Rapport BIPM-2008/04

BUREAU INTERNATIONAL DES POIDS ET MESURES

DETERMINATION OF THE DIFFERENTIAL TIME CORRECTIONS FOR GPS TIME EQUIPMENT LOCATED AT THE OP, CNM, NIST, USNO and NRC

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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 13 August 2005 to 21 April 2006, involving GPS time equipment located at the Observatoire de Paris (OP, Paris, France), the Centro Nacional de Metrologia (CNM, Querétaro, Mexico), the National Institute of Standards and Technology (NIST, Boulder, USA), the U.S. Naval Observatory (USNO, Washington D.C., USA) and the National Research Council of Canada (NRC, Ottawa, Canada).

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 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 in the past.

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 13 August 2005 to 21 April 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
CNM	AOA	TTR-6	448
NIST	NIST	TTR-5	NBS10
USNO	AOS	TTS-2	014
NRC	Collins	NBS/GPS-2	0023
BIPM portable receiver	AOS	TTS-2	036

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

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

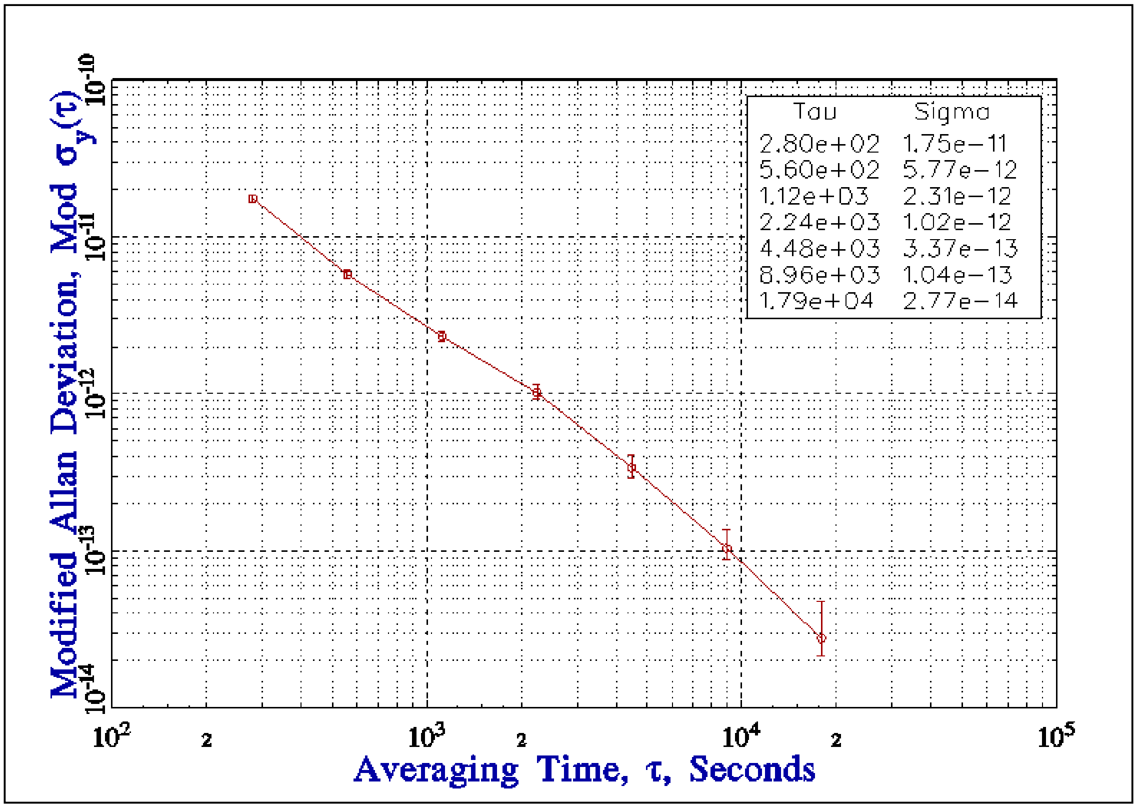

Figure 1. Square root of the modified Allan variance of the time series dt_{OP} for the period: 14 April 2006 to 21 April 2006.

