53rd CGSIC Meeting - Timing Subcommittee

Nashville, Tennessee, 16 September 2013

Chair: **Włodzimierz Lewandowski, BIPM**
Co-Chair: **Victor Zhang, NIST**

09:00 Introduction – ***Włodzimierz Lewandowski, BIPM, presented by Victor Zhang***
09:30 Report from NIST – ***Victor Zhang, NIST***
10:00 Report from USNO – ***Demetrios Matsakis, USNO***
10:30 Coffee Break
11:00 Galileo IOV System Time Status – ***Joerg Hahn, ESA, given by Demetrios Matsakis***
11:20 Time and Navigation Exhibition at the Smithsonian: Report on Opening
– ***Andrew Johnston, National Museum of American History***
11:40 Update on ITU-R agenda related to time scales - ***Joe White, NRL***
12:00 Discussion
12:30 Session End

BIPM

T soft

News from the BIPM

Felicitas Arias, Włodzimierz Lewandowski

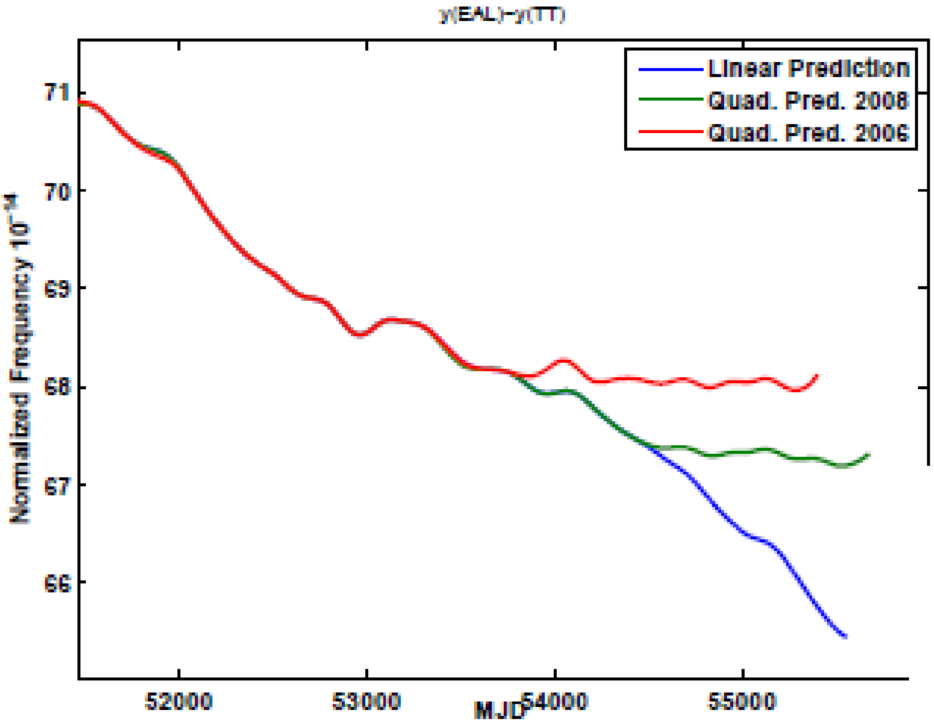
Time Department

Topics

- **Improvement of the long term stability od EAL – new model for the clock frequency prediction**
- **Improvement of time transfer**
- **Rapid UTC**

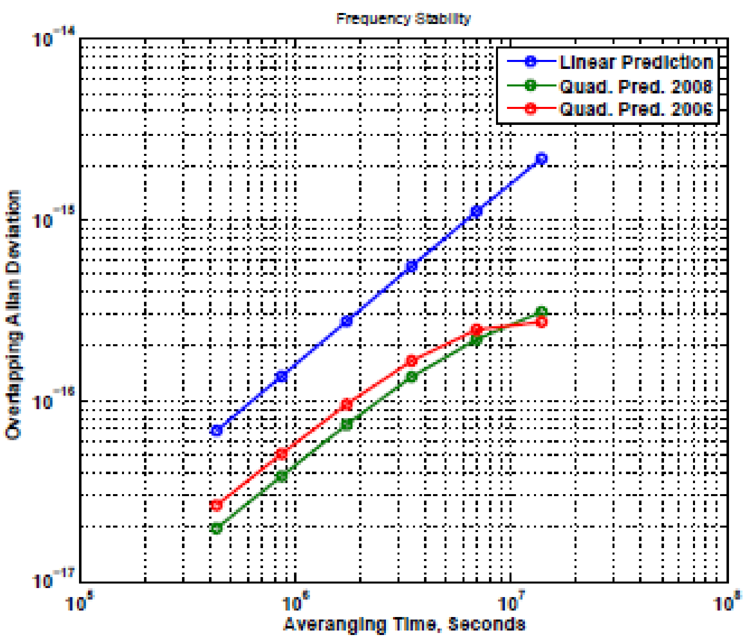
Drift of EAL, improving the long term stability

- ✓EAL presented a drift of about $+4 \times 10^{-16}$/□month with respect to TT(BIPM);
- ✓Strong monthly frequency corrections (see Section 3 *BIPM Circular T*) have shown little of not effect;
- ✓The algorithm (ALGOS) had a linear model for the clock frequency prediction
  - ✓ Well adapted when it was developed, with "young" Cs clocks, no H- masers, few primary frequency standards
  - ✓ 23% of the clocks in TAI are H-masers
  - ✓ The Cs are aging
  - ✓ About a dozen PFS report measurements, most of them Cs fountains
- ✓A new model has been implemented and incorporated in ALGOS, with a parabolic model for all clocks.(Panfilo, Harmegnies, Tisserand). *Circular T* since August 2011 was calculated with the new model.



EAL – TT(BIPM)

Published in *Metrologia*



Linear prediction (blue)
Quadratic, data since 2006 (red)
Quadratic, data since 2008 (green)

Time transfer

- ✓ **GPS/GLONASS/TW data daily reported – Only laboratories with non-adapted GPS receivers still send weekly files.**
- ✓ **All laboratories post data in specific ftp directories.**
- ✓ **Combined GPS/GLONASS and TWPPP links are routinely used in the calculation of UTC.**
- ✓ **New calibration system for GPS links, allowing maintenance of TW calibration.**

Characteristics of UTCr

– **Based on daily data reported (daily) by contributing laboratories**

– **Weekly access to daily values of [*UTCr*-*UTC*(*k*)]**

– **Automatically generated weekly solution over four weeks of data (sliding solution)**

Implementation of UTCr

- **September 2011**: UTC contributing laboratories have been invited to participate on a voluntary basis to a pilot experiment.
- **January 2012**: Pilot experiment started, with the target of reporting to the CCTF in September 2012.
- **July 2013**: Operational production of UTCr.

