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Determination of reference GPS "INTDLY" values of Group 1 geodetic receivers in the initial Group 1 trip (Cal_Id = 1001-2014)

Introduction

This TM describes the procedure to choose reference values for "INTDLY" of Group 1 (hereafter G1) geodetic receivers participating in the initial G1 trip.

Part A deals with P1/P2 values. Following the BIPM calibration guidelines, the chosen reference values should
- be derived from the measurements carried out in Group 1 laboratories in 2013-2014
- globally provide a minimal change with respect to past values obtained from past BIPM calibration and used in CGGTTS data. This minimal change should be appreciated for those systems which do have a past reference.

Part B deals with the C1 values. Version 7 of TM243 proposes to now base the reference of C1 calibrations on the same ensemble of G1 systems as for P1/P2 and lists the conventional C1 internal delay values for all G1 systems. It is shown that the subsequent changes in the C/A UTC links from legacy C/A-only receivers or from other receivers are within the present standard uncertainty of C/A time links.

A. Determination of reference P1/P2 INTDLY values

A.1. Methodology

Group 1 laboratories were chosen during 2014. They are
- For EURAMET: OP, PTB, ROA
- For APMP: NICT, NIM, TL
- For SIM: NIST, USNO
- For COOMET: SU

All EURAMET and APMP G1 laboratories were visited by the BIPM calibrator (B3TS) over April 2013-September 2014. See Table 1a for the list of systems concerned.
Among those systems, only four have been calibrated by the BIPM in the past and are still operating as a reference system. Three in G1 laboratories (OP, PTB and TL) and one in NMIJ, a Group 2 laboratory visited during this campaign.
It is proposed to define the reference values of G1 systems as follows:
1. Present a solution of the 2013-2014 EURAMET-APMP G1 trips which is globally consistent but which P1/P2 reference values are arbitrary chosen to be one of the BIPM reference. See Section A.2.
2. Set the P1/P2 reference values so as to minimize changes for the NMIJ, OP, PTB and TL INTDLY values compared to the values from past BIPM calibrations. See Section A.3.
3. Transfer this new Group 1 P1/P2 reference to obtain final results for equipment visited in the 2013-2014 EURAMET and APMP G1 trip. See Section A.4.
4. Transfer this new Group 1 P1/P2 reference to additional G1 equipment visited in the 2015 SIM-EURAMET G1 trip, as mentioned in Table 1b. See Section A.5. Results for the COOMET G1 trip have been derived similarly. See Section A.5B.
5. We then use, for all systems, the most recent results obtained from either trip, taken from sections A.4 or A.5, to derive final results of the Initial Group 1 calibration trip (referred to by the Calibration identifier 1001-2014). See Section A.6.

In the future, it is expected that the BIPM will maintain Group 1 by regularly performing trips visiting the whole G1 network. The ensemble of G1 systems will then be used to provide a stable reference.

Table 1a. Information on equipment concerned in the 2013-2014 EURAMET-APMP G1 trips

Institute	**Status of equipment**		**BIPM code**	**RINEX name**	**Receiver type**
BIPM	Traveling		BP1C	BP1C	Septentrio PolaRx3eTR
BIPM	Traveling		BP0T	BP0T	Dicom GTR50
BIPM	Traveling		BP0U	BP0U	Dicom GTR50
BIPM	BIPM reference		BP0R	BP0R	Septentrio PolaRx2eTR
OP	G1 reference		OP02	OPMT	Ashtech Z12-T
PTB	G1 reference		PT02	PTBB	Ashtech Z12-T
PTB	G1 reference		PT03	PTBG	Ashtech Z12-T
TL	G1 reference		TL1Z	TWTF	Ashtech Z12-T
NMIJ	G2 reference		NM0C	NM0C	Ashtech Z12-T
NICT	G1 reference		NC02	NC02	Septentrio PolaRx2
NICT	G1 reference		????	SEPA	Septentrio PolaRx2
NIM	G1 reference		IM06	IMEJ	Dicom GTR50
NIM	G1 reference		IMEU	IMEU	Javad E_GGD
NIM	G1 reference		????	BJNM	PolaRx3eTR
ROA	G1 reference		????	RO_4	Septentrio PolaRx2
ROA	G1 reference		RO_5	RO_5	Dicom GTR50
ROA	G1 reference		ROAP	RO_6	Septentrio PolaRx3eTR
ROA	G1 reference		????	RO_7	Septentrio PolaRx4TR

Table 1b. Information on equipment concerned in the 2015 SIM-EURAMET G1 trip

Institute	**Status of equipment**		**BIPM code**	**RINEX name**	**Receiver type**
BIPM	Traveling		BP1C	BP1C	Septentrio PolaRx3eTR
BIPM	Traveling		BP0U	BP0U	Dicom GTR50
BIPM	BIPM reference		BP0R	BP0R	Septentrio PolaRx2eTR
NIST	G1 reference		NIST	NIST	Novatel OEM4-G2
NIST	G1 backup		NIS3	NIS3	Novatel OEM5
NIST	G1 backup		NIS3	NIS4	Novatel OEM5
USNO	G1 reference		USN6	USN6	NovAtel ProPak-V3
USNO	G1 backup		USN7	USN7	ASHTECH Z-XII3T
OP	G1 reference		OPMT	OPMT	Ashtech Z12T
OP	G1 backup		OPM7	OPM7	Septentrio PolaRx4
OP	G1 backup		OPM8	OPM8	Septentrio PolaRx4
PTB	G1 reference		PTBB	PTBB	ASHTECH Z-XII3T
PTB	G1 backup		PTBB	PTBB	ASHTECH Z-XII3T

A.2. Results of the April 2013-September 2014 EURAMET-APMP trips

At the processing stage, the April 2013-September 2014 trips have been split into two phases

- Phase 1 when the traveling systems are BP0T and BP0U and for which two BIPM references BP0R and BP0C have been considered.
- Phase 2 when the traveling systems are BP1C and BP0U and for which the BIPM reference BP0R has been considered.

