Annex 4
Template for the calibration report

Author of the calibration report

Template for calibration report to the BIPM

15/04/2014 Version 2 (Significant modifications are identified in blue)**:**
15/02/2015 Version 3 (Significant modifications are identified in red)**:**
29/08/2015 Version 3.1 (minor edition for typos etc..)

Notes:

This template takes several elements from a calibration report written by A. Bauch (PTB) relative to a GPS dual-frequency calibration trip at ESTEC in 2012. Therefore several tables are based on equipment names and characteristics originating from this report. However all numeric information are random numbers with the proper order of magnitude and don't correspond to any true result.

The notations, e.g. for the code designation, will follow the rules of the CGGTTS format V2E, when adopted by the CCTF WG on GNSS.

The example in this template corresponds to a Group 2 trip where one reference Group 1 system is visited at beginning and end of the trip. When the Group 1 reference is not the closure, it should be adapted accordingly. For Group 1 trips, the reference value will be determined by the ensemble of the participating systems and section 4 of the report will be presented differently.

This template is written for P3. A similar design can be used for C1 with obvious changes (simplifications).

Version 2 has been reworked in order to

- **better identify the role of each measurement in the formation of the results and of the uncertainties;**

- **make it clear that the final calibration results (delay values) are expressed so that they are relevant to the visited system (not a link) and are consistent with the CGGTTS format; and that, on the other hand, the stated uncertainties concern the differential calibration, i.e. the link visited-reference (not the delays of the visited system);**

- **consider the possibility of merging the cable delay with the internal delay if there is an advantage to do so.**

Version 3 has been reworked in order to

- **specify the software dclrinex proposed by the BIPM to compute raw code differences**

Summary

The summary should at least provide the following:

- General information on the calibration trip

- Timetable: dates of
    - the planning – declaration to the BIPM
    - the trip
    - the analysis
    - the report to the BIPM

- Information on the content of successive versions of the report, if any

1. Description of equipment and operations

This section should provide

- A description of the traveling equipment

There is no specific form, but it should describe
- the traveling system, including the relevant information on its past behavior (stability etc…);
- any other traveling equipment (counter etc…)

- A description of the visited equipment

There is no specific form. However one detailed "information sheet" following the BIPM template should be provided for each visited laboratory (in annex).

- A summary table

Providing the essential information, e.g. allowing easy visualization of the order of visits, dates, names and types of equipment..

Table 1. Summary information on the calibration trip

Institute	Status of equipment	Dates of measurement	Receiver type	BIPM code	RINEX name
PTB	Traveling		DICOM GTR50	PT07	
PTB	Group 1 reference	56100-56103	Ashtech Z12-T	PT02	PTBB
ESTEC	Group 2	56110-56113	Septentrio PolaRx3	ES03	ES03
ESTEC	Group 2	56114-56117	Septentrio PolaRx4	ES04	ES04
PTB	Group 1 reference	56120-56123	Ashtech Z12-T	PT02	PTBB

2. Data used

This short section should explain how the data files used in the analysis are obtained, where they are saved, etc...

For each code to be calibrated, code measurements are used. They can be REFGPS values taken from CGGTTS files but other options are possible:
- For GNSS C1 receivers: the only option is CGGTTS data files generated by the receiver;
- For GPS geodetic receivers providing Rinex files: code measurements may be taken from:
  - the pseudoranges directly read in the Rinex files by the software dclrinex dedicated to differential calibration, as provided by the BIPM, see Annex 3 of the Guidelines.
  - the CGGTTS files obtained from Rinex files via R2CGGTTS
  - the CGGTTS files generated by the receiver.
  In the case of CGGTTS data, it should be ensured that the antenna coordinates used are consistent with those derived from a PPP solution.

When CGGTTS files are used, the parameters used to generate them should be filled in the "Information sheets" provided in Annex.

3. Results of raw data processing

The section should provide

- A reference to the relevant guidelines describing the raw data processing (e.g. Annex 3 of the Guidelines if the BIPM dclrinex software is used) or a detailed description of the raw data processing;
- For each pair (traveling – visited) or (traveling – reference) and each measured code:
  - A plot of the raw (REFGPS as taken from CGGTTS files or pseudorange values as taken from Rinex files) data differences and a plot of the statistical analysis (Tdev), in Annex to the report;
  - The inferred average value, noted RAWDIF, and its uncertainty from the statistical analysis.
- A summary table, e.g.

