# Report of the CCTF WG on TWSTFT

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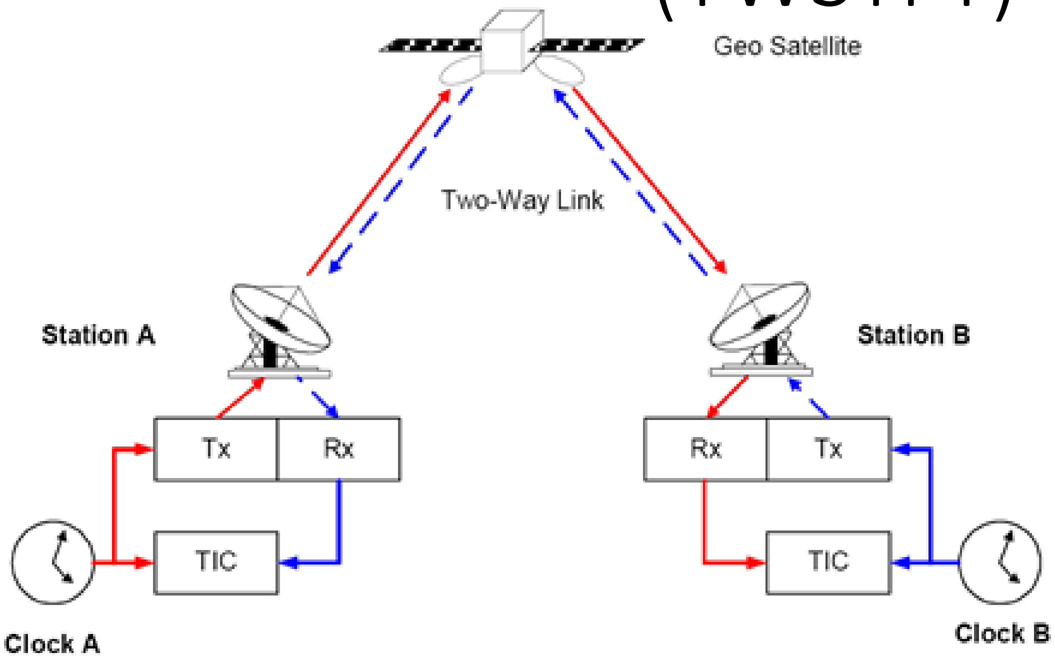
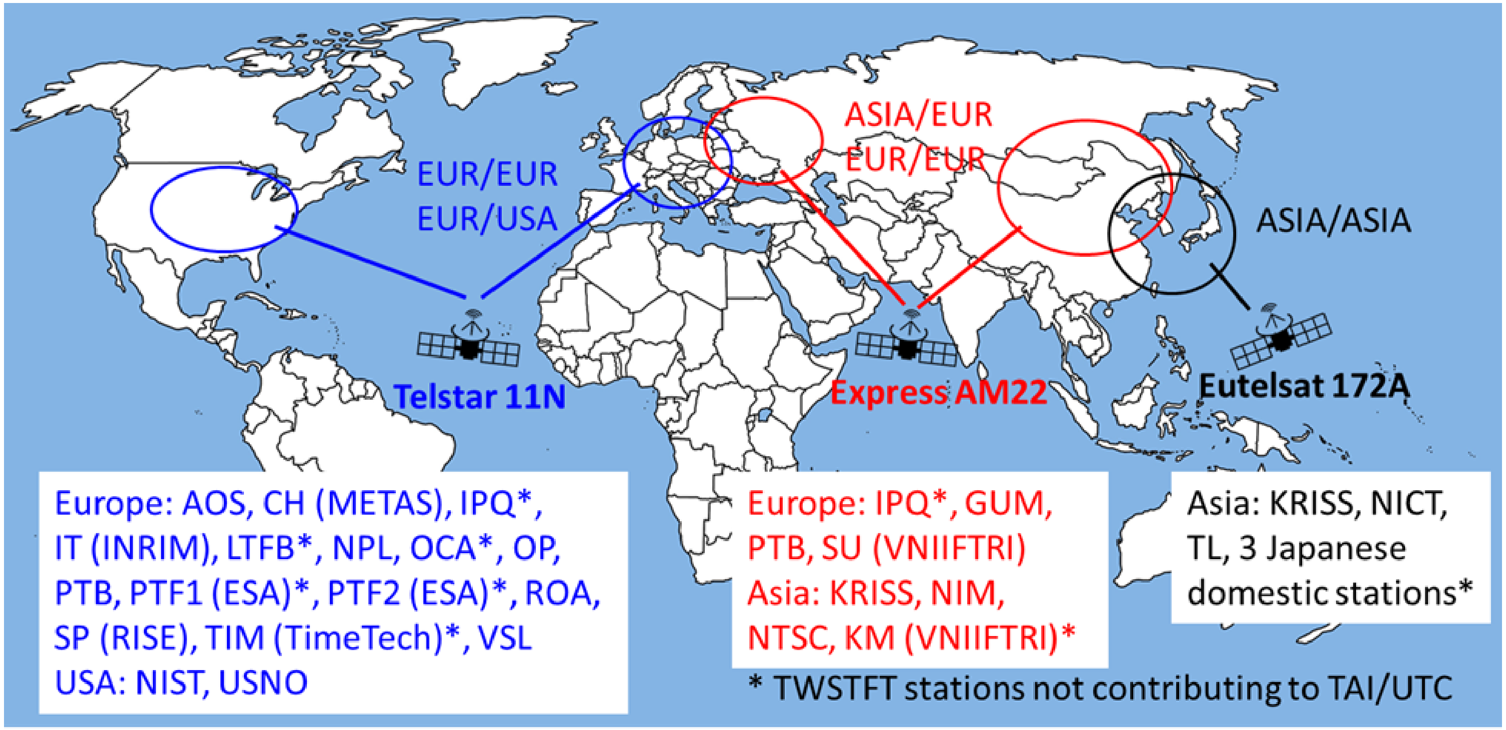
# Two-Way Satellite Time and Frequency Transfer (TWSTFT)