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

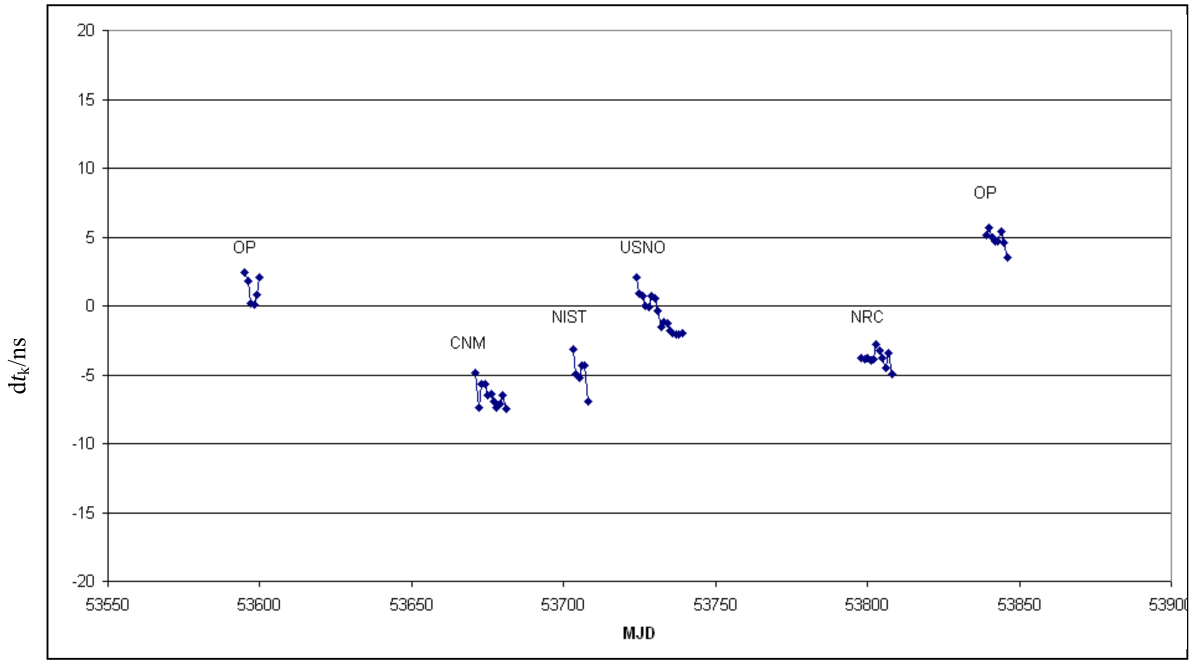

Figure 2. Daily averages of $dt_{k,i}$ for each laboratory *k* (see Appendix III).

Next, we computed mean offsets for the full duration of 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	13/08 - 18/08/05	406	2.62	3.07	0.4	2.08
CNM	28/10 - 07/11/05	276	–6.62	2.25	0.3	0.85
NIST	29/11 - 04/12/05	215	–4.92	3.15	0.6	1.25
USNO	20/12/05 - 04/01/06	7227	–0.66	2.53	0.3	1.32
NRC	4/03 - 14/03/06	299	–3.83	3.08	0.4	0.57
OP	14/04 - 21/04/06	323	4.97	2.93	0.3	0.65

The "closure" – the difference between the first and last sets of measurements made at the OP – was within a few nanoseconds, 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*(CNM)-*UTC*(OP)]	–10.4	3.0
[*UTC*(NIST)-*UTC*(OP)]	–8.7	3.0
[*UTC*(USNO)-*UTC*(OP)]	–4.5	3.0
[*UTC*(NRC)-*UTC*(OP)]	–7.6	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 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]
December 2005	–8.7*	3.0	[12]

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 with a good closure of travelling equipment at the OP.

