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Event Timer A033-ET: Advancement and Performance Characteristics

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Abstract. *The Riga event timer A033-ET uses the specific event timing method based on Digital Signal Processing and already offers the resolution and measurement speed that are quite enough for Satellite Laser Ranging applications. Nevertheless there are some drawbacks such as not fully proven measurement resolution specified using uncertified test signal sources, insufficient calibration stability and fine repeatability, relatively low interface speed, and other minor ones. Addressing these drawbacks along with the improvement of the performance parameters have been covered in this paper.*

1. Introduction

The Riga event timers are computer-based instruments that measure time instants when input events (represented by NIM logic pulses) occur. The timers are based on the innovative DSP-based technology for event timing [Artyukh, 2001], which uses a generation of a specific analogue signal directly from input events with its following digitizing and processing. The latest model A033-ET of the Riga event timers offers typical single-shot RMS resolution of about 3 ps (for time intervals) and the "dead" time of 50 ns [Artyukh, 2011]. The A033-ET has been already on the market from 2010. Since that time there have been further advancements of the A033-ET itself and the development of some other products associated with the DSP method utilization.

- Very accurate and reliable performance testing instruments have to be used. Since such specialized instruments are practically unavailable on the market, specific test pulse generators had to be designed and characterized.
- The calibration procedure of the A033-ET during external temperature variation sometimes required repetition and might take longer time than accepted (although rarely), therefore a new approach to the calibration had to be taken for stable calibration results.
- A relatively low data throughput rate via the parallel port interface with the computer as well as the interfacing problem with modern computers that do not usually support the parallel ports, and especially with 64-bit operational systems such as Windows 7, 8, etc.
- Some applications may require incorporating event timers into specific customized systems. In such cases a smaller all-in-one timer module might be needed.
- An option to have either the NIM input signal levels or the LVTTL ones had to be introduced.

These new advancements will be covered below in more details.

2. The Additional Designs

To check the resolution of the Event Timers and test functionality specific ***test devices*** were made. The best of them is the Event Timer Test Generator (ETTG-1). A special method was developed for estimating test generators stability [Bespal'ko, 2011]. This method allows through the covariance of results of parallel measurements by two timers to get jitter estimations with sub-picosecond precision. In figure 1 the results of parallel measurements of the ETTG-1 output intervals are shown. Each measurement cycle includes 16000 measurements of these intervals. For the next measurement cycle the interval value was slightly changed by a value about 7-9 ps. Standard deviations of the measurement results was calculated and shown in figure 1.

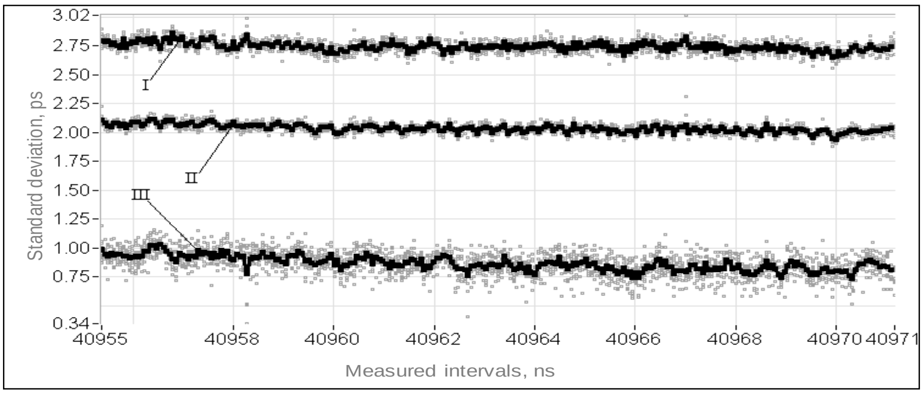

Figure 1. The standard deviations: I – of intervals that are measured by one A033-ET; II – of half-sum of intervals that are measured by two A033-ET. III – of intervals that are generated by the ETTG-1. Grey points show estimations in the each measurement cycle; black points present the averaging of 10 estimations.

As shown in [Bespal'ko, 2012] the standard deviation of the generated intervals is equal to covariance of measurement results from two independent meters. The results of the estimation of the ETTG-1 show that its period standard deviation lies in the range from 1 ps up to 0.75 ps depending on the ETTG-1 adjusted frequency.

