TWSTFT time link Calibrations

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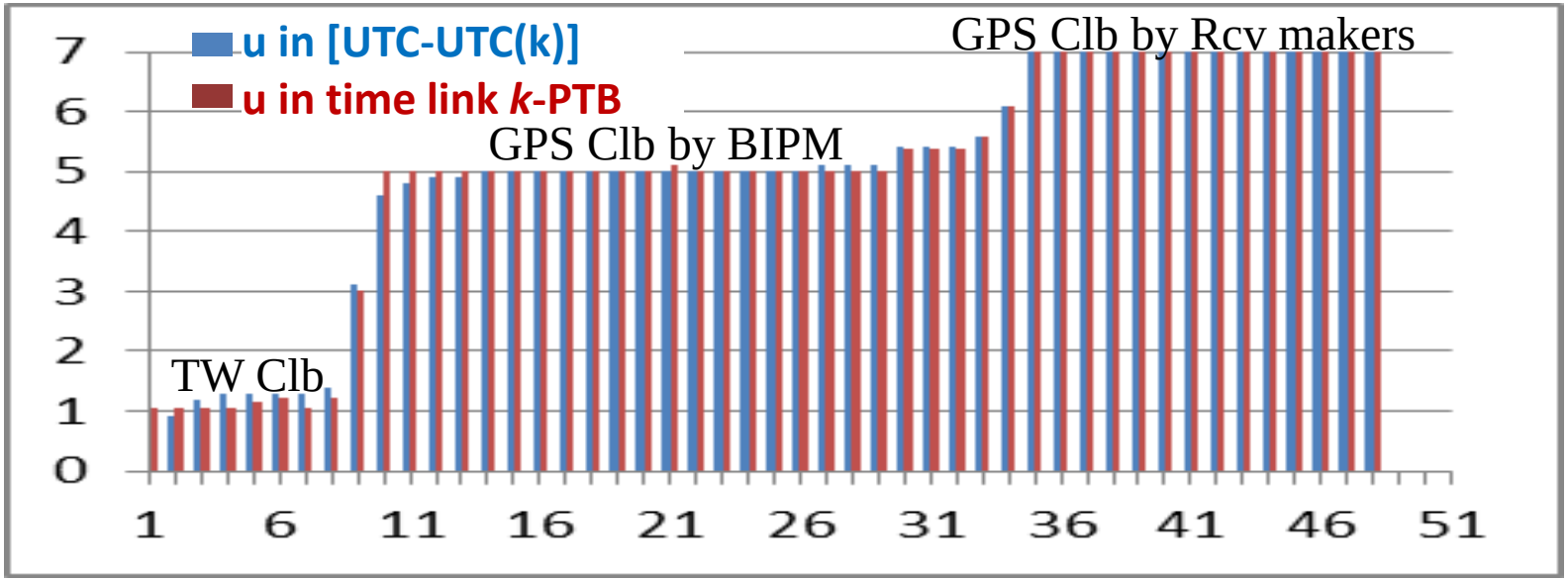
CCTF - LAB contributing to TAI, 16 Sept. 2015, BIPM

Outline

- The TWSTFT calibration guideline approved by the 23rd CCTF WGTW , BIPM, Sept 2015
- The TWSTFT time link calibrations by the TW mobile station (MOB) station and by the GPS calibrator
- The uncertainties

Where do u,u_A/u_B in [UTC-UTC(k)] come from?



Uncertainty Sources	Uncertainty on average		
	u_A	u_B	u
a) [UTC-UTC(k)]	0.8	4.9	5.1
b) Time transfer	0.8	4.8	5.0
(b)/(a)	**99%**	**99%**	**98%**

➔ **99% from the time link [UTC(PTB)-UTC(k)]**

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The guideline

- Calibration is a key point to improve [*UTC-UTC*(*k*)]
- TW has been used for time transfer for >20 years but without a calibration guideline
- Recommendation of the 22nd CCTF WGTW, VNIIFTRI, Mendeleev, Russia, Sept 2014
- The Guideline draft Task Group 2014-2015
- Approved by the 23rd CCTF WGTW, BIPM, on 8 Sept 2015

Calibration guideline 1/4

Consensus on:

