

TWSTFT time link Calibrations

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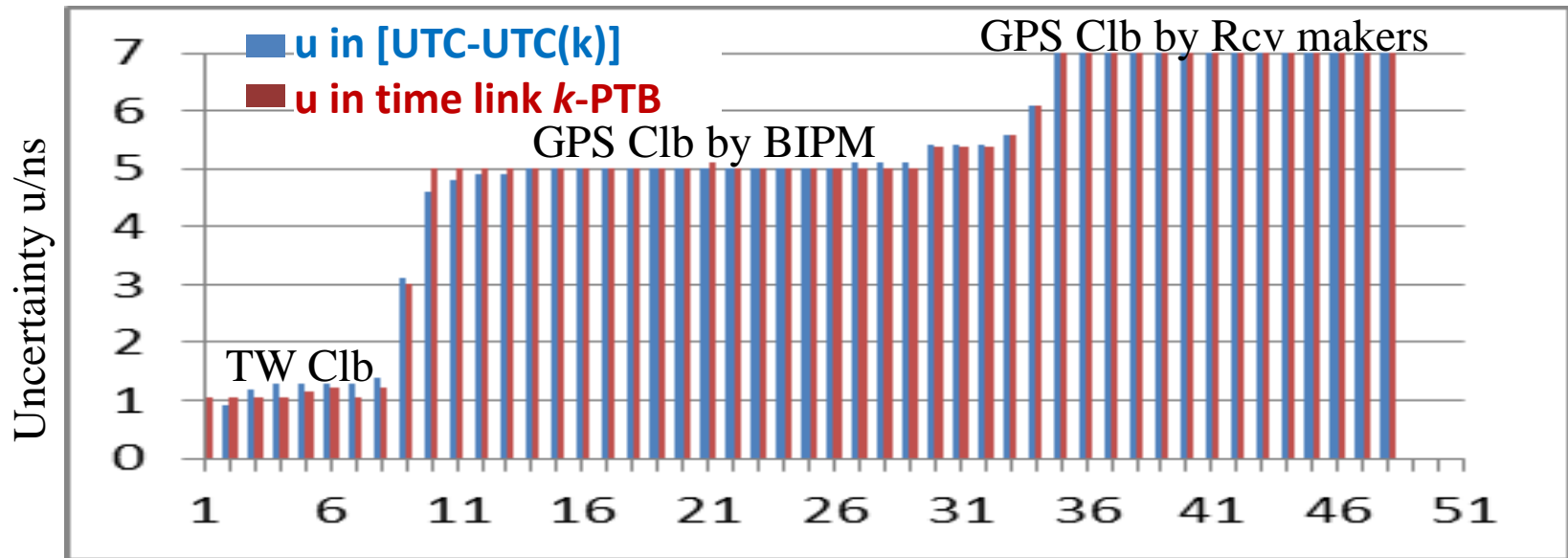
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CCTF - LAB contributing to TAI, 16 Sept. 2015, BIPM

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)]

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:

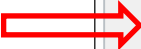
- A calibration requires a **full coordination** between Participants + Mobile_Station_Provider + BIPM
 - Staff of TW PS **have skills** to properly perform a TW calibration under the guideline, which cannot cover all the technical details
- ➔ Clear and **Simple** without technical details:
- A five-page main document
 - Two Annexes (non mandatory)

