# G1-2 calibrations for UTC

## Update on guidelines, results and changes in Circular T

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GNSS WG Meeting

14 September 2015

Bureau International des Poids et Mesures

# Outline

- Goals and principles of the new GNSS calibration scheme
- Dissemination of results, web access
- Calibration Guidelines
- Status of GPS Group 1 calibrations
- Next actions and changes in BIPM Circular T

# Goals

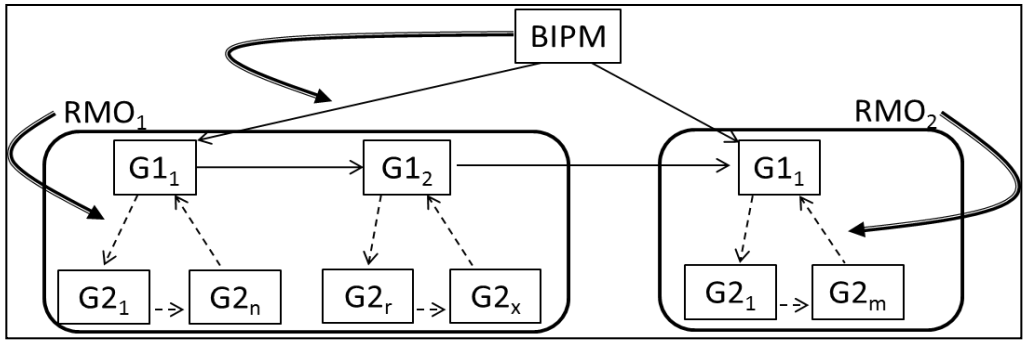
- Maintain the calibration of the time transfer facilities in laboratories contributing to UTC.
  - Including new calibrations for the many uncalibrated systems or updating outdated values
- Use the calibration trips contributed by RMOs and individual laboratories in a consistent and optimal manner.
- Optimize the set of $u_B$ uncertainties for UTC.

- The initial Guidelines document covers ‘GNSS equipment calibration'.

- Another document covers ‘link calibration’ i.e. the computation is carried out for links using PPP and is used to calibrate time links e.g. TW links

# Principles

- Two groups of laboratories
  - Group 1: Calibration trips regularly carried out by the BIPM
  - Group 2: Other laboratories. Calibration trips for group 2 are performed under responsibility of the RMOs.
  - Group 1 laboratories are proposed by the RMOs. Typically < 10 such labs. List may evolve with time.




- The BIPM will maintain an open database with all calibration results.
  - Each calibration report will be identified by a unique calibration identifier Cal_Id to be used as a reference for the calibration info (e.g. in CGGTTS header)
- $u_{CAL}$ calibration uncertainties for UTC links are set by the BIPM

