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Time transfer by laser link - T2L2: Microwave link comparison

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Abstract. T2L2 (Time Transfer by Laser Link), developed by both CNES and OCA permits the synchronization of remote ultra stable clocks over intercontinental distances. The principle is derived from laser telemetry technology with dedicated space equipment designed to record arrival times of laser pulses at the satellite. T2L2 allows to realize some links between distant clocks with time stability of a few picoseconds and accuracy better than 100 ps.

Several campaigns were done to demonstrate both the ultimate time accuracy and time stability capabilities. Here we describe the recent campaign done to accurately compare T2L2 with microwave time transfer GPS. These comparisons are based on a global calibration of both laser stations and GNSS equipment between Herstmonceux, Observatoire de Paris, OCA and Wettzell. This paper also focuses on the last metrologies developed at OCA for accuracy and time stability.

Introduction

T2L2 is a time transfer technique based on laser ranging network at ground and a dedicated space segment. The project was launched in 2008 on the Jason-2 satellite for a 2 years mission, mission that has been extended until end of 2014 [i], [ii], [iii]. T2L2 permits the synchronization of remote ultra stable clocks over intercontinental distances and also the synchronization of the time reference onboard the satellite as compared to the ground. T2L2 principle is issued from classical laser telemetry techniques, with a specific instrumentation implemented onboard the satellite capable to time tag laser pulses.

T2L2 relies on the propagation of laser pulses that permit to enhance the performance of time transfer by one or two order of magnitudes as compared to existing microwave techniques such as GPS and Two-Way Satellite Time and Frequency Transfer (TWSTFT).

It provides the capability to compare today's most stable frequency standards with unprecedented stability and accuracy [iv],[v]. Ultimate expected T2L2 performances are in the 100 ps range for accuracy, with a time stability of about 1 ps over 1,000 s and 10 ps over one day [vi].

The project is fully operational since 2008. Since that date T2L2 records continuously laser events coming from the whole laser station network. About 45,000 laser passes involving between 20 and 25 laser stations and 60,000,000 laser events have been detected since the beginning of the mission,

Several scientific objectives are simultaneously purchased through regular observations and also through some dedicated campaigns lead with 2, 3 or 4 stations:

- Ground to ground and Ground to Space time transfer

- Laser station synchronization
- Microwave link - T2L2 time transfer comparisons
- Fundamental physics
- One way laser ranging
- Link budget
- Jason 2 (DORIS and one way laser ranging)

The years 2012-2013 were especially devoted to T2L2 accuracy, T2L2 long term time stability, GPS-T2L2 comparison and fundamental physics.

T2L2 Accuracy

T2L2 ground to ground time transfer accuracy depends on various factors:

- Internal calibration of the laser station; determination of the absolute time delay from the station to the corner cube as compared to the cross axes of the laser station
- T2L2 laser station calibration; determination of the absolute timing of laser pulses as compared to the PPS reference
- Time tagging of laser pulse in the satellite time reference; determination of the time offset introduced by the pulse width difference between laser stations
- Optical geometry; determination of the time offset introduced by the geometry of both Jason 2 corner cube and T2L2 photo detection module.

Laser station calibration is a crucial process for T2L2 accuracy. OCA designed dedicated calibration mobile equipment in order to perform this calibration. This equipment consists in a sub picosecond SigmaTime event timer STX301 [vii], a high speed (25 GHz) photo detector and a single mode optical fiber linked to an optical module. All the time delay determinations listed above depend on the laser pulse width of every laser station. Up to now, the pulse width was determined through a dedicated process using the high speed photo detection triggered alternatively from positive to negative slope. This process is perfectly well suited to our needs but requires good laser energy stability. Some pulse widths in the range of 20 ps were measured through this process. When the energy stability is not high enough, the measure can be biased by a significant factor. In this case a single photon measurement could be preferred. The pulse width is determined from acquisitions made with a dual channel event timer triggered by a multi photo detector and stopped by a single photon detector. The final issue is to calibrate the single photon detector with an experimental setup including the 25 GHz high speed detector and a very stable laser. This calibration would permit to directly use the single photon detector as an absolute detection device permitting to measure simultaneously pulse width and absolute time delay.

The single photo detection module has been designed with a 200 µm a single photon avalanche photo-diode [viii] integrated on a dedicated electronic card for thermal stabilization and Geiger signal generation and a special mechanical module to link the photodiode with a mono mode optical fiber. This instrumentation (STH114) is housed in a 2U-19 inches rack. Figure 1 is a time distribution of the single photon detection module measured with a 30 ps FWHM laser and a SigmaTime STX301 event timer.