- A calibration requires a full coordination between Participants + Mobile_Station_Provider + BIPM
- Staff of TW PS have skills to properly perform a TW calibration under the guideline, which cannot cover all the technical details

➔ Clear and Simple without technical details:

- A five-page main document
- Two Annexes (non mandatory)

Calibration guideline 2/4

The plan in 4 steps

1. CCTF WGTW meeting Sept/2014 → Task group
2. PTTI TW PS meeting Dec/2014 → draft version v1.x
3. EFTF TW PS meeting Apr/2015 → near-final version v2
4. → **Final v3**, submitted to the 23rd CCTF WGTW meeting on 8/9/2015 for approval

- Will be updated at the future annual CCTF WGTW meetings

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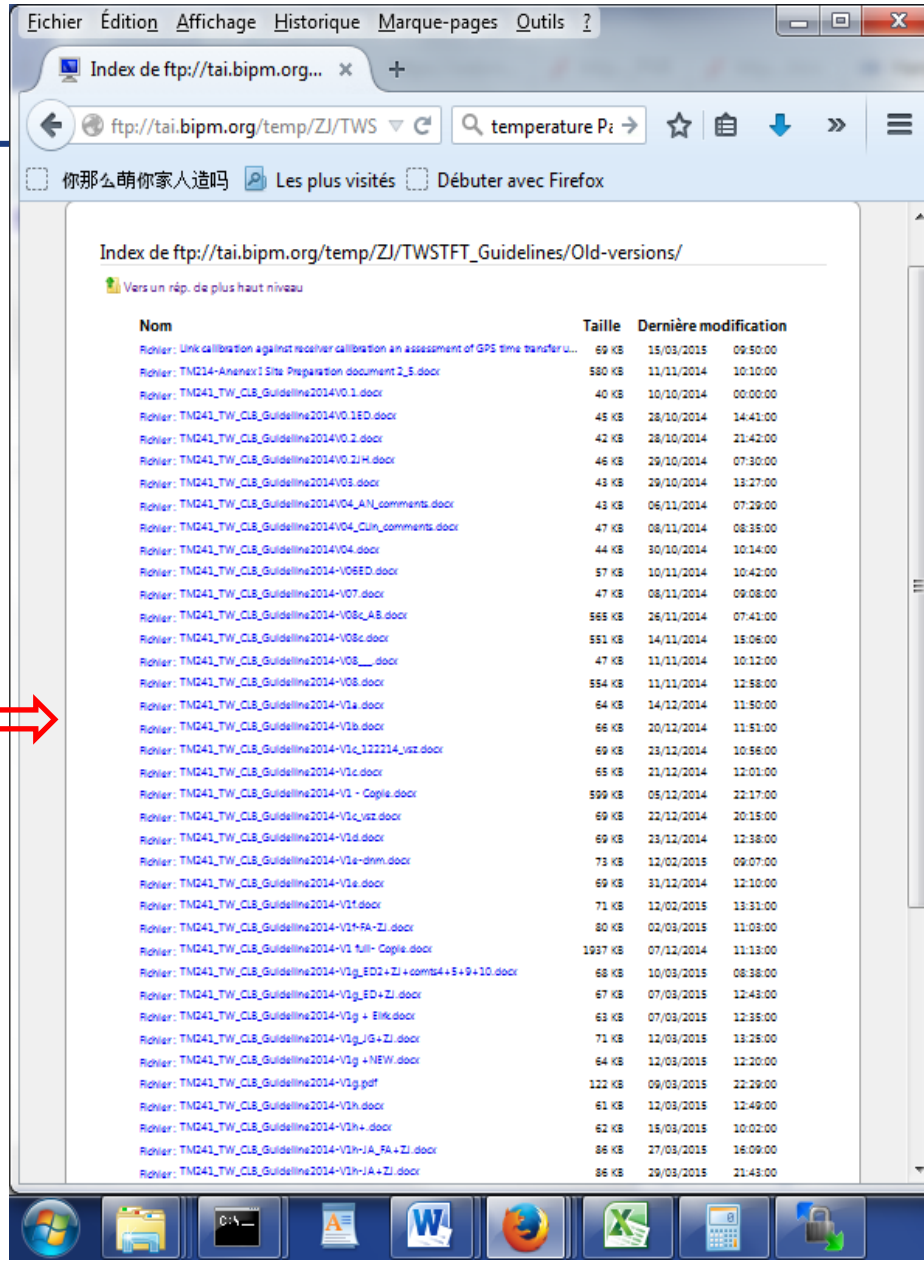
Version evolution

