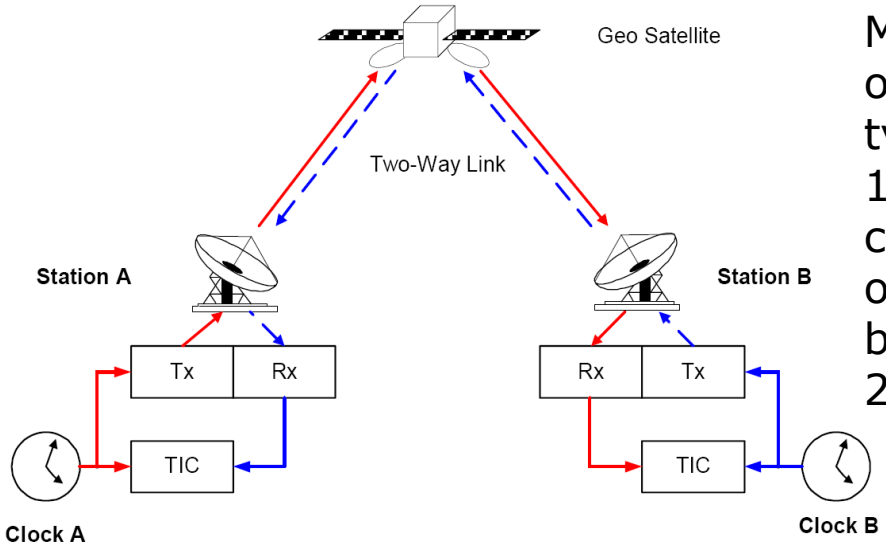
Report of the CCTF WG on TWSTFT

Dirk Piester

20th Meeting of the CCTF, BIPM, 17-18 September 2015

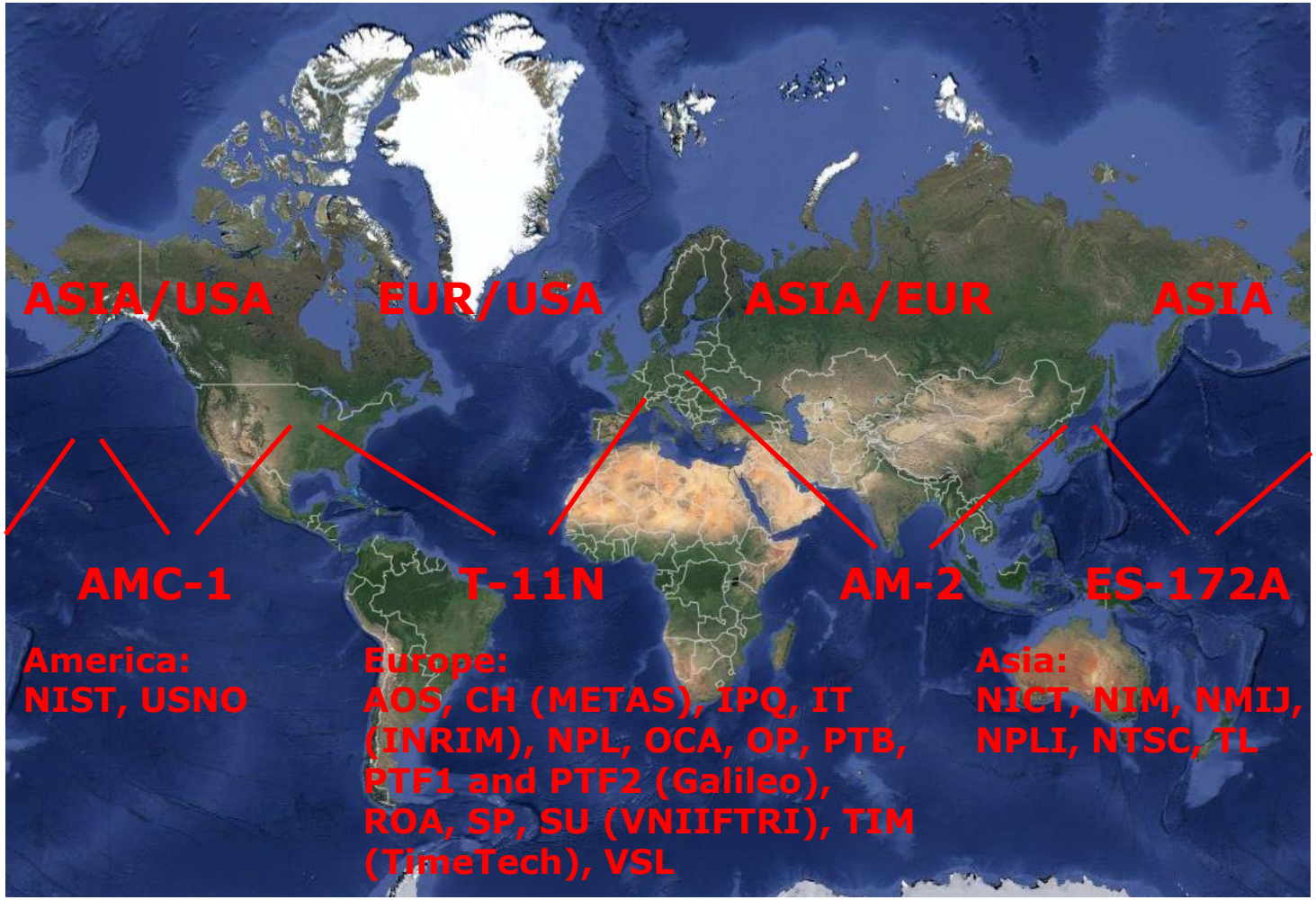
Two-way satellite time and frequency transfer (TWSTFT)
How does it work?