- One of the primary techniques for UTC generation
- $u_B$ ~ 1 ns and $u_A$ ~ 0.5 ns (Circular T)
- Accurate and precise clock comparison results available in near real time
- Independent of and complementary to GNSS time transfer

- Timing signals (phase coherent to a local clock) are carried by pseudo-random noise (PRN) codes (1 – 2.5 Mchip/s).
- Coded timing signals are exchanged between two stations in Ku-band (11-14.5 GHz) transponders (1.6 – 2.5 MHz bandwidth) on geostationary satellites.
- Each station measures the time difference of its transmit and received signals.
- Clock difference is obtained by differencing the measurements of two station with delay corrections.

# TWSTFT Networks (May, 2017)




| Satellite | Network | Status |
|---|---|---|
| Telstar 11N | Europe/Europe, Europe/USA | New contract: 11/26/2016-5/26/2021 |
| Express AM22 | Asia/Europe, Europe/Europe | Searching for a new satellite |
| Eutelsat 172A | Asia/Asia | Stable in near future |

# TWSTFT Participating Laboratories (May, 2017)

Asia: BIRMM*, KRISS, NICT, NIM, NIMJ, NPLI, NTSC, TL

Europe: AOS, CH (METAS), GUM, IPQ*, IT (INRIM), LTFB*, NPL, OCA*, OP, PTB, PTF1 (ESA)*, PTF2 (ESA)*, ROA, SP (RISE), SU (VNIIFTRI), TIM (TimeTech)*, VSL

U.S.A.: NIST, USNO

Links used in TAI/UTC computation

* Participating stations have no direct links to PTB or not contributing to TAI/UTC computation

