CCTF

GNSS calibration status: update

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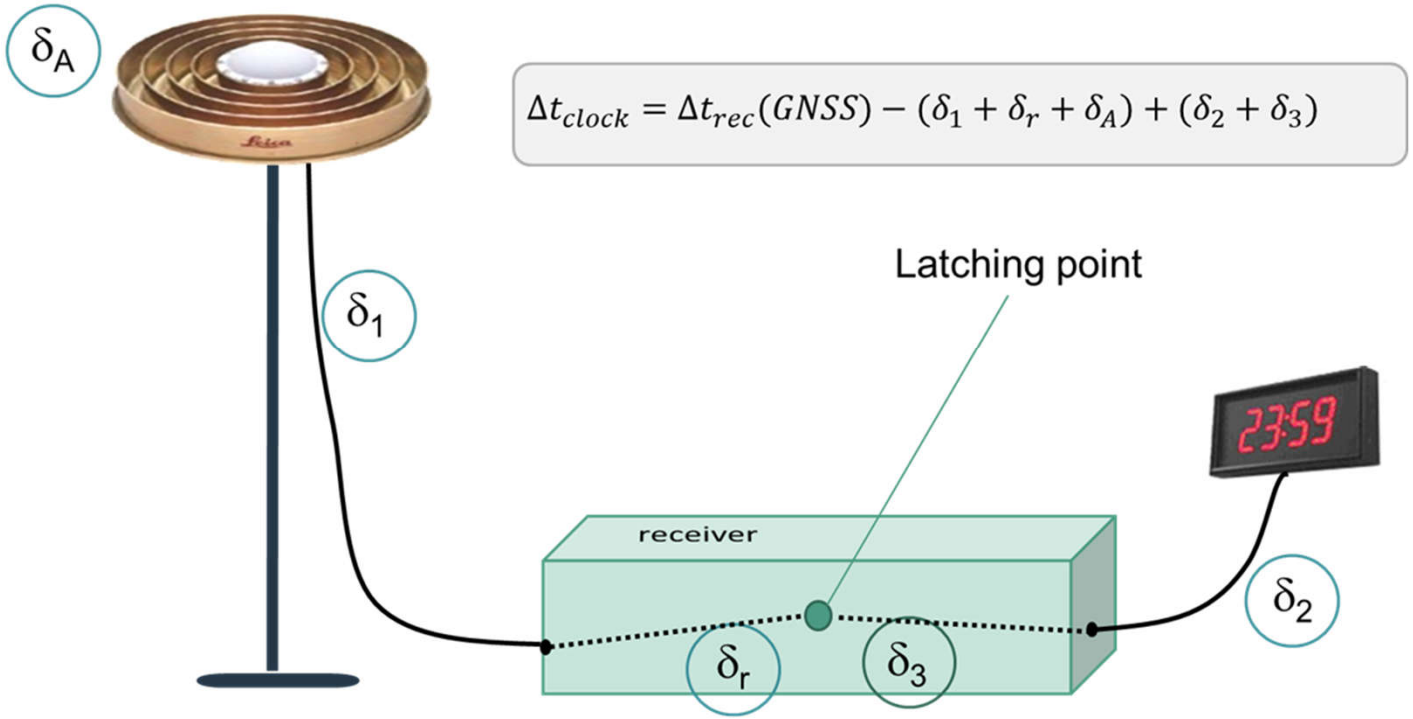
Chair of the WG on GNSS

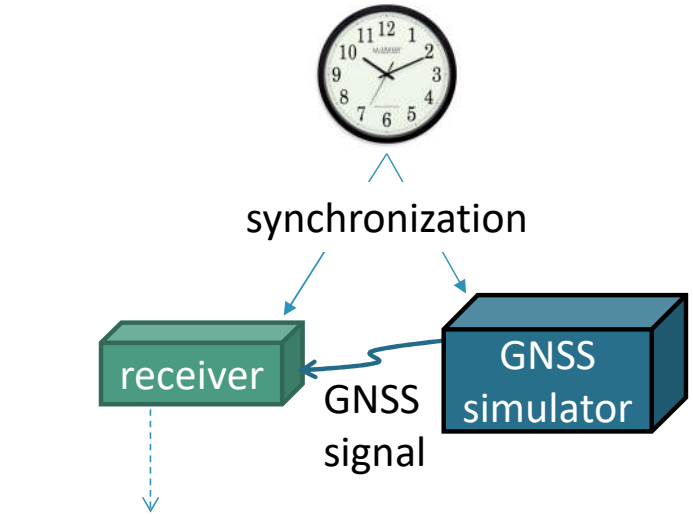
CONSULTATIVE COMMITTEE
FOR TIME AND FREQUENCY