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 difference between them have never exceeded a few nanoseconds in the past. However, this time it exceeded –8 ns, and requires appropriate checking of involved equipment (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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[6] BIPM Letter of 15 June 1988, BG/9G.69.
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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.*
[12] This Report.

Appendix I

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:	9 August 2005 (53591)
Date and hour of the end of measurements:	18 August 2005 (53600)

Receiver setup information

	Local: NBS51	Portable: BP0N
• Maker:	Allen Osborne Associates	BIPM
• Type:	TTR-5	TTS-2
• Serial number:	051	S/N 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		
• Set temperature value :	-	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

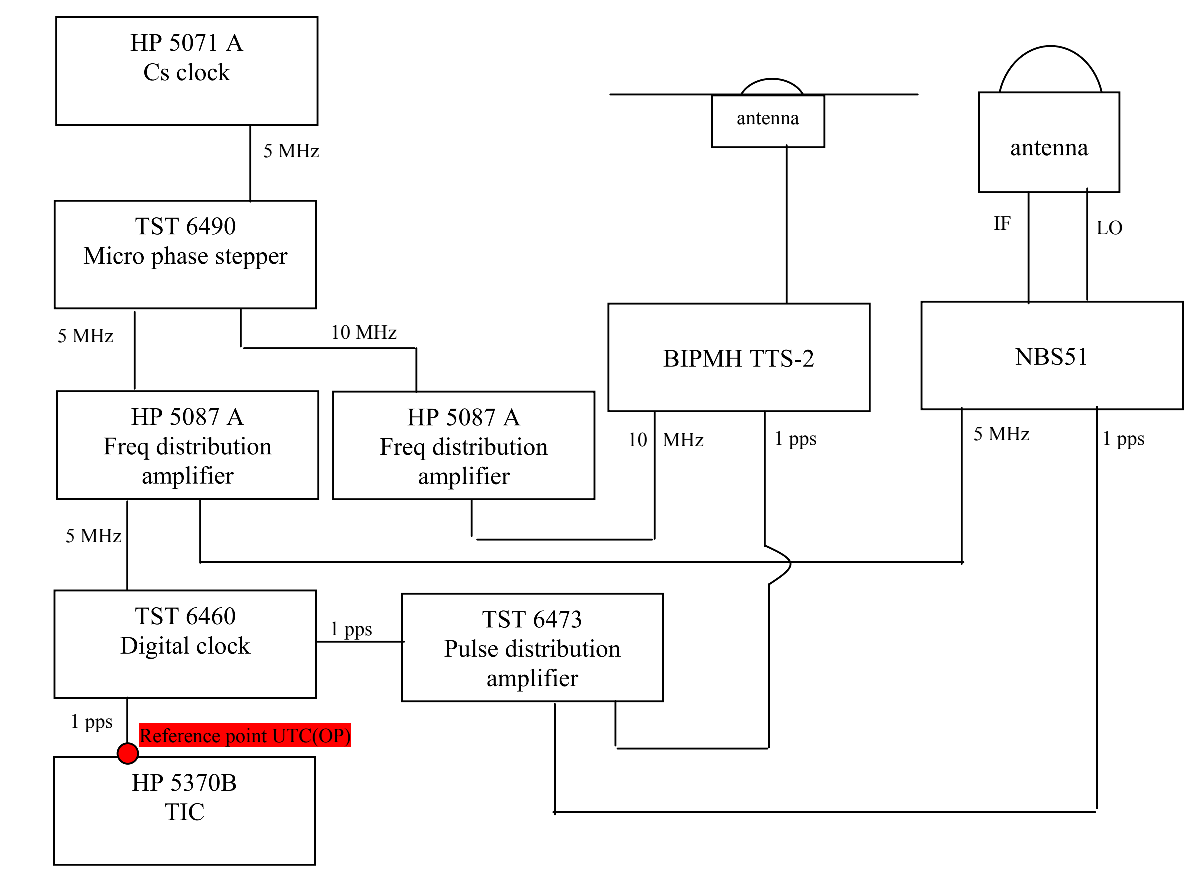
• Rise time of the local UTC pulse:	4 ns
• Is the laboratory air conditioned:	Yes
• Set temperature value and uncertainty :	(21.5 +/- 2) °C
• Set humidity value and uncertainty :	-