See the report of Initial Group 1 calibration trip for Phase 1 and Phase 2 for details.
Below we specify how to choose results from the different possibilities offered with two traveling systems:

For phase 1:

- The results using BP0T or BP0U as traveling system differ from one another by at most 0.1 ns.
- The mis-closures, expressed as the difference for 2 visits at the BIPM 30 days apart, are (0.4 ns P1, 0.2 ns P2) for BP0U and (0.5 ns P1, 0.4 ns P2) for BP0T.

For phase 2:

- The mis-closures, expressed as the maximum difference over 6 visits at the BIPM spanning 500 days, are (0.5 ns P1, 0.6 ns P2) for BP0U and (2.3 ns P1, 2.0 ns P2) for BP1C. Mis-closures for BP1C are dominated by one "outlier" but are still noisier than for BP0U when the outlier is removed.
- The results using BP1C as traveling system are typically 0.6 to 1.0 ns higher than those using BP0U as traveling system. Out of the six BP1C results at the BIPM (see the Phase 2 report) it would require using only two to provide results generally consistent with BP0U (at a level of a few hundred ps), which is not considered satisfactory.

Because of the larger mis-closure for BP1C in Phase 2, and because BP0U was used in both phases, **the results used in this document are based on those obtained with BP0U as a traveling system**. They are expressed (Table 2) as INTDLY values computed from the BP0R nominal values (221.5 ns P1, 224.5 ns P2). As indicated in Section A.1, this choice of nominal values is arbitrary and final values will be selected in next Section.
All P1/P2 results will be reported with 2 digit numeric precision in order to minimize rounding errors when computing P3 linear combinations. Final results for the CGGTTS should be rounded to 1 digit.

Table 2. P1/P2 INTDLY values for all systems visited during the 2013-2014 EURAMET-APMP trips (all values in ns), using the indicated reference values for the system BP0R. **ΔINTDLY** is the difference (Visited – BP0R) and **$INTDLY_V$** is the value inferred for the visited system.

Pair	Date	P1		P2	
		ΔINTDLY	$INTDLY_V$	ΔINTDLY	$INTDLY_V$
BP0R reference values			221.5		224.5
OPMT/1-BP0R	2013.3	85.70	307.20	94.93	319.43
OPMT/2-BP0R	2013.3	86.11	307.61	95.34	319.84
PTBB-BP0R	2013.5	83.35	304.85	96.39	320.89
PTBB-BP0R	2014.6	83.41	304.91	96.37	320.87
PTBG-BP0R	2013.5	80.74	302.24	100.85	325.35
PTBG-BP0R	2014.6	80.85	302.35	100.98	325.48
TWTF-BP0R	2013.9	83.33	304.83	89.99	314.49
TWTF-BP0R	2014.0	83.20	304.70	89.26	313.76
NM0C-BP0R	2014.2	85.17	306.67	95.50	320.00
NC02-BP0R	2014.2	-2.84	218.66	1.08	225.58
SEPA-BP0R	2014.2	-5.11	216.39	-2.46	222.04

IMEJ-BP0R	2014.4	-220.16	1.34	-220.31	4.19
IMEU-BP0R	2014.4	-248.22	-26.72	-237.49	-12.99
BJNM-BP0R	2014.4	-148.55	72.95	-143.07	81.43
RO_4-BP0R	2014.7	-22.87	198.63	-20.82	203.68
RO_5-BP0R	2014.7	-220.36	1.14	-225.19	-0.69
RO_6-BP0R	2014.7	-167.74	53.76	-172.82	51.68
RO_7-BP0R	2014.7	-166.99	54.51	-171.44	53.06

A.3. Computation of optimal P1/P2 reference values to generate Group 1 results

Past BIPM calibration exists for OPMT, PTBB, TWTF and NM0C. Results of the 2013-2014 calibration are expressed in Table 2 with respect to the conventional reference values of BP0R. Here we determine a new reference that will provide “minimal change” with respect to the past INTDLY values for these four systems. There exist a number of ways to realize this and the selected one is presented below.

Let us first note that, in Table 2, there are two results for OPMT: set-up 1 where the visiting receivers are in common clock with OPMT, and set-up 2 where the visiting receivers are referenced to UTC(OP) and linked to OPMT through the standard procedure used for UTC(OP). The two results differ by 0.5 ns, which is considered not statistically different. We here choose set-up 2 because it represents the way OPMT is used to generate CGGTTS files and, as indicated below, we will favor “minimal change” as being with respect to the present configuration.

We also note that there are two results for PTBB, at two different epochs, but they differ by less than 0.1 ns.

We further note that there are two results for TWTF, corresponding to two sessions separated by about one month. We note that during the first session, the TWTF system was severely disturbed with noise in the P2 measurements about 3-4 times higher than typical, while the second session was better behaved. We therefore choose the results of the second session. Finally we mention that TL has reported [see TM218] that the set-up of TWTF has changed since the 2005 BIPM calibration. However the REFDLY value has not been re-measured in the new set-up so that, in principle, it is not possible to compare INTDLY values of the past and recent calibration. **Results for TWTF are indicated for information but will not be used in establishing the final reference values**.

For the four systems, Table 3 lists the different sets of INTDLY values.

Table 3. List of INTDLY values and differences “New-Old”: New (in red) is from the 2013-2014 trip; Old is either from the last calibration, or from the current CGGTTS files.

