An ultra stable event timer designed for T2L2

E. Samain[1], P. Fridelance[2], Ph. Guillemot[3]

[1]*OCA - Observatoire de la Côte d'Azur, Caussol, France*
etienne.samain@obs-azur.fr

[2]*Phusipus Intégration, Saint Vallier de Thiey, France*

[3]*CNES - French Space Agency, Toulouse, France*

Abstract - The T2L2 experiment on Jason 2 is a space project that performs time transfer between remote clocks at the picoseconds level. It is based on laser ranging technologies with some laser stations at ground linked to the clocks to synchronize and a dedicated equipment onboard the satellite.

Laser stations are designed to range the orbit of some satellites equipped with corner cubes. For that purpose laser stations measure very accurately the time interval between the start of laser pulses and the return after reflection on the corner cubes but the absolute start time is only required at the 100 ns level. For the T2L2 requirements, both the start time and the return time of each laser pulses need to be measured at the 50 ps level. In order to obtain this accuracy, it will be necessary to calibrate the laser station network and possibly to upgrade the time tagging system of some stations.

For these reasons it has been decided to develop, from the studies of the space design, an event timer and a high speed photo detection system dedicated for the ground operations. The precision of the system is 0.6 picoseconds and the linearity is 0.3 picoseconds. The global instrument includes a frequency synthesis and up to 4 time tagging units able to work simultaneously. This event timer is also well suited for metrology applications in the time and frequency domain (high resolution time stability studies, delay propagation, phase measurement…). A commercial version of the timer is now manufactured by Phusipus Integration.

1. INTRODUCTION

T2L2 [1],[2] is a very high resolution two way time transfer technique based on the timing of optical pulses emitted by a laser station and detected by a dedicated space instrument. T2L2 was launched as a passenger instrument on the altimetry Jason-2 satellite in June 2008 [3],[4]. Both the start time and the return time of each laser pulse emitted by the laser station need to be measured with a repeatability error in the range of a few picoseconds and an accuracy of 50 ps. In order to obtain this accuracy, the laser station network has to be carefully calibrated. Furthermore, some stations only measure the time interval between the start and the return and do not measure separately the start and return time. For these reasons, OCA supported by CNES, has decided to develop, from the studies of the T2L2 space design, an event timer and a high speed photo detection system dedicated for these ground operations.

Since 1998 OCA has designed several event timers in the framework of T2L2 and laser ranging. A breadboard of the T2L2 space instrumentation was built in 2002. Since then, the T2L2 project was accepted by CNES on the satellite Jason 2 and OCA and CNES have started the development of the space instrumentation in mid 2005. Three models were built: a prototype, an engineering model and the flight model. The flight model is operated since June 2008 on-board the Jason-2 satellite. In 2008, with the collaboration of the manufacturer Phusipus Integration and CNES, OCA started the design of a ground version of the event timer. The objective was to build a versatile instrument for both the time and frequency and laser ranging communities.

2. EVENT TIMER

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 considered as a counter driven by a time reference. When an event occurs, the value of the counter is extracted and his 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 PPS. A time interval is computed from the difference between two arrival times. The most important characteristics of an event timer are: the repeatability error, the linearity, the time stability and the dead time.

Ideally, the linearity error has to be good enough so that the repeatability error of the timer do not rely on the position of the event in the time scale produced by the clock. 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 laser ranging, 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 of 120 ns permits to range ground targets at only 18 m. This is an important requirement to calibrate a laser station with an external ground target.

3. DESCRIPTION

The schematic description of the event timer is given in figure 1. The main part of the instrument is the vernier which gives the arrival time of the event with the sub-picosecond resolution. It is driven by a frequency synthesis module designed to translate the reference clock signal (between 10 to 100 MHz) to 500 MHz. The global performances of the timer depend on these two elements. The principle of the vernier relies on the digitalization of a reference periodic signal. It gives the arrival time with a dynamic of 2 ns. The solution of the arrival time is deduced from the digitalized data without any external information or any internal calibration. The frequency synthesis is built from an ultra low noise quartz oscillator @ 500 MHz controlled with a Phase Lock Loop (PLL) based on a digital phase measurement. The PLL is tuned to get a frequency cut at 100 Hz with a damping factor of 3. These two elements are completed with a digital sub-system divided in 3 parts. The first one is a digital 56 bits counter driven by the frequency synthesis signal divided by 2. It gives the arrival time of the event with a time resolution of 4 ns. The second one is a high speed 3 bits 1 GHz counter designed to give the arrival time in a dynamic of 8 ns with a time resolution of 1 ns. The third one is the global logic of the timer. It includes a high speed fifo and the tools needed for the USB communication. These 3 parts are inside a FPGA circuit. All these elements are on a single card (Europe format). When the timer is used with an external frequency synthesis the onboard PLL can be deactivated. The event timer can receive three distinct inputs. Two of them are connected on fast 8 GHz comparators. Both threshold and slope can be adjusted by software. The third input is differential. It permits to get the best performance of the timer. A 20 GHz module (optional) can be interfaced with this differential entry. This module gives the possibility to detect very fast signal in the bandwidth DC-20 GHz corresponding for instance to very short laser pulse having a pulse width of 20 ps.