Table 2. Summary information on the raw calibration results (all values in ns)

Pair	Date	RAWDIF(P1)	Unc	RAWDIF(P2)	Unc
PT07-PT02	56100-56103	3.06	0.2	0.11	0.2
PT07-ES03	56110-56113	-4.17	0.2	-6.03	0.2
PT07-ES04	56114-56117	-2.18	0.2	-5.03	0.2
PT07-PT02	56120-56123	3.14	0.2	0.35	0.2

The Table can be split into two sub-tables: a first one for the measurements carried out at the laboratory where the closure is done; a second one for the other visited laboratories.
Table 2.1 Raw differential results for all pairs (Traveling – Reference) (ns)
Table 2.2 Raw differential results for all pairs (Traveling – Visited) (ns)

4. Calibration results

We follow the notations in the CGGTTS format where
- CABDLY is the antenna cable delay;
- INTDLY is the internal signal delay (antenna + receiver internal);
- REFDLY represents the offset between the UTC reference point in the laboratory and the reference point of the receiver (this depends on the receiver type, see Annex 1 of the Guidelines);

In addition we use below the following notations:
- SYSDLY = INTDLY + CABDLY
- TOTDLY = SYSDLY – REFDLY

We also note that for a pair of systems RAWDIF, as defined in section 3, is equal to ΔTOTDLY.

[The following text was reworked in V3, but without substantial changes]
In principle, the calibration results are ΔINTDLY (Visited-Reference) values for each code. After validation of the report by the BIPM, INTDLY values are computed for all visited systems. Note that the quantity SYSDLY = INTDLY + CABDLY is used in the computations. It may be reported as the result of Group 2 calibrations, instead of reporting the two independent values INTDLY and CABDLY, if the antenna cable delay cannot be measured[1]. Group 1 trips aim at reporting INTDLY values, which represent (in principle) the physical invariant quantity for a GNSS system.

For a pair of systems noted A-B (T-R for Traveling-Reference or T-V for Traveling-Visited) and each code[2], we note

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[1] In the CGGTTS V02 format, the SYSDLY value should then appear under INTDLY with CABDLY reported as 0.0.
[2] In general REFDLY and CABDLY are not considered to depend on the code, therefore Code is not specified for them

$\Delta SYSDLY_{A-B}(Code) = SYSDLY_A(Code) - SYSDLY_B(Code)$
which is computed as
$\Delta SYSDLY_{A-B}(Code) = RAWDIF_{A-B}(Code) + REFDLY_A - REFDLY_B$ (1)
where RAWDIF(Code) is read in Table 2 and where the values ΔREFDLY should be derived from the measurements reported in the "information sheets".

The **ΔSYSDLY** values are reported in Table 3 for the pairs Traveling-Reference (section 4.1) and in Table 4 for the pairs Traveling-Visited (section 4.2).

In the second step one computes **ΔSYSDLY** (Visited-Reference) for all visited systems.
$\Delta SYSDLY_{V-R} = \Delta SYSDLY_{T-R} - \Delta SYSDLY_{T-V.}$ (2)
One can then compute **ΔINTDLY** (Visited-Reference) for all visited systems when CABDLY values are available.
$\Delta INTDLY_{V-R} = \Delta SYSDLY_{V-R} - CABDLY_V + CABDLY_R$ (3)
where the values CABDLY are taken from the "information sheets". Note that the traveling system serves only as an intermediate for this calibration trip, therefore the true value of $SYSDLY_T$ is in practice irrelevant and the quantity $CABDLY_T$ does not need to be explicitly considered.

A table 5 reports the values **ΔSYSDLY$_{V-R}$** and the results **ΔINTDLY$_{V-R}$** for the pairs Visited-Reference (section 4.3).
The uncertainty budget is explicated in section 4.4.

4.1 Traveling system with respect to the reference system

In the standard case, there is one reference (Group 1) system that is visited twice, at the beginning and end of the trip[3]. Then the (Traveling-Reference) values are determined as an average between the two sets of measurements. Details on the closure can be shown on this Table.
The Table 3 provides the values **ΔSYSDLY$_{T-R}$** (Code) computed from (1). REFDLY values are from the information sheets.

Table 3. Traveling vs. Reference system (all values in ns)

Pair	Date	REFDLY$_T$	REFDLY$_R$	L1 (ns)		L2 (ns)	
				RAWDIF	ΔSYSDLY$_{T-R}$	RAWDIF	ΔSYSDLY$_{T-R}$
PT07-PT02	56100-56103	20.0	10.0	3.06	**13.06**	0.11	**10.11**
PT07-PT02	56120-56123	20.0	9.6	3.14	**13.54**	0.35	**10.75**
Misclosure					**0.48**		**0.64**
Mean					**13.30**		**10.43**

4.2 Traveling system with respect to the visited systems

The Table 4 provides the values **ΔSYSDLY$_{T-V}$** (Code) computed from (1). REFDLY values are from the information sheets.

