Coherent Time and Frequency for an Improved Global Geodetic Observing System

U. Schreiber[2], J. Kodet[2], T. Klügel[1] and T. Schüler[1]

[1] Bundesamt für Kartographie und Geodäsie,
GO Wettzell, Sackenrieder Str. 25, 93444 Bad Kötzting

[2] Technische Universität München,
GO Wettzell, Sackenrieder Str. 25, 93444 Bad Kötzting

Abstract

The toolbox of space geodesy contains a number of measurement techniques, which are globally distributed. In this diverse network fundamental stations are playing an important role as they are forming the backbone of the global geodetic observing system. They provide the ties for the combination of the techniques.

Until recently these ties were only considering the spatial relationship between the measurement techniques. Upon closer inspection it turns out that clocks are also playing an important role. Variable delays within the main techniques of space geodesy, namely SLR, VLBI, GNSS and DORIS are limiting the stability of the measurements and hence the entire observing system. This leads to the rather paradox situation, that each technique has to adjust the clock offsets independently. Although all main measurements systems on an observatory are usually based on the same clock, each technique provides different offsets, thus weakening the local ties. This reflects the fact that the clock adjustments are also contaminated with (variable) system specific delays. Increasing the coherence of time on these GGOS observatories disentangles erroneous system delays from local ties, thus strengthening the entire observing system.

We have designed and built such a coherent time and frequency distribution system for the Geodetic Observatory Wettzell. It is based on a mode-locked fs- pulse laser, fed into a network of actively delay controlled two-way optical pulse transmission links. This utilizes the ultra low noise properties of optical frequency combs, both in the optical and electronic regime. Together with a common central inter- and intra- technique reference target time can provide consistency for the complex instrumentation of SLR and VLBI systems in situ, which was not possible before. This talk outlines the concept and its potential for GGOS.

Controlling signal delays by optical 2-way link stabilization

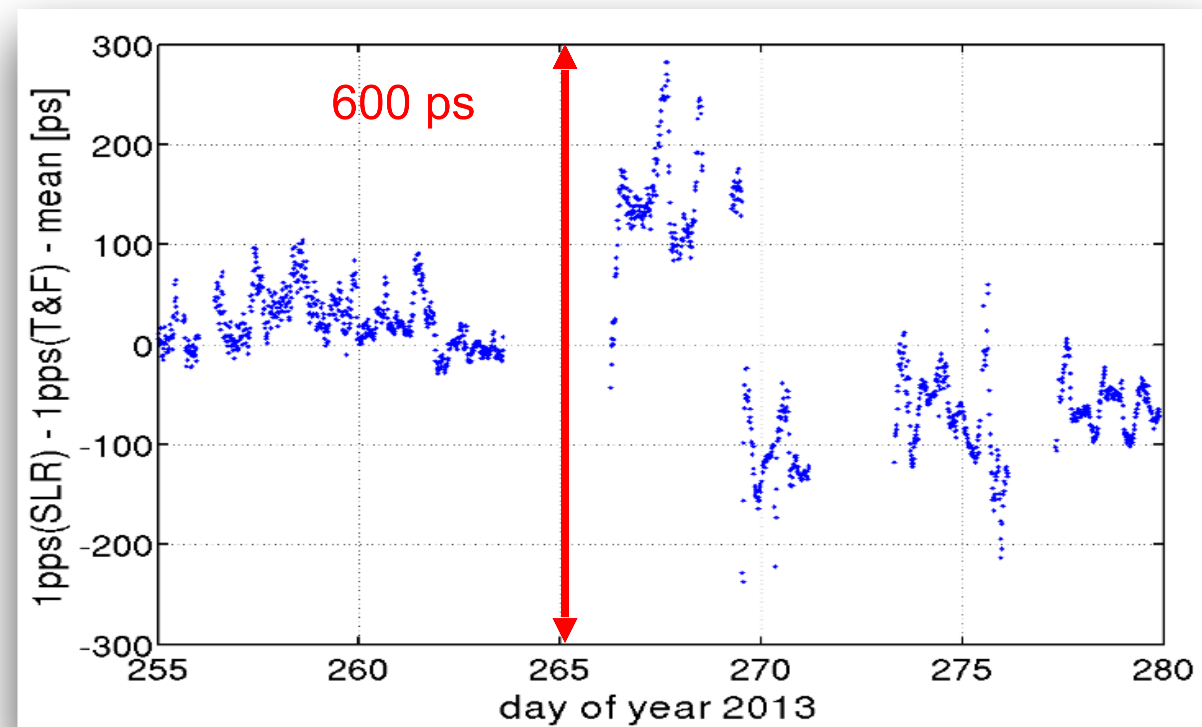
Space Geodesy has progressed to the point where systematic measurement errors become the largest residual error source.

