An Ultra Stable Event Timer

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Abstract
An ultra stable event timer was designed at OCA (Observatoire de la Côte d'Azur). It includes a vernier, a logic counter, and a 100 MHz frequency synthesis. The event timer has a precision better than 3 ps rms, a time stability better than 0.01 ps over 1000 s and a linearity in the range of 1 ps. The thermal drift of the 100 MHz synthesis has been measured at the level of 0.03 ps/°C. The dead time between two consecutive events is 10 µs. These performances are among the best in the world. A prototype of the device is actually working at OCA. A space design is also under study for the space segment of the T2L2 [1, 2] (Time Transfer by Laser Link) project.

1. Introduction

An event timer is a system able to get the time position of an event in the time scale of a clock. It can be consider as a counter driven by the clock which is the time reference. The typical resolution of a precise event timer is in the range of 1 picosecond. When an event occurs, the value of the counter is extracted and this value represents the arrival time of the event. The time origin of such an event timer has to be measured with a reference signal like a PPS. A time interval is computed from the difference between two arrival times. The most important characteristics of an event timer are : the precision, the linearity, the time stability and the dead time.

Ideally, the linearity error has to be good enough so that the precision of the timer do not rely on the position of the event in the time scale produced by the clock. A precision of few picoseconds requires then a linearity error in the range of one picosecond. The time stability $\sigma_x(\tau)$ permits to evaluate the performances of the instrument when the events are acquired during τ. In the framework of the laser ranging activities, this is an important characteristic to construct the normal point. In the frame of the time transfer this important to evaluate the noise introduce by the timer as compared to the noise introduce by the clocks. The start time and the arrival time can be measured from the same event timer if the dead time between two consecutive measurements is small enough. A dead time in the range of 10 µs permits to range ground targets at 1500 m. This is a minimum requirement to be able to calibrate a laser station with an external ground target.

An event timer has been designed at OCA in the frame work of both the Time Transfert by Laser Link (T2L2) project and the laser ranging activities. The prototype of the timer is now fully operational. The characteristics are :

- Precision : < 3 ps
- Linearity error : 1 ps rms
- Time stability : < 0,01 ps over 1000 s
- Dead time < 10 µs.

2. Description.

The event timer contains 4 modules (figure 1) :

- vernier
- frequency synthesis
- calibration
- digital

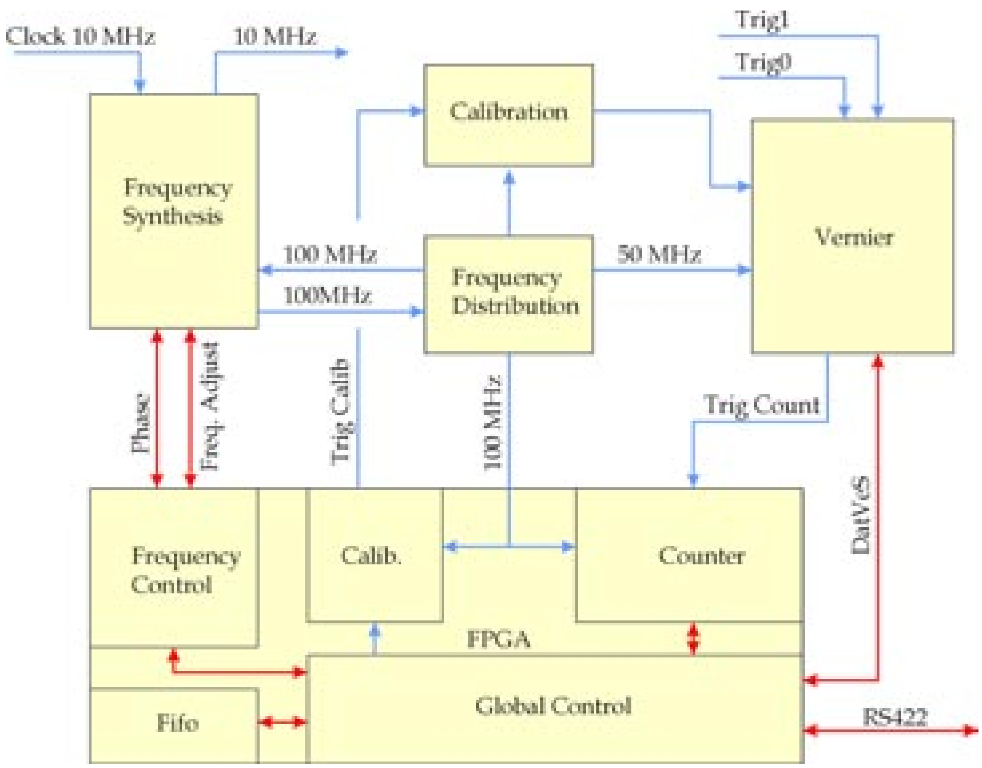

Figure 1 : Synoptic of the OCA event timer.

