
Instrumentation for Creating KHz SLR Timing Systems

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Abstract

The instrumentation provides basic tools for creating SLR timing systems operating at repetition rate up to a few KHz. There is a test setup to simulate the process of ranging to various satellites and to evaluate capabilities of this instrumentation for the KHz system design. The simulation of the CHAMP laser ranging at 2 KHz repetition rate is considered as an example. Test results show that the proposed instrumentation offers sufficient performance to be used in the KHz SLR systems.

Timing system architecture

As known, increasing the SLR repetition rate up to KHz provides a variety of essential benefits. Currently there are a few SLR stations which already use this technique or will have it in the near future. However KHz SLR usually need essential upgrading of SLR equipment, including the timing system for satellite range measurement. In view of that we propose an instrumental basis to create various KHz SLR timing systems adapted to the specific user requirements.

There is the well-known custom timing system for KHz SLR at Graz SLR station [1]. In general terms, architecture of timing systems based on the proposed instrumentation and principles of their operation are similar. But there are distinctions in some essential details. Specifically, in our case the specialized hardware is offered as two compatible stand-alone devices (Event Timer A032-ET and Range Gate Generator). PC interacts with these devices and coordinates their operation via standard parallel ports working in the EPP (Enhanced Parallel Port) mode (Fig.1).

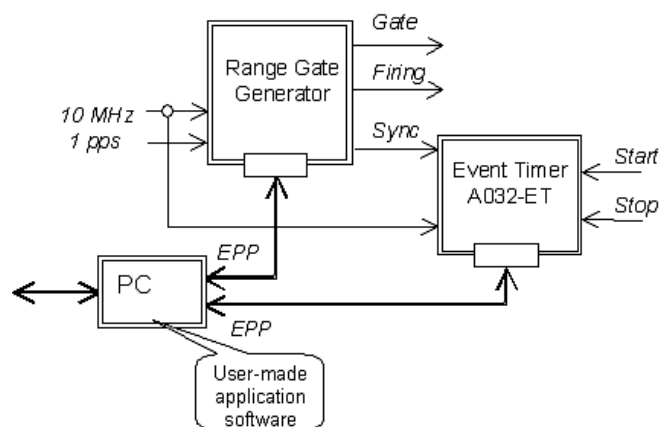


Figure 1. Timing system architecture

As for the application software, it should be custom-made according to the specific application requirements with the reference to the sample program (source code written in C). This program defines device-specific software functions which can be directly built in the user software to support the interactions with hardware. In this way the instrumentation can be used as a basis for various timing system designs.

System hardware

Event Timer

The basic system hardware component is Riga Event Timer A032-ET. It offers two independent inputs for *Start* and *Stop* measurement with RMS resolution about 7-8 ps. Distinctive feature of this device is exceptionally small “dead time” (60 ns) due to the advanced interpolating technique of event timing. This allows sequential measurement of *Start* and *Stop* using simple single-channel hardware structure (Fig.2). Note that such solution simplifies the timer’s implementation and makes it relatively inexpensive.

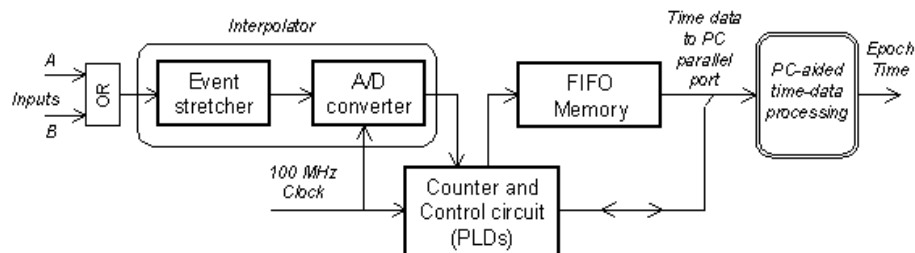


Figure 2. Schematic block diagram of the Event Timer

Although small “dead time” allows the burst rate of event timing up to 17 MHz (for up to 12K sequential events), the average rate is limited down to 10-15 KHz by the available speed of data transfer to PC. However it seems that this rate is quite enough for KHz SLR. In more details the A032-ET features are described in [2].

Range Gate Generator

The Range Gate Generator (RGG) is based on the well-known scheme of Digit-to-Event conversion (Fig.3). Continuous counting of 100 MHz clock pulses forms the 25-bit time-scale with 335 ms periodicity. Such periodicity directly conforms to the maximum value of range gate delay.