Impact of a rapid realization of UTC

- **On UTC contributing laboratories:**
  - **More frequent assessing of the UTC(K) steering, and consequently better stability and accuracy of [UTC(k)];**
  - **Traceability to UTC will be enhanced.**
- **On users of UTC(K):**
  - **Access to a better "local" reference, and indirectly, better traceability to the UTC "global" reference.**
- **On GNSS:**
  - **Better synchronization of GNSS times to UTC, through improved UTC and UTC(k) predictions: case of UTC(USNO) for GPS, UTC(SU) for GLONASS, UTC(k) used in the generation of Galileo ST, BeiDou ST and Gagan ST.**

Publication

- Every Wednesday before 18:00 UTC
- on
- ftp://tai.bipm.org/UTCr/Results/

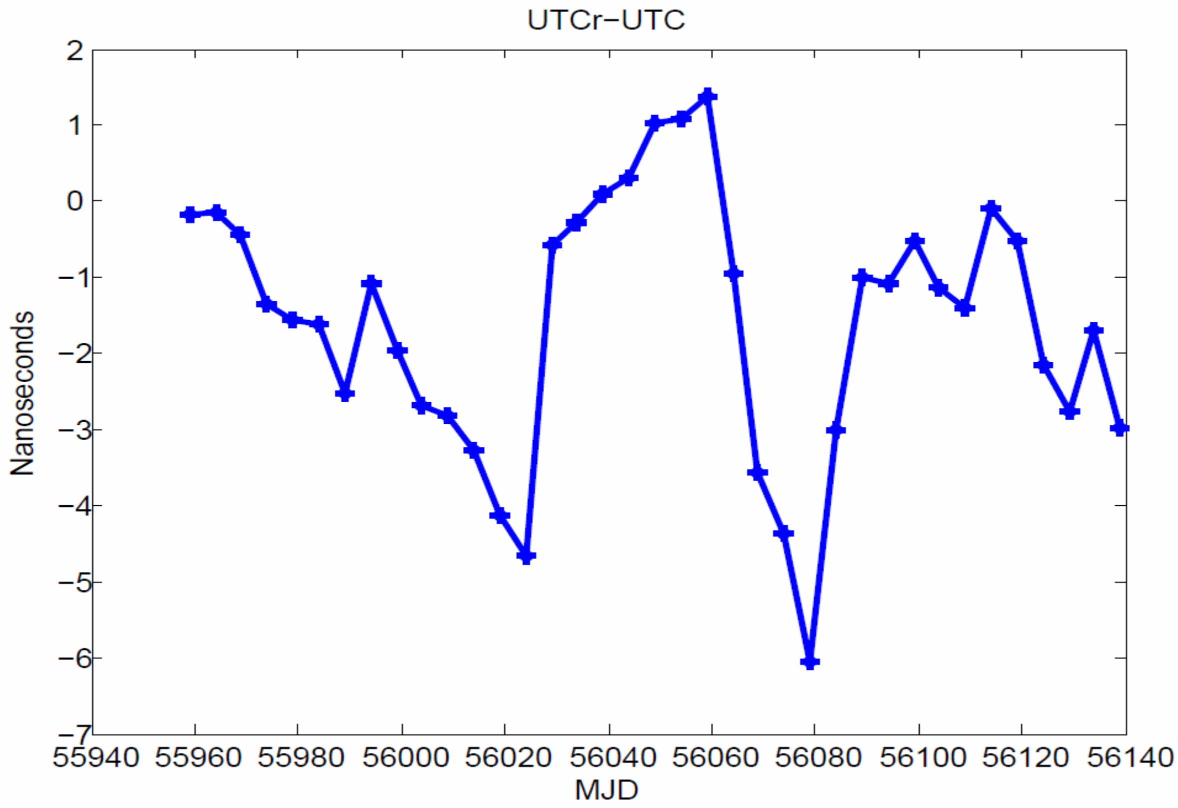
UTCr_1211
2012 MARCH 21, 13h UTC

The results in this page are established by the BIPM Time Department in the frame of the pilot experiment on a rapid UTC, UTCr. The computed values [UTCr-UTC(k)] are reported.

Date 2012 0h UTC	MAR 12	MAR 13	MAR 14	MAR 15	MAR 16	MAR 17	MAR 18
MJD	55998	55999	56000	56001	56002	56003	56004
Laboratory k				[UTCr-UTC(k)]/ns			
AOS (Borowiec)	-2.6	-2.4	-1.9	-1.3	-1.9	-1.9	-1.2
BEV (Wien)	11.9	11.3	10.3	6.5	0.4	-2.3	-5.7
CAO (Cagliari)	-6291.7	-6290.8	-6293.1	-6291.4	-6298.8	-6308.3	-6300.0
CH (Bern)	-12.5	-12.3	-12.0	-10.9	-9.8	-9.2	-9.3
CNM (Queretaro)	-13.8	-15.0	-15.5	-14.9	-17.3	-18.4	-17.1
CNMP (Panama)	75.8	81.4	85.5	83.1	83.8	83.0	88.0
DTAG (Frankfurt/M)	6.8	5.1	5.8	5.7	6.8	6.4	7.7
IFAG (Wettzell)	-620.2	-619.1	-623.8	-627.3	-627.8	-626.7	-627.4
IGNA (Buenos Aires)	6691.8	6700.6	6711.9	6724.6	6737.0	6747.7	6762.6
INTI (Buenos Aires)	-26.4	-32.2	-32.6	-32.7	-32.5	-31.6	-36.7
IPQ (Caparica)	-23.1	-29.1	-27.5	-24.7	-22.6	-16.5	-12.5
IT (Torino)	1.2	2.3	2.6	3.0	3.4	3.8	4.0
KRIS (Daejeon)	-8.3	-8.7	-9.4	-	-	-	-
LT (Vilnius)	42.4	39.1	32.9	35.0	30.1	37.5	43.8
MSL (Lower Hutt)	67.0	61.2	55.3	-	-	-	-
NAO (Mizusawa)	54.8	49.9	52.4	54.7	50.1	49.0	50.8
NICT (Tokyo)	2.5	2.7	2.6	3.1	3.4	3.2	3.2
NIM (Beijing)	-7.1	-7.5	-8.3	-8.9	-9.8	-9.8	-10.7
NIMT (Pathumthani)	987.6	1008.5	1026.4	1042.7	1058.3	1074.2	1090.9
NIS (Cairo)	-782.1	-784.0	-783.8	-786.8	-794.0	-797.0	-799.5
NIST (Boulder)	-4.1	-5.0	-4.2	-3.9	-6.6	-6.3	-5.2
NMIJ (Tsukuba)	-8.7	-8.4	-8.5	-8.2	-7.7	-8.0	-8.2
NMLS (Sepang)	-664.4	-665.1	-667.1	-667.0	-670.4	-672.4	-674.5
NRC (Ottawa)	-18.1	-14.2	-15.1	-13.9	-13.8	-14.0	-13.6
NTSC (Lintong)	0.8	2.2	2.1	5.0	4.3	4.5	3.8
ONRJ (Rio de Janeiro)	-12.3	-9.7	-6.9	-7.5	-7.8	-4.7	-1.9
OP (Paris)	-24.5	-22.8	-23.7	-21.8	-21.4	-21.8	-24.5
ORB (Bruxelles)	-0.4	-0.1	0.5	0.0	0.4	-0.5	-1.0
PL (Warszawa)	15.8	16.5	18.1	16.1	15.0	12.4	12.8
PTB (Braunschweig)	-3.2	-3.4	-3.6	-3.5	-4.0	-4.0	-4.6
ROA (San Fernando)	-2.8	-2.2	-2.7	-3.1	-3.5	-3.8	-4.4
SCL (Hong Kong)	13.8	11.5	5.2	5.5	2.8	-5.8	-2.0
SG (Singapore)	9.6	9.3	7.5	7.8	7.8	7.4	6.6
SP (Boras)	-15.7	-15.6	-15.5	-15.6	-15.5	-15.6	-16.0
SU (Moskva)	1.4	1.2	2.0	2.2	0.6	0.3	0.9
TL (Chung-Li)	6.4	6.5	5.5	4.9	4.2	2.7	1.3
UME (Gebze-Kocaeli)	103.3	100.2	104.3	109.5	107.7	105.3	107.1
USNO (Washington DC)	-0.7	-1.1	-1.2	-1.3	-1.5	-1.5	-1.5
VSL (Delft)	10.0	8.1	3.6	3.2	4.4	4.5	4.6