GNSS calibration

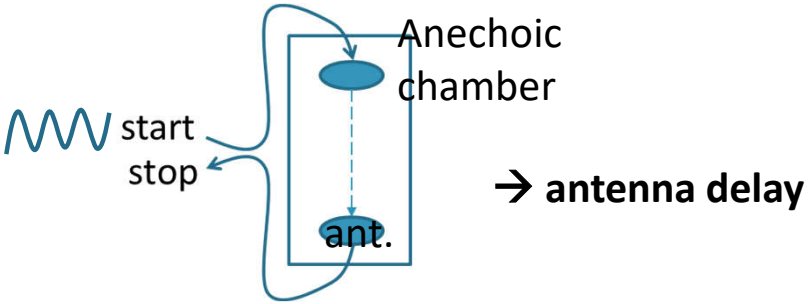


$$\Delta t_{clock} = \Delta t_{rec}(GNSS) - (\delta_1 + \delta_r + \delta_A) + (\delta_2 + \delta_3)$$

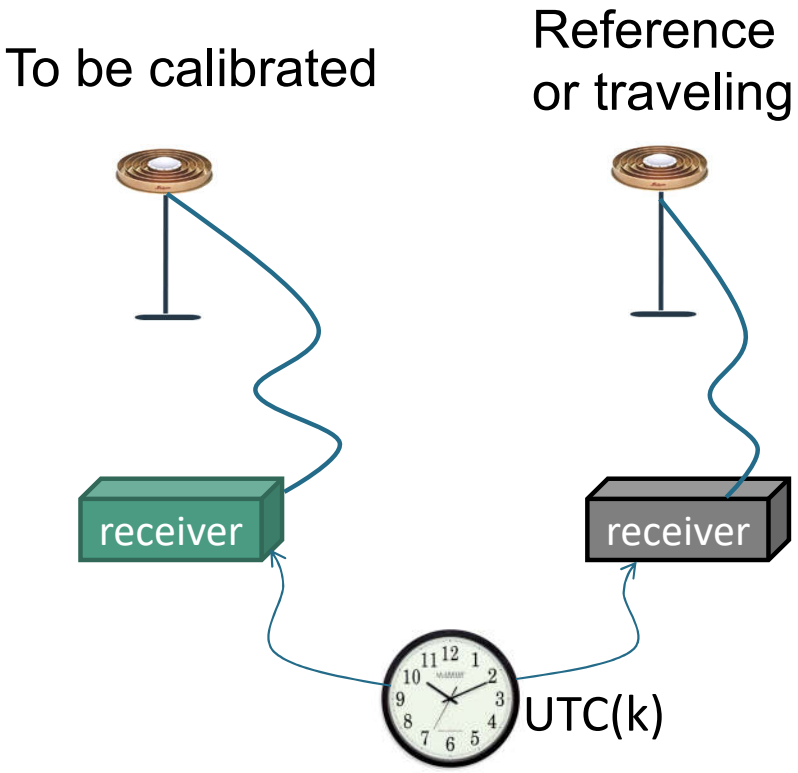
Absolute / Relative



Measurements → **receiver delays**



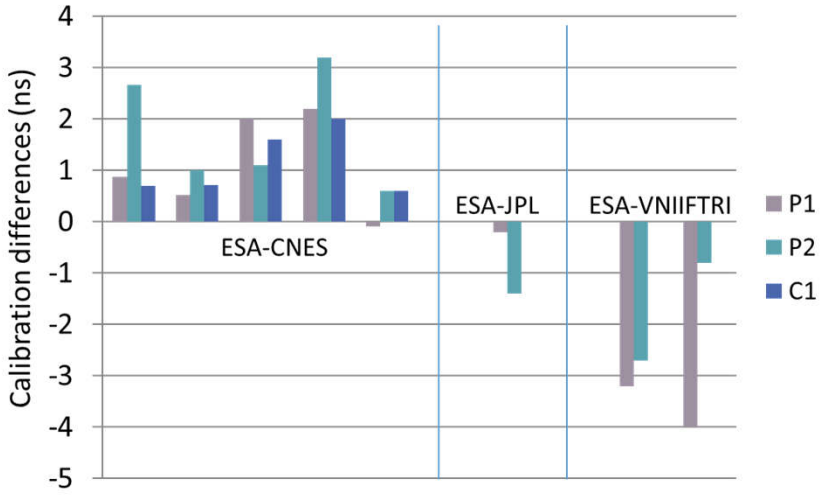
→ **antenna delay**



Measurement differences → **station delays**

Status on Absolute calibration

- Important for :
  - Having some reference for the differential calibrations
  - Mandatory for the validation of $bUTC_{GNSS}$ through (UTC-UTC(k)) – (UTC(k)-$bUTC_{GNSS}$)
- Consistency of the different results at the level of 1-2 ns (a bit larger than the combined uncertainties)
- To date: results available for GPS, Galileo, GLONASS, BDS-2 and BDS-3.



Recommendations to the CCTF (2021):

- **On absolute calibration of GNSS equipment for time transfer**

– **recommends** that

