Selective Time Interval Counter for SLR Applications

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Abstract. Selective Time Interval Counter is a PC-based system, which offers a solution of the whole of measurement problems in SLR applications. The counter allows to measure in parallel a few time intervals in the range from 50 ns to 320 ms provided that they correspond to the predetermined limitations for their duration. It offers both high measurement resolution (down to 12 ps RMS) and extended functionality covering the conventional and advanced ranging modes. Additionally the counter provides itself specific functions usually required for SLR applications; such as on line controllable gating the input signals, precise Start-pulse timing by internal real-time clock, etc.

The counter's hardware is built as a compact device connected to PC via its standard parallel port (LPT). The software option is developed as a specific application within MS-Windows environment. Depending on user's particular needs, the counter can be implemented in various customized options.

1. Introduction

As well known, customized measurement systems for SLR applications allow to optimize solution of the whole of the measurement problems with provision for the specifics of particular application. However such systems usually are expensive and their development needs much time. In this paper we propose a solution of this problem by development of a high-performance and relatively inexpensive measurement system which both retains all advantages of customized systems and can be easily adapted to particular user requirements. We hope that our experience in the area of customized system development (see relevant publications [1-2]) for various users and long-term collaboration with the personnel of SLR-station „Riga-1884", is a good prerequisite to solve the problem successfully.

2. Counter Architecture

Fundamental counter architecture (Fig.1) is oriented to the fast development of various specific applications options, mainly by software modification. It includes specialized measurement hardware and typical PC supporting specific application software, usually within MS-Windows environment. The hardware and PC interact via standard high-speed parallel port working in EPP mode.

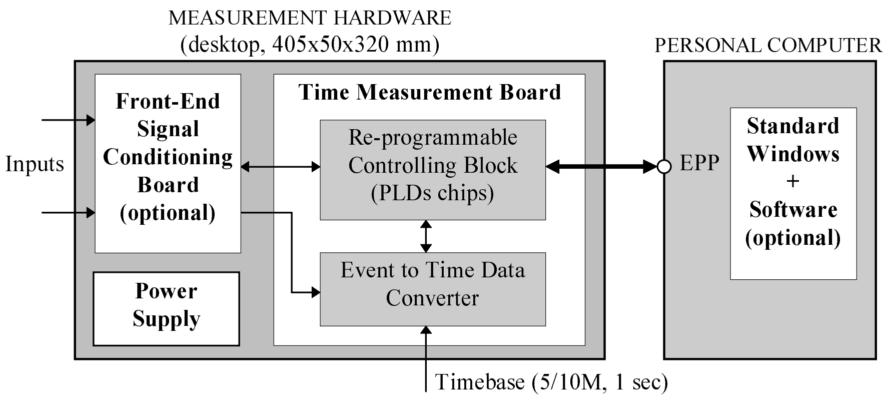

Fig.1. The Fundamental Counter Architecture

The hardware is characterized by extended functionality, covering a wide range of possible applications, in combination with relatively simple design. Two boards placed in one-plain, form a functional core of the hardware. Signal Conditioning Board interfaces the transducer outputs to Time Measurement Board: it performs input signal conversion into standard pulses, arranging, gating for interference proofing, etc. Time Measurement Board controls the Signal Conditioning Board (by means of optionally programmed Controlling Block) and converts the selected events (e.g., input signal threshold crossing) to the corresponding intermediate time data. Additionally an internal real-time clock provides time stamping the Start-pulse relatively to the diurnal time scale. The main part of specific digital functions is implemented inside two ASICs designed on the basis of PLD-technology from ALTERA Inc.

After finishing every measurement cycle, the time data is transferred from the hardware to the computer and digitally processed to estimate required time intervals between input signals and to set the gating parameters for the next measurement cycle. Specific software option defines data processing algorithm, result display, etc. depending on specific user's needs.

3. Measurement Method

The main special feature of the counter is unconventional method of time interval measurements named Enhanced Event Timing (EET) [3, 4]. It allows to reach high performance (in particular, enhanced resolution of time interval measurement) in combination with simplicity of hardware. Briefly, EET-method includes the event conversion to a specifically shaped analog signal, its digitizing and digital processing to estimate location of this signal (and the corresponding event) on the time axis.