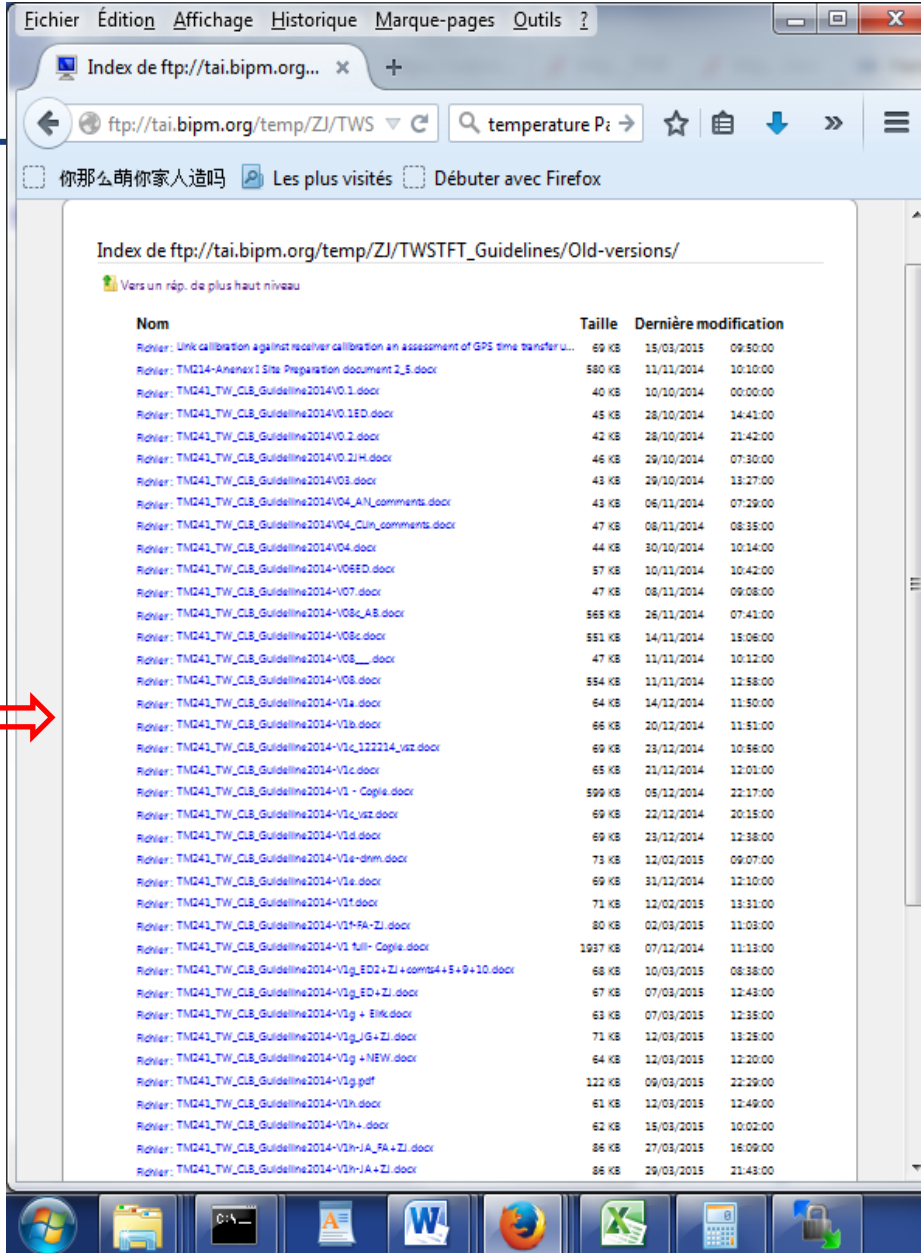
Calibration guideline ^{2/4}

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

Version evolution

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



Fichier Édition Affichage Historique Marque-pages Outils ?

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temperature P: →

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Index de ftp://tai.bipm.org/temp/ZJ/TWSTFT_Guidelines/Old-versions/

Vers un rép. de plus haut niveau

Nom	Taille	Dernière modification
Rohler: Unk calibration against receiver calibration an assessment of GPS time transfer u...	69 KB	15/03/2015 09:50:00
Rohler: TMD14-Anexex1 Site Preparation document 2_5.docx	580 KB	11/11/2014 10:10:00
Rohler: TMD41_TW_CIB_Guideline2014V0.1.docx	40 KB	10/10/2014 00:00:00
Rohler: TMD41_TW_CIB_Guideline2014V0.1ED.docx	45 KB	28/10/2014 14:41:00
Rohler: TMD41_TW_CIB_Guideline2014V0.2.docx	42 KB	28/10/2014 21:42:00
Rohler: TMD41_TW_CIB_Guideline2014V0.2H.docx	46 KB	29/10/2014 07:30:00
Rohler: TMD41_TW_CIB_Guideline2014V03.docx	43 KB	29/10/2014 13:27:00
Rohler: TMD41_TW_CIB_Guideline2014V04_A1_comments.docx	43 KB	06/11/2014 07:29:00
Rohler: TMD41_TW_CIB_Guideline2014V04_C1n_comments.docx	47 KB	08/11/2014 08:35:00
Rohler: TMD41_TW_CIB_Guideline2014V04.docx	44 KB	30/10/2014 10:14:00
Rohler: TMD41_TW_CIB_Guideline2014-V06ED.docx	57 KB	10/11/2014 10:42:00
Rohler: TMD41_TW_CIB_Guideline2014-V07.docx	47 KB	08/11/2014 09:08:00
Rohler: TMD41_TW_CIB_Guideline2014-V08c_A8.docx	568 KB	26/11/2014 07:41:00
Rohler: TMD41_TW_CIB_Guideline2014-V08c.docx	551 KB	14/11/2014 15:06:00
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Rohler: TMD41_TW_CIB_Guideline2014-V1d.docx	69 KB	23/12/2014 12:38:00
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Rohler: TMD41_TW_CIB_Guideline2014-V1h+.docx	62 KB	15/03/2015 10:02:00
Rohler: TMD41_TW_CIB_Guideline2014-V1h-FA+ZJ.docx	86 KB	27/03/2015 16:09:00
Rohler: TMD41_TW_CIB_Guideline2014-V1h-JA+ZJ.docx	86 KB	29/03/2015 21:43:00

