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# Local ties control in application of laser time transfer

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**Abstract.** *In many fundamental physical experiments time plays an important role. The standard way for the comparison of time and frequency is the application of GNSS signals and the Two-Way Satellite Time and Frequency Transfer - TWSTFT. Recently, there is a rapid increase of the optical time comparison development, which uses the Satellite Laser Ranging network (SLR). Currently the French project T2L2 operating on board Jason 2 and the LTT project on board of Compass GNSS are operational. European Space Agency project ELT in support of the Atomic Clock Ensemble in Space (ACES) is under development. The main aim of these projects is the time synchronization with a precision below 40 ps rms and an absolute error well below 100 ps. A lot of effort went into the development of a symmetric two-way measurement technique to identify unaccounted system delays between the WLRS and the master clock of the Geodetic Observatory Wettzell. The paper discusses the obtained results and proposes how to deal with the timing system and calibration in applications of the optical time transfers.*

## Introduction

The precise and accurate time transfer is a prerequisite of a number of experiments in fundamental physics, Earth science, global navigation and many other disciplines. One of the most challenging disciplines is the time transfer ground to space. The standard techniques used recently are based on radio frequencies. They do provide nanosecond accuracies Defraigne2008. A significant improvement in time transfer accuracy between ground and space is expected to be achieved by using optical frequencies Pearlman2002. The contributors of systematic error to the overall error budget in the optical domain may be reduced to the level of 10 picoseconds.

The laser time transfer (LTT) ground to satellite is an extension of the standard measurement technique of the satellite laser ranging (SLR). A ground SLR station fires laser pulses toward the satellite and records the local times of the laser firings. On board of a satellite the laser pulses are detected and time tagged to the satellite time scale. At the same time the laser pulses are reflected by a system of a retro-reflectors back toward the ground station, which, again, detects the return pulses and time tags them to the ground time scale. The recorded data on board of the satellite is then sent to the ground using a standard telemetry channel.

Combining the laser firing times, propagation and instrumental delays and satellite arrival times, the space and the station clocks may be compared.

Doing the time transfer using SLR technique requires deep understanding of the individual timing systems of each site. First of all it is important determine from which reference point the optical time transfer is performed. In case of optical time transfer actually the time transfer is realized between the satellite time scale and the time scale which is realized inside the event timer. It

requires a very good synchronization of the event timing system relative to the local time scales, which we want to compare.