The designed all-in-one module (the Event Timer A093-ET) includes timing circuitry, Master clock PLL and USB interface with PC. It has only one input for events and requires the special environment for calibration. Some simplifications allowed decreasing size, weight and power consumption but degraded the resolution up **to 5 ps**.

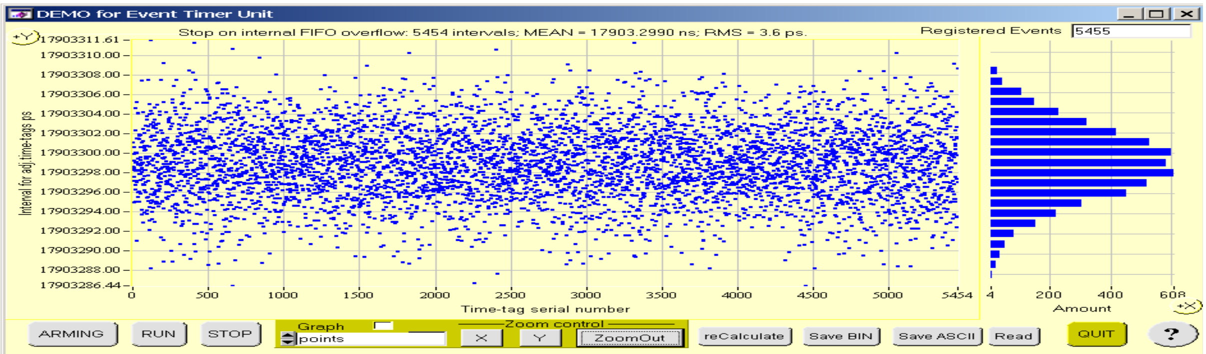

Figure 2. A093-ET measurements of ETTG-1 period: measured intervals and deviation histogram.

The module board size is 160mm x 180mm, power consumption is 8W. At the present time we are working on a new version of such all-in-one board with two measurement inputs. The expected board size is 120mm x 160mm or less, power consumption less than 2W.

3. New Features of the A033-ET

A free running oscillator was used in the previous version of the A033-ET as a source of the calibration signal. In the process of the temperature change that might cause the calibration process delays and give the worse resolution. Figure 3 shows the estimations of resolution after recalibration during about 60 hours of testing. During the test the ambient temperature was linearly changed from 5 up to 45 ^{o}C and vice versa with average rate about 5^{o} C/ hour.

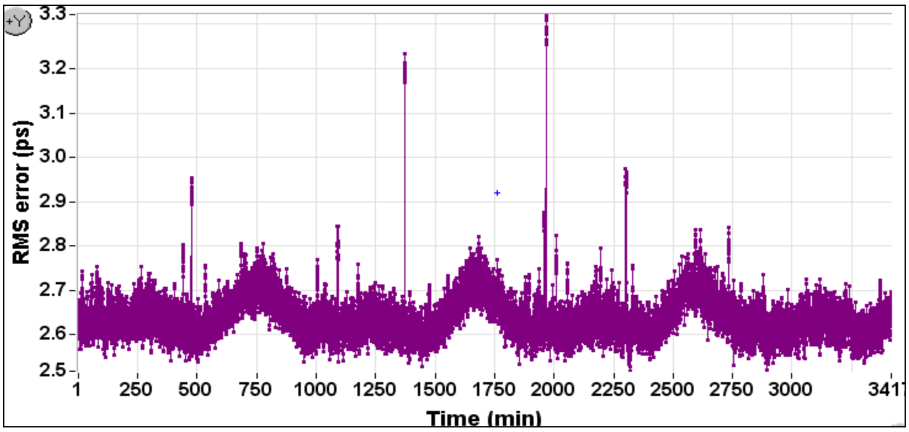

Figure 3. Resolution after re-calibration during the test in temperature range 5 – 45 ^{o}C.

The newly designed calibration signal and master clock generation board consists of several PLL circuits. The frequency of the calibrating signal is derived from the master clock by using in the PLL the special numbers for dividers. By that solution, the module provides the repeatability of calibration results and the constant minimal calibration time of 10 s.