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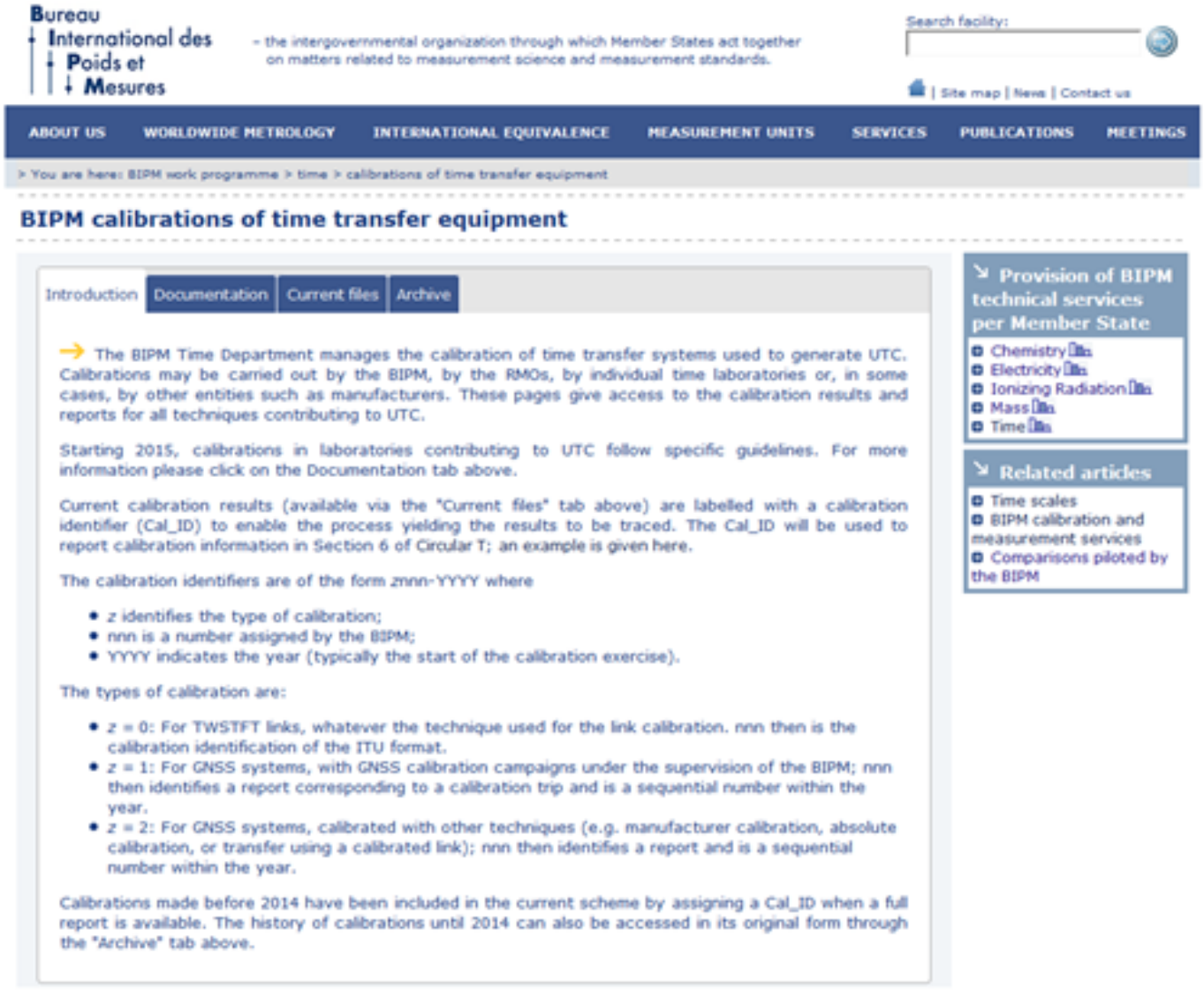
