Delay compensated Optical Time and Frequency Distribution for Space Geodesy

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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. 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).
**Observation:** Variable Delays due to electronics

\[ \Delta \tau \]

\[ \tau_1 \rightarrow \Delta \tau \rightarrow \tau_2 \]

![Graph 1](image1)

![Graph 2](image2)
The distribution of the broadband PPS time signal also shows variability at the level of several hundred ps.

... over a longer period: $\Delta t \leq 5$ ns
SLR: ranging in the optical domain

SLR: timing in the microwave domain

Systematics

Mode-locked fs-lasers

ultra-low noise optical pulse trains

ultra-low noise microwave signals
Two-Way Timing Techniques (local)

- 2-Way compensation technique only possible in the optical domain

- Required broadband signal available from fs-pulse lasers only

- Expected uncertainty < 100 fs: ≈ 5 orders of magnitude gain over current situation

- Consequences for Local Survey: 1 mm = 3 ps

Example: FEL in Trieste
Interpolator

lossless distribution

Maser → fs-pulses

Correlator

Station Fiducial

VLBI

SLR

GNSS

Consistency Check by "Closure-Techniques"

Single Point of Reference in Time and Space
lossless distribution

Single Point of Reference in Time and Space

Consistency Check by "Closure" Techniques

Geodetic Techniques

VLBI

SLR

GNSS

Station Fiducial

Correlator

fs-pulses

Maser

Comp. Clock

Opt. Ref. Cavities

fiber links

Interpolator

Opt. Ref. Cavities

f, t, \Delta \tau

2-way
ELT (Time Transfer via ACES)
Common Clock for Space Geodetic Techniques

Electrical timing signals

Timing stability ~1ps

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

6.4 fs r.m.s.


MenloSystems

Two way optical link stabilization 10 - 100 fs

“electrical” Timing stability ~1ps

Electrical timing signals

Electronic

Laser Front-end

Laser Back-end

Electronic

Electrical timing signals
Common Clock for Space Geodetic Techniques

TWIN

MenloSystems

Electronic

Laser Front-end

Electrical timing signals

stabilized delay

stabilized delay

WLRS

Laser Back-end

Electronic

T&WOTT

T&F

Laser Back-end

Electronic
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.

... over a longer period: $\Delta t \leq 5$ ns
Closure via the clock

$\tau_1$

$\tau_2$

2-way

1-way
global station fiducial
Target/Source
Technique independent Closure for Space Geodesy

VLBI

PCAL signal

τᵢ

ADC

Δφ

τᵣ

SLR

Calib. signal

WTCO

link stabilization

fs-laser

H-maser

Timer
The establishment of accurate local ties of different space geodetic techniques at fundamental geodetic observatories poses a long-standing problem. While geometric ties can be determined at sub-millimeter-level, the relation to physical phase centers of the instruments and temporal stability of such offsets are usually known with significantly lower precision. Novel ways for inter-technique calibration at a geodetic site need to be developed using existing and new sensors and technologies, such as highly accurate time and frequency transfer, ultra-stable clocks, and co-location targets. Complementary to such development the tying of techniques shall be exploited to their limits at the analysis level e.g. to using common clock and troposphere parameters.