

Delay compensated Optical Time and Frequency Distribution for Space Geodesy

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Abstract: In order to achieve a delay compensated time and frequency distribution, we have designed an all optical two-way system, which allows the campus synchronization of a distributed set of geodetic measurement systems in time and frequency with an accuracy of 1 ps with respect to each other. The goal is to make it possible to eventually use time as an observable and not as an adjustment parameter in a non-linear fitting process. With a centralized fs-pulse laser and a star like fiber network it is possible to reference all measurements to the same time scale and to control system biases. This opens the door to accurate closure measurements of system delays within each geodetic measurement technique and from one technique to the next (e.g. from SLR to VLBI).

Introduction: In a very much simplified description, one could say that the time of flight of a laser pulse is obtained by time tagging a laser pulse at the exit of the laser and again when it reaches the detector after passing through some distance in air. Let us assume that this distance is fairly small and within the compound of a satellite laser ranging facility. In this case the measurement would look like the sketch in fig. 1 a) and resembles the calibration process of a SLR system. Although the optical beam path is always the same, the measured time delay between the start and the stop detection shows a certain variability. This is illustrated for a rather small period of about 10 days in fig. 1 b) and over a period of about 1 year in fig. 1c). One can see that the variation of a fixed optical delay path can vary over more than 40 ps over a couple of days and more than 200 ps over the span of a year.

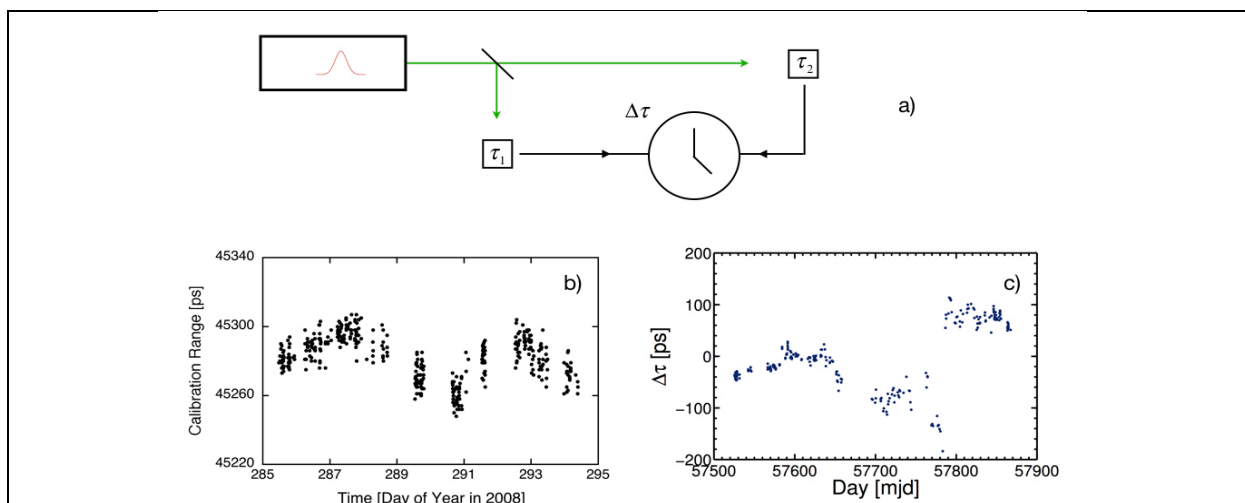


Fig. 1: Short term and long term stability of a local time of flight measurement. While there is little or no variability in the optical signals, there is a significant variation in the delay of the electrical signal.

None of the delays is caused by the laser or the geometrical condition during the measurement. All the variability is generated in the detector and the respective subsequent electronic circuitry. Since this behavior is known, SLR requires this type of calibration measurement in order to correct the range measurement to the satellites. The basic assumption is that both the calibration delay and the measurement delay are identical and by subtracting one from the other, these systematic errors are removed as a common mode effect. Unfortunately this is not entirely the case and a small amount of variable systematic errors remain uncontrolled.

Signal Delay Compensation: In order to improve this situation, we are employing a mode-locked fs-pulse laser in order to distribute time and frequency at an observatory. These lasers have ultra-low noise properties both in the optical and microwave regime. The goal is to make the local time and frequency distribution coherent enough, that the phase of the clock signal can be used to identify and remove this electronic induced variability down to a level of 1 ps. An active delay compensated two-way optical time and frequency distribution system serves for this purpose and is described in more detail in [1]. Figure 2 shows a comparison between the transfer stability of the 1 pps signal across the campus for the cable transfer a) and the two-way delay compensated optical fiber transfer b). There is a difference of more than a factor of 100 in stability between the optically and the electronically distributed timing signals.