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:

BIPM GPS calibration information sheet

Laboratory:	**Centro Nacional de Metrología**
Date and hour of the beginning of measurements:	28/Oct/2005 (MJD 53671) 17h34m UTC
Date and hour of the end of measurements:	7/Nov/2005 (MJD 53681) 16h54m UTC

Receiver setup information

	Local:	**Portable: BP0N**
• Maker:	**ALLEN OSBORNE ASSOCIATES**	EMDE Electronics
• Type:	**TTR-6**	TTS-2
• Serial number:	**448**	S/N 036
• Receiver internal delay (GPS) :	**52 ns**	8.0
• Receiver internal delay (GLO) :	**-**	-
• Antenna cable identification:	**Coaxial RG 58A/U AWM 1354**	C128
Corresponding cable delay :	**235 ns**	187.75 ns ± 0.4 ns
• Delay to local UTC :	**8 ns ± 0.5 ns**	**12. 8 ns**
• Receiver trigger level:	**--**	0.5 V
• Coordinates reference frame:	**ITRF**	**ITRF**
Latitude or X m	**-1064065.42**	**-1064065.22**
Longitude or Y m	**-5881557.19**	**-5881557.04**
Height or Z m	**+2224142.96**	**+2224142.59**

Antenna information

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

Local antenna cable information

• Maker:	**---**
• Type:	**Coaxial RG 58A/U AWM 1354**
• Is it a phase stabilised cable:	**No**
• Length of cable outside the building :	**~ 19 m**

General information

• Rise time of the local UTC pulse:	**5 ns ± 0.5 ns**
• Is the laboratory air conditioned:	**Yes**
• Set temperature value and uncertainty :	**(22 ± 1) ºC**
• Set humidity value and uncertainty :	**(58 ± 10)%**

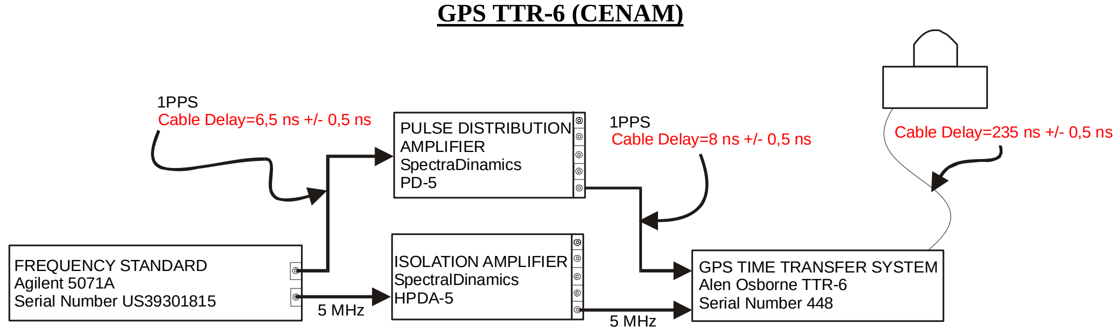
Cable delay control

Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187.75 ns ± 0.4 ns	**187.5 ns ± 0.5 ns**

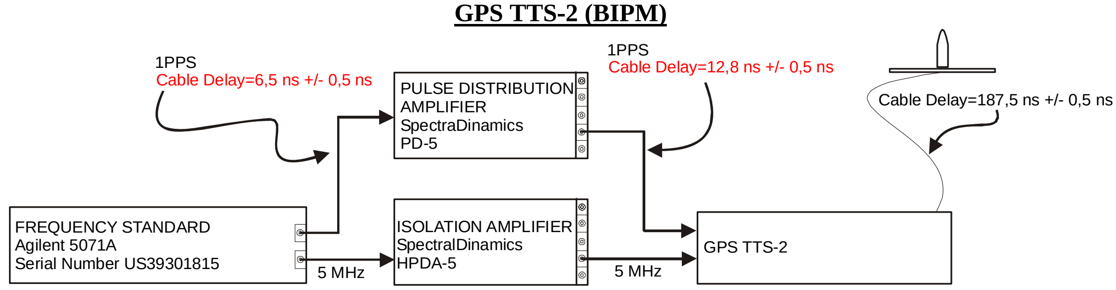
Plot of the experiment set-up:

Link to the local UTC of both receivers and Antenna positions

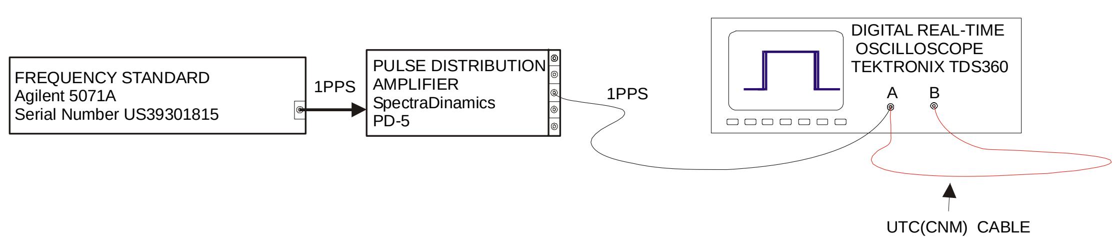
GPS TTR-6 (CENAM)



GPS TTS-2 (BIPM)



Description of the local method of cable delay measurement:



BIPM GPS calibration information sheet

Laboratory:	NIST
Date and hour of the beginning of measurements:	**November 29, 2005 (MJD 53703) 22:50:00**
Date and hour of the end of measurements:	**December 7, 2005 (MJD 53711) 14:54:00**

Receiver setup information

	Local:	**Portable: BP0N**
• Maker:	NIST	EMDE Electronics
• Type:	NBS (TTR-5)	TTS-2
• Serial number:	NBS10	S/N 036
• Receiver internal delay (GPS) :	53.0ns	8.0
• Receiver internal delay (GLO) :	N/A	-
• Antenna cable identification:	None	C128
Corresponding cable delay :	199.9ns	187.75 ns ± 0.4 ns
• UTC cable identification:	None	None
Corresponding cable delay :	66.7ns	678.9ns
Delay to local UTC :	0ns	0ns
• Receiver trigger level:	0.5V	0.5 V
• Coordinates reference frame:	WGS84	ITRF
Latitude or X m	-1288398.40 m	-1288332.08 m
Longitude or Y m	-4721697.47 m	-4721663.43 m
Height or Z m	+4078625.85 m	+4078680.34 m

Antenna information

	Local:	**Portable:**
• Maker:	NIST	Motorola
• Type:	GPS	GPS
• Serial number:	NBS10	AN16N00210
If the antenna is temperature stabilised		
• Set temperature value :	N/A	-

Local antenna cable information

• Maker:	Andrew
• Type:	FSJ1-50A
• Is it a phase stabilised cable:	YES
• Length of cable outside the building :	~30m

