

G1-2 calibrations for UTC

Update on guidelines, results and changes in Circular T

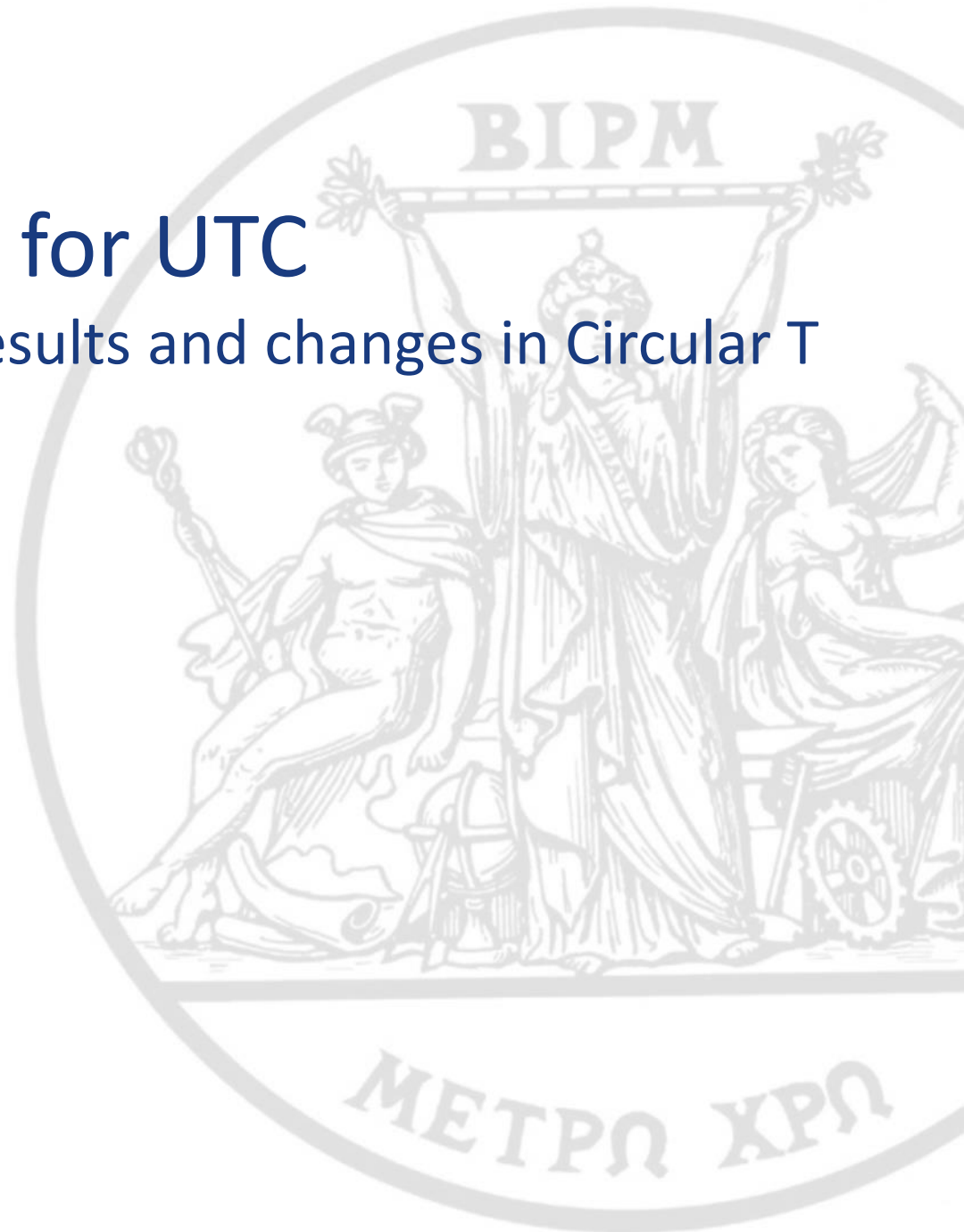
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BIPM Time Department