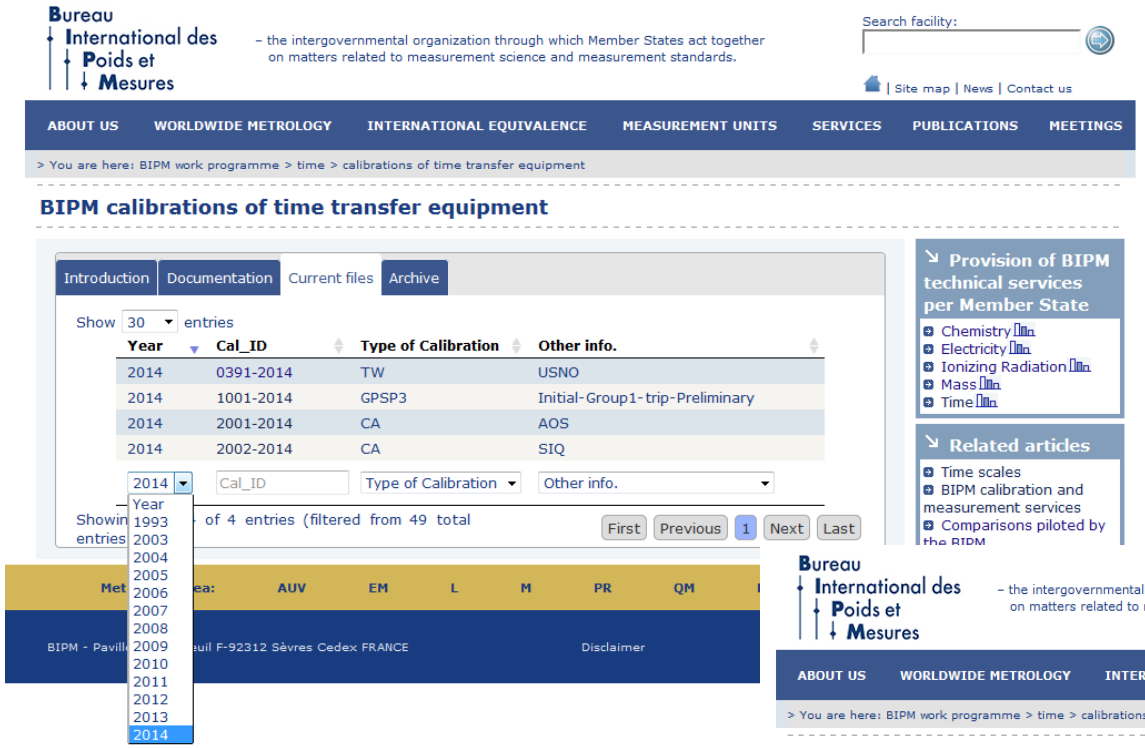
# Calibrations web page

