Rapport BIPM-2008/03

BUREAU INTERNATIONAL DES POIDS ET MESURES

DETERMINATION OF THE DIFFERENTIAL TIME CORRECTIONS FOR GPS TIME EQUIPMENT LOCATED AT THE OP, TCC, ONBA, IGMA and CNMP

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Abstract

The BIPM continues a series of differential calibrations of GPS equipment located in time laboratories contributing to TAI. This report details measurements which took place from 22 March 2004 to 13 May 2005, involving GPS time equipment located at the Observatoire de Paris (OP, Paris, France), the TIGO Concepcion Chile (TCC, Concepcion, Chile), the Observatorio Naval Buenos Aires (ONBA, Buenos Aires, Argentina), the Instituto Geografico Militar (IGMA, Buenos Aires, Argentina) and the Centro Nacional de Metrologia de Panama (CNMP, Panama).

INTRODUCTION

The BIPM is conducting a series of differential calibrations of GPS equipment located in time laboratories contributing to TAI.

As for previous trips, the GPS time equipment located at the OP was chosen as reference. To check the reproducibility of the measurements, the calibrations were organized as round trips beginning and ending at the OP. The OP often served in the past as the reference laboratory for GPS calibrations. Over the last twenty years its GPS time receiver has been compared several times with the NIST absolutely-calibrated reference GPS time receiver. The difference between these two has never exceeded a few nanoseconds.

Repeated determinations of the differential time corrections for the GPS time equipment located in the various laboratories should:

- improve the accuracy of the access to UTC of participating laboratories;
- provide valuable information about the stability of GPS time equipment; and
- serve as provisional differential calibrations of the two-way equipment at the laboratories.

This report details an exercise which took place from 22 March 2004 to 13 May 2006. Succeeding visits are scheduled to take place at four to five month intervals.

EQUIPMENT

Details of the receivers involved are provided in Table 1. More information about the set-up of equipment at each location is provided in Appendix I.

Table 1. GPS equipment involved in this comparison.

Laboratory	Receiver Maker	Receiver Type	Receiver Ser. No
OP	AOA	TTR-5	051
TCC	AOA	TTR-6	443
ONBA	AOS	TTS-2	021
IGMA	BIPM	TTS-2	BP0H
CNMP	EMDE Electronics	TTS-2	029
BIPM portable receiver	AOS	TTS-2	028

The portable BIPM receiver is equipped with a C123 cable. Its delay measured at the BIPM is 178.8 ns with a standard deviation of 0.4 ns.

This delay was measured using a double-weight pulse method with a time interval counter steered by an external frequency source (an Active Hydrogen Maser CH1-75, KVARZ). We measured at the very beginning of the linear part of the rising pulse at each end of the cable using a 0.5 V trigger level [1].

The delay of this cable was also measured at the visited laboratories. The results are reported in Appendix II.

CONDITIONS OF COMPARISON

For the present comparison, the portable equipment comprised the receiver, its antenna and a calibrated antenna cable. The laboratories visited supplied: (a) a 10 MHz reference signal; and (b) a series of 1 s pulses from the local reference, UTC(*k*), via a cable of known delay. In each laboratory the portable receiver was connected to the same clock as the local receiver and the antenna of the portable receiver was placed close to the local antenna. The differential coordinates of the antenna phase centres were known at each site with standard uncertainties (1σ) of a few centimetres.

RESULTS

The processing of the comparison data obtained in laboratory *k* consists first of computing, for each track *i*, the time differences:

$dt_{k,i}=[UTC(k) - GPS\ time]_{\mathrm{BIPM},i} - [UTC(\mathrm{k}) - GPS\ time]_{k,i}$.

The noise exhibited by the time series dt_k is then analysed, for each of the laboratories visited, by use of the modified Allan variance. In each case, white phase noise was exhibited up to an averaging interval of about one day. We illustrate this in Figure 1.