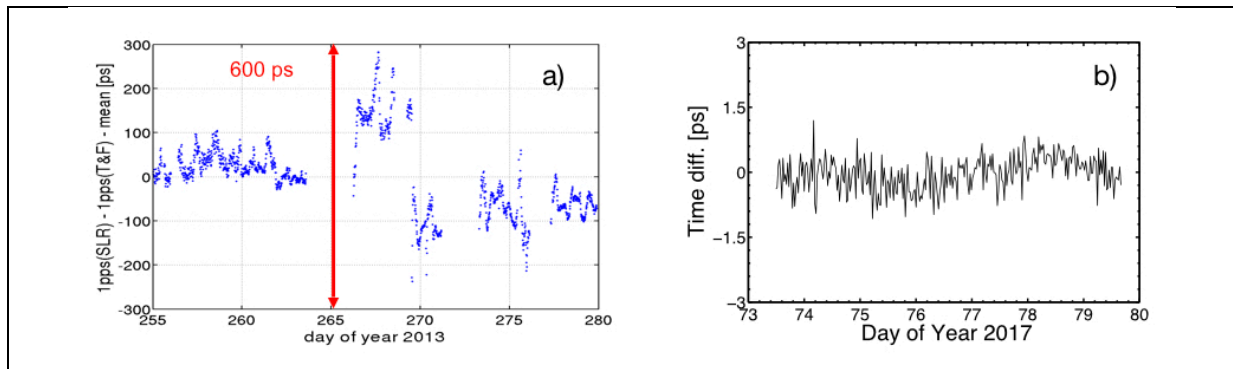


Fig. 2: Comparison of the stability of the pulse per second signal leading edge for an electronic signal transfer a) and a delay compensated optical link b). The difference in the signal stability exceeds two orders of magnitude.

Reduction of systematic errors by closure measurements: Once the phase of the clock signal can be established with an uncertainty as low as 1 ps, this coherence in time can be used to identify and remove systematic measurement errors by performing closure measurements based on highly resolved time comparisons. Figure 3 depicts this process for SLR. The central part is the clock with two compensated fiber links. One link is connected up to the SLR timer, while the other is positioned on the local ground target. That means the delays τ_1 and τ_2 are constant and known. When the SLR system performs the SLR measurements, it references the invariant point of the SLR system to the local target. An additional timer on the target establishes the 1-way range at the same time. Since both the SLR system and the target have perfectly synchronized clocks, almost every source of delay is known and have to cancel in the closure measurement. This assumes however that the conversion delay of the optical pulse to the electrical pulse is identical for both detectors, the one on the target and the one on the SLR system. Therefore it is advantageous to choose identical detectors and identical electronic circuitry for this purpose. We refer to the work of Prochazka et al. [2,3] for important conclusions on the flawless detection of optical pulses. If the closure is not zero or worse if the measured offset is not stable over time, there is a source of (variable) systematic errors somewhere fouling up the measurement process. Repeating the measurements while changing the operational parameters in a controlled way will quickly identify the source of the problem, so

that it can be removed. While initial bench tests have demonstrated the sensitivity of this control procedure to identify systematic errors, the entire setup is still awaiting the completion of the implementation.

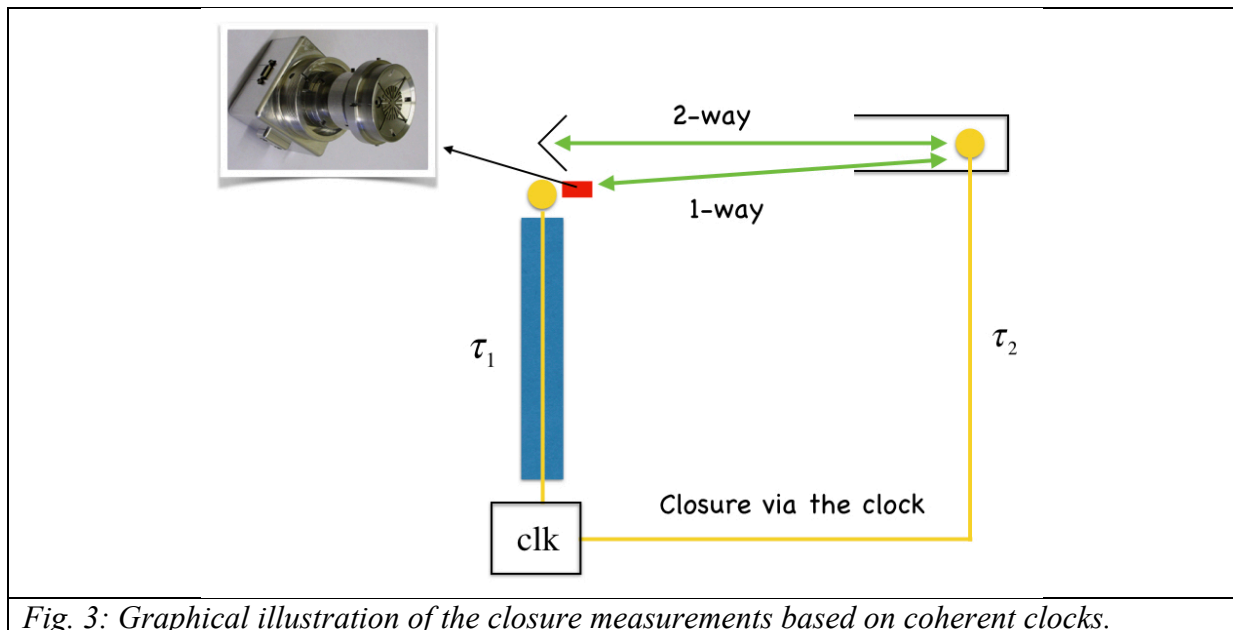


Fig. 3: Graphical illustration of the closure measurements based on coherent clocks.

Summary: The detection of systematic errors at the level of about 30 ps in the SLR ranging equipment is a tedious task. This is mostly because small differences in the calibration and ranging procedure prohibit the full cancellation of internal electronic system delays. We have started to design a time and frequency distribution system that allows the creation of a long-term stable coherence of the distributed frequency and time at the level of 1 ps over distances of several hundred meters. This allows the operation of the station clock in a closure measurement configuration in order to identify and eliminate systematic ranging errors. The same general concept applies also to the VLBI systems, which can apply the same closure approach for the assessment of systematic errors in the system delay [1]. That means that this common calibration target offers the opportunity to define a single point of reference on a fundamental station, both for space and time.

References:

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