Table 4. Traveling vs. Visited systems (all values in ns)

Pair	Date	REFDLY$_T$	REFDLY$_V$	L1 (ns)		L2 (ns)	
				RAWDIF	**ΔSYSDLY$_{T-V}$**	**RAWDIF**	**ΔSYSDLY$_{T-V}$**
PT07-ES03	56110-56113	20.0	5.0	-4.17	**10.83**	-6.03	**8.97**
PT07-ES04	56114-56117	20.0	0.0	-2.18	**17.82**	-5.03	**14.97**

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[3] If the Group 1 reference is not the closure point, the report should be modified accordingly, e.g. using the closure system as 'intermediate reference'.

4.3 Visited systems with respect to reference system

The Table 5 provides the values obtained by differencing **ΔSYSDLY** in Tables 3 and 4. CABDLY values are from the information sheets.

Table 5. Visited vs. Reference (all values in ns)

Pair	Date	CABDLY$_V$	CABDLY$_R$	P1		P2	
				ΔSYSDLY$_{V-R}$	ΔINTDLY$_{V-R}$	ΔSYSDLY$_{V-R}$	ΔINTDLY$_{V-R}$
ES03-PT02	2012.5	314.5	300.0	2.47	**-12.03**	1.46	**-13.04**
ES04-PT02	2012.5	319.0	300.0	-4.52	**-23.52**	-4.54	**-23.54**

4.4 Uncertainty estimation

In this section, we consider NOT the uncertainty of the INTDLY (or SYSDLY) value of a visited system, which would depend on the uncertainty of the value of the corresponding quantity of the reference system. We are concerned with the uncertainty of the differential calibration process i.e. in estimating all components that can affect the accuracy of equation (3)[4]. We note u$_{CAL0}$ the overall uncertainty of this quantity which may be interpreted as the accuracy of the link at the epoch of calibration. In principle, one such value (and the corresponding uncertainty budget leading to it, see Table 6) should be established for each pair (visited – reference). If applicable, it may be possible to provide a generic table valid for all visited systems, emphasizing possible exceptions which may result in larger, or smaller, uncertainties.

u$_{CAL0}$ is given by an equation of the form (all values are considered to be 1-sigma)

$$U_{CAL} = \sqrt{u_a^2 + u_b^2} ,$$

with the statistical uncertainty u$_a$ and the systematic uncertainty u$_b$.
The statistical uncertainty u$_a$ originates from RAWDIF and is given by the statistical analysis of the raw code differences (section 3), combining (Traveling-Reference) and (Traveling-Visited), see Table 2.
The systematic uncertainty is given by

$$u_b = \sqrt{\sum_n u_{b,n}} .$$

where all possible terms to be considered in the sum are to be listed in Table 6 and some detail on their estimation should be provided in annex. When two codes are measured, they should appear separately for each code and for the difference of the two codes (e.g. L1, L2 and L1-L2).
The components in Table 6 are separated in several categories:
- components related to the code differences. RAWDIF
- components related to the links to the local references UTC(k),
- one component accounts for the mis-closure between the two reference measurements and it is proposed to add this component to compute all values u$_b$ (even though the mis-closure may be partly or totally accounted for by other components of the table).

This organization serves as a guide: lines may be added if necessary and some may be unnecessary (e.g. if the traveling system is linked to UTC(k) directly with the provided cable and no additional measurement is necessary, u$_{b,21}$ and/or u$_{b,22}$ may be skipped or set to zero.

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[4] It is somewhat arbitrary to choose SYSDLY to estimate the link accuracy. This reflects the fact that the REFDLY is subject to change e.g. with change of reference clock or distribution and that its uncertainty should better be taken into account.

When antenna cable delays are measured, their uncertainties should be indicated in Table 6.

