Rapport BIPM-2004/06

BUREAU INTERNATIONAL DES POIDS ET MESURES

DETERMINATION OF THE DIFFERENTIAL TIME CORRECTIONS FOR GPS TIME EQUIPMENT LOCATED AT THE OP, PTB, AOS, KRISS, CRL, NIST, USNO and APL

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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 2003 to 11 February 2004, involving GPS time equipment located at the Observatoire de Paris (OP, Paris, France), the Physikalisch-Technische Bundesanstalt (PTB, Braunschweig, Germany), the Astrogeodynamical Observatory Space Research Centre P.A.S. (AOS, Borowiec, Poland), the Korea Research Institute of Standards and Science (KRIS, Daejeon, Rep. Of Korea), the Communications Research Laboratory (CRL, Tokyo, Japan), the National Institute of Standards and Technology (NIST, Boulder, USA), the U.S. Naval Observatory (USNO, Washington D.C., USA) and the Applied Physics Laboratory (APL, Laurel, Mass., USA).

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. It has 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.

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;
- serve as provisional differential calibrations of the two-way equipment at the laboratories.

This report details an exercise which took place from 13 August 2003 to 11 February 2004. 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
PTB	AOA	TTR-5A	156
AOS	AOS	TTS-2	023
KRIS	CSIRO NML	Topcon Euro-80 L1/L2	023C10474
CRL	JAVAD	Euro-80	8PN45EETDKW
NIST	NIST	TTR-5	NBS10
USNO	AOS SRC	TTS-2	014
APL	TFS-NPL	GPSCV	TFS112
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:

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

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.

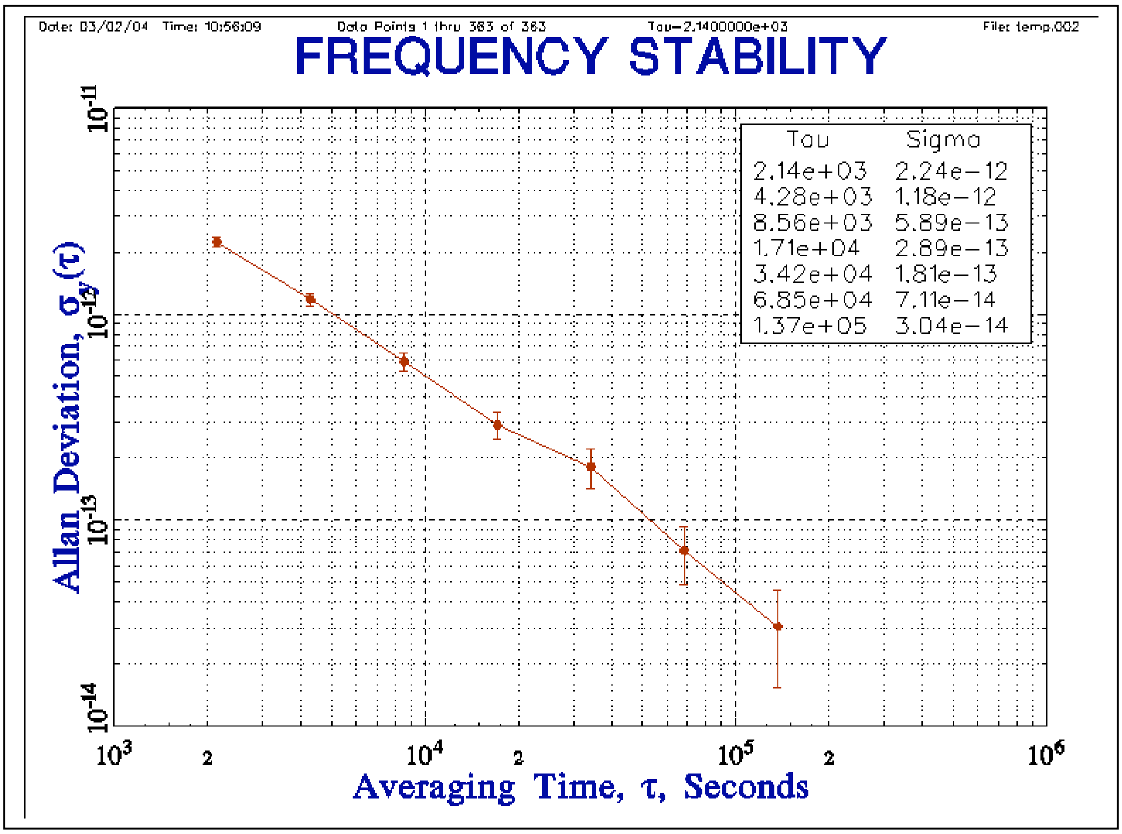


Figure 1. Square root of the modified Allan variance of the time series dt_{OP} for the period: 02 February 2004 to 11 February 2004.

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

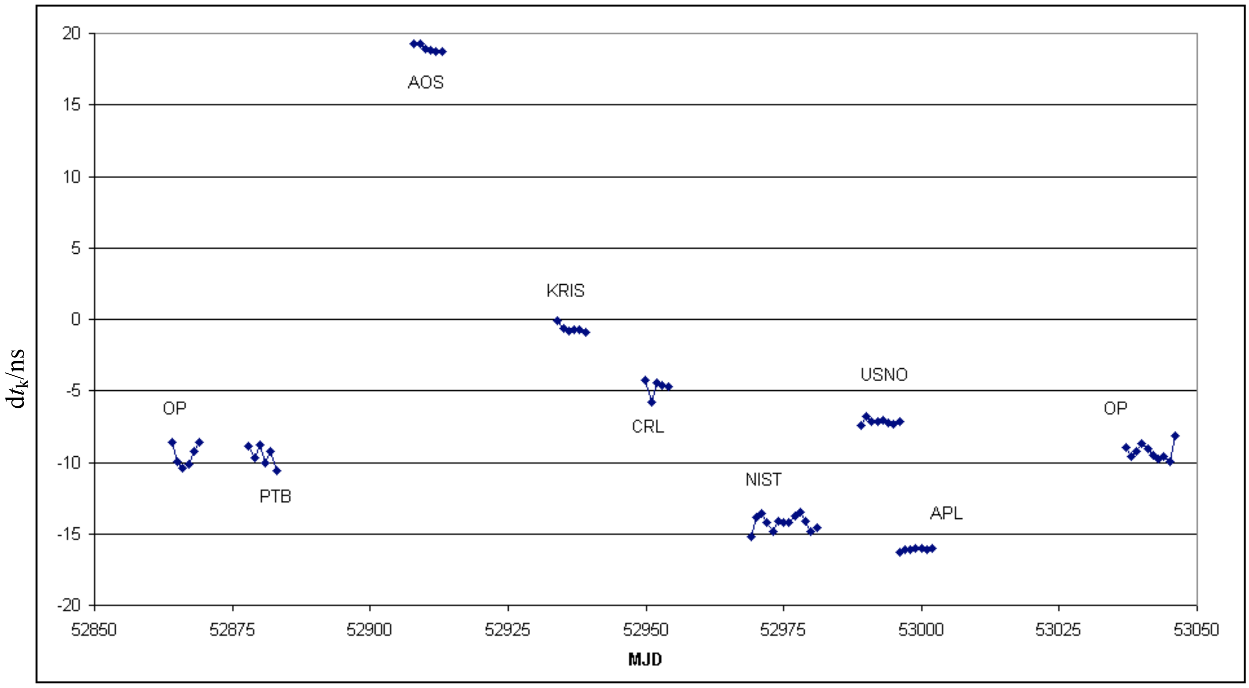


Figure 2. Daily averages of $dt_{k,i}$ for each laboratory k (see Appendix III).