- One year since last Sept.
- 7 drafters + 3 reviewers
- >3 verifications among the WGTW members
- 55 Task Group editions



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Calibration guideline 3/4

Characteristics 1/2

- **Primary** technique: **TWSTFT mobile station** with uncertainty ≤ 1 ns

- **Alternative** technique: **GPS time link calibration** with uncertainty ~ 1.5 ns ← **new**
  - When TWSTFT MOB cannot be used

  ←*indispensable for inter-continental TW links*

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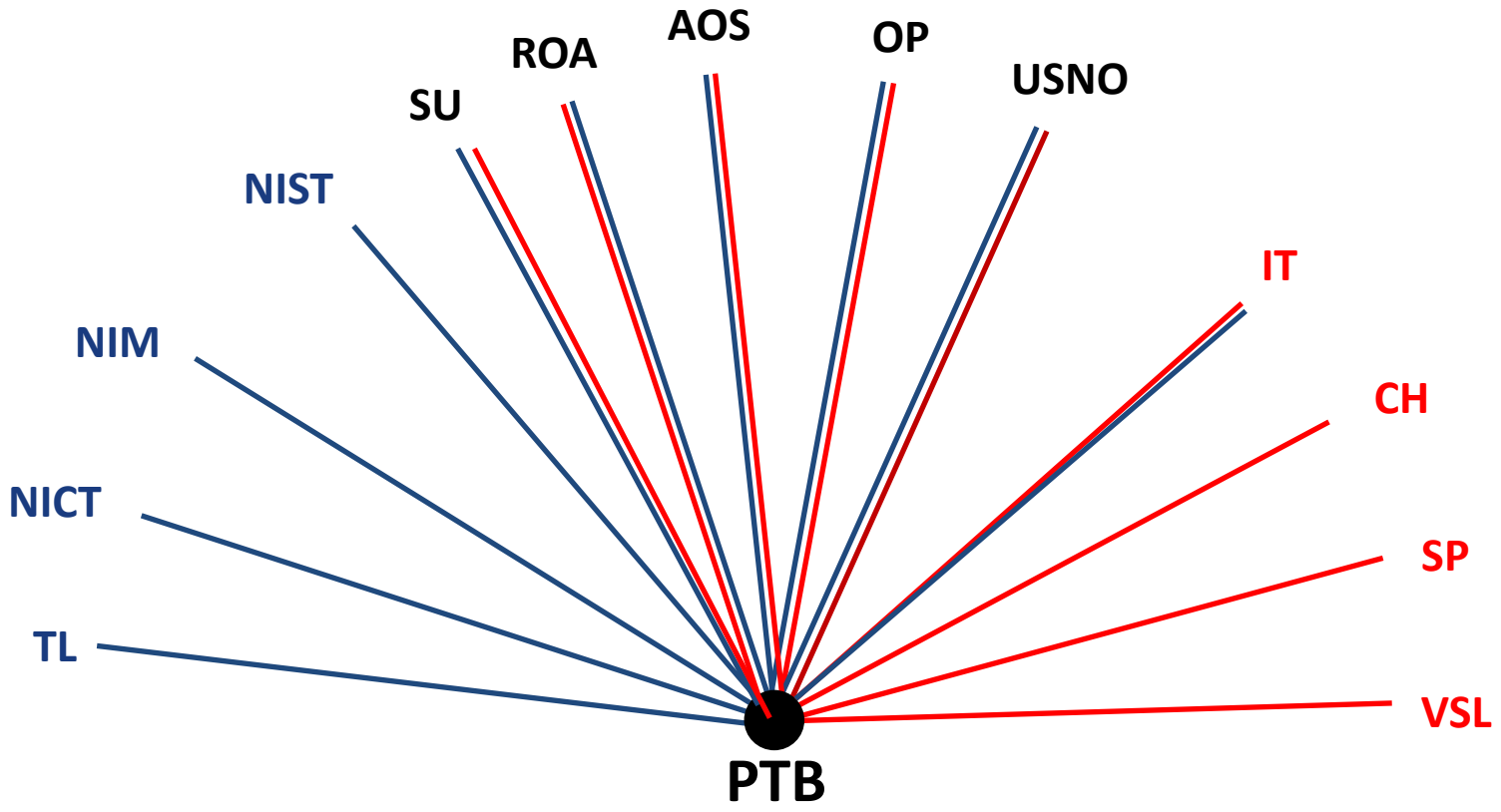
Calibration guideline 4/4

