A010 Family of Time Interval Counters Adapted to SLR applications

Yu. Artyukh[1], V. Bespal'ko[1], E. Boole[1], K. Lapushka[2]

[1]*Institute of Electronics and Computer Science, University of Latvia*
[2]*Institute of Astronomy, University of Latvia*
14 Dzerbenes Str., LV-1006 Riga, LATVIA. E-mail:artyukh@edi.lv

1. Introduction

A010 family of time interval counters has been developed to cover typical needs in high-performance but inexpensive timing system tailored to meet different special requirements of SLR applications. Compared to the counters currently most popular for SLR (like SR620 and HP 5370B), the counters from A010 family are characterised by higher linearity and resolution, offer some special features useful for SLR. Specifically, they are capable of measuring not only one-shot time intervals, but continuous sequence of time intervals as well; time interval measurement is attended by START pulse timing relative to the internal real-time clock. The basis of A010 family development is Modular Time Interval Counter considered early in [1].

Presently A010 family includes three basic models of time interval counters (A013, A012 and A011) which differ mainly by single-shot RMS resolution (frequently named also RMS jitter). Each counter represents typical PC-based virtual instrument characterised by the software function predominance. This simplifies the hardware design and makes it possible to integrate the counter highly with specific software. Every counter is available both as a ready-to-use instrument (including custom-made options) and a set of hardware-software tools for creating various timing systems by user himself. By now about 20 counters have been made (mainly in custom-made options) and used.

2. Measurement concept

Operation of the counters is based on high-speed single-channel event timing (Fig.1). Any of the input signals (except GATE) can be connected to the event timer input in a program defined order. Once these events (up to thousands in every measurement cycle) have been timed, the time intervals between any two events can be calculated from the timing results. Since the timing is performed uniformly for every event, this results in high linearity and temporal stability of the time interval measurement. It is also significant that the single-channel timing is minimised in hardware, making the counters more reliable and inexpensive.

However, the mentioned advantages have been gained at the expense of a restriction on the minimum time interval between adjacent events (it should be greater than the event timing dead time). Next disadvantage is a pronounced non-linearity error for measurement of small (close to the dead time) time intervals. This is caused by the impact of a certain recovery process after previous event timing.

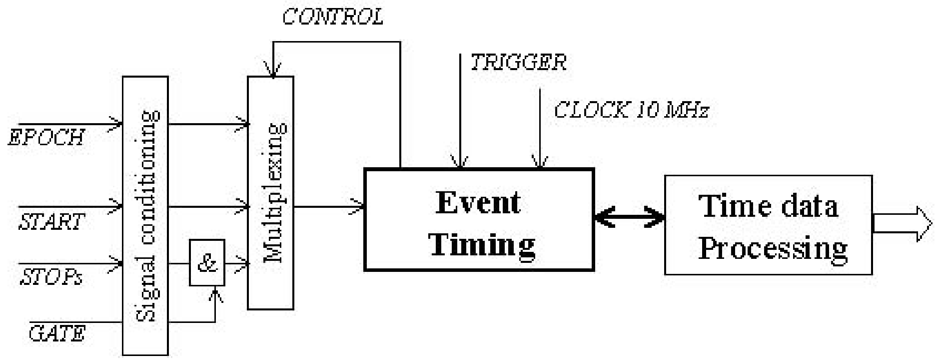

Fig.1. Block diagram of counter operation

3. Event timing

In our case the event timing is based on the original interpolating method [2] embodied in a relatively simple specialised hardware (Fig.2) and supporting software. The hardware is housed in a standard case (desktop), along with an ancillary board and primary power supply. The software is written in C language and may be built in various application systems depending on the specific user needs.