The simplified diagram of the Wettzell Observatory timing system is shown in Figure 1. It consists of four buildings separated by several tens of meaters in distance. We are operating several Cesium atomic standards, where HP1732 is considered as the master clock establishing UTC(IFAG). In addition we are operating several H-Masers which are used for Very Long Baseline Interferometry (VLBI) measurements as well as SLR observations. In each observation point the local time scale is generated out of distributed frequency sources. From a distribution of the generated 1pps signals, 1pps is sent back to the Master Clock (MC) room where the localy generated time scales are compared to the Master Clock time scale (UTC(IFAG)) every 3 hours. For measuring these time delays between the time scales the time interval counter SR620 is used measuring the delays with a resolution of 1 ns.
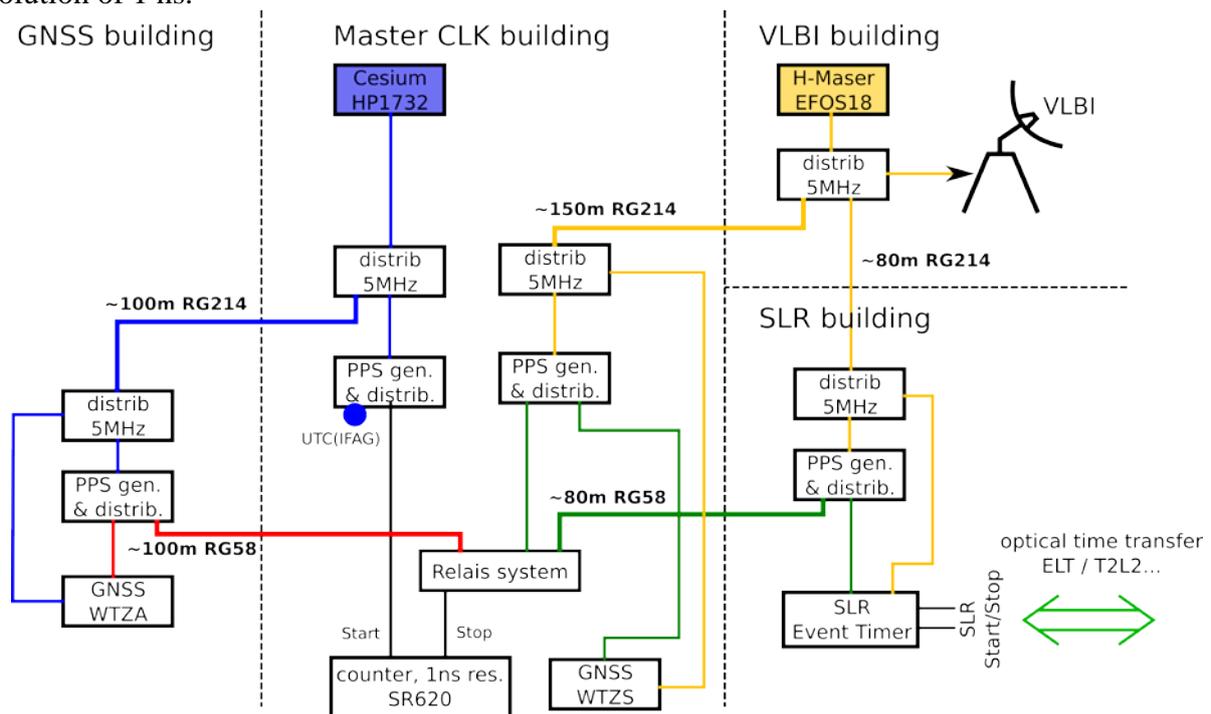


**Figure 1.** The simplified block diagram of the timing sytem in Wettzell Observatory. There are several atomic clocks distributing frequency between different building, where the geodetic observation techniques are located. The time scales are generated in

For the optical time transfer between ground and space measuring biases between local time scales with an accuracy of 1 ns can be one of the limiting factors of the entire experiment.

For monitoring these biases we applied the recently introduced TWTT method, which is based on two or more interconnected event timing systems linked with a single cable Panek2013. This method allows a time scale comparison with picosecond precision and accuracy.

**Two Way Time Transfer principle**

For comparing the time scales we are using Event Timing (ET) devices which were developed at the Czech Technical University Pánek2008. The ET allows the detection of Times of Arrival (ToA) of input pulses with respect to a local time base. The single shot precision is 700 fs RMS per channel.

The technique of the Two Way Time Transfer (TWTT) via single coaxial cable was inspired by the comparison of the two event timers using pulses and a signal splitter. The pulse from a signal source is split into two equal pulses and connected to the ET A using cable $C_1$ and to ET B using cable $C_2$;

The times of arrival (ToA) at both devices are measured and the time difference is computed ($\text{Diff}_1$). Then the cables are exchanged (ET A -> $C_2$ and ET B -> $C_1$) and time difference ($\text{Diff}_2$) is computed again. The time scales difference between both event timers then becomes

$$\hat{\Delta}_c = \frac{1}{2}\left(Diff_1 + Diff_2\right) .$$

The advantage of exchanging the cables is that the time scale differences do not depend on the length of the cables $C_1$ and $C_2$.