The most prominent contribution comes from internal instrumental time delays, which are not captured by the system calibration.

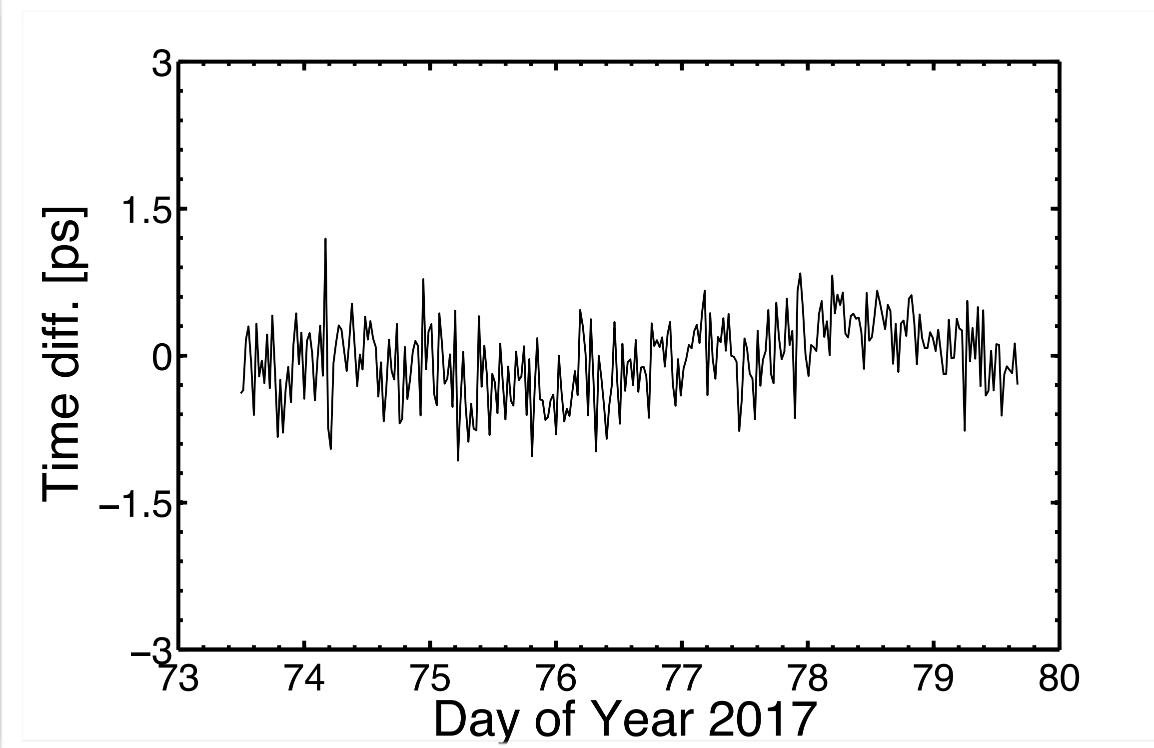
A limited **bandwidth**, variable electrical **ground potential** fluctuations, **temperature fluctuations** of electronic devices for relevant timing functions and **phase noise** are the most prominent contributors.

The distribution of the broadband PPS time signal over cable and electronic devices shows variability at the level of several hundred ps - and next to none over a compensated fiber link

