SF2A 2007
J. Bouvier, A. Chalabaev, C. Charbonnel (eds)

TIME TRANSFER BY LASER LINK PERFORMANCES AND PROGRESSES

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Abstract. The idea of transfering time using optical devices has been implemented by OCA[1] and CNES[2] through the T2L2 (Time Transfer by Laser Link) space instrument. Its goal is to permit the synchronization of remote ultra stable clocks and the determination of their performances over intercontinental distances. The principle is derived from laser telemetry technology with dedicated space equipment embarked on the satellite Jason 2. The instrument has recently been integrated on the satellite scheduled to launch in June of 2008. The T2L2 scheme will allow an improvement of one to two orders of magnitude as compared to the performances of existing time transfer systems.

1 Introduction

T2L2 is a high performance time transfer experiment jointly designed by CNES and OCA. The instrument will be launched in 2008 aboard the Jason 2 altimetric satellite. It will permit to perform time transfer between remote ground clocks and to compare their frequency stabilities with performances never reached before. The objectives of the T2L2 mission are threefold:

- Technological validation of optical time transfer, including the validation of the experiment and its time stability and accuracy. The success of such a two-way time transfer experiment would also represent a strategic step toward one-way laser ranging.
- Various scientific applications concerning time and frequency metrology, fundamental physics, earth observation or very long baseline interferometry (VLBI).
- Improvement of the orbit accuracy through the follow-on of the DORIS oscillator used for positioning and subjected to abnormal drifts. This also represent a contribution to the Jason 2 laser ranging core mission.

This paper will first describe the T2L2 principle and functionalities. We will then propose three possibilities of experiments that could be implemented with this new time transfer technique.

2 What is T2L2?

2.1 Principle of T2L2

The principle is based on the propagation of light pulses between laser stations and a satellite equipped with a specific instrumentation. A laser station emits asynchronous short light pulses towards the satellite. A LRA corner-cubes return a fraction of the received photons back to the station. 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. For a given light pulse emitted from a ground station, time transfer χ_{AS}

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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:

$$\chi_{AS} = \frac{t_{start} + t_{return}}{2} - t_{board} + \tau_{relativity} + \tau_{atmosphere} + \tau_{geometry} \quad (2.1)$$

where $\tau_{relativity}$ considers relativistic effects, $\tau_{atmosphere}$ is the atmospheric delay, $\tau_{geometry}$ takes account of the geometrical offset between the reflection and detection equivalent points, further depending on elevation and attitude of the satellite.

2.2 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. The orbit parameters of Jason 2 (Table 1) and the 110 degrees field of view of the detectors make the satellite

Table 1. Jason 2 orbit parameters

Parameter	Value
Semi-mayor axis	7714.4278 km
Inclination	66.039°
Altitude	1,336 km
Nodal period	112'42"
Repetitive period	9.9156 days
Passes per cycle	254

simultaneously visible from stations separated by a distance up to 6,500 km at the earth's surface. The time interval between two passes varies from 2 to 14 hours with an average duration of about 1000 s. Jason 2 is build around a Proteus platform equipped with a Poseidon 3 altimeter to measure the height above sea surface and a microwave radiometer to study the water vapor contained in the troposphere. For the needs

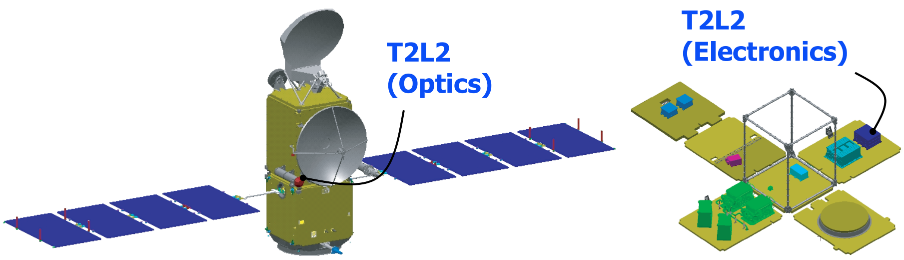

Fig. 1. The integration of the T2L2 device inside the Jason 2 spacecraft.

of precise determination of the satellite orbit, three independant positioning systems are also embarked: a Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) Doppler tracking antenna, a Global Positioning System Payload (GPSP) and a Laser Retroreflector Array (LRA) working with ground laser stations to track satellite and calibrate the other satellite location systems, and verify altimeter measurements. The T2L2 instrument and two radiation studying payloads (Carmen 2, France and LPT, Japan) are completing the satellite instrumentation with complementary objectives. The T2L2 specific instrumentation is composed of an optical and an electronic subsystem (Fig. 1):

- 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 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. 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.

The T2L2 specific instrumentation has an estimated mass of 10 kg and a power consumption of 42 W. The experiment also uses the Jason 2 laser ranging array (LRA) and the Doris ultra-stable oscillator USO.