Calibration guideline ^{3/4}

Characteristics ^{1/2}

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

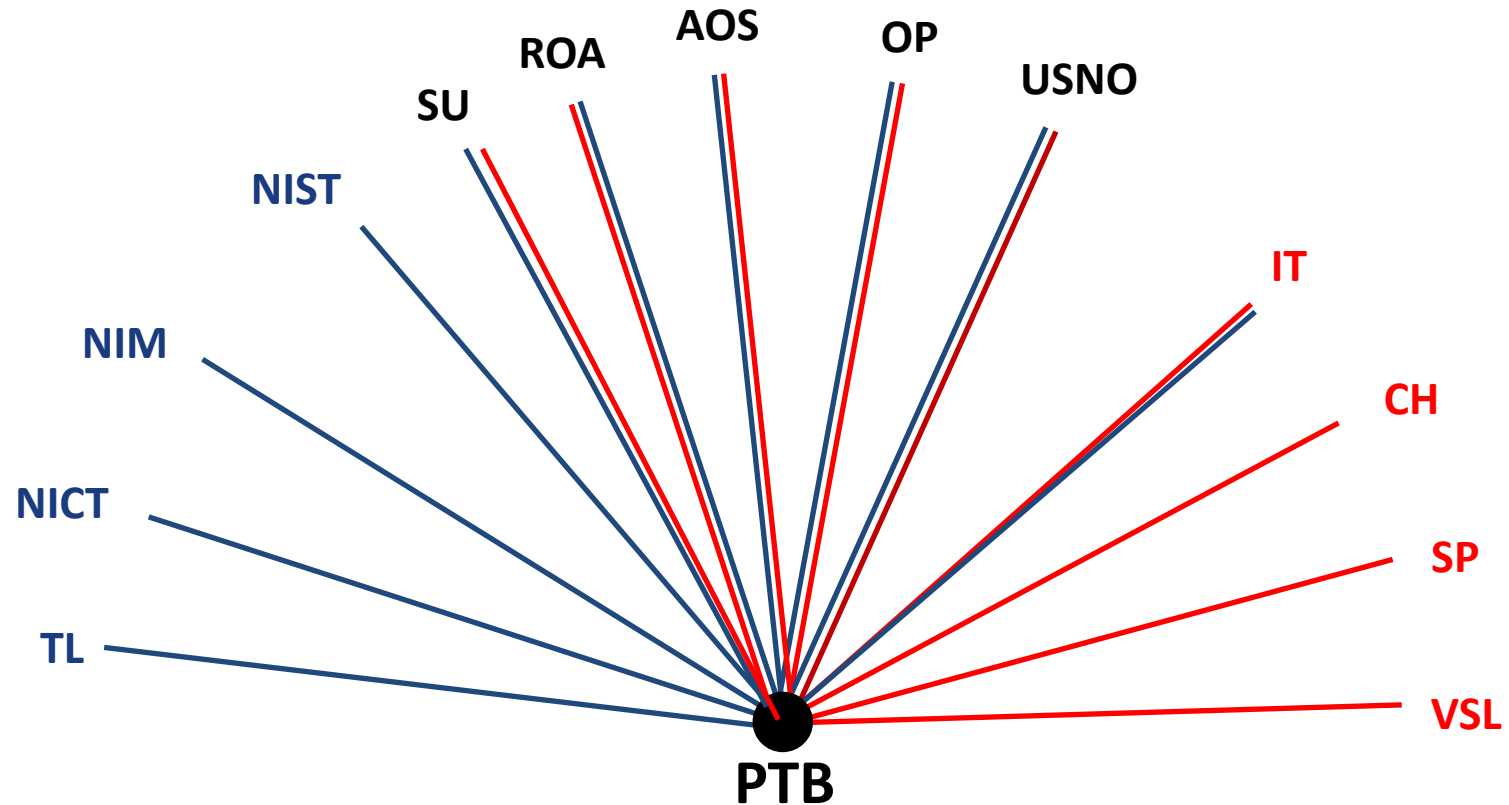
- **Alternative** technique: **GPS time link calibration** with uncertainty ~ 1.5 ns **← new**
 - When TWSTFT MOB cannot be used
← indispensable for inter-continental TW links

