Event Timer A033-ET:
Advancement and Performance Characteristics

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ATTĪSTĪBAS FONDS

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Presentation #13-0426: reporter Eugene Boole
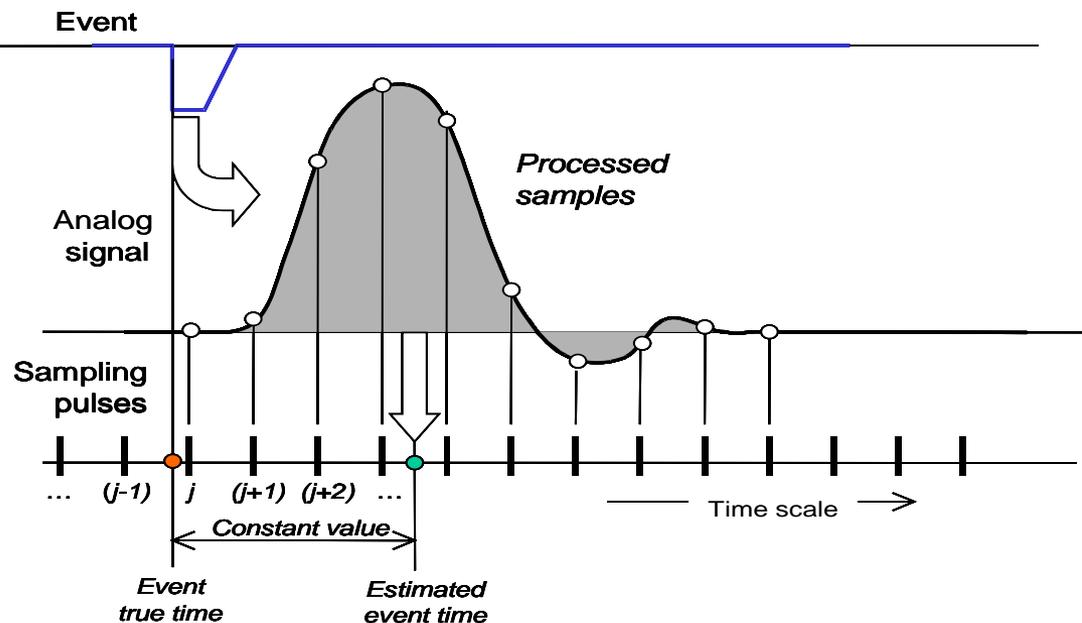
A specific analog signal with limited duration and constant shape is generated at the instant determined by the input Event. Then the signal is digitised and digitally processed to estimate its position relatively to the time-scale presented by a numbered sequence of sampling pulses. Obtained in this way the estimate represents sought value of event time. Sampling pulses are rigidly coupled in frequency and phase with the external reference 10 MHz

The common-used DSP facilities dominate in a measurement realisation, resulting in considerable simplifying of the specialised hardware. The timer's hardware becomes similar to the commonly used analog signal digitisers.
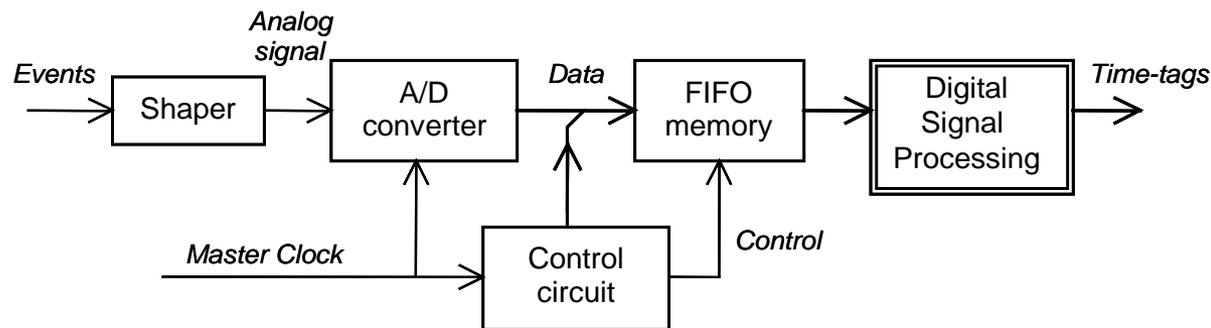
This method is the most advanced both in theoretical and practical aspects, resulting in well-proved specific technology for event timing. During further advancement of this method the measurement rate has became more than 20 MEPS and single-shot RMS resolution has became better than 3 ps.

Implementation of the DSP-based Event Timing technology

Event Timer A033-ET

Event Timer A093-ET module

Event Timer A033-ET/usb

Event Timer A033-ET is a hardware-software system and presents our last implementation of the DSP-based Event Timing technology. It is commercially available from 2010, and up to now more than 30 devices have been manufactured and carefully tested. Consequently, sufficient statistics have been accumulated to reliably specify the A033-ET typical performance characteristics (following slides).

In 2011 under Licensee Agreement the rights for manufacturing and distributing of A033-ET are transferred to Eventech Ltd (Latvia).

Comparing to A033-ET consisting of timing, PLL, interface and power modules the Event Timer A093-ET is "all in one" module. It has only one input for events and USB2 interface with PC. Some simplifications allowed decreasing size, weight and power consumption. But it requires the special environment for calibration and the measurement resolution is degraded up to 5 ps.

Device A033-ET/usb is a last version of the A033-ET and the only change is an USB2 interface in place of parallel port. This is an experimental device under test having the average measurement rate more than 1.3 MEPS. The interface specific requires the essential software modification comparing to A033-ET.