- Competent laboratories continue their efforts in determining signal delays in GNSS receiver installations, including antenna, antenna cable and receiver electronics, providing so-called “absolute calibrations” for existing and emerging GNSS signals,
- BIPM maintains a list and a follow-up of the absolutely calibrated GNSS stations and their comparisons with the receiver systems operated in G1 laboratories.

Status on Relative calibration

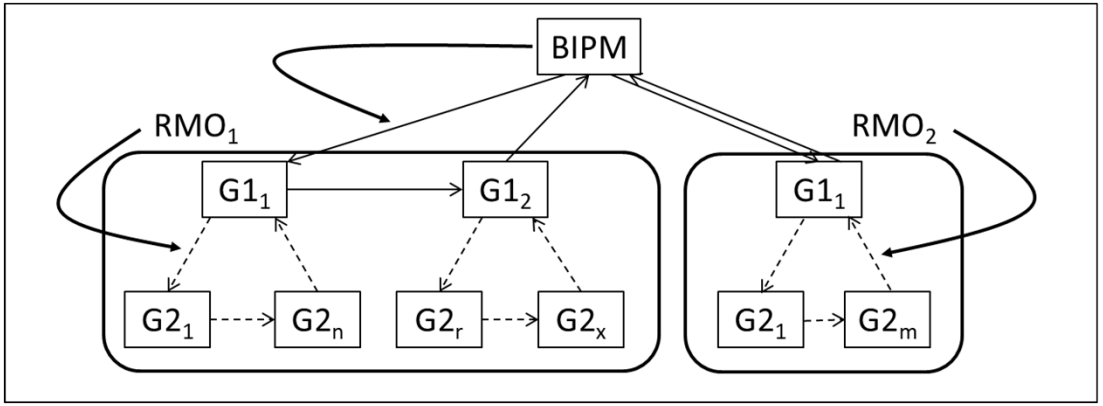
- Guidelines for GNSS calibration: v4.0 (August 2021)

https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/bipmcalibration_guidelines_v40.pdf

- Synthetic document: “How to get GNSS calibration for UTC(k) laboratories” (July 2021, following the CCTF survey)

https://webtai.bipm.org/ftp/pub/tai/publication/gnss-calibration/guidelines/How-to-get-calibration-July2021.pdf

Relative calibration scheme for UTC



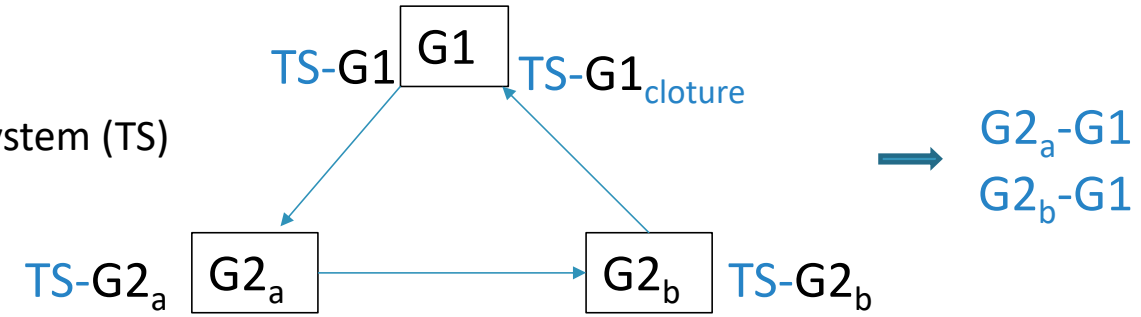
BIPM organises the calibration of some labs (named Group 1, G1) in each RMO using a Traveling System