Table 6. Uncertainty contributions. Values P3 are computed as P1 + 1.545*(P1-P2)

Unc.	Value P1 (ns)	Value P2 (ns)	Value P1-P2 (ns)	Value P3 (ns)	Description
u_a (T-V)	0.2	0.2	0.3		RAWDIF (traveling-visited)
u_a (T-R)	0.2	0.2	0.3		RAWDIF (traveling-reference)
u_a	0.3	0.3	0.4	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_{CAL0}				1.7	Composed of u_a and $u_{b,SYS}$
Antenna cable delays					
$u_{b,41}$	0.5	0.5	0		CABDLY$_R$
$u_{b,42}$	0.5	0.5	0		CABDLY$_V$

5 Final results for the visited systems

After validation by the BIPM, the info in this section will be entered in the BIPM data base.
Final results are presented for each visited system as they need to be entered to produce timing data in the CGGTTS format, i.e. in the form of INTDLY (or SYSDLY if the antenna cable delays are not available).

The value u_{CAL}(Code) is obtained from Table 6. It is used by the BIPM to assign the value u_b which will apply to all links (Code) to which the system participates. See section A.3.5 of the Master document.

Table 7. Summary of final results

Reference system	Cal_Id	Date		INTDLY L1 /ns	INTDLY L2 /ns
PT02	1-201101-GPSP3	2011.x		r.r1	r.r2
Visited system	**Cal_Id**	**Date**	**u_{CAL} (P3) /ns**	**INTDLY L1 /ns**	**INTDLY L2 /ns**
ES03	2-201201-GPSP3	2012.5	**1.7**	**x.x1**	**x.x2**
ES04	2-201201-GPSP3	2012.5	**1.7**	**y.y1**	**y.y2**

Annexes

Annex A: BIPM Information sheets
Annex B: Plots of raw data and Tdev analysis
Annex C: Details on the systematic uncertainties

Annex A: BIPM Information sheets

Any additional information on the set-up at the reference and visited laboratories.

Complete information sheet shown in Annex 1 of the Guidelines, repeated here for convenience.

Information Sheet (to be repeated for each calibrated system)

Laboratory:	
Date and hour of the beginning of measurements:	
Date and hour of the end of measurements:	

Information on the system

	Local:	Travelling:
4-character BIPM code		
• Receiver maker and type: Receiver serial number:		
1 PPS trigger level /V:		
• Antenna cable maker and type: Phase stabilised cable (Y/N):		
Length outside the building /m:		
• Antenna maker and type: Antenna serial number:		
Temperature (if stabilised) /°C		

Measured delays /ns if needed fill box "Additional Information" further below)

	Local:	Travelling:
• Delay from local UTC to receiver 1 PPS-in:		
from 1 PPS-in to internal reference (if different) (see section 2 for details)		
• Antenna cable delay:		(1)
Splitter delay (if any):		(1)
Additional cable delay (if any):		(1)

Data used for the generation of CGGTTS files

• INT DLY (GPS) /ns:	
• INT DLY (GLONASS) /ns:	
• CAB DLY /ns:	
• REF DLY /ns:	
• Coordinates reference frame:	
Latitude or X /m:	
Longitude or Y /m:	
Height or Z /m:	

General information

• Rise time of the local UTC pulse:	
• Is the laboratory air conditioned:	
Set temperature value and uncertainty:	
Set humidity value and uncertainty:	

(1) For a trip with closure, not needed if the traveling equipment is used in the same set-up throughout.