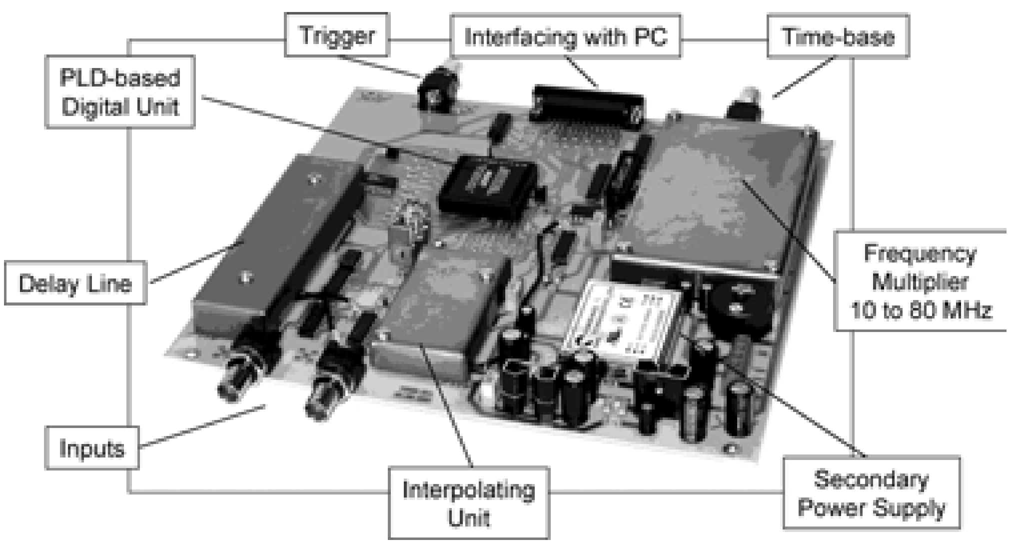

Fig.2. Event timer hardware design (single board, 220x230 mm)

The event timer uses 80 MHz internal clock locked to external 10 MHz timebase. In the simplest case it assures 30-35 ps single-shot time-interval RMS resolution and 100 ns dead time (A011 option). However the special hardware adjusting and modification of the software together make it possible to improve the RMS resolution to 15-20 ps (A012 option). Finally this resolution can be improved to 7-10 ps by using repeated interpolations (A013 option). These options of the event timer represent the basis of the corresponding counter models.

Specifying of single-shot LSD (named also resolution) needs a special clarification. In our case the event timing is based on non-uniform quantizing wherein the time scale divisions are dissimilar but predetermined with high precision. As a result the smallest displayed increment (LSD) is always 1 ps, while the mean of time scale divisions can be much greater (depends on the timer option). In particular, the mean of time scale divisions is about 2-3 ps for the option A013 allowing highest (<10 ps) single-shot RMS resolution. Generally our opinion is that the RMS resolution itself specifies precision of the event timer adequately.

4. Bench testing

Taking into account that the counters from A010 family are almost identical in the main features (except the RMS resolution), we focused our experiments on the most advanced counter A013, more exactly - on “SLR Timing System” based on this counter. The system has been developed both as a demonstrator of the counter possibilities and a pilot system for its following adaptation to the specifics of particular SLR application. It is capable of measuring a sequence of single shot time intervals at rate up to 100 Hz, displaying the measurement results in real-time, their current mean and RMS deviation. Measurement can be performed in either of two operating modes: BASIC (<20 ps RMS resolution, 100 ns to 209 ms range) or PRECISION (<10 ps RMS resolution, 1 μs to 209 ms range). Both of these modes give the measurements identical in systematic error. Measurement results, including the time-stamps of every START, are auto-saved in practically unlimited size. Application software of the system has been developed with a help of LabWindow/CVI 5.0 and operates under MS-Windows’95 and higher versions. As an external timebase we have used standard oven-controlled crystal oscillator.

Evaluation of the single-shot RMS resolution has been based on repeatable measurement of low-jittered time interval (Fig.3).

