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TIME TRANSFER BY LASER LINK THE T2L2 EXPERIMENT ON JASON-2

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Abstract. The new generation of optical time transfer will allow the synchronization of remote ultra stable clocks and the determination of their performances over intercontinental distances. The principle of T2L2 (Time Transfer by Laser Link) is based on laser ranging technique coupled with time-frequency metrology and consists in synchronizing ground and space clocks using short light pulses traveling between the ground and a satellite. The instrument will be integrated to the Jason-2 altimetric satellite billed for launch in 2008. The experiment should enhance the performances of time transfer by one or two magnitudes as compared to existing microwave techniques like GPS and Two-Way.

1 Introduction

The Time Transfer by Laser Link experiment (T2L2), under development at OCA (Observatoire de la Côte d'Azur) and CNES (Centre National d'Études 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 to synchronize remote ground clocks and compare their frequency stabilities with a performance never reached before. T2L2 will allow to perform a synchronization of a ground and space clock and also to measure the stability of remote ground clocks over continental distances, itself having a time stability in the range of 1 ps over 1000 s.

This paper will shortly explain the T2L2 optical time transfer principle and give an overview of the instrumental heritage up to the recent acceptation on Jason-2. After a description of the Jason-2 mission, more details will be given concerning the T2L2 instrument, the stakes and the objectives of the project, supplemented by a preliminary performance budget based on measurements conducted by OCA through a ground experiment performed in 2004 and several tests on electronic prototypes. Finally, a quick look on the calendar will give an idea of the progress and the current status of the project.

2 Principle of T2L2

T2L2 allows the synchronization of remote clocks on Earth and the monitoring of satellite clocks. The principle is based on the propagation of light pulses between laser stations and a satellite equipped with a specific instrumentation. The role of the space segment is to get the timing of the optical pulse when arriving at the satellite in complement to the ground timing of emission and reception at the telescope. The T2L2 payload is constituted of a photodetection device and a time-tagging unit. The experiment also uses the Jason-2 laser ranging array (LRA) and the DORIS ultra-stable oscillator USO. The laser station emits asynchronous short light pulses toward the satellite and the LRA corner-cubes return a fraction of the received photons back to the station (Figure 1). The station records the start (t_{start}) and return (t_{return}) time of each light pulse. The T2L2 payload records the arrival time (t_{board}) in the temporal reference frame of the onboard oscillator. These data are regularly downloaded to the ground via a regular microwave communication link.

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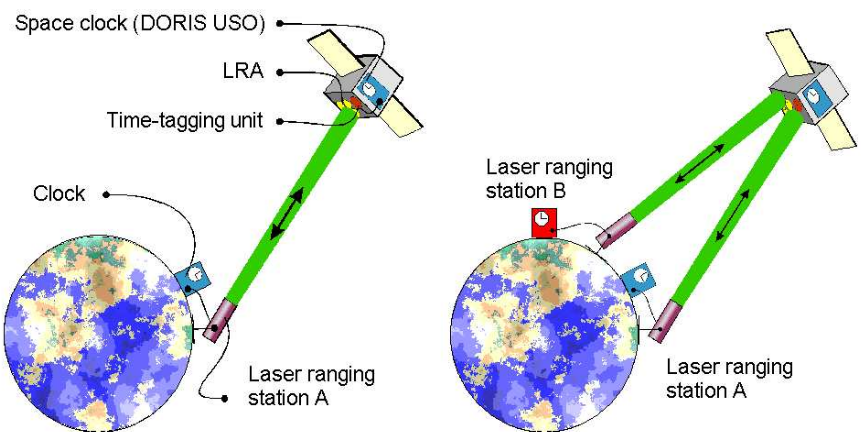

Fig. 1. The T2L2 experiment principle: single and common-view pass

For a given light pulse emitted from a ground station, time transfer χ_{AS} between ground clock A and space clock S is deduced from triplets of measurements $\{t_{start}, t_{board}, t_{return}\}$ with the following time equation:

$$\chi_{AS} = \frac{t_{start} + t_{return}}{2} - t_{board} + \tau_{relativity} + \tau_{atmosphere} + \tau_{geometry}$$

In common view configuration, with two laser ranging stations A and B firing towards the satellite simultaneously, the noise of the onboard oscillator has to be considered over very short time, in such a way that it can be considered negligible in the global error budget. The time transfer between ground clocks A and B is then deduced from the difference between χ_A and χ_B. In a non-common view mode, the temporal information is carried by the satellite local oscillator over the distance separating the two ground stations visibility. The respective time walk of the onboard clock has to be taken into account.