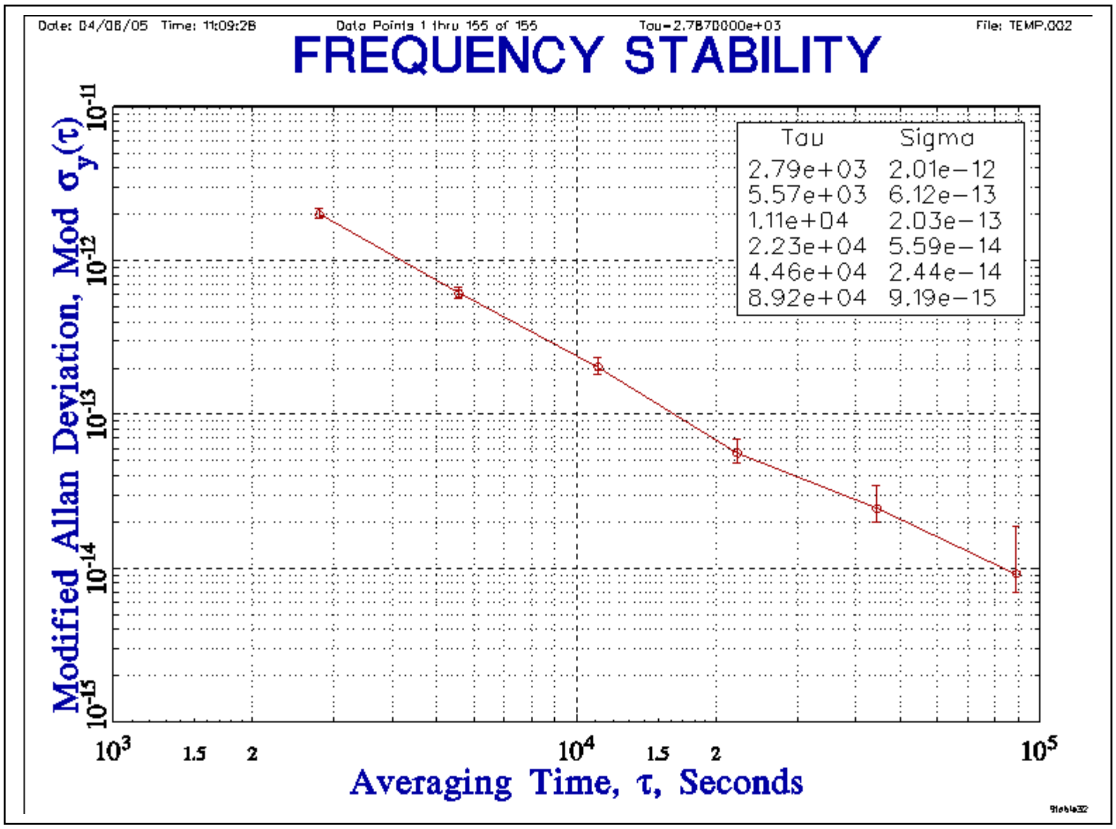

Figure 1. Square root of the modified Allan variance of the time series dt_{OP} for the period: 22 March 2004 to 26 March 2004.

The one-day averages are reported in Figure 2 and Appendix III. The level of noise for one-day averaging period is reported in Table 2.

[REF(Lab*k*)-(GPS TIME)]$_{BIPM}$ -[REF(Lab*k*)-(GPS TIME)]$_{Labk}$

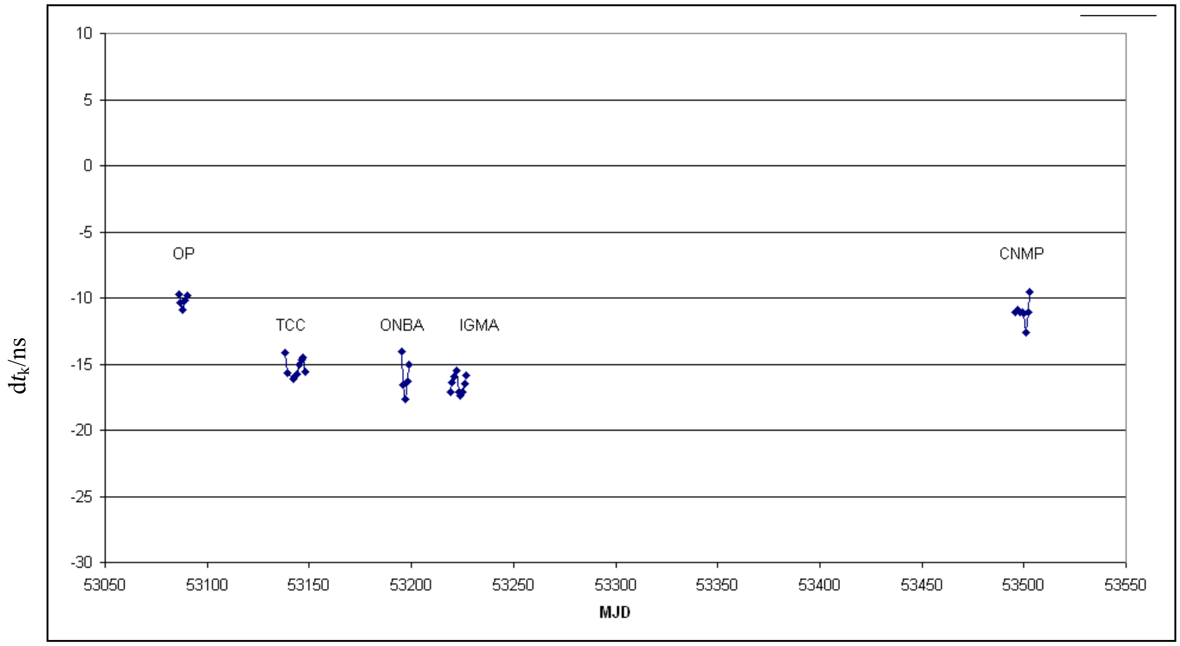

Figure 2. Daily averages of $dt_{k,i}$ for each laboratory *k* (see Appendix III).

Next, we computed mean offsets for the full duration of comparison at each location, and the corresponding standard deviations of individual common view measurements (see Table 2).

Table 2. Mean offsets for the full duration of the comparison at each location.