To illustrate the essence of EET-method more clearly, let's consider a simple example. Let's assume, that every timed j-event (j=0, 1, 2, …) is converted into a linearly rising analog signal $u_j(t) = k(t - t_j)$, where t_j is an instant when the j-event has happened and t varies from t_j to $t_j + \Theta$ (Fig.2). The analog signal $u_j(t)$ is periodically sampled at some predetermined instants $\{t_{ji}\}$ (i=0, 1, 2, … N-1).

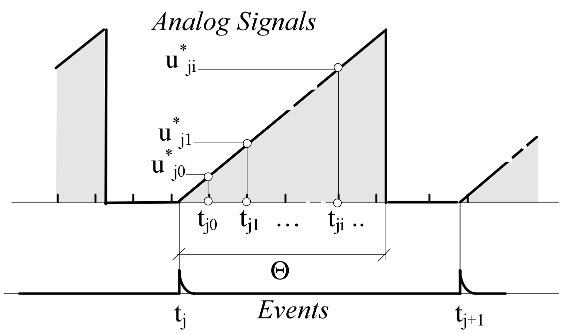

Fig.2. Principle of event timing based on sequential measurements of the analog signal

Evidently that the instant t_j can be easily estimated through any single sample u^*_{ji} of the analog signal:

$$t_j \cong t_{ji} - u^*_{ji}/k = t_j + \Delta_{ji}/k,$$

where $\Delta_{ji} = u^*_{ji} - kt_{ji}$ - some equivalent error caused by finite amplitude resolution, jitter of sampling instants, fluctuation of the analog signal parameters, etc.

However using all available samples of the same analog signal for multiple estimations of the instant t_j and then their averaging, the resulting error of estimating t_j can be significantly reduced:

$$t^*_j \cong t_{j0} + \frac{(N_j+1)}{N_j}\tau + \frac{1}{N_j}\sum_{i=0}^{N_j-1} u^*_{ji}/k = t_j + \frac{1}{N_j}\sum_{i=0}^{N_j-1}\Delta_{ji}/k .$$

Thus, EET-method allows not only to estimate the time of single events generally but also to do this with higher resolution using several available samples of the analog signals formed from the events. Achievable resolution depends on a number of samples being used and is limited mainly by allowable measurement rate. In such a manner continuously obtained precise time-stamps of the events further can be used for calculation of the required time intervals.

4. Principles of operations

Time interval measurement. The above shown effect of error minimization can be also achieved when the analog signals have more complicated shape in view of technical way of their forming and sampling. In particular, we used event conversion into a train of bell-shaped pulses (about 20 MHz repetition rate) where the train length could be optionally controlled depending on the allowable „dead time“ of event timing to reach the best available resolution. However, in the case of such conversion the specific algorithm of signal processing is not so simple as above shown: it includes threshold detection of available signal samples, their matching to falling or rising edges of the pulses, special non-linear converting the values of samples into resulting time-data, etc. Nevertheless such algorithms can be easily performed in real time by means of a typical PC.

As it is usually accepted, the counter employs two gates for Stop-pulse selection before timing the corresponding events (Fig.3):

- *Gate R* - for selection of Stop-pulses reflected from Satellite. The delay of this gate relatively to Start-pulse and its width are independently controllable in every ranging cycle with 20 ns LSB resolution in conformity to the expected (pre-calculated) value of ranging delay.
- *Gate C* - for selection of Stop-pulses reflected from ground-based target used for calibration. The time parameters of this gate usually are being set optionally depending on specific user requirements.

