FISRT APPLICATION OF THE T2L2 GROUND TO SPACE TIME TRANSFER : CHARACTERISATION OF THE DORIS USO.

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Abstract— The Time Transfer by Laser Link experiment is a joint CNES and OCA space mission that shall allow ground to ground time transfer with an expected stability of about 1 ps over 1,000 s and 10 ps over one day and an accuracy in the 100 ps range. The T2L2 instrument has been successfully launched with the Jason-2 space vehicle on the 20th of June 2008 and switched on 5 days later. It is been undergoing continuous operation since this date. The first days of operation have been devoted to functional tests, followed by a first evaluation of the performances of both the space instrument and the whole system. First results are very promising, preliminary data analysis shows a short term time stability of some tens of ps for an integration time of 1s, without any compensation of the behavior of the instrument. The next step, in progress, is improving of data processing, with the introduction of the relativistic compensation and of the numerical model of the instrument. That shall allow us to perform rapidly ground to space and ground to ground time transfer with the expected performances.

Among science objectives of the mission, a first application of T2L2 shall be to precisely characterize the DORIS Ultra Stable Oscillator (USO) aboard Jason 2, independently from the DORIS system and with a better precision. By using an hydrogen maser as ground clock, relative stability of both T2L2 and DORIS USO shall allow to "read" the USO frequency for integration time of some tens of seconds. This paper will present the first restitution of the USO frequency thanks to the T2L2 ground to space time transfer.

1. INTRODUCTION

Space altimetry and ocean topography rely on both altimeters and precise orbit restitution. Since 1992 and the TOPEX mission, major altimetry space missions take on board a DORIS system. DORIS (Doppler Orbitography and Radiopositioning Integrated in Space) is a Doppler satellite tracking system developed for precise orbit determination and precise ground location. Its ultimate aim is to achieve an accuracy of one centimeter. The DORIS system was designed by CNES (Centre National d'Etudes Spatiales), in partnership with French mapping and survey agency IGN and space geodesic research institute GRGS, to answer to this one centimeter challenge.

DORIS performances depends partly on the stability of the frequency of its on-board Ultra Stable Oscillator (USO). This frequency is used as a reference for the measurement of the beacons of the DORIS ground network. Thus, the final performance of the orbit restitution depends on our ability to rebuild the USO frequency. Nevertheless, inside the DORIS system, the USO frequency is only computed when the DORIS receiver (and so the space vehicle) is above a so called "master beacon". The frequency offset of the on board USO estimated there is then use a along the orbit, assuming a rather quiet behavior of the USO [8]. Using an atomic frequency standard to synchronize those "master beacon", it is possible to determine the on-board USO frequency over one pass with an uncertainty of a few 10^{-12}.

After first flights with SPOT2 and TOPEX-POSEIDON missions, DORIS has been put on board the SPOT series space vehicles (SPOT 3, 4 and 5), ENVISAT and Jason-1. However, whereas SPOT and ENVISAT missions are at an altitude of 830 km, TOPEX-POSEIDON are at 1336 km which is known to be very severe in terms of radiations.

A few months after its launch, the DORIS USO on board Jason-1 has exhibited some unattended frequency variations (Figure 1). The observed discontinuous

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frequency variations (1 to 6.10^{-11} peak-to-peak) are strongly correlated to the run of the satellite through the South Atlantic Anomaly (SAA) [3]. The radiation environment of Low Earth Orbit (LEO) corresponds to radiation exposures with relaxation periods. The flux of protons during orbit is not continuous. Cycles coincide with transits through the SAA proton belt. Such variations have lead to a degradation of the orbit restitution and of the ground location in the SAA area.

