Rapport BIPM-2010/02

BUREAU INTERNATIONAL DES POIDS ET MESURES

Relative characterization of GPS time equipment delays at the OP, AOS, GUM, LT, TP, BEV, OMH, NIMB, NMC, and ZMDM

W. Lewandowski and L. Tisserand

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Pavillon de Breteuil, F-92312 SEVRES Cedex

Abstract

The BIPM continues a series of differential calibrations of GPS equipment located in time laboratories contributing to TAI. This report details measurements that took place from 4 September 2006 to 25 January 2007, involving GPS time equipment located at the Observatoire de Paris (OP, Paris, France), the Astrogeodynamical Observatory Space Research Centre P.A.S. (AOS, Borowiec, Poland), the Główny Urząd Miar (Central Office of Measures, GUM, Warsaw, Poland), the Lithuanian National Metrology Institute (LT, Vilnius, Lithuania), the Institute of Radio Engineering and Electronics, Academy of Sciences of the Czech Republic (TP, Prague, Czech Republic), the Bundesamt für Eich- und Vermessungswesen (BEV, Vienna, Austria), the Országos Mérésügyi Hivatal (National Office of Measures) (OMH*, Budapest, Hungary), the National Institute of Metrology (NIMB, Bucharest, Romania), the National Centre of Metrology (NMC**, Sofiya, Bulgaria) and the Bureau of Measures and Precious Metals (ZMDM***, Belgrade, Serbia).

INTRODUCTION

The BIPM is conducting a series of differential calibrations of GPS equipment located in time laboratories contributing to TAI. This report details an exercise that took place from 4 September 2006 to 25 January 2007.

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 access to UTC for 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.

EQUIPMENT

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

* Now the Hungarian Trade Licensing Office, MKEH.
** Now the Bulgarian Institute of Metrology, BIM.
*** Now the Directorate of Measures and Precious Metals, DMDM.

Table 1. GPS equipment involved in this comparison.

Laboratory	Receiver Maker	Receiver Type	Receiver Ser. No
OP	AOA	TTR-5	051
AOS	AOS	TTS-2	021
GUM	AOS	TTS-2	014
LT	-	TTS-2	-
TP	DICOM	GTR-50	002
BEV	AOS	TTS-2	024
OMH	AOA	TTR-6	028
NIMB	AOS	TTS-2	046
NMC	AOA	TTR-6	467
ZMDM	AOS	TTS-2	043
BIPM portable receiver	AOS	TTS-2	036

The BIPM portable receiver is equipped with a C128 cable. Its delay measured at the BIPM was 187.75 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:

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

The noise exhibited by the time series $\mathrm{d}t_k$ is then analysed, for each of the laboratories visited, using 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.

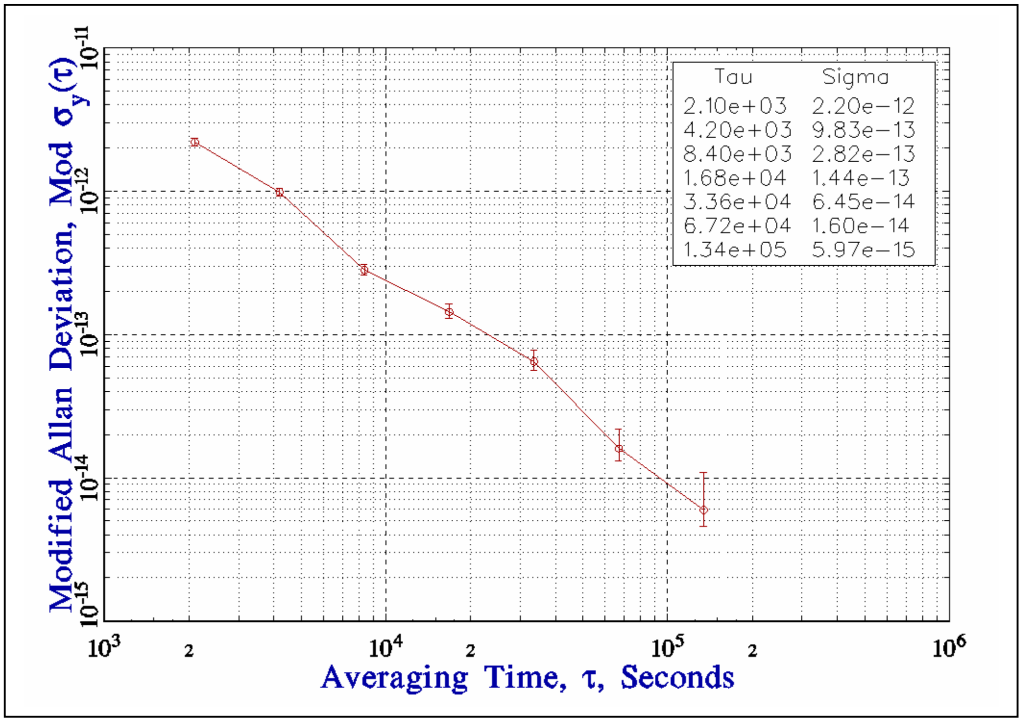

Figure 1. Square root of the modified Allan variance of the time series dt_{OP} for the period: 4-10 September 2006.

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

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

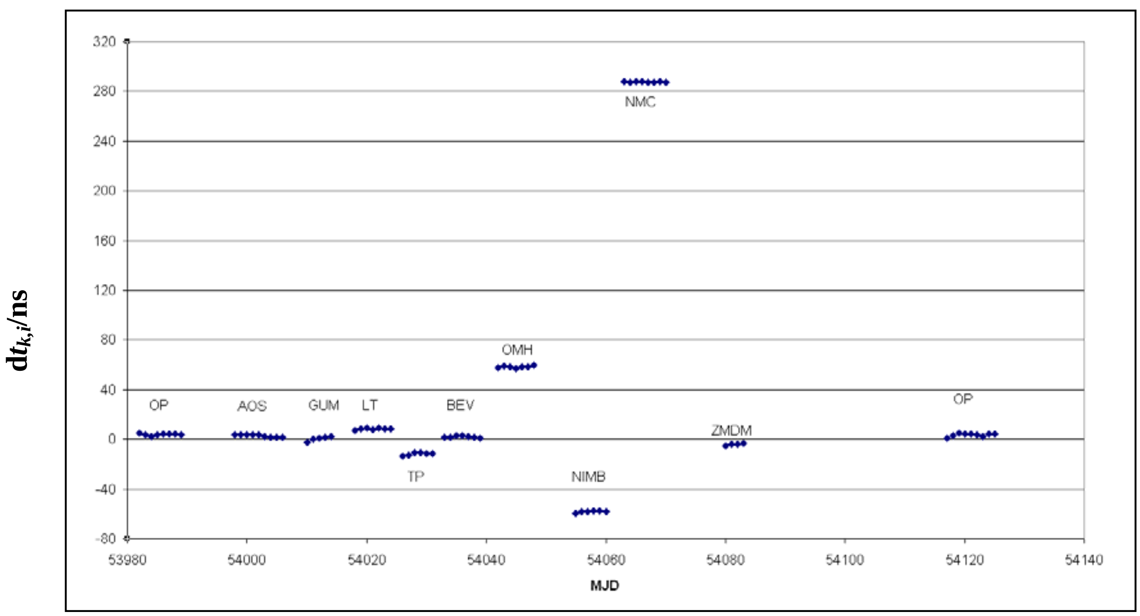

Figure 2. Daily averages of $dt_{k,i}$ for each laboratory k (see Appendix III).