General information

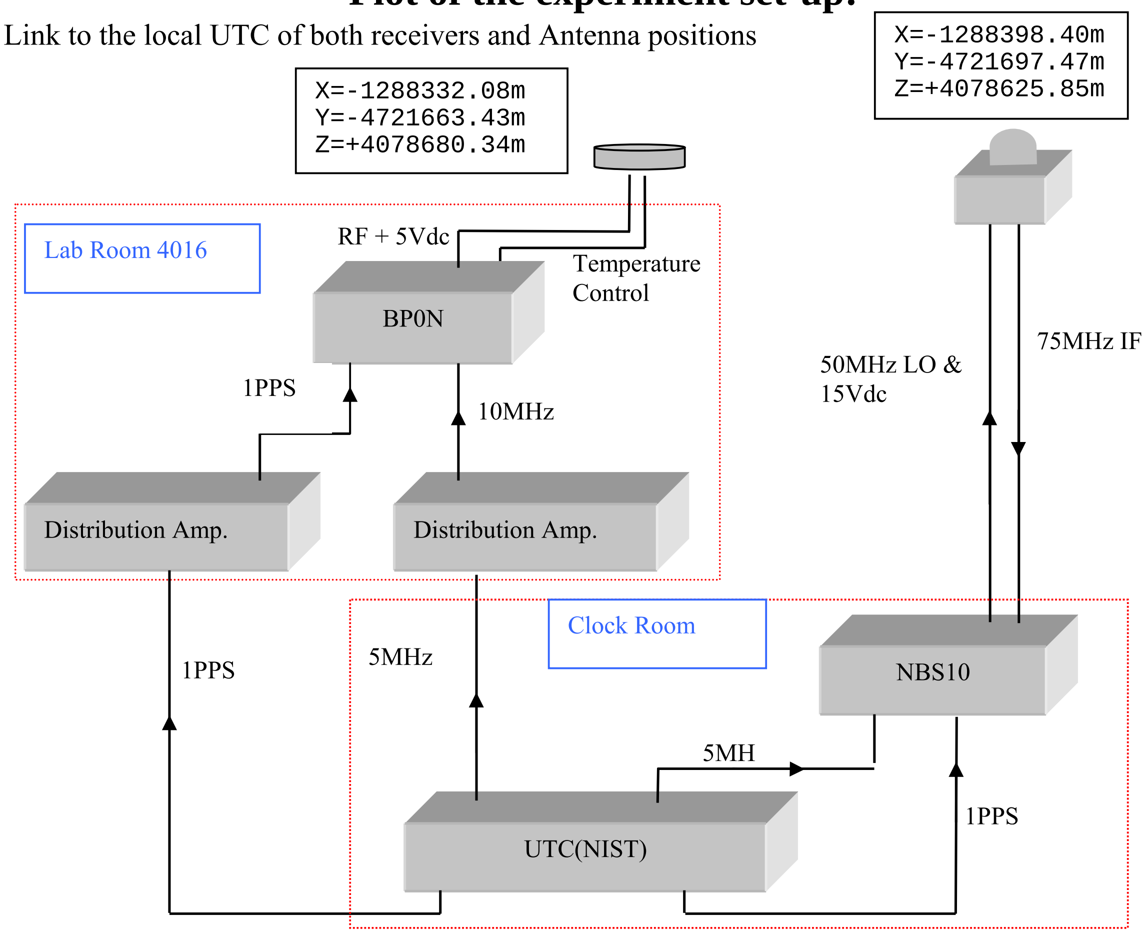
• Rise time of the local UTC pulse:	~1.5 ns (from 0Vdc to 0.5Vdc)
• Is the laboratory air conditioned:	YES
• Set temperature value and uncertainty :	Local: 23±1°C, Portable: 20±2°c
• Set humidity value and uncertainty :	9% to 32%

Cable delay control

Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187.75 ns ± 0.4 ns	186.6ns ±0.2ns (loss = 10.7dB)

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:

Measure the cable’s group delay at 1575.42MHz ± 10MHz with a HP network analyzer.

BIPM GPS calibration information sheet

Laboratory:	USNO
Date and hour of the beginning of measurements:	20 December 2005 (MJD 53724) 1500 UT
Date and hour of the end of measurements:	04 January 2006 (MJD 53739) 1153UT

Receiver setup information

	Local: MOT1	**Portable: BP0N**
• Maker:	AOS SRC	EMDE Electronics
• Type:	TTS-2	TTS-2
• Serial number:	S/N 014	S/N 036
• Receiver internal delay (GPS) :	-55.1	8.0
• Receiver internal delay (GLO) :	N/A	-
• Antenna cable identification:	SPS	C128
Corresponding cable delay :	172.06	187.75 ns ± 0.4 ns
• Delay to local UTC :	0.0 ns	0.0 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	ITRF	ITRF
Latitude or X m	+1112161.100	+1112166.543
Longitude or Y m	-4842855.428	-4842851.812
Height or Z m	+3985494.354	+3985493.910