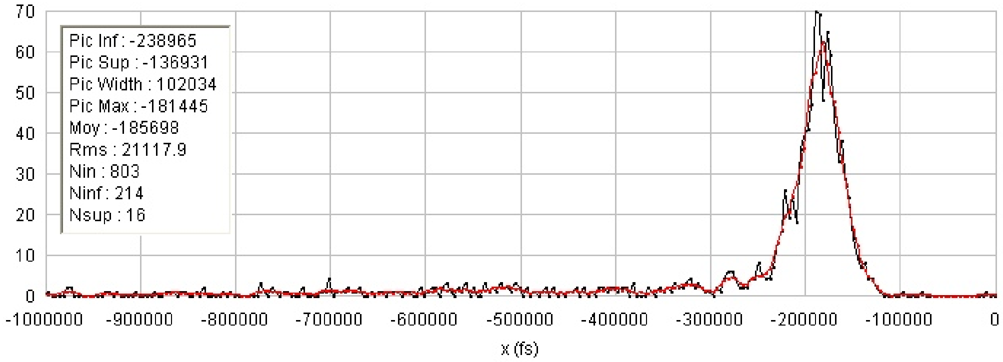

Figure 1. Time distribution of the STH114 single photon detection module measured with a 30 ps FWHM laser. The repeatability error is 21 ps rms.

T2L2 long term time stability: Ultra stable time distribution

Getting a time transfer at the picosecond level requires an ultra stable time distribution between the reference clock and the laser stations. If one considers a typical distance between stations and clock reference of 100 m, a thermal sensitivity of the cable used to propagate the time reference of 100 fs/m °C and a long term thermal variation in the range 20°, the total delay variation can reach 200 ps which is far away to T2L2 picosecond objective.
To solve this difficulty, OCA and Phusipus Integration designed an ultra stable time signal generator SigmaTime STS201 [ix]including an event timer able to monitor the absolute time delay variation in the propagation of the signals (Figure.1). This monitoring is made through a double propagation of the signal emitted by the distributor and repeated by the final user (laser station event timer).

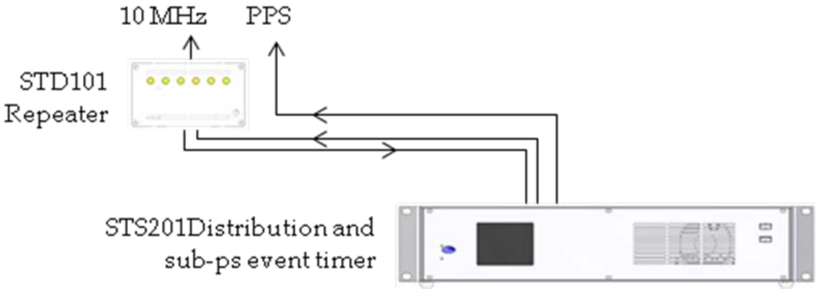

Figure 1. Temporal distribution scheme. The ultra stable time signal generator SigmaTime STS201 includes a programmable generator and a sub-picosecond event timer able to measure the time propagation of the signals. STD101 repeats the incoming 10 MHz signal.

The repeatability error of the instrument is better than 1 ps rms for the PPS distribution and better than 800 fs rms for the time delay measurement made by the event timer.

