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BUREAU INTERNATIONAL DES POIDS ET MESURES

DETERMINATION OF THE DIFFERENTIAL TIME CORRECTIONS FOR GPS TIME EQUIPMENT LOCATED AT THE OP and CH

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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 16 October 2003 to 2 February 2004, involving GPS time equipment located at the Observatoire de Paris (OP, Paris, France) and the Metrology and Accreditation Switzerland (CH, Bern, Swiss).

INTRODUCTION

The BIPM is conducting a series of differential calibrations of GPS equipment located in time laboratories contributing to TAI [1].

As for previous comparisons 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 the OP's 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 16 October 2003 to 2 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
CH	AOA	TTR-5a	275
BIPM H portable receiver	AOS	TTS-2	021

The portable BIPM H receiver is equipped with a C101 cable. Its delay measured at the BIPM is 179.0 ns with a standard deviation of 0.5 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 beginning of the linear part of the rising pulse at each end of the cable using a 0.5 V trigger level [2].

The delay of this cable was also measured at the laboratories visited. 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:

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

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

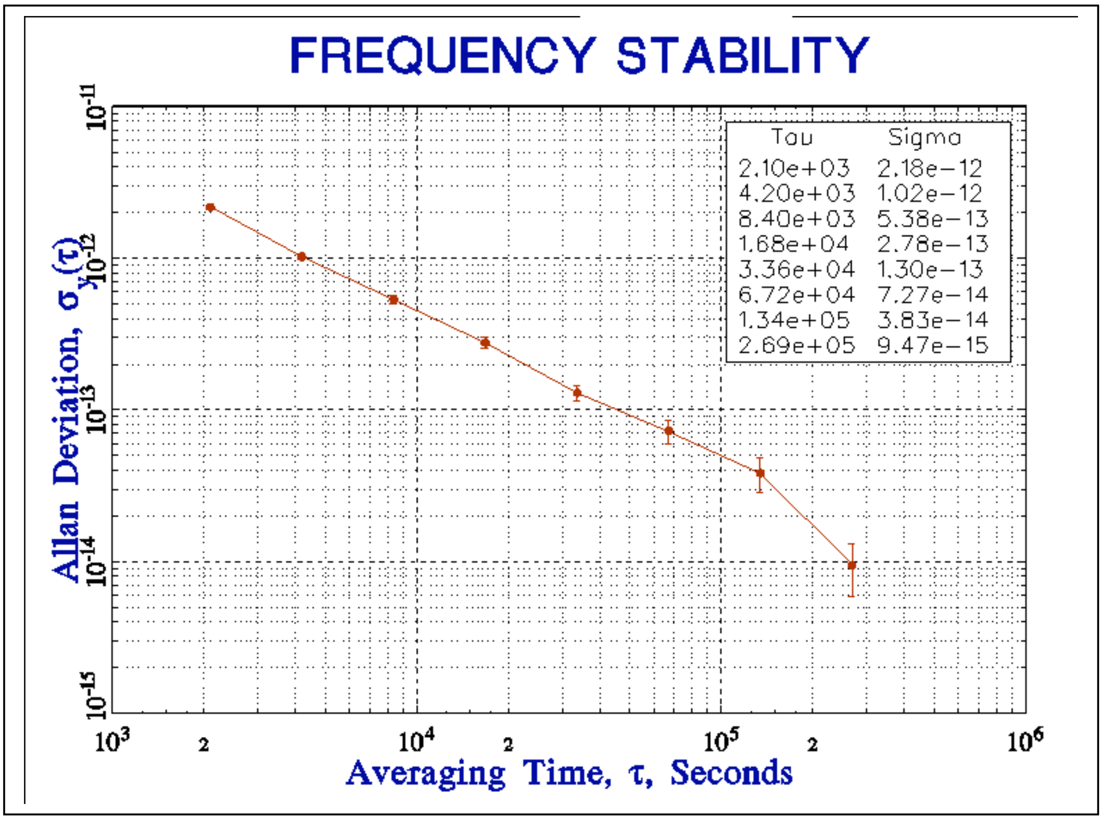


Figure 1. Square root of the modified Allan variance of the time series $\mathrm{d}t_{\mathrm{CH}}$ for the period: 17 December 2003 to 12 January 2004.