Lab	Period	Total number of common views	Mean offset /ns	Standard deviation of individual common view observations /ns	Level of noise for 1 day /ns	Dispersion of daily mean /ns
OP	22/03 – 26/03/04	155	-10.31	2.98	0.5	0.47
TCC	13/05 – 23/05/04	128	-15.27	2.58	0.5	0.70
ONBA	9/07 - 13/07/04	2120	-15.84	3.89	0.4	1.42
IGMA	2/08 – 10/08/04	4725	-16.59	2.29	0.5	0.66
CNMP	6/05 – 13/05/05	3388	-11.16	4.53	0.6	0.82

The "closure" – the difference between the first and last sets of measurements made at the OP – was within one nanosecond, which is an excellent result. After averaging the results of the two sets of measurements at the OP, we then derived differential time corrections which should be made (added) to time differences derived during the GPS comparisons of the time scales kept by the laboratories. The results are summarized in Table 3.

Table 3. Differential time correction *d* to be added to [$UTC(k_1)$ – $UTC(k_2)$], and its estimated uncertainty *u*(*d*) for the period of comparison (1σ).

[$UTC(k_1)$-$UTC(k_2)$]	*d*/ns	*u*(*d*)/ns
[*UTC*(TCC)-*UTC*(OP)]	-4.5	4.0
[*UTC*(ONBA)-*UTC*(OP)]	-5.1	4.0
[*UTC*(IGMA)-*UTC*(OP)]	-5.8	4.0
[*UTC*(CNMP)-*UTC*(OP)]	0.4	4.0

The uncertainties given in this table are conservative. They are mainly driven by the uncertainty due to the 'round-trip' reproducibility at the OP.

For information we provide in Table 4 results of some past calibrations between NIST and OP.

Table 4. Some past calibrations between NIST and OP: *d* are differential time corrections to be added to [*UTC*(NIST)-*UTC*(OP)], and *u(d)* are estimated uncertainties for the periods of comparisons.

Date	*d*/ns	*u(d)*/ns	Reference
July 1983	0.0	2.0	[2]
January 1985	–7.0#	13.0	[3]
September 1986	0.7*	2.0	[4]
October 1986	–1.4*	2.0	[4]
January 1988	–3.8*	3.0	[5]
April 1988	0.6*	3.0	[6]
March 1995	–3.7*	1.0	[7]
May 1996	–0.7*	1.5	[8]
May 2002	–5.0*	3.0	[9]
July 2003	–5.6*	1.9	[10]
December 2003	-4.6*	3.0	[11]

NBS03 receiver at NIST
* NBS10 receiver at NIST

CONCLUSION

These measurements are part of a series of differential calibrations of GPS equipment located in time laboratories contributing to TAI. They improve the accuracy of the access to UTC of participating laboratories.

The present measurements were performed under good conditions in the visited laboratories. However, closure at the OP could not be performed due to the failure of travelling receiver. This is why the uncertainty of the determined offsets is 4 ns; that is, slightly larger than the usual 3 ns.

The GPS time equipment of all visited laboratories agrees within a few nanoseconds with reference equipment at the OP (see Table 3). This confirms good previous calibration.

The GPS time equipment located at the NIST and the OP are excellent references for GPS calibration trips. This equipment was compared several times during the past two decades. The differences between them have never exceeded a few nanoseconds (see Table 4).

Acknowledgements

The authors wish to express their gratitude to their colleagues for unreserved collaboration they received. Without this, the work could not have been accomplished.

REFERENCES

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[2] D. Allan, D. Davis, M.A. Weiss, Personal communication, 1983.
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[10] M.A. Weiss, "Calibration of OP Receiver AOA51 Against NIST Receiver NBS10" July 2003.
[11] W. Lewandowski, L. Tisserand, "Determination of the differential time corrections for GPS time equipment located at the OP, PTB, AOS, KRISS, CRL, NIST, USNO and APL", *BIPM Report -2004/06.*

Appendix I

Set-ups of local and portable equipment at each location (forms completed by the participating laboratories)

BIPM GPS calibration information sheet

Laboratory:	TCC
Date and hour of the beginning of measurements:	May 13 at 13:15 (Aprox) UTC
Date and hour of the end of measurements:	May 24 at 20:10 (Aprox)UTC

Receiver setup information

	Local:	**Portable: BIPM K**
• Maker:	TCC	BIPM
• Type:	TTR6	TTS-2
• Serial number:	443	S/N 028
• Receiver internal delay (GPS) :	57.0 ns	0.0 (not calibrated)
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	TTR6-A	C123
Corresponding cable delay :	231.0 ns	178.78 ns ± 0.4 ns
• UTC cable identification:	TTR6-U	
Corresponding cable delay :	8.0 ns	16 ns
Delay to local UTC :	8.0 ns	16 ns
• Receiver trigger level:	0.4 V	0.5 V
• Coordinates reference frame:	WGS 84	ITRF
Latitude or X m	1492037.87 m	
Longitude or Y m	-4887963.89 m	
Height or Z m	-38033560.61 m	

Antenna information

	Local:	**Portable:**
• Maker:	Allen Osborne Associates INC	ITR TSA-2
• Type:	-	GPS
• Serial number:	-	3-072002
If the antenna is temperature stabilised	NO	
• Set temperature value :	-	-

Local antenna cable information

• Maker:	TCC
• Type:	RG
• Is it a phase stabilised cable:	NO
• Length of cable outside the building :	Aprox 9 m