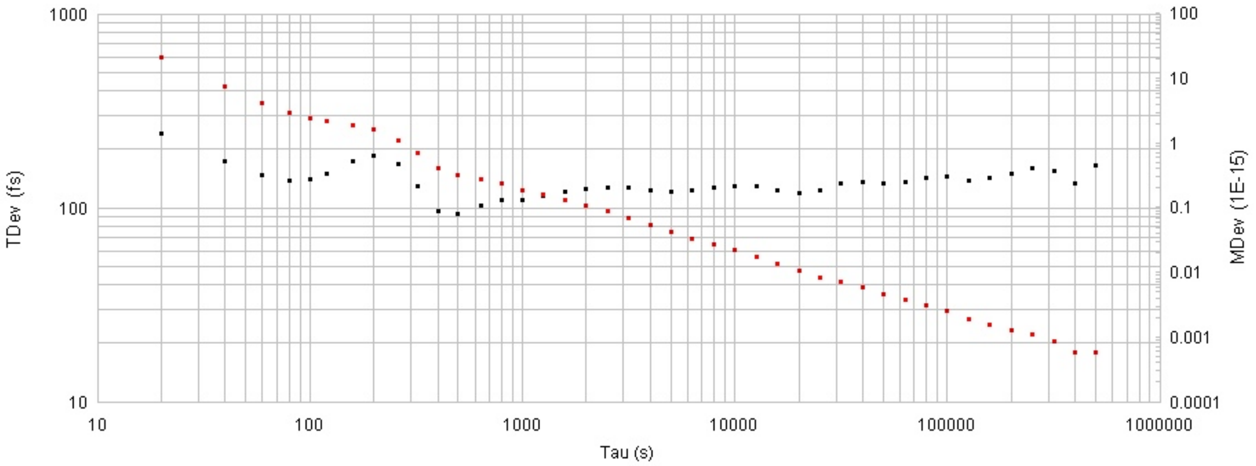

Figure 2. Time deviation (Tdev) of the STS201 instrument through a 50 cm propagation. Black: Tdev ; Red: Mdev. Temporal stability better than 10^{-18} is obtained over 5 days. The global drift is 1 ps over 10 days. The 200 fs peak observed @ 200 s is due to air-conditioner of the laboratory that introduces thermal periodic variation of 2 degrees.

In some real conditions, the repeatability error measured for a 70 m distribution is better than 1.5 ps rms.

A dedicated collocation campaign was done in January 2013 at OCA between FTLRS and Meo stations. Both stations were equipped with the time distribution scheme presented in figure 1. Figure 3 is the time stability (TDev) of the T2L2 time transfer calculated between MeO and FTLRS during that campaign.

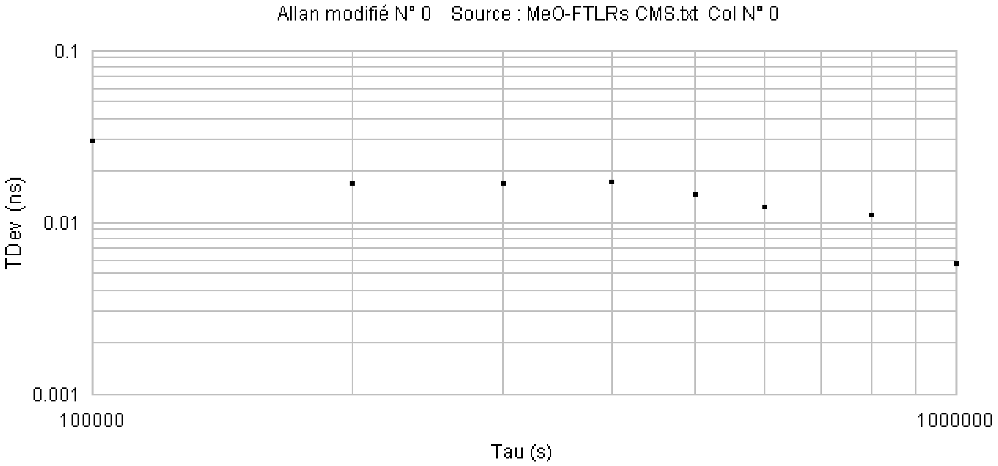

Figure 3. T2L2 Time stability (TDev) measured between Meo and FTLRS in a collocation (< 100 m) configuration.

GPS-T2L2 Comparison

A GPS-T2L2 time transfer comparison campaign was done in September - October 2013 between:

- GRSM 7845 OCA Grasse France
- FTLRS 7828 OP Paris France
- HERL 7840 NERC Herstmonceux United Kingdom
- WETL 8834 BKG Wettzell Germany

The final objective of that campaign is twofold:

- Perform a sub nanosecond comparison between T2L2 and GPS techniques.
- Perform an ultra stable T2L2 time transfer between distant H-Masers.

Each laser station includes an H-maser, a GPS receiver, a PPS generator and some frequency and PPS distributors. The H-maser is first connected to a frequency distribution linked to the SLR event timer, the GPS receiver and the PPS generator (figure 4). FTLRS and MeO stations are equipped with the SigmaTime STS201 generator to distribute PPS and 10 MHz signals from the time and frequency laboratory to the laser station. The monitoring of that distribution is performed continuously during the whole campaign.