GNSS WG Meeting

14 September 2015

Bureau
International des
Poids et
Mesures



Outline

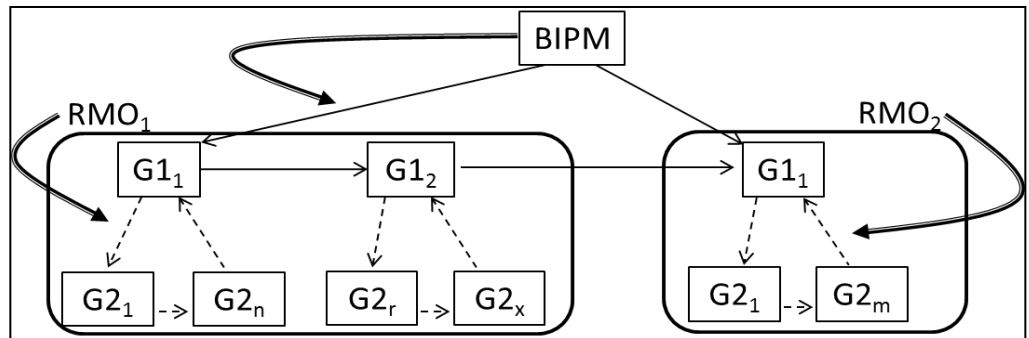
- ◆ Goals and principles of the new GNSS calibration scheme
- ◆ Dissemination of results, web access
- ◆ Calibration Guidelines
- ◆ Status of GPS Group 1 calibrations
- ◆ Next actions and changes in BIPM Circular T

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 - Including new calibrations for the many uncalibrated systems or updating outdated values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

Calibrations web page

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

The screenshot shows the BIPM website interface. At the top left is the BIPM logo: 'Bureau International des Poids et Mesures' with a vertical line and arrows. To its right is the text: '- the intergovernmental organization through which Member States act together on matters related to measurement science and measurement standards.' On the top right, there is a search facility with a text input field and a magnifying glass icon, and links for 'Site map | News | Contact us'. Below the header is a dark blue navigation bar with white text: 'ABOUT US | WORLDWIDE METROLOGY | INTERNATIONAL EQUIVALENCE | MEASUREMENT UNITS | SERVICES | PUBLICATIONS | MEETINGS'. Below this is a breadcrumb trail: '> You are here: BIPM work programme > time > calibrations of time transfer equipment'. The main content area is titled 'BIPM calibrations of time transfer equipment'. It has a sub-header with tabs: 'Introduction' (selected), 'Documentation', 'Current files', and 'Archive'. The main text starts with an arrow icon and says: 'The BIPM Time Department manages the calibration of time transfer systems used to generate UTC. Calibrations may be carried out by the BIPM, by the RMOs, by individual time laboratories or, in some cases, by other entities such as manufacturers. These pages give access to the calibration results and reports for all techniques contributing to UTC.' It then discusses guidelines starting in 2015 and how calibration results are labeled with a Cal_ID. It explains the form 'znnn-YYYY' and lists the meaning of z, nnn, and YYYY. It also lists the types of calibration (z=0, 1, 2) and their details. At the bottom, it mentions that calibrations made before 2014 are included in the current scheme. On the right side, there are two sidebars. The top one is 'Provision of BIPM technical services per Member State' with links for Chemistry, Electricity, Ionizing Radiation, Mass, and Time. The bottom one is 'Related articles' with links for Time scales, BIPM calibration and measurement services, and Comparisons piloted by the BIPM.

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- the intergovernmental organization through which Member States act together on matters related to measurement science and measurement standards.

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BIPM calibrations of time transfer equipment

Introduction | Documentation | Current files | Archive

→ The BIPM Time Department manages the calibration of time transfer systems used to generate UTC. Calibrations may be carried out by the BIPM, by the RMOs, by individual time laboratories or, in some cases, by other entities such as manufacturers. These pages give access to the calibration results and reports for all techniques contributing to UTC.

Starting 2015, calibrations in laboratories contributing to UTC follow specific guidelines. For more information please click on the Documentation tab above.