General information

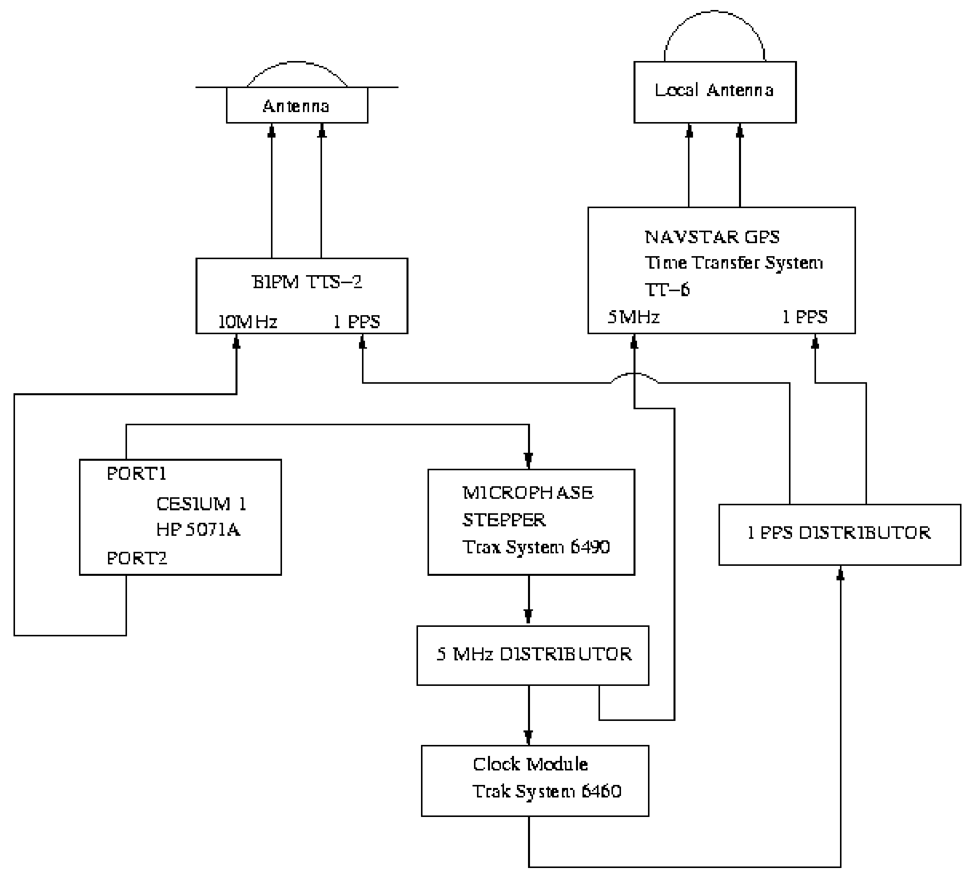
• Rise time of the local UTC pulse:	6 ns
• Is the laboratory air conditioned:	yes
• Set temperature value and uncertainty :	20+- 1º C
• Set humidity value and uncertainty :	40+- 5%

Cable delay control

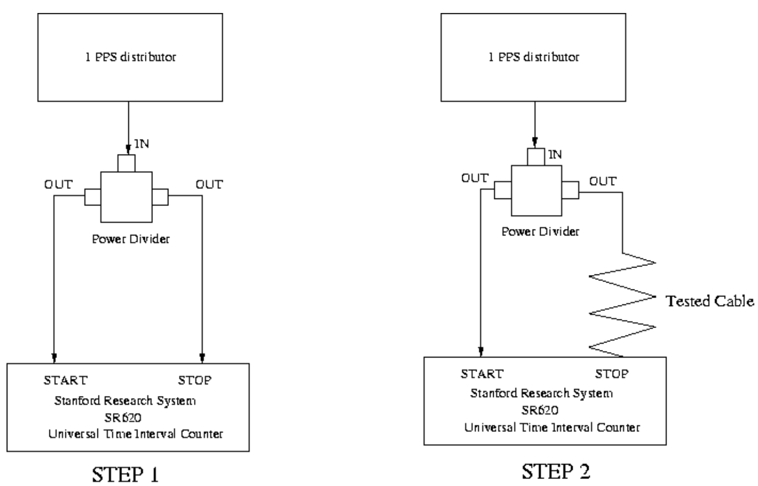
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178.78 ns ± 0.4 ns	180.1 ns

Plot of the experiment set-up:

Link to the local UTC of both receivers and Antenna positions



Description of the local method of cable delay measurement:



DELAY= STEP 2 –STEP 1

BIPM GPS calibration information sheet

Laboratory:	ONBA
Date and hour of the beginning of measurements:	MJD 53192 21:20 UTC
Date and hour of the end of measurements:	MJD 53205 14.04 UTC

Receiver setup information

	Local:	Portable: BIPM K
• Maker:	ONBA	BIPM
• Type:	TTS-2	TTS-2
• Serial number:	--	S/N 028
• Receiver internal delay (GPS) :	--	0.0 (not calibrated)
• Receiver internal delay (GLO) :	--	-
• Antenna cable identification:	PH(203) 949-8400	C123
Corresponding cable delay :	160.4 ns	178.78 ns ± 0.4 ns
• UTC cable identification:	--	
Corresponding cable delay :	--	
Delay to local UTC :	48.9 ns	21.8 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	ITRF 1987 (epoch 2001.0)	ITRF 2000 (epoch 2004.5)
Latitude or X m	2756757.33 m	2756757.78 m
Longitude or Y m	-4473139.02 m	-4473139.04 m
Height or Z m	-3603454.25 m	-3603454.33 m

Antenna information

	Local:	Portable:
• Maker:	TRC PROCOM	ITR TSA-2
• Type:	DENMARK GPS 2000	GPS
• Serial number:	-	3-072002
If the antenna is temperature stabilised NO		
• Set temperature value :	-	-

Local antenna cable information

• Maker:	
• Type:	RG-58
• Is it a phase stabilised cable:	NO
• Length of cable outside the building	15 mts aprox.