cable based

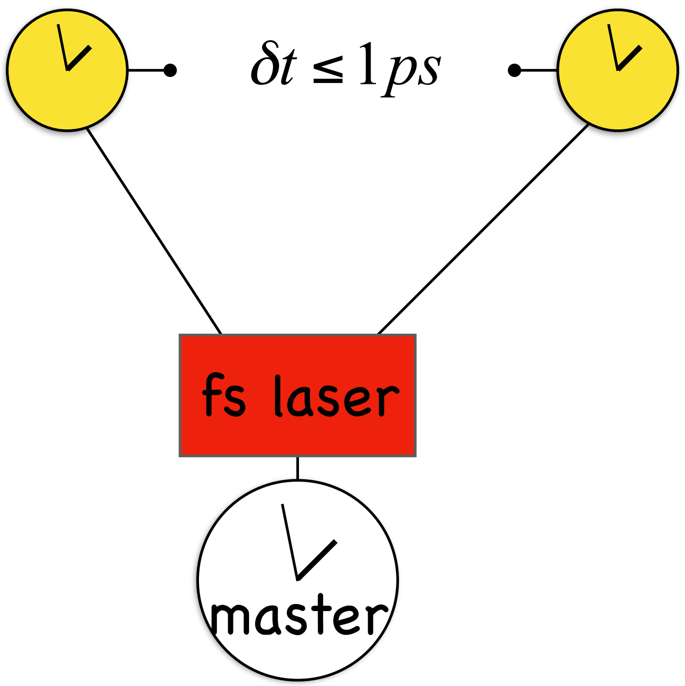


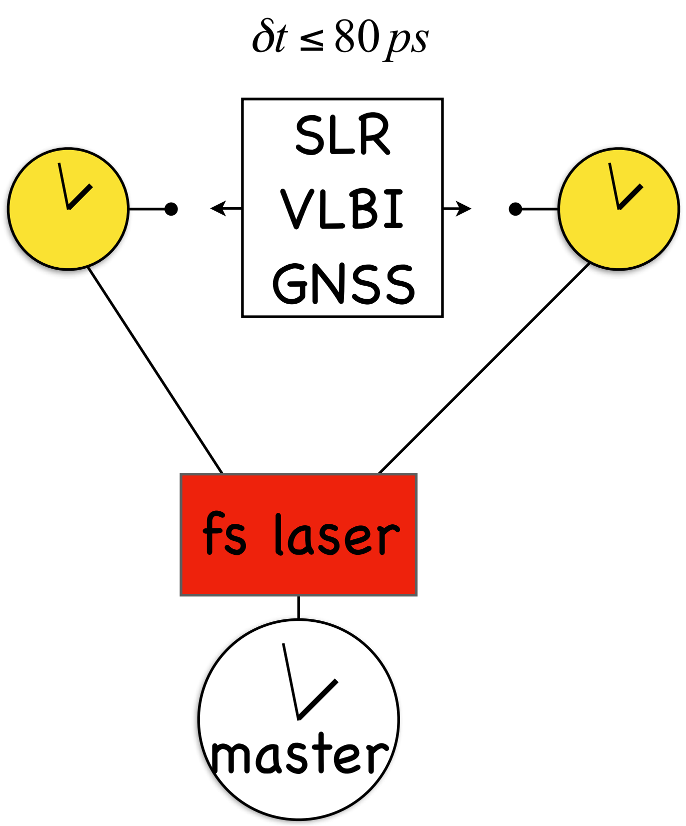
compensated fiber based



Optical 2-way time and frequency distribution is the most promising way to overcome the problem of variable time delays, because delays between the endpoints are actively compensated.

Active control over the internal system delays improves the longterm system stability of VLBI, SLR and GNSS

