T2L2 – Time Transfer by Laser Link

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Abstract

The new generation of optical time transfer T2L2 [1,2] (Time Transfer by Laser Link) has recently been accepted as a passenger of the Jason 2 satellite. The main objective of T2L2 on Jason2 is to compare remote clocks on earth. The project will also permit to follow-up from the ground, the on board clock of the DORIS[1] System. The performances expected are enhanced by one or two order of magnitudes as compared to existing microwave time transfer techniques, like GPS and TWSTFT[2]. After a description of the space instrumentation principle, we will present the metrological performances and give the current status of the project. Jason 2 will be launched in 2008 for a nominal mission duration of 3 years (5 expected) .

Introduction

The Time Transfer by Laser Link experiment (T2L2), initiated by OCA (Observatoire de la Côte d'Azur) and accepted by CNES (Centre National d'Etudes Spatiales), France, will be launched in mid-2008 on the altimetric satellite Jason 2. The experiment principle is issued from the classical laser telemetry techniques, with a specific instrumentation implemented onboard the satellite capable to tag the arrival time of laser pulses.

T2L2 history

T2L2 is the follow-on mission to LASSO (LAser Synchronization from Stationary Orbit) which was proposed in 1972 and launched in 1988 onboard the geostationary orbit satellite Meteosat P2. A first optical time transfer had successfully been achieved in 1992 between OCA, France and MacDonald, Texas [3]. This experiment measured a stability of 10^{-13} over 1000s and validated the feasibility of the concept. In 1996, a T2L2 instrument was proposed in the framework of the French PERSEUS mission to the Russian space station MIR, but the project was finally stopped at the end of the phase A. In the meantime it was accepted by ESA in 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 de-scoped in 2001 for some technical reasons concerning the whole ACES mission. Feasibility studies have been led by CNES and OCA for other flight opportunities (Myriade Micro-satellite, Galileo Test Bed), and 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 confirmed the high interest to put a T2L2 instrument onto this altimetry-dedicated space vehicle and CNES decided to select the T2L2 instrument as a passenger on the Jason 2 mission.

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[1] DORIS : Radio electric positioning system
[2] TWSTFT: Two-Way Satellite Time and Frequency Transfer

Principle and purpose of the experiment

T2L2 is an optical experiment that is able to establish a temporal link between remote clocks. The principle is based on the propagation of light pulses between laser stations and a satellite equipped with a specific instrumentation. The T2L2 payload is made with a photodetection device, a time-tagging unit, a clock (the DORIS ultra-stable oscillator (USO)) and a Laser Ranging Array (LRA). The ground station emits asynchronous laser pulses towards the satellite. LRA return a fraction of the received photons back to the station, while another fraction is detected and timed in the temporal reference frame of the onboard clock as (t_{board}). Each station records the start (t_{start}) and return (t_{return}) time each light pulse.

For a given light pulse emitted from station A, the synchronization χ_{AS} between the ground clock A and the satellite clock S is then derived from these data:

$$\chi_{AS} = \frac{t_{start} + t_{return}}{2} - t_{board} + \tau_{relativity} + \tau_{atmosphere} + \tau_{geometry} \quad (1)$$

$\tau_{relativity}$ is coming from relativistic effects, $\tau_{atmosphere}$ is the atmospheric delay and $\tau_{geometry}$ takes account of the geometrical offset between the reflection and detection equivalent points, depending on the relative position of the station and the satellite.

The same experiment can be lead from another station B and χ_{BS} can then be measured. The time transfer between A and B is then deduced from the difference between χ_{AS} and χ_{BS}. In a common view configuration, i.e. the two laser ranging stations are firing simultaneously towards the satellite, the noise of the onboard oscillator has to be considered over a very short time (time interval between consecutive pulses), so that it can be considered as negligible in the global error budget.

In a non-common view mode, the satellite local oscillator carries the temporal information over the distance separating laser stations. In the case of Jason 2 (driven by a quartz oscillator), we will have a significant degradation of the performances as soon as the time interval between passes is a few seconds (the maximum distance that allow this common view mode is roughly 7000 km). But in some cases, it will possible to keep a good time transfer performances even if the distance is greater than 7000 km by the use of intermediary laser stations located between station A and B. These stations will permit to build a virtual DORIS time scale from the clocks of each station.

Participation to the T2L2 experiment

The T2L2 ground segment is a laser station equipped with instrumentation to measure accurately both the start and return time of laser pulses. The laser station has to shoot with a 532 nm pulsed Nd:YAG laser having a pulse width between 10 to 200ps FWHM. The station can work between 10 Hz to a few Khz. Concerning the link budget, the conception of the space segment has been studied to detect low energy signals: the detection level onboard is comparable to the level in the ground. As a rule, if the ground station detects the impulse back, the same impulse should have been detected onboard as well.