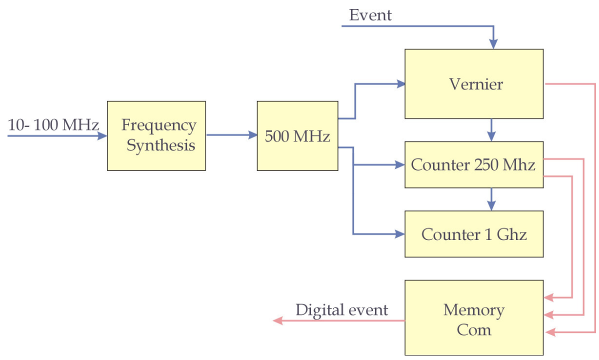

Fig. 1: Schematic description of the individual event timer.

The global instrument is the assembly of several modules (Figure 2). It includes:

- 1 to 4 event timers,
- a frequency synthesis,
- an embedded PC,
- a power supply,
- an optional clock module.

All these modules are inside a 19 inches 4U rack. The rear side of the instrument is devoted to the metrology modules, the other side to Human Machine Interface. When used with several event timers, all event timers are naturally synchronized together so that it is possible to make some absolute differential measurements without any calibration. The global synchronization of the event timer is done by an external Pulse Per Second (PPS) connected to the frequency synthesis module. This module distributes the PPS to the event timers.

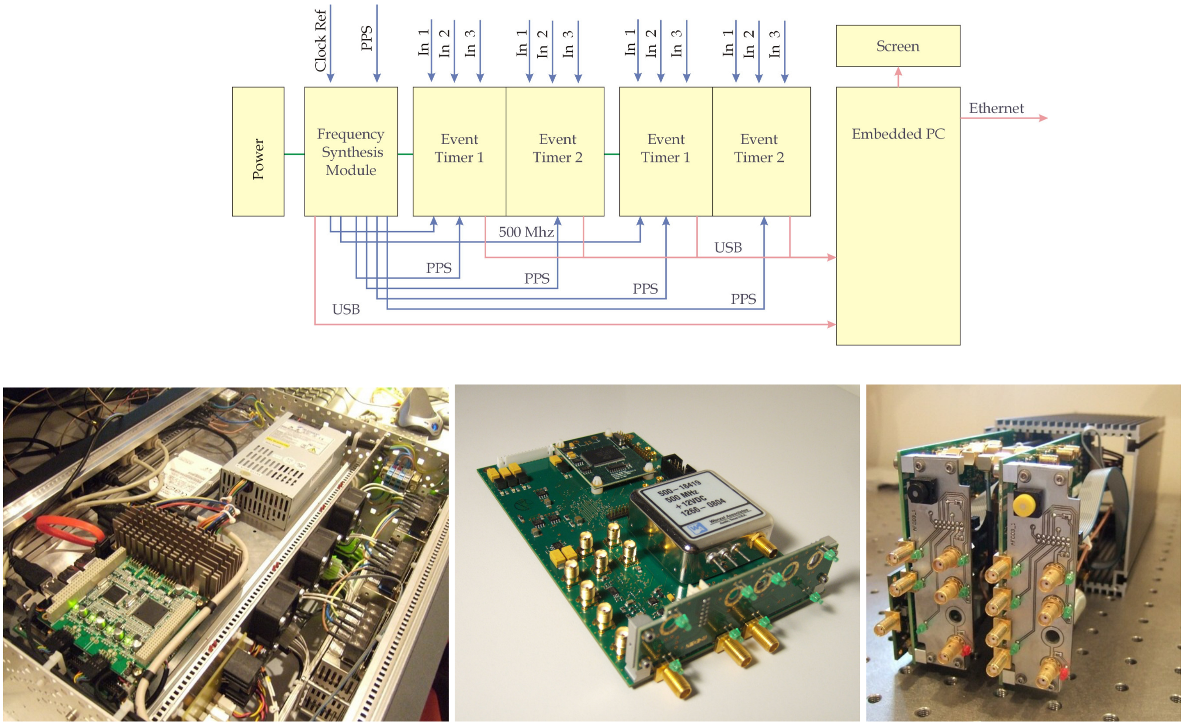

Fig 2:Above: Instrument synoptic with 4 event timers. Below left: the global instrument. Center: the frequency synthesis card. Right: module with 2 event timers.

4. MEASUREMENT MODE AND HUMAN MACHINE INTERFACE

The instrument includes an embedded PC and a screen on the front face (figure 3). The PC realizes several tasks:

- Date computations
- Data recording
- Instrument configuration (slope threshold, …)
- Computation of 3 measurement types
- Results display
- Ethernet interface to remote control and data transfer

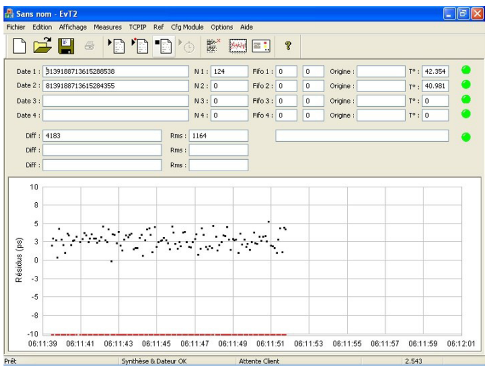

Fig 3: PC Display.

