GNSS calibration status: update

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Chair of the WG on GNSS
GNSS calibration

\[ \Delta t_{\text{clock}} = \Delta t_{\text{rec}}(\text{GNSS}) - (\delta_1 + \delta_r + \delta_A) + (\delta_2 + \delta_3) \]
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Absolute / Relative

**Absolute**
- Receiver
- GNSS simulator
- GNSS signal
- Synchronization
- Measurements → **receiver delays**
- Anechoic chamber
- Start stop
- Antenna delay

**Relative**
- To be calibrated
- Reference or traveling
- Receiver
- UTC(k)
- Measurement differences → **station delays**
Status on Absolute calibration

- Important for:
  - Having some reference for the differential calibrations
  - Mandatory for the validation of $\text{bUTC}_{\text{GNSS}}$ through $(\text{UTC}-\text{UTC}(k)) - (\text{UTC}(k)-\text{bUTC}_{\text{GNSS}})$
- 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)

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

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

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” \( \rightarrow \Delta u_{TC} \)

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

<table>
<thead>
<tr>
<th>Ensemble</th>
<th># rec</th>
<th>ΔIDP1/E1</th>
<th>ΔIDP2/E5a</th>
<th>ΔIDC1</th>
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<td>0.03</td>
<td>0.00</td>
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<td>0.01 (0.6)</td>
<td>0.14 (0.5)</td>
<td>-0.03 (0.6)</td>
<td>-0.19 (0.7)</td>
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</table>

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)

- APMP:
  - >5 yr
  - 2018
  - 2021
  - 2022

- SIM:
  - >5 yr
  - 2018
  - 2019
  - 2020
  - 2021
  - 2022

- COOMET:
  - >5 yr
  - 2018
  - 2019
  - 2020
  - 2021
  - 2022

- EURAMET:
  - >5 yr
  - 2018
  - 2019
  - 2020
  - 2021
  - 2022

- GULFMET:
  - >5 yr
  - 2018
  - 2019
  - 2020
  - 2021
  - 2022

- AFRIMETS:
  - >5 yr
  - 2018
  - 2019
  - 2020
  - 2021
  - 2022
Stability of G2 calibration results

difference between successive G2 calibrations

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Stability of G2 calibration results

Difference between successive G2 calibrations (P3)

\[ u_B = 2.5 \text{ ns} \]
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

<table>
<thead>
<tr>
<th>APMP TCTF G1 Coordinator:</th>
<th>NICT</th>
<th>NIM</th>
<th>TL</th>
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<tbody>
<tr>
<td>Michael Wouters</td>
<td>Ryuichi Ichikawa</td>
<td>Zhiqiang Yang</td>
<td>Shinn-Yan Lin</td>
</tr>
<tr>
<td><a href="mailto:Michael.Wouters@measurement.gov.au">Michael.Wouters@measurement.gov.au</a></td>
<td><a href="mailto:richi@nict.go.jp">richi@nict.go.jp</a></td>
<td><a href="mailto:yangzq@nim.ac.cn">yangzq@nim.ac.cn</a></td>
<td><a href="mailto:sylin@cht.com.tw">sylin@cht.com.tw</a></td>
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<tr>
<td></td>
<td>Hector Esteban</td>
<td>Andreas Bauch</td>
<td>Pierre Uhrich</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:hesteban@roa.es">hesteban@roa.es</a></td>
<td><a href="mailto:andreas.bauch@ptb.de">andreas.bauch@ptb.de</a></td>
<td><a href="mailto:Pierre.Uhrich@obspm.fr">Pierre.Uhrich@obspm.fr</a></td>
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<tr>
<th>SIM</th>
<th>NIST</th>
<th>USNO</th>
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<tr>
<td></td>
<td>Bijunath Patla</td>
<td>James Hanssen</td>
</tr>
<tr>
<td></td>
<td><a href="mailto:brp1@nist.gov">brp1@nist.gov</a></td>
<td><a href="mailto:james.hanssen@navy.mil">james.hanssen@navy.mil</a></td>
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<tbody>
<tr>
<td></td>
<td>Artem Karaush</td>
<td></td>
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<tr>
<td></td>
<td><a href="mailto:karaush_aa@vniiftri.ru">karaush_aa@vniiftri.ru</a></td>
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<tr>
<td>GULFMET</td>
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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.