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.

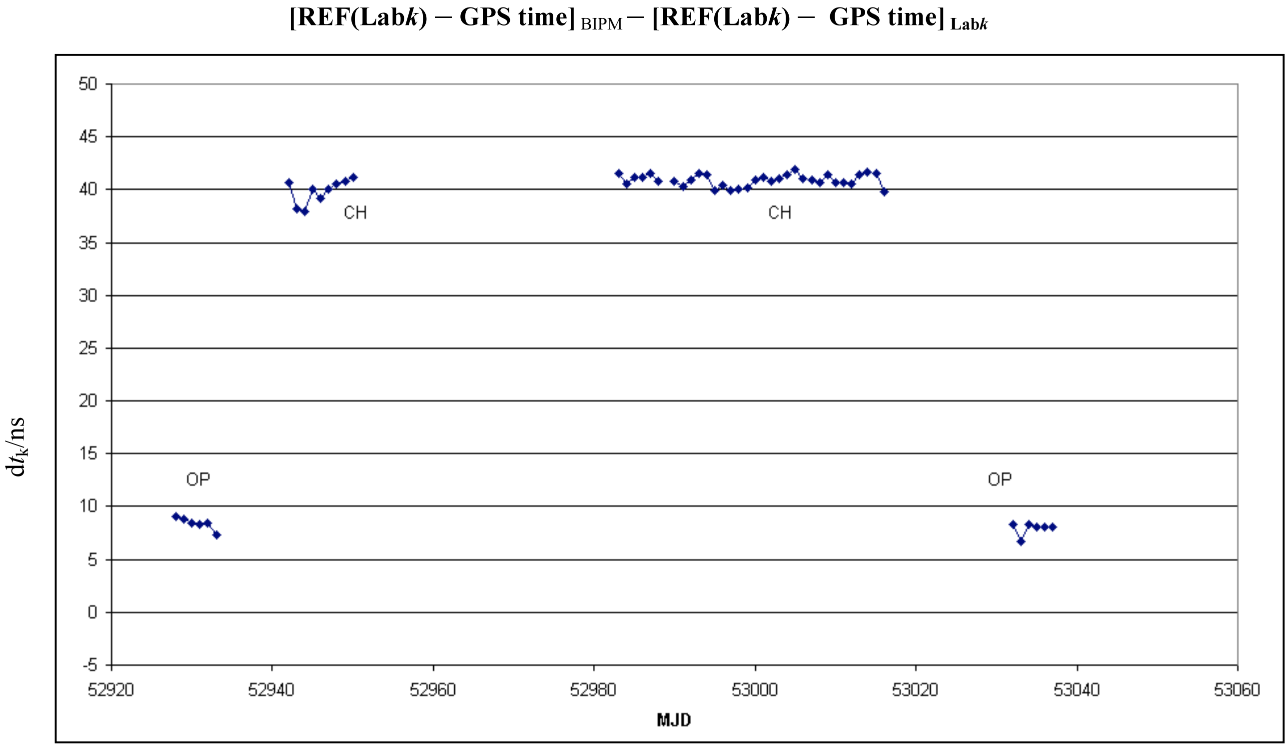


Figure 2. Daily averages of $dt_{k,i}$ for each laboratory k (see Appendix III).

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 *k*	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	16/10/03 – 21/10/03	220	8.45	2.54	0.3	0.58
CH	30/10/03 – 16/01/04	1624	40.59	3.03	0.4	1.16
OP	28/01/04 – 02/02/04	218	7.85	2.68	0.5	0.63

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 correction which should be made (added) to time difference derived during the GPS comparison of the time scales kept by the visited 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
$[UTC(CH) - UTC(OP)]$	+32.4	3.0

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

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 the participating laboratories.

The present measurements were performed under good conditions with excellent closure of the travelling equipment at the OP. At the CH, the differential correction is large, and readjustment of the delay of GPS time equipment might be considered.

Acknowledgements

The authors wish to express their gratitude to Laurent-Guy Bernier for the unreserved collaboration they have received. Without this help, the work could not have been accomplished.

REFERENCES

[1] 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.