Next, we computed mean offsets for the full duration of the 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	4/09 – 10/09/06	287	3.92	3.22	0.6	0.85
AOS	20/09 – 28/09/06	4254	2.74	2.18	0.5	0.97
GUM	2/10 – 6/10/06	2366	0.33	3.06	0.4	1.73
LT	10/10 – 16/10/06	981	8.44	3.47	0.4	0.58
TP	18/10 – 23/10/06	2217	–11.80	1.72	0.5	1.01
BEV	25/10 – 31/10/06	3434	2.08	4.29	0.4	0.78
OMH	3/11 – 9/11/06	123	58.30	2.46	0.7	0.84
NIMB	16/11 – 21/11/06	2945	–57.99	2.51	0.3	0.73
NMC	24/11 – 1/12/06	182	287.51	2.39	0.4	0.42
ZMDM	11/12 – 14/12/06	2017	–4.27	3.02	0.5	0.75
OP	17/01 – 25/01/07	334	3.63	2.83	0.7	1.33

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 $[UTC(\mathrm{k}_1) - UTC(\mathrm{k}_2)]$, and its estimated uncertainty $u(d)$ for the period of comparison (1σ).

$[UTC(\mathrm{k}_1) - UTC(\mathrm{k}_2)]$	d/ns	$u(d)$/ns
[*UTC*(AOS) – *UTC*(OP)]	–1.0	3.0
[*UTC*(GUM) – *UTC*(OP)]	–3.4	3.0
[*UTC*(LT) – *UTC*(OP)]	4.7	3.0
[*UTC*(TP) – *UTC*(OP)]	–15.6	3.0
[*UTC*(BEV) – *UTC*(OP)]	–1.7	3.0
[*UTC*(OMH) – *UTC*(OP)]	54.5	3.0
[*UTC*(NIMB) – *UTC*(OP)]	–61.8	3.0
[*UTC*(NMC) – *UTC*(OP)]	283.7	3.0
[*UTC*(ZMDM) – *UTC*(OP)]	–8.0	3.0

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 the 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. The NBS10 receiver was used unless otherwise stated.

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]
December 2005	–8.7	3.0	[12]

NBS03 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 access to UTC for the participating laboratories.

The present measurements were performed under good conditions with excellent closure of travelling equipment at the OP. The GPS time equipment of some of the visited laboratories differs by tens of nanoseconds from the reference equipment at the OP, and required an appropriate correction.

The GPS time equipment located at the NIST and the OP are excellent references for the GPS calibration trips. The two sets of equipment have been compared several times over the past three decades, and the difference between them has never exceeded a few nanoseconds (see Table 4).

Acknowledgements

The authors express their gratitude to their colleagues fat the participating laboratories for their collaboration, without which the work could not have been accomplished.

REFERENCES

[1] G. de Jong, "Measuring the propagation time of coaxial cables used with GPS receivers," *Proc. 17th PTTI,* pp. 223-232, December 1985.

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[5] BIPM Calibration Certificate of 19 January 1988.

[6] BIPM Letter of 15 June 1988, BG/9G.69.

[7] M.A. Weiss, "Calibration of OP Receiver AOA51 Against NIST Receiver NBS10" March 1995.

[8] M.A. Weiss, "Calibration of OP Receiver AOA51 Against NIST Receiver NBS10" March 1996.

[9] W. Lewandowski, P. Moussay, "Determination of the differential time corrections for GPS time equipment located at the OP, IEN, ROA, PTB, NIST, and USNO", *Rapport BIPM -2002/02*.

[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", *Rapport BIPM -2004/06*.

[12] W. Lewandowski, L. Tisserand, "Determination of the differential time corrections for GPS time equipment located at the OP, CNM, NIST, USNO and NRC", *Rapport BIPM -2008/04*.

<u>Appendix I</u>

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

BIPM GPS calibration information sheet

Laboratory:	LNE/OP-SYRTE (Observatoire de Paris)
Date and hour of the beginning of measurements:	04 September 2006
Date and hour of the end of measurements:	10 September 2006

Receiver setup information

	Local: NBS51	Portable: BP0N
• Maker:	Allen Osborne Associates	AOS
• Type:	TTR-5	TTS-2
• Serial number:	051	036
• Receiver internal delay (GPS) :	54 ns	8.0
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	505 IF	C128
Corresponding cable delay :	168 ns +/- 0,3 ns	187,75 ns ± 0,4 ns
• Delay to local UTC :	304 ns	306 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	ITRF	ITRF
Latitude or X m	4 202 780,30 m	4 202 783,64 m
Longitude or Y m	171 370,03 m	171 367,43 m
Height or Z m	4 778 660,12 m	4 778 657,39 m

Antenna information

	Local:	Portable:
• Maker:	Allen Osborne Associates	Motorola
• Type:	-	GPS
• Serial number:	-	AN16N00210
• If the antenna is temperature stabilised		
- give its temperature setting :	-	60 °C

Local antenna cable information

• Maker:	-
• Type:	RG-58
• Is it a phase stabilised cable:	No
• Length of cable outside the building :	Approximately 6 meters

General information

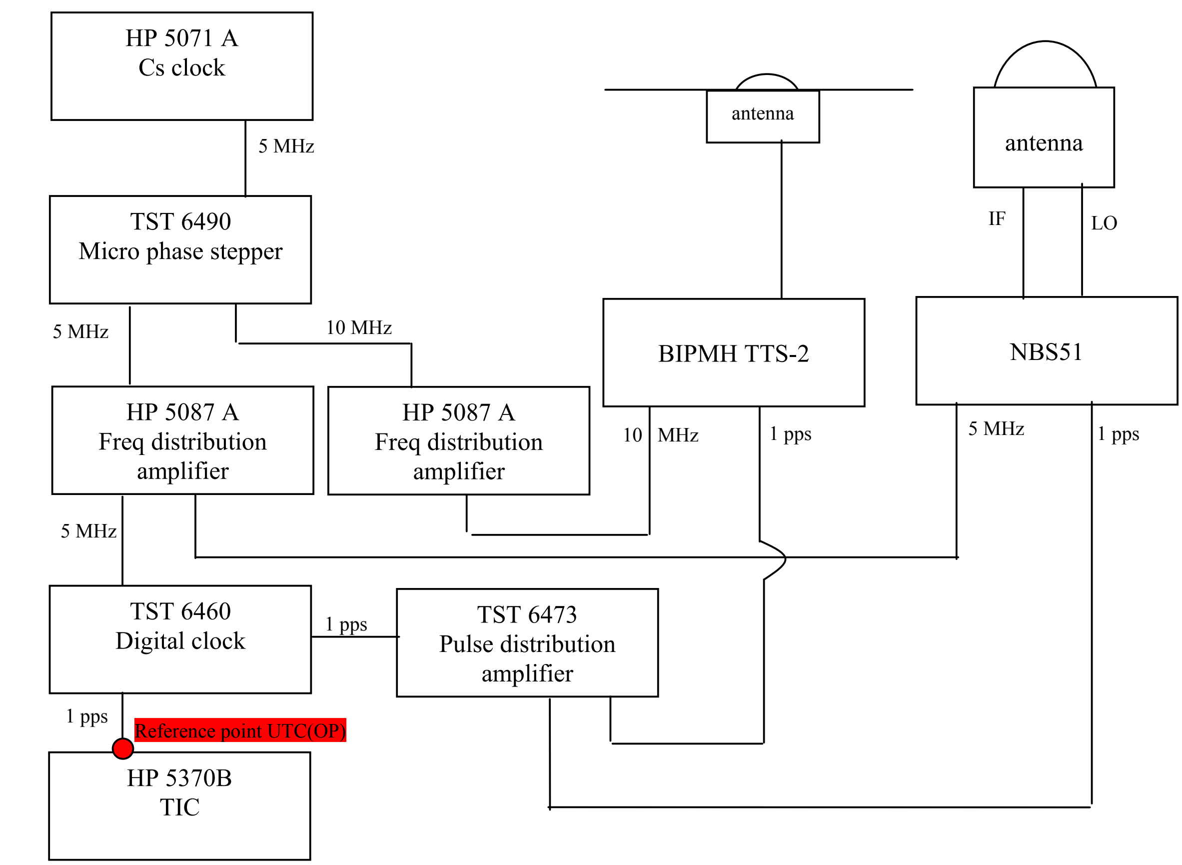
• Rise time of the local UTC pulse:	4 ns
• If the laboratory air conditioned:	Yes
- temperature value and its stability :	(21,5 +/- 2) °C
- humidity value and its stability :	-