Among the 40 laser stations in the world, 25 regularly range Jason 1 and will probably track Jason 2. Many laser stations have indicated their interest in participating to the T2L2 experiment (Figure 1).

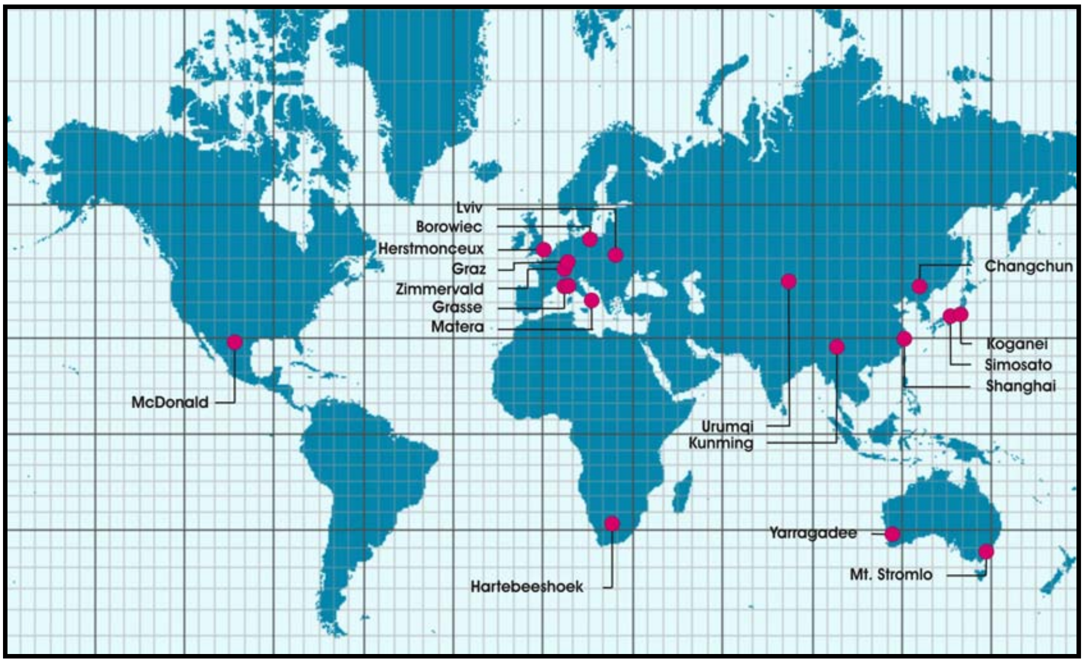

Figure 1: *T2L2 participation (October 2006)*

T2L2 on Jason 2

Jason 2 is a French-American follow-on mission to Jason 1 and Topex/Poseidon. Conducted by CNES and NASA, 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. For the needs of precise determination of the satellite orbit, three independent positioning systems are embarked: a Doris transponder, a GPS receiver and a LRA (Laser Ranging Array) target. The T2L2 instrument and two radiation studying payloads (Carmen-2, France and LPT, Japan) are supplementing the satellite instrumentation with some complementary objectives.

The satellite will be placed by a Delta launcher on the Jason 1's orbit at an altitude of 1,336 km and an inclination of 66°. This orbit allows common views at continental scale (about 7000 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 a mass of 10 kg and a power consumption of 45 W. It includes (Figure 2):

- Two photo detection units located outside the main Jason 2 payload on the LRA boom (figure 3 right). Both are composed of avalanche photo detectors. The first one is working in a Geiger mode for precise chronometry[4,5] 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 minimise 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 (figure 3 right). The detection unit ensures the conversion of the laser pulse into an electronic signal and the event timer [6].

