Multi-Technique Combination for UTC/TAI Time/Frequency Transfers

-- example of Combining GPS PPP and TW

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Techniques for UTC/TAI T/F transfers

TW: Two-Way Satellite Time Frequency transfer (Geostationary Telecommunication Satellites)

GNSS: Global Navigation Satellite System: GPS and Glonass

At present

29 labs operate at least **two** techniques; **9** operate the **three**;

In the coming future

Galileo, Compass, T2L2 … …

Lab	GPS	GLN	TW
AOS	GPS	GLN	TW
AUS	GPS		TW
CH	GPS		TW
IT	GPS	GLN	TW
KIM	GPS	GLN	
KRIS	GPS	GLN	TW
KZ	GPS	GLN	
LDS	GPS	GLN	
MIKE	GPS	GLN	
NICT	GPS		TW
NIM	GPS		TW *
NIS	GPS	GLN	
NIST	GPS	GLN	TW
NMIJ	GPS		TW
NPL	GPS		TW
NRL	GPS	GLN	TW
NPLI	GPS	GLN	
NTSC	GPS		TW
OP	GPS	GLN	TW
PTB	GPS	GLN	TW
ROA	GPS		TW
SG	GPS	GLN	TW
SP	GPS		TW
SU	GPS	GLN	
TL	GPS		TW
UME	GPS	GLN	
USNO	GPS	GLN	TW
VSL	GPS	GLN	TW
ZA	GPS	GLN	

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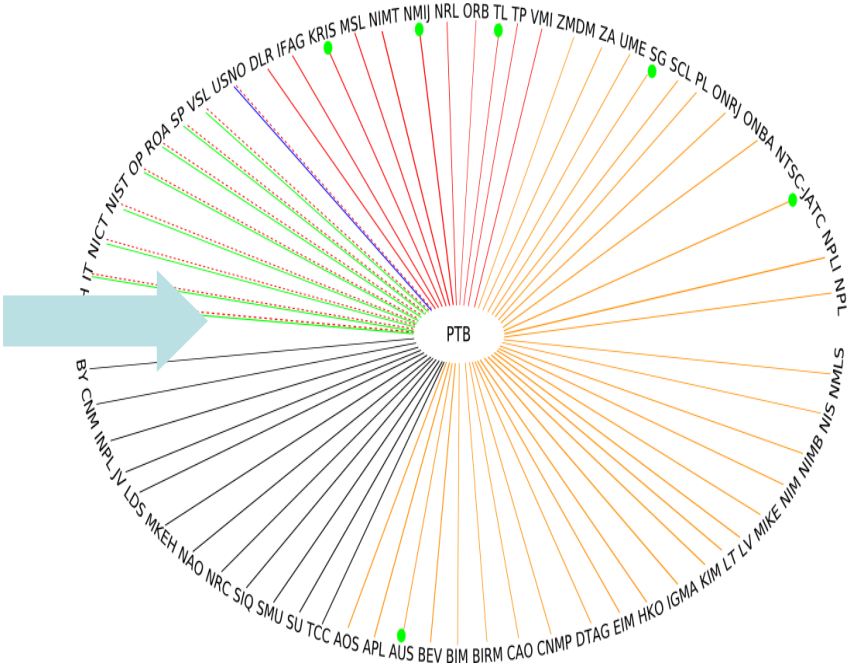
The present T/F transfer Strategy

1. Use either TW or GPS
2. Use TW before GPS
3. Use only one link

➔ *Single-technique-Single-link strategy*



68 UTC/TAI Labs and
the 67 primary links

Advantages of TW and GNSS

- **TW :**
  - Calibration and reproducibility ≈ 1ns
  - Long term stability
  - Atmosphere delay free symmetric trajectories
  - uA: 0.2~0.5 ns when diurnals off

- **GNSS :**
  - World-wide transfer without geometric limit GPST
  - Short term stability carrier phase information
  - distance independent
  - Hardware-manpower less cost
  - uA: ≤ 0.3 ns (GPS PPP)

disAdvantages of TW and GNSS

- **TW :**

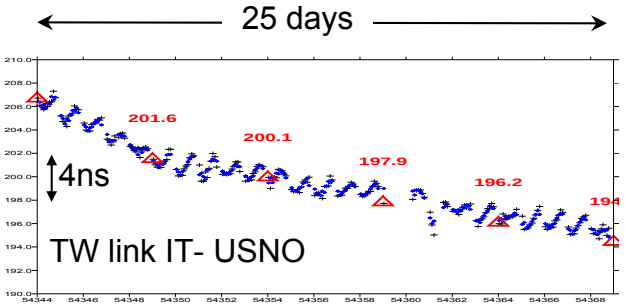
  - Diurnals (dominant error source)
  - Baseline fixed and distance dependent (geometric limit)
  - Hardware-manpower cost vs. GNSS