Cable delay control

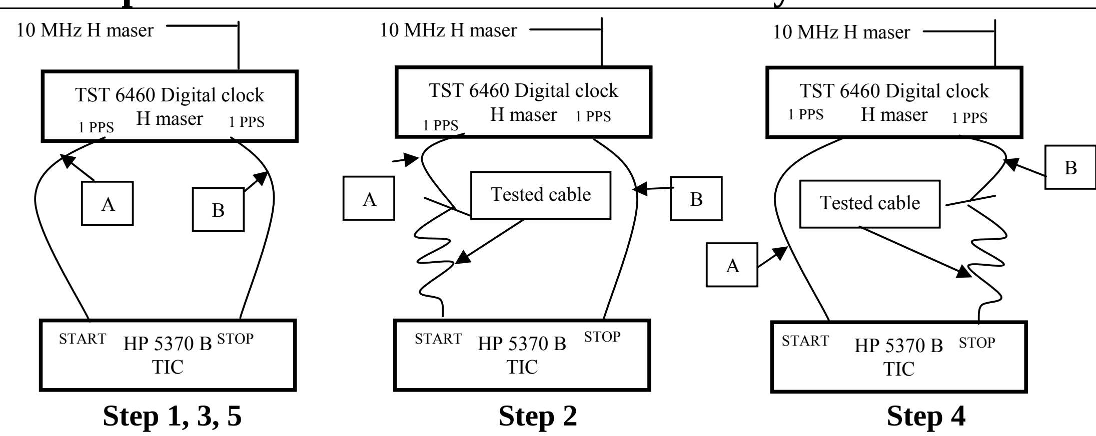
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187,75 ns ± 0,4 ns	187,23 ns ± 0,3 ns

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:



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 result (R_i)of 100 measurments.
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 adaptators : - 0,1 ns / adaptator

BIPM GPS calibration information sheet

Laboratory:	AOS
Date and hour of the beginning of measurements:	**MJD:53998, 10:06**
Date and hour of the end of measurements:	**MJD:53406, 11:40**

Receiver setup information

	Local:	**Portable: BP0N**
• Maker:	AOS	AOS
• Type:	TTS-2	TTS-2
• Serial number:	021	036
• Receiver internal delay (GPS) :	-7.7 ns	8.0 ns
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	A-01	C128
Corresponding cable delay :	149.3 ± 0.3 ns	187.75 ns ± 0.4 ns
• Delay to local UTC :	20.4 ns	15.3 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	ITRF	ITRF
Latitude or X m	3738369.22 m	3738368.17 m
Longitude or Y m	1148164.25 m	1148162.72 m
Height or Z m	5021810.46 m	5021811.35 m

Antenna information

	Local:	**Portable:**
• Maker:	3S Navigation	Motorola
• Type:	TSA (GPS/GLONASS)	GPS
• Serial number:		AN16N00210
If the antenna is temperature stabilised		
• Set temperature value :	40 °C	60 °C

Local antenna cable information

• Maker:	Belden
• Type:	RG-58 type, high freq., 50Ω
• Is it a phase stabilised cable:	No
• Length of cable outside the building :	5 m

General information

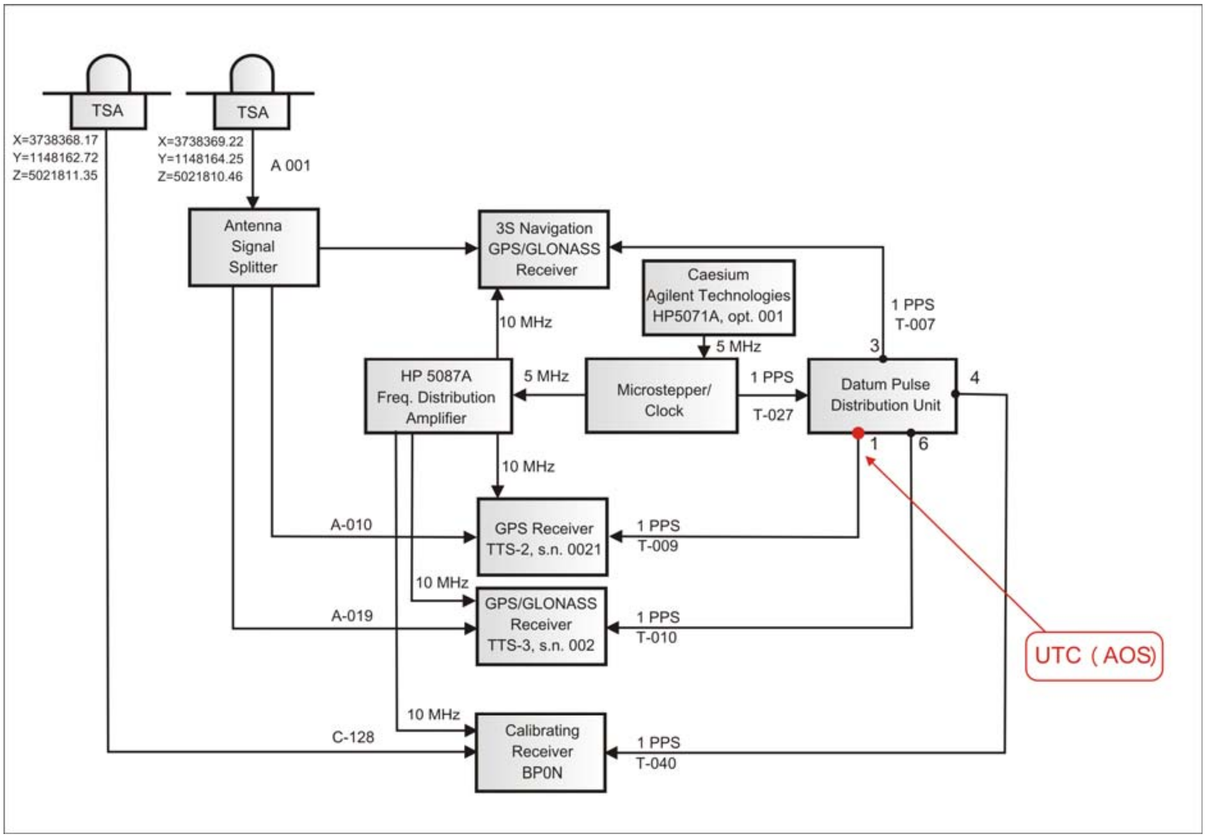
• Rise time of the local UTC pulse:	4 ns
• Is the laboratory air conditioned:	Yes
• Set temperature value and its stability:	22 ± 0.5 °C
• Set humidity value and its stability:	40 ± 5 %