Characteristics 2/2 ← new

- Accept **TCC** (Triangle Closure Calibration)
- Accept a UTC laboratory (not necessarily PTB) as the starting-closing point
- Above should be agreed by the participants together with the corresponding uncertainty evaluation for each case

The recently calibrated 13 UTC TW links (2013-14)



4 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

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TWSTFT Mobile calibrators

USNO/USA

SU/Russia

TimeTech/Germany

Calibration tours involving 8 Labs:
PTB, CH, OP, VSL, AOS, SP, SU, ROA, IT, USNO

u_B 0.6 ~ 1.1 ns

→ The talk of J. Galindo

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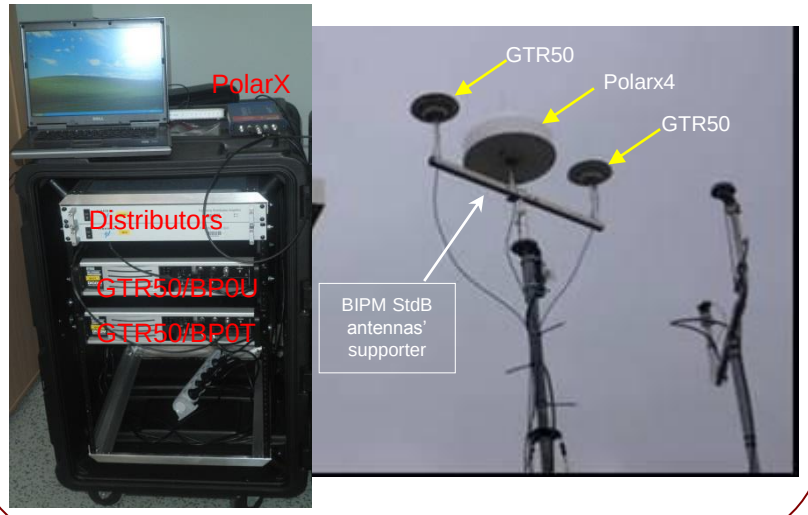
GPS calibrator -BIPM METODE pilot project

MEasurement of **TO**tal **DE**lay

Portable GPS calibrator with 2-3 receivers



- [UTC-UTC(k)] is a time link
- difference of METODE of a UTC link
- GPS calibrator is a Pre-cabled Black box with unknown sub-delays
- Only require: short-term stability during calibration period (~3 months)
- Total delay uncertainty with sub-uncertainties not accumulated

