High Resolution Modular Time Interval Counter

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Abstract. A high-performance modular time interval counter is described. It allows to measure time intervals in the range from 100 ns to 209 ms with RMS resolution less than 20 ps. From 1 to 4680 intervals can be measured in every measurement cycle depending on the external "window" duration. The counter provides high resolution, multi-purpose functionality, self-control and it is well suited for embedding into various types of PC-based measurement systems, including modular systems for SLR applications.

Key words: Time interval counter. Event timing. Laser ranging. Precision testing.

1. Introduction

Previously we considered Selective Time Interval Counter (SETIC) which had been expressly developed for SLR-station "Riga-1884" in respect to the specifics of this station and requirements of end-user [1]. In fact such counter is more than a common measurement instrument. It is virtually a "ready-to-use" PC-integrated system in which a high-precision measurement of time intervals is combined with performing the basic special functions needed for SLR (programmable Stop-pulse windowing, Start-pulse timing, friendly interfacing, etc.). Designed by this means customized systems allow to achieve the best specific-task performance in terms of functionality, accuracy, reliability, hardware size, etc.

However such approach to system design is not accessible always. In many cases end-user develops or upgrades himself a needful to him measurement system by using available modular components and some self-made tools. The principal problem then is to find well suited (in terms of performance, compatibility and cost) applicable measurement modules. Time interval counters represent one of a such often needed basic module. Description of an advanced time interval counter, well suited for applications in modular measurement SLR systems (and not only for them), follows.

2. Main function of the counter

The counter measures continuously time intervals between adjacent input pulses. Duration of each measurement cycle is determined by corresponding input "window" (see Fig.1).

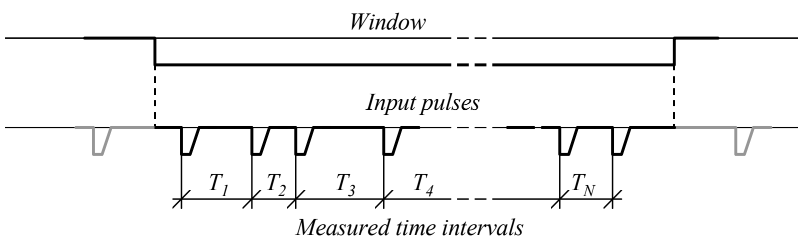

Figure 1. Schematic time diagram of measurement

Each time interval is measured in the range from 100 ns to 209 ms with RMS resolution less than 20 ps. Up to 4680 intervals can be measured in every measurement cycle. Measurement results are accumulated as data files in PC and they can be further processed and/or displayed in various ways.

The "window" is formed externally. Duration of the "window" depends on the particular user task. For example, the window can be formed from Start-pulse to a certain N-th Stop-pulse (N=1,2,…).

Therefore the counter is applicable in this way both for traditional "one-shot" and continuous measurements of time intervals as needed for the specific application.

In addition to this basic operating mode, it is possible to start measurement by a program or by a front-edge of the "window". In these cases the measurement cycle can be stopped by the program at any given time or after the maximum number of time intervals have been measured.

3. Method of measurement

Time interval measurement process includes high resolution event timing and following calculation of time intervals between the adjacent time stamps. The event timing is performed on the basis of EET-method [2]. As compared to the conventional methods of event timing, EET-method emphasizes digital signal processing and that leads to reduction of number of operations with analog signal and, consequently, to achieving better measurement resolution as well as simplified hardware implementation.

According to EET-method, a secondary bell-shaped signal is formed from front edge of every input pulse. Sequence of these signals is continuously converted by ADC to sequence of digital samples. Four first samples <S_{j1}, S_{j2}, S_{j3}, S_{j4}> after input pulse appearance at the input and serial number N_j of the first sample S_{j1}, combine into a data block (Fig.2).

