T2L2 ON JASON-2: FIRST EVALUATION OF THE FLYING MODEL

Ph. Guillemot, I. Petitbon

Microwave & Time-Frequency Department
CNES – French Space Agency
Toulouse, France

E. Samain, P. Vrancken, J. Weick, D. Albanese, F. Para, J.-M. Torre
R&D Metrology CNRS/GEMINI
Observatoire de la Côte d'Azur
Caussol, France

E-mail: ***philippe.guillemot@cnes.fr***

Abstract

The new generation of optical time transfer (T2L2: Time Transfer by Laser Link [1]) under development at OCA and CNES shall allow the synchronization of remote ultra-stable clocks and the determination of their performances over intercontinental distances. The principle is based on the propagation of light pulses between clocks for synchronization. T2L2 is the follow-on mission to LASSO [2] (LAser Synchronization from Stationary Orbit) with performances improved by two orders of magnitude.

A T2L2 payload shall be launched in mid 2008, together with the Jason-2 space vehicle dedicated to the observation of the oceans. A preliminary performance budget and a ground experiment conducted by the OCA permit to envision a performance improvement of at least one order of magnitude as compared to the best time transfer techniques available. Expected performances are in the 100 ps range for accuracy, with an ultimate stability better than 1 ps over 1000 s (one pass) and than 10 ps over 1 day. Time transfer performances in a common view mode are driven by the noise of both the ground and the onboard timers, whereas the performances in a non-common view configuration are limited by the onboard clock (DORIS USO). The main objectives of the T2L2 mission are technological (In-orbit functional and performance validation), scientific (Time & Frequency metrology and Fundamental physics tests), and a contribution to the Jason-2 core mission (Evaluation of the behaviors, versus radiations, of the DORIS USO).

A first breadboards of the electronics have been developed and measurements conducted by the OCA are very promising [3]. Since then, both an engineering and a flight model have been developed. By the time of the conference, the flying model of T2L2 instrument shall be delivered to CNES and performance characterization shall be running. After a quick reminder of mission hypothesis and objectives, with associated preliminary link budget and expected performances, this paper will present last results obtained on both a T2L2 engineering model and a flying model.

I. INTRODUCTION

The "Time Transfer by Laser Link" experiment T2L2 **[1]**, under development at OCA (Observatoire de la Côte d'Azur) and CNES (Centre National d'Etudes Spatiales), France, will be launched in 2008 on the altimetric satellite Jason 2. The experiment principle is issued from laser telemetry, i.e. the timing of transmitted and reflected laser pulses. T2L2 on Jason 2 will permit the synchronization of remote ground clocks and comparison of their frequency stabilities with a performance never reached before. T2L2 will allow the measurement of the stability of remote ground clocks over continental distances, itself having a time stability in the range of 1 ps over 1000 s.

The objectives of the T2L2 experiment on Jason-2 are threefold:

- Technological validation of optical time transfer, including the validation of the experiment and its time stability and accuracy, and of one way laser ranging.

- Characterization of the onboard Doris oscillator for Jason-2 purposes and a contribution to the Jason-2 laser ranging core mission.

- Various scientific applications concerning time and frequency metrology, fundamental physics, earth observation or very long baseline interferometry (VLBI).

II. T2L2 PRINCIPLE

T2L2 allows the synchronization of remote clocks on Earth and the monitoring of satellite clocks. The experiment is based on the propagation of light pulses between the clocks to be synchronized. The light pulses carry the temporal information from one clock to another.

