Rapport BIPM-94/2

BUREAU INTERNATIONAL DES POIDS ET MESURES

DETERMINATION OF THE DIFFERENTIAL TIME CORRECTION BETWEEN THE GPS TIME RECEIVERS LOCATED AT THE PARIS OBSERVATORY, PARIS, FRANCE, AND THE NATIONAL PHYSICAL LABORATORY, TEDDINGTON, UNITED KINGDOM

by

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Correction du retard interne du récepteur GPS de référence de l'Observatoire de Paris.

Le LPTF (Observatoire de Paris, Bureau National de Métrologie) possède 4 récepteurs GPS utilisés comme suit:

- Un récepteur de référence pour les comparaisons horaires par GPS, de type NBS et dénommé NBS51, sur lequel sont programmées les poursuites du programme international de poursuites édité par le BIPM.
- Un autre récepteur de type NBS, doublure du récepteur de référence, programmé sur les mêmes poursuites en parallèle du NBS51, et comparé en permanence au NBS51, dénommé VSL15.
- Un récepteur de type NBS, dénommé TTR06, affecté aux étalonnages des liaisons horaires françaises.
- Un récepteur de type SERCEL NRT2, dénommé NRT28, utilisé à des fins expérimentales (CE-GPS, ...).

Au cours du mois de juillet 1993, un glissement a été observé sur les différences entre les récepteurs VSL15 et NBS51. Des comparaisons aux autres récepteurs du laboratoire, ou à d'autres récepteurs français par l'intermédiaire du TTR06, ont confirmé l'amplitude et le signe de ce glissement, attribué avec certitude à une variation inexpliquée du retard interne du NBS51, dont la valeur numérique était jusque-là de + 50 ns.

En conséquence, il a été décidé de corriger le retard interne du NBS51 par une valeur déterminée comme l'écart entre la moyenne des différences [UTC(OP)-GPS(VSL15)] - [UTC(OP)-GPS(NBS51)] sur le mois de juin 1993, et la moyenne analogue sur le mois d'août 1993:

MOY_{juin}([UTC(OP)-GPS(VSL15)] - [UTC(OP)-GPS(NBS51)]) = - 0.51 ns, $\sigma = 0.34$ ns
$MOY_{août}$([UTC(OP)-GPS(VSL15)] - [UTC(OP)-GPS(NBS51)]) = - 4.70 ns, $\sigma = 0.34$ ns

La valeur numérique choisie est donc:

Correction retard NBS51 = + 4.2 ns, incertitude = 0.4 ns (1σ)

Le nouveau retard programmé sur le NBS51 est de + 54 ns.

Cette correction est intervenue le 23 mars 1994 à 0 h UT.

ABSTRACT

The method of clock comparisons using GPS satellites in common view can now reach an accuracy of a few nanoseconds. However errors of calibration of the internal delays of GPS time receivers can limit this accuracy. The method which best permits removal of calibration errors is the comparison of remote receivers by transfer of a portable receiver from one location to another.

We report here the conditions of such an exercise organized under the auspices of the BIPM and which took place in January-February 1994: the comparison of the internal delays of the GPS time receivers located at the Paris Observatory (OP), Paris, France, and the National Physical Laboratory (NPL), Teddington, United Kingdom, was carried out by means of a portable GPS time receiver belonging to the BIPM. The found offset was nearly compensated by the physical introduction, on 23 March 1994 at 0h UTC, of a correction to the internal delay of the GPS time receiver in operation at OP. It follows that, since 23 March 1994 0h UTC, the differential correction to be added to the GPS comparison of the time scales kept by the OP and the NPL, has been very small and of the same order of magnitude than its estimated uncertainty. In consequence, it is the view of the BIPM that it should not be taken into account.