Three types of measurements can be made:

- Asynchronous
- Differential
- Edge

In the first Asynchronous mode, the events of all the event timers are recorded without any relation between the events. In the second mode, the user expects a predefined time interval between two events. The instrument computes the time difference in real time between the event timers. Three differences between three different event timer pairs can be computed simultaneously. In the last Edge mode, the instrument is used as an oscilloscope. It can construct a xy graph where x is time and y is voltage. One event timer is used as the trigger for the time reference, another event timer is used to measure the signal. The x axe is the time difference between event timers, the y axe is determined by adjustment of the threshold of the input. This mode can be used to measure the shape of a PPS signal for instance (figure 4).

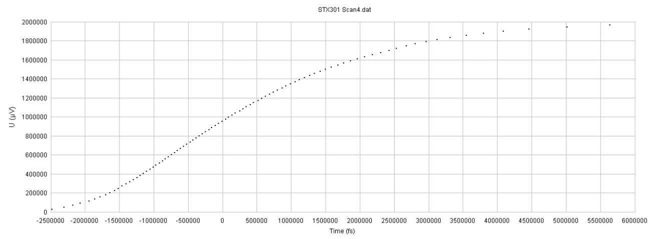

Fig. 4: an example of a temporal shape of a PPS signal determined by Edge measurement

5. PERFORMANCES

Figure 5 is an illustration of the repeatability error of the timer. It is measured in a synchronous mode in which the timer measures zero crossings of a common clock signal.

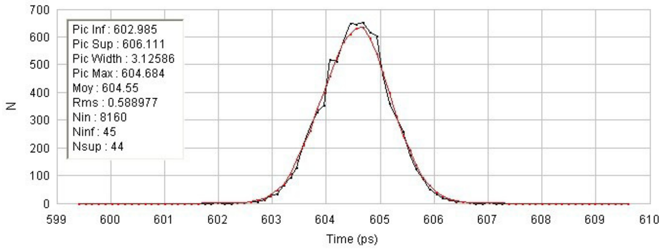

Fig. 5: time distribution of a synchronous signal. The repeatability error of the instrument is 0.6 ps rms.

Figure 6 is a computation of the linearity error of the vernier. It is measured by generation of clock ticks having a period of 1 ms + 2 ps. This period permits to scan the whole dynamic of the vernier (2 ns) in 1000 measurements. The ticks are generated by an independent rubidium clock while the reference clock of the timer is produced by an ultra stable clock (DORIS USO).

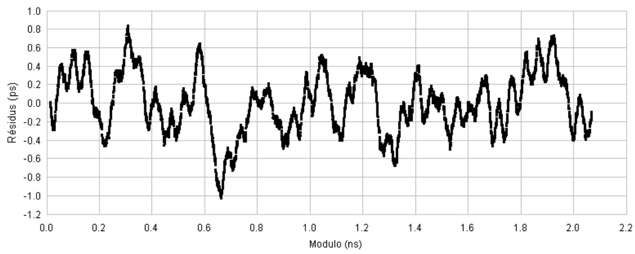

Fig. 6: time linearity on the vernier period. The linearity is 0.3 ps rms

Global characteristics of the event timer are given in table 1.

Table 1 : Global characteristic of the event timer

Input frequency	10 MHz to 100 MHz sinus 0 dBm to 13 dBm
Event timer	1 to 4 independent events timers
Event input (per event timer)	2 analog single ended inputs, 1 differential
Input Bandwidth	8 GHz and 20 GHz (optional)
Local oscillator	500 MHz; noise floor : -150 dBc
FPGA frequency	250 MHz

Dynamic	36 years
Vernier period	2 ns
Vernier resolution	1 fs
Repeatability error	0.6 ps rms
Vernier linearity	0.3 ps rms
Vernier Time Stability	< 10 fs over 10 s
Vernier Thermal sensitivity	< 0.5 ps/°C
Communication	Ethernet
Continuous rate	25 kHz with 2 event timers
Dead time	120 ns (1000 events)
Size	375x480x180 mm
Power consumption	200 W

5. CONCLUSIONS

This event timer has been designed in the frame work of the T2L2 project. The design of the instrument is derived from the space model which is now running in space for 2 years. When used as the reference system to calibrate the laser station network, it should permit to get the start and return times of laser pulse with an absolute accuracy of 50 ps and a differential accuracy better than 10 ps. When used as the start and stop event timer for laser stations at ground, it permits to fulfil the specifications in term of repeatability error (0.6 ps rms), time stability (< 10 fs over 10 s). Even if the instrument has been built for T2L2 it has also been designed to have a versatile instrument able to measures any electrical events for many domains such as time and frequency metrology, laser ranging, altimetry, 3D localisation, and electronics. The manufacturer Phusipus Integration (France) is now building the instrument for a commercial use.

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