System	Date	P1		P2	
		INTDLY	ΔINTDLY	INTDLY	ΔINTDLY
			New-Old		New-Old
OPMT	2013.3	307.61		319.84	
OPMT (BIPM Calib)	2008	311.4	-3.79	322.1	-2.26
OPMT (CGGTTS files)	Current	311.3	-3.69	323.3	-3.46
PTBB	2014.6	304.88		320.88	
PTBB (BIPM Calib)	2008	303.2	+1.68	317.4	+3.48
PTBB (CGGTTS files)	Current	304.5	+0.38	318.9	+1.98
TWTF	2014.0	304.70		313.76	
TWTF (BIPM Calib)	2005	304.3	+0.40	315.6	-1.84
TWTF (CGGTTS files)	Current	304.3	+0.40	315.6	-1.84
NM0C	2014.2	306.67		320.00	
NM0C (BIPM Calib)	2005	306.5	+0.17	319.4	+0.60
NM0C (CGGTTS files)	Since 56748	306.5	+0.17	319.4	+0.60

Table 4. Computation of the average change in calibration: "New" from the 2013-2014 trip with respect to the current CGGTTS files. All values in ns. Note that the mean is computed for P1 and P2. P3 = 2.545*P1-1.545*P2.

System	New – CGGTTS files		
	P1	**P2**	**P3**
OPMT	-3.69	-3.46	-4.05
PTBB	+0.38	+1.98	-2.09
TWTF	+0.40	-1.84	3.86
NM0C	+0.17	+0.60	-0.49
Mean (without TWTF)	**-1.05**	**-0.29**	**-2.21**
Mean (with TWTF)	-0.69	-0.68	-0.69

We note that the values in the CGGTTS files for OPMT and PTBB do not correspond exactly to the past BIPM calibration, it is not clear what is the exact origin of this small difference. In any case, the differences are not significant with respect to the stated uncertainties of past calibration and it is more important to ensure the best continuity with the CGGTTS data presently generated. Therefore we shall ensure the "minimal change" condition for the NMIJ, OP and PTB equipment with respect to the values in the CGGTTS files. This is done by computing the mean P1/P2 INTDLY change for the considered systems (Table 4). The mean values (P1: -1.05 ns; P2: -0.29 ns) are then applied to all INTDLY values of Table 2, see Table 5.

A.4. Results of the 2013-2014 EURAMET-APMP initial Group 1 trip

The resulting P1/P2 INTDLY values are obtained for all systems by subtracting the mean values from Section 3 (P1: -1.05 ns; P2: -0.29 ns) to the provisional values of Table 2. The results are indicated in Table 5 along with the REFDLY and CABDLY values that were valid at the epoch of calibration. Note that the ΔP3 value in Table 5 is the change in TOTDLY(P3) with respect to the value computed from the CGGTTS header at the time of calibration and, due to rounding effects, they can slightly differ from ΔP3 values inferred from Table 4.

It happens that, with the reference chosen as explained in the previous section, the change in P3 Total delay for PTBB with respect to the present CGGTTS files (-0.1 ns) is negligible. Therefore, in practice for P3/PPP links to PTB, the values computed with the new calibrations are the same as if PTBB had been chosen as a reference for the calibration trip.

Table 5. P1/P2 INTDLY values from the 2013-2014 EURAMET-APMP Group 1 trip, indicated with 2-digit numeric precision for internal consistency in this report. Values of REFDLY and CABDLY at the epoch of calibration and of TOTDLY(P3) are also indicated for reference (all values in ns). ΔP3 is the change in TOTDLY(P3) with respect to the value derived from the CGGTTS header at the time of calibration (N/A means no CGGTTS files available).

System	Date	INTDLY P1	INTDLY P2	REFDLY	CABDLY	TOTDLY P3	ΔP3
BP0R		222.55	224.79				
OPMT	2013.3	308.66	320.13	117.2	156.5	330.2	-1.9
PTBB	2014.6	305.90	321.18	75.3	301.7	508.7	-0.1
PTBG	2014.6	303.40	325.77	48.2	251.4	472.0	+0.9
TWTF (see Note)	2014.0	305.75	314.05	52.0	119.8	360.7	+6.1
NC02	2014.2	219.71	225.87	429.7	248.5	29.0	-1.8
SEPA	2014.2	217.44	222.33	406.1	213.4	17.2	N/A
IMEJ	2014.4	2.39	4.48	0.0	0.0	-0.8	-0.8
IMEU	2014.4	-25.67	-12.70	115.5	250.3	89.1	N/A
BJNM	2014.4	74.00	81.72	315.3	125.0	-128.2	N/A

RO_4	2014.7	199.68	203.97	218.9	217.5	191.7	N/A
RO_5	2014.7	2.19	-0.40	0.3	0.0	5.9	+5.9
RO_6	2014.7	54.81	51.97	218.3	66.7	-92.4	-2.3
RO_7	2014.7	55.56	53.35	171.5	61.9	-50.6	N/A
NM0C (G2)	2014.2	307.72	320.29	32.4	234.1	490.0	+1.7

Note: Results for TWTF are expressed as INTDLY for consistency with the CGGTTS V2 format. **However they should NOT be used as true INTDLY values**: Only "Total delay" as defined in CGTTS V3 format (TOTDLY = INTDLY + CABDLY – REFDLY) has a physical meaning for TWTF. Note also that the REFDLY value in the CGGTTS files of TWTF (TL1Z) was changed to 46.3 ns on MJD 56763.

A.5. Results of the 2015 SIM-EURAMET trip

At the processing stage, the 2015 SIM-EURAMET trip is considered as one phase of 1001-2014:

- Phase 4 with the traveling systems BP1C and BP0U, using the BIPM reference BP0R.

