Advances of High-precision Riga Event Timers

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Abstract

Two main directions to advancement of high-precision Riga event timers are considered. The first direction is related to updating of the well-known event timer A032-ET. Retaining the basic operating characteristics of the A032-ET, RMS resolution of the updated model (A033-ET) has been increased from previous 7-8 ps to 3-4 ps. The second direction concerns development an event timer module (ETM) fitted to including into various customized timing systems. The ETM is similar to the A033-ET in precision but differs by an extended functional flexibility and hardware compactness.

Introduction

The Riga Event Timer A032-ET is one of a few high-performance event timer systems commercially available for SLR applications (Bespal'ko et al., 2008). Generally it still well conforms to the current demands of these applications in terms of price/performance ratio. However, to make such event timer commercially available in the future, some obsolete electronic components of its hardware (which became unavailable) should be replaced by the latter-day ones. This is the main practical reason to update the A032-ET, replacing it by next model A033-ET. At the same time we wished to increase the timer precision, optimise its design, extend applicability, etc., retaining the familiar basic features of the previous model.

Additionally we have taken into account actual demands for high-performance event timer modules that can be used as a basis for creating different customised event timing systems. We suppose that the basic concept of Riga event timer development is well suited for such module design, combining high performance characteristics with compact hardware implementation.

Basics of the Riga event timer designs

Usually the high precision of event timers is provided by an interpolation measurement that is used in addition to the basic measurement performed in a digital way. There are a few well-known methods for interpolation measurements (such as time interval stretching, time-to-amplitude conversion, vernier method, etc). However, mostly the interpolation measurements performed on the basis of these methods are characterised by a high hardware complexity, requiring considerable engineering know-how for designing, manufacturing and adjusting of the hardware. Mainly for this reason the most of top-quality event timers are distinguished by rather high manufacturing costs.

To solve this problem, a specific DSP-based method for event timing is used in the latest designs of Riga Event Timers (Artyukh, 2001). According to this method, each input event is converted to an analog signal with some predefined shape. Actually this is simply a generating of such signal at the time instant determined by the respective input pulse. Then this signal is digitised using typical A/D converter and digitally processed to estimate its position relative to the periodic sampling pulse sequence (Fig.1). If the ordinal numbers of the processed signal samples are known, the signal processing made in the proper way will result in an estimate of the time of event occurring.

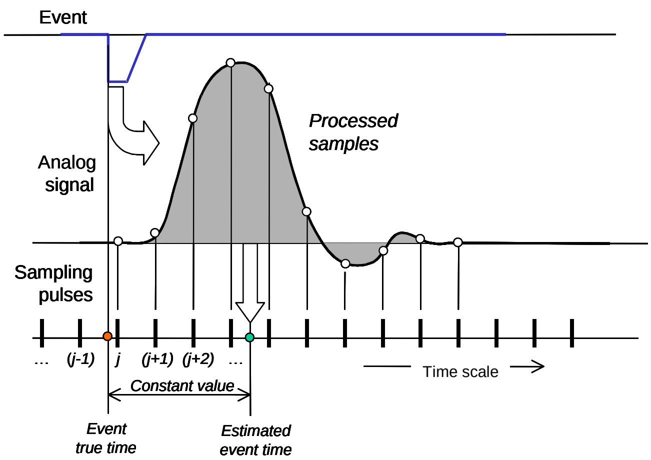

Figure 1. Principle of DSP-based method for event timing

Thus, in comparison with the traditional methods, this method provides considerable reducing of highly specialized hardware components by using instead of them typical DSP facilities. This results in hardware simplifying and increasing its reliability.

As for achievable performance characteristics, there are many essential realisation details to provide good final result. First and foremost, it is important to correctly choose the best practice of analog signal generation and matched algorithm for signal processing. Specifically, we generate the analog signal in the shape of near-triangular pulse. To provide sufficiently high measurement rate, we use not more than four samples of each such signal for further processing. Algorithm for such processing is based on a specific selection of two most informative samples of the signal and non-linear conversion of the difference between them to the target time-tag.

Updating the event timer A032-ET

Background for precision increasing

To avoid confusion, let us note that we define the timer's precision as the standard deviation of measured time for single event, unlike the timer's resolution, which traditionally is defined as the standard deviation of measured difference (time interval) between two events. The precision can be simply translated into the resolution and contrariwise if desired.

Three basic error components can be marked out as the main reasons for precision limitation of the Riga event timers:

- quantizing errors which directly depends on the resolution of A/D converter;
- integral non-linearity errors which mainly are caused by an imperfectness of the timer calibration;
- internal noise caused by trigger errors, sampling jitter, induced interferences, etc.

Note that the integral non-linearity errors are considered as systematic ones only in the case of synchronous measurements; otherwise they are like internal noises (Artyukh et al., 2008).