Antenna information

	Local:	**Portable:**
• Maker:	3S Navigation	Motorola
• Type:	TSA 100	GPS
• Serial number:	12	AN16N00210
If the antenna is temperature stabilised		
• Set temperature value :	105F	60 °C

Local antenna cable information

• Maker:	Andrews
• Type:	FSJ1-50A
• Is it a phase stabilised cable:	Yes
• Length of cable outside the building :	6 meters

General information

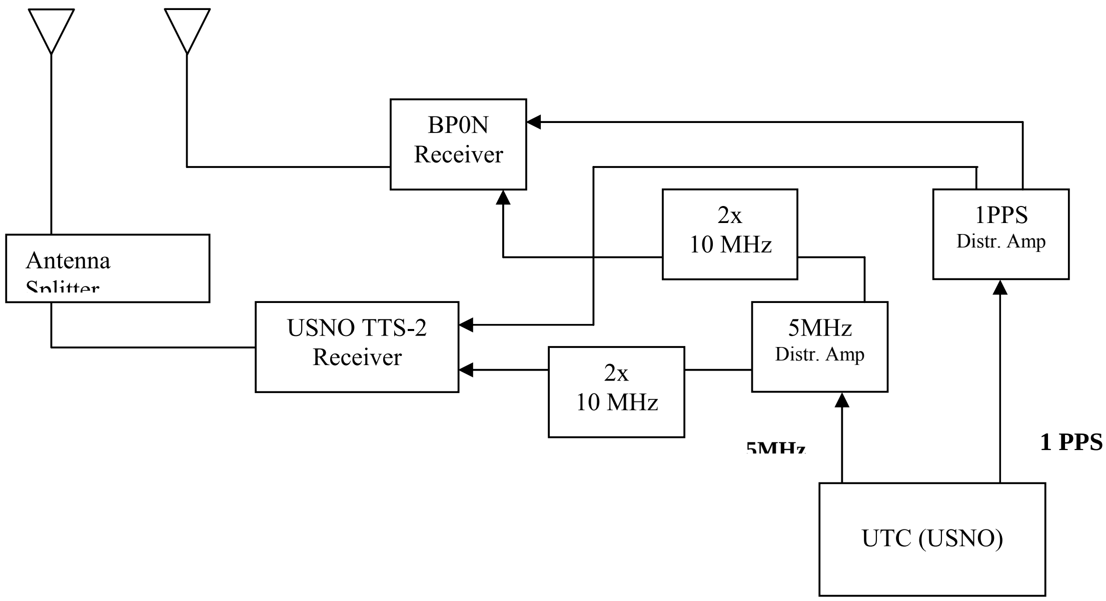
• Rise time of the local UTC pulse:	4.1 ns
• Is the laboratory air conditioned:	Yes
• Set temperature value and uncertainty :	23.5C, +/-0.5C
• Set humidity value and uncertainty :	13% to 36%

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:

BIPM GPS calibration information sheet

Laboratory:	NRC NRCC8
Date and hour of the beginning of measurements:	MJD 53790 17:50 UTC
Date and hour of the end of measurements:	MJD 53797 14:23 UTC

Receiver setup information

	Local:	**Portable: BP0N**
• Maker:	Collins	EMDE Electronics
• Type:	NBS/GPS-2	TTS-2
• Serial number:	0023	S/N 036
• Receiver internal delay (GPS) :	57.8 nS	8.0
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	-	C128
Corresponding cable delay :	226.728 nS	187.75 ns ± 0.4 ns
• Delay to local UTC :	26.219 nS	24.4 nS
• Receiver trigger level:	-	0.5 V
• Coordinates reference frame:		ITRF88
Latitude or X m	+1112782.135	1112779.805
Longitude or Y m	-4341476.882	-4341477.976
Height or Z m	+4522953.436	4522953.392