3 T2L2 experiments

3.1 Comparizon between ultra-stable atomic clocks

The availability of transportable cold-atoms clocks in Europe, such as the mobile atomic fountain developed at LNE-SYRTE, could lead to an experiment consisting in synchronizing two cold-atoms clocks over 1,000 km. The transportable clock will be installed at OCA near the MeO laser station, while the French Transportable Laser Ranging System (FTLRS) developed at OCA and dedicated to participate to such specific missions will be able to play the role of the local laser station at SYRTE, Paris. The prospective performances of T2L2 in this kind

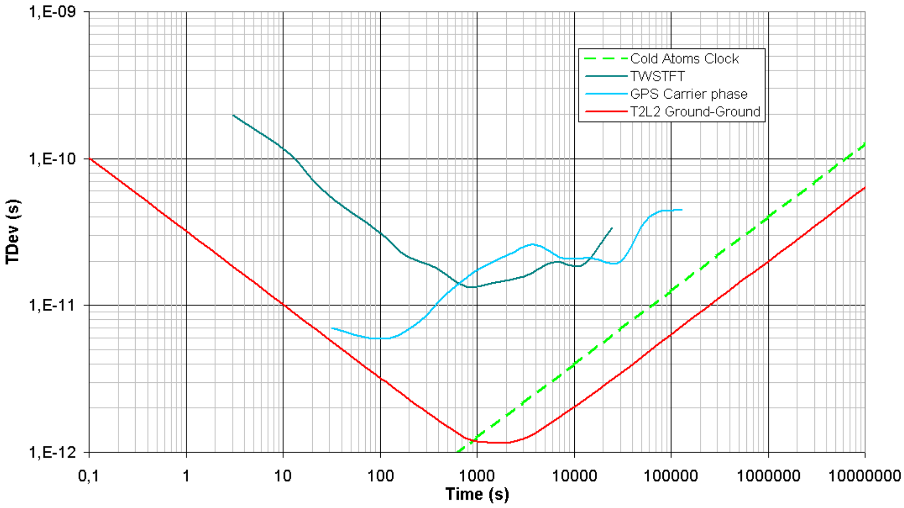

Fig. 2. Microwave links and cold atoms stabilities compared with T2L2.

of configuration represent an important improvement. The ultimate stability will be in the range of 1 ps over 1000 s and better than 10 ps over one day and will thus allow an improvement of one to two orders of magnitude with respect to the performances of existing time transfer systems, like GPS or Two-Way Satellite Time and Frequency Transfer (TWSTFT). In term of accuracy, the uncertainty is dominated by our capability to calibrate the equipments and to monitor their drifts. Calibration accuracy is difficult to evaluate precisely, but a fine analysis of the ground and space equipment should lead under the 100 ps level. This order of performance represents an enhancement of one magnitude in accuracy as compared to the existing links which are at the nanosecond level. As a result, it will allow the calibration of these radiofrequency systems, and comparisons of cold atoms clocks at a level never reached before. This contribution will be profitable for the atomic time scales generation. We must notice that a second transportable laser station could allow to extend this configuration to any time-frequency lab in the world, for calibration purpose of the existing microwave links.
The prospective time stability of the T2L2 experiment in a common-view mode can be compared with the microwave time transfer techniques and the cold-atoms clocks as shown on Fig. 2. With a difference of at least one order of magnitude, T2L2 offers the capability to calibrate existing radio-frequency time transfer systems.

3.2 Transatlantic time transfer

If two stations are separated by a distance of more than 6,500 km, time transfer can still be proceeded, but in a non-common view mode, for example between the US and France. Greenbelt and Grasse laser stations are

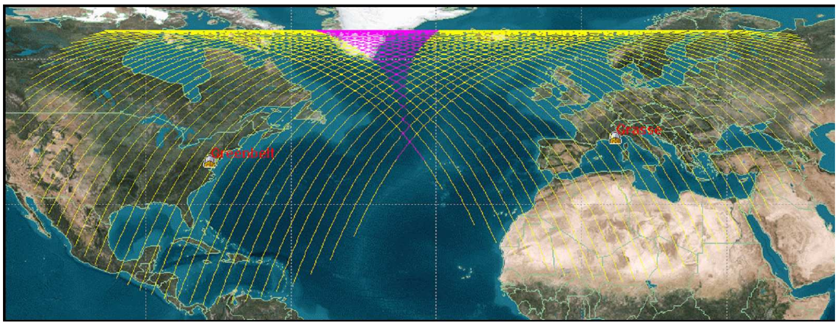

Fig. 3. Satellite visibility ($> 5^\circ$ elev.) over Grasse and Greenbelt (yellow), non-visibility (purple).

separated by a distance of 6,700 km (Fig. 3). In a repetitivity period of about ten days, the satellite covers a 315 km-width grid at the earth's surface. The mean duration of a pass for a ground station is about 14 minutes of visibility over five degrees elevation, with four to five consecutive passes every day separated by two hours. In a period of ten days, among the 75 visible passes over each of the Grasse and Greenbelt stations, 45 are favorable for experimentating T2L2. The satellite starts being visible from the Grasse laser station only two minutes after leaving the Greenbelt's field of view. This short dead time between the two observations minimizes the degradation imposed by the onboard clock's drifts at less than 30 ps.