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 -18/08/03	197	-9.70	3.69	0.4	0.79
PTB	27/08 - 01/09/03	199	-9.42	3.13	0.6	0.71
AOS	26/09 - 01/10/03	2108	18.93	1.82	0.2	0.24
KRIS	22/10 - 28/10/03	1641	-0.69	2.37	0.1	0.29
CRL	07/11 - 11/11/03	1149	-4.77	3.37	0.5	0.59
NIST	26/11 - 08/12/03	541	-14.16	3.18	0.3	0.51
USNO	16/12 - 23/12/03	3675	-7.12	2.63	0.1	0.18
APL*	23/12 - 29/12/03	3048	-16.07	0.61	0.4	0.11
OP	02/02 - 11/02/04	363	-9.35	2.81	0.3	0.55

*Note: At the APL local and visiting receivers were connected to the same antenna.

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*(PTB)-*UTC*(OP)]	+0.1	3.0
[*UTC*(AOS)-*UTC*(OP)]	+28.5	3.0
[*UTC*(KRIS)-*UTC*(OP)]	+8.8	3.0
[*UTC*(CRL)-*UTC*(OP)]	+4.8	3.0
[*UTC*(NIST)-*UTC*(OP)]	-4.6	3.0
[*UTC*(USNO)-*UTC*(OP)]	+2.4	3.0
[*UTC*(APL)-*UTC*(OP)]	-6.5	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]

NBS03 receiver at NIST
* NBS10 receiver at NIST

CONCLUSION

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

The present measurements were performed under good conditions with a very good closure of travelling equipment at the OP. The GPS time equipment of most of participating laboratories agrees within a few nanoseconds with reference equipment at the NIST and the OP. At the AOS the offset is large, but this was already well known before.

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).

The next trip involving the some of visited laboratories is scheduled for 2004.

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

[1] G. de Jong, "Measuring the propagation time of coaxial cables used with GPS receivers," *Proc. 17th PTTI,* pp. 223-232, December 1985.
[2] D. Allan, D. Davis, M.A. Weiss, Personal communication, 1983.
[3] J. Buisson, Personal communication, 1985.
[4] W. Lewandowski, M. A. Weiss, "A Calibration of GPS Equipment at Time and Frequency Standards Laboratories in the USA and Europe", *Metrologia,* **24**, pp. 181-186, 1987.
[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", *BIPM Report -2002/02*, July 2002.
[10] M.A. Weiss, "Calibration of OP Receiver AOA51 Against NIST Receiver NBS10" July 2003.
[11] 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:	BNM – SYRTE, Observatoire de Paris
Date and hour of the beginning of measurements:	13 August 2003
Date and hour of the end of measurements:	18 August 2003

Receiver setup information

	Local: NBS 51	Portable: BIPM K
• Maker:	Allen Osborne Associates	AOS
• Type:	TTR-5	TTS-2
• Serial number:	051	S/N 028
• Receiver internal delay (GPS) :	54 ns	0.0 (not calibrated)
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	505 IF	C123
Corresponding cable delay :	168 ns ± 0,3 ns	178,78 ns ± 0,4 ns
• UTC cable identification:	503	497
Corresponding cable delay :	-	-
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	4 778 657,38 m

Antenna information

	Local:	Portable:
• Maker:	A.O.A.	ITR TSA-2
• Type:	-	GPS
• Serial number:	-	3-072002
If the antenna is temperature stabilised		
• Set temperature value :	-	-

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

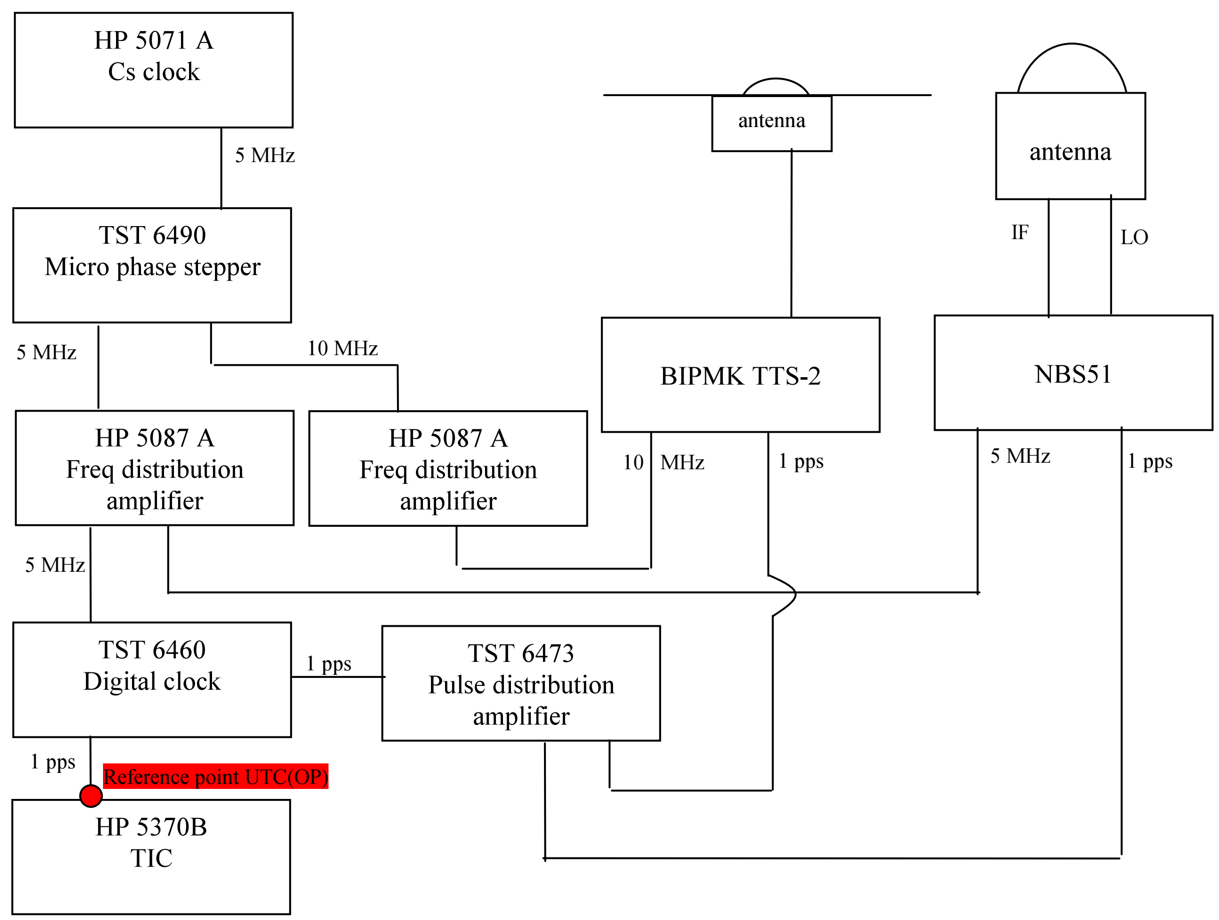
• Rise time of the local UTC pulse:	4 ns
• Is the laboratory air conditioned:	Yes
• Set temperature value and uncertainty :	(21,5 ± 2) °C
• Set humidity value and uncertainty :	/