Correspondingly all these three kinds of errors in the most cases can be specified in statistical terms (by RMS values). In particular, the A032-ET precision is typically characterized by the following RMS values of error components:

- Quantizing errors: 3.5 ps approx.
- Integral non-linearity errors: 2.6 ps approx.
- Internal noises: 2.0 ps approx.

Considering these error components as statistically independent, the precision and resolution of the A032-ET can be estimated as follows:

- Precision: 4.8 ps
- Resolution: 6.8 ps

These estimates well conform to the RMS resolution (6-8 ps) experimentally evaluated for a number of the A032-ET event timers.

As can be seen, the quantizing errors dominate in the total error of the A032-ET. Correspondingly, the use of the A/D converter with higher resolution should noticeably increase the timer's precision. In addition, more careful hardware design and advancing of calibration procedure have to reduce other error components.

Hardware redesign

First and foremost, in the process of redesign the previous 10-bit A/D converter has been replaced by more advanced 12-bit converter AD9432 from "Analog Devices Inc." and obsolete high-speed logical NECL chips - by the modern LVPECL chips. Additionally, some special means for stabilization of temperature-depended parameters of the analog signal have been added, RF lines between the most sensitive hardware components have been revised and more careful PCB design has been carried out. All these modifications resulted in a fully new main board of the timer's hardware (Fig.2).

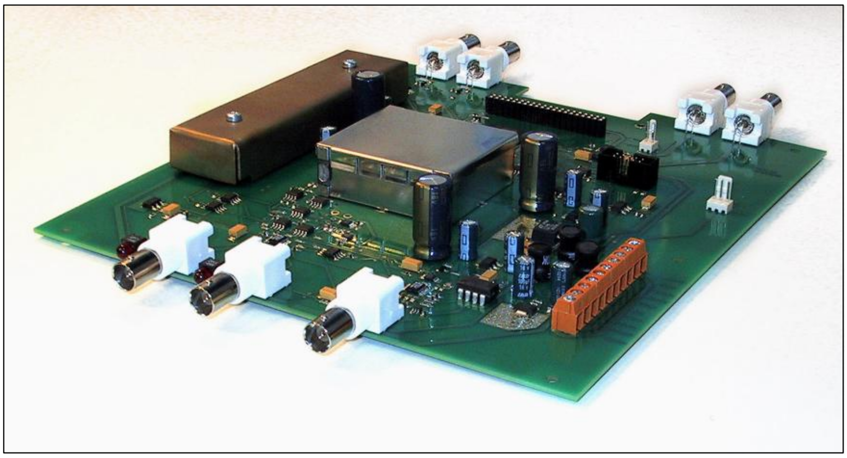

Figure 2. Main board of the A033-ET hardware

All blocks of the A033-ET hardware (the main board, clock frequency synthesizer and power supply) are assembled in a standard enclosure (EUROCASE; dimension: 367x250x76 mm). To provide compatibility of the A033-ET with the previous model, most interfacing connectors and their arrangement are preserved.

Software modifications

Functional features of the A033-ET are almost identical to those of the previous model. There are some software modifications caused by the changing of data formats and minor distinctions in control commands. In addition, more complicated calibration procedure is used to minimize the integral non-linearity. But this procedure is defined as a library function and its using does not require any special skill from the user.

Preliminary A033-ET tests

Preliminary tests of the A033-ET pilot version showed, that, as a result of the mentioned modifications, the A033-ET error components are characterized by the RMS values as follows:

- Quantizing errors: 1.1 ps approx.
- Integral non-linearity errors: 1.7 ps approx.
- Internal noises: 1.1 ps approx.

In this case the dominating integral non-linearity errors have been experimentally evaluated directly after device calibration (Fig.3).

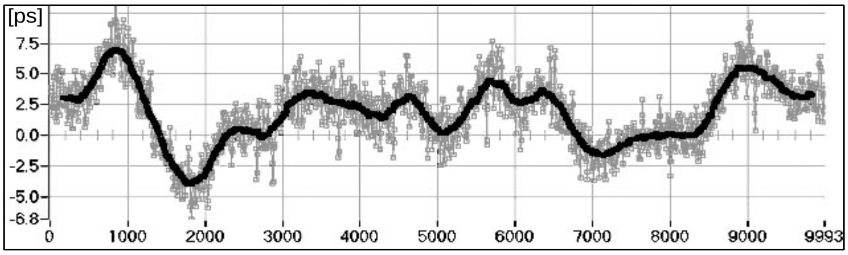

Figure 3. A033-ET integral non-linearity errors over interpolation interval

The above estimates conform to the calculated RMS precision of about 2.3 ps and RMS resolution of about 3.3 ps. Broadly speaking, the precision of the A033-ET has to be twice as better than that for the A032-ET. Such assumption was confirmed by the resolution test under temperature-varying operating conditions (Fig.4).