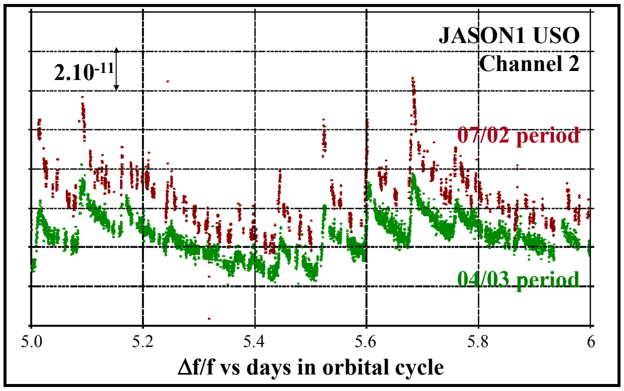

Figure 1: Frequency variations (without slope) of the Channel 1 USO observed in July 2002 and April 2003 on-board JASON1 satellite over a period of 1 day.

Some specific ground processing and the use of data from DORIS on-board TOPEX-POSEIDON have allow to work around the problem. Nevertheless, an independent restitution of the DORIS USO frequency would be of great interest.

II. T2L2 TO CHARACTERIZE THE DORIS USO

T2L2 "Time Transfer by Laser Link" [1] is a high performance time transfer experiment. It is based on a space instrument that has been designed at CNES and OCA (Observatoire de la Côte d'Azur). It will permit to perform time transfer between remote ground clocks and to compare their frequency stabilities with a performance never reached before. In common view mode (i.e. two laser stations are communicating with T2L2 at the same time), T2L2 will measure the stability of remote ground clocks, itself having a time stability in the range of 1 ps over 1000 s [2].

Launched in June 2008 aboard the Jason 2 altimetry satellite, T2L2 instrument use the DORIS USO as its reference clocks. The ground to space time transfer capability of T2L2 is thus a unique opportunity to perform an independent characterization of the USO. For that matter a contribution to the DORIS mission, through the improvement of the frequency restitution of the USO and of the ground location inside the SAA area, is one of the three main objectives of the T2L2 mission [4].

From the DORIS point of view, the needs can be quantified as :

- First, to be able to read the USO frequency for integration times of some tens of seconds (The specification for the USO short term stability is $\sigma_{Piccibono}(\tau = 10) < 4\times10^{-13}$),
- Second, to have a resolution at least at the same level than the DORIS system one, with an objective to be better than 10^{-12}.

Those two requirements leads for T2L2 to a specification for the ground to space time transfer, translated into time variance, of a time variance of a few picoseconds for an integration time of some tens of seconds. The overall time stability of the time transfer from a ground station to on-board clock on space could be deduced from the following equation [5] :

$$\begin{aligned}\sigma^2_{X,G/S}(\tau) &= \frac{1}{4}\left(\sigma^2_{X,Start}(\tau)+\sigma^2_{X,Ret}(\tau)+\sigma^2_{X,Cal}(\tau)\right)\\ &+\frac{1}{2}\sigma^2_{X,Timer}(\tau)+\sigma^2_{X,T2L2}(\tau)\\ &+\sigma^2_{X,Geom}(\tau)+\sigma^2_{X,Rel}(\tau)+\sigma^2_{X,Atm}(\tau)\end{aligned}$$

Where

- $\sigma_{X,Start}(\tau)$ and $\sigma_{X,Ret}(\tau)$ are the contribution of the ground photo detection for the start and return date,
- $\sigma_{X,Cal}(\tau)$ is the contribution of the calibration of the ground station,
- $\sigma_{X,Tim}(\tau)$ is the contribution of the ground timer (for both the start and return dates),
- $\sigma_{X,T2L2}(\tau)$ is the contribution of the on-board instrument, limited to its photo detection unit (contribution of the timer is negligible), which depends on the number of photons that are received,
- $\sigma_{X,Geom}(\tau)$ is the contribution of the on-board geometry versus the attitude of the space vehicle (reference points for the ranging and for the timing are not at the same place)
- $\sigma_{X,Rel}(\tau)$ is the contribution of the residuals of the relativity corrections
- and $\sigma_{X,Atm}(\tau)$ is the contribution of the propagation in the atmosphere

The expected performance budget is given in Table 1 [5]. We can seen on Figure 2 that the requirement should be met for integration time from 30s, where the expected time stability of the ground to space time transfer crosses the measured time stability of the USO.