The ground and satellite clocks (the ultra-stable oscillator USO of DORIS in the case of Jason-2) to be synchronized are linked to a laser station and to the T2L2 space equipment, respectively. The T2L2 payload is constituted of a photo-detection device, a time tagging unit, and a retro-reflector. The laser station emits asynchronous, short light pulses (~ 20 ps FWHM) towards the satellite. Retro-reflecting corner-cubes return a fraction of the received photons back to the station. The station records the start (t_S) and return (t_R) time of each light pulse. The T2L2 payload records the arrival time (t_B) in the temporal reference frame of the on-board oscillator. These data are downloaded to the ground via a regular microwave communication link. For a given light pulse emitted from station A, the synchronization χ_A between the ground clock A and the satellite clock is then derived from:

$$\chi_A = \frac{t_S + t_R}{2} - t_{T2L2} + \tau_{Relativity} + \tau_{Atmosphere} + \tau_{Geom}$$

Figure 1 shows the synoptic of the whole T2L2 space instrument. The photo-detection unit is composed of two avalanche photo-detectors. One is working in a special "Geiger" mode for precise chronometry; the other one is in linear gain mode in order to trigger the system and to measure the received optical energy **[4-6]**. The event timer is a dedicated design, built with a programmable logic array at 100 MHz for rough timing and a vernier for precise measurement with a resolution of 1 ps **[7]**.

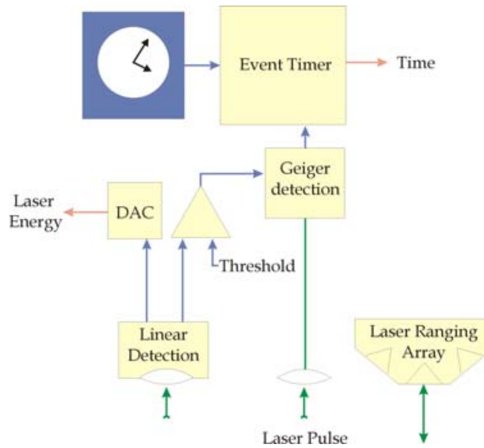

Figure 1. Synoptic of the whole T2L2 space instrument. The linear photo detection is able to pre-trigger the Geiger module with an advance of a few ns. This delay is generated by an optical delay line connected to the Geiger detection.

The T2L2 payload shall be launched in mid 2008, together with the Jason-2 space vehicle dedicated to the observation of the oceans. Jason 2 is a French-American follow-on mission to Jason 1 and Topex/Poseïdon. Its goal is to study the internal structure and dynamics of ocean currents, mainly by radar altimetry. Jason-2's core mission consists in a dual-frequency radar altimeter Poseidon 3, a radiometer (AMR – Advanced Microwave Radiometer) to measure the water vapor content in the troposphere and derive the appropriate radar path delay correction, a DORIS receiver and a GPS receiver for precise determination of the orbit of the satellite, and a laser retro-reflector (LRA - Laser Ranging Array) to complete the orbit tracking. T2L2 will use the ultra-stable oscillator of the DORIS receiver as the reference clock for the onboard time tagging and the LRA to reflect the light pulses.

The altitude of Jason-2 (1,336 km, 66°) will allow common views at the continental scale (up to 5000 km baseline), with 6 passes per day over each participating ground station. The dead time between two consecutive passes is about 120 mn; their average duration is 1000 s (for passes with a maximal elevation greater than 20°).

III. T2L2 ENGINEERING MODEL

Delivered only 6 months after the first prototype **[3]**, the engineering model is the first complete model of the electronic unit of the T2L2 instrument. In particular, it associates for the first time metrological electronics, linear and nonlinear photo detection, a counter, a vernier, and a calibration generator, with the control electronics, a microcontroller, a 1553 satellite bus interface, and a power supply. It represents the unique opportunity to validate both functional and performances of the instrument before starting the realization of the flight model.

The validation of the T2L2 engineering model has been performed by the OCA team in July 2006. Tests have been performed into two steps, the first one without laser pulses to characterize the event timer and the second one with 532 nm and 778 nm laser pulses to check the photo detection system. The performances are measured using a reference bench, an event timer from Dassault Electronic, with a stability better than 30 fs over 1000 s, a precision between 2 and 5 ps rms, a linearity better than 1 ps rms, and a thermal sensitivity lower than 0.5 ps/°C.

Excepted and real performances of the engineering model are given in Table 1. The driving elements for the T2L2 final performance are the nonlinear detection chain and the event timer.

Table 1. The tests that were so far conducted on the T2L2 engineering model of the electronic unit show already the compliance with the metrology specifications for both the photo detection and the event timer.