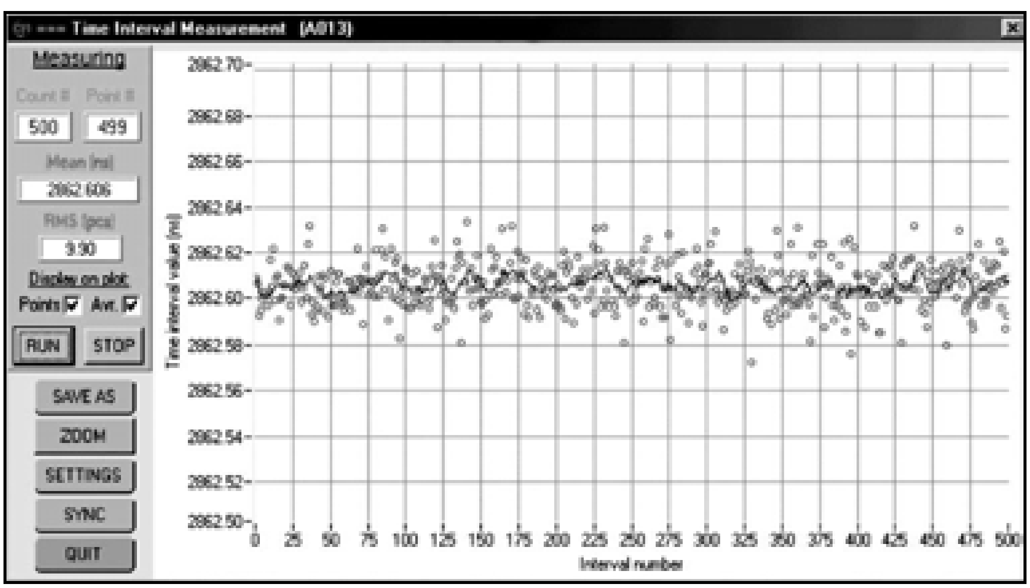

Fig.3. Example of time interval repeatable measurement in PRECISION mode (virtual control panel of the system shows single-shot readings at 20 Hz rate, moving averaging of 10 readings and statistics for 500 sequential readings)

Under these conditions RMS deviation of the measured values was typically about 10 ps in PRECISION mode and 16-18 ps in BASIC mode. Taking into account that the test signal jitter is included (about 5-7 ps RMS), the single-shot RMS resolution of the tested counter is certainly less than the mentioned estimates. Note that the counter A013 (as well as other counter models) ensures the best resolution if it has been pre-calibrated under actual and relatively stable in temperature (<±5^{0}C) operating condition. Calibration procedure can be called out at any instant and is performed automatically during several seconds.

The similar experiment characterises the offset drift (named also stability) when the measurements are repeated over a long period of time under specified operating conditions. As known, this drift is caused mainly by the ambient temperature variation in time. We have evaluated the offset drift as a function of temperature inside the case during the warming up process directly after power-up (Fig.4).

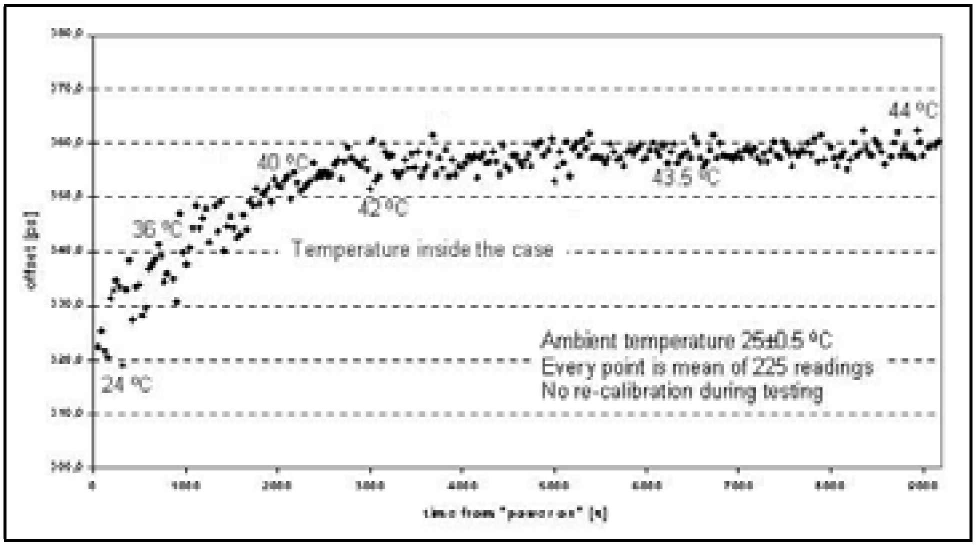

Fig.4. Offset drift during warming up process

After 3 hr warming up period the offset drift is hardly visible against a background of random errors, timebase and test signal long-term instability. Supposedly it is less than ±1 ps/^{0}C. Temporal stability is dominated by the timebase stability and in our case is not specified.

Let's note that in our case the offset error is caused mainly by the difference between START and STOP pulse internal delays before these pulses combining at the event timer input (see Fig.1). If START and STOP pulses income through common input, this difference is zeroed and the offset drift was absent under the same warming up conditions.

For linearity evaluation we used the special test methods showing the linearity error versus measured time interval in any part of the full measurement range. Figure 5 shows a typical result of linearity error evaluation for PRECISION mode in the range from 0.7 ms. The linearity error is less than the errors of its evaluation. As the time interval decreases down to 5 μs, the linearity error increases up to 2 ps (Fig.6). This error is well reproduced and thereafter has been corrected by the program, resulting in the linearity error less than ±1 ps in the range 5 μs to 209 ms.