Cable delay control

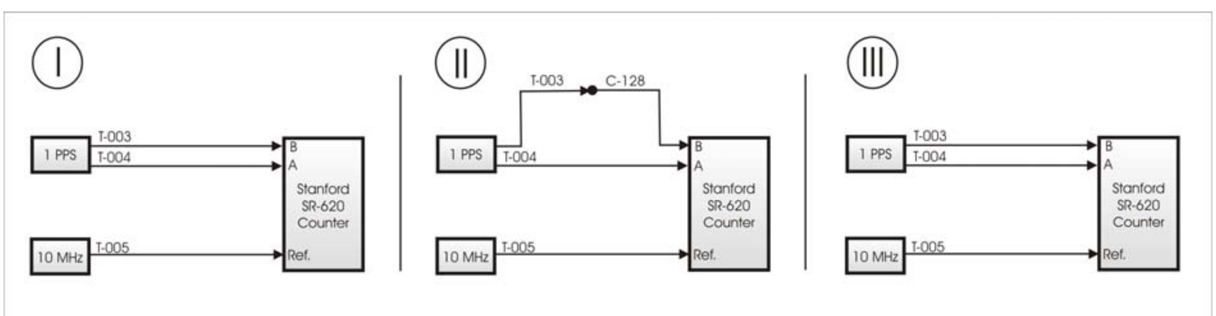
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187.75 ns ± 0.4 ns	186.33 ± 0.4 ns

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:



Pulse method of measurement used for antenna and 1pps cables.

Test cable delay = Meas_II – (Meas_I + Meas_III)/2, trig. level = 0.5 V

Meas_I = 31.63 ns, Meas_II = 217.96ns , Meas_III = 31.63 ns, $Delay_{(C\text{-}128)}$ = 186.33 ns

BIPM GPS calibration information sheet

Laboratory:	TP, Institute of Radio Engineering and Electronics, Czech Academy of Sciences
Date and hour of the beginning of measurements:	MJD 54026 6:54 UTC
Date and hour of the end of measurements:	MJD 54031 6:15 UTC

Receiver setup information

	Local:	Portable: BP0N
• Maker:	DICOM	AOS
• Type:	GTR50	TTS-2
• Serial number:	002 , FW version 1.10	036
• Receiver internal delay (GPS) :	Not known. The overall chain delay =161.6 ns (antenna+ cable+ receiver) based on previous calibrations against our old TTR-6 /SN 260.	8.0
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	LDF1-50	C128
Corresponding cable delay :	137.5 ns ± 1 ns	187.75 ns ± 0.4 ns
• Delay to local UTC :	0 ns. Note: UTC(TP) is defined at the GTR50/SN002 input	19.3 ns at 1V/50Ω, positive
• Receiver trigger level:	1.0 V	
• Coordinates reference frame:	ITRF94	ITRF94
Latitude or X m	+3967285.27	+3967279.56
Longitude or Y m	+1022539.57	+1022545.42
Height or Z m	+4872412.62	+4872413.83

Antenna information

	Local:	Portable:
• Maker:	Novatel	Motorola
• Type:	GPS-702, Dual frequency	GPS
• Serial number:	NVH03400007	AN16N00210
If the antenna is temperature stabilised		
• Set temperature value :	45 °C	60 °C

Local antenna cable information

• Maker:	Andrew Heliax
• Type:	LDF1-50
• Is it a phase stabilised cable:	No. Temperature delay coefficient <10 ppm/K (from specifications)
• Length of cable outside the building :	≈ 20 m

General information

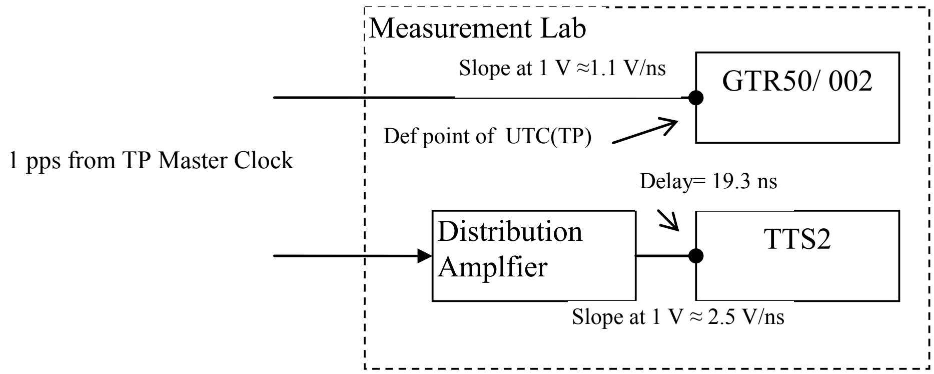
• Rise time of the local UTC pulse:	See the figure below.
• Is the laboratory air conditioned:	Yes, temperature only
• Set temperature value and uncertainty :	24.4 ± 1.0 °C
• Set humidity value and uncertainty :	30 to 40%

Cable delay control

Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187.75 ns ± 0.4 ns	186.4 ± 1.5 ns

Plot of the experiment set-up:

Link to the local UTC of both receivers and Antenna positions



IREE's GTR50 antennas (distance between the poles is 3 m); the antenna building rim is oriented from north (right-hand side) to south. The GTR50/002 antenna that was employed in the calibration is on the left-hand side.
The TTS-2 antenna was placed on the black roof about 8 m from the rim (perpendicular to about the midpoint between the GTR50 antennas) at a high of 55 cm.

Description of the local method of cable delay measurement:

Since we didn't have appropriate connector couplers, we employed a simple reflection method using a 500 MHz BW oscilloscope.

BIPM GPS calibration information sheet

Laboratory:	**BEV**
Date and hour of the beginning of measurements:	25.10.2006, 14 UTC
Date and hour of the end of measurements:	31.10.2006, 10 UTC

Receiver setup information

	Local 1: UTC(BEV)	**Local 2: TTS2_temp**	**Portable: BP0N**
• Maker:	AOS	AOS	AOS
• Type:	TTS-2	TTS-2	TTS-2
• Serial number:	024	054	036
• Receiver internal delay (GPS) :	-15 ns	0.8 ns	8.0 ns
• Receiver internal delay (GLO) :	-	-	-
• Antenna cable identification:	BEV01	BEV02	BEV03
Corresponding cable delay :	310 ns	288.8 ns	233.3 ns
• Delay to local UTC :	15.2 ns	15.2 ns	49.3 ns
• Receiver trigger level:	1V ?	1V ?	
• Coordinates reference frame:	ITRF 97	ITRF 97	ITRF 97
Latitude or X m	48°12’33.7453’’	48°12’33.5828’’	48°12’33.6301’’
Longitude or Y m	16°19’06.3635’’	16°19’06.3035’’	16°19’06.3196’’
Height or Z m	292.263	290.570	290.578

Antenna information

	Local 1:	**Local 2:**	**Portable:**
• Maker:	Motorola	Motorola	Motorola
• Type:	GPS	GPS	GPS
• Serial number:			AN16N00210
If the antenna is temperature stabilised			
• Set temperature value :	-	60°C	60 °C

Local antenna cable information

• Maker:	AOS	AOS	AOS
• Type:			
• Is it a phase stabilised cable:	yes	yes	yes
• Length of cable outside the building :	5 m	5 m	40 m