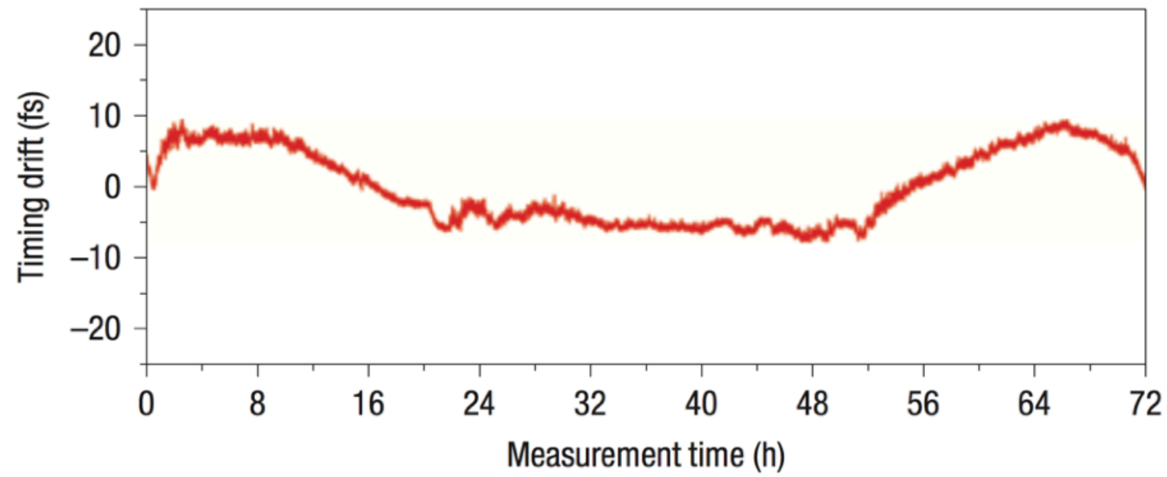




A closed loop two-way time and frequency distribution with a relative stability of 1 ps between two arms can be used to track and remove unknown internal system delays

Common Clock for Space Geodetic Techniques

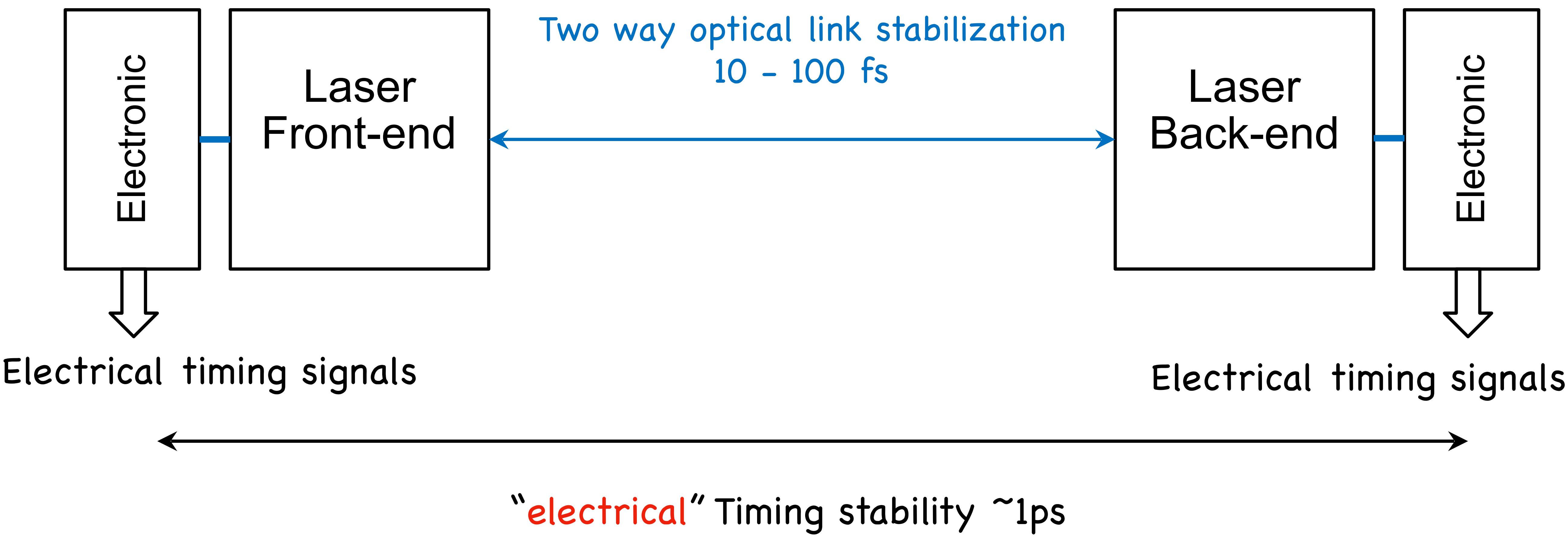
optical cross- correlation of
2 fiber lines (300 m)



6.4 fs r.m.s.