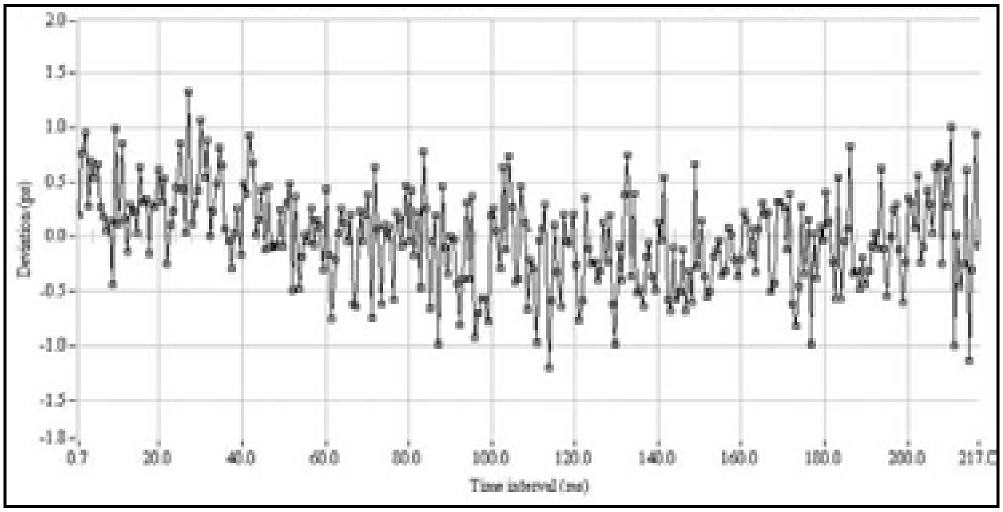

Fig.5. Linearity error for time intervals from 0.7 ms (PRECISION mode; showed mean of 1000 reading provides the evaluation error about ± 1.0 ps p-p)

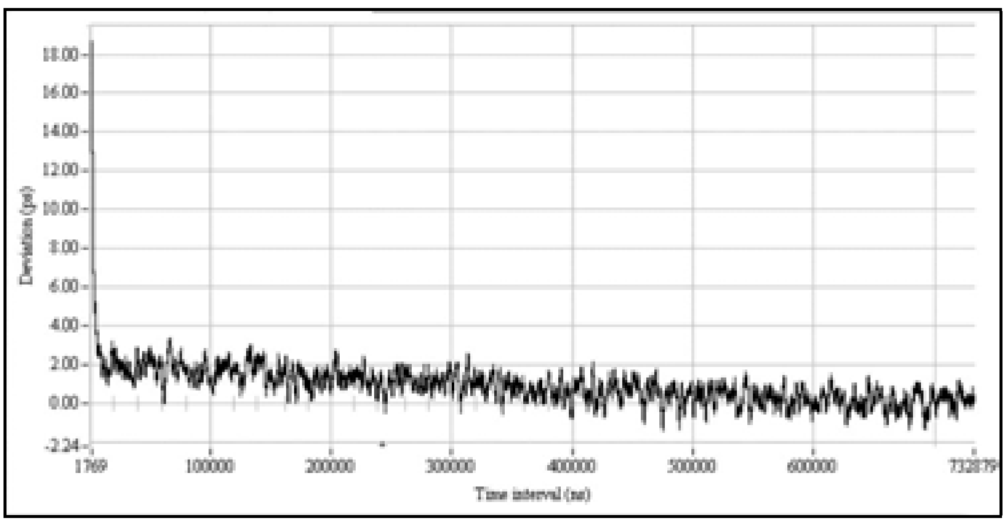

Fig.6. Linearity error for time intervals smaller than 0.7 ms before correction (PRECISION mode; moving averaging over 2 μs provides the evaluation error about ±1.5 ps p-p)

Measurement in PRECISION mode of smaller time intervals (down to 1 μs) is available but not recommended in view of essential linearity error and some problems with its correction. In this case BASIC mode is preferable since it ensures much smaller dead time. In particular, the evaluation results showed that in this mode the linearity error is negligible small in the range from 1 μs but rises essentially (to 20 ps) for smaller time intervals. However this error also has been thereafter corrected by the program, resulting in the linearity error less than ±1 ps in practically full measurement range (Fig.7).