Performance evaluation environment

To check the resolution of the Event Timers and test functionality the special 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. This method allows through the covariation of results of parallel measurements by two timers to get jitter estimations with subpicosecond precision.

| STOP period	$0.08... \times 2^{K1}$ ns (K1=0, 1, 2, ... 9)
START period	81928×2^{K2} us (K2=0, 1, 2, ... 12)
Period STD	< 1ps
PC Interface	RS232
Power; size	8 W; 250x170x60 mm
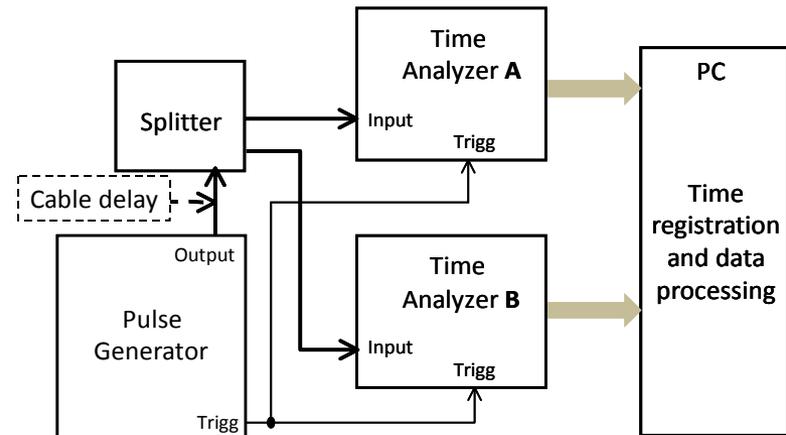
So the specified in next slides resolution can be rectified from this test generator jitter.

Beside these test generators we are using Arbitrary form generators, temperature chamber, GPS-disciplined oscillators. And enormous number of testing software.

Generally the device A033-ET is the commercially available instrument that distinguishes by an attractive price/ performance ratio. But we continue works directed to increasing of performance, stability and reliability. Today characteristics are presented below.

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 A033-ET supports single-shot RMS resolution in the range 2.5-3.0 ps depending on the hardware unique features.
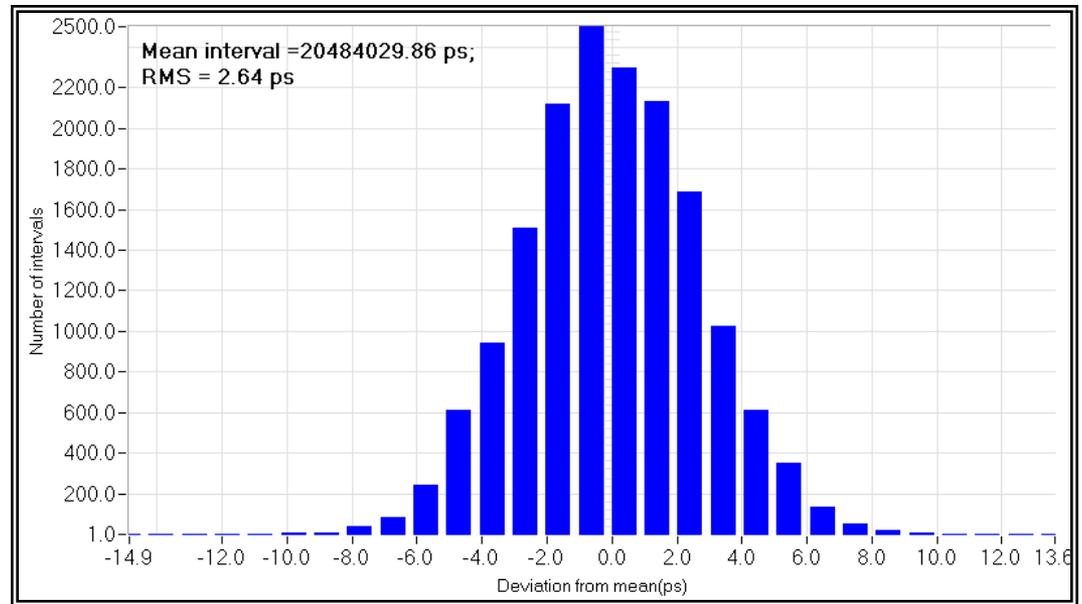

Histogram of errors in measurement of ETTG period .

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.
**More over, if we subtract the ETTG jitter we will get 1.6 – 2.0 ps.**

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.
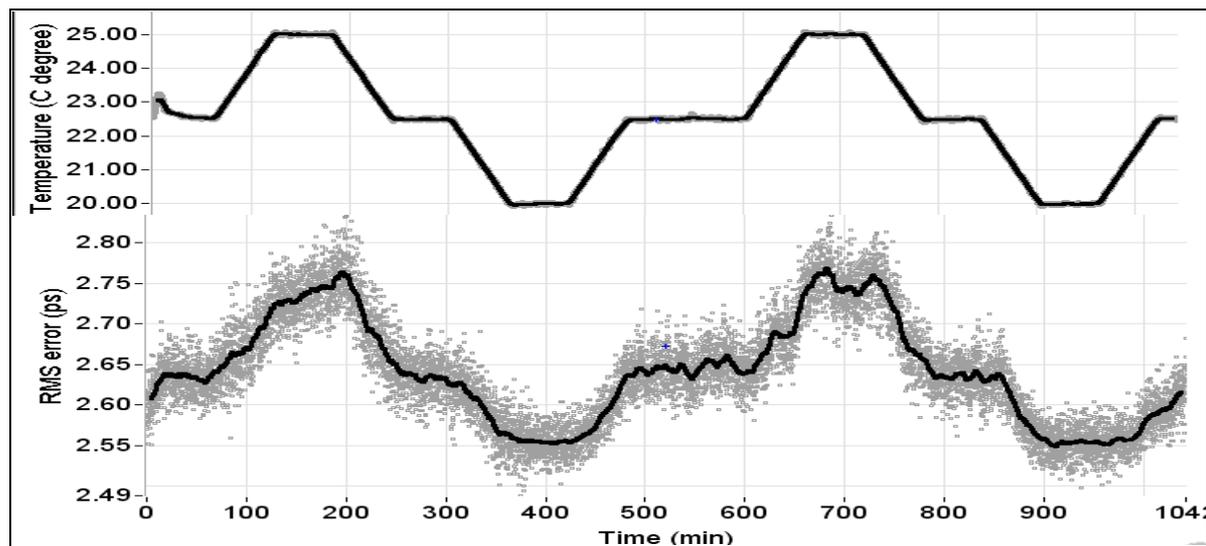
Single-shot RMS resolution vs. time during variation of ambient-temperature variation in the range $\pm 2.5\ ^0C$ without re-calibration.