Phase coherent to a local clock pseudo random noise phase-shift keying spread spectrum signals are exchanged between two stations typically in the Ku-band 11 – 14.5 GHz.



Modulation of operational links is typically 1 – 2.5 Mcps, corresponding to occupied transponder bandwidth of about 2 – 4 MHz.

Two-way satellite time and frequency transfer (TWSTFT)
The global metrology network - until December 2014



Not all stations can access to all intercontinental links.

Members

The members of the working group are representatives and especially experts of the participating institutes as well as representatives of prospective participating institutes.

America:
NIST, USNO

Asia:
NICT, NIM, NMIJ, NPLI, NTSC, TL

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

Chair:
D. Piester (2009-2015) -> Victor Zhang, NIST (2015-)
Secretary:
Zhiheng Jiang

Meetings

Annual Meetings:

21st Meeting, 5th and 6st September 2013, Taipei, Taiwan

22nd Meeting, 15th and 16th September 2014, VNIIFTRI, Mendeleevo, Russia

23rd Meeting , 7th and 8th September 2015, BIPM, Sèvres, France

Meetings

Participating Stations Meetings at Conferences:

44th PTTI, 26-29 Nov 2012, Reston, Virginia, USA

Joint UFFC, EFTF and PFM, 21-25 Jul 2013, Prague, Czech Republic

45th PTTI, 2-5 Dec 2013, Bellevue (Seattle), WA, USA

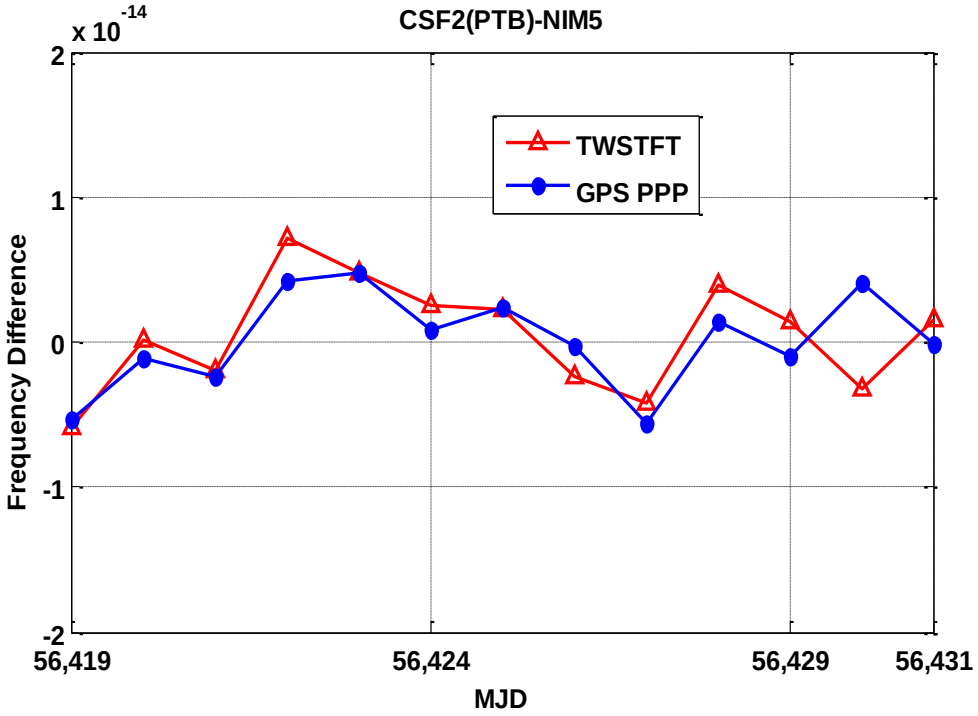
28th EFTF, 23-26 Jun 2014, Neuchâtel, Switzerland

ION PTTI 2014, 1-4 Dec 2014, Boston, MA, USA

2015 Joint IEEE IFCS & EFTF, 12-16 Apr 2015, Denver, CO, USA

New developments in TWSTFT

Fountain clock comparisons:



6 Cs fountain clocks in 4 institutes in Asia and Europe were compared by TWSTFT and GPS CP in May 2013.

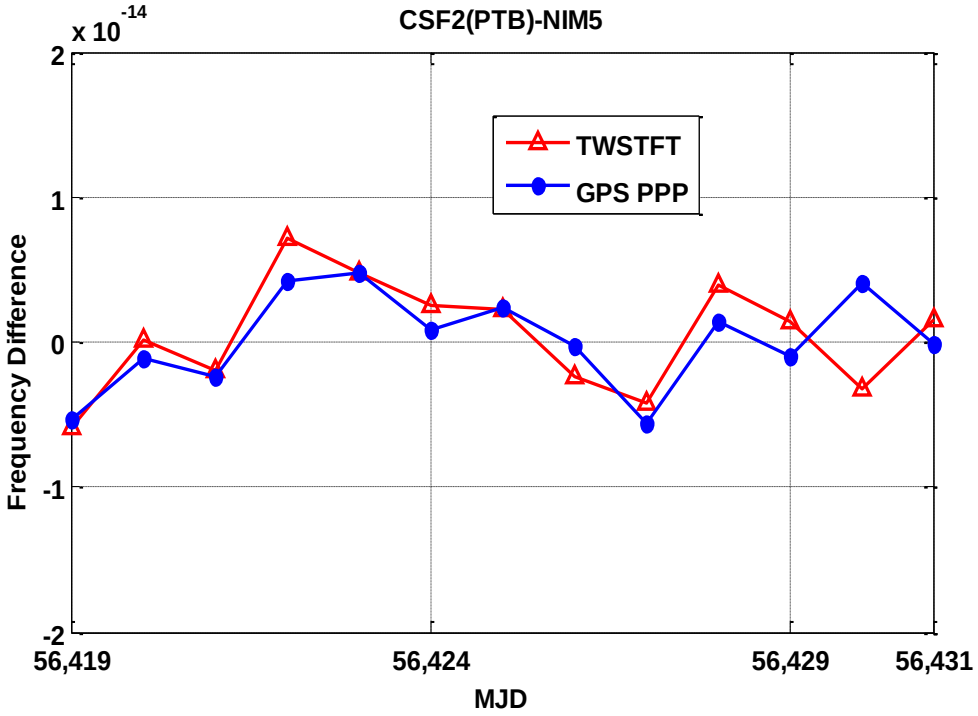
Participating institutes:
NIM
NPLI
PTB
VNIIFTRI

Satellite: AM-2
Chiprate: 2.5 Mcps

Duration: 20 days

New developments in TWSTFT

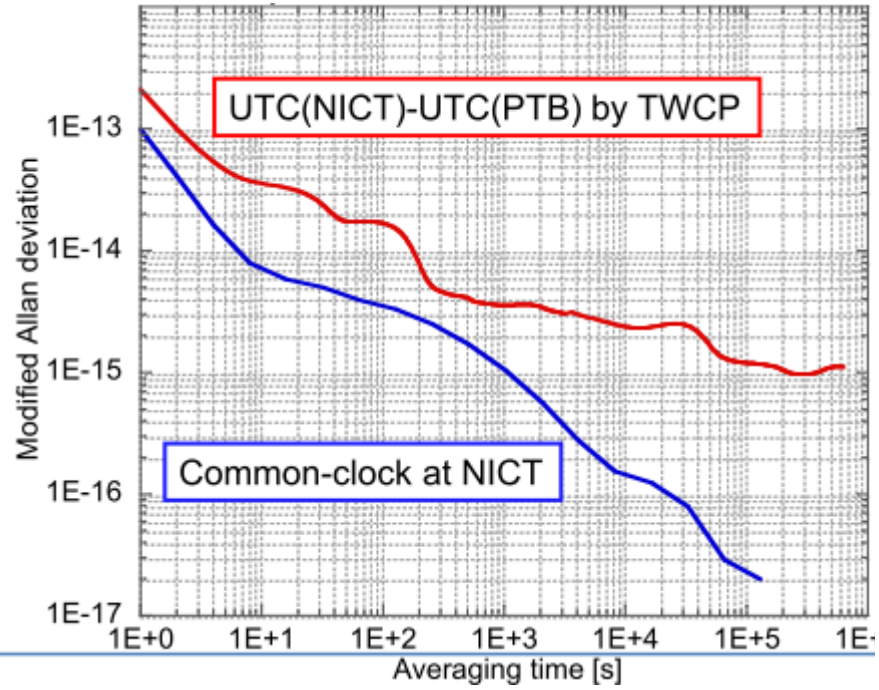
Fountain clock comparisons:

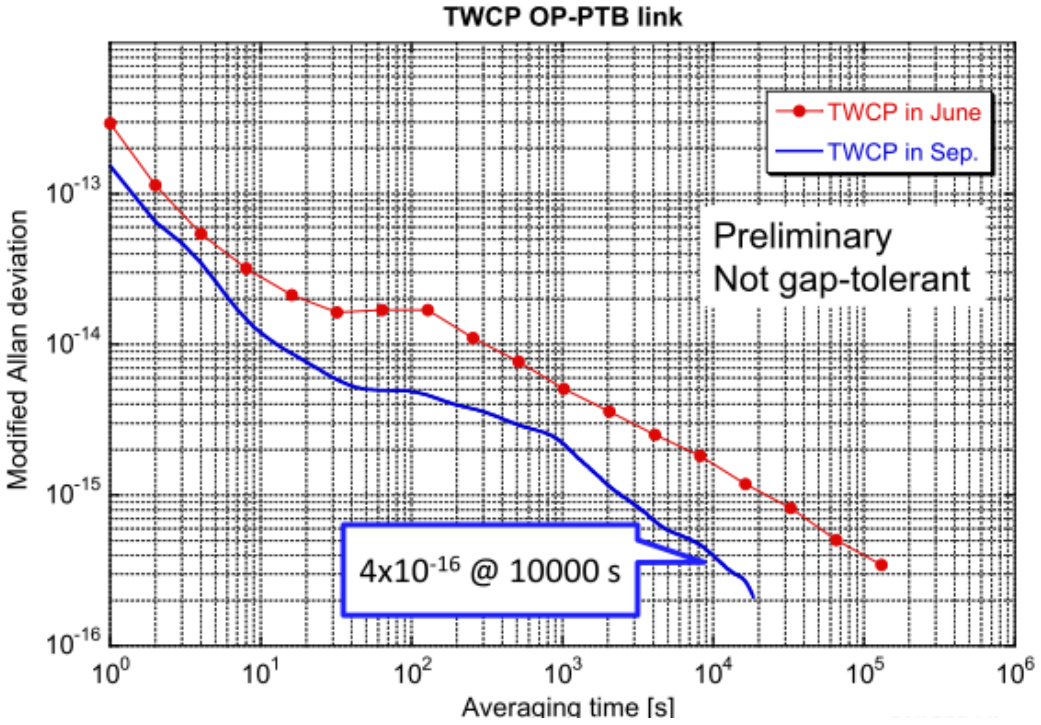


Pair of fountains	TWSTFT (1e-15)	GPS CP (1e-15)	U (1e-15)
PTB CSF1-NIM	0.3	-0.1	2.3
PTB CSF2-NIM	0.5	0.1	2.2
SU CSF1-NIM	0.2	-1.1	2.9
SU CSF2-NIM	0.5	-0.8	2.2
PTB CSF1-SU CSF1	-0.1	1.1	1.2
PTB CSF1-SU CSF2	-0.7	0.5	1.0
PTB CSF2-SU CSF1	-0.2	1.0	1.8
PTB CSF2-SU CSF2	-0.8	0.4	0.8
PTB CSF1-NPLI	1.2	1.0	2.6
PTB CSF2-NPLI	1.1	0.9	2.6
NIM-NPLI	0.0	0.5	3.3
SU CSF1-NPLI	1.1	-0.1	3.1
SU CSF2-NPLI	1.8	0.6	2.6

New developments in TWSTFT

TWSTFT carrier phase:

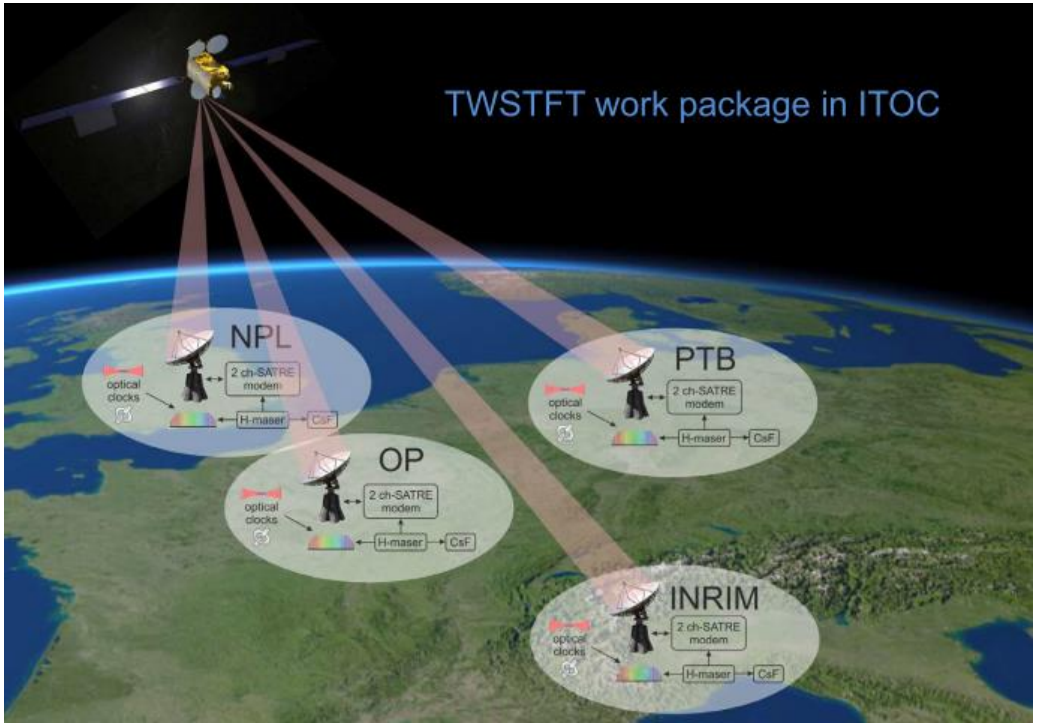




Application:
First direct intercontinental comparison of optical clocks in 2013
[Hachisu et al., Opt. Lett., 39(14), 4072, 2014.]