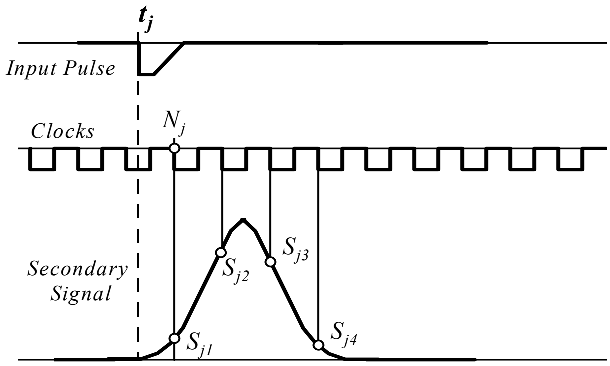

Figure 2. Time diagram showing the principle of event timing

Such blocks sequentially are memorized in buffer memory. Memorized data blocks are transferred to PC at the end of measurement cycle and further processed. The samples of each secondary signal are used to estimate the position of corresponding event between adjacent clocks and, eventually, to precisely calculate an instant t_j when this event occurs.

A self-calibration of the counter is provided before measurements. That leads to better establishing of the true relationship between the sample values and the event position under actual operating conditions.

4. Design of the counter

Schematic structure of the counter is shown in Fig.3. It consists of measurement hardware and software working under MS Window on IBM-compatible PC. The interaction between the hardware and software modules occurs via standard Enhanced Parallel Port. The hardware is implemented as a single board (E2 size standard) which can be placed into various user's frames.

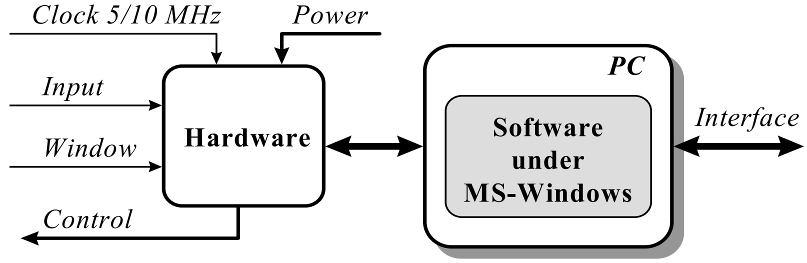

Figure 3. Simplified structure of the modular time interval counter.

The hardware structure is conceptually close to the structure of typical data acquisition blocks working at 80 MHz sampling rate. Internal 80 MHz clock is formed from internal (5MHz/25ppm) or external (5 or 10MHz and higher stability) time-base. As optional to the main measurement function, the hardware has a special mode for transmition of a required control signal from the software-run blocks to the conditioning board.

The software has been written in C language with the help of LabWindows/CVI 5.0 toolkit and it is operating within MS-Windows environment. It is possible to build the same software into other operating systems if this is especially needed. Additionally to the basic software, the counter is supplemented with the service software tools for functional testing, precision monitoring, etc.

5. Precision of the counter

The counter is characterized by rather high precision of time interval measurements. In our case the counter precision has been determined by the significant RMS error which is held during certain time without any intermediate re-calibrations. That RMS error typically is about 15–18 ps (with 0.95 confidence probability) during at least one hour under normal temperature conditions (20 ± 5^0C). The bias error of the measured time interval normally is negligible (at least for the specified measurement range to 209 ms). This is due to the fact that Start- and Stop- events for every measured time interval are timed by the same electronic units and under practically equal temperature conditions. Correspondingly a bias error of event timing is compensated after calculation of difference between adjacent time-stamps.

A special feature of the EET-method is that it permits estimating the true precision of the counter directly in measurement mode. Practically any input signal, which does not need to be high stable, can be used for that. In particular, the precision of the counter can be estimated continuously by a special testing program. The instantaneous RMS errors versus time are observed during a defined period and the testing protocol is generated at the end. Fig.4 shows a typical result of the precision estimation for 15 sec periods during one hour. The counter is under established temperature conditions; its RMS error is varied in time from 16 to 18.5 ps.