The most important module is the vernier that is able to give the arrival time of the event with a resolution of 1 ps. It is driven by the digital frequency synthesis module designed to translate the 10 MHz clock signal to 50 and 100 MHz. The global performances of the timer rely on these two modules. The calibration module permits to improve the long term stability of the timer. It generates calibrated events that are timed by the event timer. The digital module is divided in 3 sub-modules. The first one is a digital counter driven by the frequency synthesis signal. It gives the arrival time of the event with a time resolution equal to the period of this signal. The second one is the frequency control that allow the digital phase lock loop of the frequency synthesis module. The last one is the global control of the timer. It controls all the modules and the serial interface.

Figure 2 shows a photography of the vernier. Its dynamic is 20 ns and its resolution is 1 ps. The dead time between two consecutive events is 10 µs. The output is a 32 bits word. There are 2 vernier cards in the event timer to use the instrument as an interval counter if the delay between the start and the stop has to be smaller than 10 µs.

Figure 2 : Vernier card

The frequency synthesis uses an ultra low noise oscillator @ 100 MHz. The floor noise is better than –165 dBc. This local oscillator is controled with a digital phase lock loop (PLL) having a dynamic of 20 bits. The input frequency is adjusted for a 10 MHz application but other input frequency can be selected since the PLL uses a programmable 8 bits counter to divide the local oscillator signal. The thermal sensitivity is below 0,1 ps/°K over 10 to 30 °C. The frequency synthesis is also designed to generate the calibration events.
The digital modules of the timer uses 3 identical cards based on a FPGA (figure 3). There are 3 different programmable codes for each module : the counter, the frequency synthesis control and the global control. The global control card has an internal memory able to save 10 000 events. It includes a 16 bits analog to digital converter : for each timing process, 8 analog measurements can be performed. The global control card has a RS 422 @ 1 Mbits serial interface.

Figure 3 : Digital module. There are 3 programmable cards for the counter, the frequency synthesis control, and the global control.

All these modules are gathered into a 19 inch rack (figure 4). A space design is under study in the frame work of T2L2. Among other things, the space design will be more compact, it will minimize the power consumption and some components will be replaced by some space component.

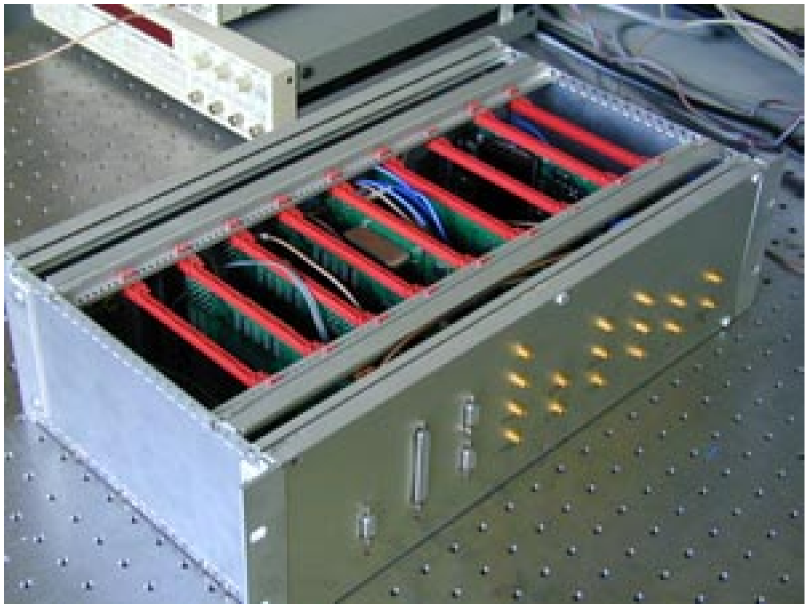

Figure 4 : OCA event timer.

The figure 5 shows the mechanical design that will be used for this space instrument.