Single-shot RMS resolution versus temperature.
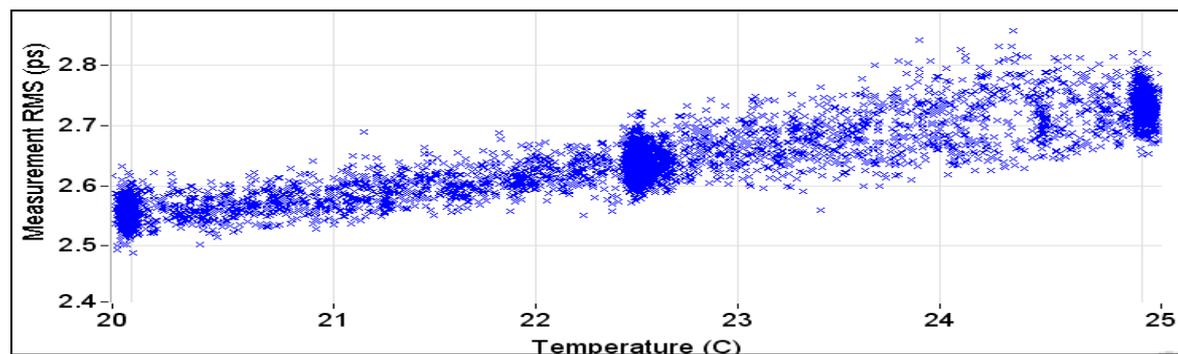
Integral non-linearity error is a systematic error in event measurement that depends on the position of measured event over interpolation interval.

In the average this error is specified by the value of its standard deviation over interpolation interval, representing significant component of single-shot RMS resolution.

*Differential non-linearity error over 10000 ps interpolation interval*
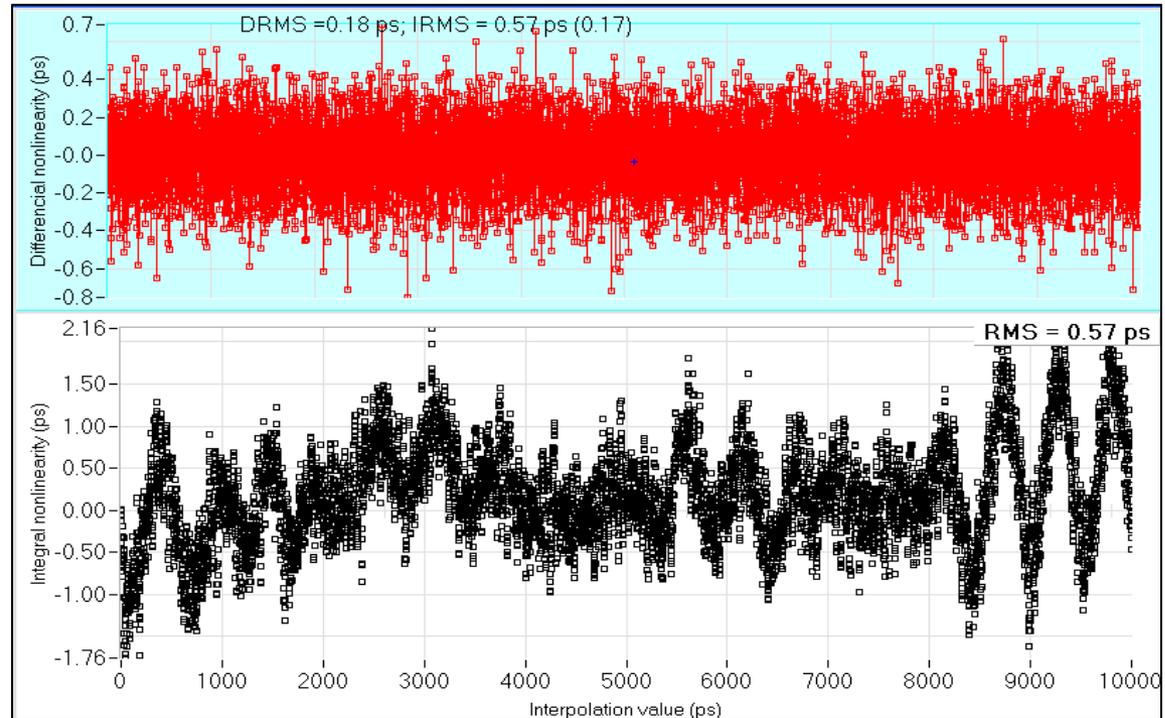
Integral non-linearity error over 10 000 ps interpolation interval

Typically the A033-ET integral non-linearity RMS error is less than 1 ps directly after device calibration. Thereafter an ambient temperature variation can increase this error and impair the RMS resolution as a whole.