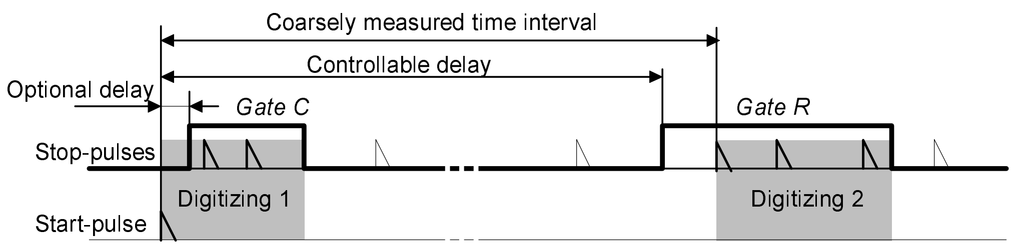

Fig.3. Time diagram showing principle of event gating and timing

But in our case the gates are formed always in pair (independently on the actual operating mode) and correspondingly the measurement hardware works equally in all operating modes. The modes differ mainly by signal processing algorithms where certain time data obtained by hardware are used fully or partly.

To digitize the analog signals we used a typical 8-bit ADC at 100 MHz sampling rate and a high-speed buffer RAM. However in the case of simplified (based only on digitizing process) realizations of EET-method there is strict limitation for the range of time interval measurement related to the maximum size of buffer RAM. To extend the range of measurement without increasing the size of buffer RAM, the analog signal digitizing is performed discontinuously at two stages: from Start-pulse and from the first Stop-pulse placed within Gate R (see Fig.3). Additionally the time interval between these pulses is coarsely measured by direct counting at sampling rate. That allows to measure precisely time intervals between any pairs of events placed both within Gate C and Gate R. Size of the buffer RAM (32K words) can be optionally divided between the stages of digitizing to obtain most suitable ratio between the ranges of gating.

Time-stamping the Start-pulse. Start-pulse is always timed in every ranging cycle using internal real-time clock. It consists of a coarse counter allowing 10 ms LSB resolution and digital interpolator, which enhances LSB resolution down to 10 ns. If desired it is possible to further enhance the resolution. The clock interacts with PC after every coming Start-pulse and synchronizes the joint cyclical work of the hardware and software in real time.

The clock is synchronized with an external time base through second marks matched with a standard time scale. After initial procedure of synchronization the clock works as a stand-alone unit.

Interaction between the hardware and PC. The measurement hardware interacts with PC in the interrupt mode through two interrupts within every ranging cycle. The first interrupt comes always after Start-pulse coming and causes time-data reading from the real-time clock. The second interrupt comes after Gate R having ended (if corresponding Stop-pulse has been recorded in the current ranging cycle) and causes a time-data reading from the buffer RAM, re-setting the gating parameters for the next ranging cycle and so on. If the Stop-pulse is absent for any reason, the second interrupt comes after certain fixed delay to prepare the system for the next ranging cycle. During the rest of the time PC processes the obtained time-data according to the operating mode being set.

Software. Software of the counter is developed as a specific 16-bit real-time application within standard MS-Windows environment. Although MS-Windows were not developed as a real-time system (in the sense of ultra-fast responses to the current demands), they have some significant features for the solution of our task, such as:

- possibility of operation with full size of PC RAM that is important taking into account a large amount of data to be processed in SLR applications;
- possibility of simple and effective programming the parallel processes performed in real time which usually are typical for intricate signal processing in SLR applications;
- handy user's interface and, finally,
- actual widespread popularity of MS-Windows, readiness of many users for its application.

Our experience showed that certain problems of unconventional using MS-Windows for real-time applications could be successfully solved by development of a special driver of external devices. Such a driver has been developed. It offers an access to parallel PC ports and provides a fast handling of interrupts. In principle the developed system's software allows to handle up to thousand of interrupts per second. But achievable maximum repetition rate of ranging cycles is restricted mainly by the complexity of data processing algorithms in the specific application.

Operating modes. In principle the counter's hardware can record continuously a lot of input pulses (up to hundreds) within every digitizing stage. Developed software option of the counter utilizes only three main pulses from all possible: Start-pulse and two Stop-pulses. Correspondingly the option provides following ranging modes:

1. Satellite Ranging when Start-pulse and 1-st Stop-pulse located within *Gate R* (as it is expected, reflected from Satellite) is used for measurement of the corresponding time interval (Fig.4 shows the basic user interface in the mode of Satellite Ranging);

2. Calibrating Ranging when Start-pulse and 1-st Stop-pulse located within *Gate C* (as it is expected, reflected from a ground-based target) is used for measurement of the corresponding time interval;

3. Combined Ranging where both mentioned time intervals are measured simultaneously in every ranging cycle to compensate more accurately the measurement error caused by long-time deviation of environment conditions (such unconventional ranging mode is possible in SLR station „Riga 1884").