Cable delay control

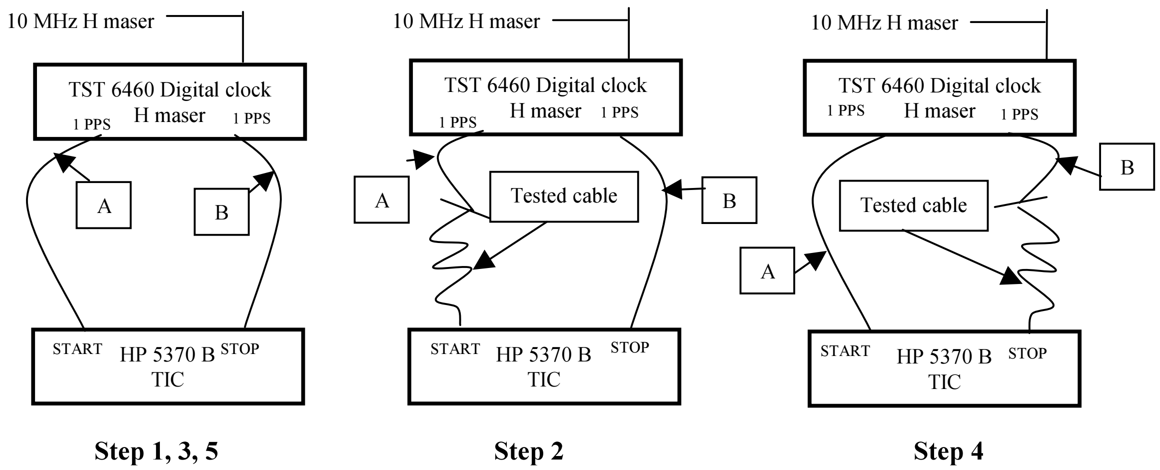
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178,78 ns ± 0,4 ns	179,9 ns ± 0,3 ns

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:	PTB
Date and hour of the beginning of measurements:	2003-08-27 06:34 UTC
Date and hour of the end of measurements:	2003-09-01 06:30 UTC

Receiver setup information

	Local:	Portable: BIPM K
• Maker:	AOA	AOS
• Type:	TTR-5A	TTS-2
• Serial number:	S/N 0156	S/N 028
• Receiver internal delay (GPS) :	58.0 ns	0.0 (not calibrated)
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	-	C123
Corresponding cable delay :	215 ns (entered (215+23) ns)	178.78 ns ± 0.4 ns
• UTC cable identification:	-	
Corresponding cable delay :	-	
Delay to local UTC :	-23 ns (entered 0 ns)	96.7 ns ± 0.2 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	ITRF	ITRF
Latitude or X m	+3844066.36 m	+3844064.47 m
Longitude or Y m	+709657.18 m	+709657.61 m
Height or Z m	+5023125.00 m	+5023126.50 m

Antenna information

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

Local antenna cable information

• Maker:	Air Dielectric Cables
• Type:	?
• Is it a phase stabilised cable:	no
• Length of cable outside the building :	about 30 m

General information

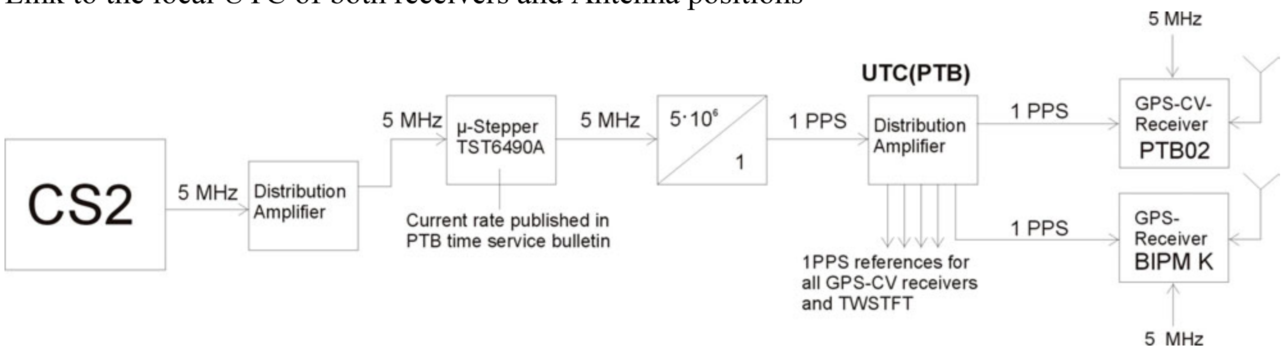
• Rise time of the local UTC pulse:	5 ns
• Is the laboratory air conditioned:	yes
• Set temperature value and uncertainty :	(23 ± 1) °C
• Set humidity value and uncertainty :	max. 50 % RF

Cable delay control

Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178.78 ns ± 0.4 ns	178.5 ns ± 0.2 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:

1. Pulse method: Cable under test in Stop-Input of the Time-Interval-Counter.

BIPM GPS calibration information sheet

Laboratory:	AOS
Date and hour of the beginning of measurements:	**26.09.2003 (MJD: 52908), 20:18 UTC**
Date and hour of the end of measurements:	**01.10.2003 (MJD: 52913), 00:12 UTC**

Receiver setup information		
	Local:	**Portable: BIPM K**
• Maker:	AOS	AOS
• Type:	TTS-2	TTS-2
• Serial number:	S/N 023	S/N 028
• Receiver internal delay (GPS) :	20.8 ns	0.0 (not calibrated)
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	A-001	C123
Corresponding cable delay :	149.3 ns ± 0.3 ns	178,78 ns ± 0,4 ns
• UTC cable identification:	T-014	T-028
Corresponding cable delay :	20.4 ns ± 0.3 ns	20.2 ns ± 0.3 ns
Delay to local UTC :	20.4 ns	20.3 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	ITRF 88	ITRF 88
Latitude or X m	3738369.22 m	3738369.26 m
Longitude or Y m	1148164.25 m	1148161.57 m
Height or Z m	5021810.46 m	5021810.81 m

Antenna information		
	Local:	**Portable:**
• Maker:	3S Navigation	ITR TSA-2
• Type:	TSA-100	GPS
• Serial number:	0016	3-072002
If the antenna is temperature stabilised		
• Set temperature value :	40.5°C (105°F)	60°C

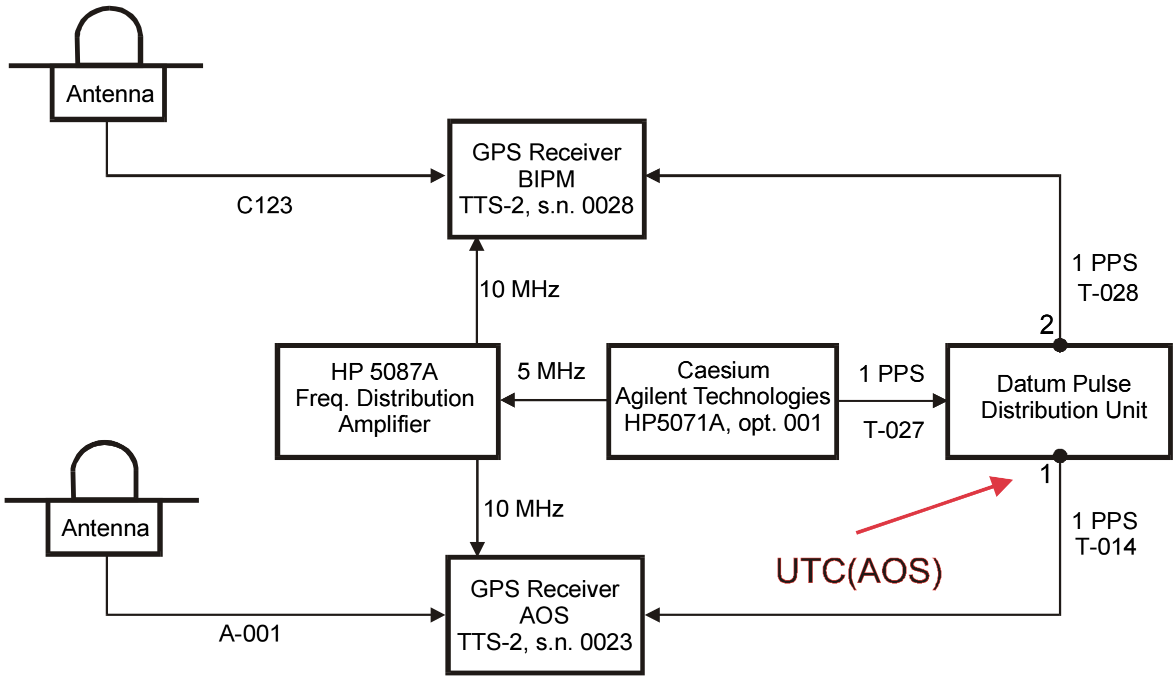
Local antenna cable information	
• Maker:	Belden
• Type:	9273, MIL-C-17G
• Is it a phase stabilised cable:	?
• Length of cable outside the building :	5 m