General information

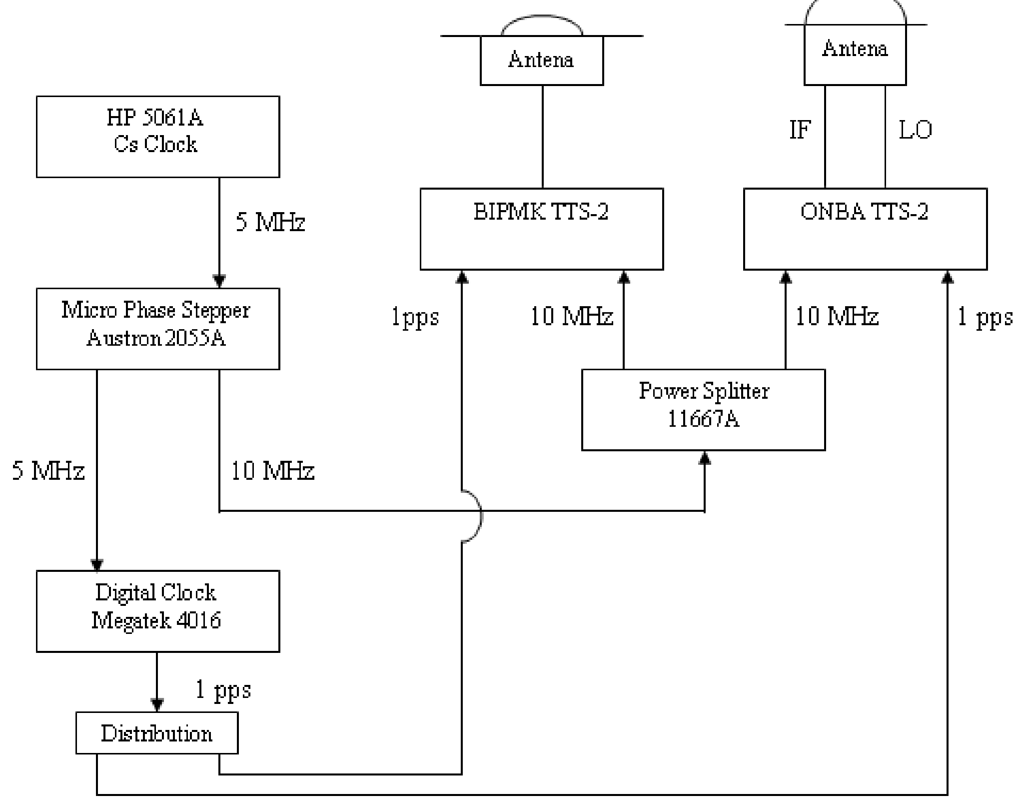
• Rise time of the local UTC pulse:	: 20 ns± 5 ns
• Is the laboratory air conditioned:	no
• Set temperature value and uncertainty	20°C ± 1°C
• Set humidity value and uncertainty :	-------

Cable delay control

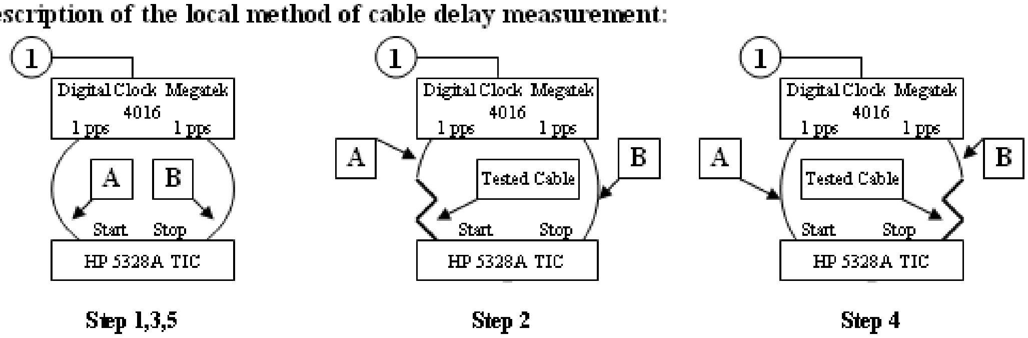
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178.78 ns ± 0.4 ns	180.67 ns ±1.25 ns

Plot of the experiment set-up

Link to the Local UTC of both receiversand Antenna positions



Description of the local method of cable delay measurement:



(1) Note: 10 MHz from Micro Phase Stepper Austron 2055 A

The method used to calibrate the cables is a double wheight method in five steps as shown above.
At each step (i) the TIC gives the results (Ri) of 100 measurments.
The test cable delay is then obtained by the following formula:

$$\text{Delay} = \frac{R_2 - \left(\dfrac{R_1 + R_3}{2}\right) + \left(\dfrac{R_3 + R_5}{2}\right) - R_4}{2} + \text{corrections}$$