See the report of Initial Group 1 calibration trip for Phase 4 for details.
Below we specify how to choose results from the different possibilities offered with two traveling systems:

- The mis-closures, expressed as the maximum difference over 3 visits at the BIPM spanning 140 days, are (0.1 ns P1, 0.2 ns P2) for BP0U and (0.3 ns P1, 0.4 ns P2) for BP1C, therefore both are satisfactory.
- Comparing the results using BP1C as traveling system are with those using BP0U, we note that they about 1.0 ns higher for systems visited at the NIST (similar to all Phase 2 results, see section A.2) while the difference is much smaller for the visits at USNO, OP, PTB.

Pursuant to the choice for the 2013-2014 APMP-EURAMET trip (see section A.2), **the results used in this document are based on those obtained with BP0U as a traveling system**. They are expressed (Table 6) as INTDLY values computed from the BP0R nominal values (221.5 ns P1, 224.5 ns P2). As indicated in Section A.1, this choice of nominal values is arbitrary and final values will be obtained similarly as in Section A.4.
All P1/P2 results will be reported with 2 digit numeric precision in order to minimize rounding errors when computing P3 linear combinations. Final results for the CGGTTS should be rounded to 1 digit.

Table 6. P1/P2 INTDLY values for all systems visited during the 2015 SIM-EURAMET trip (all values in ns), using the indicated reference values for the system BP0R. **ΔINTDLY** is the difference (Visited – BP0R) and **$INTDLY_V$** is the value inferred for the visited system.

Pair	**Date**	**P1**		**P2**	
		ΔINTDLY	**$INTDLY_V$**	**ΔINTDLY**	**$INTDLY_V$**
BP0R reference values			221.5		224.5
NIST-BP0R	2015.1	-294.58	-73.08	-296.58	-72.08
NIS3-BP0R	2015.1	-231.14	-9.64	-245.39	-20.89
NIS4-BP0R	2015.1	-232.34	-10.84	-246.08	-21.58
USN6-BP0R	2015.2	-229.08	-7.58	-234.39	-9.89
USN7-BP0R	2015.2	-228.66	-7.16	-233.92	-9.42
OPMT/1-BP0R	2015.3	86.64	308.14	95.97	320.47
OPM7/1-BP0R	2015.3	47.19	268.69	48.28	272.78
OPM8/1-BP0R	2015.3	47.24	268.74	48.34	272.84
OPMT/2-BP0R	2015.4	87.66	309.16	96.81	321.31
OPM7/2-BP0R	2015.4	48.14	269.64	49.08	273.58
OPM7/2-BP0R	2015.4	48.21	269.71	49.16	273.66
PTBB-BP0R	2015.4	81.34	302.84	94.49	318.99
PTBG-BP0R	2015.4	78.42	299.92	98.68	323.18

Final results for P1/P2 INTDLY values are obtained for all systems by subtracting the mean values from Section 3 (P1: -1.05 ns; P2: -0.29 ns) to the provisional values of Table 6. The results are indicated in Table 7 along with the REFDLY and CABDLY values that were valid at the epoch of calibration. Note that the ΔP3 value in Table 7 is the change in TOTDLY(P3) with respect to the value computed from the CGGTTS header at the time of calibration.

Table 7. P1/P2 INTDLY values from the 2015 SIM-EURAMET Group 1 trip, indicated with 2-digit numeric precision for internal consistency in this report. Values of REFDLY and CABDLY at the epoch of calibration and of TOTDLY(P3) are also indicated for reference (all values in ns). ΔP3 is the change in TOTDLY(P3) with respect to the value derived from the CGGTTS header at the time of calibration.

System	Date	INTDLY P1	INTDLY P2	REFDLY	CABDLY	TOTDLY P3	ΔP3
BP0R		222.55	224.79				
NIST	2015.1	-72.03	-71.79	80.0	275.5	123.1	+6.8
NIS3	2015.1	-8.59	-20.60	1545.8	298.5	-1237.3	N/A
NIS4	2015.1	-9.79	-21.29	1516.5	298.0	-1210.5	N/A
USN6	2015.2	-6.53	-9.60	0.0	0.0	-1.8	-1.8
USN7	2015.2	-6.11	-9.13	0.0	0.0	-1.4	-1.4
OPMT/1	2015.3	309.19	320.76	100.1	156.5	347.7	-1.4
OPM7/1	2015.3	269.74	273.07	128.1	0.0	136.5	N/A
OPM8/1	2015.3	269.79	273.13	124.6	0.0	140.0	N/A
OPMT/2	2015.4	310.21	321.60	100.1	156.5	349.0	-0.1
OPM7/2	2015.4	270.69	273.87	128.1	0.0	137.7	N/A
OPM8/2	2015.4	270.76	273.95	124.6	0.0	141.2	N/A
PTBB	2015.4	303.89	319.28	74.0	301.7	507.8	-0.9
PTBG	2015.4	300.97	323.47	46.3	251.4	471.3	+0.2

A.5B. Results of the 2015 COOMET trip

At the processing stage, the 2015 COOMET trip is considered as one phase of 1001-2014:

- Phase 3 with the traveling systems BP1K, using the BIPM reference BP0R.

See the report of Initial Group 1 calibration trip for Phase 3 for details.
Following the same procedure as in the preceding sections, the results for the COOMET trip are indicated in Table 7B.

Table 7B. P1/P2 INTDLY values from the 2015 COOMET Group 1 trip, indicated with 2-digit numeric precision for internal consistency in this report. Values of REFDLY and CABDLY at the epoch of calibration and of TOTDLY(P3) are also indicated for reference (all values in ns). ΔP3 is the change in TOTDLY(P3) with respect to the value derived from the CGGTTS header (data provided after the calibration).