The other labs (named Group 2, G2) ask G1 labs to get calibration

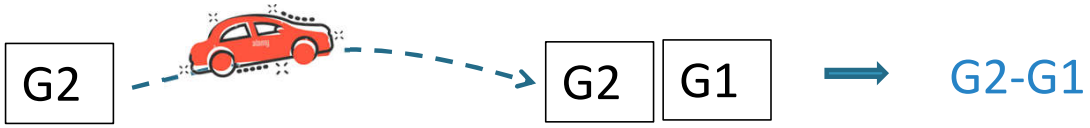
CALIBRATION PROCEDURES FOR G2 LABS

1. Calibration trip with closure

use of Traveling System (TS)



2. Direct calibration



3. authorized "third party"

G2 laboratory, a GNSS station manufacturer , …

BUT the procedure & uncertainties must be first validated by the BIPM

Uncertainties

For the link UTC(k)-UTC(s) (noted A-B) :

$$u_{CAL}(A\text{-}B)(t0) = (u_{CAL0}^2\ [+\ \Delta u_{CAL}(A/B)^2] + AGING)^{1/2}$$

Only if poor behavior during a calibration trip indicated in the report

- 1.5 ns if the receiver in B has been calibrated in a Group 1 trip;
- 2.5 ns if the receiver in B has been calibrated in a Group 2 trip;
- 4.0 ns if the receiver in B has been calibrated in a “Direct calibration” vs. a Group 1;
- 5.0 to 7.0 ns if the receiver in B has been calibrated by an “authorized third party”;

Uncertainties : evolution with time

- aging:

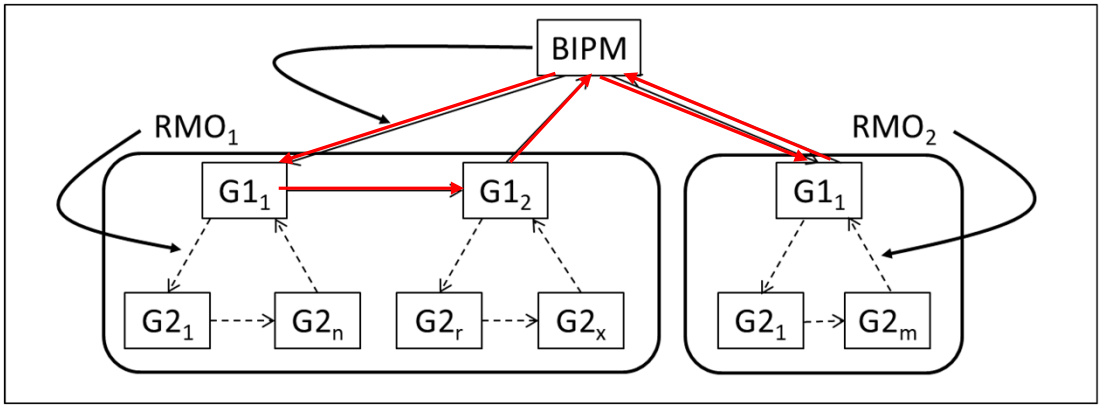
  $u_{AG} = \max (c_{AG} \times \Delta t^{1/2} - 1.0, 0.0)$

  - aging coefficient for GNSS is $c_{AG} = 0.4$ ns

- "transfer of calibration" → Δu_{TC}

$$u_{CAL}(t) = (u_{CAL0}^2 + u_{AG}^2 [+\Delta u_{TC}^2 + \Delta u_{CAL}^2])^{1/2}$$

Status on Relative calibration / G1



Group 1:

- One complete calibration (all G1 in all RMOs) every 2 years
- 1001-2020 finished (except COOMET (SU) started end 2021, paused with receiver in SU)

This calibration concerns GPS P1/P2/C1, Galileo E1/E5a

- 1001-2022 started (now in APMP) – This calibration will additionally concern BDS-2 and BDS-3