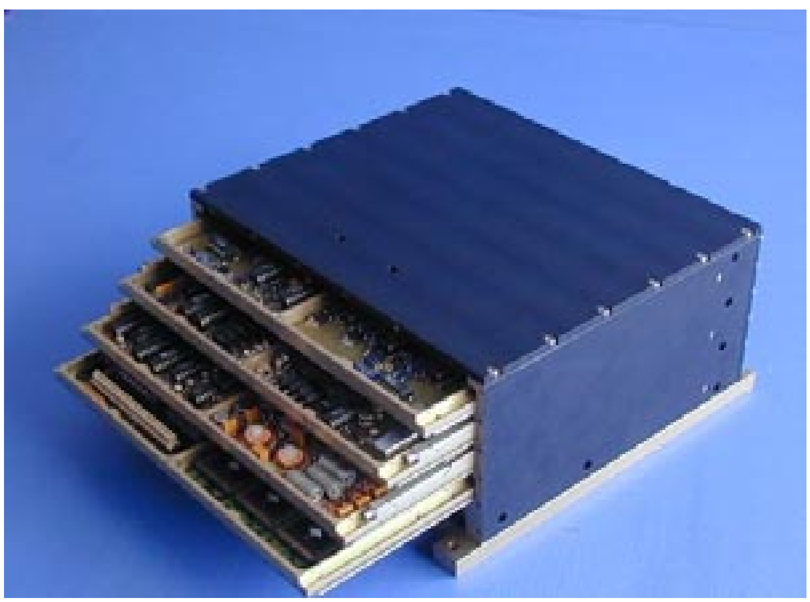

Figure 5 : Mechanical design of the space event timer.

3. Test benches

Two test benches have been implemented in order to measure the performances of the event timer. The first one is an asynchronous test bench using a Thales (Dassault Electronique) event timer [3]. Thales is considered as a reference. A single clock is used for both the OCA event timer and the Thales event timer. Some events without any time correlation with the clock are simultaneously sent to the timers. This test bench permits to measure the linearity error of the timer and its precision. Figure 6 shows the Thales event timer module inside a 19” rack (assembled by OCA).

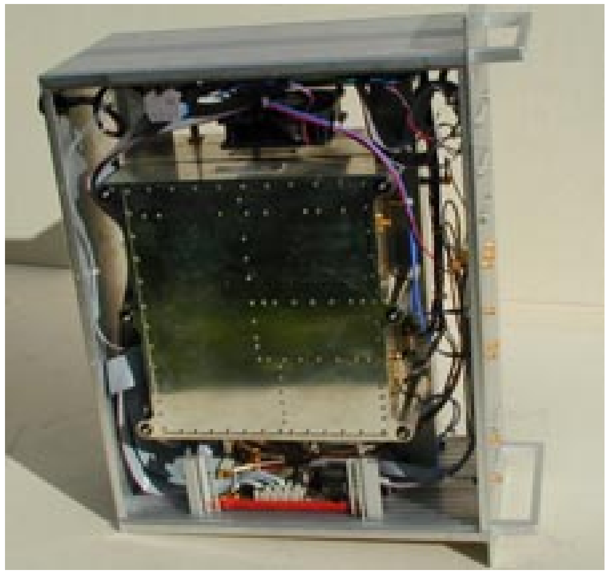

Figure 6 : Thales event timer (assembled by OCA).

Two event timer modules, one frequency synthesis module (10 to 200 MHz),

one control module (memory, RS 422 interface, 16 bits ADC)

The second test bench uses only the event timer to be measured and a module able to generate events synchronised with the event timer clock (synchronous mode). It permits to measure the time stability of the timer and the thermal sensitivity.

4. Performances

The measurements obtained with the asynchronous test bench shows a linearity error better than 1 ps rms. The most important spectral components of this error are the harmonics 1 and 2 of the clock signal @ 50 MHz (figure 7). A fine analysis of the results permits to demonstrate that the harmonic 2 is coming from a computation error in the process involved in the resolution of the raw data. This problem should be solved in the next future and a linearity error in the range of 0.5 ps is expected.

The precision in an asynchronous mode is better than 3 ps rms (it is a classical mode in which the laser events are not correlated with the clock).

The time stability is computed with the Time Variance [4] deduced from the Modified Allan variance. This characteristic is obtained with the synchronous test bench. The repetition rate is 1kHz. The calibration module of the event timer is used with an integration constant of 10 s. The floor obtained is below 0.01 ps over 1000 s (figure 8). This is an extremely low time stability.

The thermal sensitivity measured between 15 to 25 °C is better than 1 ps/°C (figure 9).