# Calibrations of TWSTFT Links

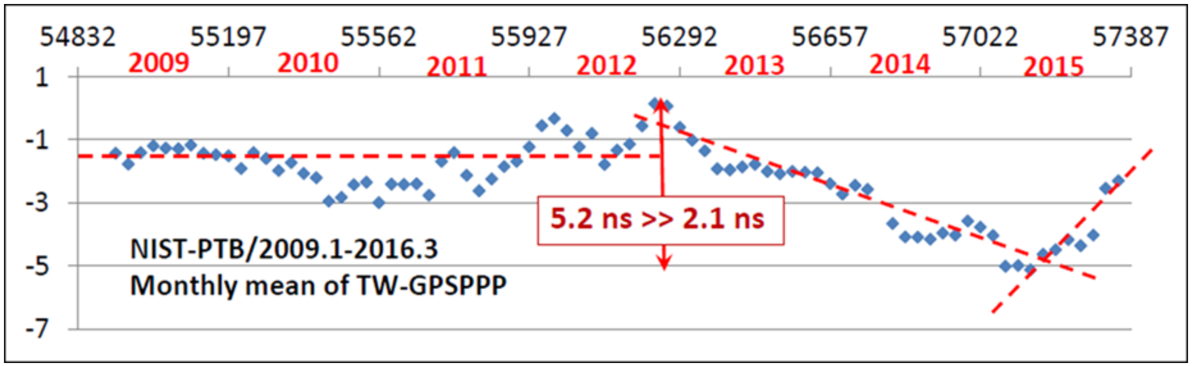
Calibration campaigns during 2015 – 2017:

- 2015 BIPM GNSS receiver: NIST, OP, PTB, USNO with Triangle Closure Calibrations to CH, IT, ROA, SP and VSL (TM268)
- 2016 TimeTech mobile station: IT, OP, PTB ROA, SP
- 2016 USNO X-band mobile station: PTB, USNO
- 2016-2017 USNO Ku-band mobile station: NIST, USNO

The "TWSTFT Calibration Guidelines for UTC Time Links" was updated in 2016

UTC link calibrations
Non-UTC link calibrations

# Activity (1): Task Group Study on Long-Term Instability of UTC Time Links

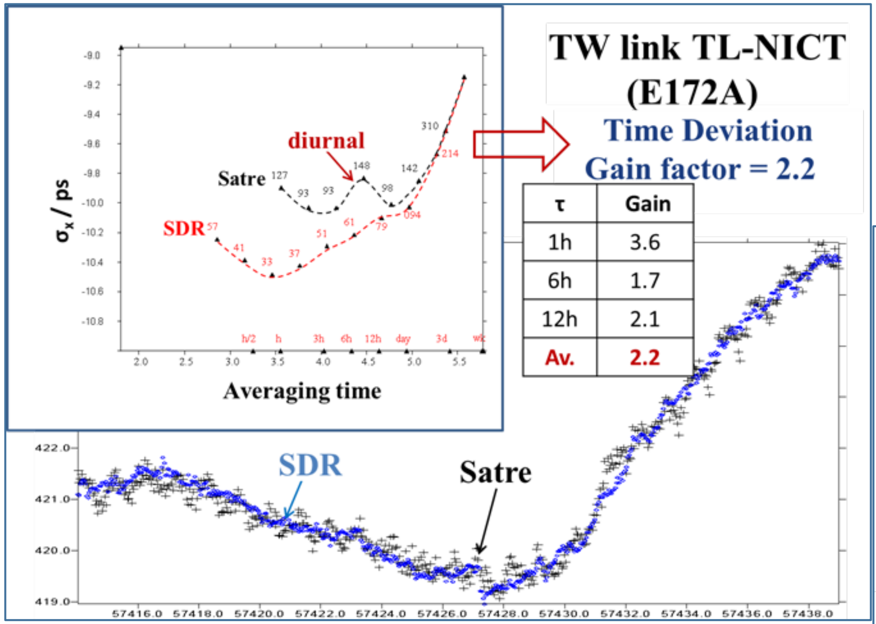



Seven-year Double-Clock Difference (DCD) of TWSTFT – GPSPPP for the NIST/PTB baseline. The vertical axis is for DCD in ns, and the horizontal axis is for MJD in days. The estimated uncertainty of the NIST/PTB link was 2.1 ns during the data period.