Kim et al. Nature Photon, **2(**12), 733–736, (2008)

MenloSystems



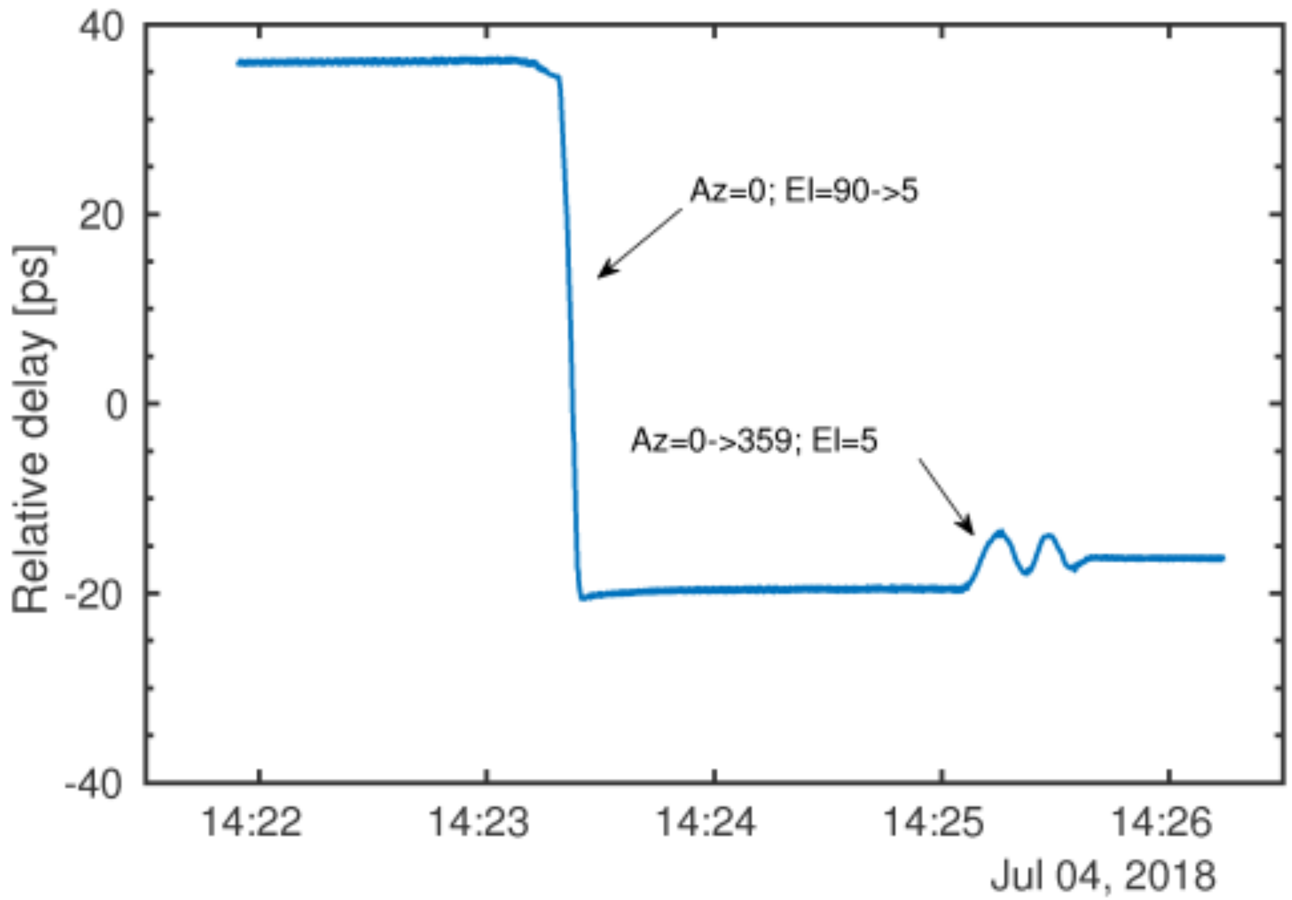
The transfer stabilization of mode-locked fs- pulses over a two-way fiber line has been demonstrated to be as stable as 6.4 fs (rms) as long as the signals are in the **optical domain**

However, since timing has to be done in the **electrical domain** some of this stability is lost. The concept realizes a **delay stability** of 1 ps, between any two endpoints of the time distribution system

We can use this property to design **closure measurements** in **time** in order to find and remove (variable) **system biases**, which otherwise go unnoticed

Systematic errors are of significant concern in the measurement techniques of space geodesy. Small biases caused for example by little technical asymmetries between the measurement and the calibration procedure cause variable offsets to the data products. Such things go entirely unnoticed, because they are shifting the mean value of the measurement as a whole by just a little bit. The **apparent discrepancy** in scale between SLR and VLBI is evidence for this issue, (whereby each measurement technique puts in its own specific bias).