3.3 Transcontinental time transfer

The experiment can be extended in a longer baseline, for example between France and China, with a distance of 9,300 km between the Grasse and Shanghai laser stations (Fig. 4). Over a period of ten days, the number of favorable configurations to transfer time with a minimum dead time is 29, with a typical distribution of three consecutives passes every day separated by two hours. The mean duration of non-visibility is ten minutes, leading to an important uncertainty of 300 ps induced by the onboard USO (Fig. 5). In order to avoid this degradation, one can use an intermediary station to extend the common view coverage. The Maidanak laser station in Uzbekistan is located at a strategic position for this kind of French-Chinese experiment. Maidanak would be used as a relay between Grasse and Shanghai by tracking the satellite to measure the oscillator's drifts during the non-visibility period and generate a DORIS corrected time along the passes. For that purpose, Maidanak will have to be equipped with a good short-term time stable clock like a Maser or a good Cesium clock. In a general way, the presence of multiple laser stations distributed at the Earth's surface and tracking Jason 2 would permit a high improvement for the very long baseline time transfers by multiplying the possibilities and the range of operation.

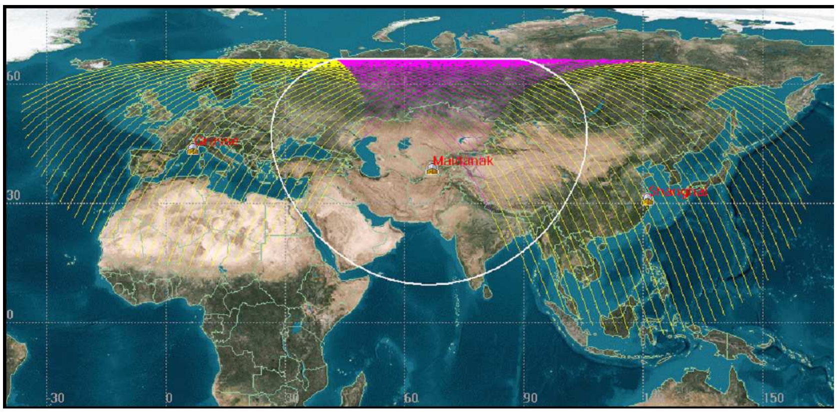

Fig. 4. Satellite visibility ($> 5^\circ$ elev.) over Grasse and Shanghai (yellow), non-visibility (purple), visibility over Maidanak (white circle).

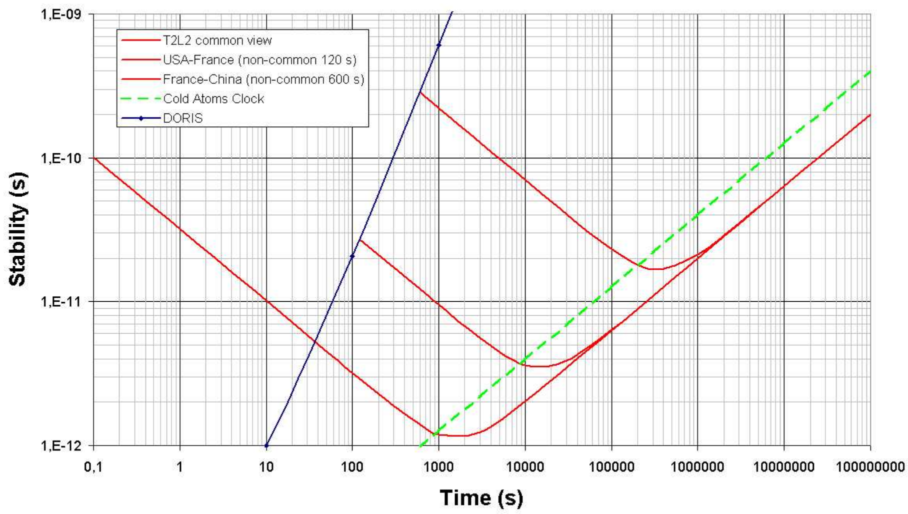

Fig. 5. T2L2 stability in a common-view mode and for transatlantic and transcontinental configurations

4 Conclusion

In June 2008, a Delta 2 rocket will place Jason 2 into orbit. The T2L2 instrument onboard will allow to process clock comparisons at the picosecond level between stations, from simultaneous to few minutes non-common view configurations. In this latter case, the DORIS USO will be the limitative factor in term of precision, confirming the high interest of a wide participation of laser stations to follow the onboard drifts and correct them.

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