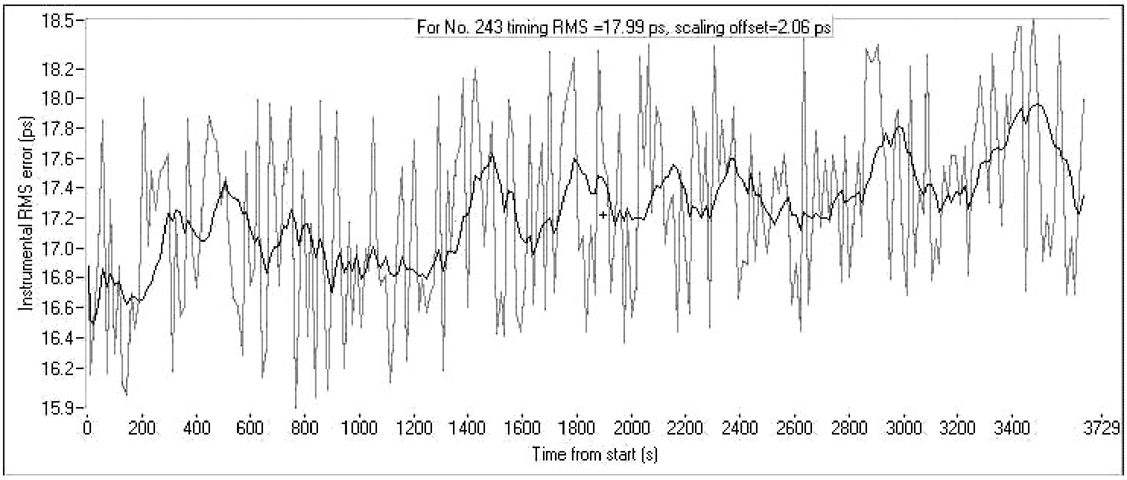

Figure 4. Continuous estimation of the counter precision

Temporal instability of the counter is reflected by trend of RMS error over a long period. In particular, black line in fig.4 shows visibly existing trend in result of instantaneous errors averaging in tens. This trend leads to increasing the initial RMS error by 1 ps approximately.

The temporal instability is caused mainly by fluctuations of environment temperature. Its impact on the precision can be essentially reduced by repeating the self-calibration process when the evaluated during measurement process RMS error exceeds the value defined by user. Similar mode of automatic re-calibration can be useful if the counter operates under essentially varied climatic conditions. Effectiveness of self-calibration is illustrated by an counter testing example when the counter is tested immediately after the counter power is switched on. In this case the temporal instability is a maximum during some transition stage and the counters usually then cannot be used for precise measurements. Fig.5 shows the counter testing protocol when self-calibration provides automatically the precision perpetuation if continuously monitored RMS error exceeds 18 ps. As shown, even in this worse case, 4 re-calibrations made during one hour have provided that the significant RMS error is less than 18 ps.

```
**********************************************
***   COUNTER TESTING PROTOCOL             ***
***                     Date: 10. 8.2000   ***
***  Device # 01        Time: 14: 7:22     ***
**********************************************
    Test period                 15 sec       +)
    Test points                 240          +)
    Test duration               60 minutes
    Rescaling                   ON           +)
    Reasonable offset           18 ps        +)
    Number of re-calibration    4
----------------------------------------------
    Test signal               EXTERNAL       +)
    Mean time interval         225.589 ns
    Averaged RMS jitter         23.3 ps
    ************************************
    ***     Counter's RMS error      ***
    ************************************
    Maximum RMS               18.2 ps
    Minimum RMS               15.6 ps
    Averaged RMS              16.7 ps
----------------------------------------------
    With confidence          RMS error
     probability (%)        is less than
----------------------------------------------
       99                      18.1 ps
       95                      17.7 ps
       90                      17.5 ps
       85                      17.3 ps
----------------------------------------------
+) parameters which was adjusted for testing
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Figure 5. Example of the counter precision testing protocol.

Note that under the same conditions, but without re-calibrations, the significant RMS error is gradually increased to 25-30 ps approximately.

6. Key Specifications of the counter

- Input — sequence of NIM pulses
- Time interval RMS resolution — <20 picoseconds typically
- Time interval range — from 100 ns to 209 ms
- Number of samples in measurement cycle — up to 4,680
- Measurement start up control — internal or external trigger
- Internal time-base — 5MHz/25ppm
- External time-base — 5 or 10 MHz available
- Output — data file contained the time interval estimations
- Mode control — via graphical user interface
- Displaying (optionally) — measured time intervals vs. their numbers; time interval distribution vs. their lengths
- Software operating system — MS-Windows'95 and higher
- Special features — self-calibration, precision self-testing
- Requirement to power supply — +5B/2A, +12B/1A, -12B/0.5A
- Dimension of the hardware — 220x233 mm

7. Conclusion

In our opinion, the described counter provides for high resolution performance, multi-purpose functionality, self-control availability and simplicity of the hardware design. These features make the counter useful for applications in high performance modular measurement systems adapted to various specific requirements.

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