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 neighborhood of the "dead time" the error can be a little greater.
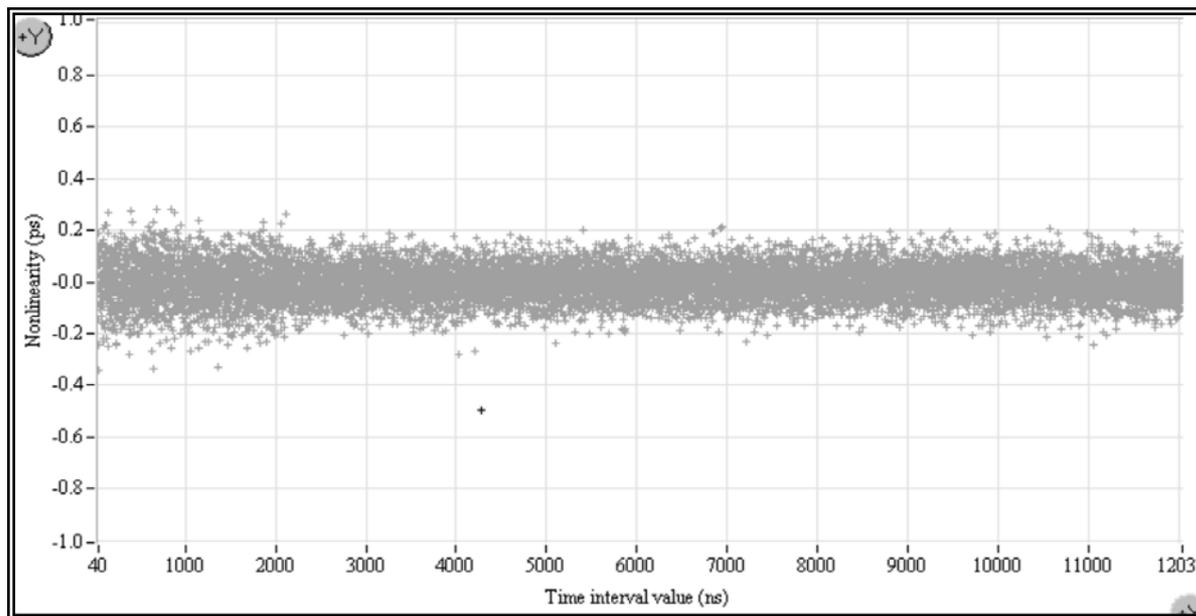

Interval non-linearity error vs. time interval

For time intervals greater than 2000 ns the interval non-linearity error is actually absent.

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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/ºC**. It is specified without regard for long-term instability of the reference frequency.
But sometimes to keep within this limit a termocompensation is included.
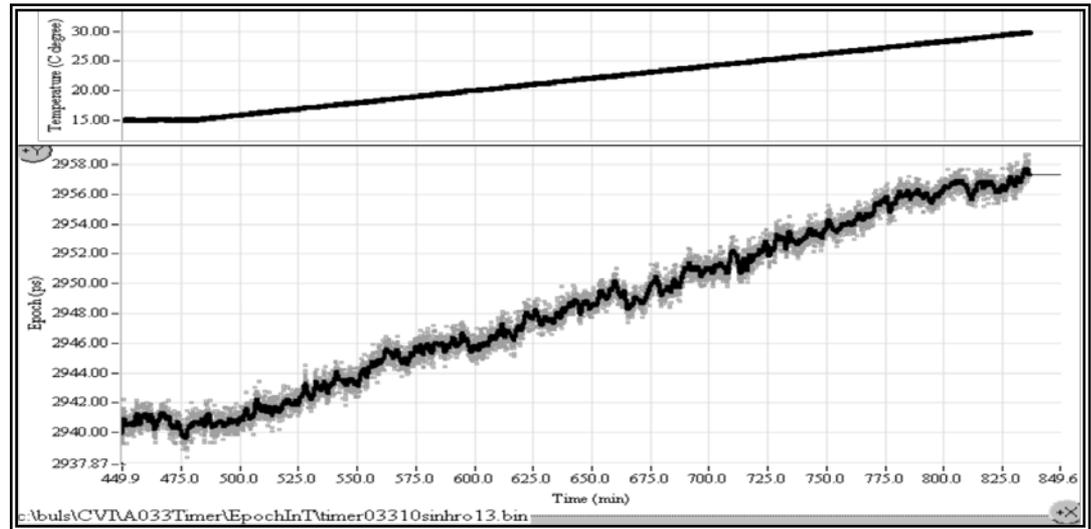
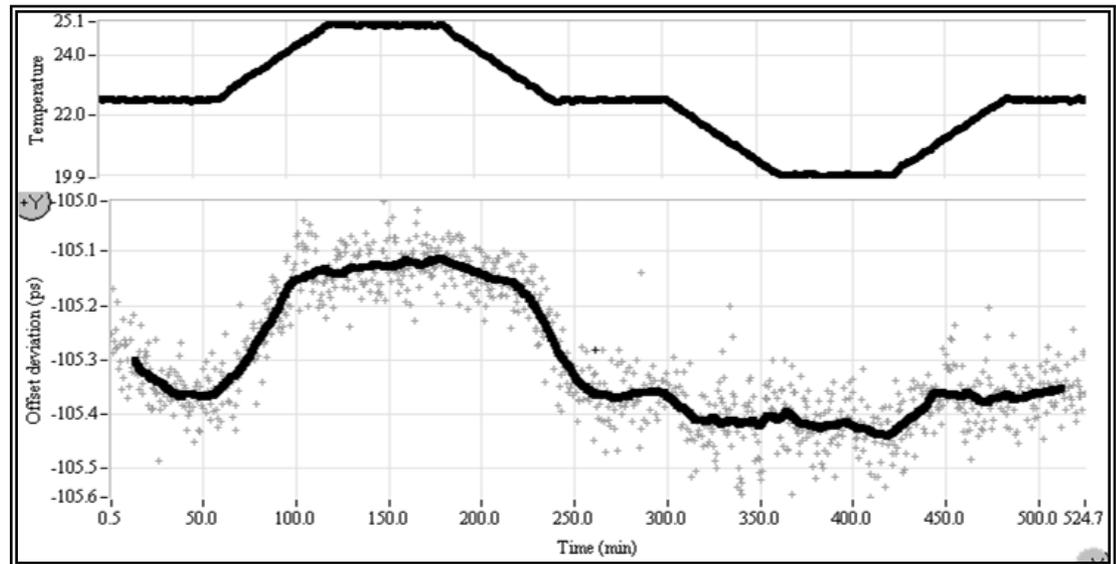*Single-input offset drift in line with slow linear changing of ambient temperature from 15 to 30 ⁰C*

With a new developed module for the master clock and calibration signal the temperature stability is much higher and termo-compensation in many cases is not necessary at all.