RESUME

La méthode de comparaison des horloges utilisant les satellites du GPS observés en vues simultanées peut, à ce jour, atteindre une exactitude de l'ordre de quelques nanosecondes. Cependant le mauvais étalonnage des retards internes des récepteurs du temps du GPS constitue l'un des facteurs limitant cette exactitude. La méthode qui permet le mieux d'éliminer les erreurs d'étalonnage consiste à comparer des récepteurs distants par transport d'un récepteur portable.

Nous explicitons ici les conditions d'une telle campagne d'étalonnage, organisée sous les auspices du BIPM, et qui a eu lieu en janvier-février 1994: la comparaison des retards internes des récepteurs situés à l'Observatoire de Paris (OP), Paris, France, et au National Physical Laboratory, Teddington, Royaume-Uni, a été effectuée au moyen d'un récepteur du temps du GPS portable appartenant au BIPM. Le décalage qui en résulte a été partiellement compensé le 23 mars 1994 à 0h UTC, par l'introduction physique d'une correction au retard interne du récepteur du temps du GPS de l'OP. Il s'en suit que, depuis le 23 mars 1994 0h UTC, la correction différentielle aux valeurs de comparaison des échelles de temps maintenues par l'OP et le NPL, est petite et du même ordre de grandeur que son incertitude estimée. Selon le BIPM, il convient donc de ne pas en tenir compte.

INTRODUCTION

The method of time transfer between remote locations using GPS satellites in common view is widely used in the time laboratories which participate in the international unification of time under the coordination of the Bureau International des Poids et Mesures [1]. The accuracy of GPS time transfer can now reach the level of a few nanoseconds [2].

Errors of calibration of the instrumental delays of GPS time receivers is one of the limiting factors to this accuracy. The method which best permits removal of calibration errors is the comparison of remote receivers by transfer of a portable receiver from one location to another [3, 4, 5]. Recently the BIPM has carried out differential calibrations on the occasions of comparisons of the GPS common-view method with other time transfer methods like LASSO and two-way [6, 7], and also on the occasion of visits to outside laboratories [8, 9].

We report here the results of a calibration exercise organized under the auspices of the BIPM. Comparison of the receivers located at the Paris Observatory (OP), Paris, France, and the National Physical Laboratory (NPL), Teddington, United Kingdom, was effected by the means of a portable GPS time receiver BIPM3 belonging to the BIPM. This was organized as a round-trip, the portable receiver coming back to OP after the visit to NPL.

EQUIPMENT

In comparisons of GPS receivers, as well as in current GPS time comparisons, the receiver software, the adopted reference frames and the constants should be identical. Differences have already been found in the software of receivers of different type, but, fortunately for the present exercise, all the receivers involved are of the so-called 'NBS design'. They are single channel, C/A code receivers. Although constructed at different times, the essential features of these receivers are identical and the constants used were updated as appropriate.

When the local time reference produces a pulse of poor shape, differences of trigger level between the receivers can produce a differential delay. Here this problem does not appear, both reference pulses having a short rise-time (3-4 ns) and all receivers using a single trigger level (0,5 V).

The principal characteristics of the receivers are listed below:

Portable receiver:	Maker	- Allen Osborne Associates,
BIPM3	Type	- NBS/TTR6,
	Serial Number	- S/N0277.

Receiver at OP: REC(OP)	Maker Type Serial Number	- Allen Osborne Associates, - NBS/TTR5, - S/N051.
Receiver at NPL: REC(NPL)	Maker Type Serial Number	- Allen Osborne Associates, - NBS/TTR5A, - S/N0276.

CONDITIONS OF COMPARISON

The portable equipment consists of the BIPM3 receiver, its antenna and a calibrated antenna cable. The individual laboratories supply:

a) a 5 MHz reference signal,

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 BIPM3 is connected to the same clock as the local receiver REC(k), and the antenna of the portable receiver is placed close (less than 2 meters away). The differential coordinates of the antenna phase centres at each site are known with uncertainties of a few centimetres.

In this exercise the receivers were programmed with the BIPM Common-View International Schedule No 22 including 48 tracks for Paris and Teddington.