These results should not be used as a prediction of UTC.
UTC remains available from the monthly Circular T at
(http://www.bipm.org/jsp/en/TimeFtp.jsp?TypePub=publication).

Comparisons between UTCr and UTC (1): results



Based on first six months (February to July 2012)

Comparisons between UTCr and UTC (2) : clocks

•Comparing the clock populations and statistics for UTCr and UTC over six months:

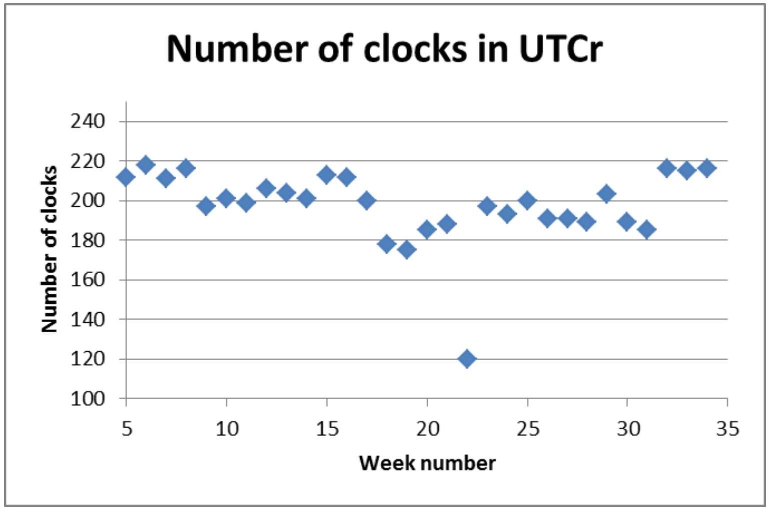
Some 60% of the TAI clocks are in UTCr

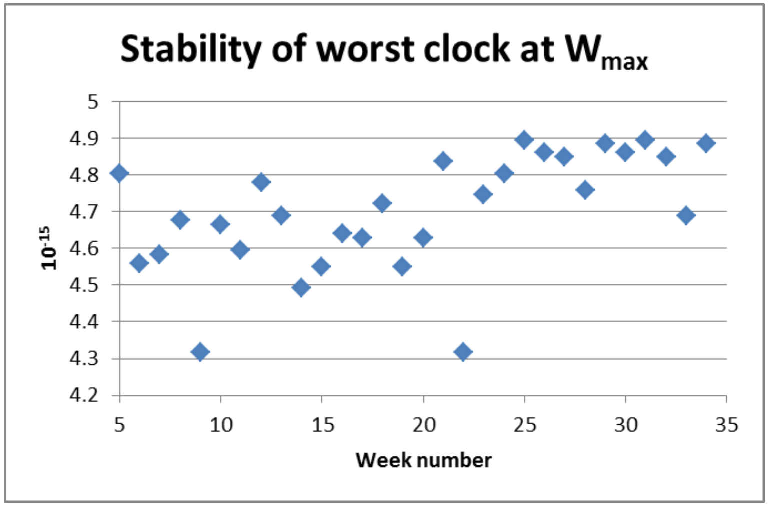
Maximum weight w_{max} has been kept as 2.5/Nclocks

Slightly less clocks (in proportion) reach w_{max} in UTCr

Globally same behavior with 60% of the clocks => UTCr 20% less stable than UTC?

	UTCr	TAI
N clocks for weight	210	360
Max weight w_{max}	1.2%	0.7%
Stability at w_{max}@ 1m	4.5-4.7x10^{-15}	4.8x10^{-15}
Total weight @ w_{max}	31-37%	40%





CCTF WG on TWSTFT
25 years of history

W. Lewandowski

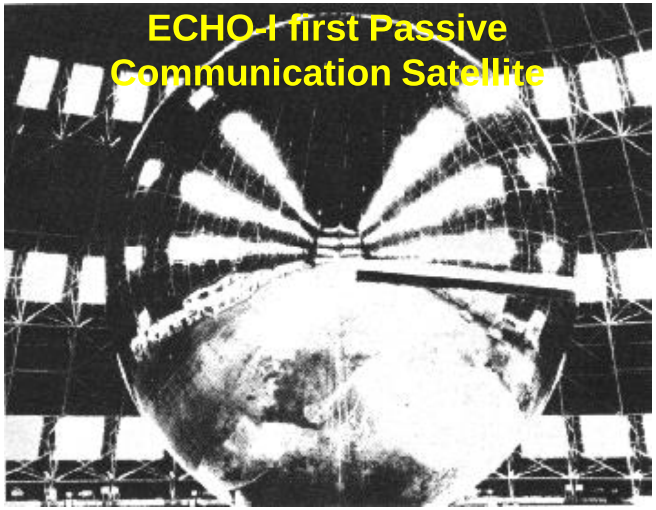
Bureau International des Poids et Measures