The corrections are estimated by adaptators = -0.1 ns / adaptator

BIPM GPS calibration information sheet

Laboratory:	IGMA
Date and hour of the beginning of measurements:	28 July 2004 DJM 53214 13h10m UTC
Date and hour of the end of measurements:	

Receiver setup information

	Local: BIPM H	Portable: BIPM K
• Maker:	BIPM	BIPM
• Type:	TTS-2	TTS-2
• Serial number:		S/N 028
• Receiver internal delay (GPS) :	-11.36 ns	0.0 (not calibrated)
• Receiver internal delay (GLO) :		-
• Antenna cable identification:	C101	C123
Corresponding cable delay :	178.33 ns ± 0.018 ns	178.78 ns ± 0.4 ns
• UTC cable identification:	CC1112	N2
Corresponding cable delay :		
Delay to local UTC :	50.349 ns ± 0.08 ns	50.063 ns ± 0.016 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	ITRF 2000 (WGS84)	ITRF 2000 (WGS84)
Latitude or X m	2 745 485.399 m	2 745 485.735 m
Longitude or Y m	-4 483 632.743 m	-4 483 632.735 m
Height or Z m	-3 599 069.668 m	-3 599 069.678 m

Antenna information

	Local:	Portable:
• Maker:	ITR TSA-2	ITR TSA-2
• Type:	GPS	GPS
• Serial number:	72 753 545	3-072002
If the antenna is temperature stabilised		
• Set temperature value :		-

Local antenna cable information

• Maker:	TIME MICROWAVE SYSTEM
• Type:	68999 RG-58
• Is it a phase stabilised cable:	NO
• Length of cable outside the building :	Approx. 33.5 m

General information

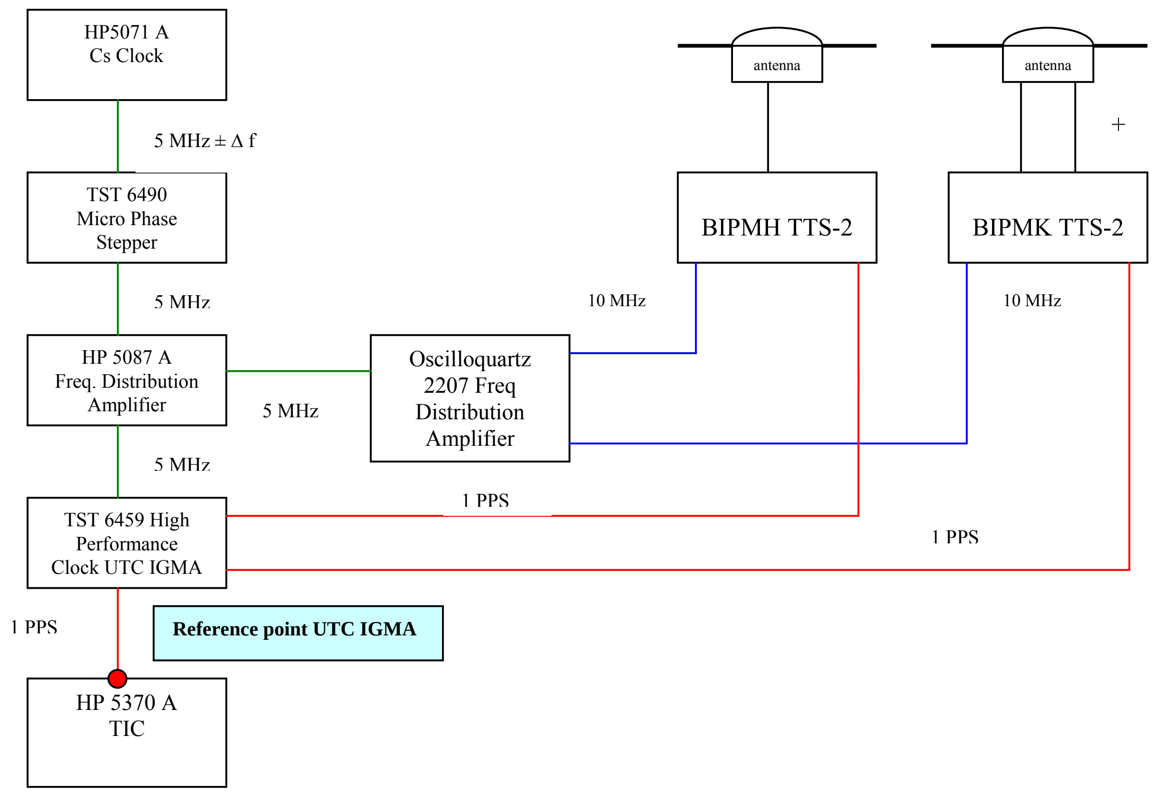
• Rise time of the local UTC pulse:	4 ns
• Is the laboratory air conditioned:	Yes
• Set temperature value and uncertainty :	21 º C ± 1 ºC
• Set humidity value and uncertainty :	45 % ± 5%