System	Date	INTDLY P1	INTDLY P2	REFDLY	CABDLY	TOTDLY P3	ΔP3
BP0R		222.55	224.79				
SU19	2015.5	-28.98	-27.50	194.5	48.2	-177.6	+0.4

A.6. Final results of the Initial Group 1 trip (Cal_Id=1001-2014)

We take for all systems the most recent results from either Table 5 for the 2013-2014 EURAMET-APMP trip, or from Table 7 for the 2015 SIM-EURAMET trip. For the systems in OP, we privilege the results from set-up 2 (where the traveling system is referred to UTC(OP) and linked to OPMT by internal measurements) because it corresponds to the way OPMT is seen by the rest of the UTC laboratories.
Final results are in Table 8.

Table 8. P1/P2 INTDLY values from the Initial Group 1 trip (Cal_Id=1001-2014), indicated with 2-digit numeric precision for internal consistency in this report. Values of REFDLY and CABDLY at the epoch of calibration and of TOTDLY(P3) are also indicated for reference (all values in ns). ΔP3 is the change in TOTDLY(P3) with respect to the value derived from the CGGTTS header at the time of calibration.

System	Date	INTDLY P1	INTDLY P2	REFDLY	CABDLY	TOTDLY P3	ΔP3
BP0R		222.55	224.79				
TWTF (see Note)	2014.0	305.75	314.05	52.0	119.8	360.7	+6.1
NC02	2014.2	219.71	225.87	429.7	248.5	29.0	-1.8
SEPA	2014.2	217.44	222.33	406.1	213.4	17.2	N/A
IMEJ	2014.4	2.39	4.48	0.0	0.0	-0.8	-0.8
IMEU	2014.4	-25.67	-12.70	115.5	250.3	89.1	N/A
BJNM	2014.4	74.00	81.72	315.3	125.0	-128.2	N/A
RO_4	2014.7	199.68	203.97	218.9	217.5	191.7	N/A
RO_5	2014.7	2.19	-0.40	0.3	0.0	5.9	+5.9
RO_6	2014.7	54.81	51.97	218.3	66.7	-92.4	-2.3
RO_7	2014.7	55.56	53.35	171.5	61.9	-50.6	N/A
NIST	2015.1	-72.03	-71.79	80.0	275.5	123.1	+6.8
NIS3	2015.1	-8.59	-20.60	1545.8	298.5	-1237.3	N/A
NIS4	2015.1	-9.79	-21.29	1516.5	298.0	-1210.5	N/A
USN6	2015.2	-6.53	-9.60	0.0	0.0	-1.8	-1.8
USN7	2015.2	-6.11	-9.13	0.0	0.0	-1.4	-1.4
OPMT	2015.4	310.21	321.60	100.1	156.5	349.0	-0.1
OPM7	2015.4	270.69	273.87	128.1	0.0	137.7	N/A
OPM8	2015.4	270.76	273.95	124.6	0.0	141.2	N/A
PTBB	2015.4	303.89	319.28	74.0	301.7	507.8	-0.8
PTBG	2015.4	300.97	323.47	46.3	251.4	471.3	+0.1
SU19	2015.5	-28.98	-27.50	194.5	48.2	-177.6	+0.4
NM0C (G2)	2014.2	307.72	320.29	32.4	234.1	490.0	+1.7

Note: Results for TWTF are expressed as INTDLY for consistency with the CGGTTS V2 format. **However they should NOT be used as true INTDLY values**: Only “Total delay” as defined in CGTTS V3 format (TOTDLY = INTDLY + CABDLY – REFDLY) has a physical meaning for TWTF. Note also that the REFDLY value in the CGGTTS files of TWTF (TL1Z) was changed to 46.3 ns on MJD 56763.

B. Determination of reference C1 INTDLY values

It is proposed to base the reference of GPS C1 calibrations on the same ensemble of Group 1 geodetic systems used for GPS P1/P2. Until 2013, BIPM GPS C1 calibration trips have been performed using a closure at the OP with the OP01 (AOA TTR6) receiver. Here we examine the details of the proposed procedure and the implications of this change of reference on GPS C1 measurements and links.

B.1. Methodology

The BIPM analysis of the side by side data taken in calibration trips also provides the (C1-P1) bias for all participating receivers. Assuming that the P1 INTDLY value of a geodetic system is set through the procedure in Part A, we could set the C1 INTDLY value to match the observed (C1-P1) bias in each system, assuming that the ensemble average (C1-P1) bias from the satellites is zero, following the IGS practice in determining its published satellite (C1-P1) biases. The problem in this approach is that the observed (C1-P1) bias is comosed of the receiver (C1-P1) bias minus the ensemble average of the (C1-P1) bias from the satellites. While the former is expected to be constant, the latter is not as it evolves with the constellation. Therefore the observed (C1-P1) bias will evolve with time, so will not provide a constant value to define the C1 INTDLY.
One solution is to determine the long-term evolution of $(C1\text{-}P1)_{SVens}$ (t), the true ensemble average bias from the satellites, assuming that the bias for each satellite is constant and that any systematic change for a given satellite is attributed to a change in the ensemble average. See section B.2.

We then can account for $(C1\text{-}P1)_{SVens}$ (t) at the time of measurement of the (C1-P1) bias to define C1 INTDLY from the P1 INTDLY. This is done in section B3 for a number of geodetic receivers from the BIPM and G1 labs.

After so doing we compare C1-only CGGTTS files generated from the geodetic receivers to CGGTTS files of classical C/A receivers in regular use for TAI. See section B.4.

We discuss in section B.5 the consequences of adopting a C1 INTDLY reference carried by the Group1 geodetic reference systems as described above.