General information

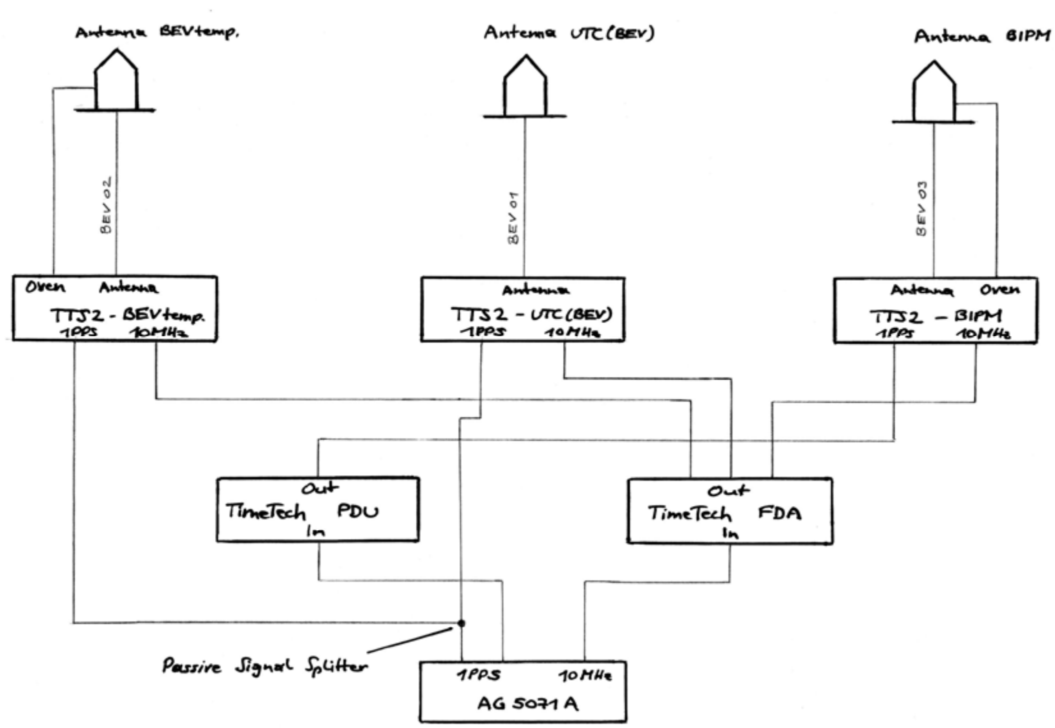
• Rise time of the local UTC pulse:	2 ns
• Is the laboratory air conditioned:	yes
• Set temperature value and uncertainty :	23°C ± 0.8°C
• Set humidity value and uncertainty :	40% ± 8%

Cable delay control

Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187.75 ns ± 0.4 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:

all cables measured by Mr. Nawrocki (AOS)

BIPM GPS calibration information sheet

Laboratory:	OMH (National Office of Measure) Hungary
Date and hour of the beginning of measurements:	**3. 11.2006 (MJD 54042) 13:50:15 (UTC)**
Date and hour of the end of measurements:	**9. 11.2006 (MJD 54048) 11:02:00 (UTC)**

Receiver setup information

	Local:	**Portable: BP0N**
• Maker:	Allen Osborne Associates	AOS
• Type:	TTR-6	TTS-2
• Serial number:	0280	036
• Receiver internal delay (GPS) :	50.0 ns	8.0
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	L.O, I.F	C128
• Corresponding cable delay :	296.0 ns	187.75 ns ± 0.4 ns
• Delay to local UTC :	204.0 ns	219.49 ns
• Receiver trigger level:	-	-
• Coordinates reference frame:	ITRF88	ITRF88
• Latitude or X m	4081857.94	4081855.39
• Longitude or Y m	1406567.20	1406566.32
• Height or Z m	4679317.42	4679314.50

Antenna information

	Local:	**Portable:**
• Maker:	Allen Osborne Associates	Motorola
• Type:	GPS	GPS
• Serial number:	0593	AN16N00210
If the antenna is temperature stabilised		
• Set temperature value :	-	60 °C

Local antenna cable information

• Maker:	Allen Osborne Associates
• Type:	RG 58 A/U
• Is it a phase stabilised cable:	-
• Length of cable outside the building :	8 m

General information

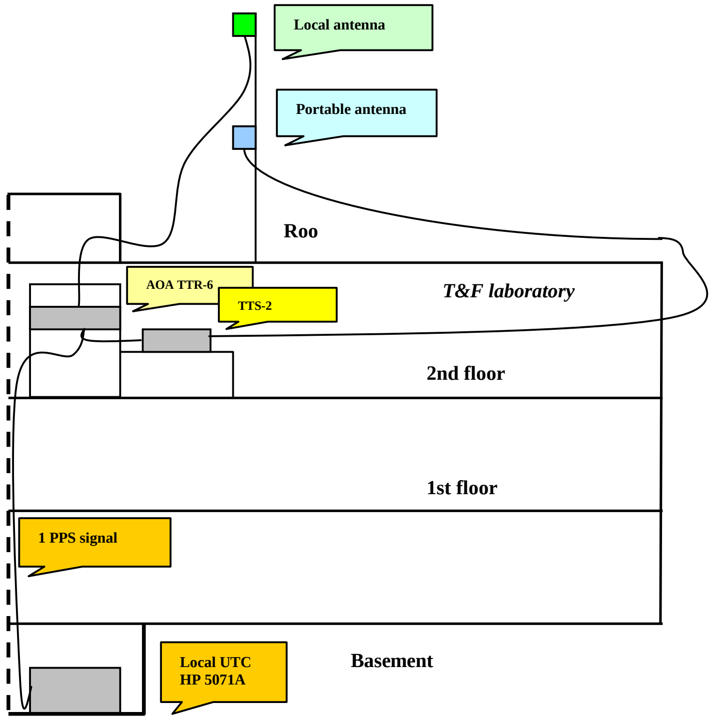
• Rise time of the local UTC pulse:	< 10 ns
• Is the laboratory air conditioned:	Yes
• Set temperature value and uncertainty :	23 ± 1 °C
• Set humidity value and uncertainty :	25 ± 4%

Cable delay control

Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187.75 ns ± 0.4 ns	187.06 ± 0.32 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:

The cable delay measurement was taken by means of an AGILENT 53132A counter. The cable was connected between the inputs Chanel I and Chanel II.
The rise edge of the pulse from impulse generator starts the time interval counter. This pulse running through the antenna cable stops the time interval measurement.
The parameters of the pulse: rise up time: 2.5 ns, level: +3 V, width: 50 ns.
The source impedance of the generator is 50 Ω and the input impedances of the TIC are 50 Ω.
The pulses were manually initiated.
The time base of the TIC based on from the National Time and Frequency Standard of OMH (HP 5071A Cesium beam oscillator, f = 10 MHz).