Input-to-input offset drift is seen as long-term deviation of systematic error in 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 of **0.1 ps/⁰C**. It is specified without regard for long-term instability of the reference frequency.

This variation is so negligible that it isn't required the attention.

Input-to-input offset drift in line with slow linear changing of ambient temperature from 20 to 25 ⁰C

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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 position 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 bus so the limiting parameters is the dead time and maximum rate is **20 M events** per second for about 2600 events. External FIFO allows **12.5 M events** per second because the each time-tag consists of 8 bytes.

32 bits → | Fast FIFO 1 K events in FPGA | → 8 bits → | External FIFO chip 16 K events | → 8 bits → | PC |
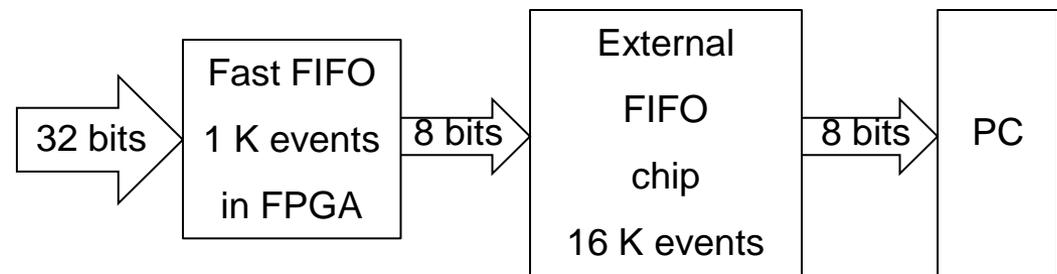
Internal memory buffers

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 computers.

But if you can read faster by the special module then the maximum reading frequency of data from the A033 device is about 30 MHz and this means 4 M events per second!
By the way new developed USB2 interface for A033-ET/usb allows PC to read data with the rate 1.3 M events per second.

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Event Timer A093-ET module include timing schematics, Master clock PLL and USB2 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**.
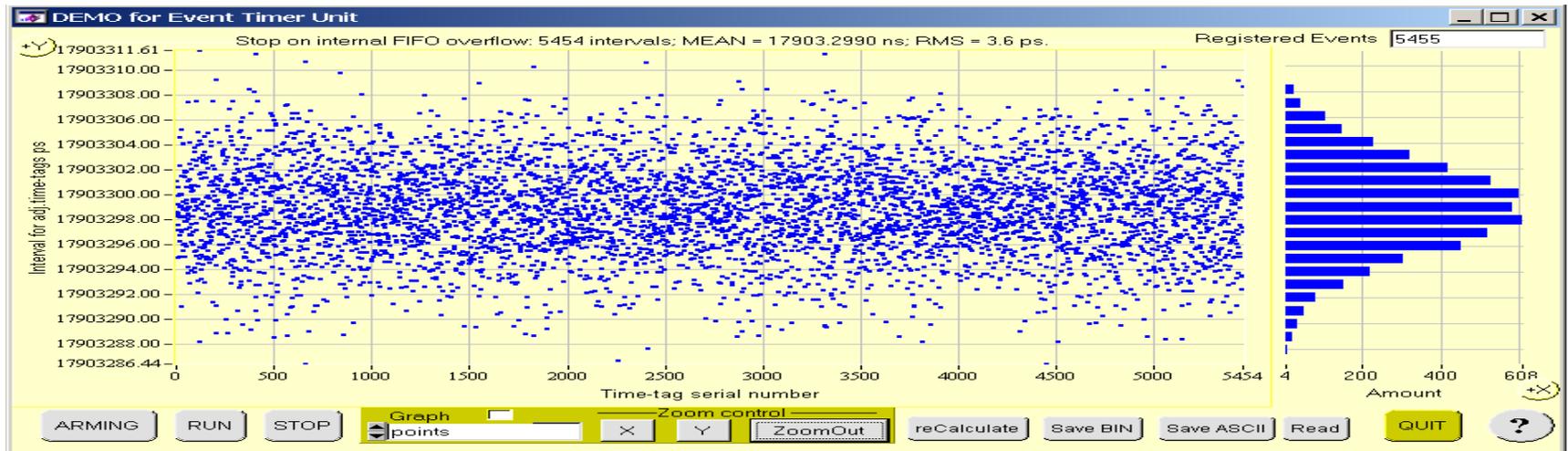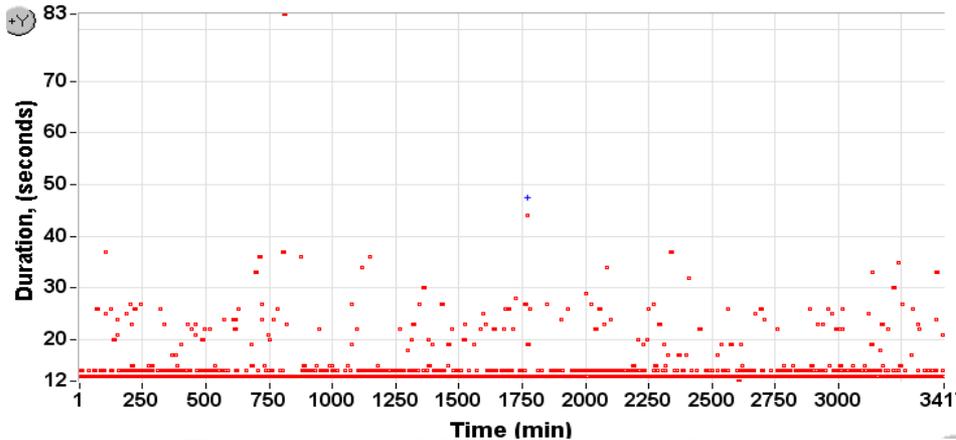