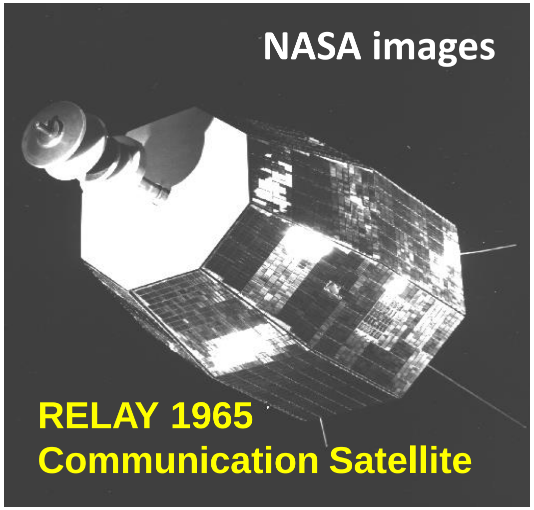
CCTF WG on TWSTFT

25 years of history

1988	CCTF recommends TWSTFT
1989	1st meeting of BIPM ad-hoc WG at VSL
1993	1st meeting of CCTF WG at NPL
1995	ITU standard format for TWSTFT data
1999	1st TWSTFT link in TAI/UTC
2005	Europe-Asia link
2013	21st meeting in Taipei

Early History of TW 1960-1997





As a promising accurate time transfer technique , TWSTT started its experiments ***earlier*** than GNSS.
-1960 Echo-I: One-way time transfer, not ideal due to the unknown propagation delays;
-1962, **Telstar:** The first transatlantic **two-way** clock comparisons between USNO-NPL (US-UK)
-1965 Relay II: The first transpacific **two-way** clock comparisons between USNO-RRL (US-Japan).
The type A (u_A) and B (u_B) uncertainties were near 100 ns and 1000 ns respectively
1970s ATS-1, 1983 Intelsat-V: u_A reached 200 ps level.

People

Prof. Hartl

Dieter Kirchner

Wayne Hanson

Terry Quinn

Lester Veenstra

Gerrit De Jong

Jacques Azoubib

Michito Imae

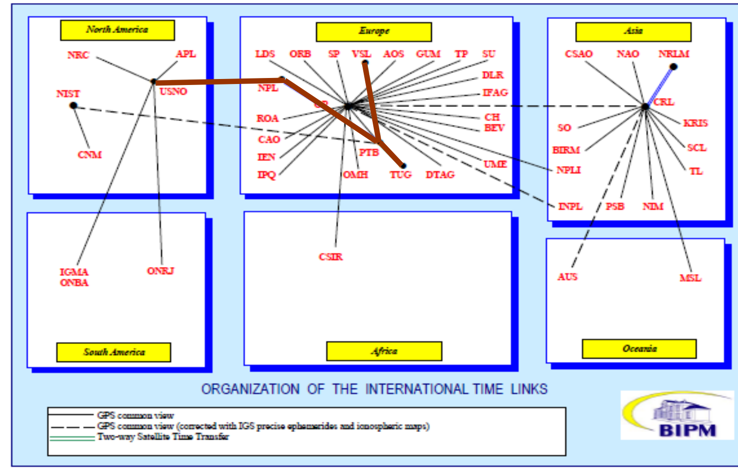
Bill Klepczynski

Wolfgang Schaefer

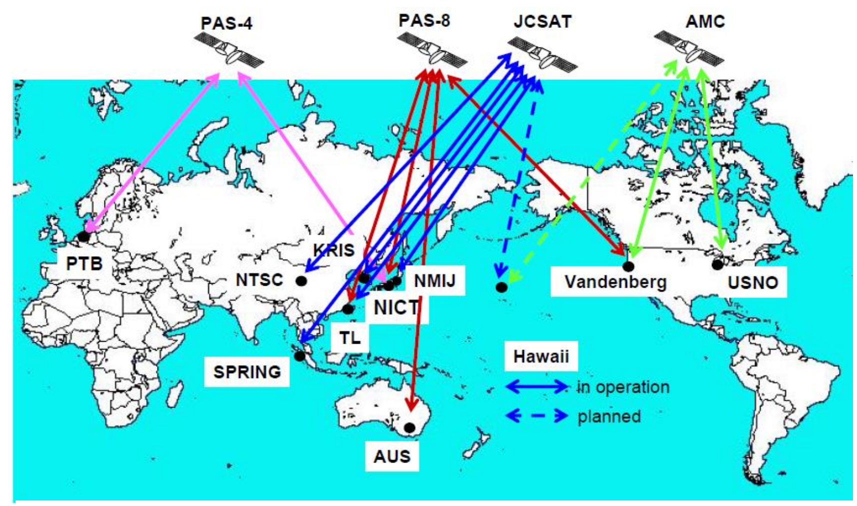
6th Meeting of the CCTF WG on TWSTFT
29-30 October 1998, San Fernando, Spain

Ongoing 1999 – present

- **ITU** approved in **1995** the standard data **format** for TWSTFT;
- The **first** TWSTT link in **UTC** was **TUG-PTB** in *Circular **T139***, Aug. **1999**
- GPS therefore finished its solo role for UTC time link
- In 2000, there were four TW time links: TUG-PTB, VSL-PTB, NPL-PTB and USNO-NPL.



The international UTC time link network in **2000**



TW links in/between Asia, Europe and America in **2005**

TW's contribution to UTC/TAI in 2009

Lab	GPS	TW
AOS	GPS	TW
AUS	GPS	TW
CH	GPS	TW
IT	GPS	TW
KRIS	GPS	TW
NICT	GPS	TW
NIM	GPS	TW
NIST	GPS	TW
NMIJ	GPS	TW
NPL	GPS	TW
NTSC	GPS	TW
OP	GPS	TW
PTB	GPS	TW
ROA	GPS	TW
SG	GPS	TW
SP	GPS	TW
TL	GPS	TW
USNO	GPS	TW
VSL	GPS	TW