General information	
• Rise time of the local UTC pulse:	5 ns
• Is the laboratory air conditioned:	No
• Set temperature value and uncertainty :	-
• Set humidity value and uncertainty :	-

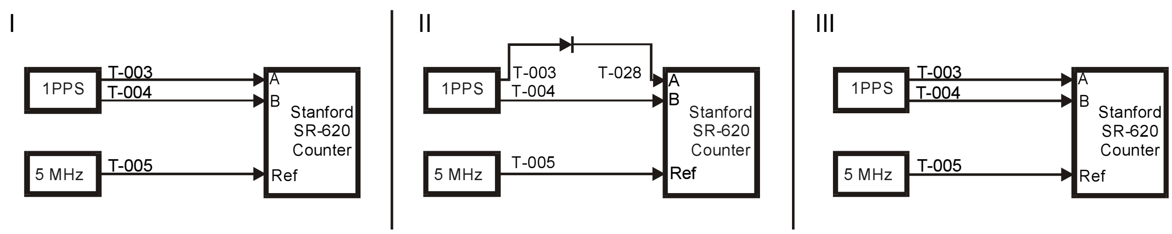
Cable delay control		
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178,78 ns ± 0,4 ns	178.5 ns ± 0,3 ns

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:



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 = 83.8 ns, Meas_II = 104.0 ns , Meas_III = 83.8 ns, Delay(T-028) = 20.2 ns

BIPM GPS calibration information sheet

Laboratory:	KRIS
Date and hour of the beginning of measurements:	MJD 52934, UTC 07h
Date and hour of the end of measurements:	MJD 52940, UTC 00h

Receiver setup information

	Local:	Portable: BIPM K
• Maker:	CSIRO NML	AOS
• Type:	Topcon Euro-80 L1/L2	TTS-2
• Serial number:	S/N 023C10474	S/N 028
• Receiver internal delay (GPS) :	45.3 ns	0.0 (not calibrated)
• Receiver internal delay (GLO) :		-
• Antenna cable identification:		C123
Corresponding cable delay :	114.8 ns	178,78 ns ± 0,4 ns
• UTC cable identification:		
Corresponding cable delay :		
Delay to local UTC :	22.4 ns	21.83 ns
• Receiver trigger level:		0.5 V
• Coordinates reference frame:		ITRF
Latitude or X m	- 3120132.700 m	36°23′18.105437″
Longitude or Y m	+4085468.179 m	127°22′10.277717″
Height or Z m	+3763043.611 m	123.791 m

Antenna information

	Local:	Portable:
• Maker:	CSIRO NML	ITR TSA-2
• Type:	Topcon Euro-80 L1/L2	GPS
• Serial number:		3-072002
If the antenna is temperature stabilised		
• Set temperature value :		-

Local antenna cable information

• Maker:	
• Type:	
• Is it a phase stabilised cable:	No
• Length of cable outside the building :	4 m

General information

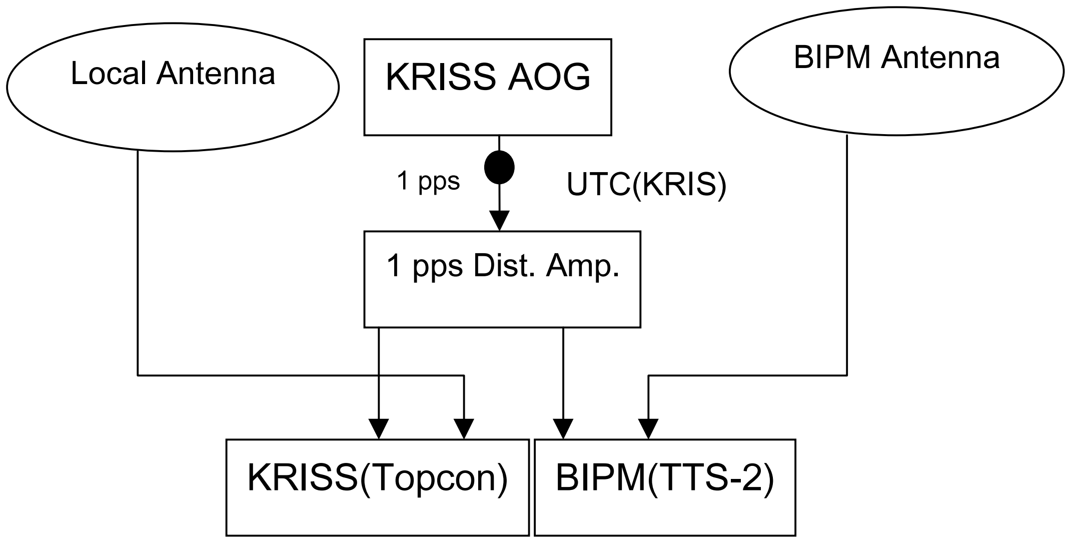
• Rise time of the local UTC pulse:	4 ns
• Is the laboratory air conditioned:	Yes
• Set temperature value and uncertainty :	23°C ± 1°C
• Set humidity value and uncertainty :	50% ± 5%

Cable delay control

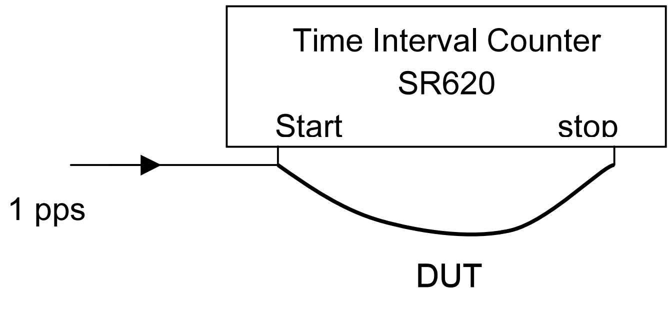
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178,78 ns ± 0,4 ns	179,36 ns ± 0,4 ns

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:	CRL TOKYO JAPAN
Date and hour of the beginning of measurements:	07 Nov. 2003 (MJD 52950) UTC:05hxxmxxs
Date and hour of the end of measurements:	11 Nov. 2003 (MJD 52954) UTC:06h00mxxs

Receiver setup information

		Local: TTR6	Local:R100	Local:E-80	Portable: BIPM K
• Maker:		AOA	3S Navigation	Javad	AOS
• Type:		TTR-6	R100 40T	Euro-80	TTS-2
• Serial number:		451	0017	8PN45EETDKW	S/N 028
• Receiver internal delay (GPS) :		44.8ns	333.0ns	47.2ns	0.0ns(not calibrated)
• Receiver internal delay (GLO) :		-	134.0ns	-	-
• Antenna cable identification:		TTR6(219.6ns)	R100a(204.0ns)	E80	C123
Corresponding cable delay :		250.0ns	204.0ns	152.15ns	178,78 ns ± 0,4 ns
• UTC cable identification:		GPS G	UTC(CRL)1pps D2	UTC(CRL)1pps C3	UTC(CRL)1pps C2
Corresponding cable delay :					
Delay to local UTC:	Header Value	316.1ns	415.5ns	344.123ns	324.230ns
	Meas. Value	306.43ns	326.39ns	344.123ns	306.36ns
• Receiver trigger level:		0.5V	0.5V	0.4V	0.5 V
• Coordinates reference frame:		WGS-84	WGS-84	WGS-84	WGS-84
Latitude or X m		-3942161.90m	-3942160.08m	-3942164.215m	-3942161.337m
Longitude or Y m		3368284.20m	3368286.24m	3368281.976m	3368284.951m
Height or Z m		3701886.69m	3701887.32m	3701887.149m	3701886.828m