**http://www.bipm.org/jsp/en/TimeCalibrations.jsp**

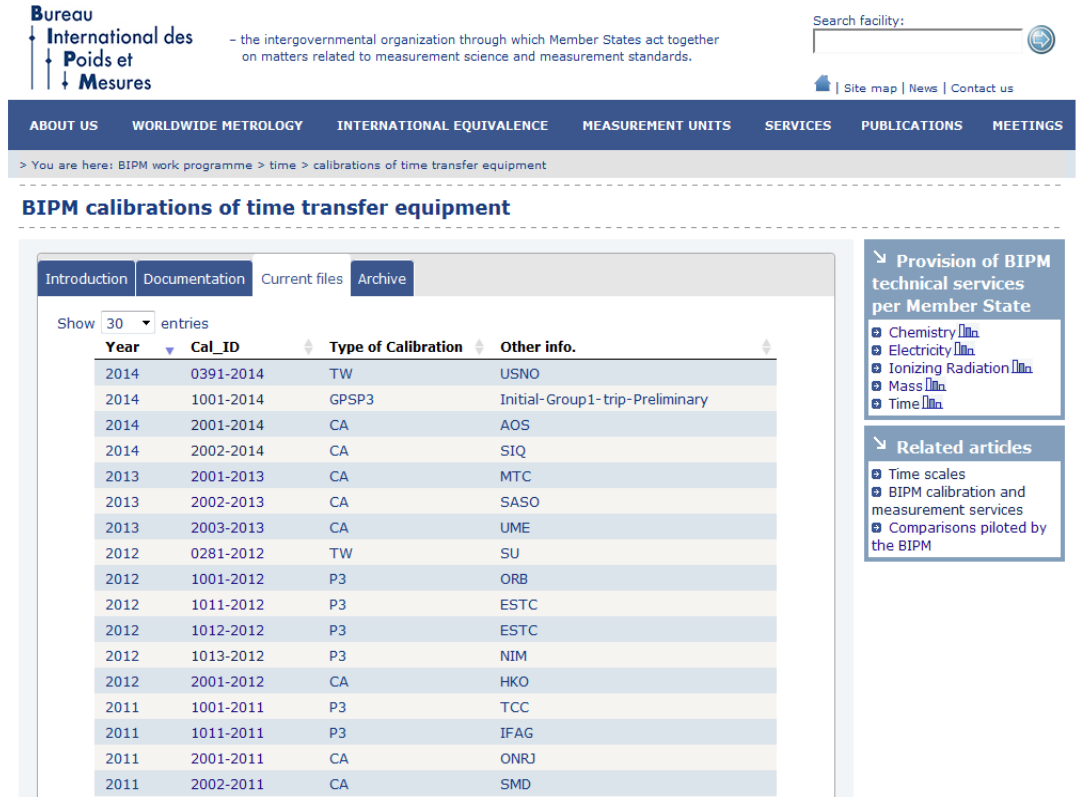
**On line 09/04/2015**

**Intended to host all reports of UTC calibrations**






- Basic display allows sorting on year and other headings.
- To be improved following return of experience.
- Eventually will be accessed through the future database.

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# Guidelines for equipment calibration

- « BIPM Guidelines for GNSS calibrations » v3.0 distributed in April 2015.
  - Minor update in v3.1 in September 2015

- Practical calibration procedures covering: operations; computation; report of results. (see Guidelines document)
  - Annex 1- Operational procedures for a visit of the traveling equipment
  - Annex 2- Procedure for computing the difference of GPS C/A code measurements (to be finalized)
  - Annex 3- Procedure for computing raw difference of GPS code measurements for geodetic receiver
  - Annex 4- Template for the calibration report to the BIPM

# Guidelines : What is next? (Annex 1)

- Annex 1- Operational procedures for a visit of the traveling equipment
- Validate the information and measurement procedure for the systems mentioned (Z12T, PolaRx2-3-4, GTR50, TTS4, different Novatel systems)
- Provide information for additional systems ?
  - GTR51 not mentioned yet;
  - question received for JAVAD Delta-3 system (from ESA); etc…
- Provide more precise hardware specifications to perform the measurements? Questions to be discussed in next presentations

# Guidelines : What is next? (Annex 2)

- Annex 2- Procedure for computing the difference of GPS C/A code measurements (to be finalized)
  - G1 calibrations already include C1 (and C2 when available). But calibration results not generated for lack of an obvious / agreed reference.
  - Propose to base C/A calibration on the same ensemble of G1 geodetic systems =>
    - C1 reference based on chosen P1 reference in the Group 1
    - C1 reference will shift by ~-4ns wrt present situation
  - procedure should accommodate comparisons of the type “Geodetic vs. C/A” (Rinex to CGGTTS) and “C/A vs. C/A” (CGGTTS to CGGTTS).
  - Procedure based on the R2CGGTTS software (thanks to Pascale)

# Guidelines : What is next? (Annex 3)

- Annex 3- Procedure for computing raw difference of GPS code measurements for geodetic receivers
  - Designed by the BIPM from scratch to compute, in a single step, the relative position of the two receivers AND the difference between all code measurements
  - Presently covers GPS C1/C2 P1/P2
  - No major change expected but can be expanded to other codes
  - Possible to implement the determination of phase-code offsets
- If laboratories have developed their own process, they can continue to use it (but it should be somehow described).

# Guidelines : What is next? (Annex 4)

- Annex 4- Template for the calibration report to the BIPM
  - The form may be adapted. E.g. link to a spreadsheet instead of a set of tables (?).
  - For Group 1: BIPM will use this kind of report.
  - For Group 2: BIPM expects to receive similar information for G2 but the form may be chosen by those reporting.

- Note that two concepts should be distinguished
  - The results of calibration are expressed as numbers (INTDLY or SYSDLY, TOTDLY not encouraged) pertinent to each system.
  - The uncertainty $u_{CAL0}$ associated to a calibration trip is relevant to the links between systems that were calibrated.

- Some of these questions to be discussed in next presentations

# Guidelines Annex 4: uncertainty budget

Observed values for $u_a$

Default values used for most $u_b$ components, unless higher value needs to be used instead (explain why).