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

TWSTFT Mobile calibrators



USNO/USA



SU/Russia



TimeTech/Germany

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

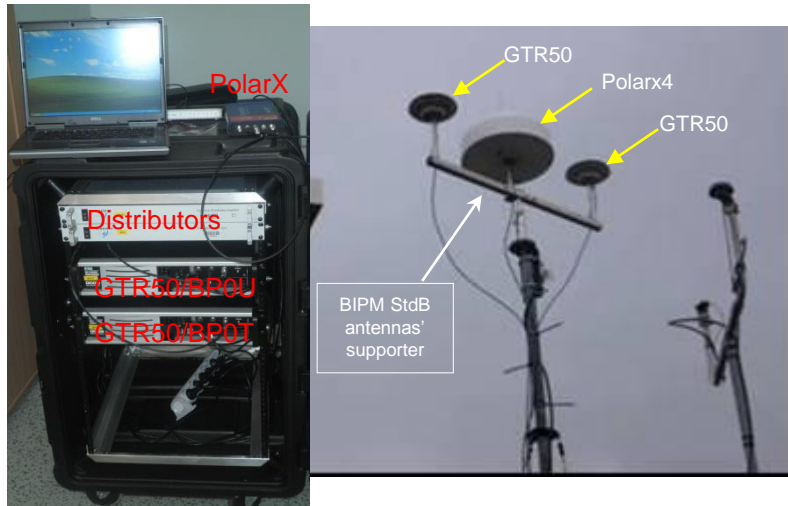
u_B 0.6 ~ 1.1 ns

→ The talk of J. Galindo

GPS calibrator -BIPM **METODE** pilot project

MEasurement of **T**otal **D**elay

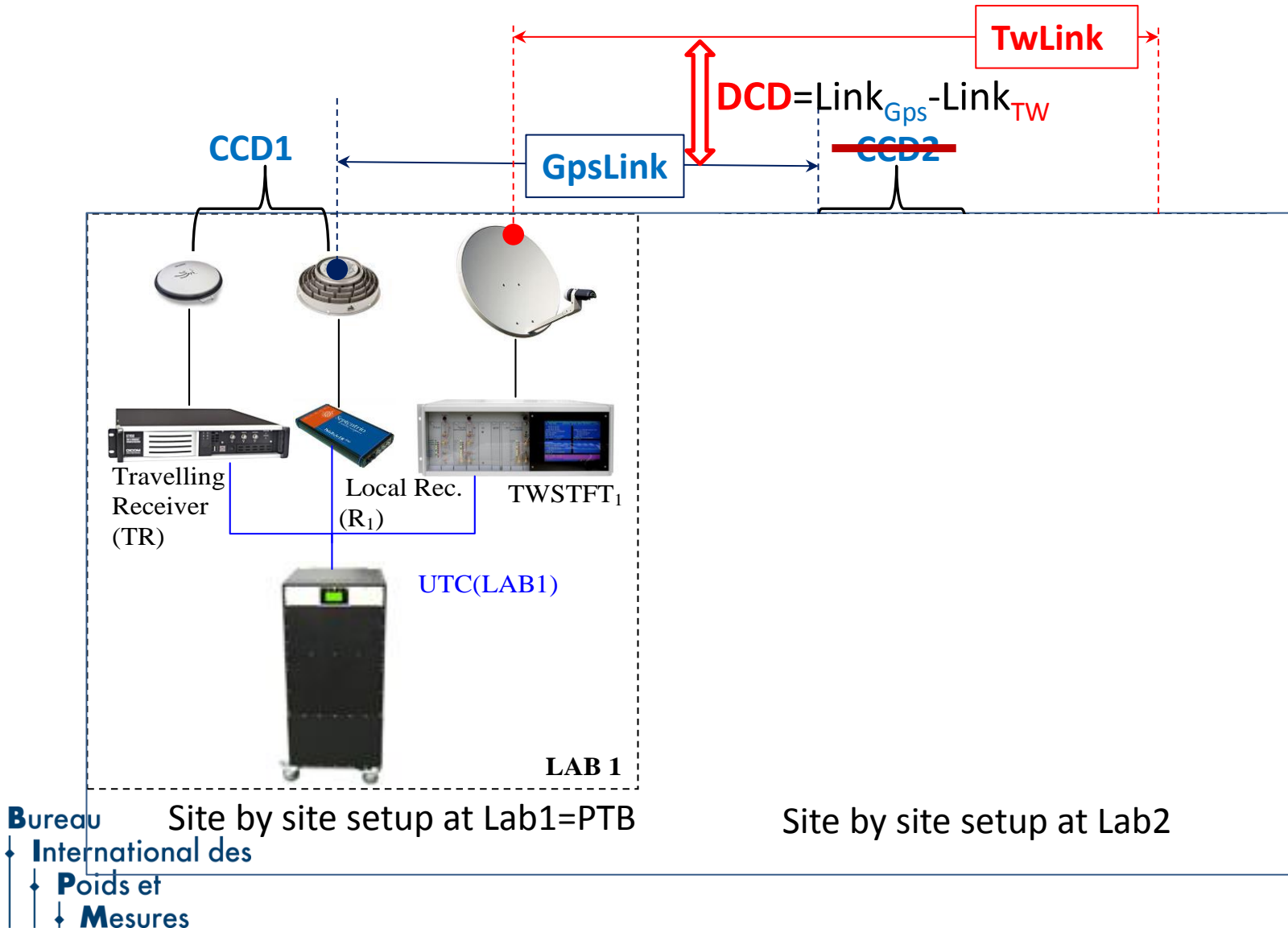
Portable GPS calibrator with 2-3 receivers