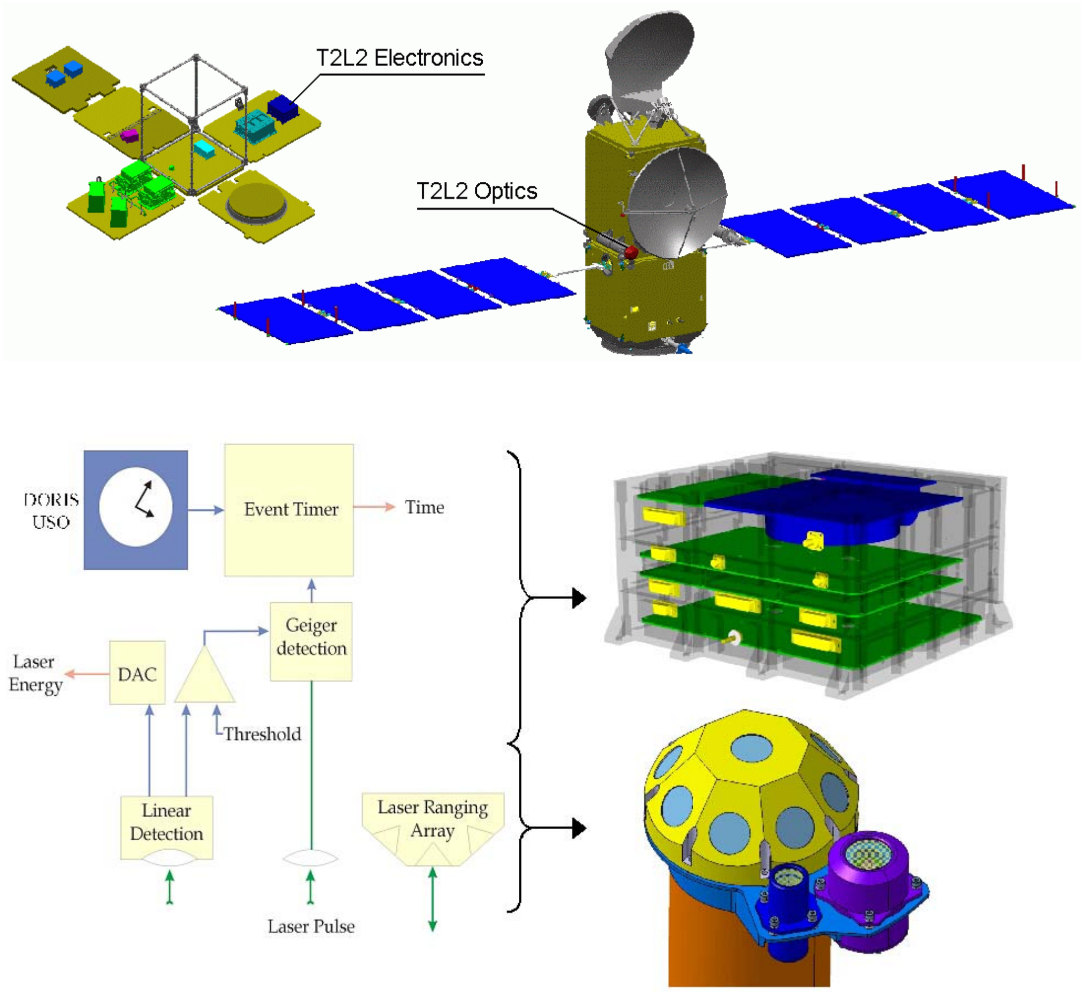

Figure 2: *The integration of the T2L2 device inside the Jason-2 spacecraft*

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 will be a first step and a demonstration for future experiment based on one way laser ranging techniques in an interplanetary range: TIPO[3]. It should also allow the de-correlation of the effects coming from the target signature. In that way, it will permit to improve the precision of the telemetry.
- Scientific applications concerning time and frequency metrology allowing the calibration of radiofrequency 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.

Performance budget

T2L2 has ground-ground time transfer accuracy better than 100 ps. This will allow inter calibration between different time transfer methods by extracting the error

[3] TIPO: *Télémétrie InterPlanétaire Optique* / Optical InterPlanetary Telemetry

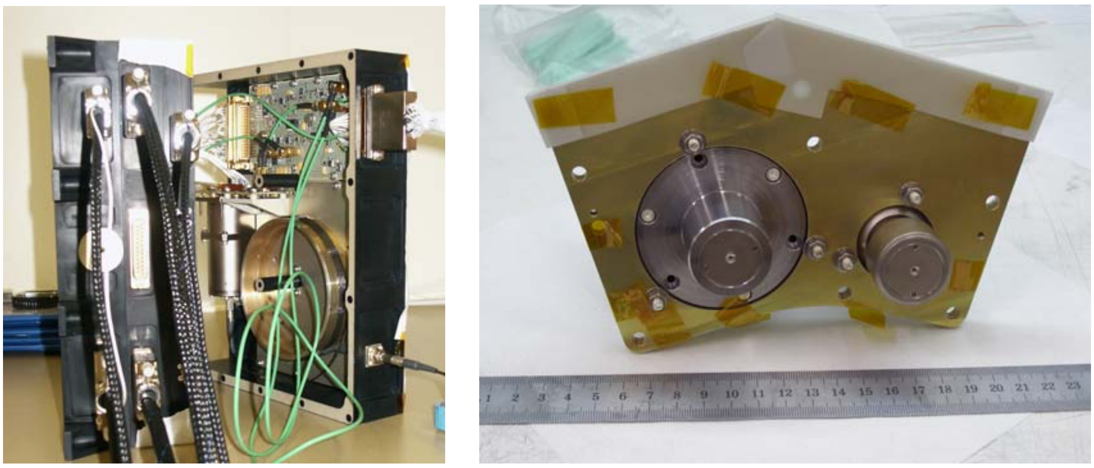

Figure 3: *Left : electronic of the flight model. The cylinder on the right side, support an multi mode optical fiber that generate a delay between the 2 photo detection. Right: the photo detection module (linear photo detector on the left side)*