How to treat the $u_{b1}$ (misclosure)? Also use a minimal default value?

| Unc. | Value P1 (ns) | Value P2 (ns) | Value P1-P2 (ns) | Value P3 (ns) | Description |
|---|---|---|---|---|---|
| $u_a$ (T-V) | 0.1-0.2 | 0.1-0.2* | 0.15-0.3* | | RAWDIF (traveling-visited) |
| $u_a$ (T-R) | 0.1-0.2 | 0.1-0.2 | 0.15-0.3 | | RAWDIF (traveling-reference) |
| $u_a$ | 0.15-0.3 | 0.15-0.3 | 0.2-0.4 | 0.35-0.7 | |
| Misclosure | | | | | |
| $u_{b,1}$ | 0.5 | 0.6 | 0.2 | | observed mis-closure |
| Systematic components related to RAWDIF | | | | | |
| $u_{b,11}$ | 0.05 | 0.05 | 0.05 | | Position error at reference |
| $u_{b,12}$ | 0.05 | 0.05 | 0.05 | | Position error at visited |
| $u_{b,13}$ | 0.3 | 0.3 | 0.4 | | Multipaths at reference |
| $u_{b,14}$ | 0.3 | 0.3 | 0.4 | | Multipaths at visited |
| Link of the Traveling system to the local UTC(k) | | | | | |
| $u_{b,21}$ | 0.5 | 0.5 | 0 | | $REFDLY_T$ (at ref lab) |
| $u_{b,22}$ | 0.5 | 0.5 | 0 | | $REFDLY_T$ (at visited lab) |
| $u_{b,TOT}$ | 1.0 | 1.0 | 0.6 | 1.4 | |
| Link of the Reference system to its local UTC(k) | | | | | |
| $u_{b,31}$ | 0.5 | 0.5 | 0 | | $REFDLY_R$ (at ref lab) |
| Link of the Visited system to its local UTC(k) | | | | | |
| $u_{b,32}$ | 0.5 | 0.5 | 0 | | $REFDLY_V$ (at visited lab) |
| $u_{b,SYS}$ | 1.2 | 1.2 | 0.6 | 1.5 | Components of equation (2) |
| | | | | | |
| $u_{CAL}$ | | | | 1.7 | Composed of $u_a$ and $u_{b,SYS}$ |

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# Status of Group 1 calibrations

- Measures with B3TS (two receiver systems)
- Two computations are carried out:
  - Equipment calibration
    - produces delays for all codes included in the comparison (presently GPS P1-P2-C1[-C2]). Such delays are e.g. used to generate GNSS files (header and values).
  - Link calibration (BIPM Pilot Study METODE with GPSPPP)
    - Direct GNSS and TWSTWT time ***link*** calibrations. Validated by TWSTWT and fibre-optic baselines, *Metrologia 2015-52*
- Both solutions (equip. and link) are computed for the G1 laboratories, and compared. They have been found consistent well within the uncertainties (typical agreement better than 0.5 ns)
- For three systems with old calibration and unchanged set-up (OP, PTB, and NMIJ which was included in G1 trip for this reason), consistency of the new results is within the estimated past uncertainties.

# Status of G1 calibrations

| EURAMET | | APMP | | SIM | | COOMET | |
|---|---|---|---|---|---|---|---|
| B3TS/GPS/Equip/Link | | B3TS/GPS/Equip/Link | | B3TS/GPS/Equip/Link | | TTS-4/GPS/Equip | |
| PTB | Concluded | NICT | Concluded | NIST | Concluded | SU | Measurements completed |
| OP | Concluded | NIM | Concluded | USNO | Concluded | | |
| ROA | Concluded | TL | Concluded | | | | |
| Phase 1 - March-April 2013: BIPM-OP-BIPM | | | | | | | |
| Phase 2 - April 2013-Sept. 2014: BIPM-PTB-BIPM-TL-BIPM-NMIJ-NICT-BIPM-NIM-BIPM-PTB-ROA-BIPM | | | | | | | |
| Phase 3 - Nov. 2014-XXXX: BIPM-SU-BIPM (also includes absolute calibration at SU) | | | | | | | |
| Phase 4 - Jan. 2015-June 2015: BIPM-NIST-USNO-BIPM-OP-PTB-BIPM | | | | | | | |