B.2. Time evolution of the ensemble average of satellites (C1-P1) bias

P1-C1 Differential Code Biases (DCB)[1] of all satellites and participating receivers are solved for and made available by e.g. the IGS analysis center CODE as monthly means since at least 20 years. They are determined from the condition that the mean of the satellite DCBs is zero. Because the actual mean of the satellite DCBs, $DCB_{SVens}(t)$, changes with the evolution of the constellation, all published receiver and satellite DCB (index $_{pub}$) are affected by the variation of the actual mean value (index $_{true}$):

$DCB_{RECtrue}(t) = DCB_{RECpub}(t) + DCB_{SVens}(t)$ (b1)

$DCB_{SVtrue}(t) = DCB_{SVpub}(t) - DCB_{SVens}(t)$ (b2)

$DCB_{SVens}(t)$ has been determined over January 2010 to July 2016 by using all SV which are continuous, see Figure 1 (left). The resulting average $DCB_{SVens}(t)$ is given on Figure 1 (right).

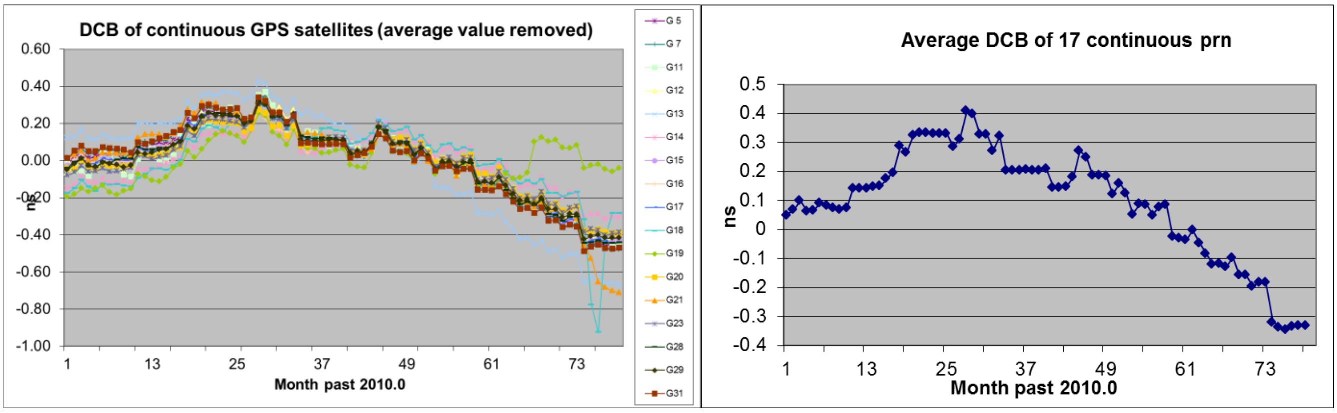

Figure 1: Left: Monthly P1C1 DCB values from CODE for 17 satellites with continuous data since 2010 (an average value has been removed for each satellite to generate the plot); Right: Monthly average of the original DCB data, noted $DCB_{SVens}(t)$.

[1] The IGS P1-C1 DCB is the opposite of the C1-P1 bias determined by the BIPM calibration analysis procedure.

Among the receivers with IGS published DCBs, a few pertain to UTC laboratories, see Figure 2 (left). After applying the correction (b1), the "true" receiver DCB is recovered, which is indeed much closer to a constant, see Figure 2 (right) where have been kept the receivers with long data span and without large spurious effects.

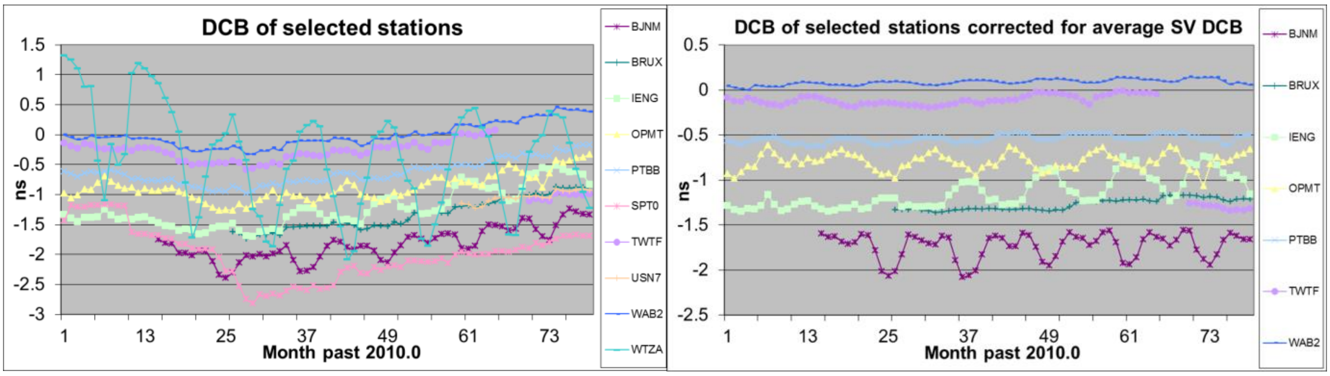

Figure 2: Left: Monthly P1C1 DCB values from CODE for 10 receivers in UTC laboratories; Right: Same data (excluding SPT0, USN7, WTZA) after correction with $DCB_{SVens}(t)$ from Figure 1, following equation (b1). Note that the station TWTF had a hardware change end 2015.

B.3. P1-inferred C1 calibration of geodetic systems

Using data collected during the initial Group 1 calibration trip, the Raw C1-P1 bias of all participating geodetic systems was determined from the C1-P1 pseudo-ranges values in the Rinex files[2]. The Raw bias was then corrected for the value of DCB_{SVens} at the date t of calibration as

$(C1\text{-}P1)_{Cor} = (C1\text{-}P1)_{Raw} - DCB_{SVens}(t)$ (b3)

Some systems have been visited several times over the two years of the complete trip. It can be verified that the correction (b3) indeed provides a more stable $(C1\text{-}P1)_{Cor}$, see Figure 3.

