T2L2 /J2: how to distribute the data

Topic : C. Instrument Processing (ID 49)

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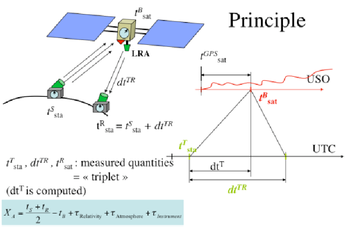
ABSTRACT

The T2L2 (Time Transfer by Laser Link) experiment has been developed by CNES and OCA, and placed onboard J2. The principle is derived from the laser telemetry technology with a dedicated space equipment deigned to record arrival time of laser pulses at th e satellite. Fisrt analysis permitted to validate some important characteristics of the instrument such as sensitivity, noises, dynamic, event timer precision and ground to space time stability. See: *Exertier et al., Adv. Space Res. « DORIS Special Issue », 2010*. The stability of the ground to space time transfer has been established to less than 10ps (around 6ps) over 30 sec. of time, depending of the quality of the ground clock.

Between 2009 and 2010, we realized a dedicated experiment in order to measure the precision and the exactness of a time transfer between two SLR (Satellite Laser Ranging) systems; we used the French Transportable Laser Ranging System on the one hand, and the MeO-7845 Grasse fixed station on the over hand. Both systems, located at Grasse observatory, used the same ground clock. The stability of the ground to ground time transfer via the space equipement has been established to 70 ps over several J2 passes (from April, 27 to May, 15 2010). The excactness has been estimated by comparing the computed offset (mean value of 157 ns) and its *in situ* measurement by an electronic kit : the « distance » between both SLR systems. The difference between both methods i s of 45 ps.

From this point of view, *in situ* calibration campaigns are needed to ensure exactness on each SLR site (to calibrate the « distance » between the System Ref. Point of the station and the reference of the PPS of the used clock). In addition, T2L2/J2 should permit to compare all the ground clocks of the participating SLR stations; but it is necessary to define a common time scale which should be as close as possible of the UTC time scale. Now, the question is to find keys to properly distribute the T2L2 dat a (the so-called triplets) for that particular goal.
We decided to define several steps : i) making calibration campaigns with a dedicated electronic kit (Grasse, Paris, and Wettzell have been calibrated already), ii) using the SLR data files in the CRD format to re-introduce the T2L2 triplets (essentially onboard dates and measured energy in microJoule /m**2, including all the instrumental corrections), iii) reducing the ground to space time transfers to each available second of onboard time and editing the corresponding ground dates in a same data base; i v) computing a synthetic time scale (on-board) to garantee a few ns of stability from a J2 orbit to another, v) comparing the results to UTC, via GPS when available. The purpose of this poster is to adress to the community some results about time transfer ing between SLR stations, and to give some informations about how the data/results will be distributed.



$$X_A = \frac{t_S + t_R}{2} - t_B + \tau_{Relativity} + \tau_{Atmosphere} + \tau_{Instrument}$$

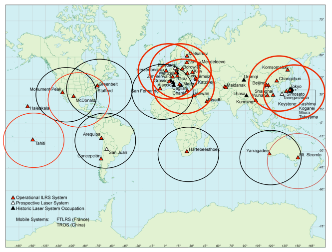
T2L2 is a two way time transfer technique based on the timing of optical pulses emitted by an SLR (Satellite Laser Ranging) station and detected by a dedicated space instrument [1], [2]. T2L2 was accepted as a passenger instrument on the Altimetry Jason-2 satellite in 2005 [3].

The space instrument is based on a photo detector and an event timer 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 CNES & JPL agencies, basically as orbit determination system in addition to the GPS and DORIS orbitography space techniques [4]. The space clock is an ultra-stable oscillator (USO, Quartz) coming from the DORIS (Doppler Orbitography and Radio-positioning Integrated on Satellite) equipment. The ground segment of the experiment is a laser station able to time both start and return times with a resolution of 1 ps. The laser stations track the satellite as soon as it is in the right field of view (at a distance of less than 5000 Km) during the whole duration of the pass (maximum duration of about 1000 s).

Basically, T2L2 realizes a ground to space time transfer 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.

« Triplets »

For a given laser pulse emitted by the laser station one get two dates (start & return) at ground and one date at the satellite, thus forming a set of 3 dates called a "triplet". From a triplet, we can extract the time delay between the ground clock and the space clock, whereas a serie of triplets permit to estimate the stability of the ground to space time transfer.
For a given SLR pass, and taking into account the lost of energy during the light travel to the satellite, the T2L2 instrument is acquiring less data than the number of transmitted laser pulses. See the number of triplets in red.



47 SLR stations form the ILRS network; 34 fired on Jason2, and 22 stations are regularly sending Full Rate (FR) data for T2L2 (in red, SLR stations usind the CRD format).

Ground SLR full rate data

For the T2L2 mission, SLR stations are providing the Full Rate ranging data (via the European Data Center based in Muenchen, Germany and the CDDIS, US); some of the SLR stations have deployed a H-Maser clock as time device, notably Changchun (China), Hersmonceux (UK), Matera (I), Koganei (J), Wettzell (G), FTLRS (Paris, Grasse, and Tahiti in 2011), and Grasse-7845 (F).

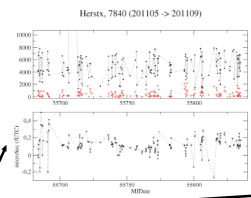
The precision of the start dates is of 5-15 ps, whereas the precision of the time travels of the light (the ranges) is of 25-35 ps for the best SLR systems [4]. In addition, the ground time stability over a satellite pass (arround 1000 seconds) should be at the picosecond level (possible when using a H-maser).