Inspired by the described method we have implemented the TWTT technique according to the schema displayed in Figure 2.
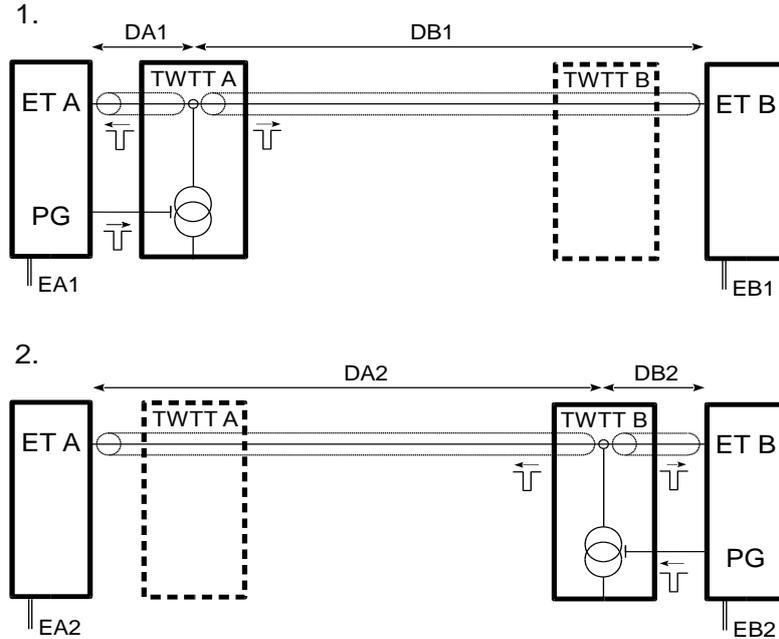


**Figure 2.** Block scheme of the Two Way Time Transfer via a single coaxial cable: 1st step when the TWTT module A is generating the test pulse, 2nd step when the TWTT module B is generating the test pulse.

The operating scheme is the following: two Event Timers ET A and ET B are equipped with TWTT modules. These modules are interconnected by a single coaxial cable. The measurement is carried out in two steps. In the first step the ET A generates a pulse, using a current driver the pulse is applied to the interconnecting cable and the ToA of the received pulse is measured by both event timers ($\text{ToA}_{A1}$ and $\text{ToA}_{B1}$). In the second step the role of the devices is exchanged. The ET B generates a similar pulse that propagates along the cable in opposite direction. After time tagging at both devices this yields $\text{ToA}_{A2}$ and $\text{ToA}_{B2}$. The timescales difference can be then computed according as

$$\hat{\Delta} = \frac{1}{2}\left(\left(ToA_{B1} - ToA_{A1}\right) + \left(ToA_{B2} - ToA_{A2}\right)\right).$$

The precision of the resulting time scale difference will depend on the precision of both event timers, the reproducibility of the pulses generated by TWTT modules and on the influence of noise induced on the interconnecting cable. Experimentally it was possible to establish time scale comparisons with a precision and an accuracy of the order of 1 ps Panek2013.

## Experiments

At the Geodetic Observatory Wettzell we carried out several TWTT experiments with two ET systems. That is why only two scales could be compared at the same time. First of all it is important to note that the operation principle is comparing the time scales held inside the event timers. When a locally generated time scales realized by 1pps signals need to be compared, they must be time-tagged at second input of each of the event timing systems.

The TWTT was implemented after considering several facts and additional measurements. First of all the repetition rate of sending pulses was chosen with respect of the communication speed as 500 Hz. The entire measurement loop was programmed in such a way that between two following 1pps pulses one TWTT measurement was done. To improve the precision of the TWTT measurement 32 pulses were exchanged between each ET. The single shot precision of the TWTT method using a 100 m long interconnecting cable of RG214 quality is 1.4 ps. With averaging a precision of the TWTT method of $1.4\,ps / \sqrt{32} = 0.25\,ps$ was obtained.

Up to now we have compared two time scales with UTC(IFAG). The first experiment performed was between MC and GNSS laboratory, where the GPS receiver WTZA (Ashtech Z12T) is located. The experiment lasted several days and is shown in Figure 3. The sudden rise of the time scales difference during 4th day was caused by an air conditioning failure. The absolute delay was compared to the absolute timing delay from the reference point of the GPS WTZA receiver up to UTC(IFAG) reference point.
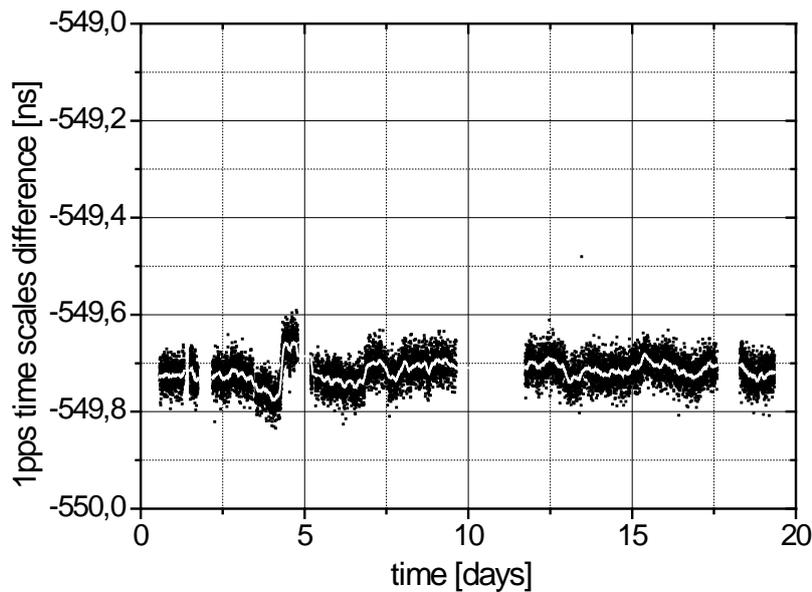