Stability of G1 results

Average difference of HW delays between 2018 and 2020 G1 campaigns

Ensemble	# rec	ΔIDP1/E1	ΔIDP2/E5a	ΔIDC1	ΔIDP3/E3
2020 – 2018 GPS					
APMP	9	0.19	0.22	0.17	0.14
EURAMET	10	-0.10	0.11	-0.21	-0.42
SIM	6	-0.07	0.03	0.00	-0.22
APMP+EURAMET+SIM	23	0.01 (0.6)	0.14 (0.5)	-0.03 (0.6)	-0.19 (0.7)
2020 – 2018 GAL					
EURAMET	6	-0.03	0.10	N/A	-0.20
SIM	3	0.07	-0.23	N/A	0.44
EURAMET+SIM	8	0.00 (0.6)	-0.01 (0.7)	N/A	0.02 (0.6)

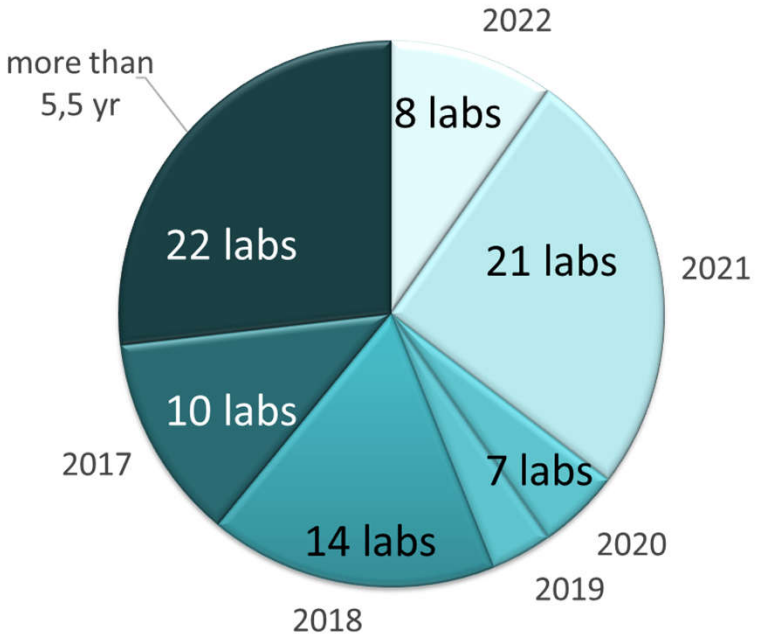
Stdev.

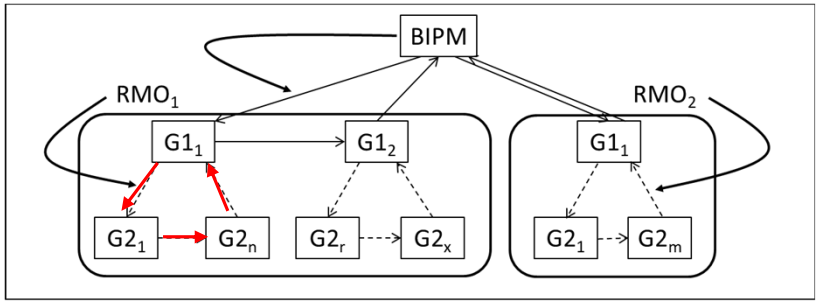
No sign of systematic variation / Stdev < 0,8 ns → G1 reference very stable

Status on G2 calibration

GPS:

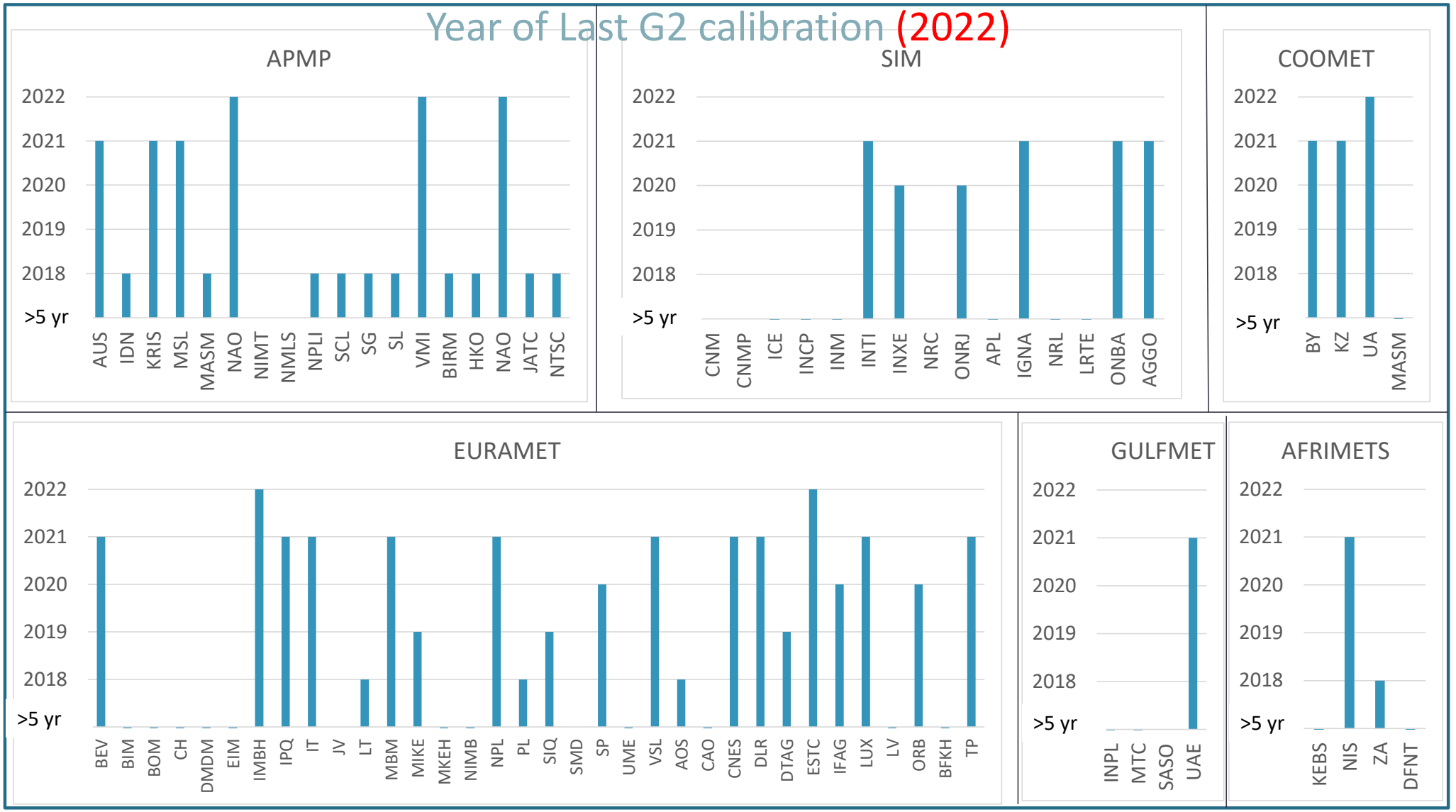
G2: Date of last calibration



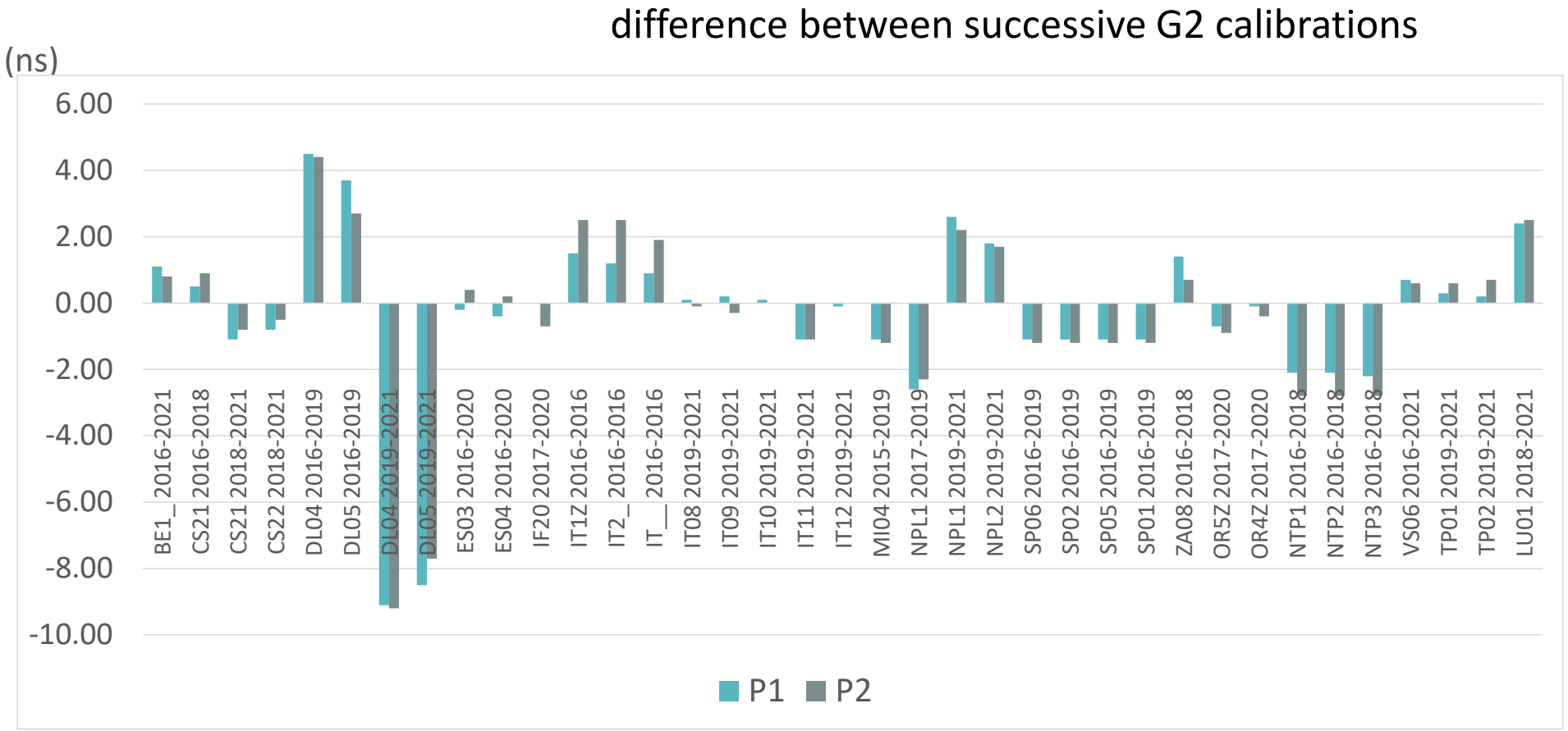