Only strict common-views (0 s common-view tolerance and 780 s exact duration of the tracks) are used in order to remove the effects of Selective Availability, currently implemented on Block II satellites.

The comparison at close distances allows the cancellation of time transfer errors arising from satellite ephemerides and imperfect modelling of the ionosphere. In addition no errors should arise from errors in the relative coordinates. As all the receivers involved are of the same type, all software anomalies are also cancelled.

RESULTS

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

$$dt_{k,i} = [\mathrm{UTC(k)} - \mathrm{GPS\ time}]_{\mathrm{BIPM3},i} - [\mathrm{UTC(k)} - \mathrm{GPS\ time}]_{\mathrm{REC(k)},i}.$$

Then the noise exhibited by the time series dt_k is analysed for each laboratory by the use of the modified Allan variance.

Here, for the comparisons at OP, at NPL and back to OP, the time series dt_k exhibit white phase noise for an averaging time of one day. This is illustrated in Figures 1, 2 and 3.

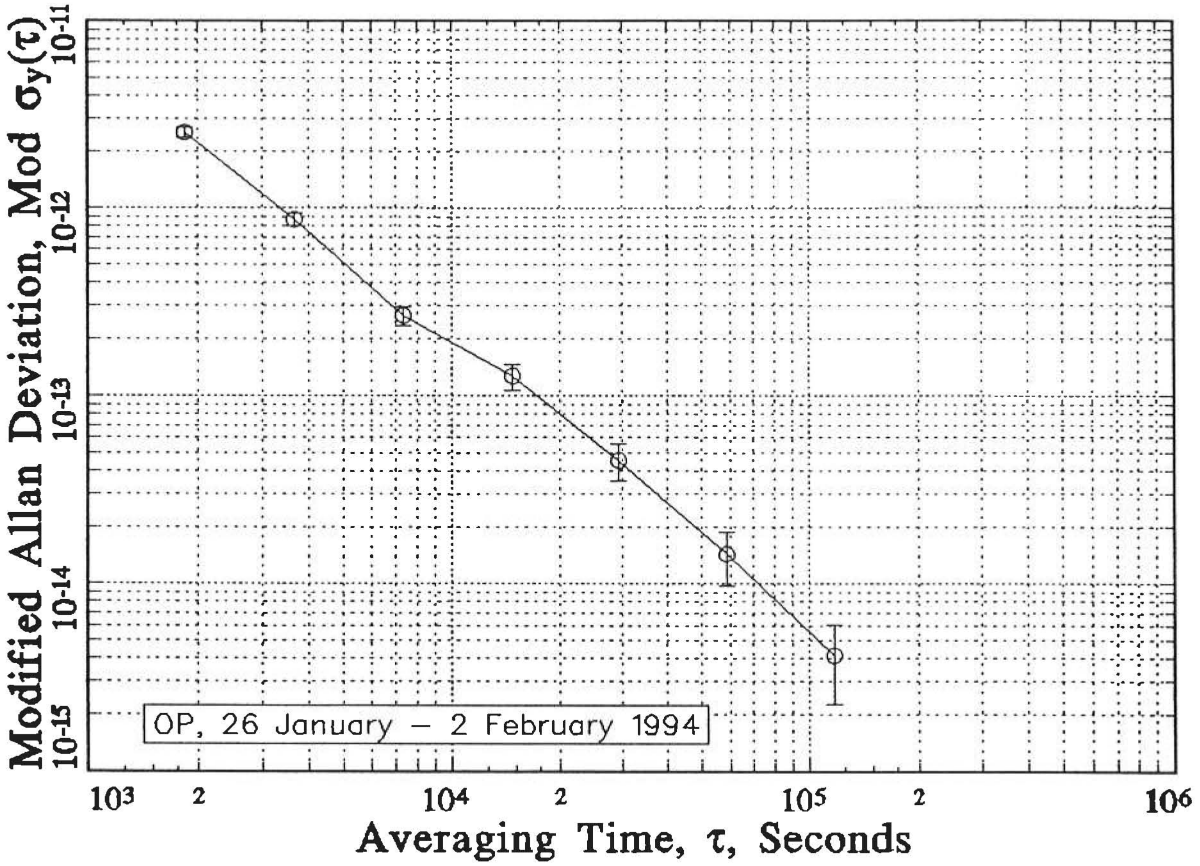

Figure 1. Square root of the modified Allan variance of the time series dt_{OP} for the period 26 January - 2 February 1994.

