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T2L2/JASON-2, FIRST YEAR OF PROCESSING ACTIVITIES

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Abstract. The T2L2 (Time Transfer by Laser Link) project, developed by CNES and OCA will 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 a dedicated space equipment designed to record arrival time of laser pulses at the satellite. T2L2 was accepted in 2005 to be on board the Jason-2 altimetry satellite. It has been successfully launched from Vandenberg (CA, US) in June 2008. T2L2 acquired the first laser pulses a few days after the launch.

First analysis permitted to validate some important characteristics of the instrument such as sensitivity, noise, dynamic, event timer precision and ground to space time stability.

1 Introduction

T2L2 is a two way time transfer technique based on the timing of optical pulses together emitted by a Satellite Laser Ranging station (SLR) and detected by a dedicated space instrument (Fridelance et al., 1996); (Fridelance & Veillet, 1995). T2L2 was accepted as a passenger instrument on the altimetry Jason-2 satellite in 2005 (Samain et al., 2008). 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. The satellite was placed on a 1,336 Km orbit with 66 inclination by a Delta launcher the 20th of June, 2008.

The objectives of the T2L2 experiment on Jason-2 are threefold: *(i)* validation of optical time transfer (it should further allow to demonstrate one-way laser ranging), *(ii)* scientific applications concerning fundamental physics and time and frequency metrology allowing the calibration of radiofrequency techniques as GPS and Two-Way, and *(iii)* characterization of the on board DORIS oscillator (the space reference clock).

2 Experimental description

The ground segment of the experiment is based on the international laser ranging network. In addition, a given satellite laser ranging (SLR) station must be able to time both start and return times of laser pulses with a resolution of 1 ps. The laser station track the satellite as soon as it is in the right field of view, that is at a distance of less than 4000 Km. The whole duration of the satellite pass over the station is of 1000 s maximum.

The space instrument is based on a photo detector (in the 532 nm wavelength domain) and an event timer (resolution of 1 ps) linked to the space clock. A Laser Ranging Array (LRA) is also used to reflect the laser pulse toward the laser station. This LRA is provided by the JPL agency, basically as orbit determination system in addition to the GPS and DORIS orbitography space techniques. The space clock is an ultra-stable oscillator (USO, Quartz) which has been developed by CNES for the DORIS (Doppler Orbitography and Radiopositioning Integrated on Satellite) equipment. The GPS receiver of the PROTEUS plateform is connected to T2L2, in order to permanently date Pulse Per Second (PPS) coming from the GPS time in the on-board time scale; the row precision of these PPS is of $\pm 1\mu$sec. In addition to the photo detector used by the event timer, T2L2 is equipped with a second photo detector in order to measure the received energy of each optical event. Taking into account the electronic behaviour of the non-linear photo diode relatively to the number of photons, the measured energy is used to correct the time walk of the diode.

The mass of the T2L2 space equipment is 8 kg for the electronic module which is inside the satellite and 1.5 kg for the photo detection module located outside. Basically, T2L2 realizes a ground to space time transfer

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between the ground clock linked to the laser station and the space clock of the satellite. The ground to ground time transfer between several remote clocks at ground is obtained through these individual space to ground time transfers. It can be obtained in a common view mode, when the distance between the laser stations is smaller than roughly 5000 Km, or in a non-common view mode when the distance is larger.

3 Data

3.1 *T2L2 on board data*

CNES is providing 1-day files of on board dates of optical events with a time delay of 1-2 days. Since the begining of the mission, T2L2 acquired roughly 150,000 to 250,000 events per day, consisting in solar noise, laser pulse, GPS PPS, or dedicated event for internal calibration.

A first data treatment has to be processed before all. The goal is to compute for each acquired event its aproximate GPS date (left part of Table 1); that permits to permanently establish a phase link between the GPS and DORIS time scales. Thanks to the GPS PPS, an absolute local frequency offset Δf is also estimated between the space clock and GPS along the time; after filtering the row data, the precisions of the phase link and of the local frequency offset have been estimated to 0.3 μsec and to 2-3.10^{-11} (in term of $\Delta f/f$ over 5000 s), respectively.

approximate date (via PPS-GPS) Julian date and secondes	code (and comment) 1, 2, 4, 6	T2L2 count : (SEC) 1-9999999	(picoSEC) 12 digits	energy 0-32164
55000 12345.000001	4 (it's a PPS)	1000001	123456123456	-
55000 12346.000001	4 (id)	1000002	123456143456	-
55000 12347.000001	4 (id)	1000003	123456163456	-
55000 12347.123400	2 (it's an optical pulse)	1000003	246856165678	1234
55000 12347.223400	2 (id)	1000003	346856167890	678
55000 12348.000001	4 (it's a PPS)	1000004	123456183456	...
55000 ...	...	...	...	-