Example: Signal delay from cable strain in a slewing VLBI Antenna



Here we show an example of strain induced signal delay only from turning the VLBI antenna, first only in elevation and then only in azimuth.

The system delay is obtained from the error signal of our actively controlled optical 2-way time and frequency distribution system.

The exact control of each individual signal lead is necessary to capture the full delay bias. **Only optical two-way techniques provide this option.**

Illustration: Closure measurements in time

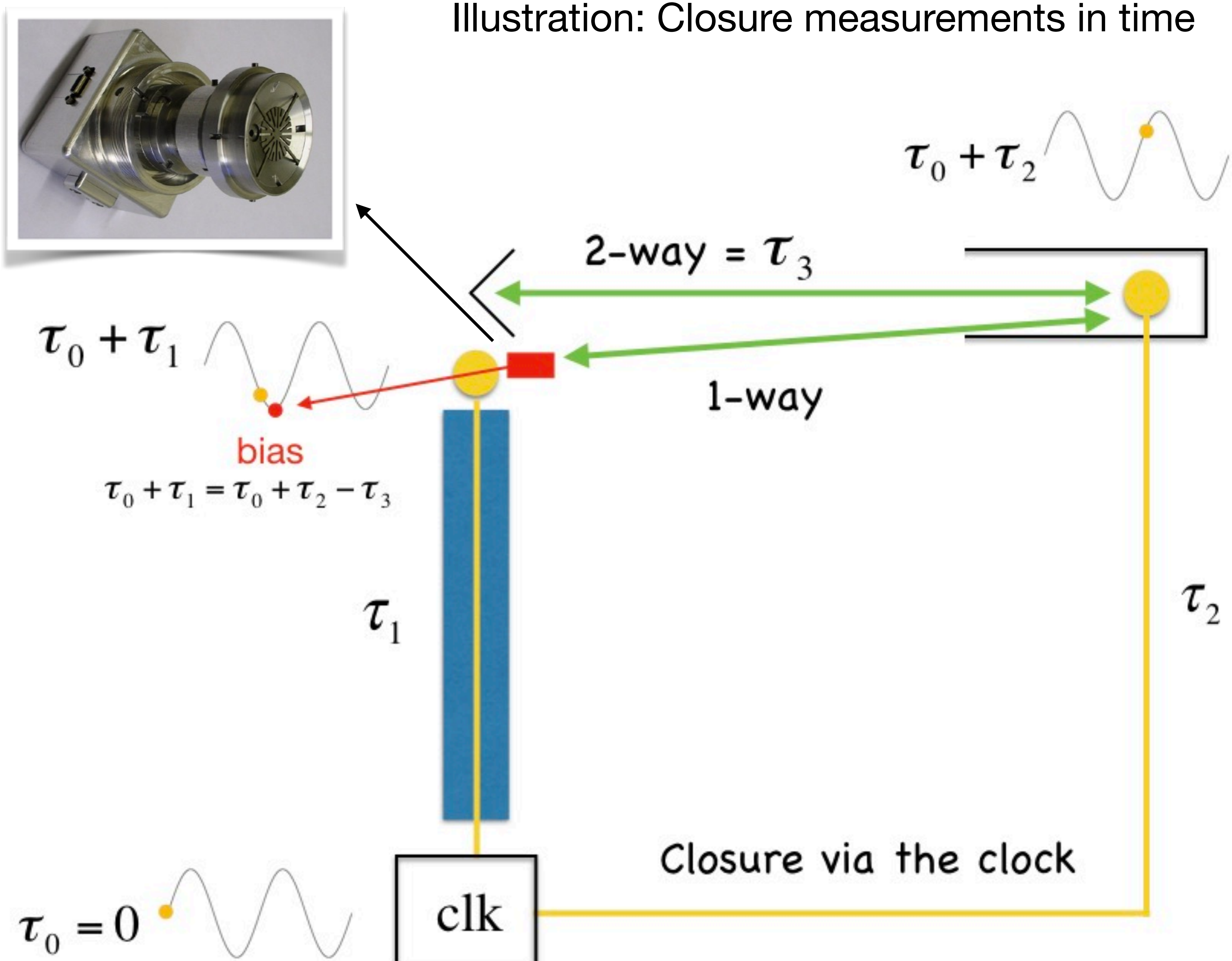
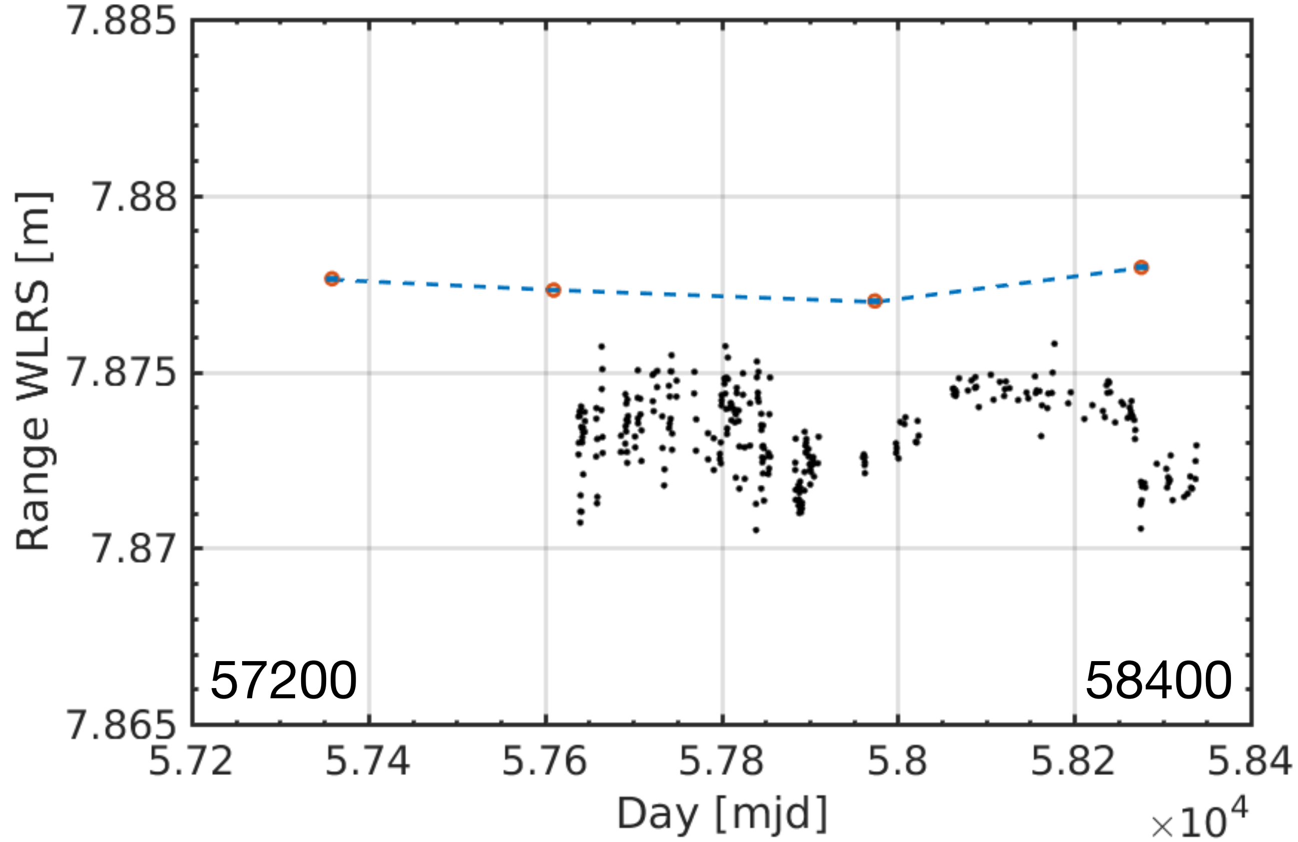