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

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:	16 October 2003
Date and hour of the end of measurements:	21 October 2003

Receiver setup information

	Local: NBS 51	**Portable: BIPM H**
• Maker:	Allen Osborne Associates	AOS
• Type:	TTR-5	TTS-2
• Serial number:	051	S/N 021
• Receiver internal delay (GPS) :	54 ns	-19.36
• Receiver internal delay (GLO) :	-	-
• Antenna cable identification:	505 IF	C101
Corresponding cable delay :	168 ns ± 0.3 ns	179.0 ns ± 0.5 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.	
• Type:	-	
• Serial number:	-	-
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

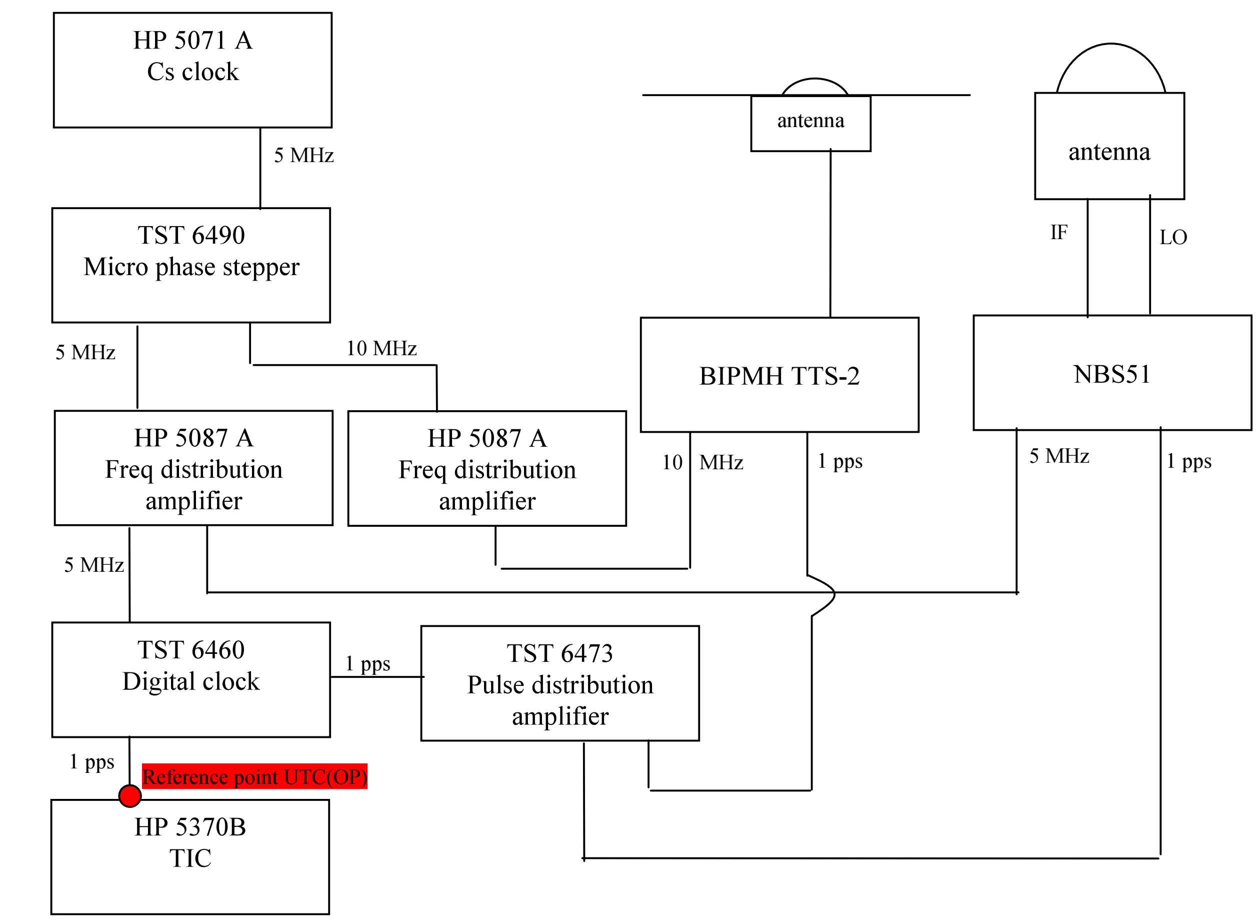
• Rise time of the local UTC pulse:	4 ns
• Is the laboratory air conditioned:	Yes
• Set temperature value and uncertainty :	(21.5 ± 2) °C
• Set humidity value and uncertainty :	/