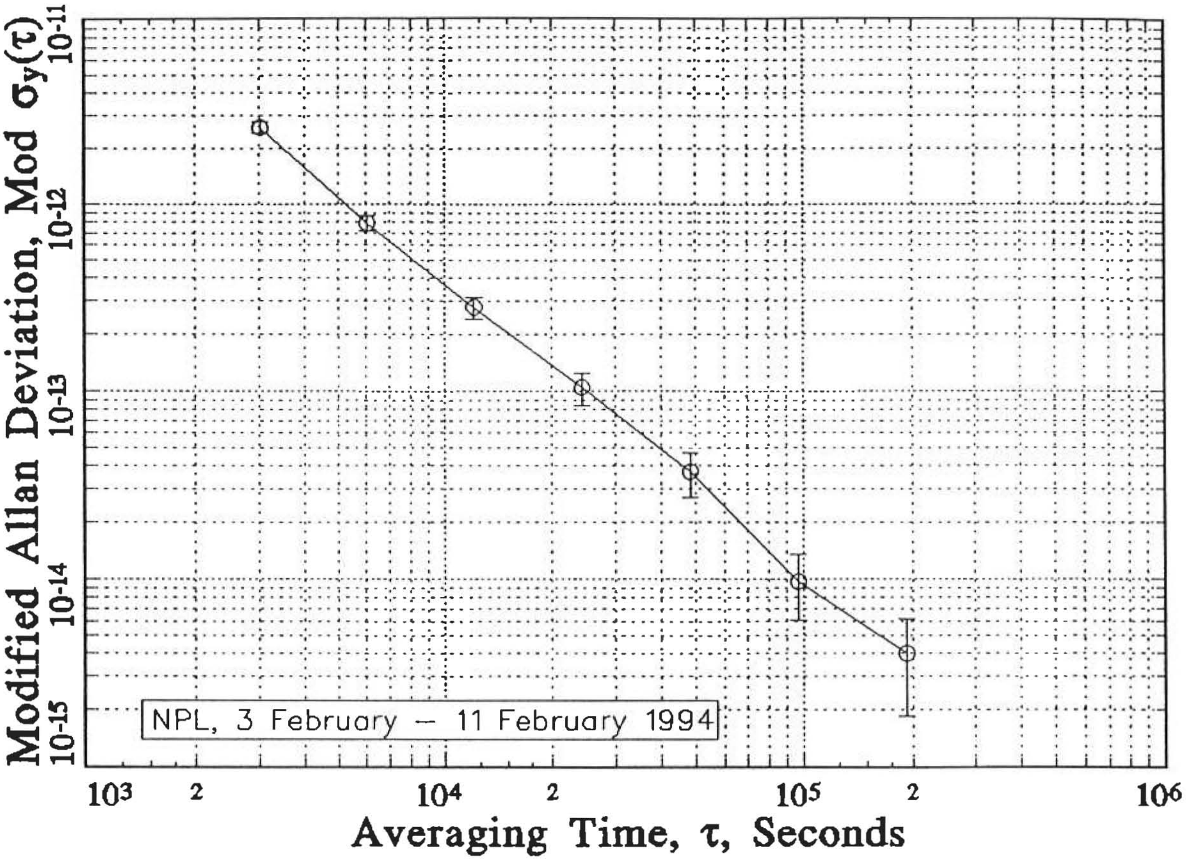

Figure 2. Square root of the modified Allan variance of the time series dt_{NPL} for the period 3 February - 11 February 1994.