- [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

GPS/TWSTFT CCD/DCD 2/2



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TWSTFT Link Calibration Computation

$$\begin{aligned} \mathbf{DCD} &= \\ & [TW(\text{Lab}_k) - TW(\text{PTB})] - [GPS(\text{TR})_{\text{Lab}_k} - GPS(\text{PTB})] \\ & = \mathbf{CALR}_{\text{Lab}_k - \text{PTB}} \neq 0 \end{aligned}$$

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

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 .

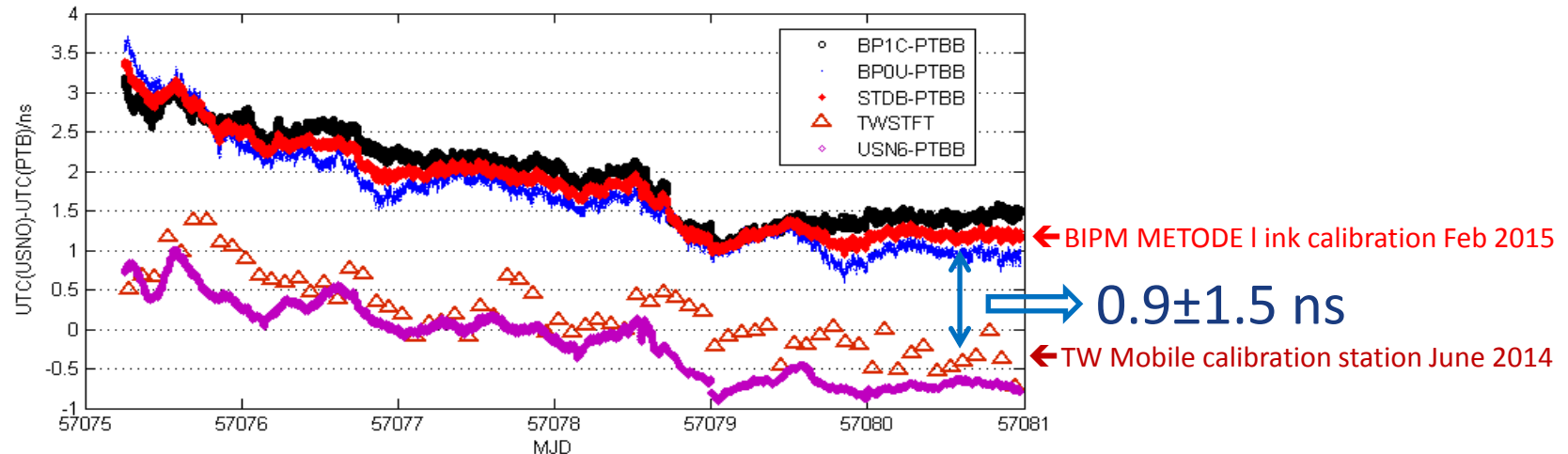
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GPS/TWSTFT calibration result USNO-PTB