Current calibration results (available via the "Current files" tab above) are labelled with a calibration identifier (Cal_ID) to enable the process yielding the results to be traced. The Cal_ID will be used to report calibration information in Section 6 of Circular T; an example is given here.

The calibration identifiers are of the form znnn-YYYY where

- z identifies the type of calibration;
- nnn is a number assigned by the BIPM;
- YYYY indicates the year (typically the start of the calibration exercise).

The types of calibration are:

- z = 0: For TWSTFT links, whatever the technique used for the link calibration. nnn then is the calibration identification of the ITU format.
- z = 1: For GNSS systems, with GNSS calibration campaigns under the supervision of the BIPM; nnn then identifies a report corresponding to a calibration trip and is a sequential number within the year.
- z = 2: For GNSS systems, calibrated with other techniques (e.g. manufacturer calibration, absolute calibration, or transfer using a calibrated link); nnn then identifies a report and is a sequential number within the year.

Calibrations made before 2014 have been included in the current scheme by assigning a Cal_ID when a full report is available. The history of calibrations until 2014 can also be accessed in its original form through the "Archive" tab above.

Provision of BIPM technical services per Member State

- Chemistry
- Electricity
- Ionizing Radiation
- Mass
- Time

Related articles

- Time scales
- BIPM calibration and measurement services
- Comparisons piloted by the BIPM

On line 09/04/2015

Intended to host all reports of UTC calibrations

BIPM calibrations of time transfer equipment

Introduction Documentation Current files Archive

Show 30 entries

Year	Cal_ID	Type of Calibration	Other info.
2014	0391-2014	TW	USNO
2014	1001-2014	GPSP3	Initial-Group1-trip-Preliminary
2014	2001-2014	CA	AOS
2014	2002-2014	CA	SIQ

2014 Cal_ID Type of Calibration Other info.

Showing 4 entries (filtered from 49 total) First Previous 1 Next Last

Provision of BIPM technical services per Member State

- Chemistry
- Electricity
- Ionizing Radiation
- Mass
- Time

Related articles

- Time scales
- BIPM calibration and measurement services
- Comparisons piloted by the BIPM

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

BIPM calibrations of time transfer equipment

Introduction Documentation Current files Archive

Show 30 entries

Year	Cal_ID	Type of Calibration	Other info.
2014	0391-2014	TW	USNO
2014	1001-2014	GPSP3	Initial-Group1-trip-Preliminary
2014	2001-2014	CA	AOS
2014	2002-2014	CA	SIQ
2013	2001-2013	CA	MTC
2013	2002-2013	CA	SASO
2013	2003-2013	CA	UME
2012	0281-2012	TW	SU
2012	1001-2012	P3	ORB
2012	1011-2012	P3	ESTC
2012	1012-2012	P3	ESTC
2012	1013-2012	P3	NIM
2012	2001-2012	CA	HKO
2011	1001-2011	P3	TCC
2011	1011-2011	P3	IFAG
2011	2001-2011	CA	ONRJ
2011	2002-2011	CA	SMD

Provision of BIPM technical services per Member State

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- Ionizing Radiation
- Mass
- Time

Related articles

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- Comparisons piloted by the BIPM

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 $\sim -4\text{ns}$ 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_{CALO} 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 $u_{b,SYS}$

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)

$$U_{CAL}(A-B)(t_0) = (U_{CAL0}^2 [+ \Delta U_{ALIGN}(A/B)^2 + \Delta U_{CAL}(A/B)^2])^{1/2}$$

- 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 t_0 : proposed generic table for P3

$t - t_0$	(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

(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=_cccccccccccc"
```

For dual-frequency CGGTTS:

```
"INT_DLY=_DDD.D_ns_(cons_code1), DDD.D_ns_(cons_code2) _____CAL_ID=_cccccccccccc"
```

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_{CAL} (U_B) uncertainty. All other time links will remain with the former uncertainty + aging.

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 alignments 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 : u_A part given from PPP characteristics and u_B 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/utis/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	u_{STB}/ns	u_{CAL}/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	
BNV /PTB	GPSPPP	0.3	3.0	BN1_/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	u_{STB}/ns	u_{CAL}/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

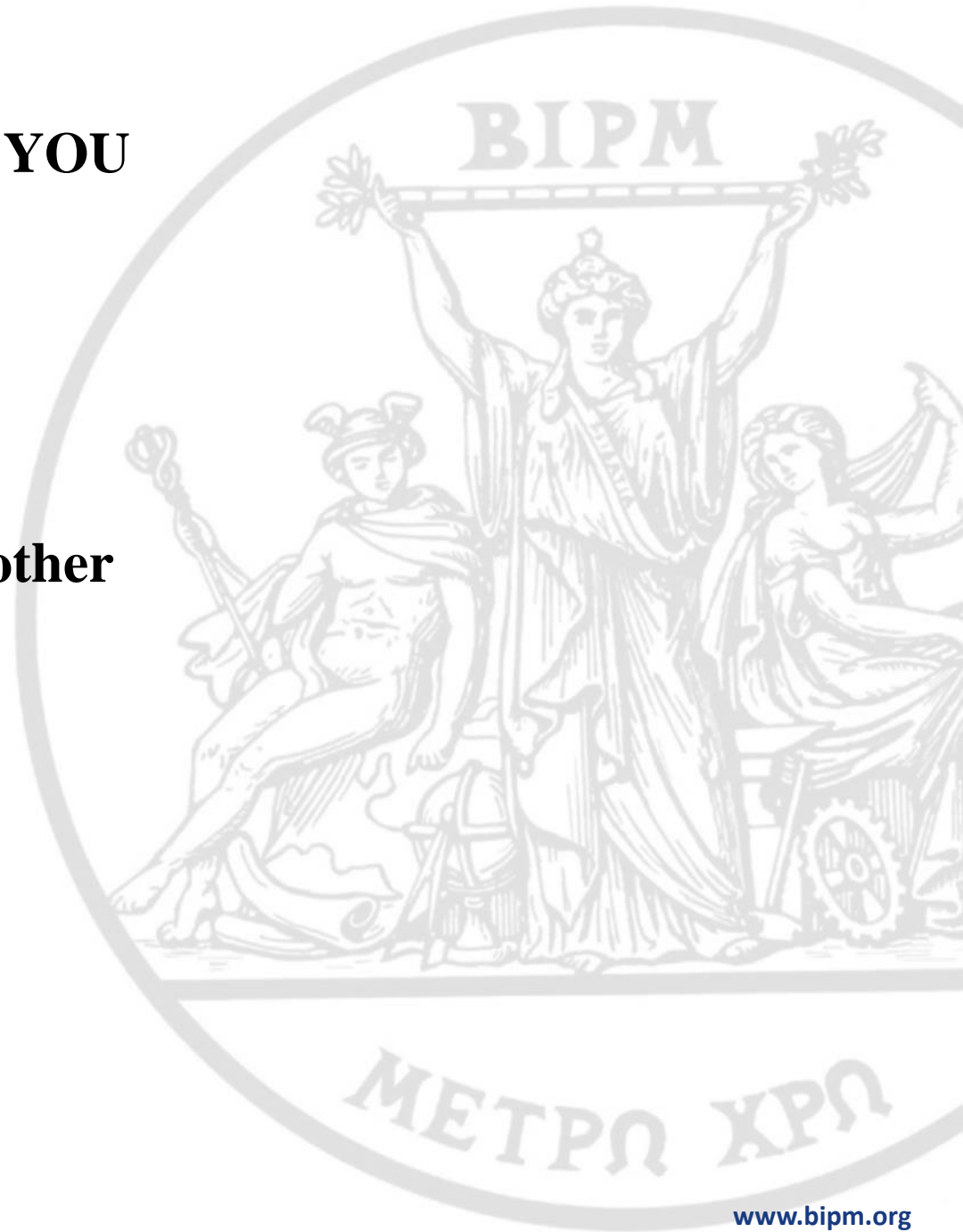
- ◆ Parallel operations with several traveling systems
 - Three systems necessary
 - Reference of all G1 more consistent

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



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