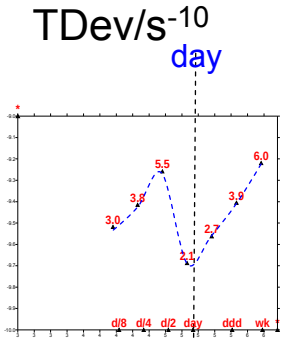
- **GNSS :**

  - Less accurate calibration vs. TW
  - Atmosphere effect corrections
  - Complex data treatment-Software depending on IGS

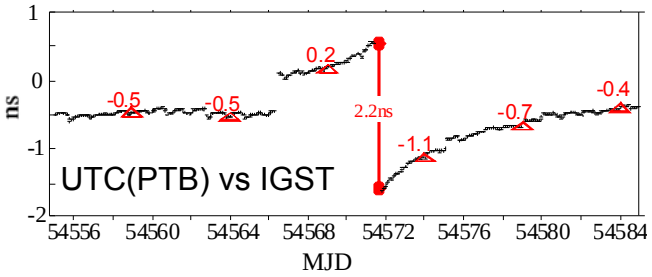
Examples of the faults in TW and GPS

Diurnals in TW





Jump in GPS PPP



➔ Non of the two has a dominant advantage vs. the other

Comparison of TW and GNSS

Terms	TW	GNSS
Calibration	~1ns	~5ns
Transfer limit	baseline	global
Distance	~dependent	~independent
Atmosphere effect	free	correction
Diurnals	yes	free
Data processing	simple/independ.	complex/depend.
Cost	expensive	less

➔Combining TW and GNSS to take the Advantages and Reduce the disAdvantages

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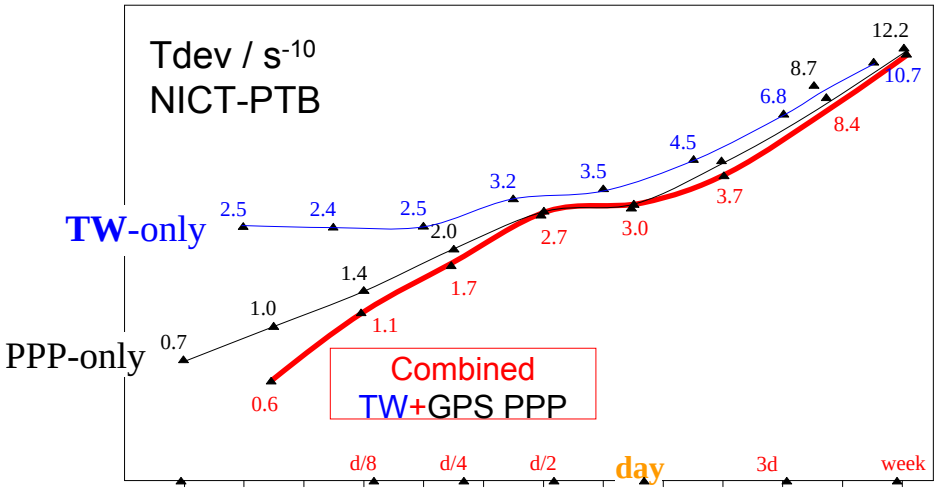
State of the art in the single-link combination

1. Weighted average of TW and GPS during the TAI generation, Petit and Jiang EFTF 2006

2. Use TW as a constraint in a GPS CP CV least-square algorithm, Defraigne and Martinez, EFTF/PTTI 2008

3. Use TW as the absolute scale of a time link and GNSS CP as its derivatives, Jiang and Petit, EFTF2006 and Metrologia 2009

