

Time transfer accuracy

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Introduction

- T2L2 has proven that SLR stations can be used to compare distant clocks with an unprecedented time accuracy¹.
- We define accurate time transfer, or comparison, the measurement at a given instant of the time difference between two different time scales as it can be performed by an accurate Time Interval Counter (TIC).

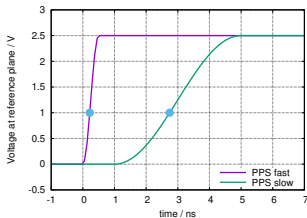
¹Exertier et al: *Metrologia* 53.6 2016.

- It has to be noticed that when comparing the frequency of distant clocks only the stability of the elements of the link is important. But when we deal with Time the delay of all the elements of the chain must be known by individual measurement or global calibration.
- A recently published paper² present some example of the uncertainty budget of delay measurement performed by commercially available TIC.

²Rovera et al: *Metrologia* 56 2019.

Time scale signals definition

- Usually the time marker TM of a 1PPS signal of a time scale is defined as the instant when the rising edge of the pulsed electrical signal crosses a voltage threshold level, at a well defined reference plane, and when properly terminated.
- Unfortunately not all the 1PPS signal are identical and the response of the measuring system to different 1PPS shape has to be taken into account.



Typical examples of 1PPS signal encountered in laboratory equipment.

Time measurements in a Laser Ranging Station

- In “Classical” laser ranging it is necessary to achieve accuracy at ps level (10 ps 1.5 mm) on the time of flight of laser pulses. This can be reached by a global calibration by performing ranging on a target on a known distance, and there is no need to measure individually the delay of all the elements of the chain.
- When a station is used for time transfer, as for T2L2 experiment, it is necessary to accurately measure the time of start of each individual laser pulse against the local time scale, also at ps level.
- I believe that it is not a easy task because the delay of all the element connecting two different worlds (electric pulses and photons) has to be measured. Hopefully in T2L2 experiment all the involved stations have been calibrated by the same equipment and an eventual bias in the calibration equipment is canceled.

Assessing the accuracy of time transfer

- It is easy to build an accurate time transfer system, or other metrology equipment, if you build only one.
- Real problems starts when you build a second one and you try to compare with the first.
- At the end your system will be fully validated when it is compared by a different system and you obtain consistent results.

Validation of T2L2 accuracy

- During the lifetime of the T2L2 experiment we had no opportunity to compare the T2L2 time transfer performances with another system with an equivalent or better accuracy.
- To assess the uncertainty of the time transfer by T2L2 the space segment has been fully characterized³. A subsequent paper reports a full uncertainty budget of the ground to ground time transfer⁴. This paper demonstrates an expanded uncertainty below 140 ps ($k = 2$).
- The validation of T2L2 in real operating conditions has been validated by comparison with GPS Common View time transfer. This technique is less accurate than T2L2 but is the only one that can be deployed in a SLR station.

³ Samain et al: *Metrologia* 51.5 2014.

⁴ Samain et al: *Metrologia* 52.2 2015.

Comparison Campaigns

A first comparison campaign has been carried out from July 27 to November 4, 2013, between 3 European Stations. During the comparison period all the GPS stations have operated almost without interruption. By using the adequate calibration factor, the time difference between the time scales of the three involved link has been computed for all the period by using the GPS Common view technique⁵.

A second comparison campaign has been carried out between 2 European and 2 Chinese Stations from August 2016 to January, 2017. Due to a problem in the local timescale we were not able to obtain useful GPS data from Shanghai station, and we only present results involving the two European stations and Changchun. The time difference between the time scales of the three involved links has been computed by using the GPS-CV and GPS-PPP for the transcontinental links.

⁵Rovera et al: *Metrologia* 51.5 2014.

Link Herstmonceux-OCA 2013

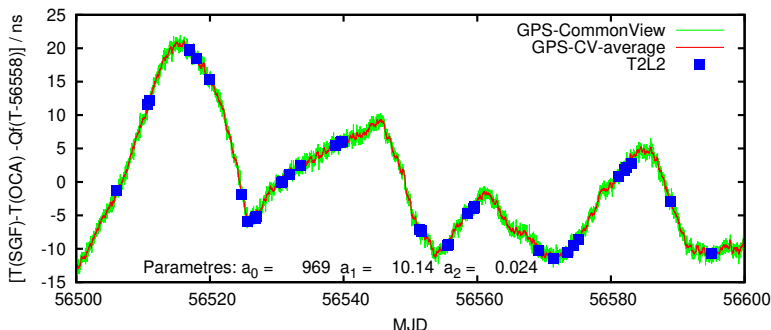


Figure: Time difference between reference points in Herstmonceux and OCA with a quadratic fit removed: green line GPS-Common view, red line GPS-CV filtered by a moving averaged over 13 samples, blue square T2L2.