Antenna information

	Local: TTR6	Local:R100	Local:E80	Portable:
• Maker:	AOA	3S Navigation	Javad	ITR TSA-2
• Type:		TSA-100	RegAnt 1,	GPS
• Serial number:	Down Converter S/N449	0010	S/N RA0238	3-072002

If the antenna is temperature stabilised

• Set temperature value :		Heater 105°F Cooler 75°F		-

Local antenna cable information

• Maker:			Times Microwave-systems	
• Type:	RG58AU	RG214/U	LMR-400 DB	
• Is it a phase stabilised cable:	No	No	No	
• Length of cable outside the building :	Approx. 18 m	Approx. 18 m	Approx. 18 m	Approx. 18 m

General information

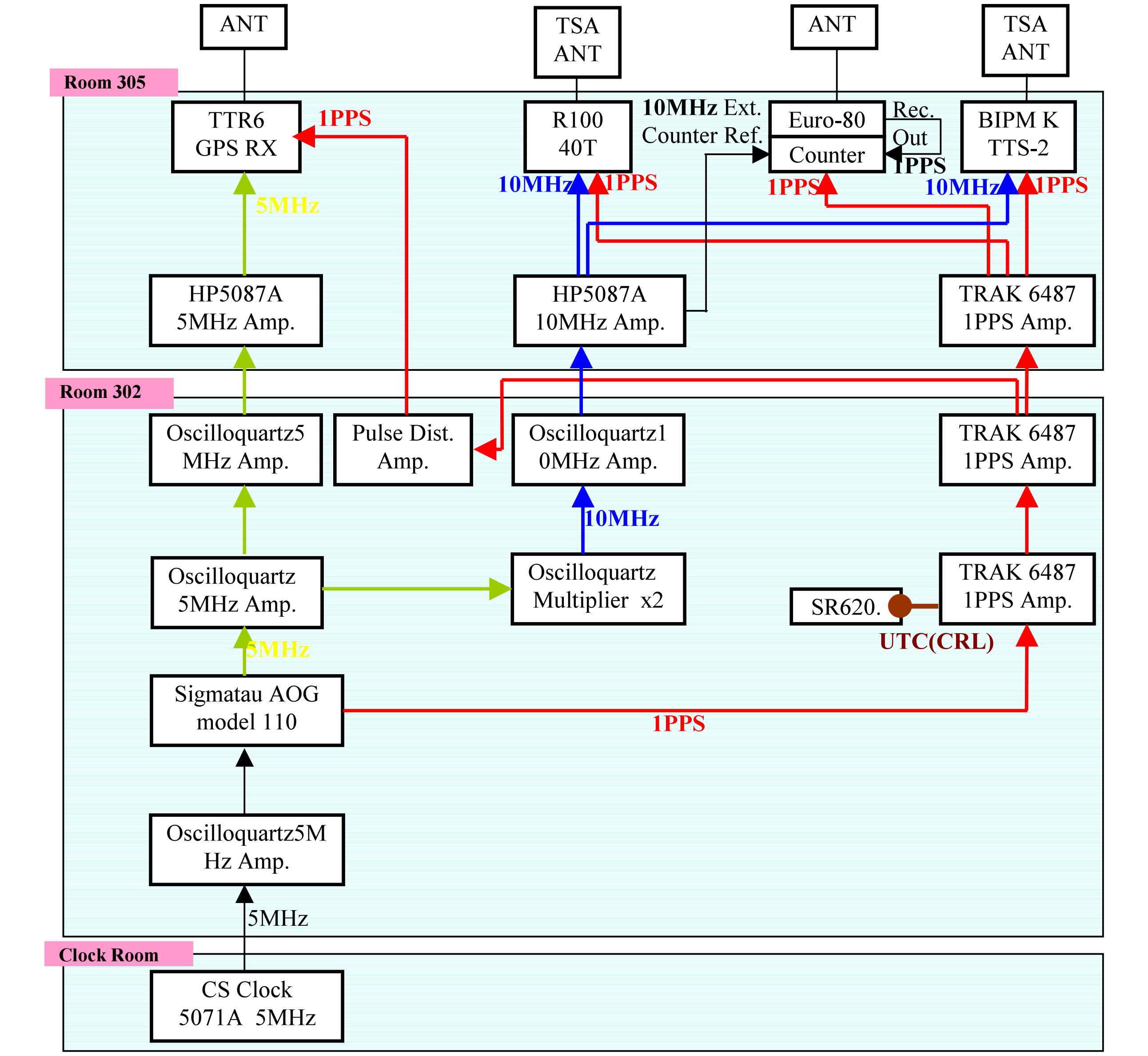
• Rise time of the local UTC pulse:	4.7ns(10%-90%)pulse height 4.59v DC
• Is the laboratory air conditioned:	YES
• Set temperature value and uncertainty :	GPS RX Room 23 ±2
• Set humidity value and uncertainty :	N/A

Cable delay control

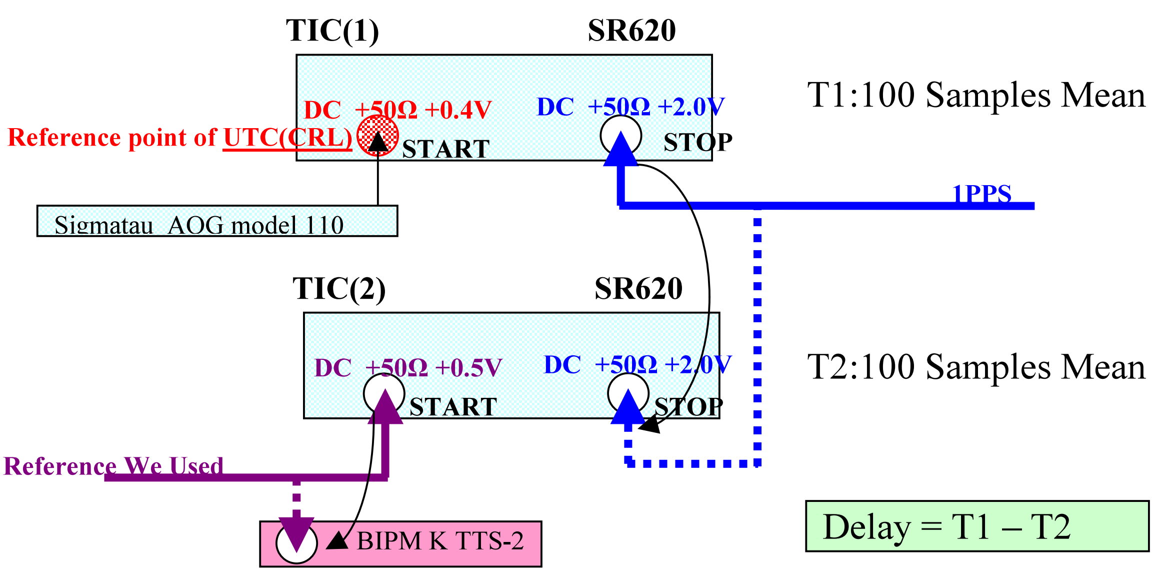
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178,78 ns ± 0,4 ns	177.46 ns : by Agilent8720ES@1.22760GHz 177.44 ns : by Agilent8720ES@1.57542GHz