Cable delay control

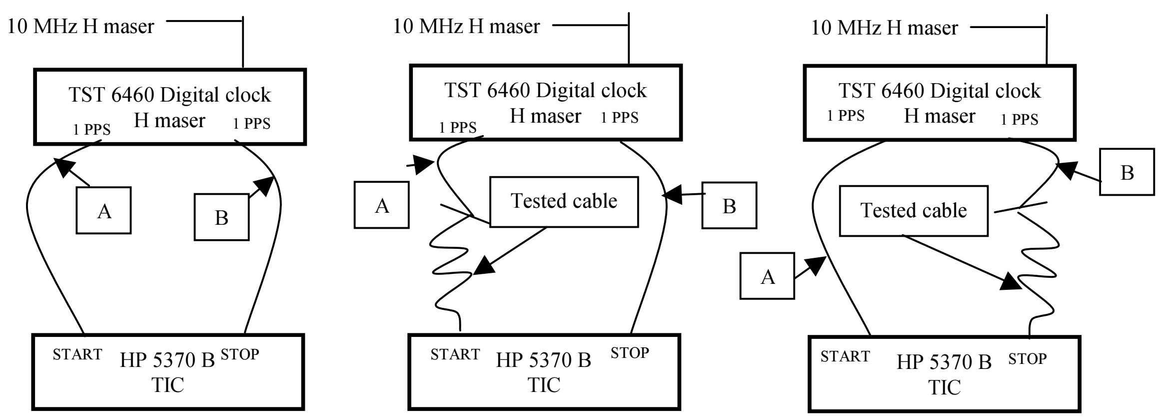
Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C101	179.0 ns ± 0.5 ns	-

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

BIPM GPS calibration information sheet

Laboratory:	CH (METAS, Bern, Switzerland)
Date and hour of the beginning of measurements:	**2003-12-16 Tue MJD 52989 UTC 09:00**
Date and hour of the end of measurements:	**2004-01-12 Mon MJD 53016 UTC 10:00**

Receiver setup information

	Local:	**Portable: BIPM H**
• Maker:	AOA	BIPM
• Type:	**TTR-5A**	**TTS-2**
• Serial number:	**S/N 275**	**S/N 021 (BIPH)**
• Receiver internal delay (GPS) :	not cal. (INT DLY = 73 ns)	-19.36 ns
• Receiver internal delay (GLO) :		-
• Antenna cable identification:	KA-KR #12	C101
Corresponding cable delay :	208.0 ± 0.5 ns	179.0 ns ± 0.5 ns
• UTC cable identification:	KA-KA#34	KA-KA#19
Corresponding cable delay :	38.2 ns	50.6 ns
Delay to local UTC :	REF-PPS(TTR-5A) = 0.0 ns	REF-PPS(BIPM) = +8.1 ns
• Receiver trigger level:	unknown	0.5 V
• Coordinates reference frame:	ITRF 2000	ITRF 2000
Latitude or X m	46° 55' 25.43051"	46° 55' 25.488228"
Longitude or Y m	7° 27' 51.2908"	7° 27' 51.3027"
Height or Z m	611.60	612.643

Antenna information

	Local:	**Portable:**
• Maker:	AOA	
• Type:	TTR-5A	
• Serial number:	0600	TTS-2 serial 021
If the antenna is temperature stabilised		
• Set temperature value :		

Local antenna cable information

• Maker:	Andrew
• Type:	HELIAX ¼" FSJ1-50A
• Is it a phase stabilised cable:	very low temperature sensitivity
• Length of cable outside the building :	about 10 m