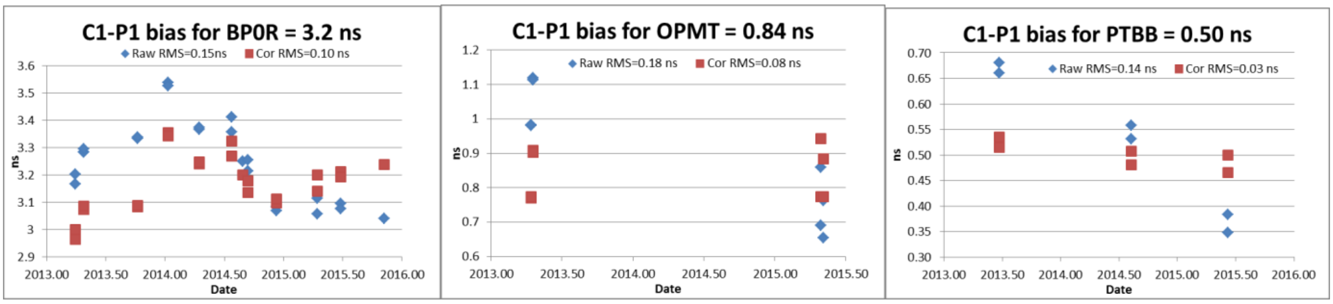

Figure 3: C1-P1 bias for three receivers, without (Raw) or with (Cor) the correction in equation (b3).

The same procedure is applied for all receivers in Table 8, yielding INTDLY(C1) from INTDLY(P1). The results are given in Table 9.

[2] Note that the BIPM analysis determines the (C1-P1) bias as the average of the pseudo-range differences, without accounting for the known variations in the satellite DCBs. Because all satellites are typically observed when taking several days of data and because the ensemble average of the satellite DCBs is zero by definition, this does not change the value of the (C1-P1) bias by more than 0.1 ns, although it somewhat worsens the dispersion of the pseudo-range differences. Note also that variations of the (C1-P1) bias at the same 0.1 ns level are observed when changing the minimum elevation of the observations.

Table 9. C1 INTDLY values from the Initial Group 1 trip (Cal_Id=1001-2014) inferred from P1 values of Table 8 following the procedure described in the text. N/A means a C1/P2 receiver. All values are in ns. Dates correspond to the calibration exercise that was used to derive the P1 INTDLY.

System	Date	INTDLY P1	C1-P1 raw	DCBSVens	C1-P1 bias	INTDLY C1
BP0R	Multiple	222.6	See Figure 3		3.2	**225.8**
TWTF (see Note)	2014.0	305.8	0.24	0.19	0.05	**305.9**
NC02	2014.2	219.7	3.30	0.16	3.14	**222.8**
SEPA	2014.2	217.4	3.11	0.16	2.95	**220.4**
IMEJ	2014.4	2.4	-3.59	0.09	-3.68	**-1.3**
IMEU	2014.4	-25.7	1.95	0.09	1.86	**-23.8**
BJNM	2014.4	74.0	1.86	0.09	1.77	**75.8**
RO_4	2014.7	199.7	3.39	0.08	3.31	**203.0**
RO_5	2014.7	2.2	-0.42	0.08	-0.50	**1.7**
RO_6	2014.7	54.8	1.39	0.08	1.31	**56.1**
RO_7	2014.7	55.6	1.18	0.08	1.10	**56.7**
NIST	2015.1	-72.0	N/A	-0.04	0.04	**-72.0**
NIS3	2015.1	-8.6	N/A	-0.04	0.04	**-8.6**
NIS4	2015.1	-9.8	N/A	-0.04	0.04	**-9.8**
USN6	2015.2	-6.5	N/A	-0.04	0.04	**-6.5**
USN7	2015.2	-6.1	1.12	-0.04	1.16	**-4.9**
OPMT	2015.4	310.2	See Figure 3		0.84	**311.0**
OPM7	2015.4	270.7	1.26	-0.10	1.36	**272.1**
OPM8	2015.4	270.8	1.26	-0.10	1.36	**272.2**
PTBB	2015.4	303.9	See Figure 3		0.50	**304.4**
PTBG	2015.4	301.0			0.13	**301.1**
SU19	2015.5	-29.0	1.62	-0.12	1.74	**-27.3**
NM0C (G2)	2014.2	307.7	1.04	0.12	0.92	**308.6**

B.4. Comparison of P1-inferred C1 calibration of geodetic systems with C/A receivers

The C1 measurements of geodetic systems are compared to those generated by legacy C/A receivers or by recent dual-frequency systems generating C/A CGGTTS (GM files). CGGTTS files are generated from the C1 measurements of the Rinex files of the geodetic receivers using the C/A version (V43) of the R2CGGTTS program and are compared to the single frequency CGGTTS files of the time transfer receivers.
The following systems have been chosen:

- OPMT can be directly compared to the single-channel receiver OP02 (AOA-TTR6) which carries the legacy of the originally calibrated NBS51 C/A receiver and to multi-channel receiver OP50 (AOS TTS-3) which also provides C/A multi-channel data for UTC.
- PTBB can be directly compared to the multi-channel receivers PT05 (AOS TTS-3) which is used to compute C/A links for UTC, and to PT07 (GTR50) which is a backup.

Results are shown in Table10 and plots of the individual comparisons and their statistical analysis are shown on Figure 4. The general conclusion is that there is a bias of a few ns between the INTDLY (C1) values from Section B3 and the values inferred from the receivers used for the UTC C/A links.