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:	NIST
Date and hour of the beginning of measurements:	**November 26, 2003 (MJD 52969) 18:50:30**
Date and hour of the end of measurements:	**December 8, 2003 (MJD 52981) 14:38:00**

Receiver setup information

	Local:	Portable: BIPM K
• Maker:	NIST	AOS
• Type:	NBS (TTR-5)	TTS-2
• Serial number:	NBS10	S/N 028
• Receiver internal delay (GPS) :	53.0ns	0.0 (not calibrated)
• Receiver internal delay (GLO) :	N/A	N/A
• Antenna cable identification:	None	C123
Corresponding cable delay :	199.9ns	178,78 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	WGS84
Latitude or X m	-1288398.27 m	-1288340.436 m
Longitude or Y m	-4721698.10 m	-4721663.646 m
Height or Z m	+4078625.68 m	+4078677.580 m

Antenna information

	Local:	Portable:
• Maker:	NIST	ITR TSA-2
• Type:	GPS	GPS
• Serial number:	NBS10	3-072002
If the antenna is temperature stabilised		
• Set temperature value :	N/A	-

Local antenna cable information

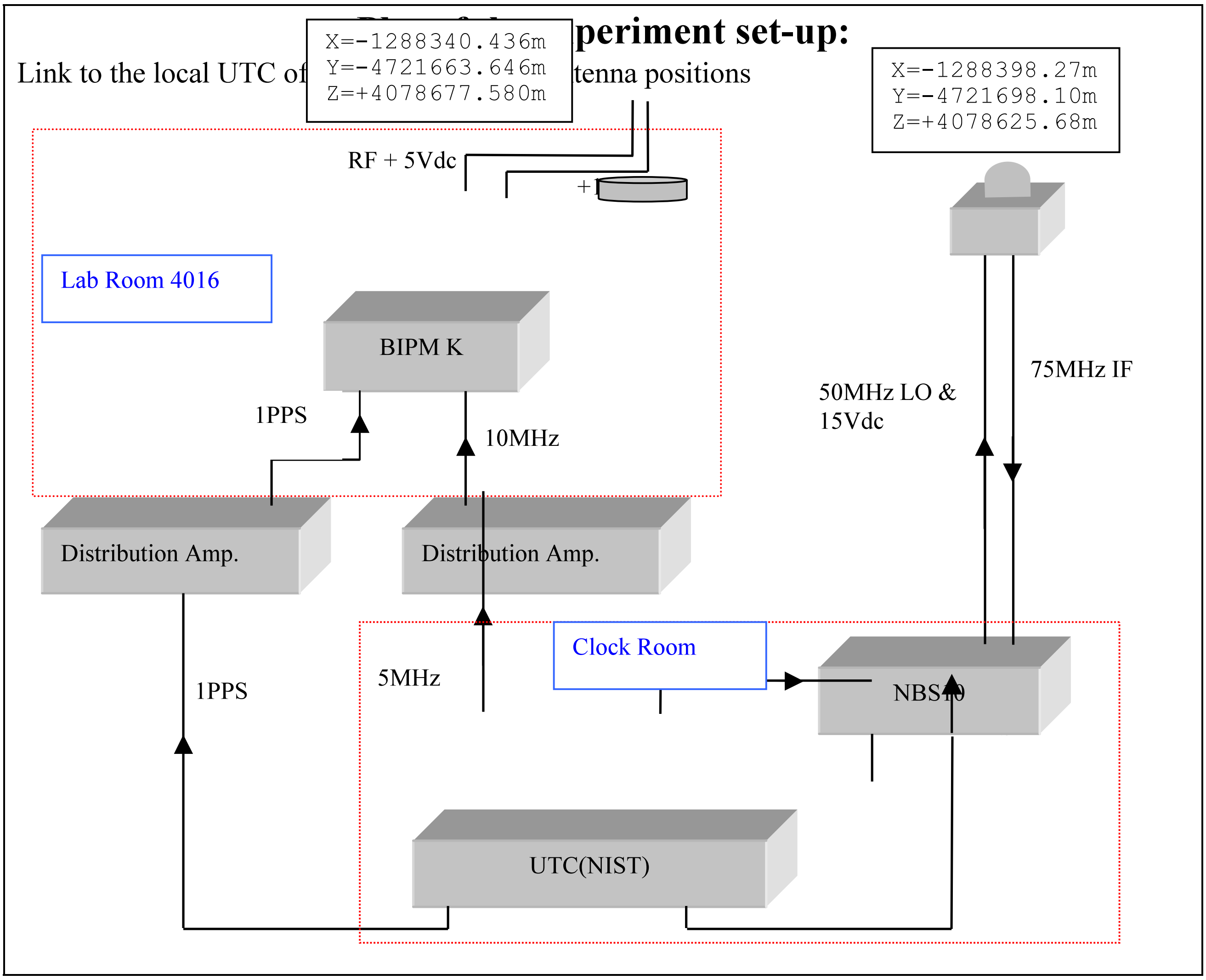
• Maker:	Andrew
• Type:	FSJ1-50A
• Is it a phase stabilised cable:	YES
• Length of cable outside the building :	~30m

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 C123	178,78 ns ± 0,4 ns	177.42ns ±0,1ns (loss = 18dB)



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:	16 December 2003 (MJD 52989) 1400 UT
Date and hour of the end of measurements:	23 December 2003 (MJD 52996) 1300 UT

Receiver setup information

	Local: MOT1	**Portable: BIPM K**
• Maker:	AOS SRC	AOS
• Type:	TTS-2	TTS-2
• Serial number:	S/N 014	S/N 028
• Receiver internal delay (GPS):	-47.9	0.0 (not calibrated)
• Receiver internal delay (GLO):	N/A	-
• Antenna cable identification:	SPS	C123
Corresponding cable delay:	172.06	178,78 ns ± 0,4 ns
• UTC cable identification:	A10	E2
Corresponding cable delay:	N/A	N/A
Delay to local UTC:	0.0 ns	-0.04 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	ITRF97	ITRF97
Latitude or X m	+1112161.100	+1112167.181
Longitude or Y m	-4842855.428	-4842851.168
Height or Z m	+3985494.354	+3985493.979

Antenna information

	Local:	**Portable:**
• Maker:	3S Navigation	ITR TSA-2
• Type:	TSA 100	GPS
• Serial number:	12	3-072002
If the antenna is temperature stabilised		
• Set temperature value:	105F	

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

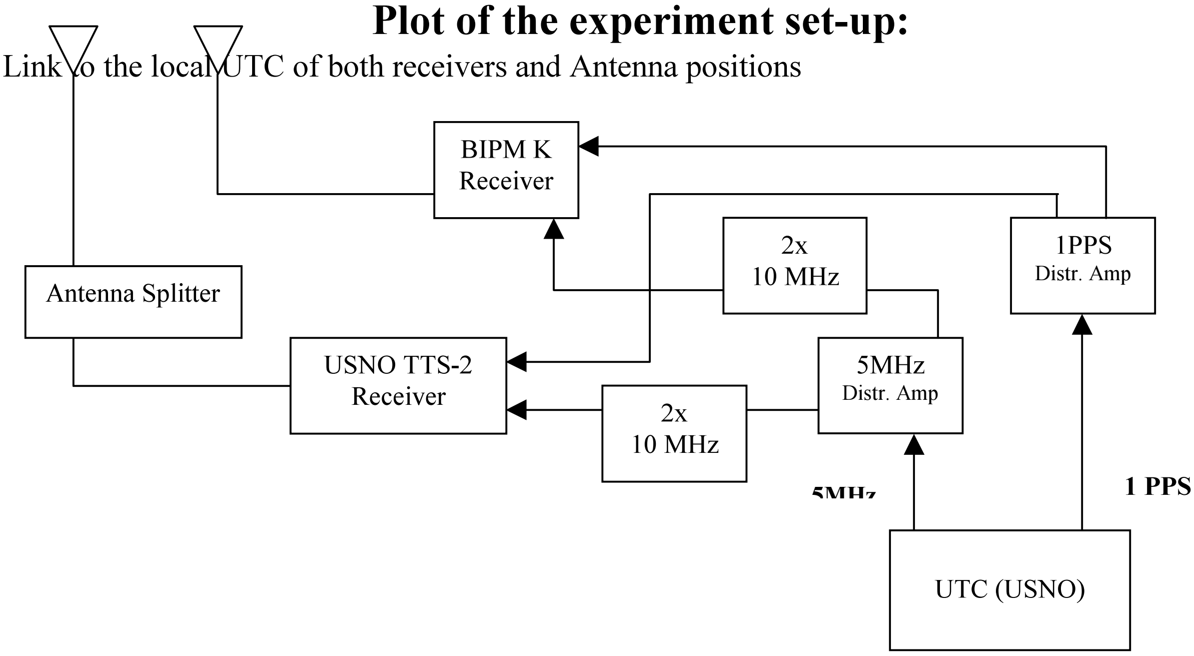
• Rise time of the local UTC pulse:	4.1 ns
• Is the laboratory air conditioned:	Yes
• Set temperature value and uncertainty:	25C, +/-0.5 C
• Set humidity value and uncertainty:	20.5%, +/-4%

