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All Optical Time and Frequency Distribution for Space Geodesy

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Abstract. *Although time is an important measurement quantity in space geodesy, time itself cannot be used as an observable. A lack of control of the phase relationship of timing signals at different locations is responsible for this. As a consequence we can determine time intervals very accurately and SLR depends on that, but we are far from establishing the epoch of a SLR measurement with the same accuracy. Therefore all the techniques of space geodesy establish timing biases from the measurements. We have started to establish an all optical time and frequency distribution system, that can control local system delays and allows an accurate tie for the time of all geodetic measurement techniques on a distributed campus like the Geodetic Observatory Wettzell.*

Introduction

One-way ranging techniques like GNSS, laser time transfer and VLBI require a synchronization of the clocks between the satellite and the ground station or in the case of VLBI for the two ground stations. However, clock offsets, system delays and limitations on the modeling of propagation delays are mixed and it is very difficult to untangle these contributions. Closure measurements such as a clock comparison between two remote clocks via different measurement techniques can illustrate this problem. Figure 1 shows such an example. The hydrogen masers of the VLBI stations Algonquin and Wettzell are compared with the GNSS and the VLBI technique. After the reduction of the offset and drift between the two masers, one can see systematic variations, which are different for each technique. This shows impressively how difficult it is to obtain proper time. Our work concentrates on the goal of providing bias free timing all across the campus of our observatory.

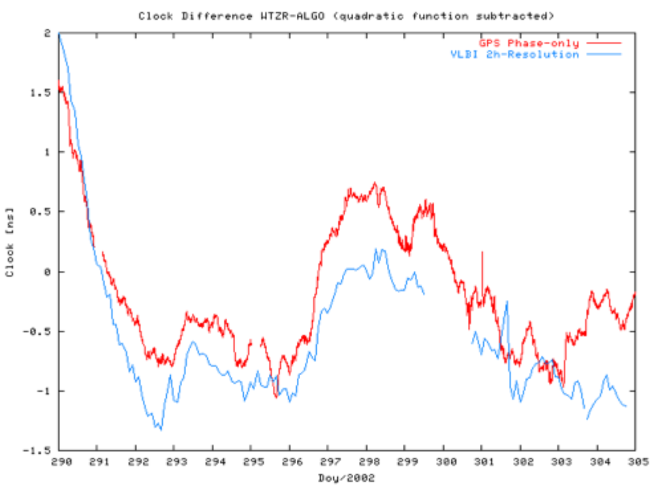

Figure 1: Illustration of variable system delays between VLBI and GNSS

The distribution of time and frequency have very different technical requirements. Frequencies can be transferred over channels with a low bandwidth, while time requires the widest possible bandwidth in order to realize a sharp signal rise time, which in turn leads to a sharp definition of an epoch value. Furthermore one requires a constant delay between the source and the endpoint of such a timing pulse (typically a PPS signal). Figure 2 shows a measurement of the time delay between the master clock of the observatory and the SLR system over 25 days.

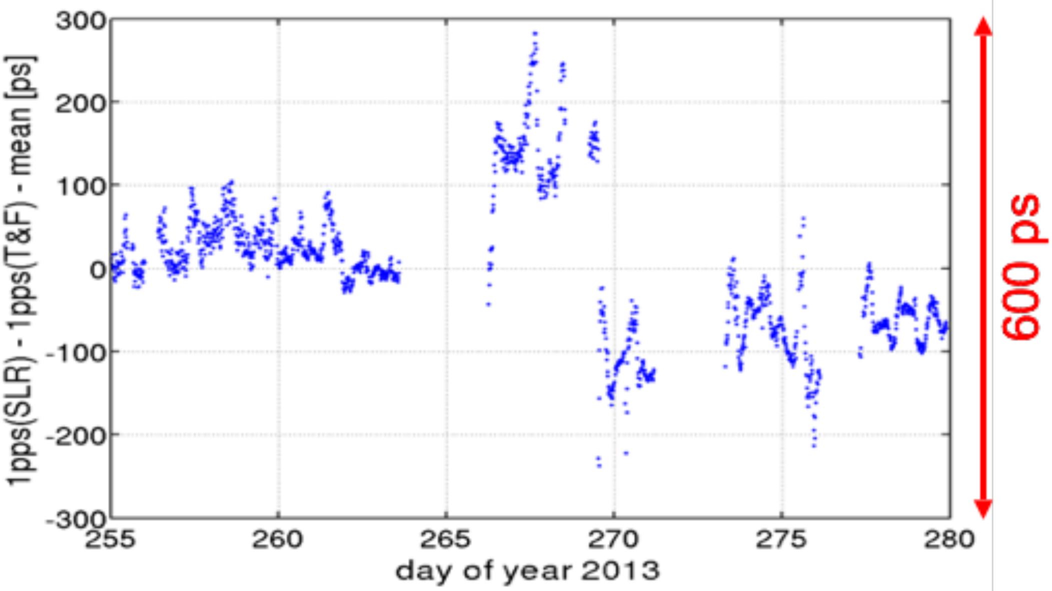

Figure 2: Variations in the time delay between the Cs master clock in one building and the SLR system in another building.