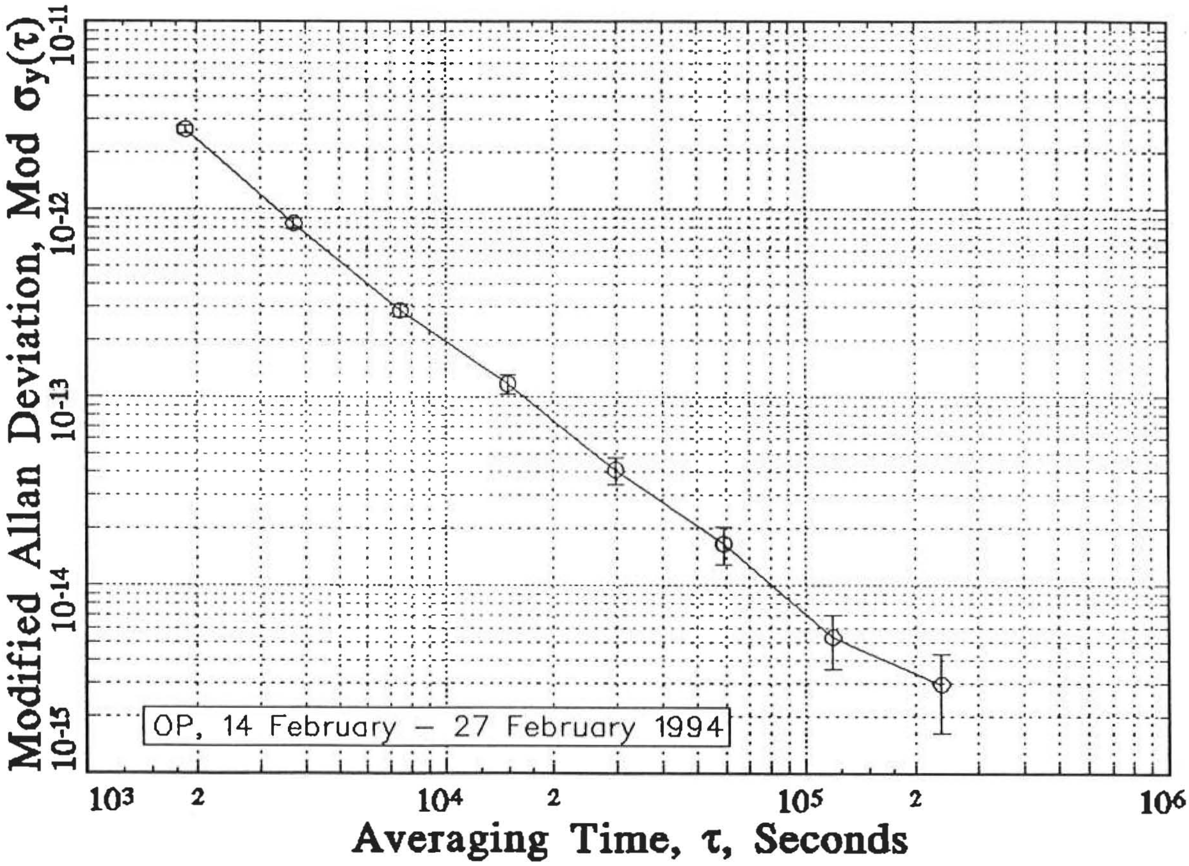

Figure 3. Square root of the modified Allan variance of the time series dt_{OP} for the period 14 February - 27 February 1994.

This justifies computation of an averaged value for one-day intervals and of the standard deviation of the mean as an expression of confidence on the obtained averaged value.