- Results of initial BIPM G1 have been published in July 2015.
- Plan is to implement them for the September 2015 Circular T

# Next actions (1): Implementation for Circular T P3/PPP links

- For now on, time transfer data is still entered as links to PTB.
- More info will be given in Section 6 of Circular T (see next slides)
- New method for computing calibration uncertainty (1-sigma values)

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

  - For Group 1: $U_{CAL0}$ as estimated in the analysis report (typically 1.7 ns)
  - For Group 2: $U_{CAL0}$ is a default value (2.5 ns)
  - Optional values $\Delta U_{CAL}$ for poor behavior during calibration trip and $\Delta U_{ALIGN}$ for alignment of a new receiver to a calibrated one;
- Aging after the time of calibration t0: proposed generic table for P3

| t – t0 | (2-3yr) | (3-5yr) | (5-10yr) | (>10yr) |
|---|---|---|---|---|
| $U_{CAL}$ /ns | 3.0 | 4.0 | 6.0 | 10.0 |

  - Value for (2-3 yr) may be lowered for Group 1

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# (1 continued): Implementation for Circular T P3/PPP links

- CGGTTS format V2E implements Cal_Id

- Waiting for V2E
  - Use COMMENTS line

COMMENTS = Frame=ITRF Cal_Id=1001-2014
INT DLY = 303.9 ns (GPS P1), 319.3 ns (GPS P2)

**Line 12:**
For single-frequency CGGTTS:
"INT_DLY_=_DDD.D_ns_(cons_code1)_____CAL_ID_=_ccccccccccc"
For dual-frequency CGGTTS:
"INT_DLY_=_DDD.D_ns_(cons_code1), DDD.D_ns_(cons_code2) _____CAL_ID_=_ccccccccccc"

The Internal delays (receiver + antenna) should be entered in ns and given with 1 decimal, only for the constellation and the code(s) used in the file. The parameter 'cons' will be GPS, GLO, GAL, BDS or QZS, and 'code1' and 'code2' will follow the convention provided in the third column of Table 1. The parameter "CAL_ID" is the reference to the calibration report where the internal delays are provided; its expression is detailed in the BIPM guidelines for calibration. As many columns as necessary.

  - This info should also be passed in HD files used for PPP (will be checked by BIPM if P3 and PPP are provided)
  - Cal_Id can be extended to accomodate the transfer of calibration to a new receiver

COMMENTS = Cal_Id=1001-2014-TL1Z

- All time links where Cal_Id information is found will be assigned the new $U_{\mathrm{CAL}}$ ($U_{\mathrm{B}}$) uncertainty. All other time links will remain with the former uncertainty + aging.

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# Section 6 of *BIPM Circular T* (present)

6 - Time links used for the computation of TAI and their uncertainties.

