GNSS calibrations for UTC and the new calibration scheme

BIPM Time Department

20th CCTF Meeting
17-18 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

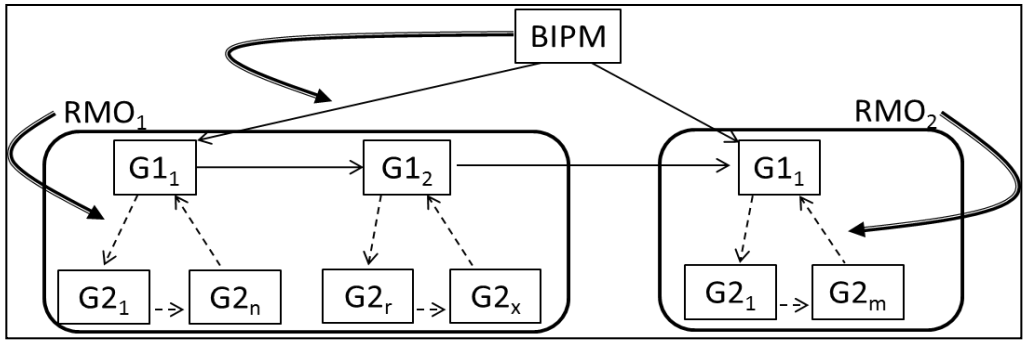
- Maintain the calibration of the time transfer facilities in laboratories contributing to UTC.
  - Including new calibrations for the many uncalibrated systems or updating outdated values
- Use the calibration trips contributed by RMOs and individual laboratories in a consistent and optimal manner.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



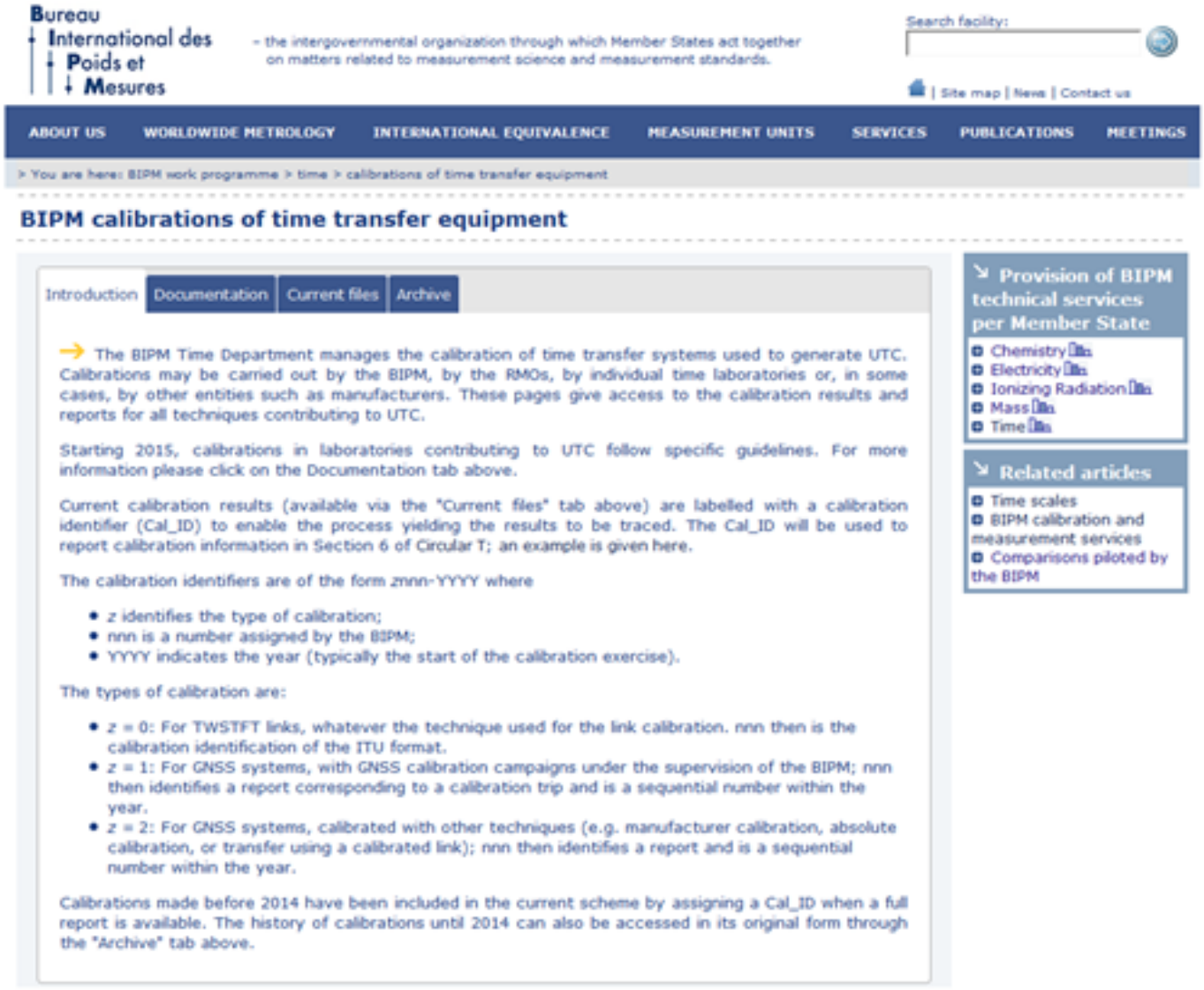
- The BIPM will maintain an open database with all calibration results.
  - Each calibration report will be identified by a unique calibration identifier Cal_Id to be used as a reference for the calibration info (e.g. in CGGTTS header)
- u_{CAL} calibration uncertainties for UTC links are set by the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