**Figure 3.** Time scale comparison between Master Clock room where UTC(IFAG) is located and the GNSS laboratory where the GPS receiver WTZA (Ashtech Z12T) is located.

As a second step the entire experiment was moved to perform time comparison between time scale used for GNSS receiver WTZS and the SLR time scale, which is important for optical time transfer. For this purpose we have developed a program, which can be used for full implementation of the measured results of time comparison into the entire ranging chain, where the epochs from the SLR measurement can be corrected. Figure 4 shows the time difference between WTZS and the SLR time scale. There are significant drifts of 600 ps peak-to-peak event thou both time scalse are derived from the same source of frequency.
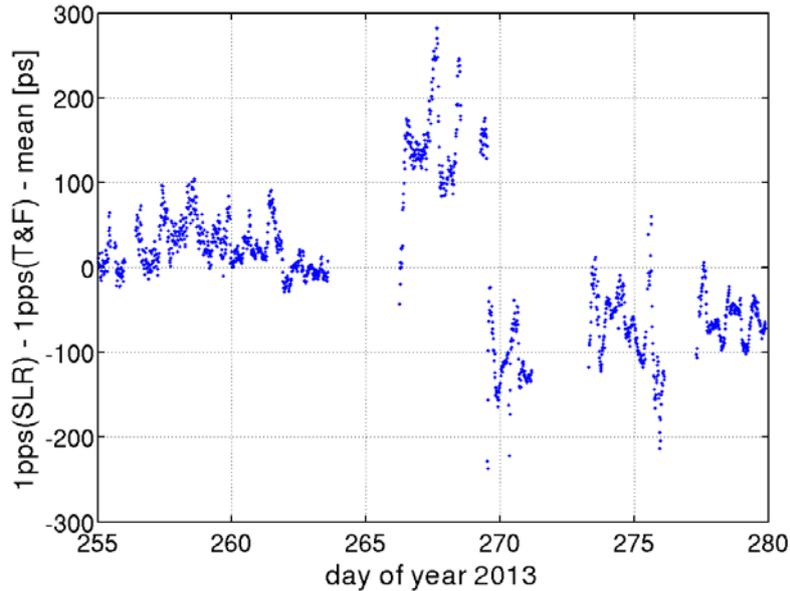
**Figure 4.** Time scale comparison between WTZS and SLR time scale.

## Conclusion

We have implemented the Two Way Time Transfer method in the Geodetic Observatory Wettzell for comparing the locally generated system time scales with our timing reference point UTC(IFAG). Up to now we have made two comparisons between UTC(IFAG) and GNSS laboratory; WTZS and SLR time scales respectively. The comparison of the time scales between UTC(IFAG) and the GNSS laboratory the time scale shows that both scales are uncorrelated for averaging times up to 200 s and the TDEV levels out at 3 ps for $\tau > 200$ s. Even though both scales are generated from the same source of frequency (Cs, HP1732) the observed drifts were caused by air-conditioning failure in GNSS laboratory.The comparison of the time scales between WTZS and SLR time scales shows significant drifts of 600 ps peak-to-peak event thou both time scalse are derived from the same source of frequency.

## ACKNOWLEDGMENT

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