Cable delay control

Cable identification	Delay measured by BIPM	Delay measured by local method
BIPM C123	178,78 ns ± 0,4 ns	178.85 +/-0.01 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:

1. Set up an SRS model 620, serial 0591, time interval counter on an external 5 MHz reference.
2. Set the counter to the "time" mode, display mean, average five events, Z=50 ohms (stop channel only), DC coupled.
3. Set up a reference 1pps signal into the "start" gate of the counter using a BNC Tee adapter.
4. Attached BNC-to-TNC adapter to the open end of the Tee, and another to the "stop" gate of the counter.
5. Lacking the proper adapters a short piece of RG-214 with type-N connectors to mate to the TNC and BNC fittings was used.
6. Two readings made of this short reference cable. One reading plugged into the TNC adapters, the other plugged into the BNC adapter after removing the TNC adapters. This allows me to estimate the adapter contribution to the cable length.
7. Reading with the TNC+RG-214 jumper was 6.706 ns, with a sigma of 2.8 ps.
8. Reading with the BNC+RG-214 jumper was 6.504 ns, with a sigma of 2.4 ps
9. The inferred contribution for the two BNC-TNC adapters is the difference, 202 ps.
10. Next, the antenna cable was substituted for the RG-214 jumper. This reading was 179.049 ns when averaged for one minute. The sigma was 6.0 ps.
11. Removing the adapter contribution gives 178.85 ns.
12. Final Answer: 178.847 ns ± 11.2 ps.

BIPM GPS calibration information sheet

Laboratory:	Applied Physics Lab
Date and hour of the beginning of measurements:	**MJD 52996 194215**
Date and hour of the end of measurements:	**MJD 53002 125800**

Receiver setup information

	Local:	**Portable: BIPM K**
• Maker:	TFS-NPL	BIPM
• Type:	GPSCV	TTS-2
• Serial number:	TFS112	S/N 028
• Receiver internal delay (GPS) :	-16 ns	0.0 (not calibrated)
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	RG 58	RG 58
Corresponding cable delay :	78.8 ns	84.78 ns
• UTC cable identification:	RG 223	RG 223
Corresponding cable delay :	-	-
Delay to local UTC :	-	5.0 ns
• Receiver trigger level:	0.5 V	0.5 V
• Coordinates reference frame:	WGS84	WGS84
Latitude or X m	1122656.561 m	1122656.561 m
Longitude or Y m	-4823036.558 m	-4823036.558 m
Height or Z m	4006474.167 m	4006474.167 m

Antenna information

	Local:	**Portable:**
• Maker:	CE	CE
• Type:	GPS	GPS
• Serial number:	0340029892	0340029892
If the antenna is temperature stabilised		
• Set temperature value :	-	-

Local antenna cable information

• Maker:	-
• Type:	RG 58
• Is it a phase stabilised cable:	no
• Length of cable outside the building :	3 m

General information

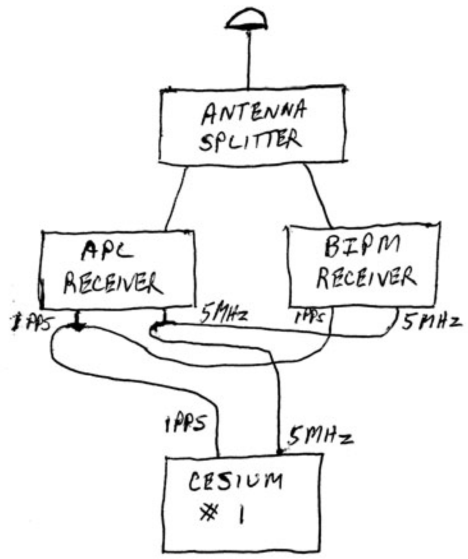
• Rise time of the local UTC pulse:	< 5 ns
• Is the laboratory air conditioned:	yes
• Set temperature value and uncertainty :	70 f ± 2 f
• Set humidity value and uncertainty :	55% ± 5%

Cable delay control

Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178,78 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:	BNM – SYRTE, Observatoire de Paris
Date and hour of the beginning of measurements:	02 February 2004
Date and hour of the end of measurements:	11 February 2004

Receiver setup information

	Local: NBS 51	**Portable: BIPM K**
• Maker:	Allen Osborne Associates	AOS
• Type:	TTR-5	TTS-2
• Serial number:	051	S/N 028
• Receiver internal delay (GPS) :	54 ns	0.0 (not calibrated)
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	505 IF	C123
Corresponding cable delay :	168 ns ± 0,3 ns	178,78 ns ± 0,4 ns
• UTC cable identification:	503	497
Corresponding cable delay :	-	-
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	4 778 657,38 m

Antenna information

	Local:	**Portable:**
• Maker:	A.O.A.	ITR TSA-2
• Type:	-	GPS
• Serial number:	-	3-072002
If the antenna is temperature stabilised		
• Set temperature value :	-	-