Annex B: Plots of raw data and Tdev analysis

Example taken from the BIPM collection
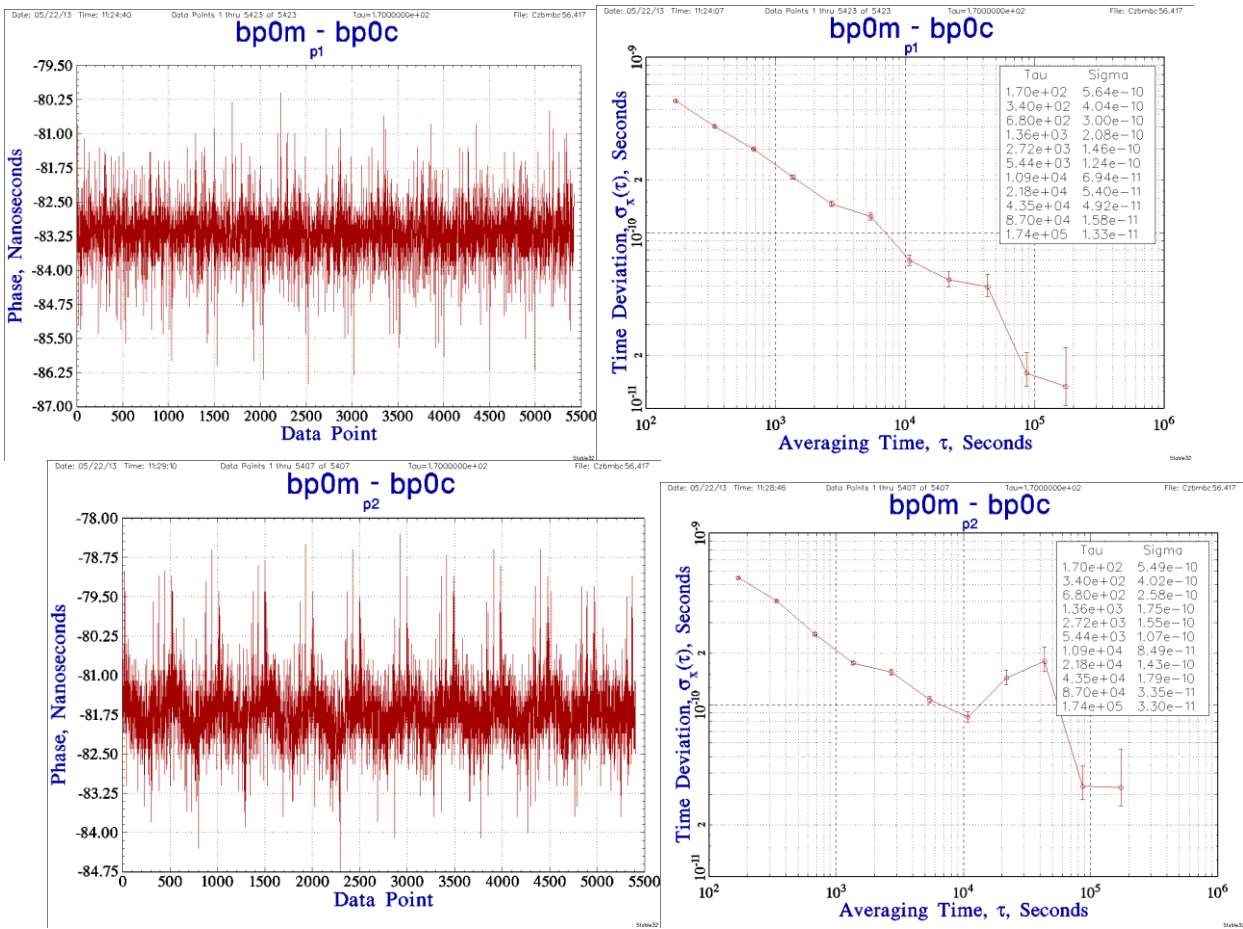
Annex C: Details on the systematic uncertainties

This is an example taken *verbatim* from the PTB report. It obviously does not follow exactly the presentation proposed in section 4.4 of the report, but is given as a source of inspiration.

Table 4. Uncertainty contributions. Values are determined either by measurements or by estimation and rounded to the second decimal.

Uncertainty	Value L1 (ns)	Value L2 (ns)	Value L1-L2 (ns)	Description
$u_{b,1}$	0.50	0.50	0	Connection to UTC(PTB)
$u_{b,2}$	0.50	0.50	0	Connection to UTC(ESA)
$u_{b,3}$	0.04	0.04	0	TIC trigger level timing error at PTB
$u_{b,4}$	0.04	0.04	0	TIC trigger level timing error at ESTEC
$u_{b,5}$	0.02	0.02	0	TR trigger level timing error at PTB
$u_{b,6}$	0.02	0.02	0	TR trigger level timing error at ESTEC
$u_{b,7}$	0.1	0.1	0	TIC nonlinearities at PTB
$u_{b,8}$	0.1	0.1	0	TIC nonlinearities at ESTEC
$u_{b,9}$	0.05	0.05	0	Jitter of the TIC measurement at PTB
$u_{b,10}$	0.05	0.05	0	Jitter of the TIC measurement at ESTEC
$u_{b,11}$	0.3	0.30	0.42	Multipath
$u_{b,12}$	0.8	0.8	0	PTBT antenna cable and antenna
$u_{b,13}$	0.5	0.5	0	ESTEC cable delay
$u_{b,14}$	0.25	0.25	0	Position error at PTB
$u_{b,15}$	0.25	0.25	0	Position error at ESTEC
$u_{b,16}$	0.51	0.3	0.6	Common-Clock difference
u_b	1.4	1.3	0.8	
U_{CAL}	1.5	1.4	0.9	

