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Improving the Local Ties of a Fundamental Station by a Multi-Technique Ground Target

Jan Kodet (1,2*), Ulrich Schreiber (1), Johann Eckl (3), Günther Herold (3), Gerhard Kronschnabl (3), Christian Plötz (3), Alexander Neidhardt (1), Swetlana Mähler (3), Torben Schüler (3), Thomas Klügel (3)

(1) Technische Universitaet Muenchen, Geodetic Observatory Wettzell, 93444 Bad Kötzting, Germany
(2) Czech Tech.Univ. in Prague, Brehova 7, 11519 Prague, Czech Republic
(3) Federal Agency for Cartography and Geodesy, Geodetic Observatory Wettzell, 93444 Bad Kötzting, Germany

*kodet@fs.wettzell.de

Abstract. *Variable system delays are an important error source for the techniques of space geodesy, such as SLR, VLBI, GNSS and DORIS. Therefore it is important to co-locate the various measurement systems in order to find and remove these systematic errors by comparing the different instruments. The Geodetic Observatory Wettzell is in a favorable position because it operates 2 SLR and 3 VLBI systems along with several GNSS receivers.*

We have designed a local ground target, which is tying all these different measurement systems to a single point on the observatory, allowing regular intra- and inter- technique comparisons between all the available measurement techniques. This talk outlines the concept of the multi-technique ground target, introduces the design properties and shows the first experimental results.

Introduction

As part of the current research and development program of the GO Wettzell, we are in the transition from a purely electrical to an actively stabilized two-way compensated optical time and frequency distribution system. We are planning to implement and investigate these functions in a closed-loop control system with an envisaged overall long-term delay stability between different instruments in the range of 1 - 10 ps (corresponding to 0.3 - 3.0 mm), not only in the presence of temperature variations affecting the underground cables on the campus, but also for the cables under variable strain in the moving VLBI telescopes. This tight delay control removes variable systematic measurement errors, which are not captured by the established system calibrations. In other words, one can use the local timing system at the observatory to provide a common clock as a consistent tie between the 2 SLR systems of the Geodetic Observatory Wettzell as well as between the 3 radio telescopes and also between the various GNSS receivers (intra-technique co-location).
The functional principle of operation of the timing system is as follows. We will synchronize an optical frequency comb with our atomic frequency standard, then we will use the ultra short laser pulses as time markers, which will distribute both time and frequency around the observatory. To keep the femtosecond pulses short, dispersion compensated optical fibers will be used. The optical frequency comb (master) will be installed in new TWIN radio-telescope control building and using a star topology to link the slaves (back ends) being installed in the SLR and RTW control rooms. Each back-end will reflect a part of the signal back to the master, where the correlation between the

sent and received signal is used to compensate for link delay variations. Hence the concept is based on a two-way approach, which is a close approximation of the "Einstein Synchronization" [1], making the link entirely independent of delay variations. The back ends will provide PPS timing signals rigidly tied to the frequency comb, as well as reference frequencies of 5, 10, and 100 MHz, which are generated from the repetition rate of the comb.

The new timing system allows to treat time as a new and independent tie between the different space geodetic techniques. Closure measurements over several measurement systems using a clock as the origin and endpoint reveal even small time delays thus going beyond the currently applied calibration schemes. Figure 1 outlines the principle of closure measurements in the techniques of space geodesy by using a common clock between two SLR stations and two radio-telescopes. The sum of all delays between clock and target must be the same at both observation paths after considering all the delays along the path of signal propagation.