- several-ns variations happen too often to ignore; they are observed in GNSS-only, TWSTFT-only, and GNSS-TWSTFT;
- past performance is not a reliable indicator of future stability;
- multiple independent GNSS systems are crucial;
- calibrations should be conducted yearly, a GNSS calibration can be complementary to a TWSTFT calibration, especially if they are done at the same time;
- environmental control is important;
- more attention must be given to recording configuration changes and environmental conditions.

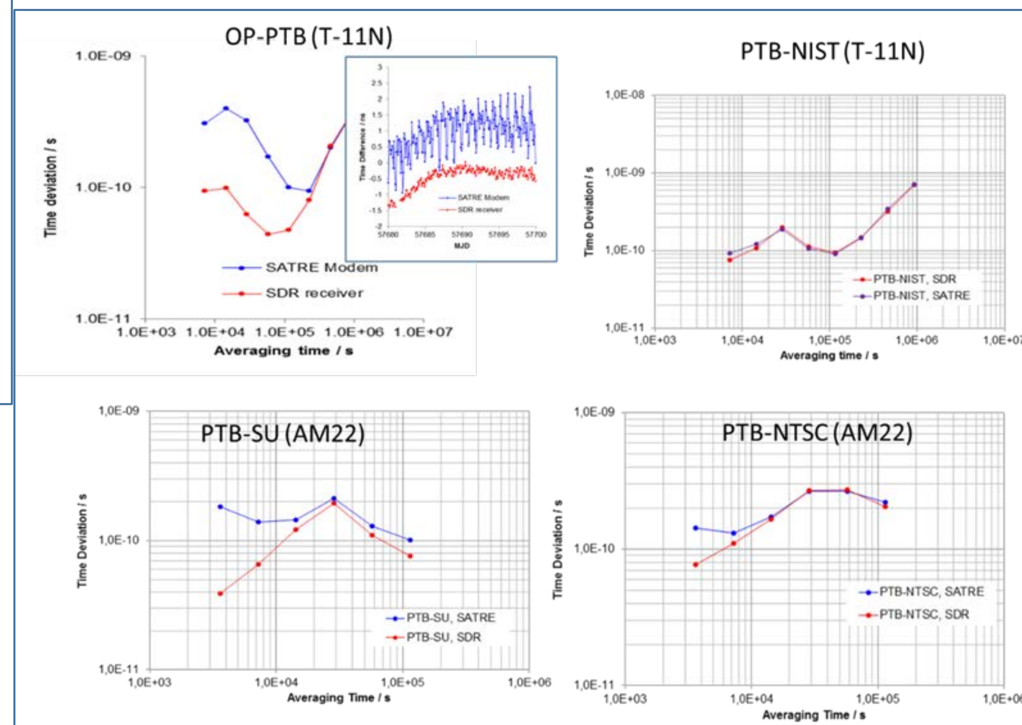
→ Recommendation "On Utilizing and Monitoring of the Redundant Time Transfer Equipment in Timing Laboratories Contributing to UTC"

# Activity (2): Pilot Study on Using Software Defined Radio (SDR) Receivers for TWSTFT




| τ | Gain |
|---|---|
| 1h | 3.6 |
| 6h | 1.7 |
| 12h | 2.1 |
| **Av.** | **2.2** |