	T-Var
Start Date	$1.6\times10^{-12}\times\tau^{-1/2} + 3.0\times10^{-15}\times\tau^{+1/2}$
Return Date	$4.7\times10^{-11}\times\tau^{-1/2} + 2.8\times10^{-14}\times\tau^{+1/2}$
Calibration	Negligible
Ground Timer	$1.6\times10^{-12}\times\tau^{-1/2} + 1.0\times10^{-15}\times\tau^{+1/2}$
T2L2 instrument	
Single photon	$1.1\times10^{-11}\times\tau^{-1/2} + 1.9\times10^{-14}\times\tau^{+1/2}$
Multi photon	$3.0\times10^{-12}\times\tau^{-1/2} + 6.0\times10^{-15}\times\tau^{+1/2}$
Geometry	Negligible
Relativity	Negligible
Atmosphere	$2.0\times10^{-11}\times\tau^{-1/2}$
Ground to Space Time Transfer	
Single photon	$3.3\times10^{-11}\times\tau^{-1/2} + 2.4\times10^{-14}\times\tau^{+1/2}$
Multi photon	$3.1\times10^{-11}\times\tau^{-1/2} + 1.5\times10^{-14}\times\tau^{+1/2}$

Table 1 : T2L2 Performance Budget : Time Stability [5].

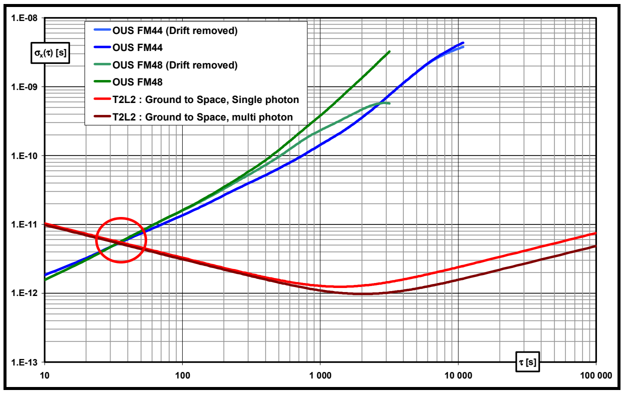

Figure 2: DORIS USO time stability (From ground measurement) and T2L2 expected time stability.

III. Experimental Setup

The first goal is to demonstrate locally the capability of T2L2, through a ground to space time transfer, to rebuild the USO frequency and to quantify the performance of this time transfer. A continuous restitution of the USO frequency a along the orbit, that will involved a complete network of Satellite Ranging Station (SLR) stations, will be considered only in a second time.

The evaluation of the performance will be done through :

- The time stability of the time transfer,
- The direct comparison of "T2L2" USO frequency with the DORIS solution

In order to reduce all the uncertainties, and among them the contribution of both the ground clocks and the connection of DORIS time and T2L2 time, it has been decided to perform a time transfer with a DORIS beacon and a SLR station synchronized by the same clock. To do that, a DORIS beacon has been installed in October 2008 at the Observatoire de la Côte d'Azur, near the MeO laser station (Figure 3). For the first tests, the ground clock will be a cesium clock (HP5071). Next test shall be performed with an hydrogen maser.

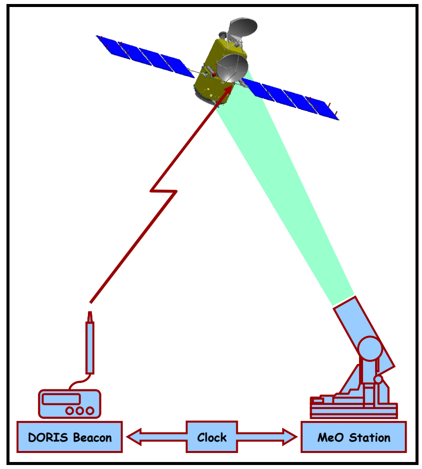

Figure 3: Experimental setup : SLR station and DORIS beacon are synchronized by the same clock.

