ~1 ps;
- Built-in amplitude meter;
- Built-in Range Gate Generator with resolution ~10 ps.

Target is to develop specialized timing devices platform which allows to combine several different functional, synchronized devices (PPM modulator, laser PWM, photon counter with ability to detect both edges of a pulse) in one measurement equipment (Fig. 6).

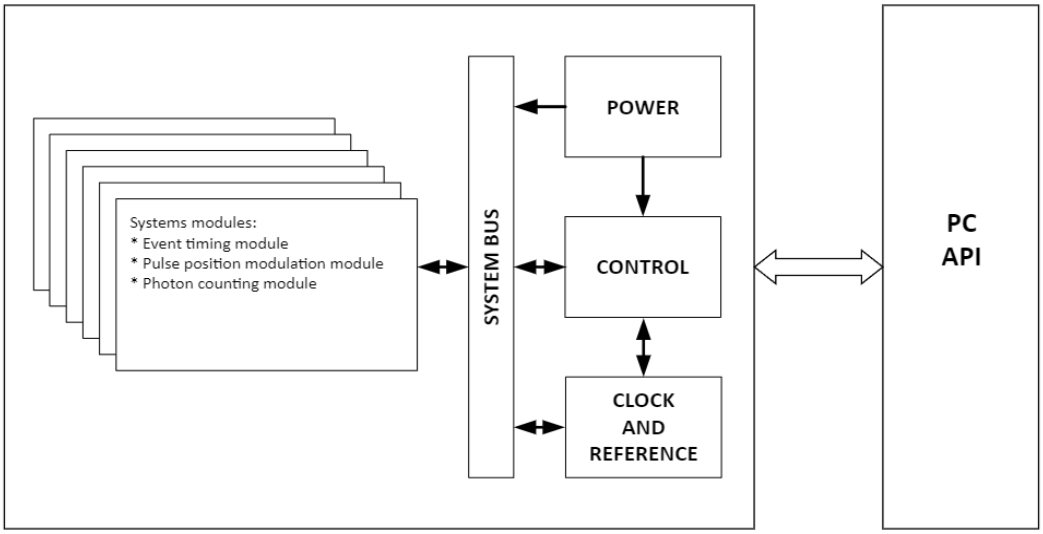

Fig. 5 multi-Channel timing device block diagram

The technology should allow multiple independent measurement channels and provide stability and binding time scales of all these channels with the required picosecond precision, as well allowing easy implementation of multiple wavelengths SLR. This can significantly increase the precision of the measurements and the amount of data that can be processed simultaneously.

In addition, the technology will be applicable to Imaging-Flash LIDAR and three-dimensional scanning systems, gravity field measurement, quantum communications, laser communications (T2L2), Internet of Space (IoS), etc. Time Transfer by Laser Link (T2L2), Time Corelated Single Photon Counting (TCSPC) and Time-Tagged Event Acquisition (TTEA).

The first prototype awaited in Q4 of 2023.

Conclusion

Eventech company's current work is dedicated to expanding the application field of high-precision event timing by upgrading existing technologies. Implementing existing event timing technology on space level components allows to create on-board application device. This opens a variety of applications (military, aerospace, space), such as 3D scanning, planetary altimetry, LiDAR, range finding, satellite communication etc.

Upgrading terrestrial event timing device into a multi-channel system will increase the accuracy and quality of the analysis of incoming signals for satellite laser location, reduce the number of errors in geodesy and improve the accuracy of imaging/wind LiDAR systems.

Acknowledgement

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