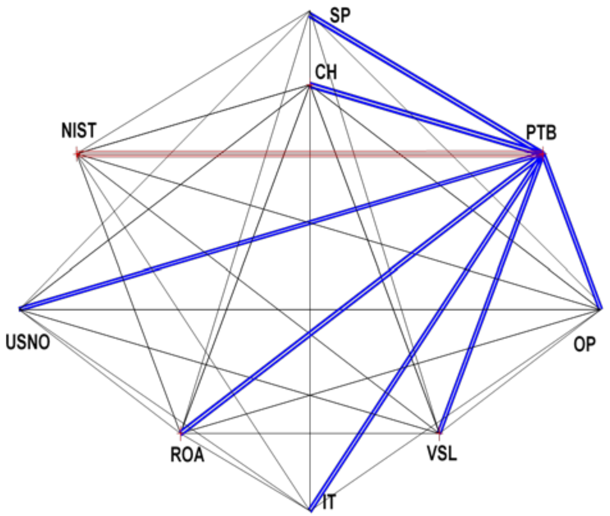
SDR TWSTFT receivers are used to measure the coded timing signals transmitted by the currently used TWSTFT equipment.




SDR TWSTFT shows

- significant reduction of diurnal and time transfer noise for most *inner-continental* TWSTFT links;
- Reduction of short-term (a few hours) time transfer noise for *inter-continental* TWSTFT links.

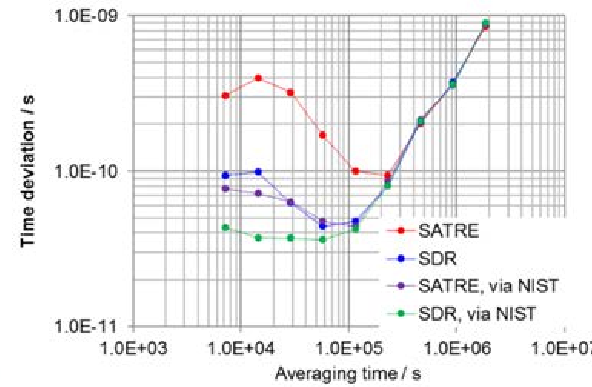
# Activity (3): Study on Using Redundant TWSTFT Measurements

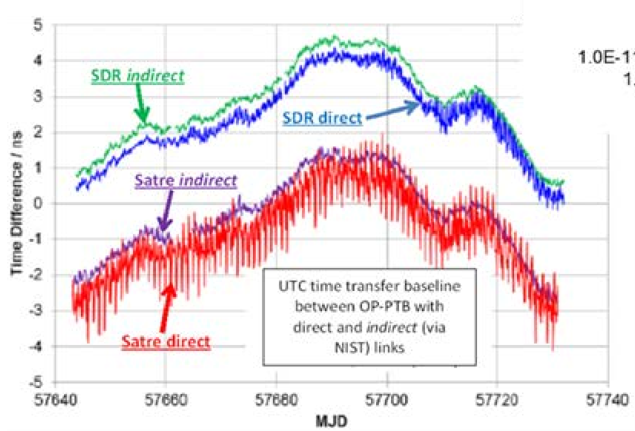



The UTC time links (blue or red lines) and the redundant/non-UTC links (black lines)
The blue links are calibrated with the TW mobile station (uB ≤ 1 ns) and red links with the GPS calibrator (uB ≤ 1.5 ns)

Example of computing OP/PTB TWSTFT difference from the NIST/OP – NIST/PTB indirect (redundant) measurements

The indirect link TWSTFT does not require additional measurements or new equipment.