IV. From Raw Data to First Results

Unlike systems such as GPS where the user can directly access the difference between its local time and GPS time, T2L2 data have to go through a complex process (i) to convey and to merge SLR data, (ii) to correlate SLR and T2L2 data, and (iii) to perform the outputs in terms of Time Transfer, comparisons with the DORIS data, etc. Dedicated software and procedures are under development at the Scientific Mission Centre (CMS, Observatoire de la Côte d'Azur) to be able to produce the different T2L2 products :

- Level I : the data reading and merging, and the correlation between SLR and instrument data leading to the identification of on-board events (Which on-board event corresponds to which SLR event);
- Level II : the computation of needed corrections and theoretical quantities, from the set of SLR station coordinates (given by ITRF2005), the Jason-2 orbit (computed by the Jason-2 project), the attitude parameters of the spacecraft, and the models for atmospheric and relativistic effects (notably, [6]). At this step, data gradually go from raw measurements to measures corrected from the orbit and then to phase difference residuals between ground and space clocks after adjustment and removal of a second order polynomial (Figure 4) [7] ;
- Level III : the estimation of Time Transfers from ground to space and ground to ground, the offsets of the DORIS-USO frequency, etc.

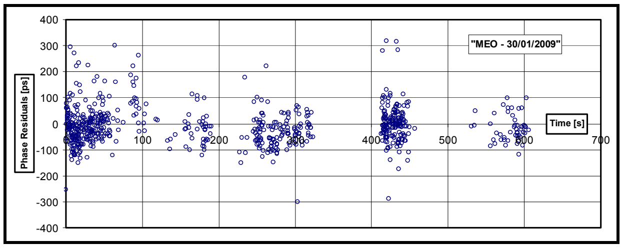

Figure 4: Phase data residuals (orbit and quadratic drift removed) for a pass above MeO SLR station (30/01/2009)

In order to validate the whole process and to have a first evaluation of the performance of the time transfer, 3 passes from the last days of January 2009 over Wettzell (Germany) and Grasse (France) SLR stations have been analyzed. Ground clocks are an hydrogen maser at Wettzell and a cesium clock at Grasse.

For both SLR station, phase residual exhibit a short term noise lower than 100 ps RMS (Figure 4). The computation of the time variances from this data is given Figure 5. These first results fit pretty well with our preliminary budget. With a stability of few picoseconds for integration times of some tens of second, these variances demonstrate the T2L2 capability to “read” the DORIS USO, with a resolution better than 10^{-12}. We also see there the contribution on the ground clocks, the cesium clocks clearly limits the performances of the transfer from Grasse SLR which is not the case with the maser at Wettzell.

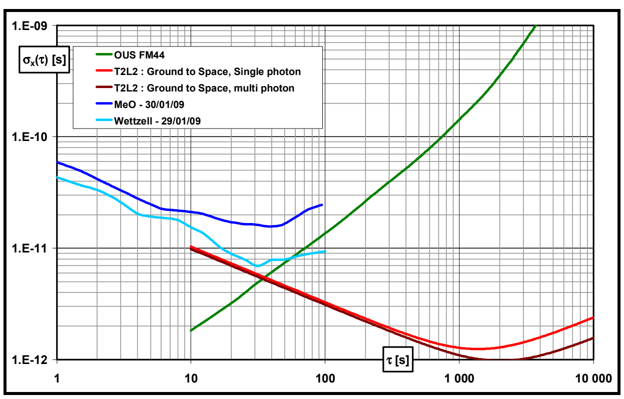

Figure 5: Time variance of the first T2L2 ground to space time transfer.

V. Conclusions

Even if the way towards the first complete restitution of the USO frequency and its comparison with DORIS results is not completely covered at this time, only a few passes in common clocks configuration have been acquired yet and are still not processed, the first results are very promising. They demonstrate for a ground to space time transfer an exceptional short term stability of some picoseconds. They also demonstrate our capability to read the DORIS USO with a resolution better than 10^{-12}.

An intensive measurement campaign has just started yet to confirm these first results. Data analysis is under going. In a second step, the possibility to take into account this data inside the DORIS system will be analyzed. Further, a complete restitution of the USO frequency, all along the orbit, is also envisaged.

Acknowledgements

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