	Requirement	**Measurements**	**Comments**
Event timer			
Counter uncertainty	< 1 ns	300 ps	
Dead time	< 2 µs	3 µs	
Vernier Precision	< 5 ps rms	1.2 ps rms	
Vernier stability	$\sigma_x < 4\times10^{-13}\times\tau^{-1/2}$	$\sigma_x < 3\times10^{-13}\times\tau^{-1/2}$	$\tau_0 = 100$ ms
Vernier drift	< 1 ps/h	< 150 fs/500s	Without calibration
Vernier resolution	< 500 fs	100 fs	
100 MHz synthesis stability	< 100 fs @ 100 s	70 fs @ 100 s	$\tau_0 = 1$ ms
Calibration stability	$\sigma_x < 2\times10^{-13}\times\tau^{-1/2}$	$\sigma_x < 80\times10^{-15}\times\tau^{-1/2}$	$\tau_0 = 1$ ms
Calibration uncertainty	< 100 ps	80 ps	
Detection			
Precision	$5 < \sigma < 25$ ps rms	OK	Depends on the number of photon
Stability	$\sigma_x < 10\times10^{-13}\times\tau^{-1/2}$	$\sigma_x < 8\times10^{-13}\times\tau^{-1/2}$	$\tau_0 = 1$ ms, $0.01 < \tau < 100$ s

III.1 NONLINEAR DETECTION

Tests have been conducted with a detector temperature of -10 °C and a breakdown voltage of –26.5 V, using both a 780 nm and a 532 nm laser. In multi-photon mode, we observed a precision lower than 25 ps and a stability of $\sigma_x(\tau) < 8\times10^{-13}\times\tau^{-1/2}$ s for $0.01 < \tau < 100$ s and $\sigma_x(\tau) < 100\times10^{-15}\times\tau^{0}$ s for $\tau > 100$ s with $\tau_0 = 0.01$ s and a laser pulse rate of 100 Hz @ 532 nm. The influence of laser rate, tested up to 1 kHz, is negligible.

These results notably include the noise and the drift of the reference TTL signal extracted from the laser driver.

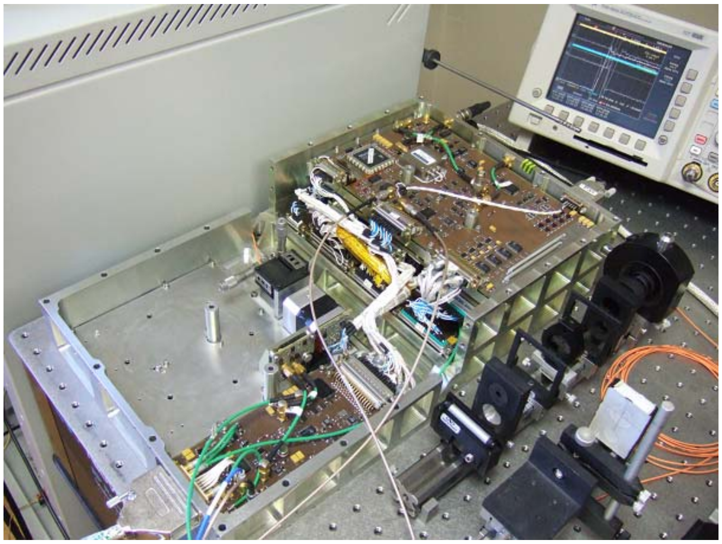

Figure 2. T2L2 engineering model: the electronic Unit, opened, during tests at the OCA.