BIPM GPS calibration information sheet

Laboratory:	NMC, Sofia
Date and hour of the beginning of measurements:	**MJD 54063 11:54**
Date and hour of the end of measurements:	**MJD 54070 08:30**

Receiver setup information

	Local:	**Portable: BP0N**
• Maker:	Allen Osborne Associates	AOS
• Type:	TTR-6	TTS-2
• Serial number:	467	036
• Receiver internal delay (GPS) :	50 ns	8.0
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	-	C128
Corresponding cable delay :	538 ns	187.75 ns ± 0.4 ns
• Delay to local UTC :	2.3 ns ± 0.6 ns	10.5 ns ± 0.6 ns
• Receiver trigger level:	-	
• Coordinates reference frame:		
Latitude or X m	42° 39' 52.1563"	42° 39' 52.1468"
Longitude or Y m	23° 21' 28.1574"	23° 21' 28.1574"
Height or Z m	642.00	640.51

Antenna information

	Local:	**Portable:**
• Maker:	Allen Osborne Associates	Motorola
• Type:	GPS	GPS
• Serial number:	583	AN16N00210
If the antenna is temperature stabilised		
• Set temperature value :	-	60 °C

Local antenna cable information

• Maker:	Allen Osborne Associates
• Type:	RG-58
• Is it a phase stabilised cable:	-
• Length of cable outside the building :	45.72 m (150 ft)

General information

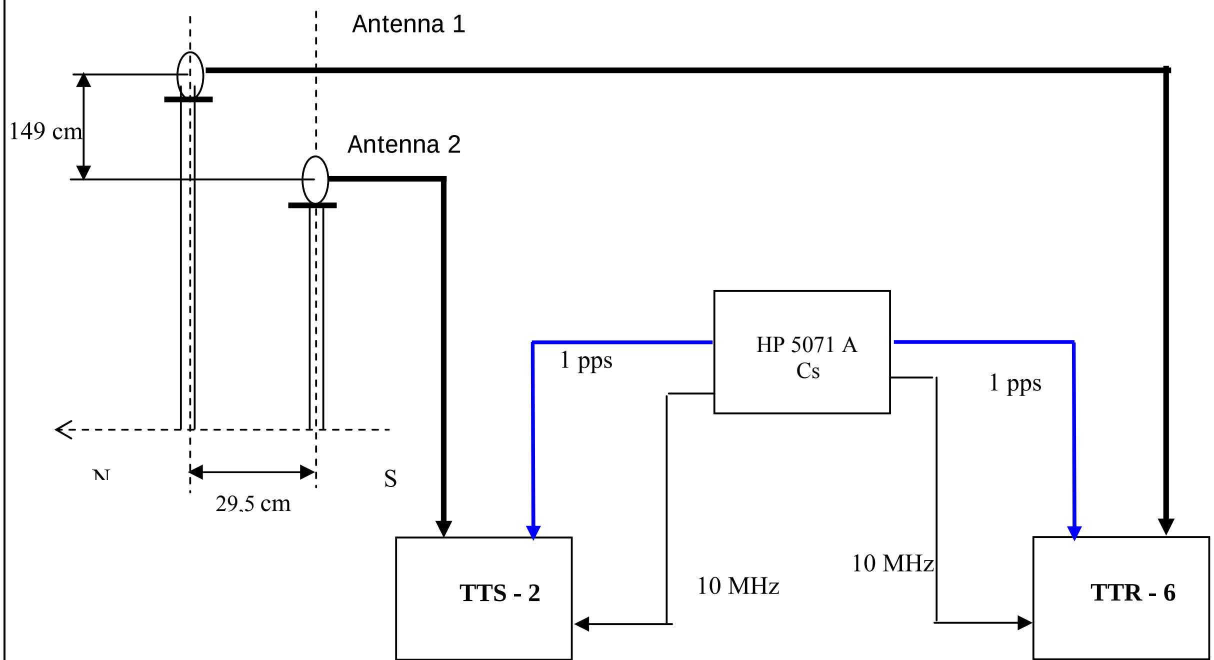
• Rise time of the local UTC pulse:	< 5 ns
• Is the laboratory air conditioned:	
• Set temperature value and uncertainty :	23 °C ± 1 °C
• Set humidity value and uncertainty :	(40 ± 10) %

Cable delay control

Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187.75 ns ± 0.4 ns	187.1 ns ± 0.6 ns

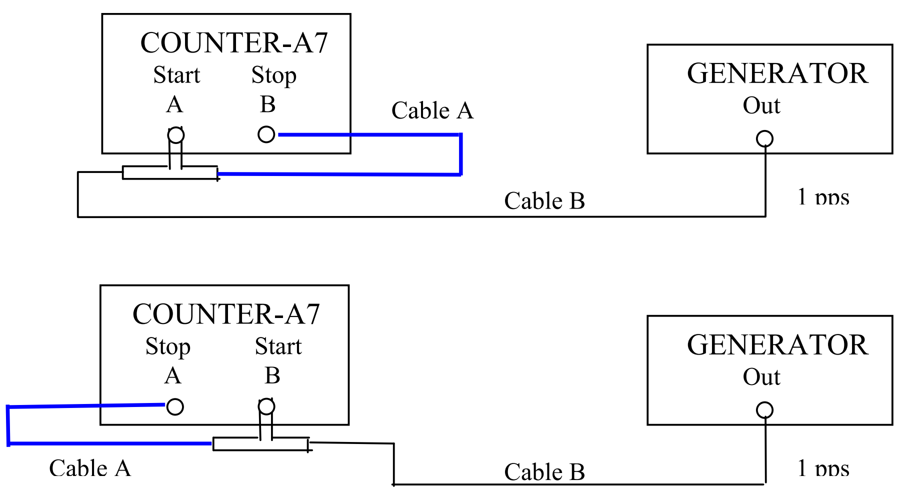
Plot of the experiment set-up:

Link to the local UTC of both receivers and Antenna positions



	Antenna 1	Antenna 2
Latitude x	42°39'52.1563"	42°39'52.1468"
Longitude y	23°21'28.1574"	23°21'28.1574"
Height z, m	642.00	640.51

Description of the local method of cable delay measurement:



BIPM GPS calibration information sheet

Laboratory: ZMDM	
Date and hour of the beginning of measurements:	11 December 2006, 00:06
Date and hour of the end of measurements:	14 December 2006, 10:21

Receiver setup information

	Local:	**Portable: BP0N**
• Maker:	EEMD Electronic	AOS
• Type:	TTS-2	TTS-2
• Serial number:	043	036
• Receiver internal delay (GPS) :	9.0	8.0
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	DEX-001	C128
Corresponding cable delay :	185.80 ns	187.75 ns ± 0.4 ns
• Delay to local UTC :	35.30 ns	36.64 ns
• Receiver trigger level:		
• Coordinates reference frame:	ITRF88	ITRF88
Latitude or X m	4245406.64 m	4245407.97 m
Longitude or Y m	1583793.99 m	1583791.09 m
Height or Z m	4473889.47 m	4473890.18 m

Antenna information

	Local:	**Portable:**
• Maker:	Motorola	Motorola
• Type:	GPS	GPS
• Serial number:	AN08960115	AN16N00210
If the antenna is temperature stabilised		
• Set temperature value :	-	60 °C

Local antenna cable information

• Maker:	-
• Type:	LMR 400
• Is it a phase stabilised cable:	YES
• Length of cable outside the building :	25 m