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



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**)

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)

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

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

➔ Supported by other independent studies cf. the references

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 ($< \pm 0.3$ ns)
2. Mobile Cs standard ($< \pm 1.0$ ns)
3. 420 km Optical fiber link ($< \pm 0.12$ ns)

$u_B < \text{RMS}$

→ 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

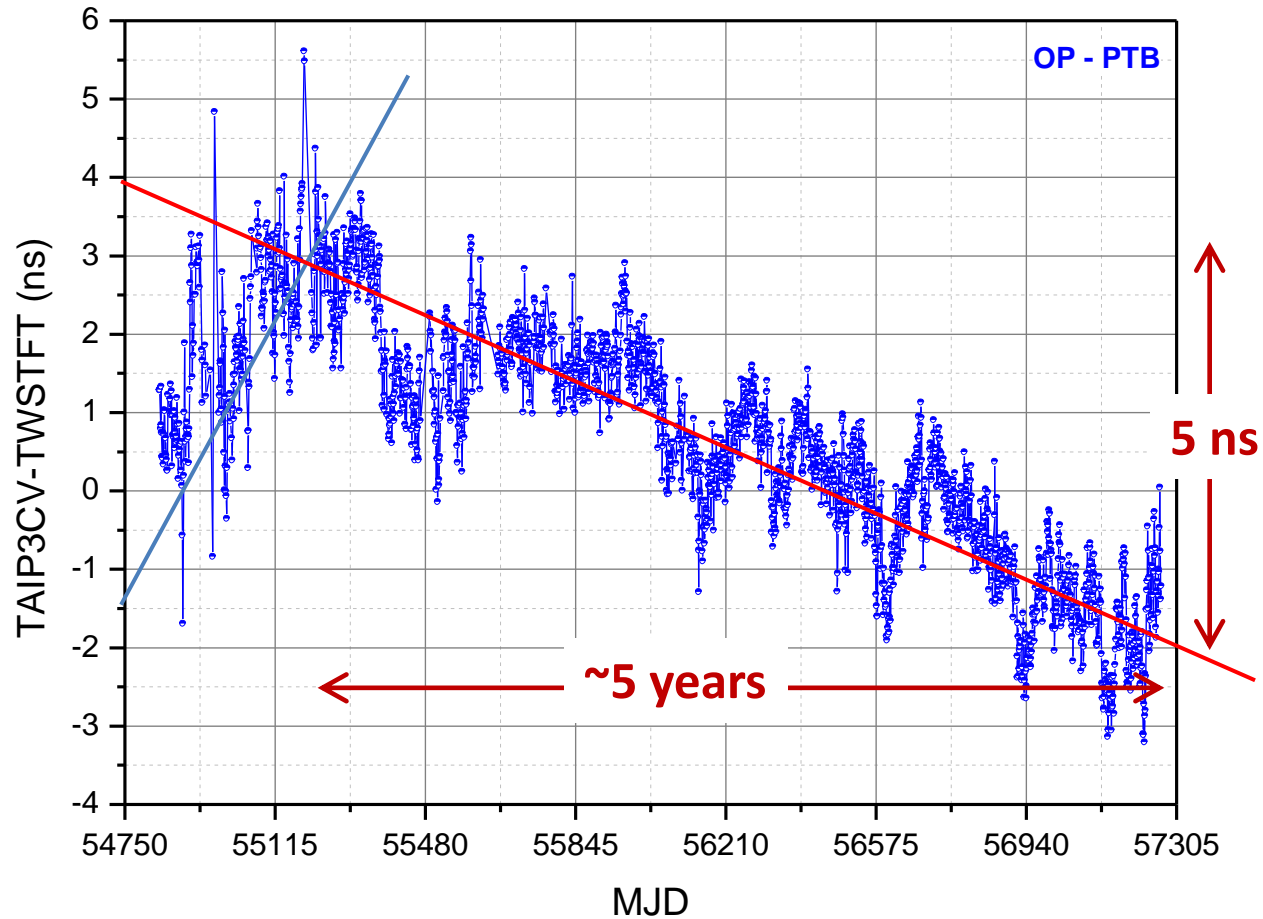
Consistency of TW_{MBS}-GPS-OF link calibrations

<i>Link</i>	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)

Differences between GPS and TWSTFT links OP-PTB - over 6 year after Achkar CCFW 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

Thanks

for your full cooperation