19 labs operate TW
28% over total 68 UTC labs

➔ **13 used for UTC**

➔**They** contribute to UTC/TAI with

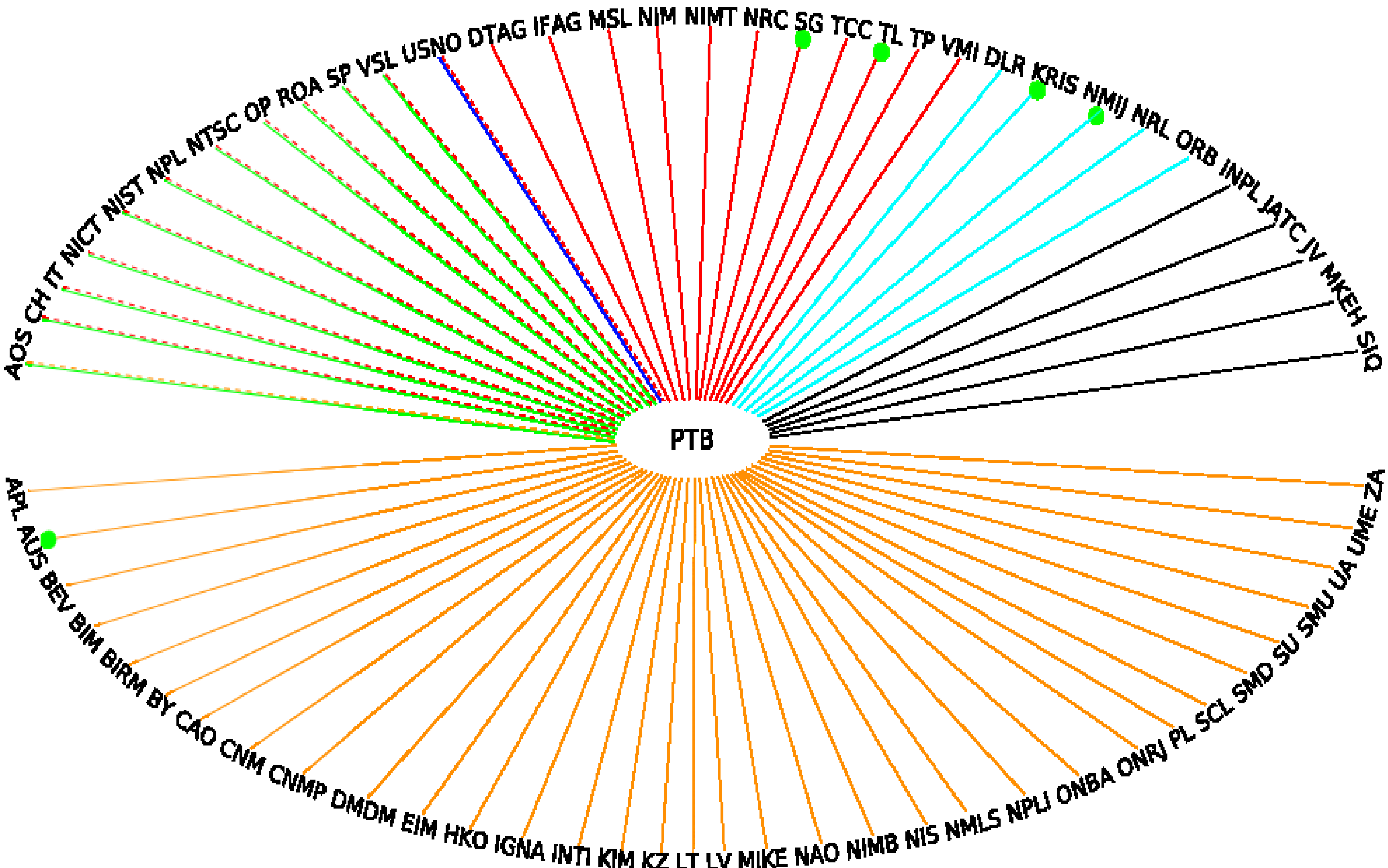
- 253 clocks (71% of total)
- 88% of total clock weight
- 11/12 Primary Frequency Standards 91%

➔➔ important role

Methods now in use

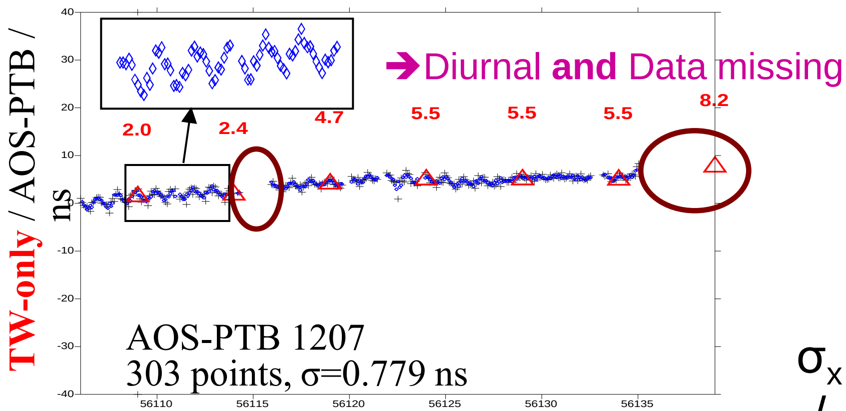
	uA/ns	uB/ns
• GPS C/A-code SCH	3.0	5.0
• GPS C/A-code MCH	1.5	5.0
• GPS/GLONASS (comb.	1.0	5.0
• GPS P3	0.7	5.0
• TW/GPS P3 (comb.)	0.7	5.0
• GPS PPP	0.3	5.0
• TWSTFT	0.5	1.0
• TW/GPS PPP (comb.)	0.3	1.0
• Fiber Optic	0.01	0.1