The counter also supports certain service modes related with system checking, synchronizing the internal real time clock, setting the mode parameters, etc.

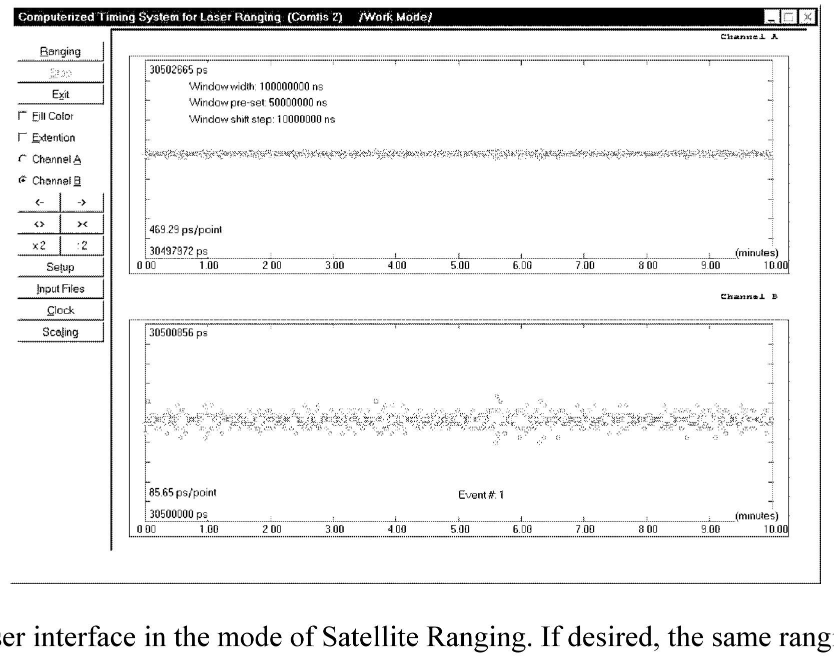

Fig.4. User interface in the mode of Satellite Ranging. If desired, the same ranging results can be observed simultaneously as a whole and in details

The software option is developed as a loading EXE-file and DLL-file. Performing this option needs from the PC: free space of HDD >20MB, free space of RAM > 8 MB and a processor working at least at 100 MHz clock.

5. Experimental studies

The first counter's option has been developed for applying at SLR-station „Riga-1884" and was tested in the real operational conditions of this station. The results of such testing were quite successful in terms of functionality, reliability and other operational characteristics of the counter.

However certain general limitations of the SLR-station did not allow to fully utilize the enhanced resolution of time interval measurements and to obtain principally better results of Satellite ranging in comparison with the counter [2] used before. Therefore we had to pay main attention to the studies of the counter's performance in special testing modes. In particular, for the most part we evaluated time interval RMS resolution of the counter.

As it was mentioned, EET-method allows to obtain time interval resolution enhanced in line with increasing the analog signal length. Therefore we evaluated such relation as the main specific performance of the counter (Fig.5).