3 Historical account

The concept of transfering time using optical devices was born in 1972 upon an ESA (European Space Agency) and CNES initiative under the name LASSO (LAser Synchronization from Stationary Orbit). A first optical time transfer had been successfully achieved in 1992 between OCA, France and Mac Donald, Texas with LASSO onboard the Meteosat P2 geostationary satellite. This experiment was able to measure a stability of 10^{-13} over 1000 s which validate the feasibility of the concept.

T2L2 was first proposed in 1996 to fly on the Russian space station Mir taking the opportunity of the French PERSEUS mission, but the project was finally stopped at the end of the phase A. In the meantime it was accepted by ESA in the framework of the ACES (Atomic Clock Ensemble in Space) program scheduled on the International Space Station (ISS). T2L2 was one of the three scientific proposals of ACES, but had to be descoped in 2001 for some technical reasons concerning the whole ACES mission. Feasibility studies have been led by CNES for other flight opportunities (Myriade Micro-satellite, Galileo Test Bed), but finally a new opportunity appeared at the end of 2004, when NASA decided to abandon the WSOA instrument, an American contribution to the Jason-2 mission. A preliminary analysis conducted at CNES has confirmed the high interest to put the T2L2 instrument onto this altimetry-dedicated space vehicle and led CNES to select the T2L2 instrument as a passenger on the Jason-2 mission.

4 T2L2 on Jason-2

Jason-2 is a French-American follow-on mission to Jason-1 and Topex/Poseidon. Conducted by NASA and CNES, its goal is to study the internal structure and dynamics of ocean currents mainly by radar altimetry. Jason-2 is build around a Proteus platform equipped with a dual-frequency radar altimeter Poseidon-3 and a microwave radiometer to measure the water vapor contained in the troposphere and derive the appropriate radar path delay correction. For the needs of precise determination of the satellite orbit, three independant positioning systems are also embarked: a DORIS transponder, a GPS receiver and a LRA (Laser Ranging Array) target, an ensemble of corner cubes dedicated to laser ranging tracking. The T2L2 instrument and two radiation studying payloads (Carmen-2, France and LPT, Japan) are supplementing the satellite instrumentation with complementary objectives which are going to be developed later on. The satellite will be placed in a 1,336 km

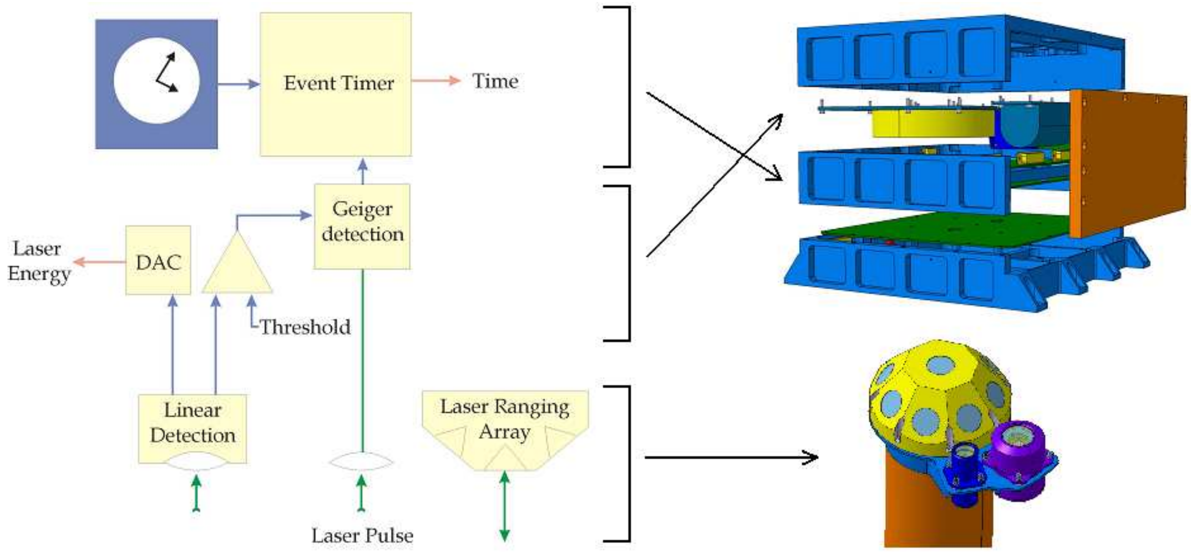

Fig. 2. T2L2 space instrument synoptic

orbit with 66° inclination by a Delta launcher. This orbit allows common views at continental scale (about 3000 km baseline between stations). The time interval between two passes varies from 2 to 14 hours with an average duration of about 1000 s.