➔ Measurements performed at 12 UTC labs

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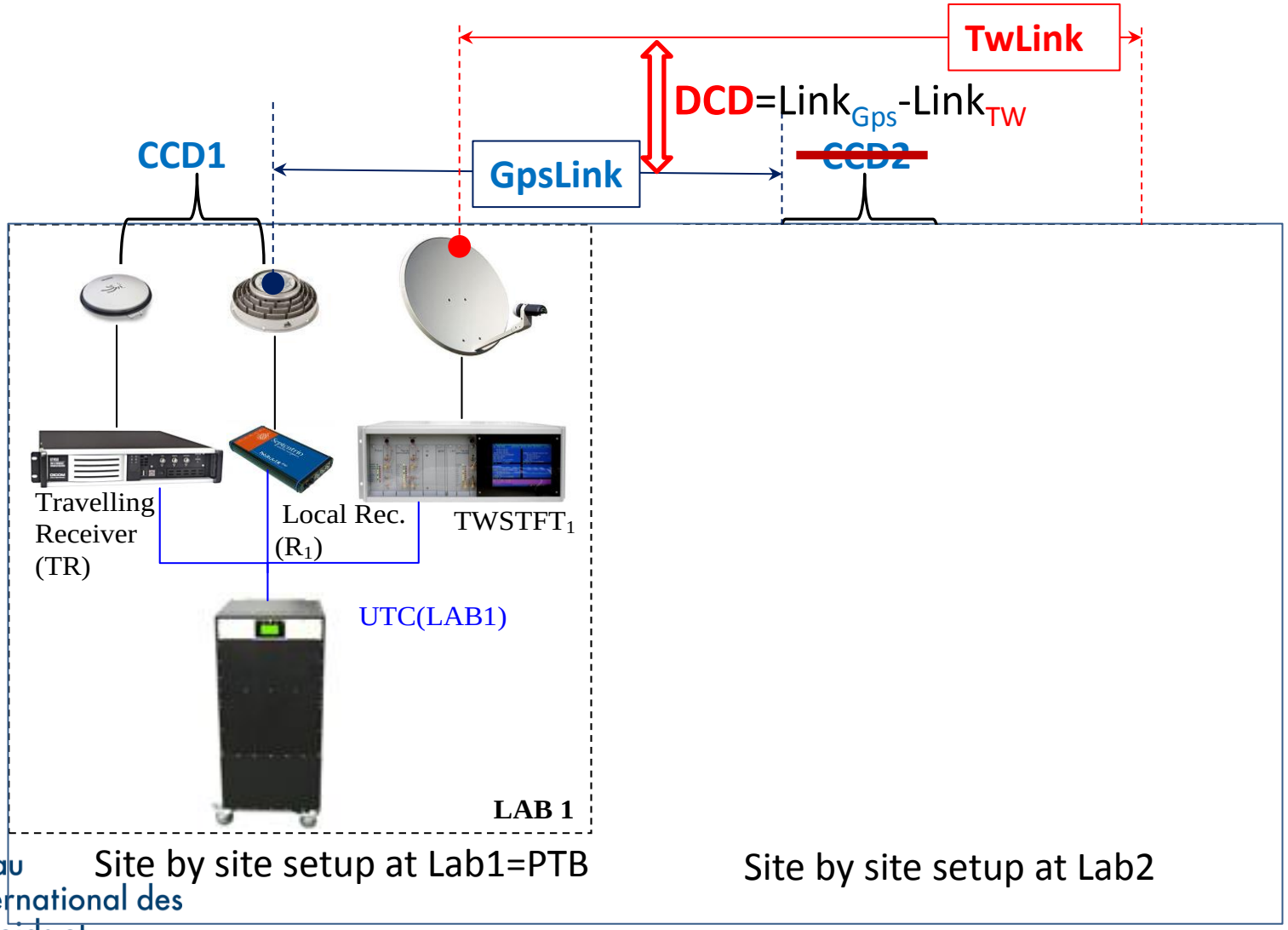
GPS/TWSTFT CCD/DCD 2/2



TWSTFT Link Calibration Computation

$$\mathbf{DCD} = [TW(Lab_k) - TW(PTB)] - [GPS(TR)_{Labk} - GPS(PTB)]$$
$$= \mathbf{CALR}_{Labk\text{-}PTB} \neq 0$$

- ✓ The travelling receiver TR should have been calibrated w.r.t. the pivot PTB

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TWSTFT UTC link calibration *with a GPS calibrator, Setups at USNO*

During 10-20 Feb., 2015 (DOY 41-51, MJD 57063-57073), the BIPM Standard Travelling Calibration Station (Std_B) visited USNO to calibrate the USNO-PTB TWSTFT link for UTC generation. This calibration followed the TWSTFT Calibration Guideline for UTC Time Links .