The uncertainties of the connection to the local UTC sites ($u_{b,1}$, $u_{b,2}$) [2] are estimated in part from long term laboratory experience and in part based on cable delay measurement. The value is dominated by the specified measurement uncertainty for time interval using a SR620 counter [3]. According to the manufacturer specifications the trigger level timing error of the travelling SR620 TIC ($u_{b,3}$, $u_{b,4}$) is given by [3]

$$\text{Trigger level timing error} = \frac{15 \text{ mV} + 0.5\,\% \text{ of trigger level}}{1 \text{ PPS slew rate}} \tag{5}$$

for start and stop channel, respectively. At both labs a trigger level of 1 V at both channels was used. The 1 PPS slew rate can be estimated to be approximately 0.5 V/ns for a signal at the endpoint of a relatively short cable. This was checked by using a scope at PTB. Thus the error is 0.04 ns for the stop channel at both labs.

The trigger level timing error of the PTBT's internal TIC ($u_{b,5}$, $u_{b,6}$) is estimated, according to information given by the manufacturer [4], as 10 mV / (1 PPS slew rate) per channel. The error of the stop channel cancels out, because it is always connected to the signal of the receiver board. PTBT was connected to a signal with a high slew rate in both cases.

The uncertainty contributions $u_{b,7}$ and $u_{b,8}$ are related to imperfections in the TIC in conjunction with the relationship between the zero-crossings of the external reference frequency and the 1 PPS signals. This "nonlinearity" is probably caused by the internal interpolation process. By connecting the traveling TIC to 5 MHz and 10 MHz generated by different clocks (masers, commercial caesium clocks), respectively, the effect was estimated to be at most 0.1 ns if 1 PPS signals with a slew rate of approximately 0.5 V/ns are used. In case of distorted signals this effect can be at the order of a nanosecond. Since the PTBT´s internal TIC uses a surface acoustic wave (SAW) filter as interpolator, its nonlinearity effect can be neglected, because it is of the order of a few picoseconds (see reference [5]).

Although the TIC jitter (SD) is the statistical uncertainty of the TIC measurements, it becomes a systematic uncertainty in terms of the GPS measurements ($u_{b,9}$, $u_{b,10}$), because the results of the TIC measurements affect all GPS measurements in the same way.

Based on an estimate in [6] an uncertainty contribution due to potential multipath disturbance is added as $u_{b,11}$. Measurement of antenna cable delays is usually done with an uncertainty of 0.5 ns, in case of PTBT two measurements were involved (standard cable and cable #2 at ESTEC). Note that this contribution $u_{B,12}$ is zero in case that the same cable is used at all sites. The term $u_{b,13}$ was reported by ESTEC.

For the generation of the CGGTTS data the PTBT antenna position is manually entered into the processing software in ITRF coordinates before the CCD measurements. These positions could differ from the "true" positions in a different way in each laboratory. This is taken into account by the contributions $u_{b,14}$ and $u_{b,15}$ in case of the code based delay calibration, because the position has an effect on the total delay. Since these effect is dominant in the height and linear for position errors up to 30 m [1], the absolute deviation of the manually entered position from the "true" position is multiplied with a coefficient which reflects the effect of the height error at each laboratory. The two uncertainty contributions, $u_{b,14}$ and $u_{b,15}$ correspond to antenna height errors of 10 cm and are based on studies published in [1].

The last uncertainty contribution, $u_{b,16}$, reflects the apparent change in PTBT operation conditions during the campaign. The combined uncertainty U_{CAL} is thus 1.5 ns for L1 and 1.4 ns for L2. to be understood as 1-σ value.

References

[1] P. Defraigne, G. Petit, 2004, *"Time Transfer to TAI using geodetic receivers,"* **Metrologia, Vol. 40,** 184-188

[2] T. Feldmann, A. Bauch, D. Piester, M. Rost, E. Goldberg, S. Mitchell, B. Fonville, 2010, *"Advanced GPS-based Time Link Calibration with PTB´s new GPS Calibration Setup,"* Proc. 42nd PTTI, Novemberr 15-18, 2010, Reston VA, USA, 509-526

[3] *"SR620 Operating Manual and Programming Reference,"* SRS

[4] P. Panek, Dicom CZ and UFE, private communication

[5] I. Prochazka, P. Panek,, 2009, *"Nonlinear effects in the time measurement device based on surface acoustic wave filter excitation,"* **Rev. Sci. Instrum, Vol. 80,** 076102

[6] W. Lewandowski, C. Thomas, 1991, *"GPS Time transfers,"* **Proc. IEEE, Vol. 79, No. 7,** 991-1000