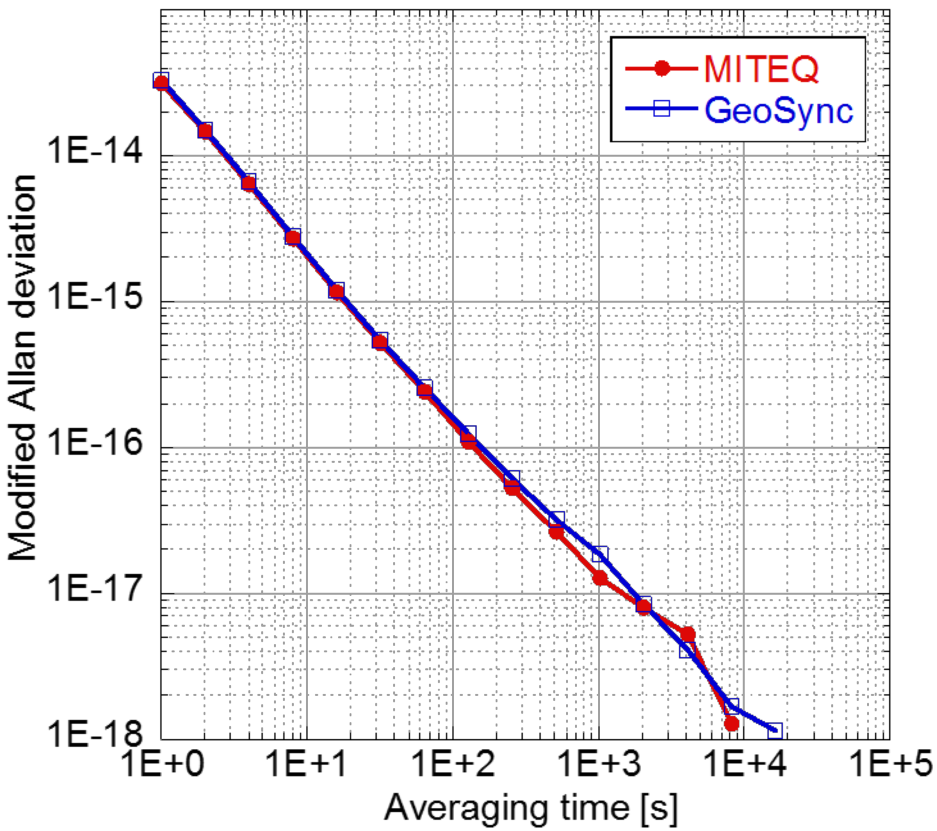


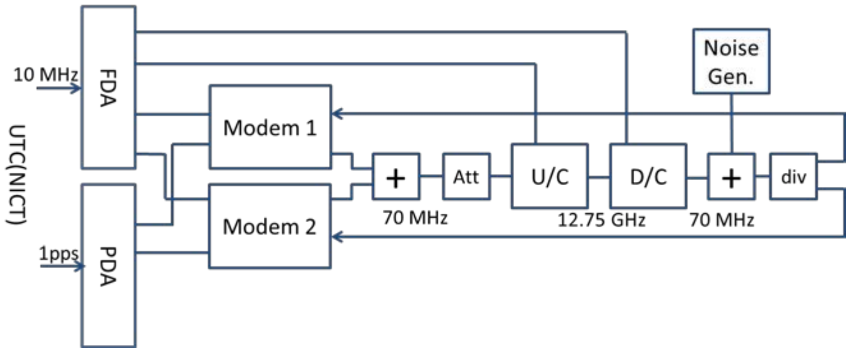

Time transfer noise and diurnal in the direct inner-Europe TWSTFT links can be reduced by using the indirect links via the transatlantic TWSTFT measurements.

# Activity (4): Developing Digital TWSTFT Modem

Carrier phase@12.75 GHz,




Common clock measurement setup




If the carrier-phase performance can be realized through the satellite TW, it has the potential to directly compare remote optical frequency standards.

# Activity (5): Meetings

Annual meetings:

- 24th Meeting, 7-8 September, 2016, NIST, Boulder, Colorado, U.S.A.
- 25th Meeting, 18-19 May, 2017, NTSC, Xi'an, China

Participating stations meetings at conferences:

- PTTI 2016, 25-28 January, 2016, Monterey, California, U.S.A.
- 30th EFTF, 4-7 April, 2016, York, United Kingdom
- PTTI 2017, 30 January – 2 February, 2017, Monterey, California, U.S.A.

Thanks for the supports from TWSTFT participating laboratories, the BIPM and CCTF members!

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