… …

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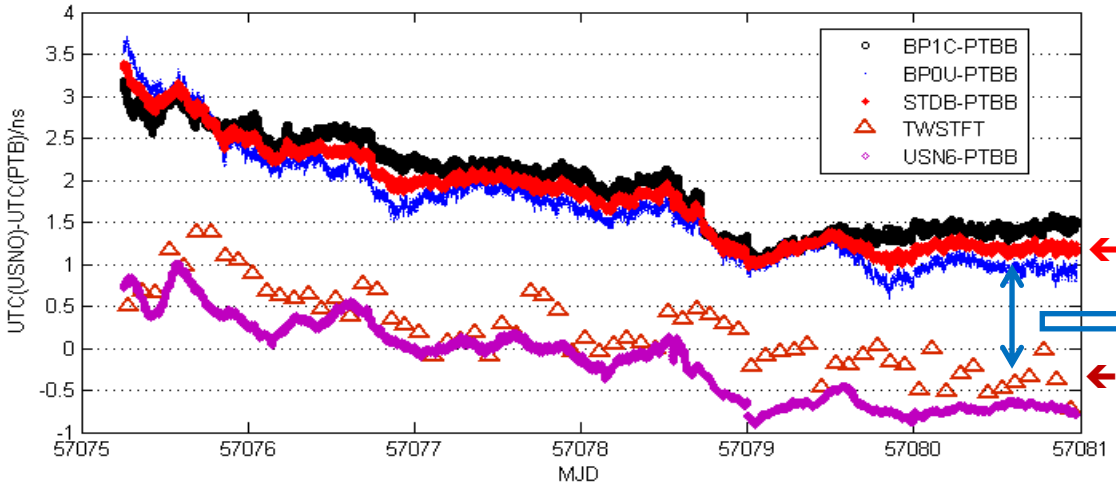
GPS/TWSTFT calibration result USNO-PTB

The total delay correction for the TWSTFT time link USNO-PTB

Lab	Time Rcv/Link	C_M/ns	u_M
Lab(k)	TWSTFT: Lab(k)-PTB	+0.9*	1.5 ns



BIPM METODE l ink calibration Feb 2015

0.9±1.5 ns

TW Mobile calibration station June 2014

The time links on the UTC baseline Lab(k)-PTB during the calibration period

violet: PPP Lab(k)-PTB; **Triangle**: TWSTFT Lab(k)-PTB; **Red:** PPP StdB-PTBB (StdB is mean of BP0U/**blue** and BP1C/**black**)

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Uncertainty, classical estimation

- $u_{A,3}$ Statistical uncertainty of TWCAL values (0.4 ns)
- $u_{B,7}$ TW stations' instabilities (0.3 ns)
- $u_{B,8}$ Uncertainty of the GPS link (0.8 ns)

$$u_{c\,TW} = \sqrt{u_{A,3}^2 + u_{B,7}^2 + u_{B,8}^2}$$

$$u_{c\,TW} = \sqrt{0,4^2 + 0,3^2 + 0,8^2} \approx 0,9 \text{ ns}$$

➔ Supported by other independent studies cf. the references

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Uncertainty of BIPM METODE Proj. 1/2

Not an analytical estimation but pure measurements
➔ No need any hypothesis

But to compare the METODE to
three *independent & more accurate* measures:

1. TIC: time interval counter (< ±0.3 ns)
2. Mobile Cs standard (< ±1.0 ns)
3. 420 km Optical fiber link (< ±0.12 ns)

u_B < RMS

➔ 0.8~1.5 ns (2 receivers)

Ref. Jiang Z et al. Comparing a GPS time link calibration to an optical fibre self-calibration with 200 ps accuracy, *Metrologia* **52** 2015

Consistency of TW_{MBS}-GPS-OF link calibrations

Link	u_B /ns TW	u_B /ns GPS	C_M /ns	Note
OP-PTB	0.8	1.0~1.5	-1.1	(4)/(3)
NPL-PTB	1.0	1.0~1.5	-0.1	(1)/(2)
AOS-PTB	1.2	1.0~1.5	0.0	(1)/(3)
ROA-PTB	0.8	1.0~1.5	0.6	(4)/(3)
USNO-PTB	0.6	1.0~1.5	0.9	(5)/(3)
PL-AOS	0.2	1.0~1.5	0.2	(6)/(3)
Mean			-0.1	
RMS			0.6	

Data from other calibration campaigns:

1) European TW calibration 2013
2) EURAMET Project 1156
3) BIPM METODE calibration
4) European TW calibration 2014
5) USNO-PTB TW calibration
6) Two-Way Optical fibre Time Transfer (TWOTT)