Cable delay control

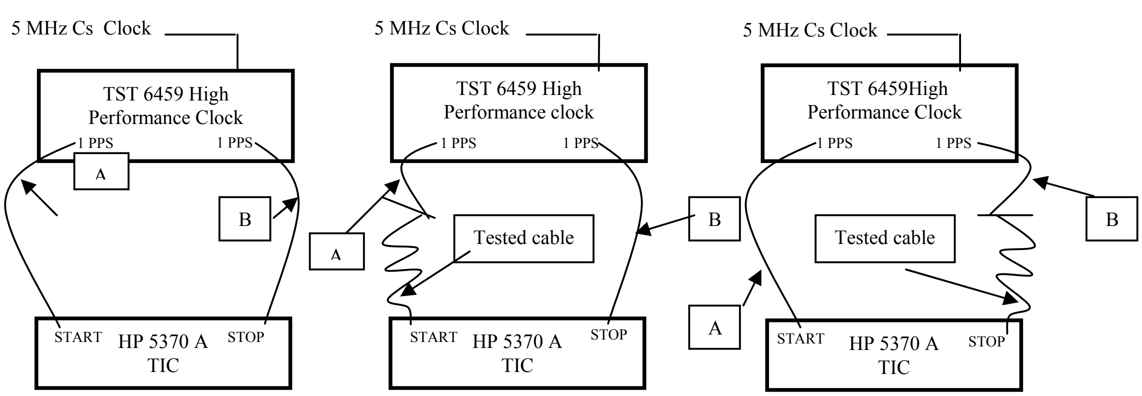
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178.78 ns ± 0.4 ns	178.63 ns ± 0.05 ns

Plot of the experiment set-up:

Link to the local UTC of both receivers and Antenna positions



Description of the local method of cable delay measurement:



Step 1, 3, 5 **Step 2** **Step 4**

The method used to calibrate the cables is a double weight method in five steps as shown above.
At each step (i) the TIC gives the result (R_i)of 100 measurements.
The test cable delay is then obtained by the following formula:

$$\text{Delay} = \frac{R_2 - \left(\frac{R_1 + R_3}{2}\right) + \left(\frac{R_3 + R_5}{2}\right) - R_4}{2} + \text{corrections}$$

The corrections are the estimated delay introduced by adaptors : - 0.01 ns / adaptor

BIPM GPS calibration information sheet

Laboratory:	**CNMP**
Date and hour of the beginning of measurements:	May 6th, 2005 @ (UTC) 05:02:15
Date and hour of the end of measurements:	May 13th, 2005 @ (UTC) 13:34:00

Receiver setup information

	Local:	**Portable: BIPM K**
• Maker:	EMDE Electronics & AOS	BIPM
• Type:	TTS-2	TTS-2
• Serial number:	S/N: 029	S/N 028
• Receiver internal delay (GPS) :	9.3 ns	0.0 (not calibrated)
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	CGPS01	C123
Corresponding cable delay :	205.1 ns	178.78 ns ± 0.4 ns
• UTC cable identification:	C012B01	C025B02
Corresponding cable delay :	5.15 ns ± 1.25 ns	10.60 ns ±1.25 ns
Delay to local UTC :	5.15 ns ± 1.25 ns	10.60 ns ±1.25 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	ITRF	ITRF
Latitude or X m	1138984.01	1138984.01
Longitude or Y m	-6196291.30	-6196291.30
Height or Z m	991541.38	991541.38

Antenna information

	Local:	**Portable:**
• Maker:	Motorola	ITR TSA-2
• Type:	GPS- Model: GCNLP271CA	GPS
• Serial number:	AN17720015	3-072002
If the antenna is temperature stabilised	NO	
• Set temperature value :	--	--

Local antenna cable information

• Maker:	SOLIDEX
• Type:	Super low loss coax. 50 ohm.
• Is it a phase stabilised cable:	NO
• Length of cable outside the building :	4 m Approx.

General information

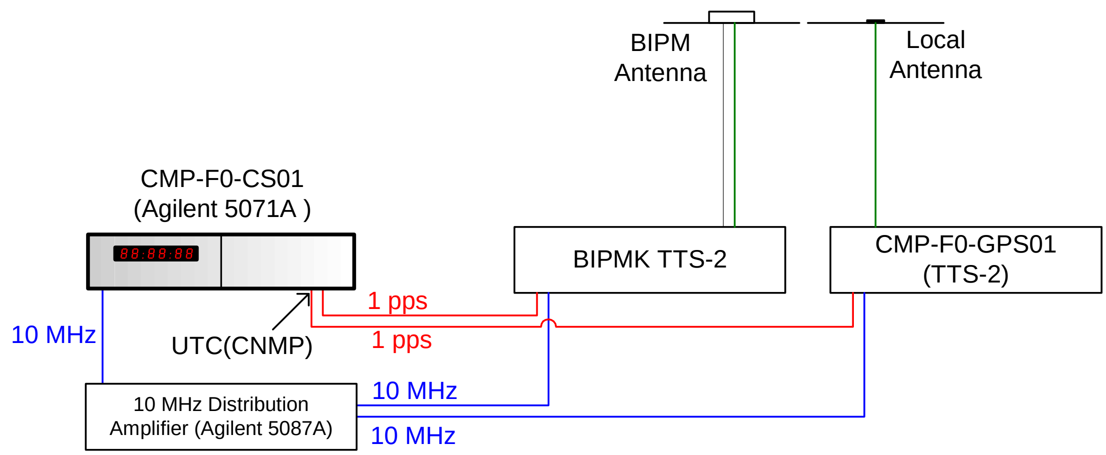
• Rise time of the local UTC pulse:	~2 ns @ 0.5 V
• Is the laboratory air conditioned:	Yes
• Set temperature value and uncertainty :	23.0 ºC ± 1.8 ºC
• Set humidity value and uncertainty :	45 %rh ± 15 %rh