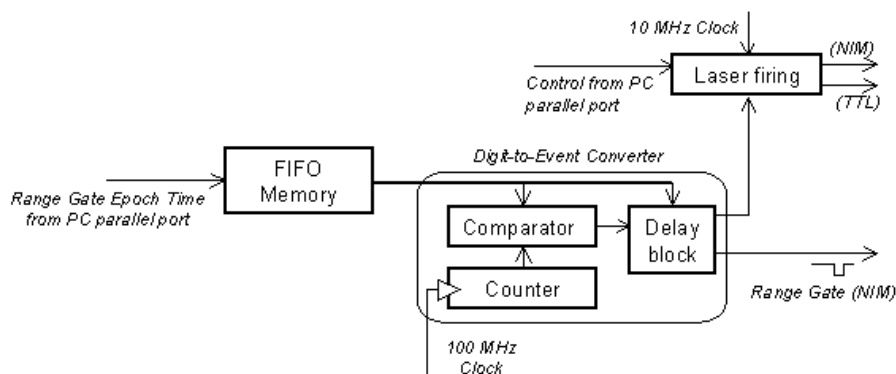


Figure 3. Schematic block diagram of the Range Gate Generator

Dual-ported FIFO memory receives the time data (Range Gate Epoch Time) from PC. In this case the data writing to this memory and data reading from it are independent asynchronous processes. Digital comparator compares the data from the FIFO memory with the current state of time-scale, providing the range gate generation with 10 ns resolution. Additional 7-bit controlled delay block (based on MC100EP196 delay chip) increases resolution up to 80 ps. However there is noticeable differential non-linearity for this chip, resulting in a noise-like error of range gate generation (80 ps RMS approx.). Most of the RGG digital functions are implemented on CPLD basis.

An important feature of the RGG is a specific firing generation. As known, the range measurement can be corrupted when a transmitted laser pulse is close to the received one. To avoid such problems each firing is generated so that it never can occur within some protected zone around any gate being generated (Fig.4).

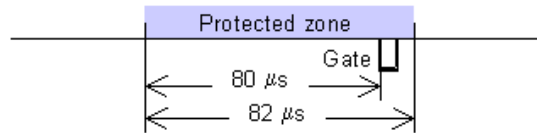


Figure 4. Zone protected from firing

To provide such condition, initially specified period of firings may sometimes be automatically (without any pre-calculations) incremented by quarter of its value. The nominal value of firing period can be set in the range from 100 μ s to 167 ms with 0.64 μ s resolution. In other words, the timing system is able to operate in a wide range of repetition rate, starting from 6 Hz.

Generally the RGG has been designed not only for KHz SLR applications. For this reason it also provides some additional features that are beyond of the direct KHz SLR needs. Specifically, it offers FIFO memory depth up to 16,000 data blocks defining the epoch times, cyclical offline operation, has two selectable outputs for two-channel event generation, etc. These features may be useful for other applications such as tests of timing devices.

General performance limitation

In the process of *Stop* gating each *Start* brings about corresponding control data at the RGG interface with some delay called “response time”. The response time is a system parameter that defines both the SLR maximum repetition rate and allowable minimum of satellite range.

There are three main components of the response time: time of data reading from the Event Timer, time of data processing and time of data writing to RGG. Usually it is desirable to dedicate the maximum time for real-time data processing. Correspondingly the total time of data reading (10 Bytes) and data writing (5 Bytes) via PC parallel ports (see Fig.1) has to be reduced as far as possible. Although formally the EPP should provide the data transfer rate up to 1-2 MB/s, actually it considerably depends on the PC operating system and its configuration. Specifically, our experiments with different MS-Windows operating systems showed that the total time of data reading/writing on average varies from 25 μ s (for Windows-98) to 150 μ s (for Windows XP). Furthermore, this time is not stable, resulting in significant variation of the response time from cycle to cycle. Unfortunately it was not possible to check other operating systems that could be better suited for real-time operation.

Experimental evaluation of system potentialities

To evaluate the potential of the proposed instrumentation a test setup has been used. This test setup has a structure which is similar to that shown in Fig.1. In this case each firing simulates *Start* and each generated gate simulates *Stop* for the Event Timer. Correspondingly a test program simulates application software. The test program performs the simplest real-time data processing related mainly to the Range Gate Epoch Time calculation and memorizing of the measurement results (no time-consuming operations such as real-time data displaying). Evaluation of the

measurement results is performed offline. The test program works under Windows XP. In this case the average response time was about 250 μ s and its maximum value - about 1 ms. Most of the response time was consumed for the data reading/writing. These timing conditions correspond to the possibility of satellite ranging from 1 ms at repetition rate up to 4 KHz.

Other experiments were related to simulations of LEO satellites laser ranging as this represents a worst case for the timing system operation in possible real applications (the higher orbit, the less problems with the response time limitations). Specifically, the simulation of the CHAMP laser ranging at 2 KHz repetition rate was performed (Fig.5). There are 550,000 sequential readings obtained continuously during 275 seconds of the CHAMP pass simulation. The satellite range is from 2.45 ms up to 7.48 ms.