- Galileo: Already 25 labs calibrated
- BeiDou starts in 2022

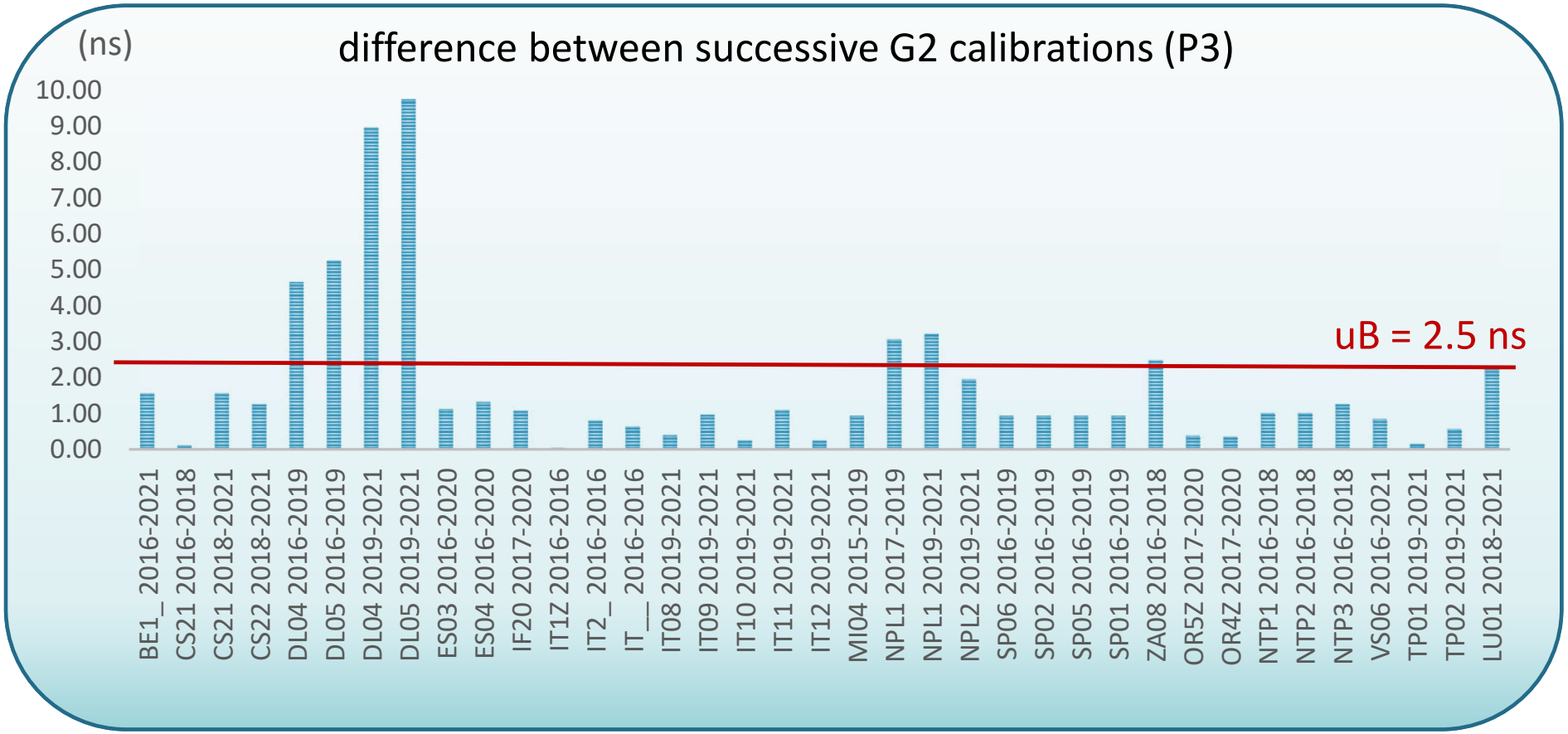
Year of Last G2 calibration (2022)