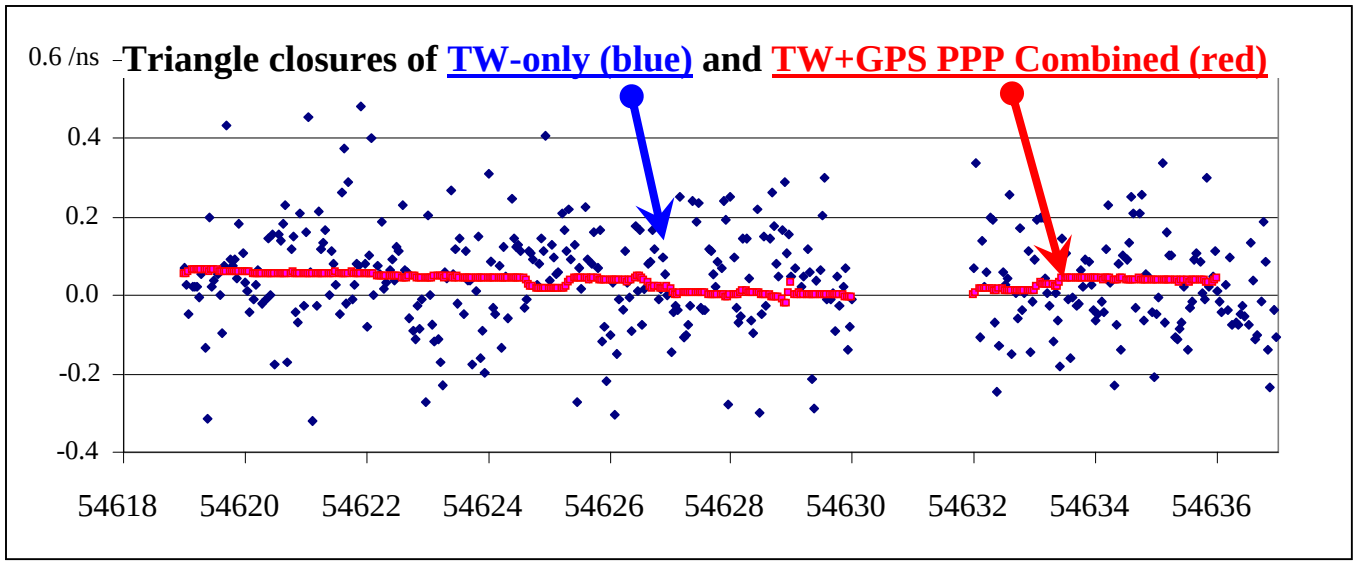
Gain in the Tdev by the combination



- Repair/Reduce the faults in raw data
- Improve short term stability

Gain in the Triangle Closures

Single link Closure Δ: TL-NICT-KRIS



Combination of TW and GNSS

1. Give a better robustness thanks to independence of TW and GNSS;
2. Repair the faults: gaps, jumps, discontinuities and drift in both TW and GNSS;
3. Keep the TW calibration and GNSS short term stability;
4. Reduce the diurnals in TW

Can the combination improve UTC/TAI ?

An example of
Combining TW and GPS PPP:

➔ **19** labs (29% of 68 labs) operate both TW and PPP

➔They contribute to UTC/TAI with
- 253 clocks (71% of total)
- 88% of total clock weight
- 12 Primary Frequency Standards (100%)

Any improvement in T/F transfer of these **19** links will have a direct gain of **88%** in UTC/TAI and **100%** in PFS

➔ TW+PPP is an Effective strategy to improve UTC/TAI

19 Labs operate **TW & GPS PPP** and their contribution to UTC/TAI

No.	Lab. TW+PPP	Nomb. Clock	Clock %	Weight %	PFS
1	AOS	13	3.7	4.0	
2	AUS	5	1.4	0.9	
3	CH	4	1.1	1.0	
4	OP	29	8.1	7.5	yes
5	IT	6	1.7	2.6	yes
6	KRIS	6	1.7	1.2	
7	NICT	27	7.6	10.9	yes
8	NIM	4	1.1	0.1	
9	NIST	12	3.4	5.7	yes
10	NMIJ	3	0.8	1.4	yes
11	NPL	4	1.1	1.7	yes
12	NTSC	22	6.2	8.0	
13	PTB	6	1.7	2.6	yes
14	ROA	6	1.7	1.8	
15	SG	3	0.8	0.4	
16	SP	14	3.9	3.2	
17	TL	15	4.2	5.8	
18	USNO	70	19.7	27.6	
19	VSL	4	1.1	1.4	.
	Total	**253**	**71%**	**88%**	.

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Summary

1. Multi-techniques dada are available but the present strategy is *Single-Technique-Single-Link transfer*
2. The multi-technique combination is an *effective strategy to improve the UTC/TAI*
3. GPS PPP and TW combination proves considerable gains in **R**obustness, **A**ccuracy and **P**recision
4. Mathematic model and software are developed at BIPM