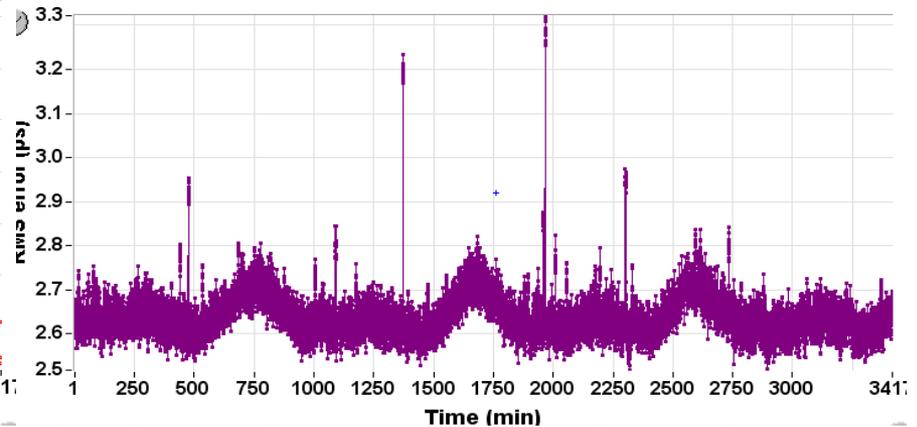*A093-ET measurements of ETTG-1 period: measured intervals and deviation histogram*

New calibration and master clock module.

In the previous realization in result of temperature variation sometimes the calibration process delays and gives worse resolution (all figures for temperature variation from 5 up to 45 oC).
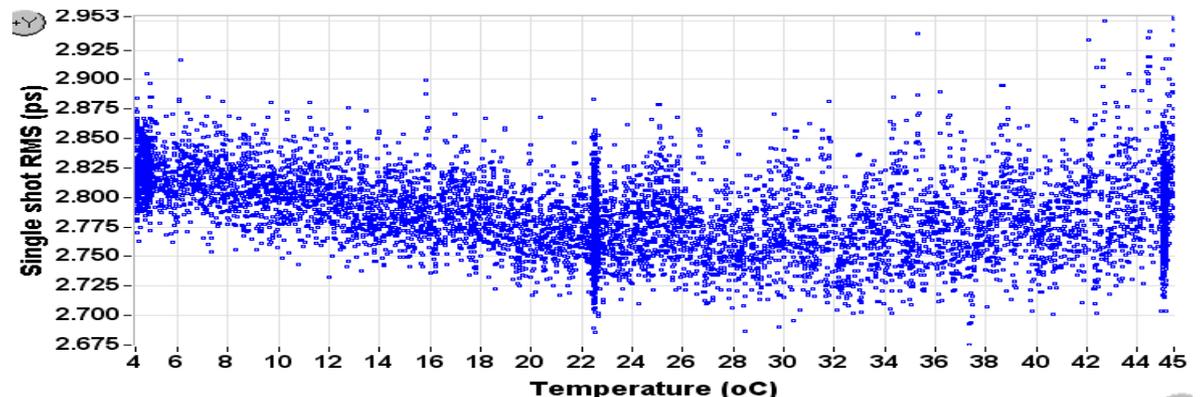

Time of re-calibration procedure

Resolution after re-calibration during the test

The new **calibration and master clock module provides the repeatability of calibration results and minimal calibration time 10 s.**
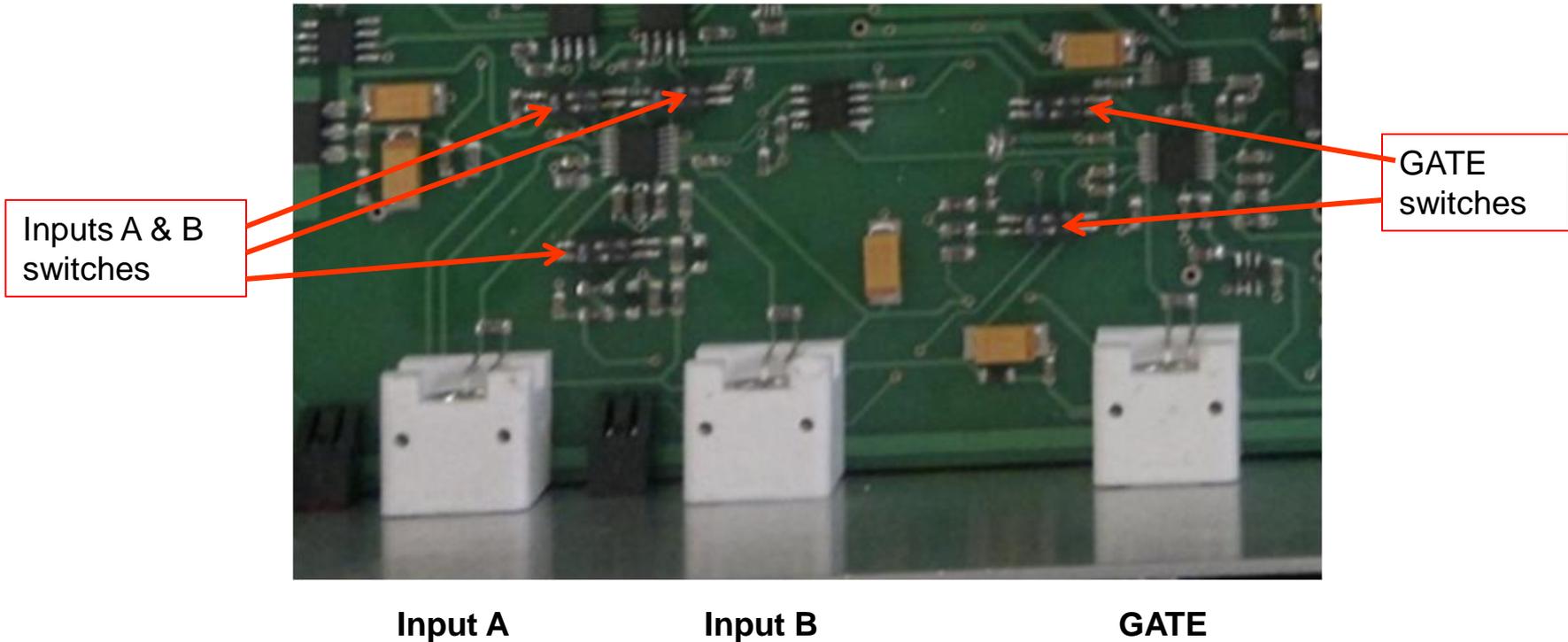