The daily results of the comparisons are then as follows:

Lab	Date 1994	Number of individual common views	Mean offset /ns	Standard deviation of individual common views /ns	Standard deviation of the mean /ns
OP	Jan 26	21	-6,45	2,31	0,51
	Jan 27	47	-7,36	2,81	0,41
	Jan 28	47	-7,71	1,97	0,29
	Jan 29	45	-7,46	2,35	0,35
	Jan 30	47	-7,59	2,96	0,43
	Jan 31	47	-7,28	2,86	0,42
	Feb 01	45	-7,71	2,16	0,32
	Feb 02	15	-7,33	2,62	0,68
NPL	Feb 03	8	-3,05	3,89	1,38
	Feb 04	30	-1,22	4,67	0,85
	Feb 05	29	-0,72	3,47	0,64
	Feb 06	30	-1,26	4,45	0,81
	Feb 07	30	-1,57	3,54	0,65
	Feb 08	26	+0,50	4,28	0,84
	Feb 09	30	-1,61	3,46	0,63
	Feb 10	26	-1,63	4,32	0,85
	Feb 11	12	-1,68	4,17	1,20
OP	Feb 14	22	-7,97	2,34	0,50
	Feb 15	43	-7,48	2,42	0,37
	Feb 16	46	-7,89	2,66	0,39
	Feb 17	44	-7,76	2,37	0,36
	Feb 18	44	-7,68	2,00	0,30
	Feb 19	46	-7,30	2,09	0,31
	Feb 20	46	-7,65	2,16	0,32
	Feb 21	45	-8,66	2,52	0,38
	Feb 22	45	-7,76	2,34	0,35
	Feb 23	48	-8,01	2,41	0,35
	Feb 24	43	-8,10	1,93	0,29
	Feb 25	48	-7,03	2,47	0,36
	Feb 26	47	-7,55	2,58	0,38
	Feb 27	44	-7,58	2,49	0,38

The following table gives averaged offsets taken over the total number of common views for each period of comparison and corresponding mean residuals, chosen as estimates of the uncertainties (1σ). These estimates are conservative and take into account eventual systematic effects which can perturb the hardware of the involved GPS time receivers.

Lab	Period 1994	Total number of common views	Mean offset /ns	Estimated uncertainty /ns
OP	26 Jan - 02 Feb	314	-7,4	0,4
NPL	03 Feb - 11 Feb	221	-1,4	0,9
OP	14 Feb - 28 Feb	611	-7,7	0,4

It is noticeable that the two measurements carried out at OP, before and after the trip to NPL, are coherent.

It follows from the preceding table that the following differential time correction should be added to the GPS comparisons of the time scales kept by the visited laboratories:

$UTC(k_1)$ - $UTC(k_2)$	Differential correction /ns	Estimated uncertainty /ns
UTC(OP) - UTC(NPL)	−6,2	1,5 (1σ)

CONCLUSIONS

The offset found in the differential calibration exercise which took place in January - February 1994 between the GPS time receivers located at the Paris Observatory (OP), Paris, France, and the National Physical Laboratory (NPL), Teddington, United Kingdom, exceeds its estimated uncertainty. A correction should thus be applied in order to improve the accuracy of GPS time links carried out at that time between these laboratories.

But, on 23 March 1994 at 0h UTC, the internal delay of the GPS receiver NBS/TTR5 S/N051, in operation at OP, has been physically modified by 4 ns (see enclosed letter):

* till 23 March 1994, 0h UTC, the internal delay value entered in the receiver was 50 ns,
* since 23 March 1994, 0h UTC, the new value entered in the receiver has been 54 ns.

It follows that, since 23 March 0h UTC, the remaining differential time correction, which should be added to the comparisons of the time scales kept by the visited laboratories, OP and NPL, has been-2,2 ns with an estimated uncertainty of 1,5 ns (1σ). This correction is small and of the same order of magnitude than its uncertainty. In consequence, it is the view of the BIPM that, since 23 March 1994 0h UTC, no differential correction be applied when GPS time comparisons are made between these laboratories, and to keep without any modification the values of the internal delays presently introduced in the GPS time receivers at OP and NPL.

ACKNOWLEDGEMENTS

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