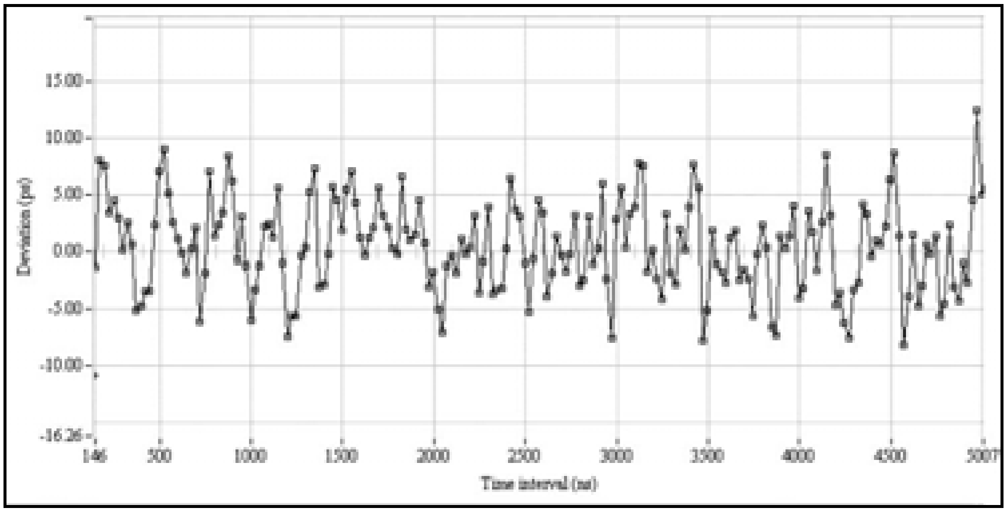

Fig.7. Linearity error in the range from 140 ns (BASIC mode; moving averaging over 50 ns provides the evaluation error about ±10 ps p-p)

5. A010 Family Specification

Input signals (50Ω): START STOP GATE EPOCH TIMEBASE	NIM pulses (falling edges) NIM pulses (falling edges) NIM pulses (high level) TTL pulses (rising edges); 1 pps 10 MHz; >0.5 V p-p	
Measurement mode	*Basic (all models)*	*Precision (A013)*
Time interval range	100 ns to 209 ms	5 μs to 209 ms
Time interval RMS resolution	<40 ps (A011) <20 ps (A012 and A013)	<10 ps
Number of continuously measured time intervals	to 4680 in each cycle	to 500 in each cycle
Integral linearity error	< ± 1 ps	
Offset drift	< ± 1 ps/ ^{0}C	
Cycle repetition rate	to 500 Hz	
LSB resolution of START timing	12.5 ns	
Timebase	external - 10 MHz; internal - 10 MHz/100 ppm;	
Warm-up time	3 hr	
Application software	Windows based “SLR Timing System”	
Software support	Example program in C	
Hardware connection to PC	via PC parallel port working in EPP mode	
Hardware dimension	375_60x233 mm	
Power supply	100 – 240 VAC	

6. Conclusion

Taking into account some problems with equipping SLR stations with high-performance and inexpensive timing systems, the A010 family offers an alternative to the standard time interval counters and some specialised instruments. The counters from this family, in our opinion, satisfy the current needs of SLR applications and have good potential for further development.

The main disadvantage of the counters is a limitation for minimum time interval, resulting in possible problems of SLR calibration. However this limitation can be reduced (if desired) at least for one-shot time interval measurement. Specifically, we have developed the counter option A013.2 allowing an additional FAST mode of measuring time intervals from 10 ns.

The performance of the counter A013 has been additionally verified by direct comparison with known Picosecond Event Timer (PET) at Wettzell station. As this experiment showed, A013 and PET appear to be closely allied in the single shot resolution and linearity error in measurement range from several ms at least. Specifically, the differences between the results of parallel measurements by PET and A013 of the same time intervals in simulation modes (WESTPAC Simulation and LAGEOS-2 Simulation) have RMS variation about 13 ps.

References

[1] Yu. Artyukh, V. Bespal'ko, E. Boole. High Resolution Modular Time Interval Counter. 12th International Workshop on Laser Ranging. Matera, Italy, 13-17 November 2000.

[2] Yu. Artyukh. A method for continuous superprecise time-interval measurement. Automatic Control and Computer Sciences, Vol.35, No.5, pp.11-18, 2001.