Apart from daily variations caused by temperature changes, one can also see transient variations, so that the transfer of an epoch changed by as much as 600 ps over the period of this comparison.

Optical Time and Frequency Comparison

In order to improve the stability of the time and frequency distribution of the observatory, we are currently setting up an all optical time and frequency distribution, which consists of a hydrogen maser as a flywheel for a stable frequency and an optical pulse distribution [Kim et al. 2008]. The maser output of 100 MHz is connected to an optical frequency comb, whose repetition rate is stabilized by the maser frequency. Both the maser and the comb are located in the same place. The optical pulse train from the comb is split up into several channels; each channel provides a dedicated point to point link for time and frequency between the comb and one of the other buildings of the campus, thus realizing a star topology. Optical fibers are connecting these endpoints. In order to ensure a constant delay between the comb and each endpoint we adopt a 2-way technique. A combination of an ordinary fiber and a conjugate fiber ensures that the pulse width of the comb pulses are not degraded by dispersion. This maintains the high resolution for the transfer of time. Since optical fibers are subject to length variation with temperature and also sensitive to phase variations due to changes of the refractive index, a suitable active compensation with sufficient bandwidth is required. Figure 3 illustrates this concept. With a repetition rate of 100 MHz, the spacing between neighboring pulses on the pulse train is 10 ns. At the end of the fiber a beam splitter takes some of the intensity of the laser pulses and reflects them back towards the origin, where an optical correlator superimposes the outgoing pulse train with the reflected signal. A feedback loop including a variable optical delay line is set up such that the relative pulse position for the outgoing and the reflected signal does not change over time.

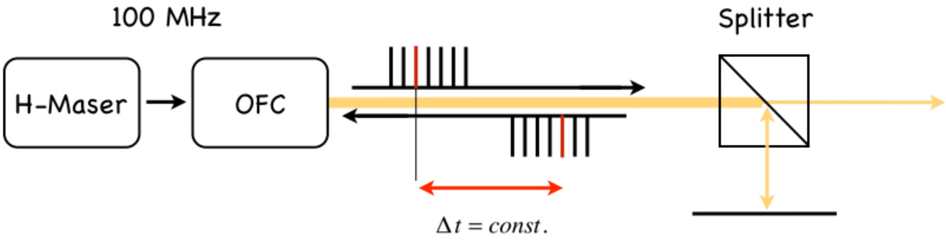

Figure 3: Block diagram of the optical time and frequency distribution.

As a consequence, the delay is stabilized to a constant value. Preliminary measurements on a single link show that a delay stability to within 3 ps has been obtained over a day.

The laser pulse train provides both, time and frequency. The frequency is recovered from the pulse train by detecting the pulses on a fast photo diode, which recovers the repetition rate of the laser pulses, namely the 100 MHz originating from the hydrogen maser clock. The output signal of the photo-detector synchronizes a set of suitable low noise oscillators, so that 3 distinct frequencies with very low phase noise, namely 5, 10 and 100 MHz, are provided at the end of each fiber link. Time is extracted separately by triggering on the rising edge of every 100-millionth laser pulse. In order to make sure that every distribution unit of the timing system, regardless of the length of each fiber link, is triggering exactly on the same pulse of the pulse train, a PPS signal is supplied to the comb and distribution link assembly. This signal is used to mark one of the pulses each second with an optical signal of another wavelength, so that the epoch is extracted from the time of arrival of each marked laser pulse. In the end this system realizes a centralized clock with a number of terminals, which are actively delay stabilized. Since the delays of the timing signals are constantly measured for each link, it is possible to relate the PPS signals of each terminal to the master clock with high accuracy, offering the option of transforming all epochs of each terminal to the same point on the central clock.

Conclusion

Improving the accuracy of the techniques of space geodesy requires a better control of the internal system delays. Combining the various measurement techniques into a global geodetic observing system (GGOS) will benefit from an actively delay-controlled common clock for all measurement devices, paving the way into the direction of a relativistic geodesy. It also allows to distribute time with high accuracy. While the frequency comb as an optical master oscillator controls the delays on an observatory, SLR can transport this with high accuracy to an atomic clock in space by exploiting a similar two-way measurement process. The European Space Agency (ESA) is in preparation of an ensemble of atomic clocks in space in the framework of the ACES experiment. The Geodetic observatory Wettzell is currently preparing to provide this modern time transfer capabilities.

Kim J., Cox, J. A., Chen, J. and Kärnter F. X., *Drift free femtosecond timing and synchronization of remote optical and microwave sources,* Nat. Phot., **2**, p.733—736, (2008)