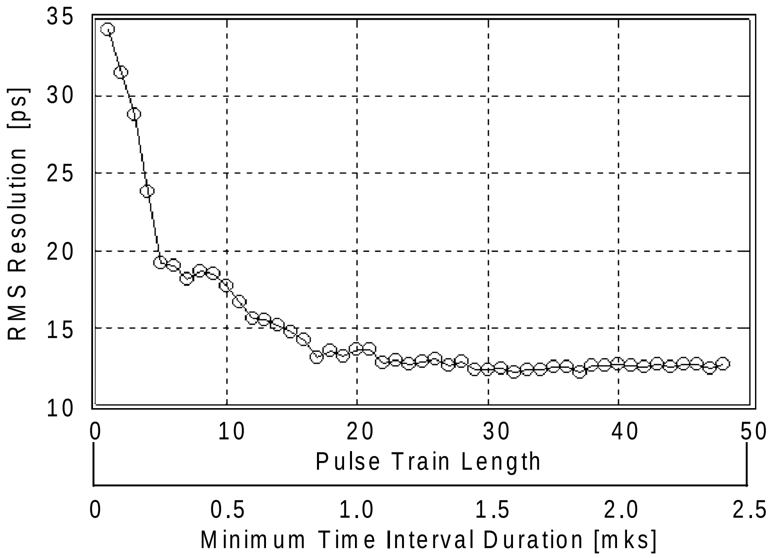

Fig.5. Experimental evaluation of time interval RMS resolution versus pulse train length and corresponding minimum time interval duration

As shown, the time interval RMS resolution depends on pulse train length and reaches 12-13 ps if this length (and corresponding time interval being measured) exceeds 1 μs. But even much shorter time intervals (down to 50 ns) can be measured with sufficiently good RMS resolution (less than 40 ps). The mentioned experimental results have been well reproduced without any additional counter calibration at least during a few hours. Let's remind that flexible adapting the „resolution/measurement rate" ratio to the actual properties of measured input signal is possible.

However the best resolution achievable via EET-method is always limited (even if the measured time interval is very long) because the real analog signal gradually loses the information about event time location due to its short-term instability. Principally the best time interval RMS resolution, which has been obtained in our experiments, is about 5 ps.

Theoretically the temperature drift and temporal stability of the counter should be lesser than a few of ps. However, to precisely evaluate the real values of these parameters, we could not correctly exclude a certain temporal instability of an external test signal. The temporal instability of the measurement results, including instability of the test signal, in our experiments did not exceed ± 15 ps per hour (peak-to-peak) in typical operational conditions (Fig.6).

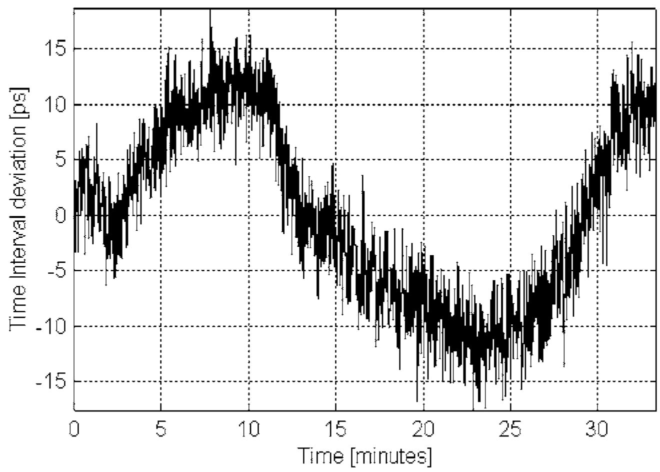

Fig.6. Typical long-term deviation of continuously measured time interval

6. Counter Main Characteristics

- *Inputs*

Inputs of Start/Stop-pulses - common or separate
Amplitude range - -3 to +3 Vdc
Pulse width - >2 ns
Slope - rising or falling edge
Threshold of crossing - optional in the range -2 to +2 Vdc
Impedance - 50 Ω

- *Time Interval Measurement*

Measurement range - 50 ns to 320 ms
Single shot RMS resolution - optional in the range 12 to 40 ps
(depending on allowable „dead time")

- *Gating*

Gate R (on line computed)
Range - 50 ns to 165 ms
Delay - 15 μsec to 335 ms
Variation step - 20 ns min.

Gate C (optional setting)
Range - 50 ns to 1 μs
Delay - 50 ns to 3 μs
Variation step - 50 ns min.

- *START-pulse Timing*

Measurement range - 24 hours
LSB resolution - 10 ns

- *Synchronizing of the Measurement*

Start of measurement - at beforehand programmable time or manually
Cycle start-up - by external signal or after finishing the every current cycle
Maximum measurement rate - up to 20 cycles/sec

- *General*

Power - 220 VAC ± 10%
Dimensions - 405x50x320 mm
Weight - 3.6 kg

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