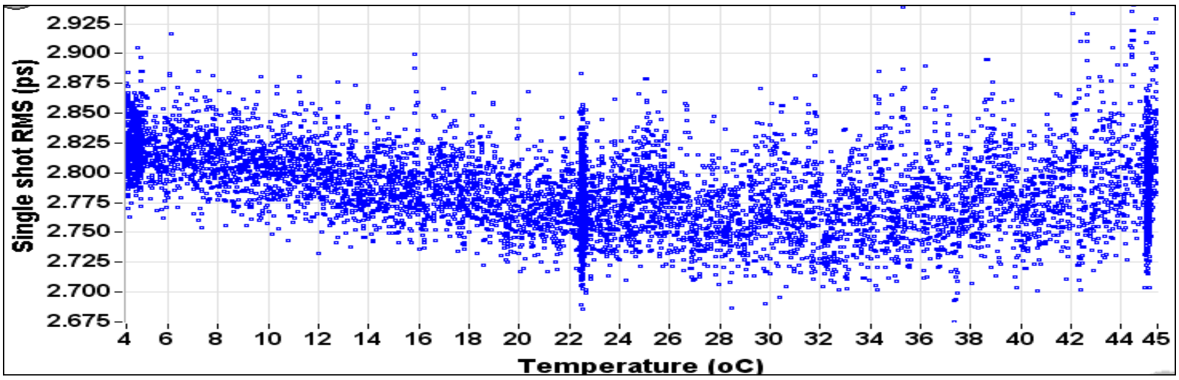

Figure 4. Resolution dependence on temperature after re-calibration.

As a minor but an important improvement a possibility to have either NIM input signals or TTL ones has been done. Several switches have been placed on the board, which allow configuring the desired signal standard.

The new USB interface module was designed as a simple replacement of the old parallel port module. The USB module allows PC to read data with the rate up to 1.3 M events per second.

4. The A033-ET Performance Improvements

Generally the device A033-ET is the commercially available instrument that distinguishes by an attractive price/ performance ratio. But more work directed to increasing of performance, stability, and reliability has been done, especially after introducing the new calibration signal and master clock generation board as well as utilizing the test pulse generator ETTG-1.

Single-shot RMS resolution 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 last implementation of the A033-ET supports the single-shot RMS resolution in the range 2.5-3.0 ps depending on the hardware unique features. But A033-ET is the Event Timer and registers time-tags for arriving events. So for the time-tags the single-shot RMS resolution is in the range 1.8 – 2.2 ps. Moreover, if the jitter of the test generator is subtracted we will get 1.6 – 2.0 ps.

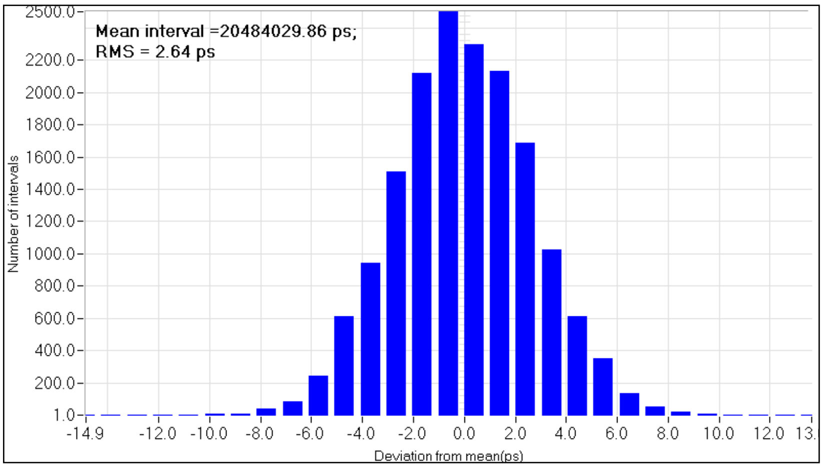

Figure 5. Histogram of errors in measurement of the ETTG-1 period.

The A033-ET offers the best single-shot RMS resolution directly after device calibration in steady-state operating conditions. Thereafter an ambient temperature variation can slightly impair the RMS resolution.