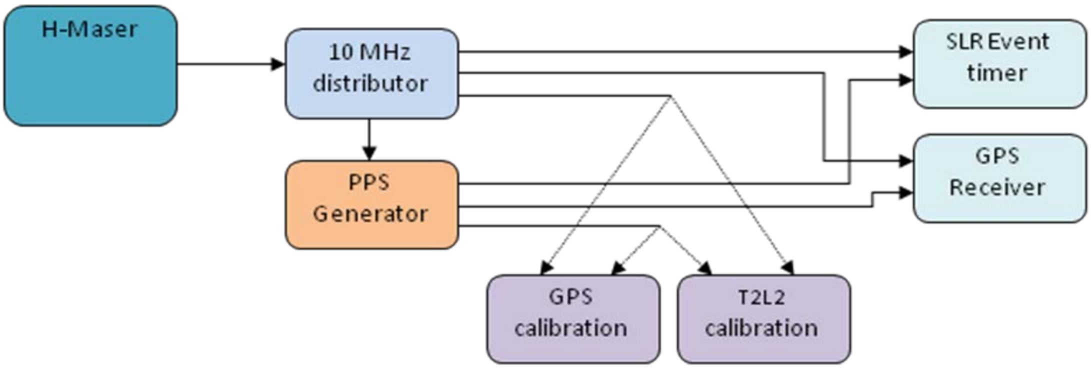

Figure 4. GPS-SLR simplified scheme for Meo FTLRS and Hersmonceux stations. GPS calibration equipment and T2L2 calibration equipment are connected (alternatively) on the same distributor outputs.

We realized for each station (except Wettzell yet) a joined calibration of both laser station and GPS receiver. The laser station calibration was done with the T2L2 calibration system and the single photon detector STH114 previously described. The GPS calibration was done with dedicated mobile equipment including 2 GPS receivers.

The campaign started on mid September and stopped by the end of October. Table 1 gives passes acquires for each laser station and the triplet numbers. A triplet is an elementary time transfer data with start and return times at the laser station and time onboard the satellite. Table 2 gives some information concerning ground to ground observation. Figure 5 illustrates the time offset between H-Maser of each station as compared to the OCA H-Maser for the whole duration of the campaign.

Table 1. Jason 2 passes obtained during the campaign (September-October 2013)

Station	Pass number	Triplet number
OCA	211	506381
OP	40	3998
Herstmonceux	51	21471
Wettzell	74	16280

Table 2. Ground to ground time transfer

	Common passes	Total common duration (s)	Period
OCA - Herstmonceux	28	5888	03/09 – 30/10
OCA- Wettzell	26	4614	04/09 – 18/10
OCA - FTLRS	13	2280	20/09 – 30/10

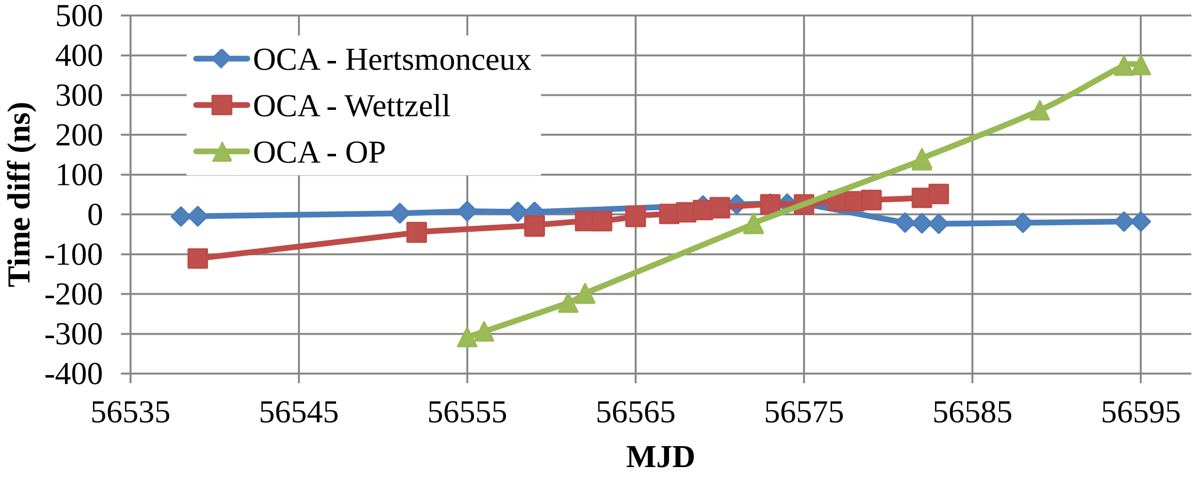

Figure 5. Time offset between OCA Hertsmonceux Wettzell and OP. An arbitrary offset has been substract to each H-Maser difference. The different slopes between the curves are coming from a real frequency offset between the H-Masers of each laboratory.

GPS time transfers are being analyzed.

Conclusions - Perspectives

Last metrology developments done at OCA for time distribution and calibration permit to significantly improve the global T2L2 time transfert. The T2L2 – GPS comparison is currently being analyzed .

Several important developments are envisioned in the next T2L2 schedule:

- Ground to ground time transfer in a non common view configuration.
- European TWSTFT calibration campaign in order to compare simultanuously T2L2 GPS and TWSTFT
- One-way and two-way link budget analysis using the onboard energy measurement.
- LRO (moon) 3D positionnement with T2L2.

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