Cable delay control

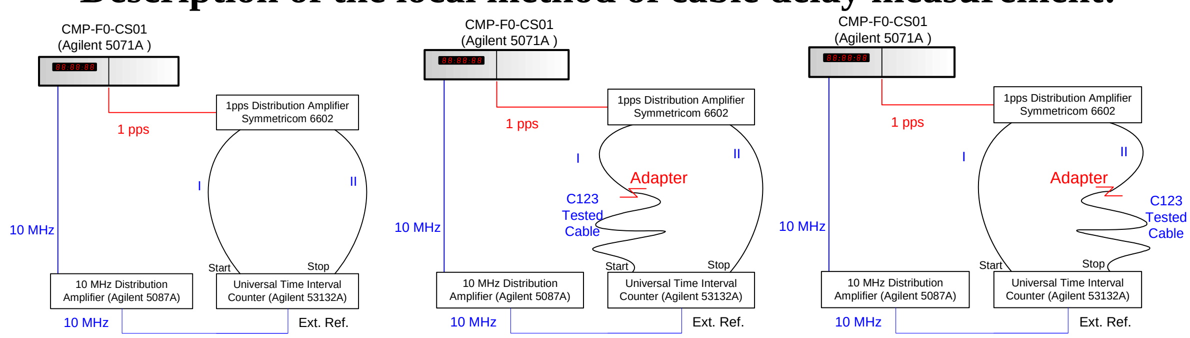
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178.78 ns ± 0.4 ns	177.80 ns ± 1.25 ns (Normal distr., k=2, Confidence Interval = 95.45%)

Plot of the experiment set-up:

Link to the local UTC of both receivers and Antenna positions



Description of the local method of cable delay measurement:



The method used to calibrate the cables is the double weight method in five test steps as shown above.
In each step the time interval counter gives the result of 100 measurements (R_i).
The test cable delay is then obtained by the following equation:

$$\text{Delay} = \frac{-R_2 + \left(\frac{R_1 + R_3}{2}\right) + R_4 - \left(\frac{R_3 + R_5}{2}\right)}{2} + \text{correction}$$

Where R_i = Stop instant – Start instant

Note 1: R_2 represents the shortest time interval between the start and stop 1pps signal pulses in test #2. R_2 is negative signed since, for this step, the stop pulse occurs first than the start pulse.
Note 2: The correction due to the adaptor is approximately: - 0.15 ns.

Appendix II

Measurement of portable cables at the visited laboratories

Laboratory	BIPM C123 cable /ns	Measurement method
BIPM	178.78 ns ± 0.4	Double Weight Pulse method
OP	-	-
TCC	180.10	Pulse method
ONBA	180.67 ±1.25	Double Weight Pulse method
IGMA	178.63 ± 0.05	Double Weight Pulse method
CNMP	177.80 ± 1.25	Double Weight Pulse method

Appendix III

Daily averages of d$t_{k,i}$ for each laboratory *k*

LAB *k*	MJD	Mean offset /ns	Standard deviation of individual common view observations /ns	Standard deviation of the mean /ns	Number of individual common views
OP	53086	-9.71	4.09	0.85	23
	53087	-10.37	3.05	0.48	40
	53088	-10.88	2.84	0.44	41
	53089	-10.17	2.57	0.43	36
	53090	-9.81	1.99	0.50	16
TCC	53138	-14.14	2.73	0.82	11
	53139	-15.69	2.66	0.84	10
	53142	-16.11	2.78	0.64	19
	53143	-15.99	2.53	0.58	19
	53144	-15.73	2.42	0.91	7
	53145	-15.04	2.26	0.53	18
	53146	-14.67	2.37	0.56	18
	53147	-14.53	2.81	0.68	17
	53148	-15.57	2.44	0.77	10
ONBA	53195	-14.01	3.57	0.16	490
	53196	-16.60	3.69	0.17	489
	53197	-17.66	3.53	0.17	420
	53198	-16.31	3.57	0.22	255
	53199	-15.07	3.90	0.18	459
IGMA	53219	-17.10	2.29	0.10	557
	53220	-16.41	2.06	0.10	461
	53221	-15.97	2.38	0.10	556
	53222	-15.51	2.00	0.08	564
	53223	-17.13	2.26	0.10	562
	53224	-17.38	2.13	0.09	559
	53225	-17.11	2.18	0.09	570
	53226	-16.49	2.51	0.10	576
	53227	-15.90	1.78	0.10	320
CNMP	53496	-11.04	4.55	0.24	370
	53497	-10.92	4.39	0.20	463
	53498	-11.12	4.38	0.20	460
	53499	-11.06	4.63	0.21	489
	53500	-11.13	4.51	0.22	423
	53501	-12.64	4.27	0.20	459
	53502	-11.12	4.52	0.21	444
	53503	-9.57	4.62	0.28	280