Stability of G2 calibration results



Stability of G2 calibration results



Thank You

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Procedure for G2 to request a calibration

- If your RMO is covered by G1:
  Contact the TCTF G1 Coordinator, if exists.
  Otherwise contact a G1 laboratory of your RMO
  A G1 lab will organize a Direct Calibration or a Calibration with Closure
- If there is no G1 laboratory in your RMO (i.e. AFRIMETS and GULFMET):
  contact either a G1 from another RMO or the BIPM that will help find a G1 or organize a Direct Calibration
- In all cases, the practical aspects of the calibration trip (shipment, customs administrative procedures…) should be considered well in advance of the planned trip.

Contacts for G1 laboratories

APMP TCTF G1 Coordinator: Michael Wouters Michael.Wouters@measurement.gov.au	**NICT** Ryuichi Ichikawa richi@nict.go.jp	**NIM** Zhiqiang Yang yangzq@nim.ac.cn	**TL** Shinn-Yan Lin sylin@cht.com.tw
EURAMET	**ROA** Hector Esteban hesteban@roa.es	**PTB** Andreas Bauch andreas.bauch@ptb.de	**OP (LNE-SYRTE)** Pierre Uhrich Pierre.Uhrich@obspm.fr
SIM	**NIST** Bijunath Patla brp1@nist.gov	**USNO** James Hanssen james.hanssen@navy.mil	
COOMET	**SU (VNIIFTRI)** Artem Karaush karaush_aa@vniiftri.ru		
AFRIMETS			
GULFMET			

CHANGE OF GNSS SETUP AT UTC(k) AFTER CALIBRATION

Possible changes on cables, receiver, antenna

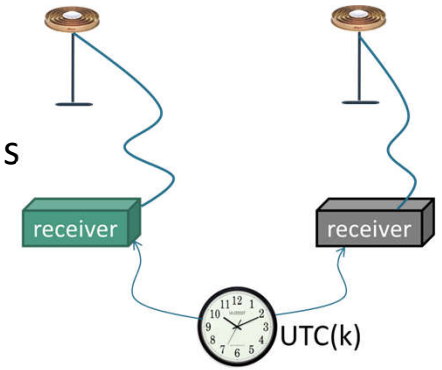
IF Only REFDLY : just use the new one, no change in the cal_id, nor in the uncertainty

All other cases :

If a second station connected to UTC(k) is available:

make a "**transfer of calibration**" :

- compute differences of code pseudoranges between the 2 stations over a few days before and a few days after the setup change
- Provide a report → BIPM
- Uncertainty expanded by the BIPM



Otherwise: stay "uncalibrated" until you get a new calibration.