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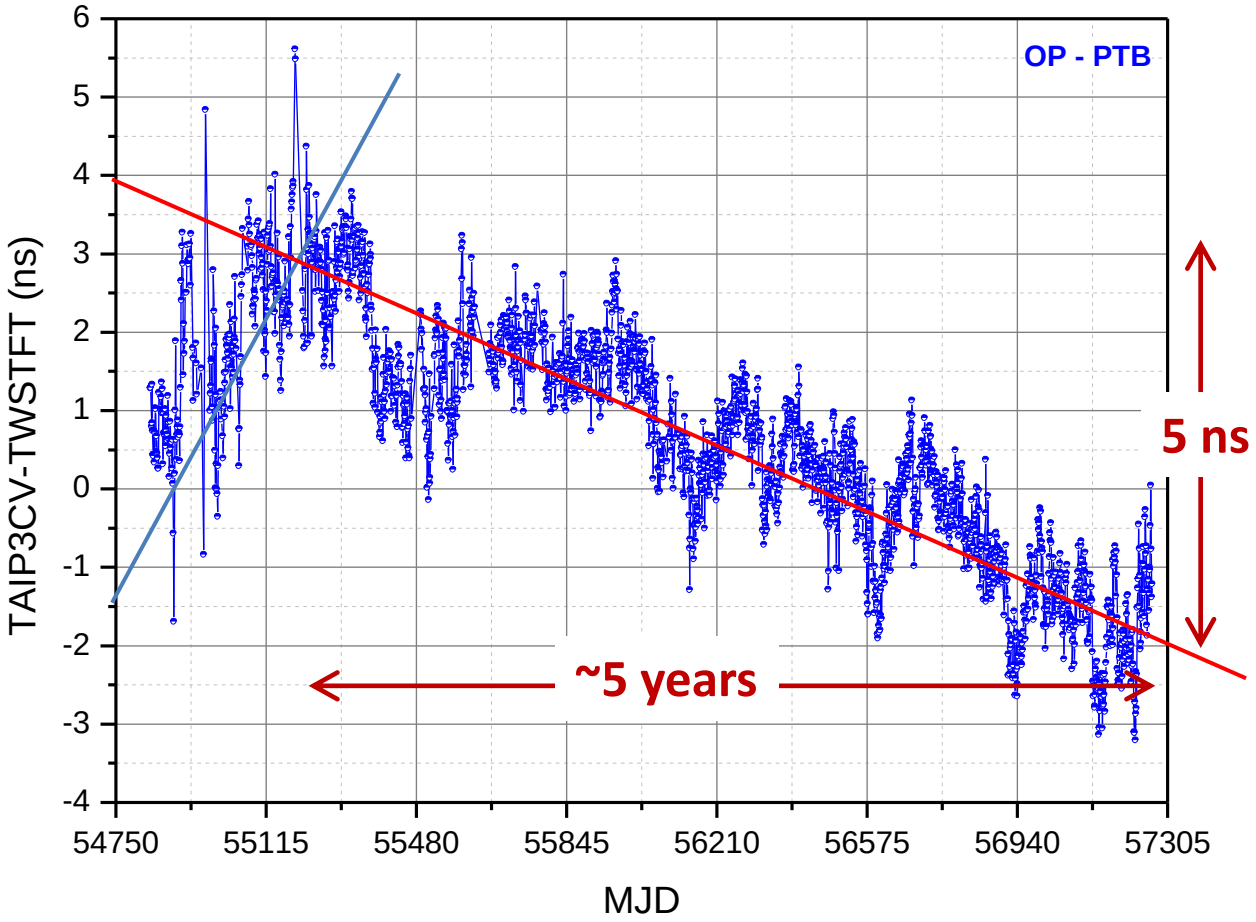
Differences between GPS and TWSTFT links OP-PTB - over 6 year after Achkar CCTF WGTW meeting 2015



Conclusion

- An achievement, the new TWSTFT calibration guidelines
- Uncertainty of nanosecond or about in TWSTFT calibration is attainable by using TW MOB or GPS link calibrator
- Conventional u_B of 1 and 1.5 are suggested respectively
- Open point: one-way drift in long-term variation of TW-GPS
- The uncertainty of calibration degrades with time. Repeated calibration every 2-years is necessary

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Thanks

for your full cooperation

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