The T2L2 specific instrumentation has an estimated mass of 10 kg and a power consumption of 42 W. It is composed of an optical and an electronic subsystem (Figure 2):

- Two photo detection units are located outside the main Jason-2 payload on the LRA boom. Both are composed of avalanche photo detectors. The first one is working in a special non-linear "Geiger" mode for precise chronometry. The other is in linear gain mode in order to trigger the whole detection chain and to measure the received optical energy and the reflected solar flux (earth albedo). To minimize the false detection rate, the detection threshold may be adjusted either by remote control or automatically as a function of the solar flux measurement.
- The electronic unit, located inside the Jason-2 payload module is composed of two main items. The detection unit ensures the conversion of the laser pulse into an electronic signal and the time-tagging unit proceeds to its timing. The role of the electronic unit also consists in controlling the whole instrument.

5 Mission's objectives

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

- Validation of optical time transfer, including the validation of the experiment, its time stability and accuracy. T2L2 should also allow decorrelating the target effects and being a first step for future experiments of one way laser ranging like TIPO (Samain et al.(2002)).
- Scientific applications concerning time and frequency metrology allowing the calibration of radio-frequency time transfer (GPS and Two-Way), fundamental physics with the measurement of light speed anisotropy and alpha fine structure constant, Earth observation and very long baseline interferometry (VLBI).
- Characterization of the onboard DORIS oscillator's drift, especially above the South Atlantic Anomaly (SAA) where the environment is highly irradiative. The two radiation instruments onboard will give the possibility to find a correlation between the expected and measured drift and propose adequate corrections

6 Preliminary performance budget

A ground-to-ground time transfer experiment has been leaded at OCA in 2004 to get the estimation of the whole error budget (Samain et al. 2006). A retro-reflector was placed on a near mountain 2.5 km away and the space segment in front of the telescope with the T2L2 corner cube linked to the time-tagging unit. This configuration between the ground and space segment allows the comparison of the clocks phase drift obtained through the T2L2 experiment on the one hand and between the two clocks directly on the other hand. Stability measurements, noise estimations and dedicated sensitivity measurements can then be deduced. The short-term white phase noise $\sigma_x(\tau) = 17.10^{-12} \times \tau^{-\frac{1}{2}}$ @ τ_0 =1 s and the long-term drift of about 5 ps/day are very close to the time stability obtained with a common clock.

Several tests on electronic prototypes have permitted to precisely evaluate the T2L2 performances. The measured time stability performance is close to the performance specifications that were deduced from a global performance budget. The time stability for the time transfer between a ground clock A and the onboard clock S with a sampling rate τ is:

$$\sigma_{AS}^2(\tau) = (23.10^{-12} \times \tau^{-\frac{1}{2}})^2 + (14.10^{-15} \times \tau^{\frac{1}{2}})^2$$

For ground to ground clock comparisons, one has to consider the time transfer between the ground clock A and B. The deadtime between the respective laser pulses can be considered negligible and we obtain:

$$\sigma_{AB}^2(\tau) = (32.10^{-12} \times \tau^{-\frac{1}{2}})^2 + (20.10^{-15} \times \tau^{\frac{1}{2}})^2$$

In common view configuration, T2L2 should reach the majority of current atomic clocks (including cold atoms) for integration times exceeding 1000 s. In non-common view, with the limitation imposed by the onboard clock, T2L2 will still offer an interesting alternative in calibration campaigns of radio-frequency techniques as well as time and frequency transfer systems based on transportable stations.

7 Current status and conclusion

The decision to put the T2L2 instrument on the Jason-2 satellite has been taken on July 2005. The phase B started the following September and entered in phase C/D in January 2006. For the optics, only a proto-flight model will be manufactured, while the electronics are developed in three steps: prototype boards of the metrological part, engineering model (EM) and flight model (FM). Metrological tests on EM have been done in July and tests on the FM are to be done in December for a delivery to Alcatel Space expected on January 2007. The results of the ground experiment performed in 2004 permitted to precisely evaluate the T2L2 performances. The measured time stability is in a good accordance as compared to the performance specifications that were deduced from the global performance budget. The tests that were so far conducted on the T2L2 electronics breadboard show the compliance with the metrology specifications for both the photo detection and the event timer. The Jason-2 launch is scheduled mid-2008 for a nominal duration of 5 years and T2L2 for 2 years.

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