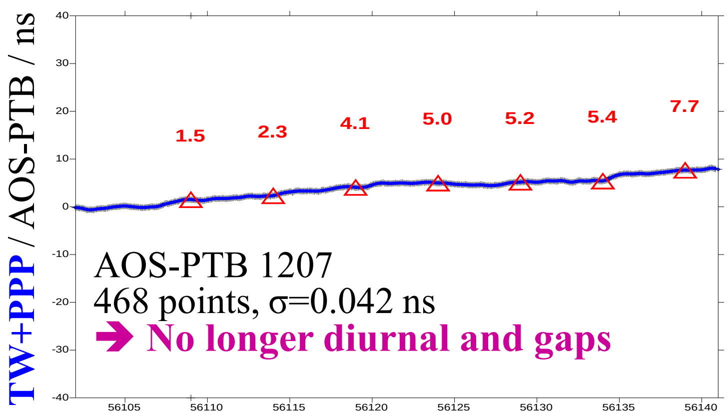
UTC time links

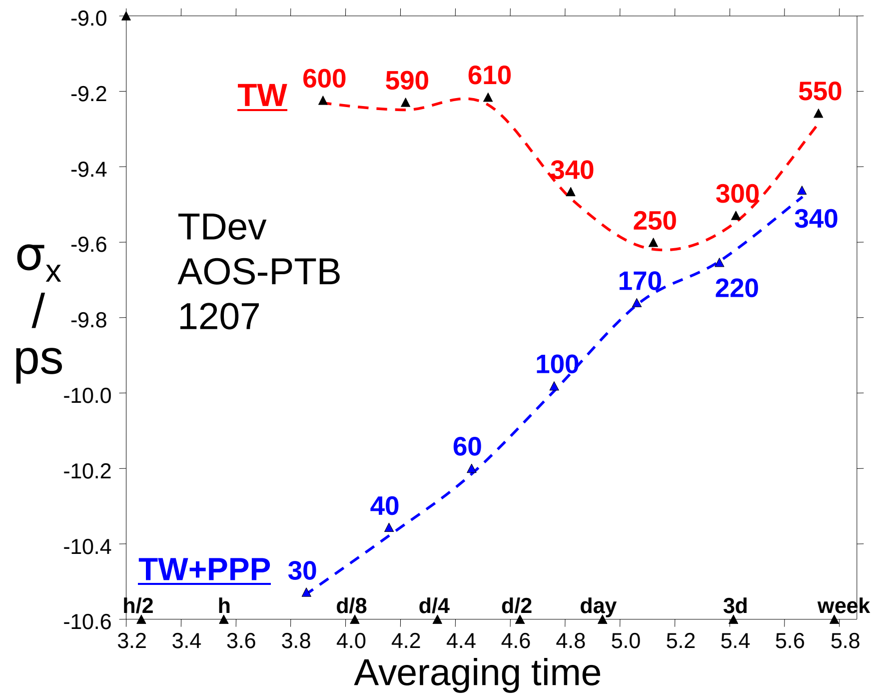


Major challenges

Diurnal







Combination of TW and GPS

Calibration

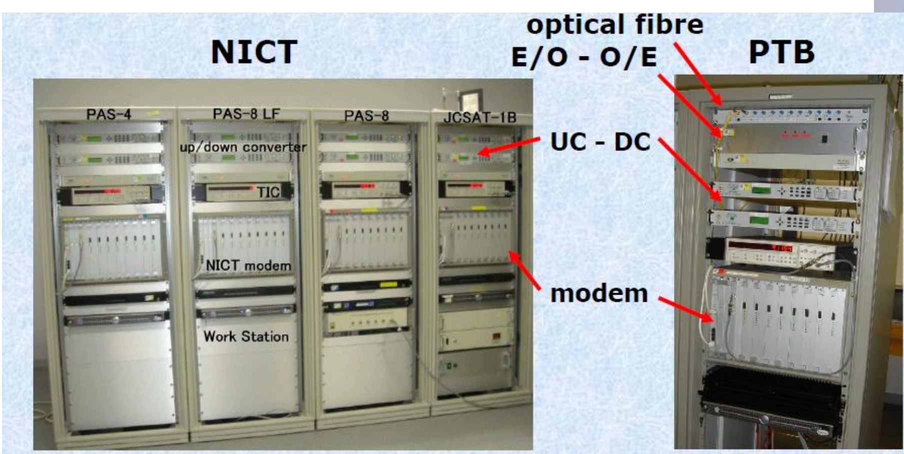
Mobile TW calibrators
The UTC links must be calibrated. Several calibration campaigns were organized in and between Europe, America and Asia.

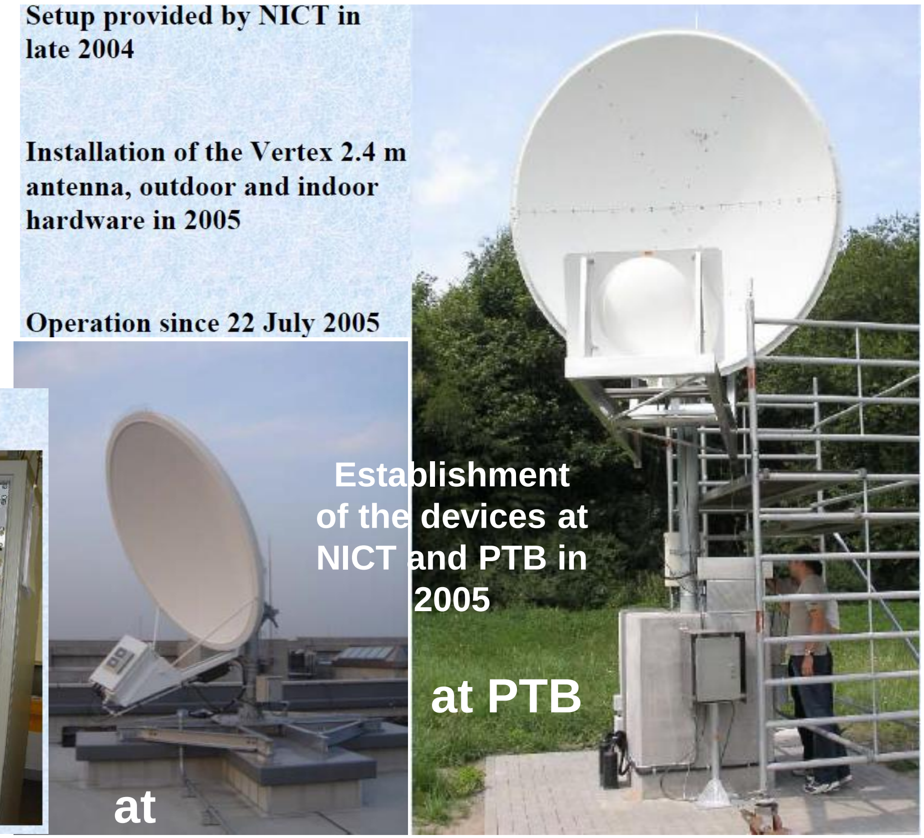
Calibration Period	Laboratories/campaigns
May-June 2003	IT-PTB-IT
July 2004	PTB-OP-NPL-VSL-PTB
Oct.-Nov. 2005	PTB-SP-VSL-NPL-OP-IT-PTB
May-June 2006	TUG-PTB-CH-TUG
Sept.-Oct. 2008	PTB-NPL-OP-IT-VSL-CH-TUG
2012-2013	PTB,OP,SP,CH,AOS …

Europe-Asia link

The Europe-Asia transcontinental link between NICT and PTB was established in 2005.

Longest UTC TW baselines





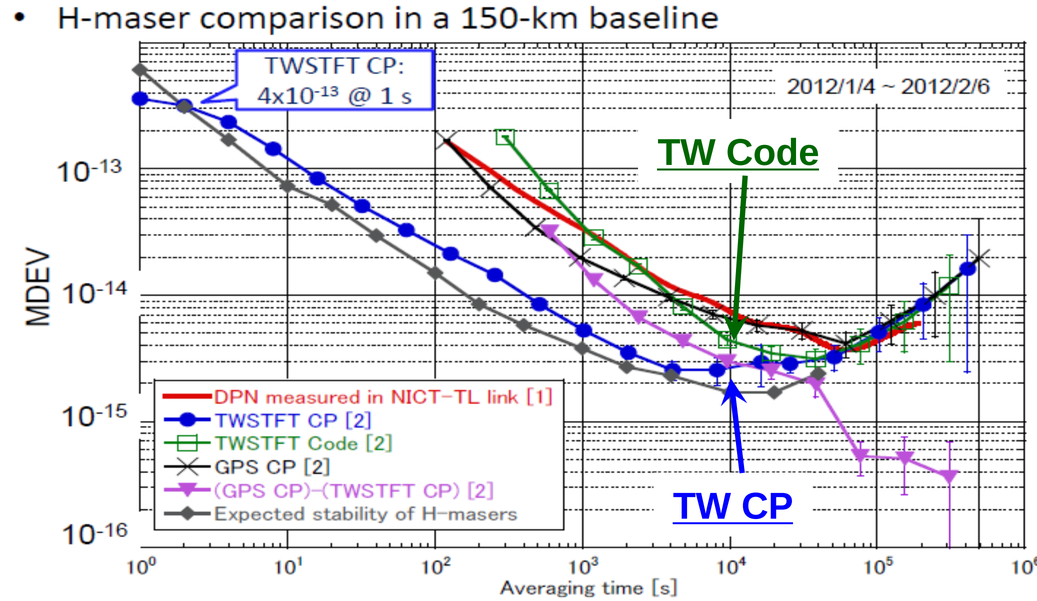
Oncoming In the coming years ? 1/6

I. Use of TW DPN and Carrier phase

TWSTFT code is affected by noise and diurnals. Further improvements should come from other observables, such as the **DPN** dual pseudo-random noise and **Carrier Phase**.