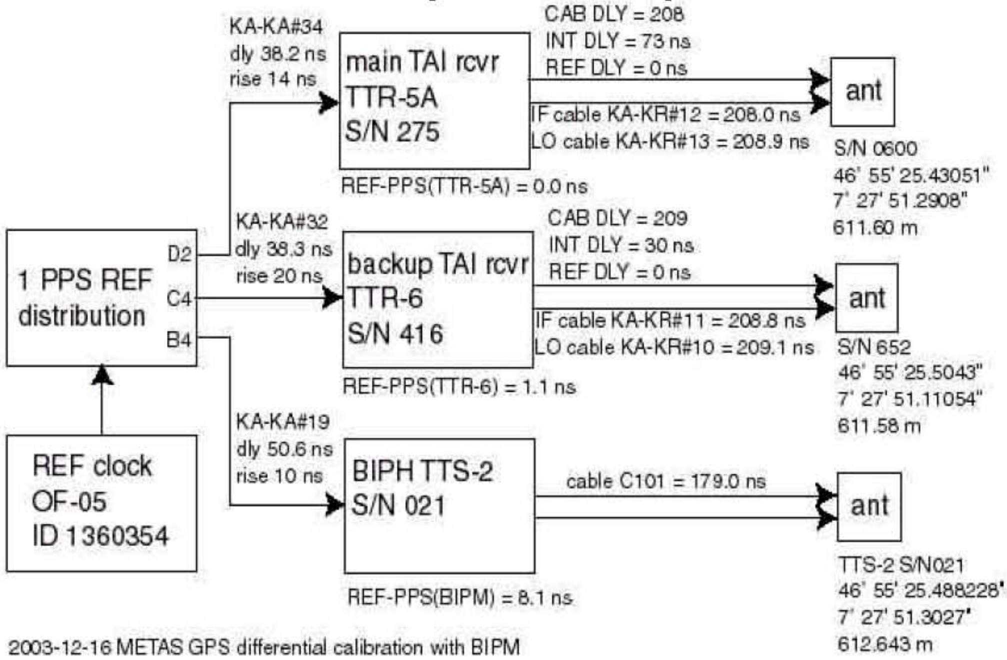
General information

• Rise time of the local UTC pulse:	14 ns to TTR-5A, 10 ns to BIPM
• Is the laboratory air conditioned:	yes
• Set temperature value and uncertainty :	21.0 ± 0.5 °C
• Set humidity value and uncertainty :	50 ± 5 %

Cable delay control

Cable identification	delay measured by BIPM	Delay measured by local method
BIPM C101	179.0 ns ± 0.5 ns	179.4 ns ± 0.5 ns

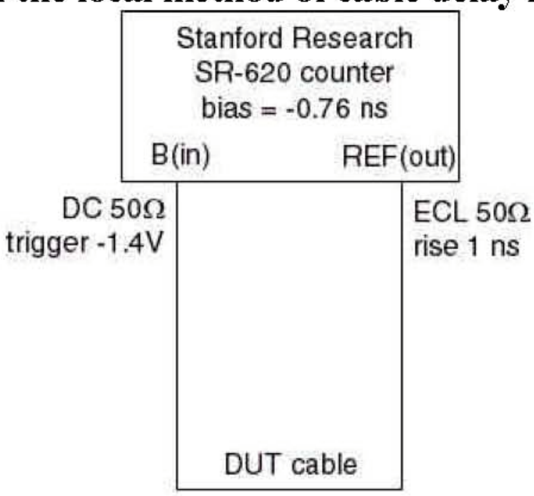
Plot of the experiment set-up:



2003-12-16 METAS GPS differential calibration with BIPM

note 01 = REF PPS signal generated by REF clock OF-05 ID 1360354
note 02 = REF PPS defined as PPS input to main GPS receiver TTR-5A
note 03 = rise time of PPS measured 20%-80% using LeCroy WavePro 950
note 04 = PPS offsets depend on both distribution internal delays and cable lengths
note 05 = PPS offset measurements measured by Time Interval Counter (TIC)
note 06 = TIC measurement SR-620 : trigger +0.5V = 10% of 5V PPS pulse,
50 ohm DC coupling, average 10 measurements

Description of the local method of cable delay measurement:



Cable delay measured by start-stop interval measurement with counter bias corrected. REF out signal is ECL with 1 ns rise time pulses. Counter bias calibrated by measuring several short cables of known length and extrapolating to zero length.