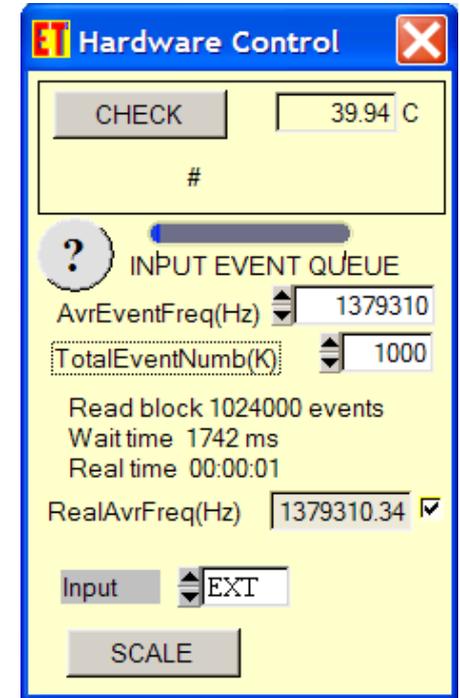*Resolution after re-calibration vs. temperature*

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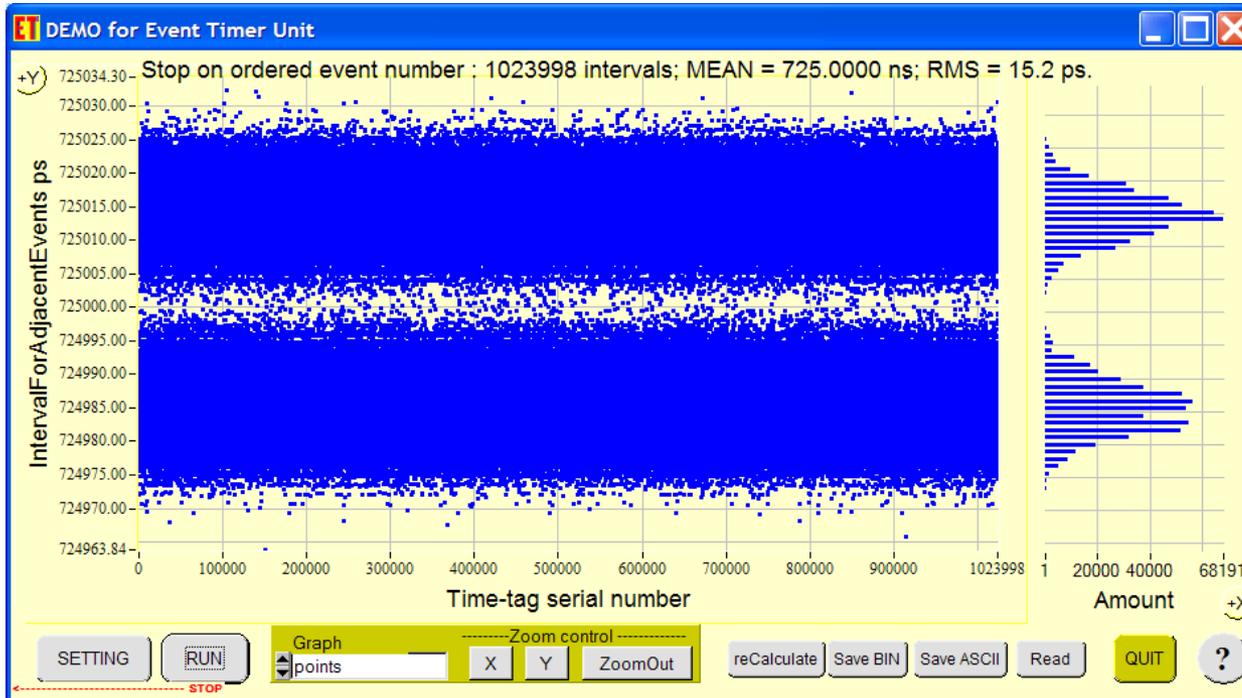**Event Timer Inputs for different standards of signal**
Additional high quality switches allows to choose between NIM and LV TTL.