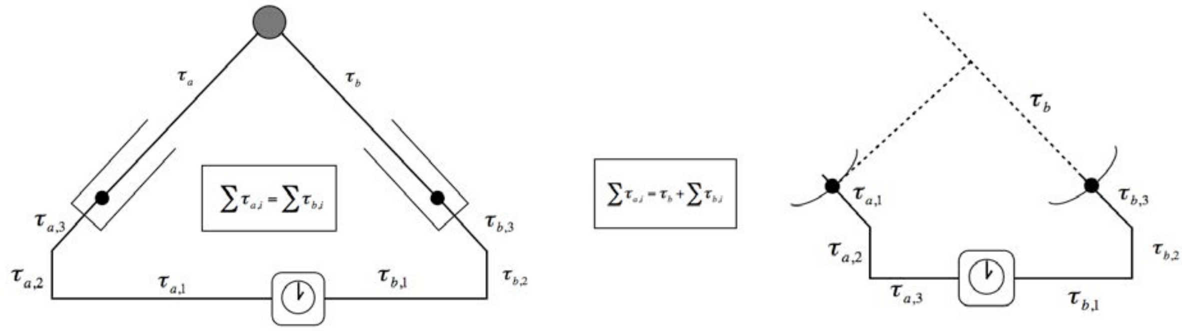


Figure 1: Using two or more measurement systems of the same technique with a common clock provides equal delays in the time regime if all systematic biases are correctly established. The illustration shows the case for SLR on the left and VLBI on the right side.

Multi-Technique Ground Target

The availability of the new timing system also opens the opportunity to establish a central point of reference, common to all techniques in the form of a multi-technique ground target. Such a target, must be geometrically well defined, accessible to the local ground survey and it must be synchronized to the new timing system. It provides optical time markers detectable using both SLR systems. Synchronized to the optical time markers it emits radio frequency signals similar to the PCAL calibration in VLBI and eventually also GNSS code signals detectable using GNSS receivers, with all signals and systems referenced to the same clock.

Since these demands are difficult to realize we have split the project into several stages. In the beginning the construction holds a GNSS receiver antenna on the top, a SLR retro-reflector mounted below the GNSS reference point and a small X band antenna for the external VLBI

calibration underneath. The current prototype of the multi-technique target is shown in Fig. 2.

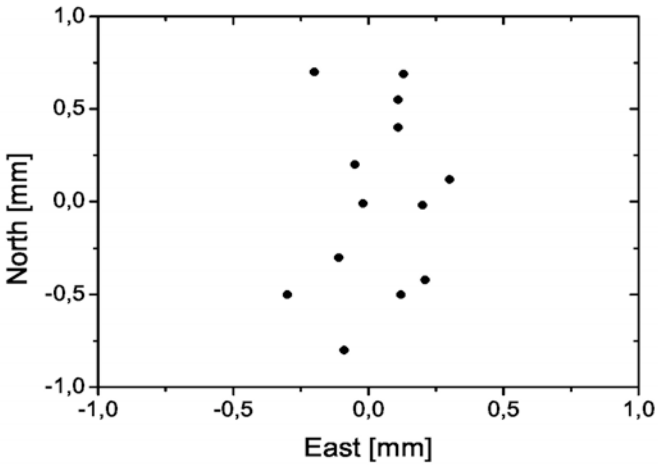
Figure 2: The development version of multi-technique ground target. On top there is a GNSS antenna, the SLR retro reflector, which will be used as a SLR calibration target and for local ties measurement, is mounted below the GNSS antenna and at the bottom there is a X-band antenna, which will be used for VLBI calibration.

This target construction was mounted on top of a 5.5 meter tower in a central position near the WLRS laser ranging station. It provides a good visibility for both SLR systems and all radio-telescopes, see Fig. 3.

Figure 3: Photograph of the Geodetic Observatory Wettzell, the multi-technique ground target (red dot) is installed on top of a 5.5 m tower located in front of the WLRS station in good visibility to all space geodetic techniques.

First Calibration Results Using Multi-Technique Ground Target

Since few weeks the multi-technique calibration target is undergoing testing. The GNSS solution demonstrates the solid construction of the monument. There is no significant target movement in



the weekly GNSS solutions, see Fig. 4.

Figure 4: North and East components of weekly GNSS solutions of the multi-technique ground target during the 13 weeks in the year 2015 (start day 200).