| Link | Type | uA/ns | uB/ns | Calibration Type | Calibration Dates |
|---|---|---|---|---|---|
| AOS /PTB | GPSPPP | 0.3 | 5.0 | LC(GPS P3) | 2011 Jun |
| APL /PTB | GPSPPP | 0.3 | 5.0 | LC(GPS MC) | 2012 Sep |
| AUS /PTB | GPSPPP | 0.3 | 5.0 | GPS EC/GPS EC | 2010 Oct/2004 Aug |
| BEV /PTB | GPSPPP | 0.3 | 3.0 | BC(GPS MC) | 2012 Mar |
| BIM /PTB | GPS MC | 1.5 | 7.0 | GPS EC/GPS EC | 2007 Nov/2006 Sep |
| BIRM/PTB | GPS MC | 1.5 | 20.0 | NA /GPS EC | NA /2006 Sep |
| BY /PTB | GPS MC | 1.5 | 7.0 | GPS EC/GPS EC | 2008 Jun/2006 Sep |
| CAO /PTB | GPS MC | 8.0 | 7.0 | GPS EC/GPS EC | 2004 Nov/2006 Sep |
| CH /PTB | TWGPPP | 0.3 | 1.0 | LC(TWSTFT)/BC(GPS PPP) | 2008 Sep/2009 Aug |
| CNM /PTB | GPS MC | 3.0 | 5.0 | BC(GPS SC) | 2008 May |
| CNMP/PTB | GPS MC | 3.5 | 5.0 | GPS EC/GPS EC | 2004 May/2006 Sep |
| DFNT/PTB | GPS MC | 1.5 | 20.0 | NA /GPS EC | NA /2006 Sep |
| DLR /PTB | NA | | | | |
| DMDM/PTB | GPSPPP | 0.3 | 7.0 | LC(GPS MC) | 2012 Jul |
| DTAG/PTB | GPSPPP | 0.3 | 10.0 | LC(GPS MC) | 2009 Jul |
| EIM /PTB | GPS MC | 7.5 | 5.0 | GPS EC/GPS EC | 2007 May/2003 Aug |
| ESTC/PTB | GPSPPP | 0.3 | 5.0 | GPS EC/GPS EC | 2012 Nov/2004 Aug |
| HKO /PTB | GPSPPP | 0.3 | 5.0 | LC(GPS MC) | 2013 Apr |
| IFAG/PTB | GPSPPP | 0.3 | 5.0 | GPS EC/GPS EC | 2003 Jun/2004 Aug |
| IGNA/PTB | NA | | | | |

$u_A$ , $u_B$ do not have a clear meaning, in particular $u_B$

Time transfer equipment is NOT identified

Calibration Types are unclear, no reference to calibrations

Tracing calibrations and alignements very difficult

# New Section 6 of *BIPM Circular T* (to be implemented in September 2015 CirT)

$u_{STB}$ replaces $u_A$ (characterizes the stability of the link)

$u_{CAL}$ replaces $u_B$ (represents the calibration uncertainty)

Time transfer equipment is identified

Cal_IDs allow to access reports of calibration or certificates

Additional info on alignments, transfer of calibration, etc.

Link to web/database from pdf version

6 - Time links used for the computation of TAI and their uncertainties.

TWGPPP : uA part given from PPP characteristics and uB obtained from TWSTFT calibration [ ]
GPSGLN : GPS calibration used as reference, GLN aligned on GPS data [ ]
Cal_Ref: Calibrations reference document. Corresponding reports can be found in
http://www.bipm.org/utils/common/TimeCalibrations/Current/ .
* AL(YYYYMM) : Alignment of link applied by the BIPM on the indicated month to ensure time link continuity.
(see ftp://tai.
* TC(LLmo-YYYYMM) : Transfer of calibration from equipment LLmo performed by laboratory LL on the indicated month

| LinkLabs | Type | uSTB/ns | uCAL/ns | Receivers | Cal_ID1/Cal_ID2 | Additional_info |
|---|---|---|---|---|---|---|
| AOS /PTB | GPSPPP | 0.3 | 5.0 | AO_4/PT02 | 1005-2008/1001-2008 | AL(201106) |
| APL /PTB | GPSPPP | 0.3 | 5.0 | AP__/PT02 | 1002-2003/1001-2008 | AL(201402)=+109.4 |
| AUS /PTB | GPSPPP | 0.3 | 5.0 | AU01/PT02 | 1002-2010/1001-2008 | |
| BEV /PTB | GPSPPP | 0.3 | 3.0 | BE1_/PT02 | 2003-2008/1005-2008 | AL(201203)=-3.2 |
| BIM /PTB | GPS MC | 1.5 | 7.0 | BM37/PT05 | 2004-2008/1005-2008 | |
| BIRM/PTB | GPS MC | 1.5 | 20.0 | BI01/PT05 | NA /1005-2008 | |
| BY /PTB | GPS MC | 1.5 | 7.0 | BY__/PT05 | 2001-2008/1005-2008 | |
| CAO /PTB | GPS MC | 8.0 | 20.0 | CA__/PT05 | NA /1005-2008 | |
| CNM /PTB | GPS MC | 2.0 | 5.0 | CN00/PT05 | 1004-2005/1005-2008 | AL(200804)=-27.3 |
| CNMP/PTB | GPS MC | 3.5 | 5.0 | MP__/PT05 | 1002-2004/1005-2008 | |