Table 10. INTDLY(C1) values for geodetic systems, inferred from C/A time transfer receivers at OP and PTB. The **ΔINTDLY C1** are the changes with respect to the values in Table 9. All values in ns.

Geodetic	C/A ref	Date	INTDLY C1	ΔINTDLY C1
OPMT	OP02	2013.3	314.5	+3.5
OPMT	OP50	2015.6	316.5	+5.5
PTBB	PT05	2015.6	306.1	+1.7
PTBB	PT07	2015.6	306.8	+2.4

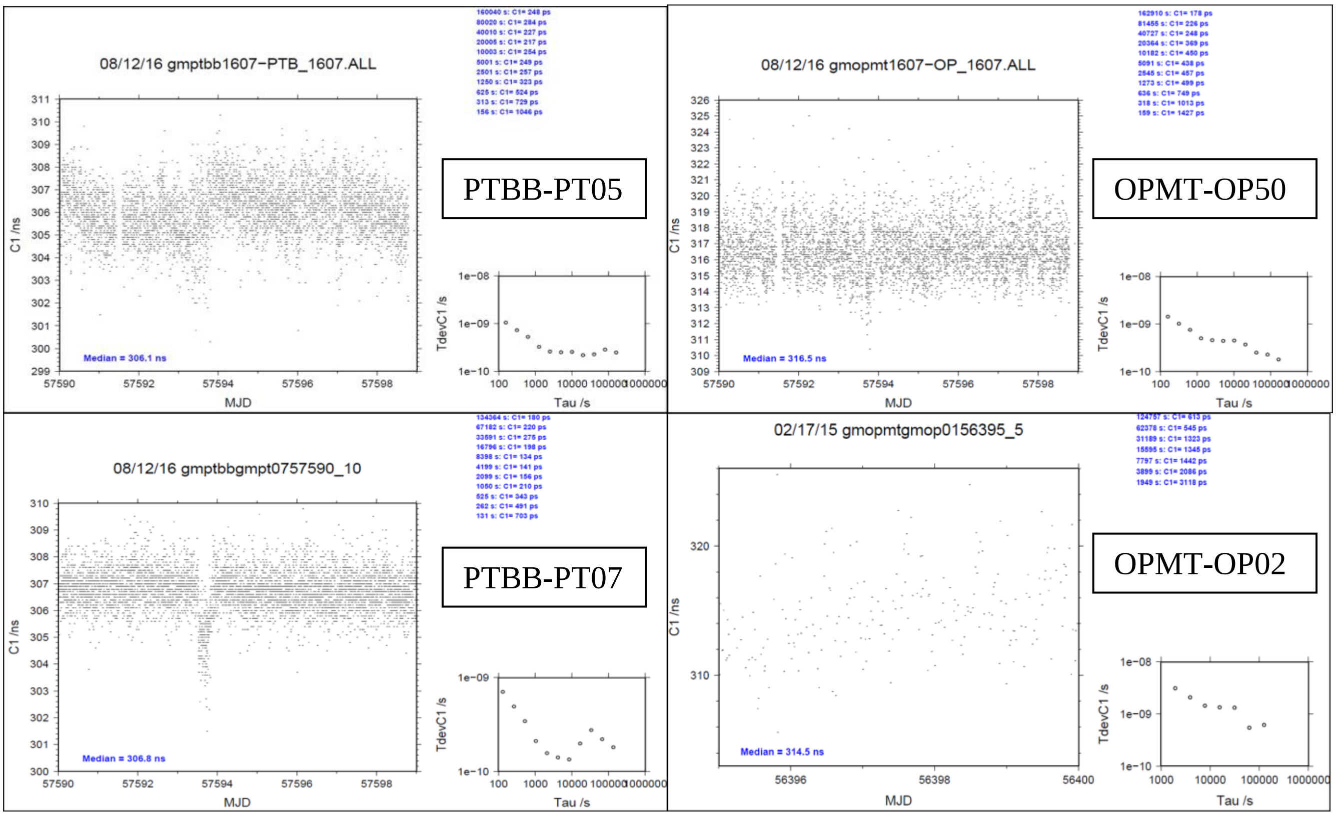

Figure 4: Comparison of C1 CGGTTS files from geodetic systems with CGGTTS files from C/A time transfer receivers at OP and PTB.

B.5. Discussion on the C1 INTDLY reference

We propose to adopt the Group 1 geodetic receivers as C1 reference, with reference values INTDLY(C1) as indicated in Table 9. Note, however, that this choice is arbitrary because the procedure described in sections B2-B3 leaves one degree of freedom to define $DCB_{SVens}(t)$, which has here been arbitrarily chosen as the average of the CODE-determined DCB values of 17 satellites having continuity over 2010-2016. In the absence of absolute calibration, any constant value can be added to $DCB_{SVens}(t)$, thus to the inferred INTDLY(C1) values, without changing the validity of the reference.[3]

The change in the calibration of classical C/A receivers will be a few ns, from the example of OP and PTB above. The changes in the multi-channel (MC) links will also be of order a few ns. E.g. in the case of the link OP-PTB the calibration change would be +3.8 ns for the MC link (OP50-PT05) and +3.1 ns for the MC link (OP50-PT07), such changes are consistent with the present uncertainty of the MC links (5 ns). In all cases using the Group 1 geodetic receivers as C1 reference will make the MC links more consistent with the P3/PPP links.

The set of Group 1 receivers will be used over the years to maintain the C1 reference and the P1 reference. It will be necessary to check the consistency of these references with the (C1-P1) biases than can be continuously measured, following the procedure described in sections B2-B3.

[3] It could then be envisioned to choose a constant so that INTDLY(C1) values match, on average, the C/A reference of time transfer receivers.