BIPM GPS calibration information sheet

Laboratory:	BNM – SYRTE, Observatoire de Paris
Date and hour of the beginning of measurements:	28 January 2004
Date and hour of the end of measurements:	02 February 2004

Receiver setup information

	Local: NBS 51	**Portable: BIPM H**
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• Type:	TTR-5	TTS-2
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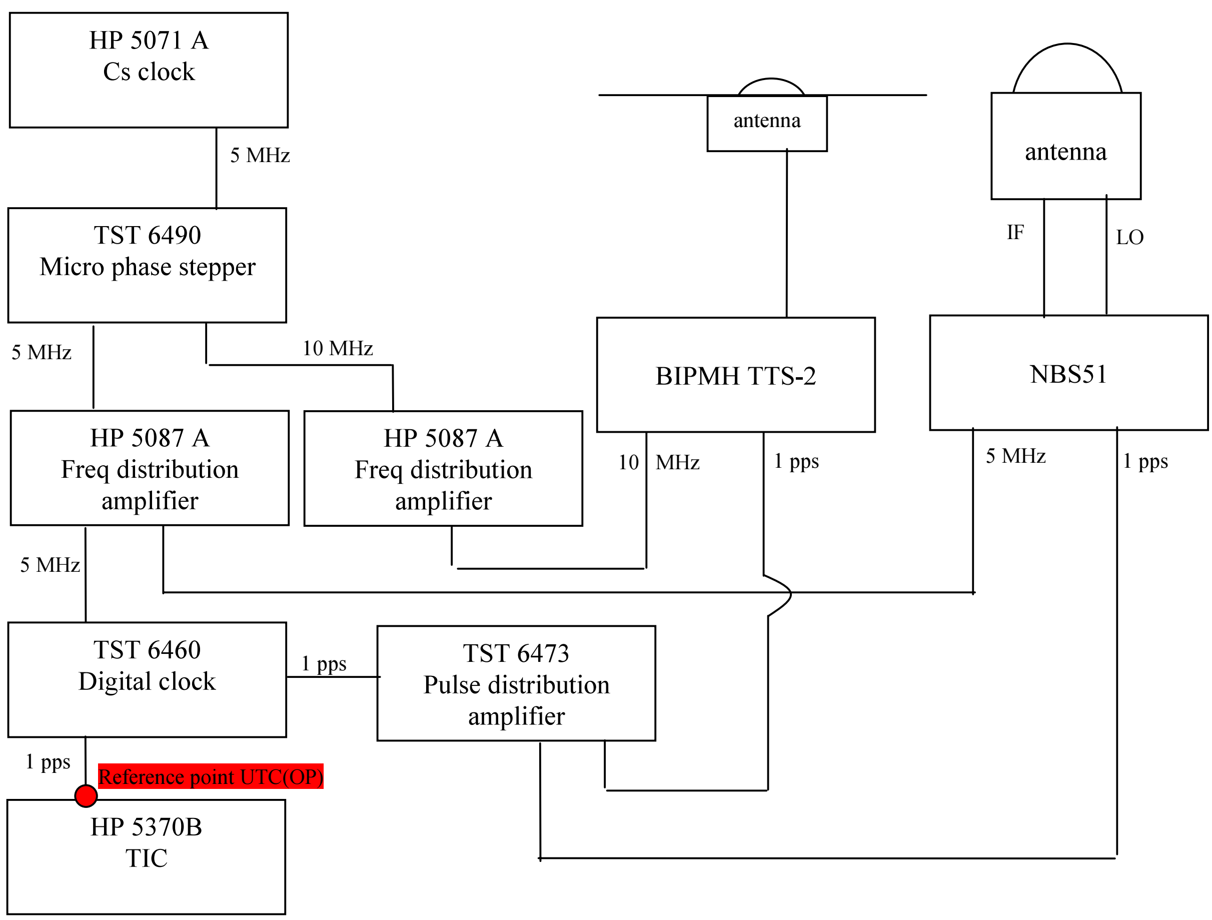