Table 1. Example of a T2L2 data file (right part) and of computed GPS date for each T2L2 event (left part). Code: 1 is an internal calibration event dedicated to the energy level, 2 is an optical event (laser pulse or noise coming from Earth's albedo), 4 is a GPS-PPS, 6 and 8 are internal calibration events

3.2 *SLR full rate data*

Since 1998, the International Laser Ranging Service (ILRS) is assuming a multi-satellite tracking for geosciences and Solar system applications from a network of 35 ground SLR stations. Among these stations, 17 are providing full rate ranging data for all Jason2 passes. A ranging data mainly consists in two quantities; *(i)* one date which is the start time (resolution of 1 ps) of a laser pulse, and *(ii)* the time of flight (tof) of this laser pulse between the station and the satellite LRA and return (which quantity is measured at the ps level).

As a system of time, a few SLR stations are using a standard Cesium but some of these have implemented an Hydrogen Maser. Thus, the precision of the start dates is of 1-5 ps, whereas the precision of the time of flight (the range) is of 25-35 ps for the best SLR systems (Exertier et al., 2006). In addition, the time stability over a satellite pass should be at 1-5 ps maximum.

From a quantitative point of view, the participating SLR stations provide betweeen 10 and 80 passes per month. In average, each pass is of 650 s duration and provides arround 1000 range measurements; SLR systems are using a 10Hz acquisition mode generally, but some of these have a 100Hz or a KiloHz mode. The SLR stations which contribute to the T2L2 tracking using all the technical requirements of the experiment are : Changchun (China), Koganei (Japan), Mt Stromlø(Aus), Herstmonceux (UK), Matera (I), Wettzell (G), and Grasse (F). But from month to month, there are new participating SLR systems.

4 Correlation between ground and on board dates

Because the T2L2 instrument is "on" permanently and is not able to identify the origin of each optical event (i.e., from which SLR station a laser pulse is coming), it is very important to make a correlation between the estimated arrival dates of laser pulses and the dates of T2L2 events that are recorded by the space clock. According to the T2L2 principle, the tof which is measured by an SLR station is used to compute the arrival date of a laser pulse at the satellite from the start date noted at ground. Obviously, this tof must be divided by 2 and, before all, must be corrected by the Sagnac effect (due to Earth's rotation) and by the on board position difference between the LRA and the T2L2 reference points which difference depends on the satellite attitude.

From this correlation, it emerges a time serie of what we call "triplet", consisting in three quantities: the ground and space times and the corresponding tof measured at ground (to be corrected). Obviously, considering the low energy level of the laser equipement serving as ranging systems (between 1 and 300 mJ), the divergence of the beam, the dispersion due to the atmosphere effect, the distance of the target, and finally the very small optical aperture of T2L2 opticalmodule, each emitted laser pulse from a ground station could have no equivalent on board. In that case, no "triplet" can be recorded. During the data processing, we effectively noted that higher energy level of SLR systems provides higher success of on-board events detection. The percentage of detected laser events by T2L2 relatively to the number of laser pulses emitted by a station varies from 1 to 100% with an average of 35%.

5 Stability of time transfer and conclusion

The ground to space time transfer represents the time offset between the space and the ground clocks. It is deduced from the following equation:

$$t_{start}^{UTC} + \frac{dt_{tof} + \delta t_{(Sagnac+attitude)}}{2} - t_{arrival}^{DORIS} + Instrumental\, corrections \tag{5.1}$$

The overall error budget of equation 5.1 should contain the precision of the laser ranging measurements (tof) which varies from an SLR station to another. But we can consider that the associated variance is decreasing with $\sqrt{N}$ where N is the number of row data. Thus, after averaging the tof over tens of seconds (typically 20-30 s) and properly filtering the data, the stability of ground to space time transfers (which is measured from a serie of "triplet") from Wettzell, Matera, Koganei or Grasse SLR stations ranges from 7 ps to 10 ps after 30 s of time integration using the TVAR estimator (Allan, 1983).

The fact that several SLR stations which time system is a Cesium (Grasse, Koganei) or better an Hydrogen Maser (Wettzell and Matera) , provide enough sets of "triplets" is extremely satisfactory in order to monitor the behaviour of the DORIS oscillator in space. For short time span, the stability of DORIS over 10 s and the very good results already obtained will permit to construct time transfers between two or several ground stations and the satellite if these stations are in common view. For longer time period (from 2 hours to few days), the monitoring of the DORIS oscillator sould be used to improve the technique as an orbitography and radio-positioning space technique available on board Jason2.

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