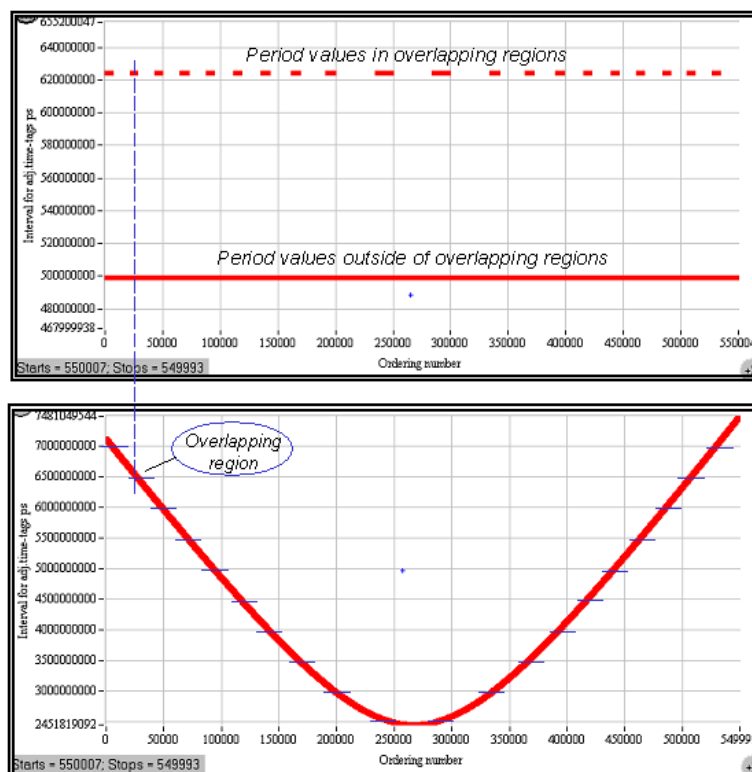


Figure 5. Period of laser firing (upper graph) and measured range (in bottom) vs. cycle number for CHAMP laser ranging simulation

As can be seen from the simulation result, there are a number of regions where the transmitting and receiving of laser pulses may overlap. Although the nominal value of repetition period was 499.2 μ s, the actual average period was increased up to 502.157 μ s (by 0.59%) due to incrementing of some firing periods (~2.4% of total number) by 0.125 ms to avoid these overlaps. Under these conditions any distortions or gaps in the measurement process were not detected. However, it should be taken into account that actually the real-time data processing can be much more complicated than that for the test setup. For this reason it is preferable to use the real-time operating systems to ensure the necessary time for data processing.

Additionally the residuals have been calculated to evaluate the system instrumental errors. When the Range Gate Epoch Times are defined for RGG with the maximum resolution (80 ps), there is a maximum non-linearity in the range gate generation (the

RGG interpolation delay varies in the full 10 ns range). Correspondingly in this case the calculated residuals reflect mainly the non-linearity errors of range gate generation (Fig.6). As can be seen, the peak-to-peak error is about 440 ps.

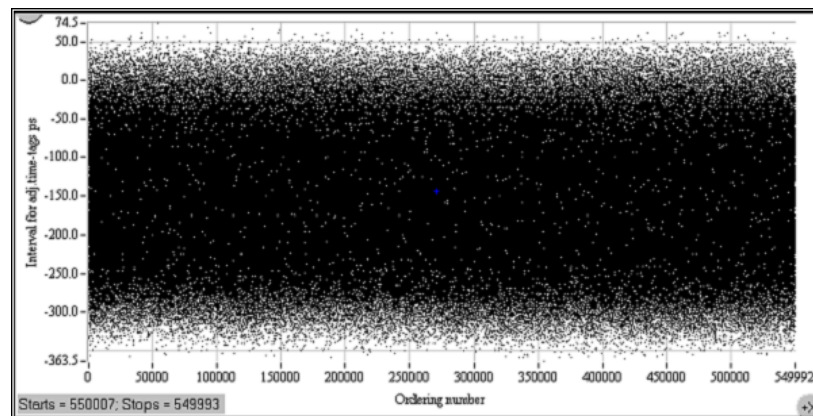


Figure 6. Residuals vs. cycle number for CHAMP laser ranging simulation

When the Range Gate Epoch Times are defined with 10 ns resolution, there is no noticeable non-linearity in range gate generation (since the RGG interpolation delay does not vary). Correspondingly in this case the residuals reflect both the errors of event timing and jitter of range gate generation. In our experiment the RMS of residual variation was about 8.9 ps. Since the actual RMS resolution of Event Timer is about 7.5 ps (this is specified by a separate test), it can be concluded that the RMS jitter of range gate generation is about 4.8 ps. Such jitter is negligible as compared to the actual RGG non-linearity.

Conclusion

We presume that KHz SLR is of vital interest for many SLR stations. Taking that into account, the proposed instrumentation offers sufficient performance for such applications and can be useful for creating new timing systems that provide SLR at repetition rate up to a few KHz. In this case the problems of timing system design can be reduced down to the development of user-specific application software.

Special thanks to Dr. Kirchner for his assistance and promotion of our latest designs. His well-known achievements concerning the KHz SLR at Graz station in many respects stimulated our activity in this area.

References

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