New developments in TWSTFT

Broadband TWSTFT:

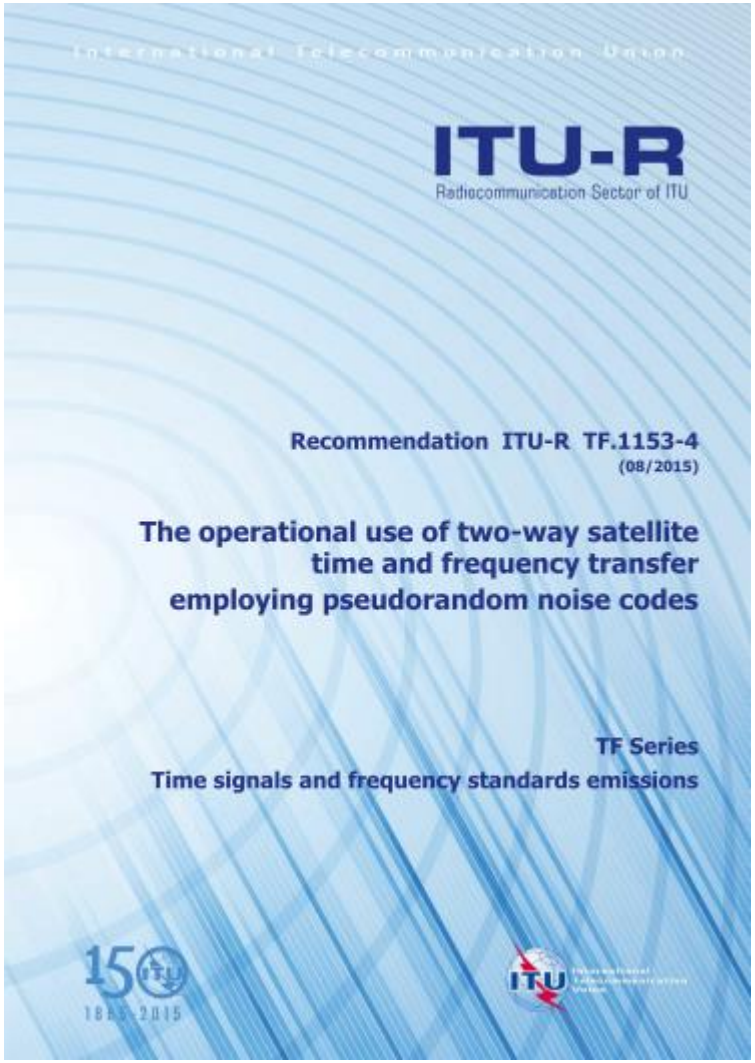


An increased chiprate of 20 Mcps decreases measurement noise significantly.

Four European institutes operated a dedicated broadband TWSTFT link to compare primary frequency standards as well as optical clocks.

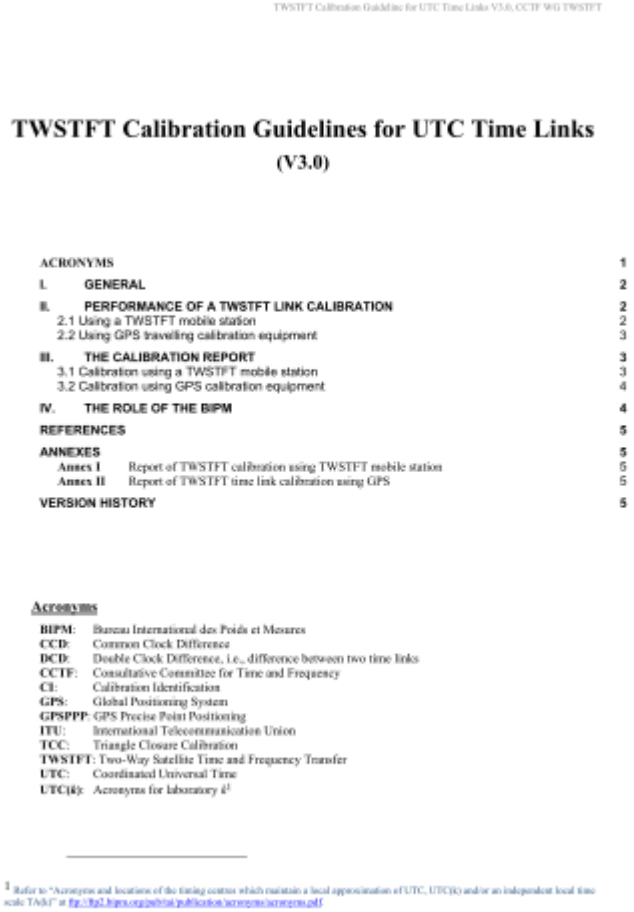
In a test campaign in October 2014 instabilites < $2 \cdot 10^{-16}$ @ 1 day averaging time was observed. The optical clock comparison took place in June 2015. Data analysis is ongoing.

Data handling and calibration guidelines



For the production of UTC measurement data are provided by the individual participating stations following the ITU Recommendations ITU-R TF.1153-3. It was found necessary to calculate corrections applied to the measurement results with a higher accuracy than considered necessary in previous editions. As the Earth is not perfectly spherical, it is considered as an ellipsoid at first approximation. For a given location, there are a single longitude and two latitudes: the geocentric latitude and the geodetic latitude. The current version ITU-R TF.1153-4 takes proper care of this in the calculation of the Sagnac correction.