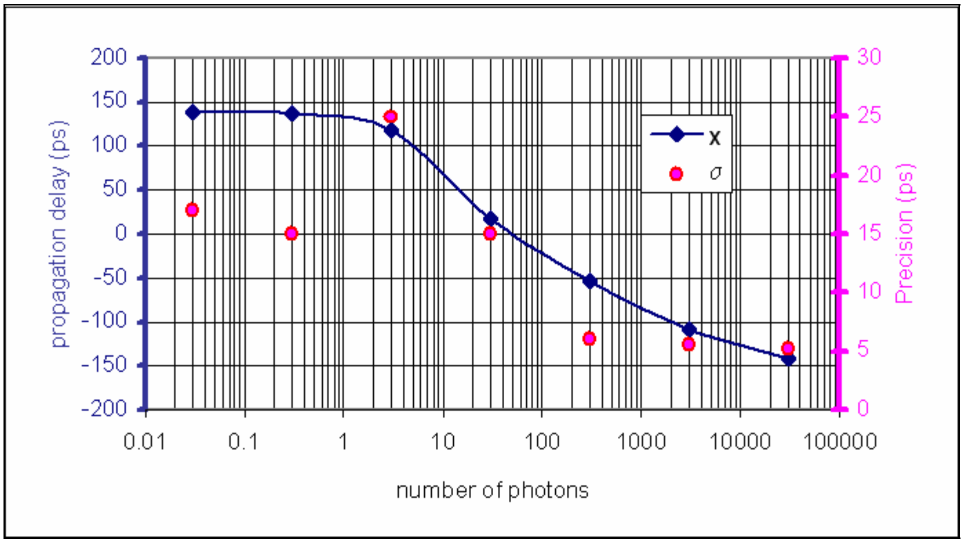

Figure 3. Precision and propagation delay of the nonlinear detection. The precision in single photon is quite good: 17 ps rms. Then the precision decreases because of the drift of the propagation delay with the increase of the number of photons. Those results include the contribution of the reference bench, which is about 5 ps.

III.2 EVENT TIMER

The first main element of the event timer is the PLL used to generate the T2L2 internal 100 MHz clock from the 10 MHz DORIS USO. The bandwidth of the PLL is set to 30 Hz for this evaluation, whereas the performance of the real DORIS USO will lead to an adjustment of this bandwidth, somewhere around 100 Hz. The stability of the 100 MHz synthesis is $\sigma_x(\tau) < 70$ fs @ 100 s.

The second main element is the vernier assuring the fine timing capability. Its evaluation has been conducted with events synchronous and asynchronous with the 100 MHz clock. In synchronous configuration, the precision is 1.2 ps rms and the time stability is $\sigma_x(\tau) < 3\times10^{-13}\times\tau^{-1/2}$ for $0.1 < \tau < 100$ s with $\tau_0 = 0.1$ s. The drift is lower than 150 fs per 500 s.

IV. T2L2 FLIGHT MODEL

Whereas the flight model of the T2L2 instrument should be delivered to the CNES only at the end of 2006 or at the beginning of 2007, a first set of metrological tests has been realized before starting the space qualification to validate the performances of the electronic unit of the instrument.

These tests were carried out at EREMS, in a configuration close to the experimental setup used for the engineering model. The main difference relates to the laser used: a Micro chip Q-switched Nd:Yag pulse laser having a FWHM of 1.3 ns @ 532 nm. Despite this relatively large pulse width (1.3 ns as compared to the nominal 20 ps), the setup was good enough to validate the whole functionality of the instrument from the detection unit to the event timer

The tests, carried out at the end of November 2006, are still being analyzed. However, the very first results, presented in table 2, are very good. They will have to be confirmed by the metrological tests on the complete instrument (electronic and optic units) that must be run at CNES in the very beginning of the year 2007.