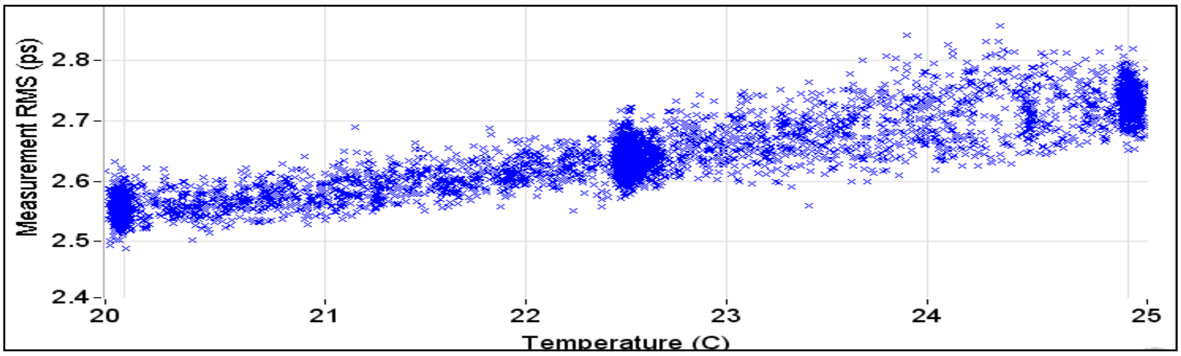

Figure 6. Single-shot RMS resolution versus temperature (without re-calibration).

Integral non-linearity error is a systematic error in event measurement that depends on the position of measured event over interpolation interval. In the average this error is specified by the value of its standard deviation over interpolation interval, representing a significant component of the single-shot RMS resolution.

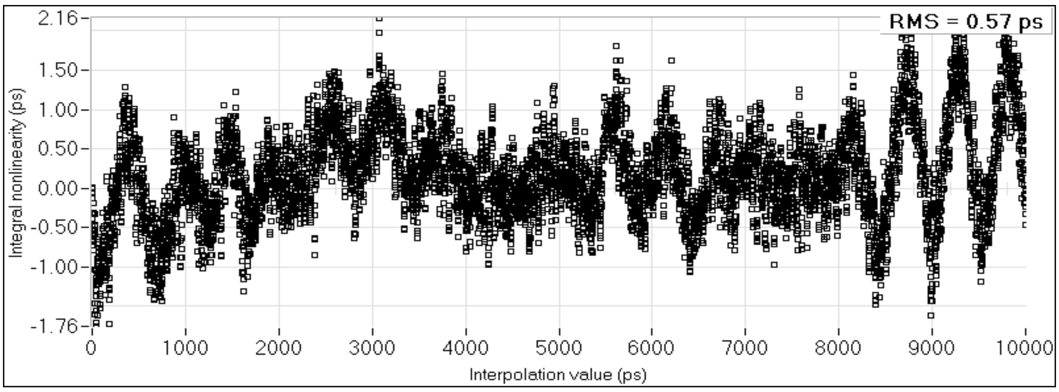

Figure 7. Integral non-linearity error over 10 000 ps interpolation interval.

Interval non-linearity error 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 non-linearity error does not exceed **±0.25 ps** for time intervals up to 2000 ns. For small time intervals close to the "dead time" the error can be a little greater. For time intervals greater than 2000 ns the interval non-linearity error is actually absent.

Single-input offset drift is seen as a long-term deviation of systematic error in measurement of events coming at the same input of the event timer. Such drift reflects long-term instability of the input delays and internal time-base relative to the external 10 MHz reference frequency, depending mainly on the ambient temperature variation. Typically the A033-ET single input offset drift does not exceed 2 ps/^{o} C. It is specified without regard for long-term instability of the reference frequency. But sometimes to keep within this limit a thermo-compensation is included. With a new developed module for the master clock and calibration signal the temperature stability is much higher and thermo-compensation in many cases is not necessary at all.