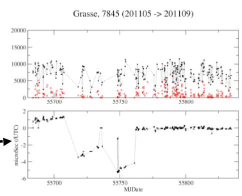
SLR stations which are poviding the FR ranging data on Jason2 are able to observe betweeen 10 and 80 passes per month, each. In average, each pass is of 600-700 second duration and provides arround 1000-2000 ranges; much of SLR systems are using a 10Hz acquisition mode, but some have a 100Hz or a KiloHz mode. See right the number of FR data per pass (in black), for SLR 7840 between May ans September 2011.

On-board data

Since the begining of the mission, T2L2 is acquiring roughly 150,000 to 250,000 dates of pulse per day, consisting in solar noise events, laser pulses, and GPS PPS. CNES is providing us 1-day files of on-board dates with a time delay of 1-2 days.

A first data treatment has to be processed before all. It consists to use the PPS provided by the on-board GPS antena, which PPS are dated by T2L2, in order to compute for each acquired event its aproximated UTC date. That permits to permanently establish a phase link between the UTC and DORIS time scales (at around 0.5 μsec: see right figures for Hx and Grasse, showing one phase link per pass during 5 months, from May to Sept. 2011) on the one hand, and to estimate a local frequency biais *Δf* (at around 10^{-11} Hz) on the other hand.

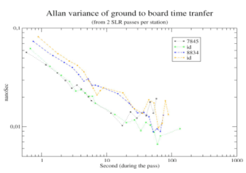




The Grasse station is using a H-maser for that period of time; its trend is of around 3.10^{-15} Hz per day

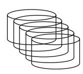
Above : estimated phase link between the Hx and Grasse ground clocks and the approximate on-board UTC, at ±0.5μsec : history for 5 months, one average value per pass.

OVER 1 PASS : the stability of a ground to space time transfer (H-Maser clock on ground) reach 6 ps @ 30-60 sec.

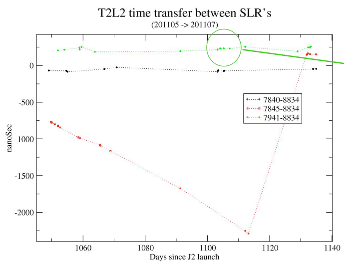


Above : diffrences between the Wettzell and Grasse SLR clocks.

A CRD data file for each SLR pass is edited after finding the triplets, eliminating noises, and computing instrumental corrections.
Records contain the « triplets »: SLR dates and FR ranges, corrected on-board dates and measured energy (μJoule /m**2), filtered 1-way transmit time from ground SLR to T2L2 detector (not the LRA).

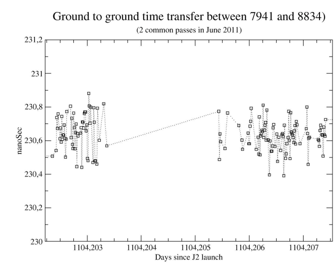


CDDIS and EDC

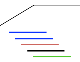


Above : averaged values, per common SLR pass (from 3 couples of SLR stations in Europe), of 1-Second differences between ground clocks via T2L2, over 3 months from May to July, 2011.

OVER several PASSes (between May and July 2011): the stability of a ground to ground time transfer (see left, the 3 examples) strongly depends on what happend on the ground; for the Grasse SLR station (in red, compared to Wettzell SLR) the H-maser being free (with a trend of 3.10^{-15} Hz /day) the slope is important; then, by modifying its phase, the difference goes from > -2 μsec to 0.2μsec.



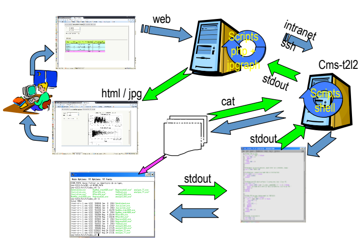
The Ground to ground Time transfer data file



One RECORD every Second (on-board time), whatever the SLR station triplet (a: blue, b: red, c:black, d: green, etc.)

OVER 1 PASS, differences between Matera and Wettzell ground clocks, at common Seconds (June 2011) : the *rms* of this time transfer between both SLR stations is of a 90 ps over 140 values, whereas the stability is reaching 50ps @ 60 sec.

T2L2 on the web : https://t2l2.oca.eu/



CONCLUSION

From each ground to space time transfer (each SLR pass on J2 providing enough triplets on-board), it is proposed to extract a set of 1-Second differences between the on-board time and the ground time. A data file containing all the 1-Second events is proposed to users, per SLR station and per pass; from these data, the resulting estimation of the time transfer between 2 SLR gives a row rms of 90ps, reaching 50ps @ 60sec.

Ground to ground time transfers are thus directly available by searching, in that file, SLR passes sharing the same 1-Second of time. If this kind of information is very well suited for J2 common passes (particularly in Europe), it is necessary to develop a synthetic time scale in order to properly transfer time between non common passes (US-Europe, Europe-Asie, etc.). In fact, the 1-Second events are based on the on-board time scale, and the stability of the Doris USO over 2000 sec. and more cannot ensure time transfer without increasing the uncertainty at a level of several nanosec. and more.

In addition, each SLR ground station should be calibrated to estimate the permanent biais thatt exists between the SLR system and the local reference PPS (which biais can reach 100ns or more). Actually, we propose to make such *in situ* campaigns by using a dedicated electronic kit (the Wettzell SLR station has been calibrated this summer). Finally, it is also necessary to properly connect the *in situ* equipment to the GPS-UTC time scale.

REFERENCES

1.Samain, E. et al., *International Journal of Modern Physics D*, **17** (7), 1043-1054, 2008
2.Exertier, P. et al., Status of T2L2, *Adv. Space Res. - Doris Special Issue », 2010*