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

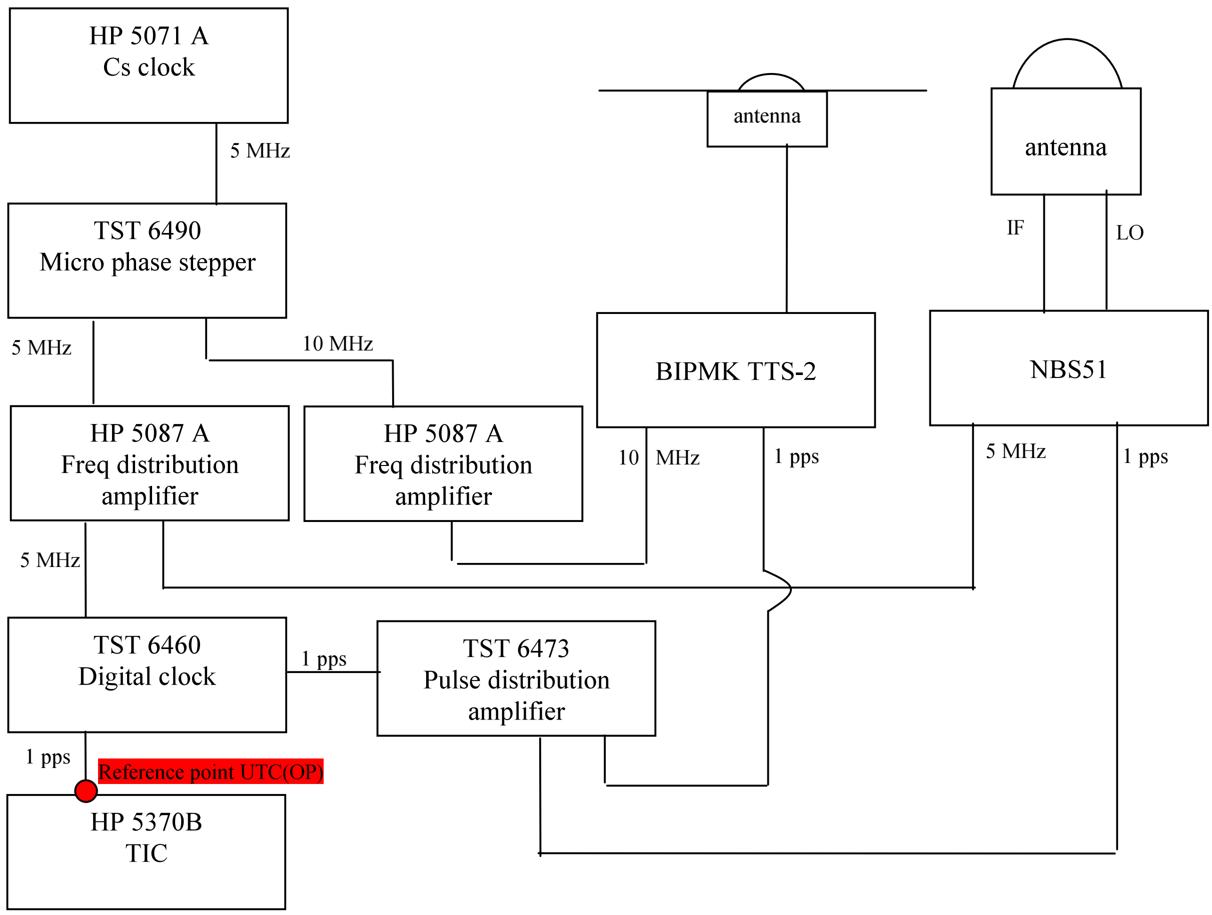
• Rise time of the local UTC pulse:	4 ns
• Is the laboratory air conditioned:	Yes
• Set temperature value and uncertainty :	(21,5 ± 2) °C
• Set humidity value and uncertainty :	/

Cable delay control

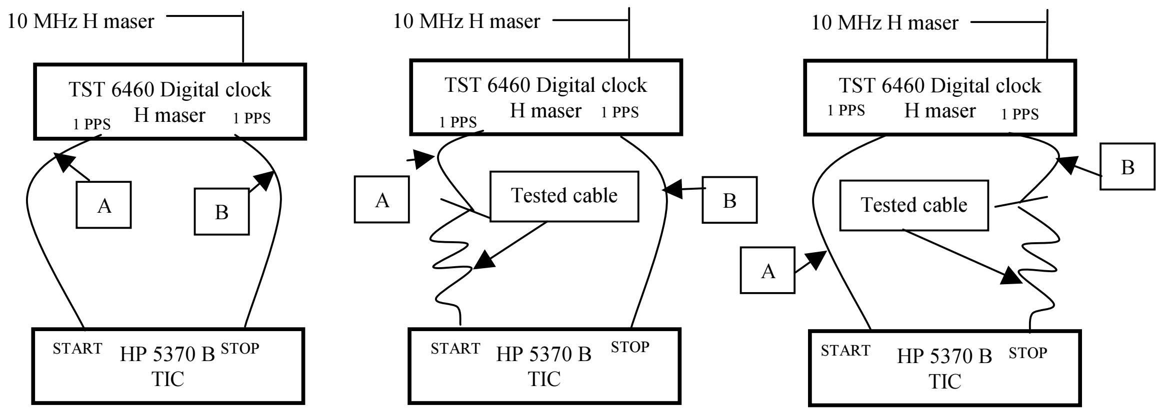
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C123	178,78 ns ± 0,4 ns	178,6 ns ± 0,3 ns

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:



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

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	178.8 ± 0.4	Double Weight Pulse method
OP (before trip)	179.9 ± 0.3	Double Weight Pulse method
PTB	178.5 ± 0.2	Pulse method
AOS	178.5 ± 0.3	Pulse method
KRIS	179.4 ± 0.4	Pulse method
CRL	177.4	Pulse method
NIST	177.42 ± 0.1	Network Analyzer
USNO	178.85 ± 0.01	Pulse method
APL	-	-
OP (after trip)	178.6 ± 0.3	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	52864	-8.64	3.66	0.78	22
	52865	-9.92	3.13	0.49	41
	52866	-10.41	4.08	0.65	40
	52867	-10.15	3.59	0.56	41
	52868	-9.20	3.94	0.63	39
	52869	-8.59	3.56	0.92	15
PTB	52878	-8.91	3.32	0.61	30
	52879	-9.68	3.13	0.49	40
	52880	-8.80	3.02	0.49	38
	52881	-10.05	3.52	0.55	41
	52882	-9.19	2.62	0.42	39
	52883	-10.63	2.94	0.85	12
AOS	52908	19.24	2.07	0.24	76
	52909	19.24	1.85	0.08	517
	52910	18.88	1.90	0.08	538
	52911	18.80	1.67	0.08	496
	52912	18.74	1.75	0.08	474
	52913	18.74	2.06	0.73	8
KRIS	52934	-0.08	2.23	0.18	154
	52935	-0.63	2.32	0.13	313
	52396	-0.80	2.55	0.15	292
	52937	-0.70	2.32	0.14	281
	52938	-0.75	2.35	0.14	292
	52939	-0.87	2.36	0.13	309
CRL	52950	-4.24	3.42	0.25	193
	52951	-5.76	3.70	0.23	262
	52952	-4.43	3.30	0.19	302
	52953	-4.59	3.10	0.18	292
	52954	-4.70	2.68	0.27	100
NIST	52969	-15.20	3.47	1.16	9
	52970	-13.87	3.27	0.47	48
	52971	-13.59	3.24	0.19	44
	52972	-14.25	3.31	0.50	44
	52973	-14.80	3.02	0.45	45
	52974	-14.11	2.99	0.43	48
	52975	-14.19	2.99	0.44	46
	52976	-14.23	3.09	0.46	45
	52977	-13.77	2.86	0.42	46
	52978	-13.47	3.69	0.54	47
	52979	-14.12	3.36	0.50	46
	52980	-14.88	2.95	0.43	46
	52981	-14.57	3.31	0.63	28

LAB	MJD	Mean offset /ns	Standard deviation of individual common view observations /ns	Standard deviation of the mean /ns	Number of individual common views
USNO	52989	-7.40	2.35	0.18	178
	52990	-6.78	2.58	0.11	555
	52991	-7.11	2.54	0.11	527
	52992	-7.17	2.68	0.11	553
	52993	-7.09	2.60	0.11	557
	52994	-7.24	2.77	0.13	434
	52995	-7.30	2.67	0.11	556
	52996	-7.13	2.65	0.15	316
APL	52996	-16.32	0.98	0.10	99
	52997	-16.09	0.65	0.03	598
	52998	-16.09	0.61	0.02	594
	52999	-16.03	0.54	0.02	584
	53000	-16.01	0.58	0.02	580
	53001	-16.09	0.62	0.03	586
	53002	-15.99	0.54	0.19	8
OP	53037	-8.99	3.10	0.71	19
	53038	-9.57	2.46	0.39	39
	53039	-9.20	2.64	0.40	43
	53040	-8.72	2.96	0.46	42
	53041	-9.03	2.52	0.39	42
	53042	-9.50	2.56	0.40	42
	53043	-9.80	2.61	0.41	41
	53044	-9.62	3.15	0.49	41
	53045	-9.97	2.38	0.37	41
	53046	-8.14	4.98	1.33	14