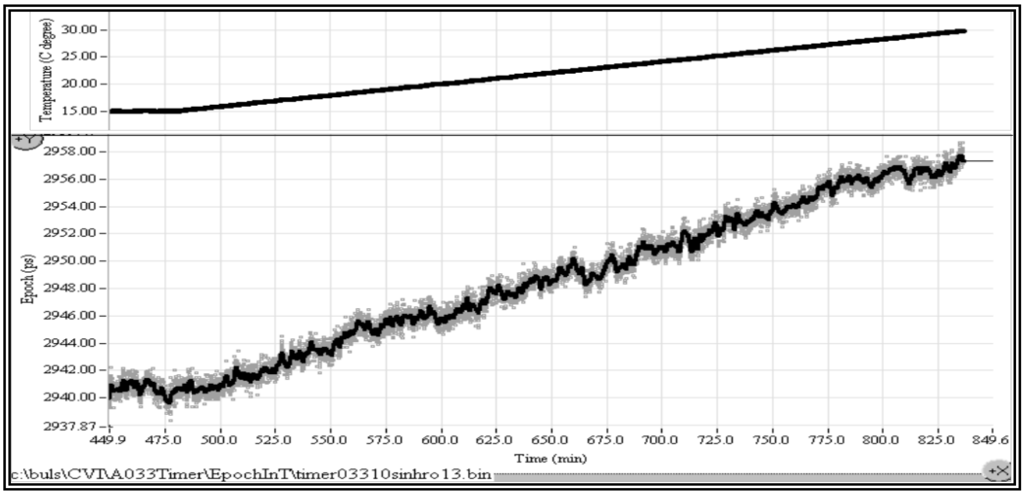

Figure 8. Single-input offset drift in line with slow linear changing of ambient temperature from 15° to 30° C.

Input-to-input offset drift is seen as long-term deviation of systematic error of time interval measurement between Start and Stop events coming at the different inputs A and B of the event timer respectively. The A033-ET input-to-input offset drift typically is about **0.1 ps/^{o} C**. It is specified without regard for long-term instability of the reference frequency.

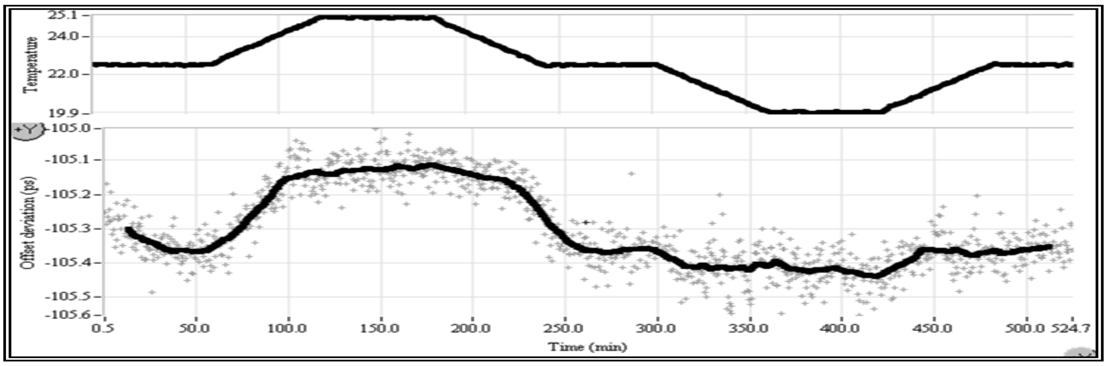

Figure 9. Input-to-input offset drift in line with slow linear changing of ambient temperature from 20° to 25° C.

Dead time: the time of arriving event processing in which the event timer is not able to register another event if it happens. It is defined by the derived signal duration. Typically the dead time for the Riga event timers is about 4-5 periods of clock pulses providing the signal sampling. This defines the **dead time from 40 ns up to 50 ns** depending on event positions relative to the sampling clock 100 MHz.

Maximum Burst Rate: the maximum measurement rate for a specified amount of sequential events. Fast FIFO has a wide data bus so the limiting parameter is the dead time and maximum rate is **20 M events** per second for about 2600 events. External FIFO has one byte data bus and allows **12.5 M events** per second because the each time-tag consists of 8 bytes.

Maximum Average Rate: the maximum rate of long-term continuous event timing. It is limited by the reading speed of the PC Parallel Port and is in the range from 30 K events up to 60 K events depending on Parallel Port realization in computers. But if one could read faster by using an external module on the base of FPGA (or fast microcontroller) for special applications then the maximum reading frequency of data bytes from the A033-ET device would be about 30 MHz and this means about 4 M events per second.

5. Summary

A new master clock and calibration signal generation board was developed for the A033-ET, which, along with thermo-compensation modifications, allowed improving the single shot RMS resolution and repeatability of results in full temperature range.

As a timer performance characteristics measurement tool, a specific low-jitter test pulse generator (the Event Timer Test Generator ETTG-1) has been designed and characterized. Its period standard deviation is less than 1 ps.

An option to have either the NIM input signal levels or the LVTTL ones has been introduced.

A new USB interface block has been designed that makes it possible to dramatically increase the average data rate for the computer communication (up to 1.3 M events per second) and generally solve the problem of interfacing the modern computers and operational systems.

An all-in-one timer module A093-ET has been designed for smaller size and lower power consumption. It can be used for event timer incorporation into application-specific systems.

Acknowledgements

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