Antenna information

	Local:	**Portable:**
• Maker:	NBS	Motorola
• Type:		GPS
• Serial number:	0157	AN16N00210
If the antenna is temperature stabilised		
• Set temperature value :	-	60 °C

Local antenna cable information

• Maker:	
• Type:	RG58
• Is it a phase stabilised cable:	NO
• Length of cable outside the building :	13 Meters

General information

• Rise time of the local UTC pulse:	3.8 nS ± 0.1 nS
• Is the laboratory air conditioned:	YES
• Set temperature value and uncertainty :	21.9ºC ± 0.5º
• Set humidity value and uncertainty :	26% ± 2%

Cable delay control

Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C128	187.75 ns ± 0.4 ns	186.9 nS ±0.5 nS

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	-	-
CNM	187.5 ns ± 0.5	Oscilloscope
NIST	186.6 ns ± 0.2	Network Analyzer
USNO	-	-
NRC	186.9 ns ± 0.5	Reflection 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	53595	2.44	2.18	0.32	47
	53596	1.77	2.49	0.37	46
	53597	0.22	1.95	0.29	45
	53598	0.11	2.48	0.37	44
	53599	0.79	2.33	0.35	44
	53600	2.09	1.95	0.42	21
CNM	53671	-4.85	1.51	0.62	2
	53672	-7.38	1.96	0.36	29
	53673	-5.68	2.45	0.44	31
	53674	-5.67	2.30	0.43	29
	53675	-6.52	2.32	0.46	26
	53676	-6.43	1.77	0.32	31
	53677	-6.94	2.44	0.44	31
	53678	-7.42	2.32	0.47	24
	53679	-7.14	2.05	0.45	21
	53680	-6.45	2.23	0.45	25
	53681	-7.46	1.84	0.38	23
NIST	53703	-3.15	2.76	1.95	2
	53704	-4.98	3.05	0.44	49
	53705	-5.24	4.01	0.58	47
	53706	-4.31	2.93	0.44	45
	53707	-4.29	2.56	0.37	48
	53708	-6.9	2.24	0.46	24
USNO	53724	2.11	2.16	0.17	162
	53725	0.89	2.17	0.10	506
	53726	0.70	2.44	0.12	397
	53727	0.01	2.29	0.10	505
	53728	-0.13	2.23	0.10	509
	53729	0.69	2.32	0.10	523
	53730	0.51	2.24	0.10	494
	53731	-0.37	2.39	0.11	498
	53732	-1.57	2.15	0.09	525
	53733	-1.17	2.29	0.11	451
	53724	-1.26	2.16	0.10	512
	53735	-1.80	2.17	0.10	497
	53736	-2.00	2.27	0.10	495
	53737	-2.05	2.25	0.10	488
	53738	-2.07	2.02	0.10	420
	53739	-1.94	2.39	0.15	245

LAB	MJD	Mean offset /ns	Standard deviation of individual common view observations /ns	Standard deviation of the mean /ns	Number of individual common views
NRC	53798	-3.81	2.87	0.54	28
	53799	-3.85	3.37	0.64	28
	53800	-3.76	3.43	0.62	31
	53801	-3.99	3.33	0.64	27
	53802	-3.83	3.05	0.61	25
	53803	-2.83	2.97	0.56	28
	53804	-3.28	3.13	0.61	26
	53805	-3.82	2.69	0.55	24
	53806	-4.48	3.02	0.57	28
	53807	-3.39	2.73	0.57	23
	53808	-4.98	3.05	0.55	31
OP	53839	5.16	2.72	0.49	31
	53840	5.71	3.62	0.54	45
	53841	5.00	2.90	0.43	46
	53842	4.70	2.64	0.39	46
	53843	4.72	2.74	0.40	46
	53844	5.39	3.35	0.49	46
	53845	4.62	2.47	0.36	47
	53846	3.54	2.23	0.56	16