Data handling and calibration guidelines



TWSTFT Calibration Guidelines for UTC Time Links V3.0, CCTF WG TWSTFT

TWSTFT Calibration Guidelines for UTC Time Links

(V3.0)

Acronyms

BIPM: Bureau International des Poids et Mesures
CCD: Common Clock Difference
DCD: Double Clock Difference, i.e., difference between two time links
CCTF: Consultative Committee for Time and Frequency
CI: Calibration Identification
GPS: Global Positioning System
GPSPPP: GPS Precise Point Positioning
ITU: International Telecommunication Union
TCC: Triangle Closure Calibration
TWSTFT: Two-Way Satellite Time and Frequency Transfer
UTC: Coordinated Universal Time
UTC(i): Acronyms for laboratory i[1]

[1] Refer to "Acronyms and locations of the timing centres which maintain a local approximation of UTC, UTC(i) and/or an independent local time scale TA(k)" at ftp://ftp2.bipm.org/pub/tai/publication/acronyms/acronyms.pdf

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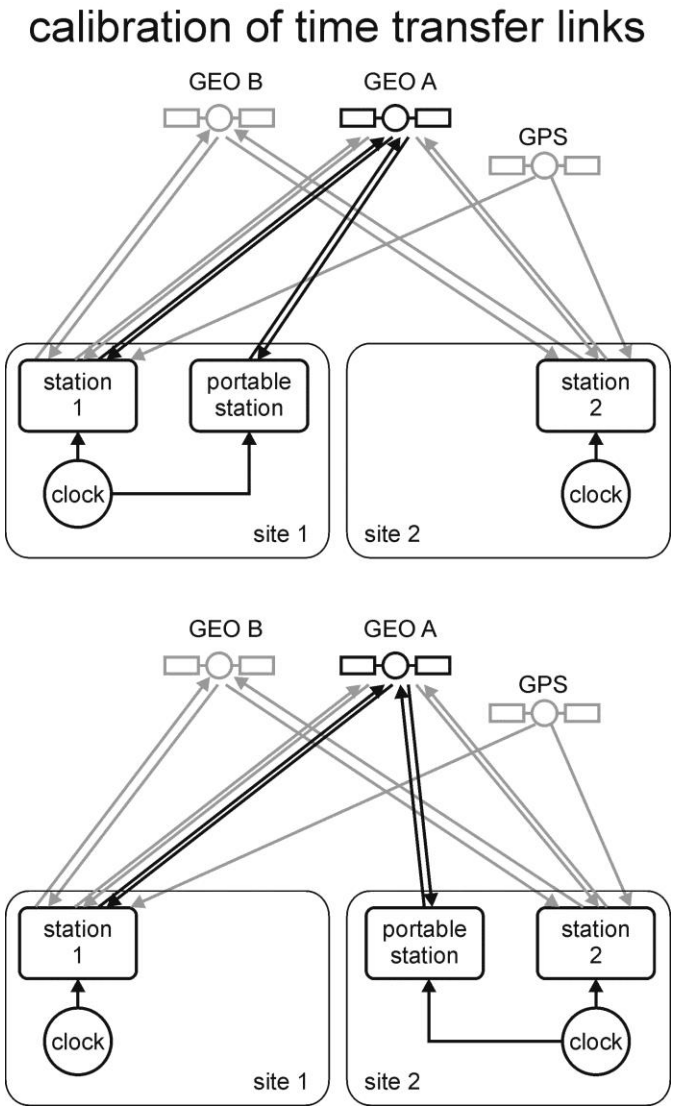
For harmonization of reporting results of TWSTFT calibration campaigns to BIPM guidelines were written and agreed.

They consist of one document describing general considerations of the procedure for calibrations by using a mobile TWSTFT station as well as the calibration of TWSTFT links using transportable GNSS receivers.

In subsequent annexes examples are given for both cases.

Calibration of TWSTFT links



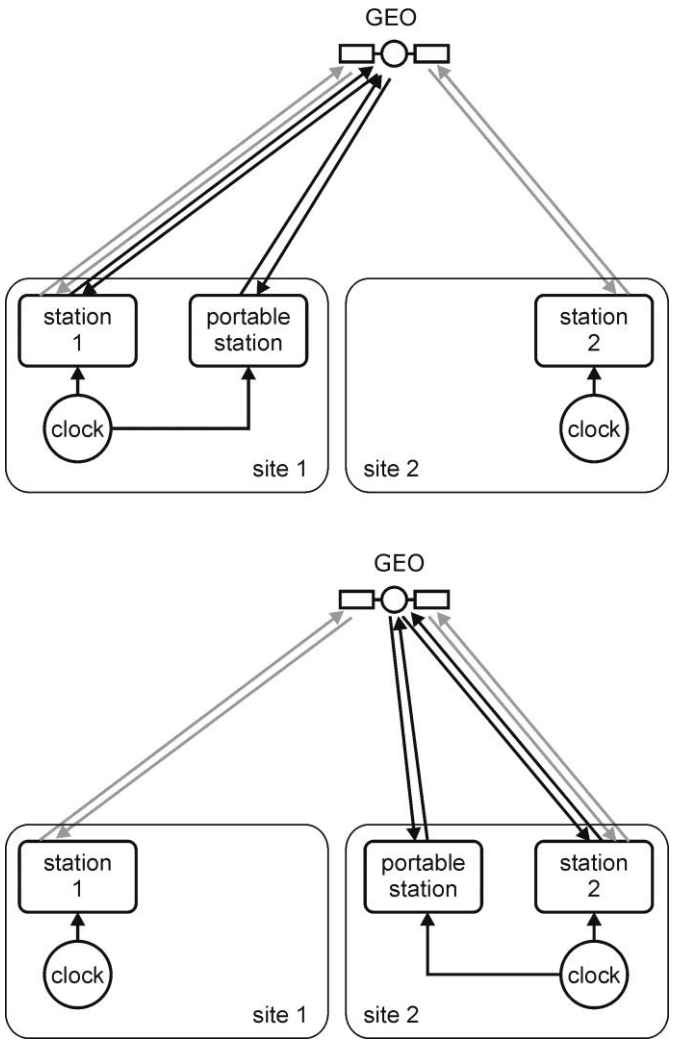
In principle two methods for calibrations