Illustration: **Closure Measurements in Time**

The two yellow dots at the end of each yellow line are marking the location of our end terminals of the time and frequency distribution. They relate to a common clock. One time module is at the station fiducial, the other at the SLR system. The delay between the clock and end terminal is known exactly from the two-way compensation link.

The SLR ground target round-trip measurement returns the range Δt between the SLR system and the station fiducial. The simultaneous SLR one-way ranging transfers the phase of the clock signal from the SLR system to the station fiducial in order to provide the closure for the clock comparison.

Any difference in the clock phase between the two clock terminals indicates a range bias. At this point in time, this measurement is consistent to within 20 ps with some structure not yet explained.

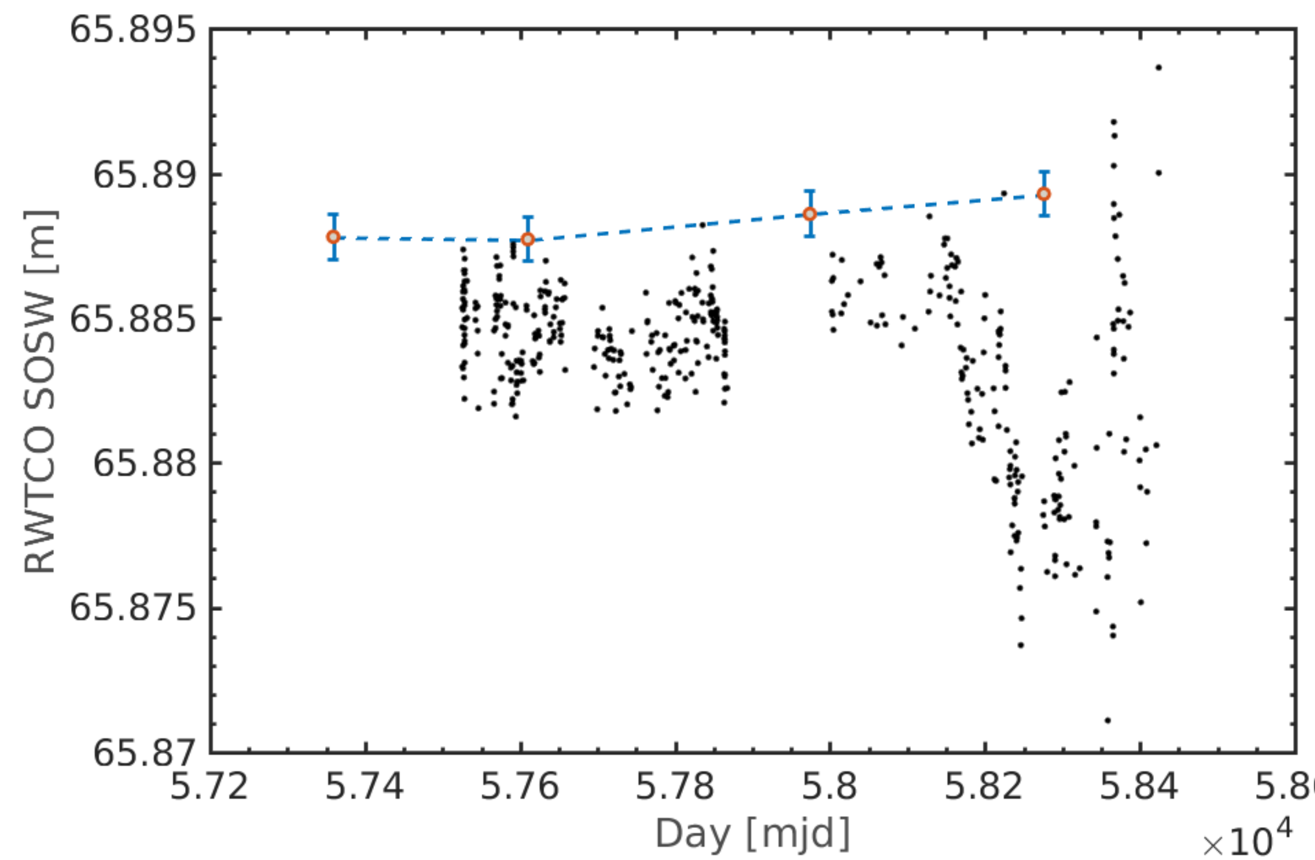


Closure Calibration WLRS

5 mm scatter with little systematics
2 mm offset (still not explained)

Closure Calibration SOS-W shows

5 mm scatter with some systematics
2 mm offset (still not explained)



Summary: A closed loop two-way time and frequency distribution system is progressively becoming available for the techniques of space geodesy

It allows to routinely perform closure measurements in time in order to maintain bias free observations across and within the techniques (once completed)

The goal is the definition of a single common clock on a geodetic fundamental station for all the techniques of space geodesy.

Optical time transfer between a stable orbiting clock, such as ACES can potentially synchronize several of these fundamental stations in order to extend the delay (bias) compensation to the entire network.