- TW DPN allows doubly reducing the measurement uncertainty, in particular that from the diurnals
- TW CP is hundred times more precise than code, TW CP transfer may reach a stabilities of 0.1 ns in time and 10^{-16}@1-day in frequency.

MDev of DPN, TW CP, TW code, GPS CP vs. a HM

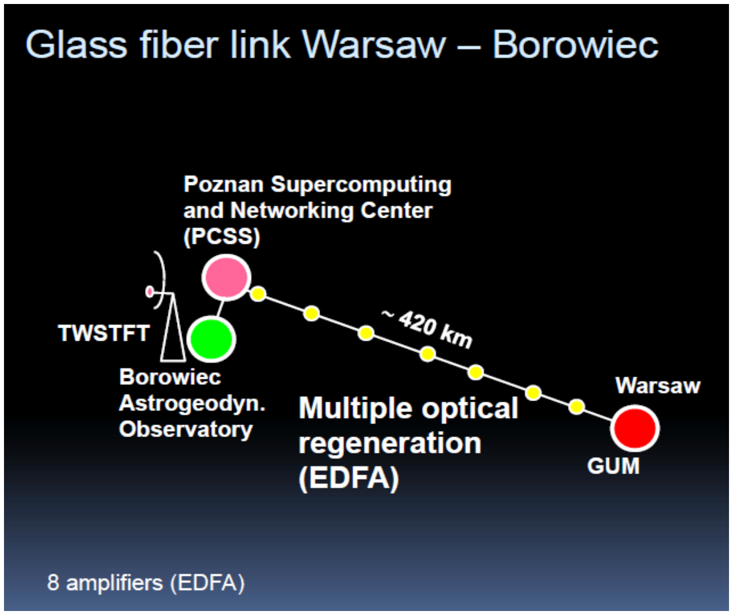


Oncoming In the coming years ? 2/6

II. Optical Fibre - TWOTFT

- Long-term goal: Compare the optical clocks ~10^{-18}@day
- More than 14 UTC laboratories actively involved
- Already operational UTC(AOS)-UTC(PL) by AGH
- Immediate Applications in UTC:
  - Validate the BIPM GNSS calibrator with u_B ~ 200 ps
  - Validate the new GNSS and TW**S**TFT techniques
- **New challenges**
  - the theoretical issues
  - the practical issues: data processing, format, programs …

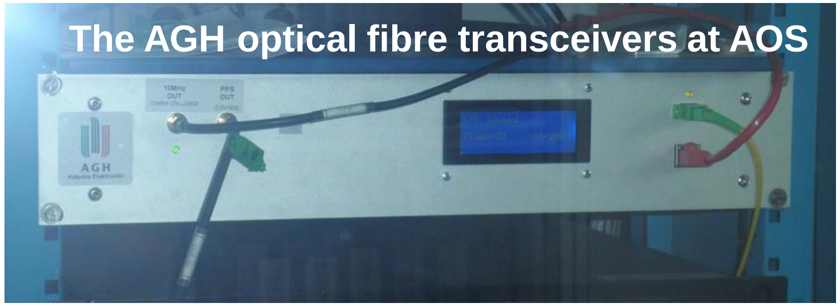
Oncoming In the coming years ? 3/6

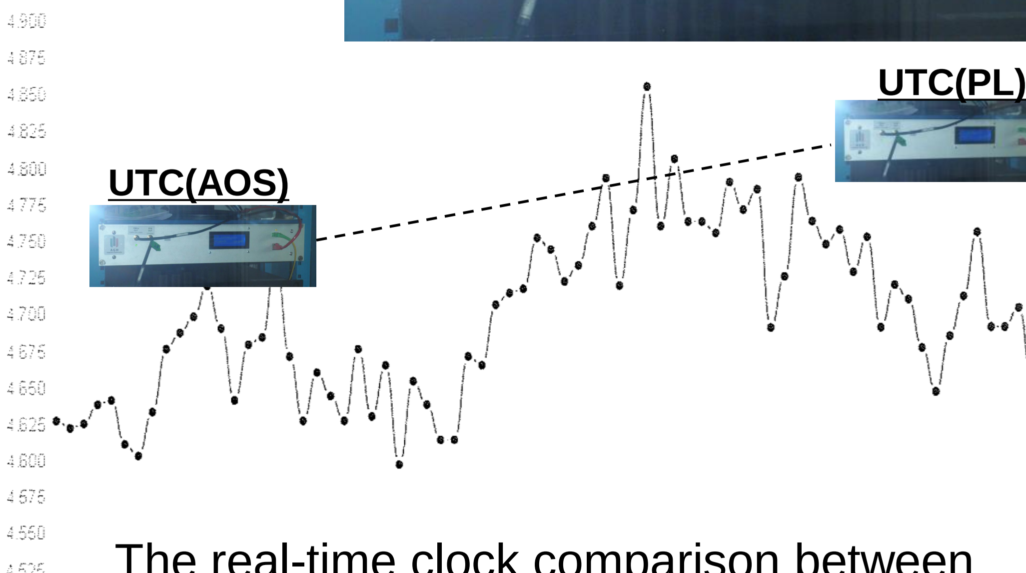


	determined quantity	estimate	sensitivity coefficient	standard uncertainty	uncertainty contribution
1	$\tau_{UTC(PL)\rightarrow REF}$ (a)	420.17 ns	1	100 ps	100 ps
2	$\tau_{REF\rightarrow RET}$ (a)	4 093 944.73 ns	0.5	100 ps	50 ps
3	$\tau_{\Delta\lambda}$ (b)	2.950 ns	0.5	19 ps	9.5 ps
4	τ_{S} (c)	-1.686 ns	0.5	5 ps	2.5 ps
5	τ_{B} (d)	0 ns	0.5	1.2 ps	0.6 ps
6	τ_{H} (e)	26.565 ns	0.5	8.8 ps	4.4 ps
	$\tau_{UTC(PL)\rightarrow OUT}$	2 047 406.45 ns	complex uncertainty:		112.3 ps