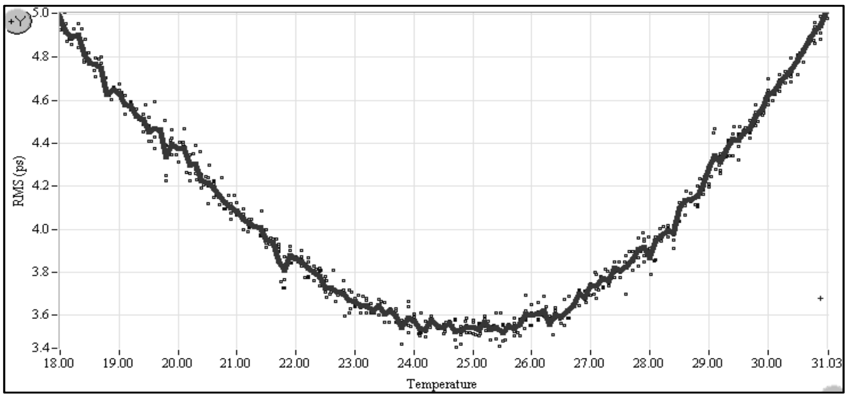

Figure 4. A033-ET RMS resolution vs. ambient temperature variation

As can be seen, the best RMS resolution (about 3.5 ps) is supported if the ambient temperature is close to the ambient temperature 25 ^{0}C when the device has been calibrated. Note that in this case an acceptable level of RMS resolution is supported without re-calibration in a sufficiently wide range of ambient temperature variation.

We also have tested long-term instability of the internal time-base through repetitive measurement of pulses strictly synchronised to the external 10 MHz frequency standard. It was established that such instability basically depends on the ambient temperature variation. In the case of temperature variation up-and-down in the range 10 to 40 ^{0}C, the results of synchronous measurements vary in the range of 35 ps approx. (Fig.5). In other words, the evaluated long-term instability of the internal time-base surely does not exceed 2 ps /1^{0}C.

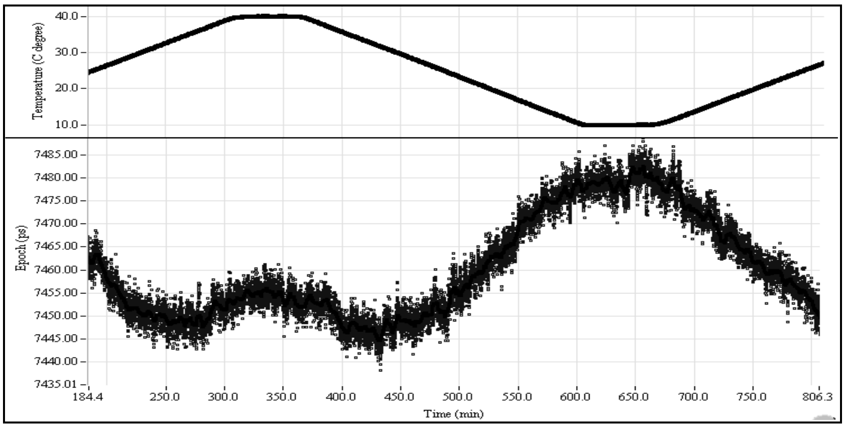

Figure 5. Internal time-base instability vs. ambient temperature variation

Event Timer Module

We consider the A033-ET as a completed product (like the A032-ET). As for the Event Timer Module (ETM), it is developed as a semi-customized product fitted to including into various customized timing systems after final ETM rework with due regard to the specific requirements. For example, the ETM can be configured so that its features will be close to those of the A033-ET.

Principles of the ETM operation are almost the same as that of the A033-ET but emphasis in its realisation is made on achievement of hardware compactness. For these purposes there are some modifications in the analog signal shaper (bulky cable delay line is removed), PLL-based clock signal synthesizer is incorporated in a module card. Re-programmable large-scale integration chip (Cyclone II) is used to provide customized modifications in ETM operation according to the specific requirements of application. Due to all these modifications a relatively small size of the ETM card (130x210 mm) and power consumption less than 6W have been achieved (Fig.6).

Figure 6. ETM design

As for the ETM precision, we expect that it will be not worse than that for the A033-ET, at least the preliminary tests confirm that. We also expect that operation speed for the ETM can be higher than that for the A033-ET. Specifically, the ETM pilot version already provide 25 MHz maximum burst rate and up to a few MHz of maximum average rate when high-speed USB 2.0 interface is used. Forasmuch as the ETM development is not completed in some details, its further improvement is possible.

Summary

The A033-ET continues the line of Riga Event Timers commercially available on multiple requests. Forasmuch as the A033-ET performance characteristics (especially precision) seem much better than that for the previous model, we hope that it can successfully replace the last one. But the final conclusion about ensured performance of the A033-ET will be made after additional checking of its performance repeatability in a small-scale production.

Unlike the A033-ET, conceptually the ETM is considered as an important component of more complicated application-specific event timer systems designed in the framework of various R&D projects. In addition, currently the ETM is used as a flexible platform for further development of DSP-based event timing technology.

Acknowledgements

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