| Link | Type | uSTB/ns | uCAL/ns | TW_Id | Cal_ID | Additional_info |
|---|---|---|---|---|---|---|
| CH /PTB | TWGPPP | 0.3 | 1.0 | CH01 /PTB01 | 0211-2011 | |
| IT /PTB | TWGPPP | 0.3 | 1.2 | IT02 /PTB01 | 0213-2011 | |
| NICT/PTB | TWGPPP | 0.3 | 5.0 | NICT14/PTB03 | 0302-2014 | |
| NIM /PTB | TWGPPP | 0.7 | 5.0 | NIM01 /PTB03 | 0305-2014 | |
| NIST/PTB | TWGPPP | 0.3 | 5.0 | NIST01/PTB01 | 0214-2011 | |
| NPLI/PTB | TWGPPP | 0.3 | 7.0 | NPLI01/PTB03 | NA | |
| NTSC/PTB | TWSTFT | 0.5 | 5.0 | NTSC02/PTB03 | 1001-2004/1005-2008 | AL(201210)=+2245.5 |
| OP /PTB | TWGPPP | 0.3 | 1.1 | OP01 /PTB01 | 0216-2011 | |
| ROA /PTB | TWGPPP | 0.3 | 5.0 | ROA01 /PTB01 | 0217-2011 | |
| SP /PTB | TWGPPP | 0.3 | 5.0 | SP01 /PTB01 | 0218-2011 | |
| SU /PTB | TWSTFT | 0.5 | 1.1 | SU01 /PTB03 | 0281-2012 | |
| TL /PTB | TWGPPP | 0.3 | 5.0 | TL01 /PTB03 | 0301-2014 | |
| USNO/PTB | TWSTFT | 0.6 | 3.0 | USNO01/PTB01 | 0391-2014 | |
| VSL /PTB | TWGPPP | 0.3 | 1.0 | VSL01 /PTB01 | 0220-2011 | |

# Next actions (2): Continuation of trips

- Group 1 SU calibration to be finalized.
- Group 2 trips can start right away.

- BIPM goal to repeat visits to G1 laboratories typically every 2 years
  - Strategy for G1 trips to be designed
  - Corresponding strategy for update of G1 results

- Base the calibration of single frequency C/A receivers on the same ensemble of G1 systems: to be implemented soon.

# Next actions (2 continued): Strategy for G1 trips

- 10 labs to visit (presently) : OP-PTB-ROA-SU-NICT-NIM-TL-NIST-USNO (+BIPM)

Two solutions:

- Sequential operations with one traveling system
  - Should not wait complete trip is over (too long, risky…)
  - Regularly, e.g. every 3-4 G1 labs:
    - Closure to check stability of traveling system
    - Update results for these 3-4 G1 labs, ensuring consistency with past results

or

- Parallel operations with several traveling systems
  - Three systems necessary
  - Reference of all G1 more consistent

# Next actions (3): Absolute calibration?

- What about absolute calibrations?
- Several possible sources:
  - Legacy of « old Z12T calibrations »
  - Recent: CNES, USNO, SU, ….
  - New efforts?

- To which level do we care?

# THANK YOU

**Thanks to all Group 1 and other participating laboratories**