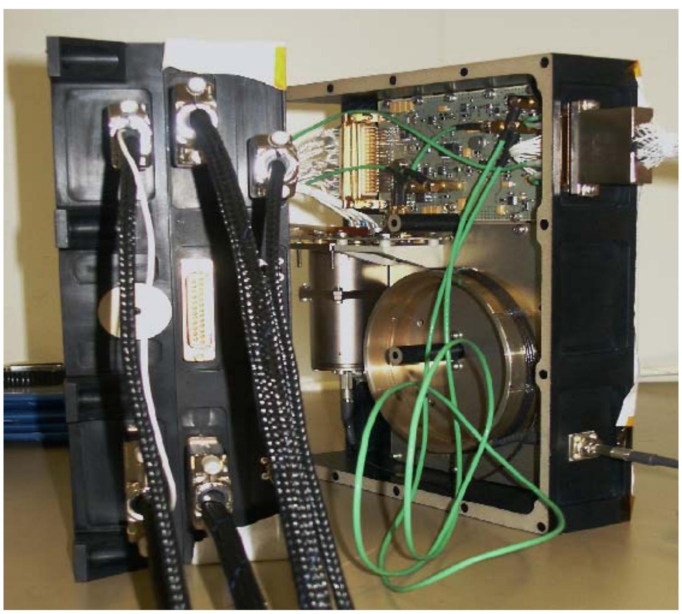

Figure 4. T2L2 Flight model: the electronic unit, opened, during tests at EREMS. We can see the optical delay line rolled up on its support and the detection board.

Table 2. The tests that were so far conducted on the T2L2 fight model of the electronic unit show already the compliance with the metrology specifications for the event timer. Results are very similar to those from the engineering model.

	Requirement	**Measurements**	**Comments**
Event timer			
Counter uncertainty	< 1 ns	500 ps	
Dead time	< 2 µs	2.5 µs	
Vernier Precision	< 5 ps rms	2 ps rms	Estimated
Vernier stability	$\sigma_x < 4\times10^{-13}\times\tau^{-1/2}$	–	
Vernier drift	< 1 ps/h	< 100 fs sur 500 s	
Vernier resolution	< 500 fs	100 fs	
100 MHz synthesis stability	< 100 fs @ 100 s	$\sigma_x = 0.09\ 10^{-12}\ \tau^0$ s	$\tau_0 = 250$ ms, $2 < \tau < 200$ s
Calibration stability	$\sigma_x < 2\times10^{-13}\times\tau^{-1/2}$	$\sigma_x = 0.15\ 10^{-12}\ \tau^{-1/2}$ s $\sigma_x = 0.09\ 10^{-12}\ \tau^0$ s	$0.04 < \tau < 2$ s $2 < \tau < 200$ s $\tau_0 = 250$ ms,
Calibration uncertainty	< 100 ps	52 ps	

V. CONCLUSION

With an expected improvement of one order of magnitude as compared to existing systems, T2L2 will allow the calibration of various existing radiofrequency time and frequency transfer systems like GPS or TWSTFT, and comparisons of cold atomic clocks at a level never reached before.

Both the characterizations of the engineering model and the first measurement of the flight model allow us to be confident in reaching an improvement. Next steps in T2L2 development are now the space qualification of the equipment and its complete metrological characterization. Then we will be able to confirm the instrument performances and so the whole system ones.

VI. REFERENCES

[1] P. Fridelance, E. Samain, and C. Veillet, 1997, "*T2L2 - Time transfer by Laser link: a new optical time transfer generation,*" **Experimental Astronomy, 7,** 191-207.

[2] P. Fridelance and C. Veillet, 1995, "*Operation and data analysis in the LASSO experiment,*" **Metrologia, 32,** 27-33.

[3] Ph. Guillemot, E. Samain, K. Gasc, I. Petitbon, P. Vrancken, J. Weick, D. Albanese, F. Para, and J.-M. Torre, 2006, "*Time Transfer by Laser Link: The T2L2 experiment on Jason 2,*" in Proceedings of the 2006 IEEE International Frequency Control Symposium, 5-7 June 2006, Miami, Florida, USA (IEEE), pp. 771-778.

[4] E. Samain , 1998, "*Timing of optical pulses by photodiode in Geiger mode,*" **Applied Optics, 37,** 502-506.

[5] I. Procazka and K. Hamal, 1995, "*Recent achievements in solid state detector technology for laser ranging*," in Proceedings of the 9th International Workshop on Laser Ranging Instrumentation, 7-11 November 1994, Canberra, Australia, **2,** p. 469.

[6] R. H. Kingston, 1978, in **Detection of Optical and Infrared Radiation** (Springer-Verlag, Berlin), p. 52.

[7] E. Samain, 2002, "*An Ultra Stable Event Timer,*" in Proceedings of the 13th International Workshop on Laser Ranging Instrumentation, 7-11 October 2002, Washington, D.C., USA.