caused by the transfer techniques themselves. T2L2 is particularly interesting to calibrate the regular time transfer used for the construction of international time scales (TAI) in particular the "Two-Way" (TWSTFT) that is about to become the quality reference for these scales. T2L2 will also permit to validate and to qualify the time transfers of Two-Way phase or GPS phase.

In term of stability, the comparison of T2L2 with the existing microwave links is shown on Figure 4. In a common view configuration (red bottom curve), the stability is better than 1 ps over an integration of 1,000 s. In non-common view, when conditions will not permit to build a virtual DORIS time scale, T2L2 will still offer an interesting alternative for radiofrequency calibration campaigns.

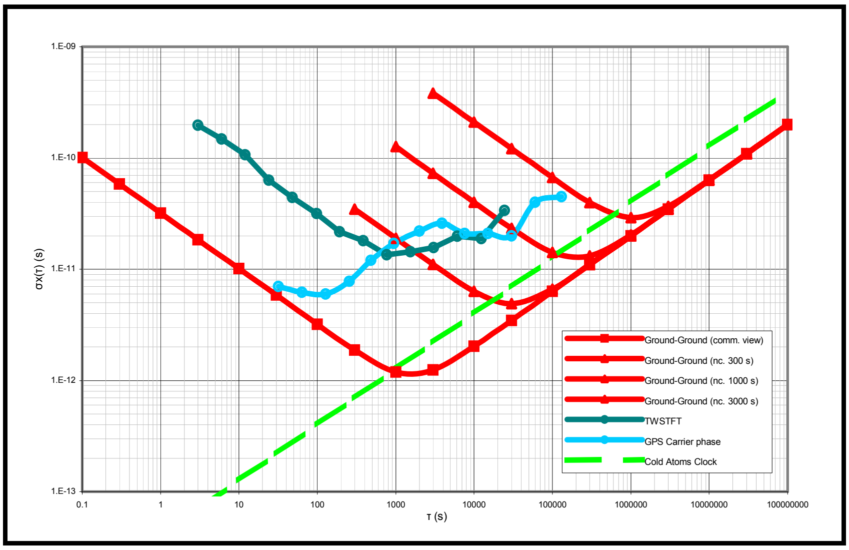

Figure 4: *T2L2 stability in common and non-common view configuration in* $\sqrt{\mathrm{TVAR}}$

Current Status

The decision to put the T2L2 instrument in the Jason-2 satellite was taken on July 2005. The phase B started in September 2005 and entered in phase C/D in January 2006. Only one proto-flight model was built for the optics, while the electronics was developed in three steps: prototype boards, engineering model (EM) and flight model (FM). Metrological tests on EM have been done in July 2006. The flight model is now fully integrated and the qualification processes is running now. The delivery of the instrument for the integration on the Jason 2 satellite is expected in April 2007.

A test bed has been developed at OCA to evaluate the metrological performances of the T2L2 space instrument and to perform some calibrations of both electronics and optics. This test bed will precisely reproduce the experimental conditions that will meet in orbit. The optical subsystem of the test bed was designed to simulate laser stations by illuminating the optics with faint laser pulses and also background illumination. The T2L2 photo detection module is mounted on 2 axes gimbals able to emulate the attitudes of the satellite in the range of ±60°. A high performance timing system is used as a timing reference. The experimental setup also includes a DORIS space clock engineering model in order to simulate the conditions on the satellite Jason 2, and alternatively a Cesium standard for time accuracy measurements. The tests that were so far conducted on the engineering model show the compliance with the metrology specifications for both the photo detection and the event timer.

Conclusion

With an improvement of one order of magnitude as compared to microwave time transfer techniques, T2L2 will give the possibility to compare cold atoms clocks at a level never reached before. It will allow the calibration of the existing radiofrequency links like GPS and TWSTFT with an improvement of at least one order of magnitude. T2L2 will also allow the precise characterization of the DORIS USO onboard Jason 2. The validation of the time and frequency transfer in space by T2L2 will represent an important step for further missions using this kind of technology, especially in a one-way mode in the solar system [7,8]. Jason 2 will be launched mid-2008 for a nominal duration of 3 years.

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