Link Herstmonceux-OCA 2013

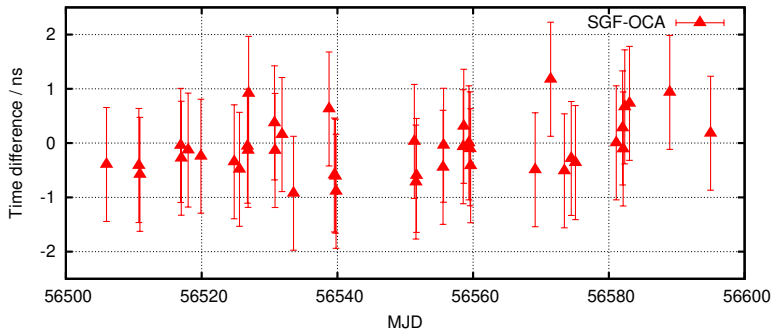


Figure: Difference between time comparisons made by GPS-CV and T2L2, the error bars represent the combined uncertainty.

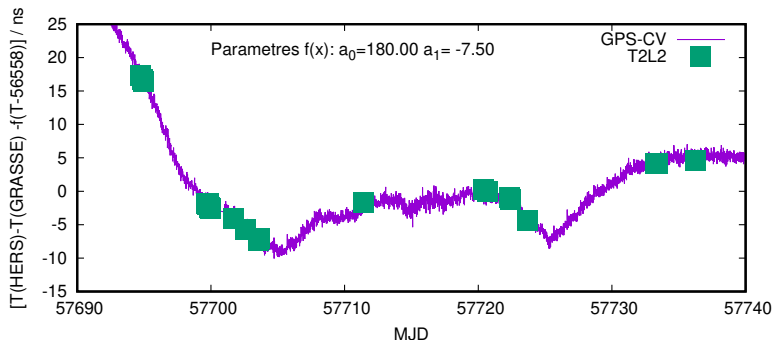
Results summary 2013

Table: Time differences between GPS CV and T2L2

Link	Number of points	Average ns	Standard Deviation / ns	
			GPS CV	GPS filtered
SGF-OCA	42	0.09	0.49	0.37
OP-OCA	12	0.24	0.48	0.25
SGF-OP	5	0.10	0.32	0.32

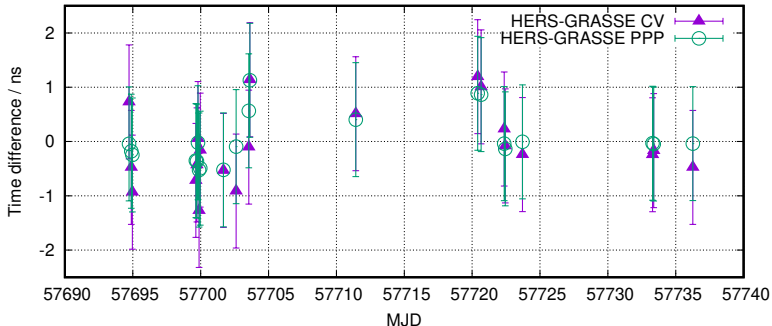
Link Herstmonceux-OCA 2016

Figure: Time difference between reference points in Herstmonceux and OCA with a linear fit removed: violet line GPS-Common view, green squares T2L2.



Link Herstmonceux-OCA 2016

Figure: Difference between time comparisons made by GPS-CV and T2L2, the error bars represent the combined uncertainty.



Results summary

Table: Time differences between T2L2 and GPS

Link	Number of points	Average ns	Standard Deviation ns
Herstmonceaux-Grasse CV	12	0.089	0.668
Changchun-Grasse CV	5	1.148	0.933
Changchun-Grasse PPP	5	0.128	0.650

Conclusion

- Laser Rangnig Stations, can be used for accurate time transfer over continental and intercontinental distances.
- Unfortunately Jason 2 is no longer in operation and there is no known satellite equipped with an instrument similar to T2L2.
- There are some rumors about a Glonass satellite equipped with a similar instrument but no clear information about it.
- All the laboratories involved in ACES project are waiting the operation of ELT link to compare ground operating atomic clocks with the PHARAO atomic clock operating onboard of ISS.
- The CCTF working group on Advanced Time and Frequency Transfer (ATFT) is currently preparing a resolution to invite the operators of GNSS to install an event timer capable of time-tag incoming laser pulses onboard of new generation of GNSS.

THANK YOU