Inputs A & B switches

GATE switches

Input A   **Input B**   **GATE**
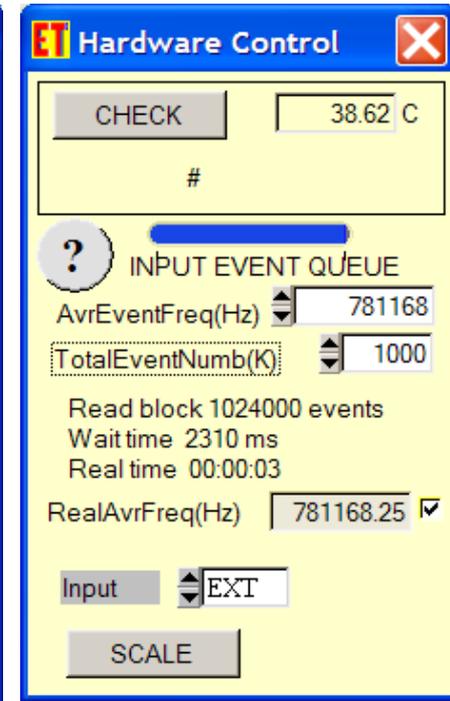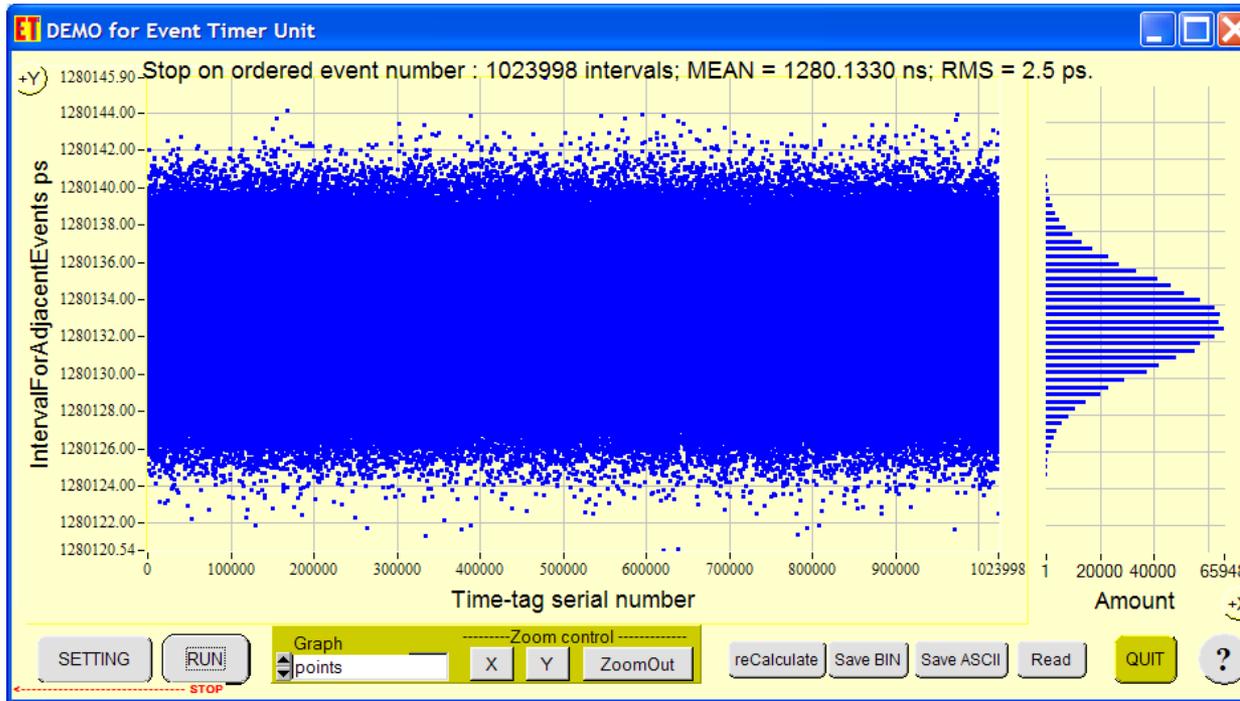
USB2 interface with computer.

1 million measurement results of time intervals 725 ns generated by AFG3251: values deviation and histogram. Panel at right shows the mean frequency 1379310 Hz

USB2 interface allowing to increase the average measurement rate up to more than 1.3 M events per second

USB2 interface with computer.

1 million measurement results of time intervals 1280.1 ns
generated by ETTG: values deviation and histogram.

USB2 interface allowing to increase the average measurement rate up to more than 1.3 M events per second

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Model	A032-ET	A033-ET	A093-ET	A033-ET/usb
Single-shot RMS resolution:				
for intervals	7 – 8 ps	2.5 – 3 ps	<5 ps	2.5 – 3 ps
for time-tags	5 - 6 ps	1.8 - 2.2 ps	<3.5 ps	1.8 - 2.2 ps
Temperature stability of RMS resolution	<1.5 ps/oC	<0.5 ps/oC	<0.5 ps/oC	<0.5 ps/oC
Integral NLE	<2ps	~1 ps	~1 ps	~1 ps
Interval NLE	<1 ps	<0.5 ps	<0.5 ps	<0.5 ps
Single-input offset drift	--	<2 ps/oC	<2 ps/oC	<2 ps/oC
Input-to-input drift	~0.4 ps/oC	~0.1 ps/oC	~0.1 ps/oC	~0.1 ps/oC
FIFO depth (events)	12000 events	16 K events	16 K events	16 K events
Max. rate for <=2600 events	16 MSPS	20 MSPS	20 MSPS	20 MSPS
Max. rate for <=16 K events	17 MSPS	12.5 MSPS	1 MSPS	12.5 MSPS
Max. rate for > 1 M events	10 KSPS	30 KSPS*	1 MSPS	1.3 MSPS

* Increasing up to 60 KSPS is possible by special agreement if the Parallel Port allows 4-bytes groups reading

1. Generally the Riga Event Timers have been conceived as commercially available instruments that are distinguished by an attractive price/ performance ratio and relatively simple and inexpensive technical solution. In principle the better resolution is possible but it leads to much higher production cost.

2. The currently offered resolution and measurement speed of the A033-ET are quite enough for the most of ground-based SLR stations. But there can be many other possible preprocessing options that may be useful for customer, for example, noise filtering.

3. We are working on integration of calibration procedure and part of data processing into big scale FPGA that can give the product that may be useful for space applications.

Thank You !