Calibration of time-transfer links

+ any other link (e.g. GPS can be calibrated directly)
+ operational parameters remain constant
- noise of three measurements

Calibration of TWSTFT links

calibration of ground stations



In principle two methods for calibrations

Calibration of time-transfer links

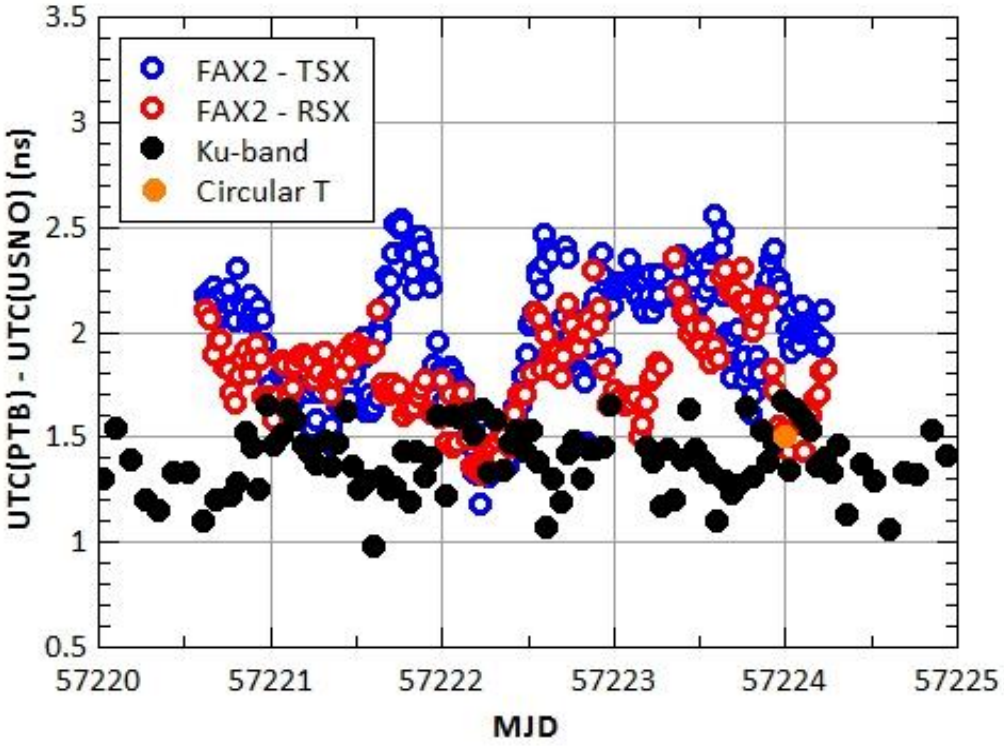
+ any other link (e.g. GPS can be calibrated directly)
+ operational parameters remain constant
- noise of three measurements

Calibration of ground stations

+ noise of two measurements
+ complete network can be calibrated easily
- Operational parameters have to be changed

July 2015: Calibration of the link UTC(USNO)-UTC(PTB) by a portable X-band station

with R. Bumgarner, J. Wright, J. Hirschauer, A. McKinley



The established X-band TWSTFT link (red and blue) was operated in parallel to the operational Ku-band TWSTFT link (black) for nearly four days.

	correction (ns)	u_A (ns)	$u_{B,1}$ (ns)	$u_{B,2}$ (ns)	$u_{B,3}$ (ns)	U (ns)
X-band - Ku-band	0.466	0.233	0.522	0.5	0.1	0.766

Calibration of TWSTFT links

Calibration campaigns during the last three years:

2012:
VNIIFTRI mobile station (+GPS, +H-maser): VNIIFTRI, PTB
TimeTech mobile station: METAS, LNE-SYRTE, PTB, TIM