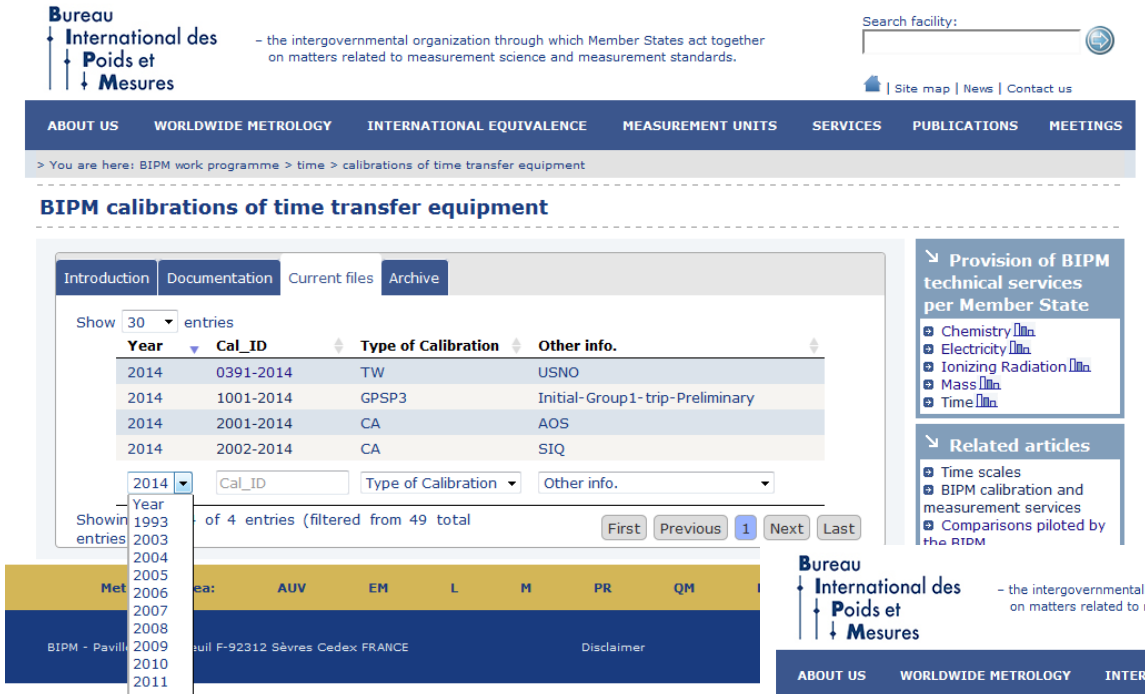
Calibrations web page

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

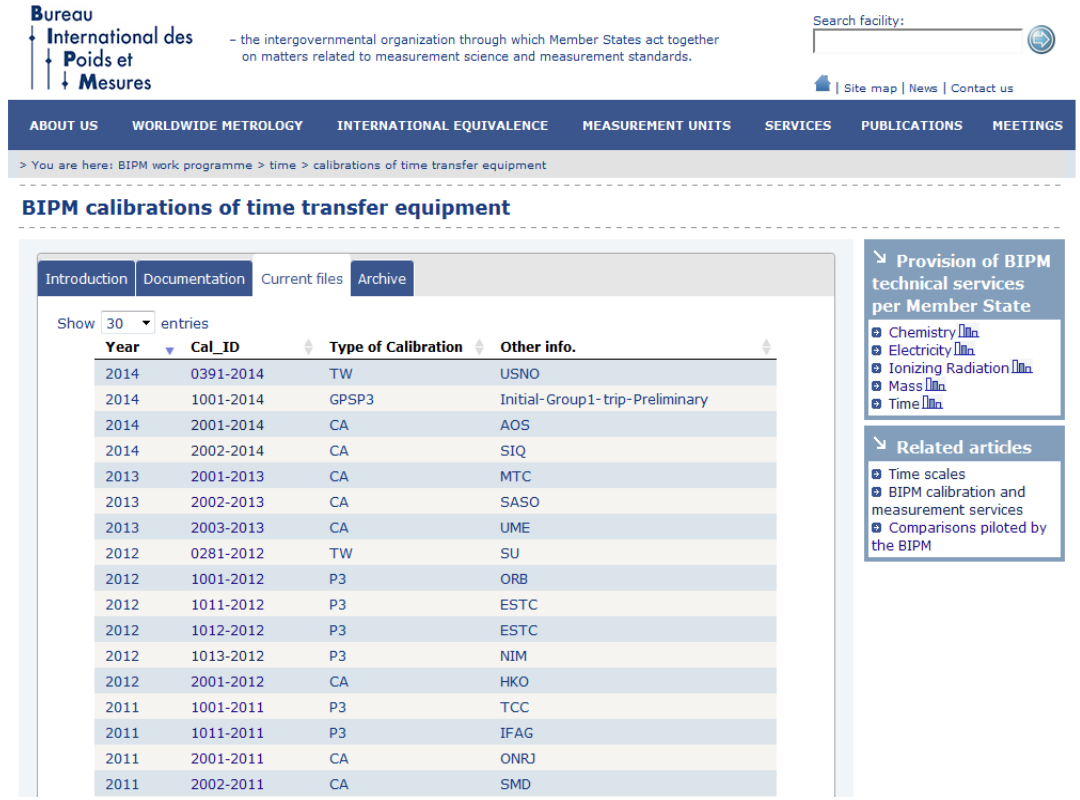
On line 09/04/2015

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 1/2 (equipment)

- « 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 2/2 (link)

- «BIPM guideline for UTC time **link** calibration (draft)**»** v2.2, March 2014.;
- Practical calibration procedures covering: operations, computation, report and implementation of results;

- When based on the same data, **equipment and link** calibrations results should be very consistent and can be converted to each other if a same calibration reference is taken, e.g., taking the pivot lab. PTB as reference;
  - This is the case for the results obtained from the Group 1 trip (see below) where equipment and link results agree within 0.5 ns for all links.

- A simplified link calibration procedure is approved by the CCTF Working Group on TWSTFT and used in the «TWSTFT Calibration Guidelines for UTC Time Links»

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

- 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 ΔU_{CAL} for poor behavior during calibration trip and ΔU_{ALIGN} for alignment of a new receiver to a calibrated one;
- Aging after the time of calibration t0

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

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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.

THANK YOU

Thanks to all Group 1 and other participating laboratories