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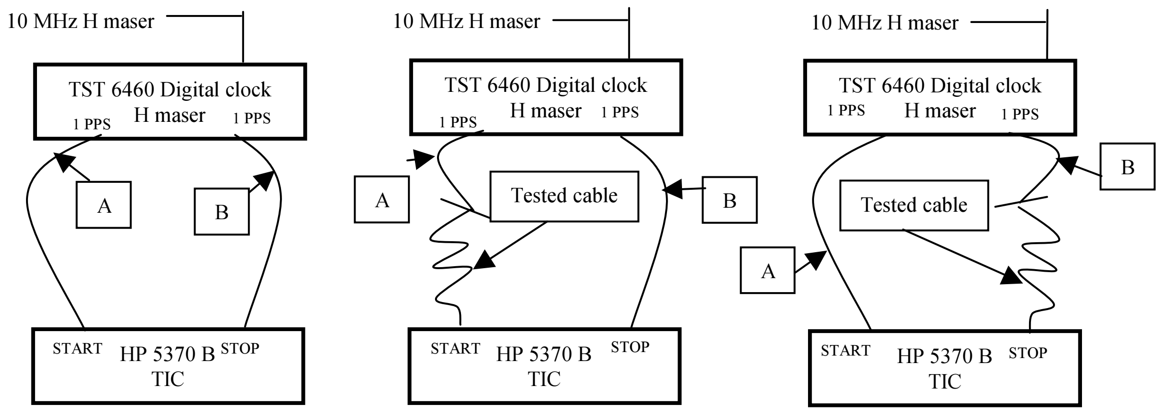

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$$\text{Delay} = \frac{R_2 - \left(\frac{R_1 + R_3}{2}\right) + \left(\frac{R_3 + R_5}{2}\right) - R_4}{2} + \text{corrections}$$

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 C101 cable /ns	Measurement method
BIPM	179.0 ± 0.5	Double Weight Pulse method
OP (before trip)	–	
CH	179.4 ± 0.5	Pulse method
OP (after trip)	–	

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	52928	9.00	2.71	0.53	26
	52929	8.79	2.84	0.42	45
	52930	8.40	2.31	0.35	44
	52931	8.30	2.32	0.35	45
	52932	8.49	2.38	0.36	44
	52933	7.36	3.04	0.74	17
CH	52942	40.68	1.88	0.37	26
	52943	38.23	2.82	0.51	31
	52944	37.87	2.43	0.41	35
	52945	40.04	2.86	0.46	38
	52946	39.21	2.26	0.36	40
	52947	40.01	2.68	0.43	38
	52948	40.51	3.76	0.59	41
	52949	40.78	2.52	0.39	41
	52983	41.48	2.80	0.53	28
	52984	40.50	2.32	0.37	40
	52985	41.12	2.91	0.46	40
	52986	41.16	3.29	0.51	41
	52987	41.59	2.40	0.38	41
	52988	40.85	2.29	0.36	40
	52990	40.81	2.22	0.36	38
	52991	40.35	2.40	0.39	39
	52992	40.87	2.99	0.46	42
	52993	41.58	2.35	0.37	41
	52994	41.44	2.29	0.37	38
	52995	39.87	2.60	0.41	40
	52996	40.38	2.85	0.46	39
	52997	39.94	2.37	0.37	41
	52998	40.05	2.82	0.44	42
	52999	40.22	2.66	0.43	39
	53000	40.93	2.08	0.34	38
	53001	41.14	2.34	0.38	39
	53002	40.78	2.90	0.45	41
	53003	41.10	2.81	0.44	41
	53004	41.45	2.71	0.45	37
	53005	41.88	3.52	0.57	38
	53006	41.05	1.90	0.31	38
	53007	40.94	2.94	0.46	40
	53008	40.69	2.52	0.40	39
	53009	41.41	2.23	0.35	41
	53010	40.61	2.63	0.41	42
	53011	40.69	2.63	0.42	39
	53012	40.53	2.27	0.37	37
	53013	41.37	2.44	0.38	41
	53014	41.71	2.40	0.39	37
	53015	41.58	2.25	0.36	39
	53016	39.78	2.52	0.73	12

OP	53032	8.30	2.93	0.55	28
	53033	6.65	2.67	0.40	45
	53034	8.34	1.98	0.30	43
	53035	8.07	3.05	0.45	45
	53036	8.05	2.47	0.37	44
	52937	8.01	2.73	0.73	14