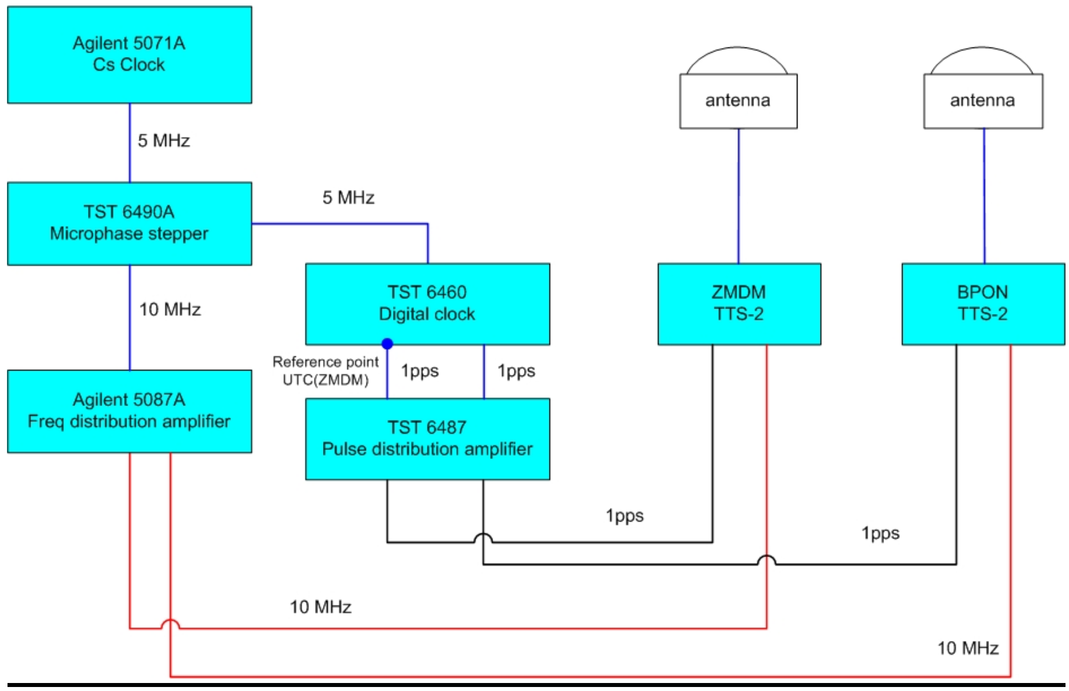
General information	
• Rise time of the local UTC pulse:	4 ns
• Is the laboratory air conditioned:	YES
• Set temperature value and uncertainty :	(23 ± 2) °C
• Set humidity value and uncertainty :	(30 ± 10)%

Cable delay control

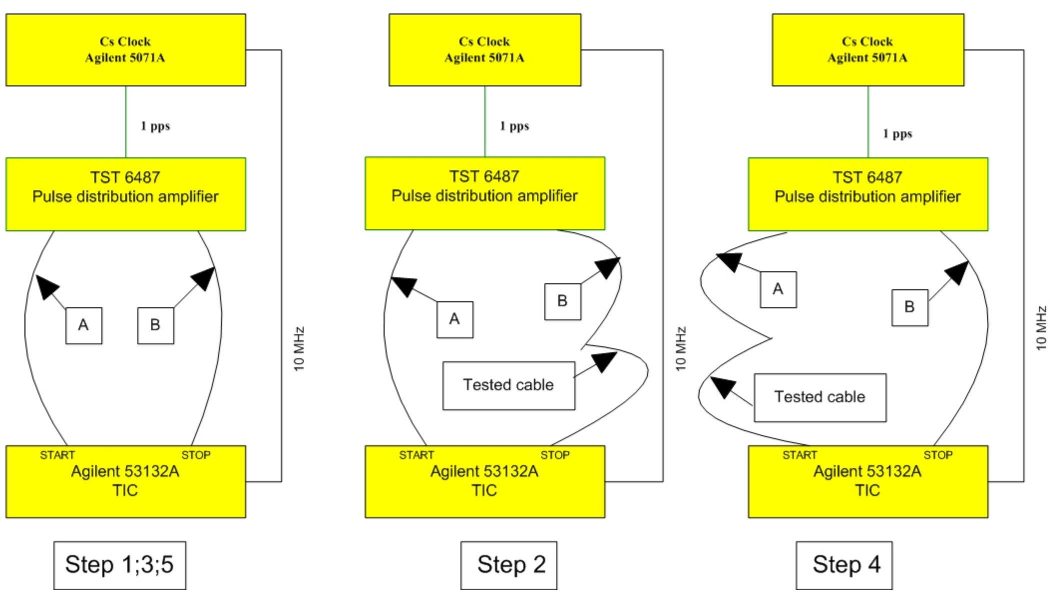
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187.75 ns ± 0.4 ns	186.58 ns ± 0.4 ns

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:



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:

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

<u>The corrections are the estimated delay introduced by adaptors : - 0.1 ns / adaptor.</u>

BIPM GPS calibration information sheet

Laboratory:	LNE/OP-SYRTE (Observatoire de Paris)
Date and hour of the beginning of measurements:	17 January 2007
Date and hour of the end of measurements:	25 January 2007

Receiver setup information

	Local: NBS51	**Portable: BP0N**
• Maker:	Allen Osborne Associates	AOS
• Type:	TTR-5	TTS-2
• Serial number:	051	036
• Receiver internal delay (GPS) :	54 ns	8.0
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	505 IF	C128
Corresponding cable delay :	168 ns +/- 0,3 ns	187,75 ns ± 0,4 ns
• Delay to local UTC :	304 ns	306 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	ITRF	ITRF
Latitude or X m	4 202 780,30 m	4 202 783,64 m
Longitude or Y m	171 370,03 m	171 367,43 m
Height or Z m	4 778 660,12 m	4 778 657,39 m

Antenna information

	Local:	**Portable:**
• Maker:	Allen Osborne Associates	Motorola
• Type:	-	GPS
• Serial number:	-	AN16N00210
• If the antenna is temperature stabilised		
- give its temperature setting :	-	60 °C

Local antenna cable information

• Maker:	-
• Type:	RG-58
• Is it a phase stabilised cable:	No
• Length of cable outside the building :	Approximately 6 meters

General information

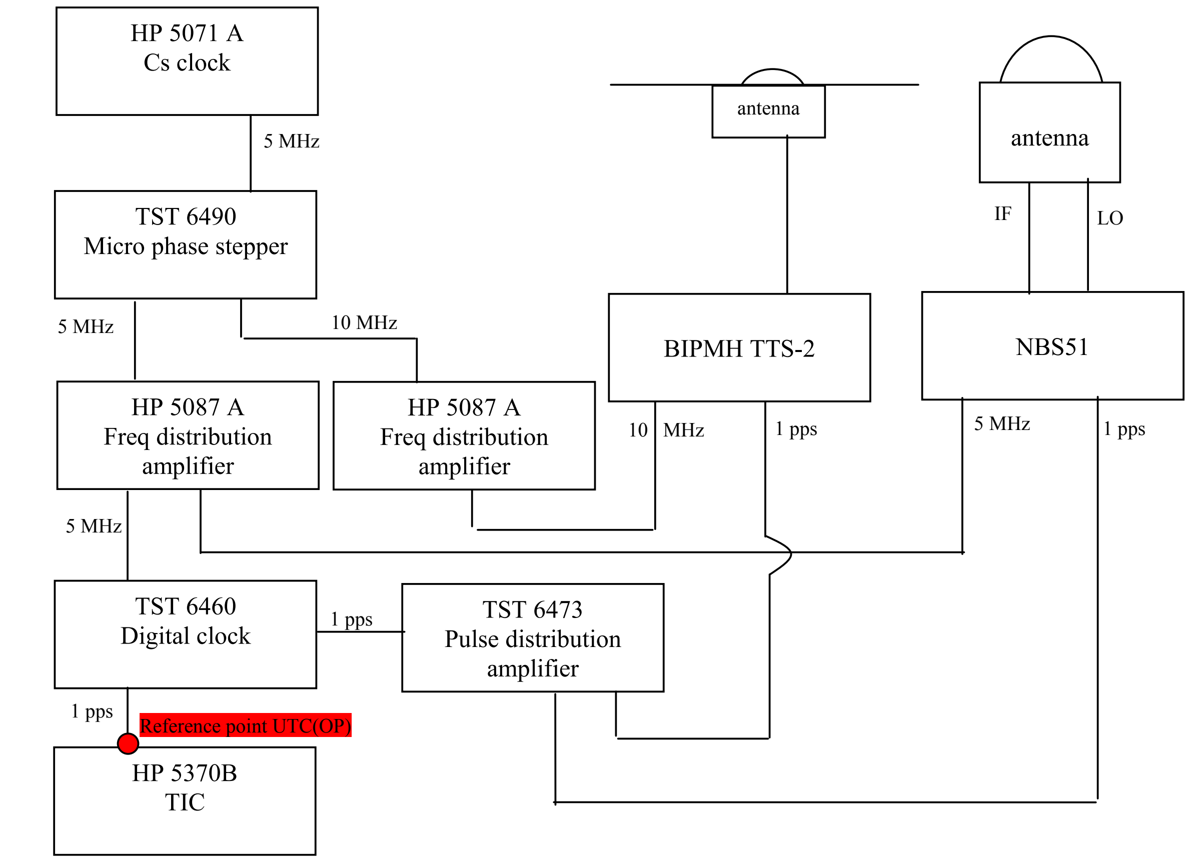
• Rise time of the local UTC pulse:	4 ns
• If the laboratory air conditioned:	Yes
- temperature value and its stability :	(21,5 +/- 2) °C
- humidity value and its stability :	-