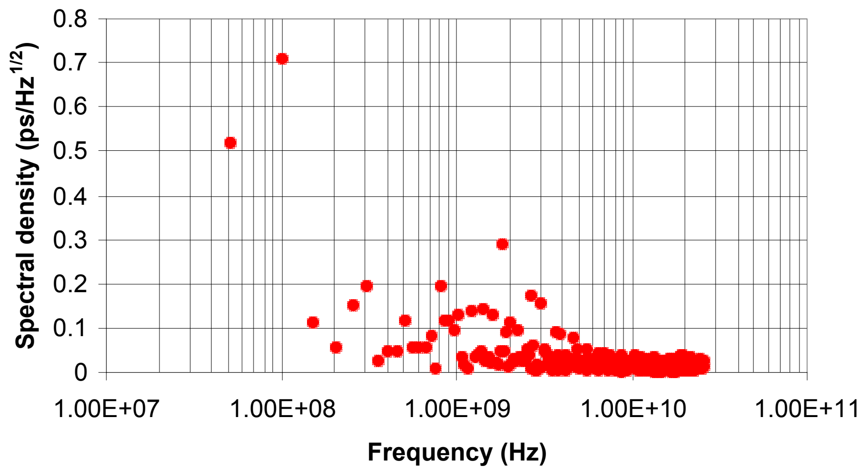

Figure 7 : Spectral density of the linearity error. 1 ps rms : +/- 1.5 ps.

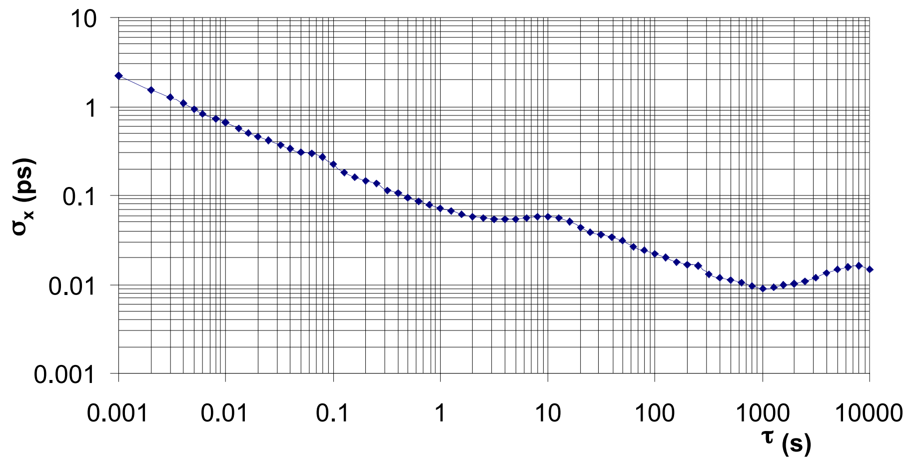

Figure 8 : Time stability of the OCA event timer. The floor obatined is better than 10 fs over 1000 s.

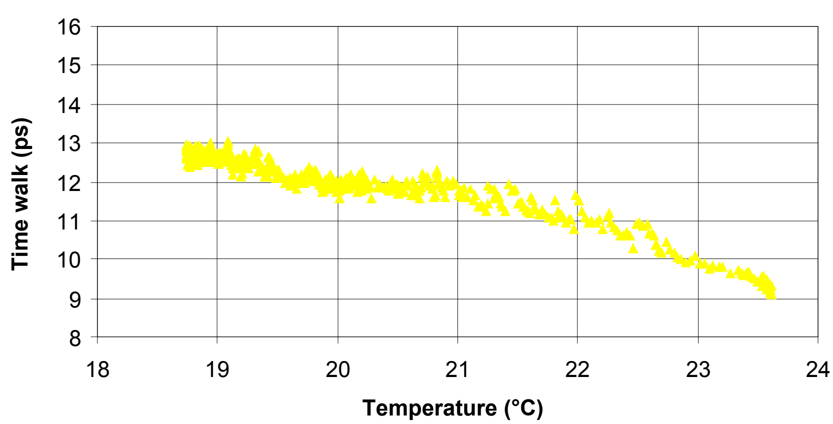

Figure 9 : Thermal sensitivity (Yellow curve) : < 1 ps/°C

5. Conclusions

The performances of this event timer are at least one order of magnitude better than the performances of the other sensitive elements (laser – photo-detection) of the best accurate laser stations. Its short dead time between two consecutive measurements permits to envision a laser station with only one timer and one photo detection system. This will allow a direct accurate laser ranging measurement without any external calibration. The design is also well suited for a space borne application. It will be on board the time transfer project T2L2. It could also be used in the framework of some interplanetary projects like TIPO [5] (One way laser ranging in the solar system) and Astrod [6] (Astrodynamical Space Test of relativity using optical devices).

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[1] P. Fridelance, E. Samain and C. Veillet, « A new optical time transfer generation », *Experimental Astronomy*, **7**, pp 191-207, 1997 .

[2] E. Samain, P. Fridelance, « Time Transfer by Laser Link (T2L2) experiment on MIR », *Metrologia*, **35**, pp 151-159, 1998.

[3] E. Samain, "Le laser Lune millimetrique et Nouvelles méthodes de datation", Thèse de docatorat de l'Université de Nice Sophia Antipolis, 1995.

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