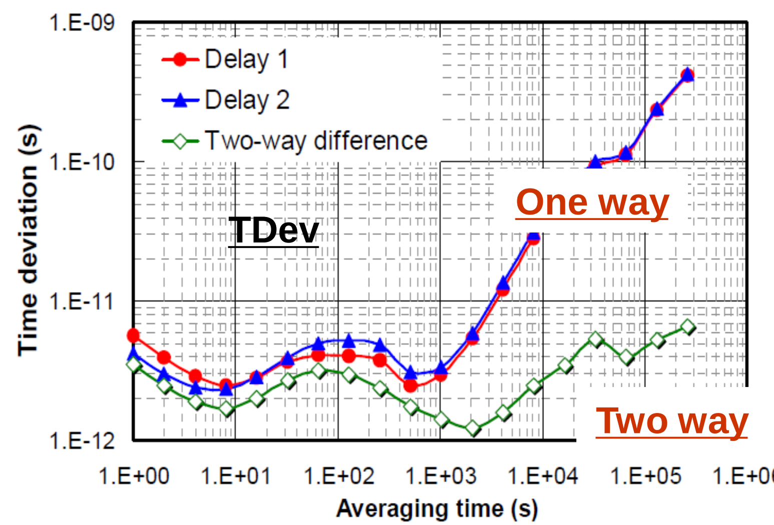
First Operational Optical Fibre Time Link
420 km between UTC Laboratories AOS-PL
Combined uncertainty **112 ps**

Oncoming In the coming years ? 4/6





The real-time clock comparison between UTC(AOS) and UTC(PL) through a fibre link, www.optime.org.pl/node/47



25 km fibre experiment at TL

Oncoming In the coming years ? 5/6

```
Table 7.2 The first 25 lines of the proposed TW%TFT data file T%PTB56.150 in unit ns for delay and ps for statistical terms
* tfptb56.150
* FORMAT    01
* LAB       PTB
* REV DATE  2011-08-03
* ES  PTB01 LA: N  52 17 49.787      LO: E  10 27 37.966   HT:   143.41 m
* REF-FRAME ITRF
* LINK   14 fibre: Dark Channel          Length: 420.00 Km    Amplifiers: 6
*           OPTICAL-TX: 1552.1500 nm RX: 1552.1550 nm
*           MODEM: Dedicated hardware    SIGNAL: 1 PPS on square wave
*           Link Stabilization:  YES
* LINK   16 fibre: AAA Network           Length:  72.00 Km    Amplifiers: 0
*           OPTICAL-TX: 1542.1000 nm RX: 1542.1500 nm
*           MODEM:  SATRE 037            SIGNAL: PRN, 20 Mcps
*           Link Stabilization:  NO
* CAL   xxx TYPE: CAL xxx BRIDGED    MJD: 55769  EST. UNCERT.:    x.xxx ns
* CAL   214 TYPE: CAL 141 BRIDGED    MJD: 55769  EST. UNCERT.:    5.000 ns
* CAL   213 TYPE: CAL 142 BRIDGED    MJD: 55769  EST. UNCERT.:    1.300 ns
* LOC-MON   NO
* COMMENTS  unit in 0.1 ps
*
--- data body proposition (I)
* EARTH-STAT  LI  MJD  STTIME NTL        TW        DRMS SMP ATL     REFDELAY      RSIG  CI S    CALR      ESDVAR   ESIG TMP HUM PRES
* LOC    REM             hhmmss  s        0.1ps     0.1ps       s     0.1ps          0.1ps          0.1ps       0.1ps  0.1ps   C   %  mbar
 PTB01  TIM01 14 56150 000400 119   265739347023X 1226X 120 119  0000000040870X 0020X 999 9 999999999  1035000X 2800X  12   98 1013
 PTB01  PTB01 14 56150 000700 119   266718670995X 2491X 120 119  0000000040870X 0020X 999 9 999999999  1035000X 2800X  12   98 1013
 PTB01  OCA01 14 56150 001000 119   264311268059X 1497X 120 119  0000000040870X 0020X 999 9 999999999  1035000X 2800X  12   98 1013
 PTB01   IT02 14 56150 001300 119   264702466195X 1937X 120 119  0000000040870X 0020X 213 1    479209X  1035000X 2800X  12   98 1013
 PTB01  ROA01 14 56150 001600 119   260338922342X 2520X 120 119  0000000040870X 0020X 217 1    298673X  1035000X 2800X  12   98 1013
```

It is suggested adapting the **ITU TWSTFT** data format for **TWOTFT**. Hence all the data exchanges, processing, calibrations, computations and the related methodology can be kept with only slight modifications. This will save huge time and man powers and speed up its applications.

Oncoming In the coming years ? 6/6

Application of TWOTFT

- Time link calibrations within a few minute?
- Time transfers with 100 ps ?
- Change in the UTC network configuration?

... ...

➔ A new era of the ground based techniques is back …

RECOMMENDATION CCTF (2012):

Development of continental-scale fiber optical time and frequency transfer networks and support to studies of improved methods for intercontinental comparisons

The Consultative Committee for Time and Frequency (CCTF), considering

- **the continuing reduction in uncertainties and instabilities of frequency standards based on optical atomic transitions**
- **that the stabilities of the time and frequency transfer techniques currently used for long-distance comparisons around the world, GNSS and TWSTFT, are insufficient for the needs of comparisons between the new frequency standards,**
- **the demonstrated capability of fiber optical links to realise frequency comparisons over distances of up to the order of 1000 km,**

CCTF recommends that

- metrology institutes vigorously pursue the development of continental-scale fiber optical time and frequency transfer networks,

- research aimed at significantly improving time and frequency transfer over intercontinental distances be actively encouraged and supported, and

- national governments, metrology institutes, optical fiber network providers and operators, space agencies and other relevant bodies consult and coordinate with each other on access to the necessary infrastructures and on possible synergies with other applications of these infrastructures.

PIONIER INTERNATIONAL CONNECTIOS

(courtesy of Pionier International)

Summary

- TW computation at the BIPM since 14 years
- TW plays a major role in evaluation of other techniques
- Combination of TW and GNSS – added value
- More TW calibration are needed
- TW DPN and CP expected
- TWOTT a bringing breaking through change
- Real-time developments
- Fundamental role of CCTF WG on TWSTFT

Where we will be in 25 years?

Thank you
for your attention!

53rd CGSIC Meeting - Timing Subcommittee

Nashville, Tennessee, 16 September 2013

Chair: **Włodzimierz Lewandowski, BIPM**
Co-Chair: **Victor Zhang, NIST**

09:00 Introduction – ***Włodzimierz Lewandowski, BIPM, presented by Victor Zhang***
09:30 Report from NIST – ***Victor Zhang, NIST***
10:00 Report from USNO – ***Demetrios Matsakis, USNO***
10:30 Coffee Break
11:00 Galileo IOV System Time Status – ***Joerg Hahn, ESA, given by Demetrios Matsakis***
11:20 Time and Navigation Exhibition at the Smithsonian: Report on Opening
– ***Andrew Johnston, National Museum of American History***
11:40 Update on ITU-R agenda related to time scales - ***Joe White, NRL***
12:00 Discussion
12:30 Session End

BIPM

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