Cable delay control

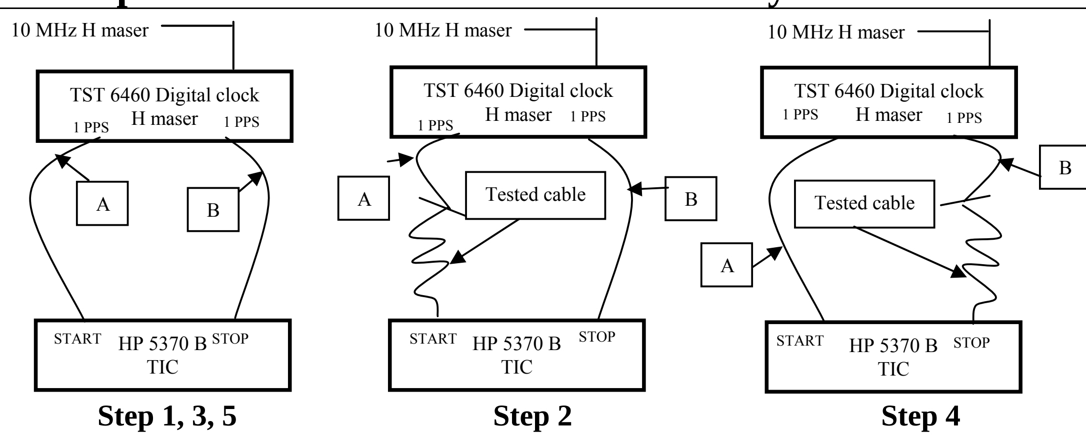
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187,75 ns ± 0,4 ns	187,23 ns ± 0,3 ns

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:



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 result (R_i)of 100 measurments.
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 adaptators : - 0,1 ns / adaptator

Appendix II

Measurement of portable cables at the visited laboratories

Laboratory	**BIPM C123 cable /ns**	**Measurement method**
BIPM	187.75 ns ± 0.4	Double Weight Pulse method
OP	187.23 ns ± 0.3	Double Weight Pulse method
AOS	186.33 ns ± 0.4	Pulse method
GUM	-	-
LT	-	-
TP	186.4 ns ± 1.5	Reflection method
BEV	-	-
OMH	187.06 ns ± 0.32	Pulse method
NIMB	-	-
NMC	187.1 ns ± 0.6	Pulse method
ZMDM	186.58 ns ± 0.4	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	53982	5.21	2.62	0.59	20
	53983	3.78	3.47	0.56	38
	53984	2.48	3.28	0.51	42
	53985	3.70	3.15	0.49	41
	53986	4.31	3.50	0.57	38
	53987	4.58	3.24	0.50	42
	53988	4.39	2.99	0.46	43
	53989	3.28	2.27	0.46	24
AOS	53998	3.83	1.93	0.21	81
	53999	3.35	2.06	0.10	429
	54000	3.59	1.94	0.08	568
	54001	3.51	1.94	0.08	589
	54002	3.60	1.95	0.08	588
	54003	2.37	2.39	0.10	560
	54004	1.64	1.99	0.08	579
	54005	1.64	1.77	0.07	573
	54006	1.59	1.73	0.10	288
GUM	54010	-2.46	3.08	0.17	336
	54011	-0.01	2.75	0.11	594
	54012	0.57	2.62	0.11	614
	54013	1.33	2.71	0.11	608
	54014	2.07	2.95	0.20	215
LT	54018	7.28	3.93	0.43	83
	54019	8.63	3.83	0.35	120
	54020	8.87	3.36	0.35	91
	54021	7.96	3.43	0.46	56
	54022	8.91	3.34	0.23	210
	54023	8.39	3.27	0.18	339
	54024	8.16	3.54	0.39	83
TP	54026	-13.41	1.79	0.10	291
	54027	-12.77	1.74	0.08	444
	54028	-11.15	1.24	0.06	448
	54029	-10.97	1.25	0.06	453
	54030	-11.47	1.46	0.07	453
	54031	-11.19	1.07	0.09	129
BEV	54033	1.23	3.93	0.28	204
	54034	1.59	4.26	0.17	606
	54035	2.67	4.25	0.18	573
	54036	3.09	4.11	0.17	592
	54037	2.06	4.33	0.18	593
	54038	1.76	4.38	0.18	609
	54039	1.03	4.25	0.26	258

LAB	MJD	Mean offset /ns	Standard deviation of individual common view observations /ns	Standard deviation of the mean /ns	Number of individual common views
OMH	54042	57.91	2.19	0.77	8
	54043	59.20	2.48	0.55	20
	54044	58.49	2.76	0.60	21
	54045	57.04	2.39	0.52	21
	54046	58.05	1.94	0.43	20
	54047	58.26	2.72	0.58	22
	54048	59.58	1.62	0.47	12
NIMB	54055	-59.42	2.74	0.16	308
	54056	-58.40	2.71	0.11	619
	54057	-57.91	2.32	0.09	615
	54058	-57.58	2.29	0.09	616
	54059	-57.40	2.31	0.09	629
	54060	-57.85	2.21	0.18	159
NMC	54063	288.04	1.86	0.45	17
	54064	287.18	2.55	0.53	23
	54065	287.96	1.98	0.36	30
	54066	287.48	2.35	0.47	25
	54067	287.04	2.56	0.49	27
	54068	286.98	2.48	0.51	24
	54069	287.78	2.69	0.52	27
	54070	287.25	3.48	1.10	10
ZMDM	54080	-5.19	2.85	0.12	608
	54081	-3.82	3.22	0.13	601
	54082	-4.07	2.80	0.11	601
	54083	-3.46	2.89	0.20	208
OP	54117	0.75	2.42	0.59	17
	54118	2.60	2.80	0.43	42
	54119	4.69	2.69	0.41	43
	54120	4.40	2.46	0.38	43
	54121	4.37	1.98	0.30	42
	54122	3.60	2.46	0.37	44
	54123	2.38	3.29	0.49	46
	54124	4.24	2.71	0.41	44
	54125	4.51	2.75	0.73	14