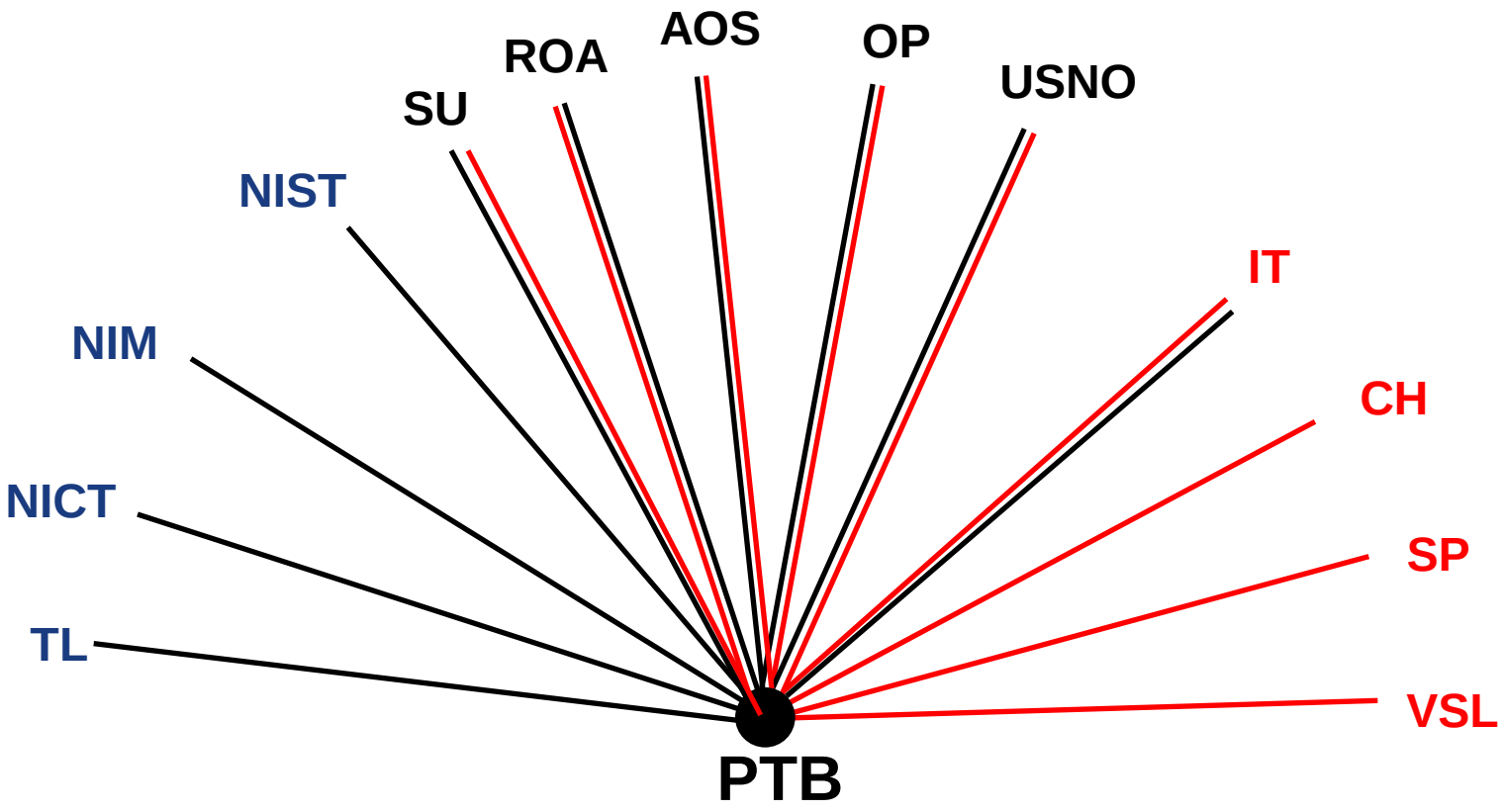
2013:
TimeTech mobile station: AOS, ESTEC, VSL, TIM
USNO fly away station: USNO, PTB

2014:
TimeTech mobile station: INRIM, LNE-SYRTE, PTB, PTF1, PTF2, ROA, SP
USNO fly away station: USNO, PTB
BIPM GNSS receiver: NICT, NIM, TL, OP, PTB, ROA

2015:
USNO fly away station: USNO, PTB
BIPM GNSS receiver: NIST, USNO, OP, PTB

Calibration of TWSTFT links

UTC TWSTFT links calibrated in 2013-2014



3 by GPS : uB ≤ 0.8~1.5 ns

3 by TW: uB ≤ 0.6~0.8 ns

6 by GPS+TW: uB ≤ 0.6~0.8 ns

Two-way satellite time and frequency transfer (TWSTFT)
The global metrology network – 2015

Not all stations can access to all intercontinental links.

Thanks for your attention!
Благодаря за вниманието!
感谢您的关注
Děkuji vám za pozornost
Dank voor uw aandacht!
Merci pour votre attention!
Σας ευχαριστώ για την προσοχή σας
Grazie per l´attenzione!
ご清聴ありがとうございます
감사합니다
Ačiū už dėmesį
Dziękuję za uwagę!
Obrigado pela vossa atenção
Спасибо за внимание
¡Gracias por su atención!
Tack för er uppmärksamhet!
உங்கள் கவனத்திற்கு நன்றி!
Danke für Ihre Aufmerksamkeit!