The SLR reflector is mounted on a turntable and integrated into SLR operations as a target for local tie measurements and as an external calibrating target for both SLR stations. We are now working on an a modification of WLRS SLR station, which will ensure eye safe operation of the telescope below 6 degrees of elevation. The second SLR station SOS-W uses a bistatic mount with separated Tx and Rx telescopes. In such a system the calibration target is too close to see it from both telescopes, therefor the Tx telescope will be used for transmitting and receiving the optical signal. So far such a setup is not tested. This process is scheduled for 2016.

The most challenging task is to establish the multi-technique ground target for VLBI calibration purposes. For that purpose we are using a small X-band antenna to transmit a microwave frequency comb with 1 MHz tone spacing, as it is illustrated in Fig. 5. The signal is directly generated from the same frequency reference which is in use for the VLBI system.

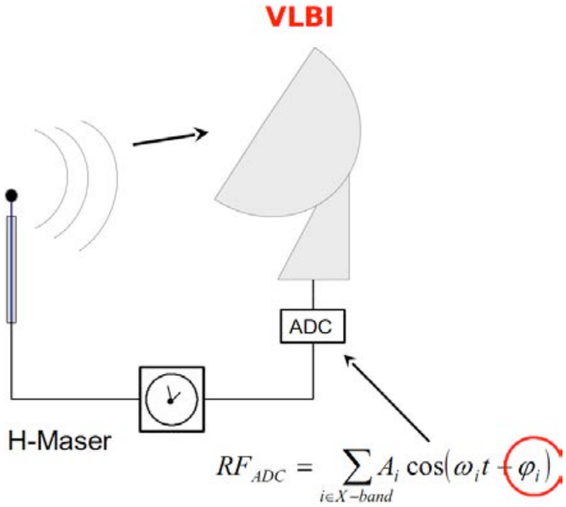


Figure 5: The schematic diagram of VLBI calibration using multi-technique ground target. The target is transmitting a microwave frequency comb. The VLBI system is recording the signal and the phase of tones is extracted in a PC.

The microwave signal is detected by the VLBI system and processed separately from the VLBI analysis. The processing algorithm is extracting phase information from each tone. Since such a signal is generated with low phase variation from the same frequency source, variations of the phase relationship gives us information about system delays. In this way we are also able to measure local ties directly by utilizing radio-telescopes. Fig. 6 shows the extracted 13 tones observed in X band channel 1 using the 20m radio-telescope Wettzell (RTW). The entire concept and technical realization is very young and still needs improvements and further development. The goal is to make such on site calibrations on a daily basis.

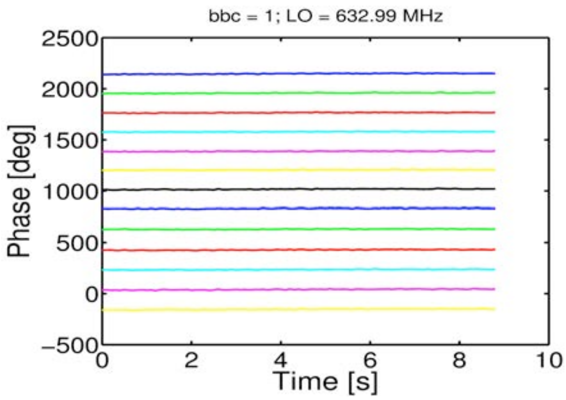


Figure 6: Example of extracted phases derived from multi-technique ground target, which is transmitting a microwave frequency comb.

Conclusion

We are systematically working on improving the local ties at the Geodetic Observatory Wettzell. Long-term measurements of the geodetic markers at the station (spanning more than 25 years) do not show significant displacements. We are therefore focusing on the co-location and comparison of the different geodetic instruments among each other and across the various techniques.

A promising approach is the use of a multi-technique ground target for the calibration of all space geodetic techniques. The goal is to establish one central geodetic reference point for all the geodetic techniques and relate instrumental reference points to this common point in in order to capture measurement biases in the form of time delays that otherwise would go unnoticed. In this way the space geodetic techniques in conjunction with a delay compensated clock distribution are used for the monitoring of the local ties.

Acknowledgement

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References

[1] A. Einstein; "Zur Elektrodynamik bewegter Körper", *Annalen der Physik*. 17, 1905, S. 891–921