Rapport BIPM-93/5

BUREAU INTERNATIONAL DES POIDS ET MESURES

# DETERMINATION OF THE DIFFERENTIAL TIME CORRECTION BETWEEN THE GPS TIME RECEIVERS LOCATED AT THE PARIS OBSERVATORY, FRANCE, AND THE STANDARDS AND CALIBRATION LABORATORY, HONG KONG

by

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## 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: the comparison of the internal delays of the GPS time receivers located at the Paris Observatory (OP), France, and the Standards and Calibration Laboratory (SCL), Hong Kong, was carried out by means of a portable GPS time receiver belonging to the BIPM. The differential correction to be added to the GPS comparison of the time scales kept by the laboratories visited is 1,8 ns with an estimated uncertainty of 1,5 ns.



## 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: la comparaison des retards internes des récepteurs situés à l'Observatoire de Paris (OP), France, et au Standards and Calibration Laboratory, Hong Kong, a été effectuée au moyen d'un récepteur de temps du GPS portable appartenant au BIPM. La correction différentielle à ajouter aux valeurs de comparaisons des échelles de temps maintenues par les laboratoires visités est de 1,8 ns avec une incertitude estimée à 1,5 ns.

## 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.

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), France, and the Standards and Calibration Laboratory (SCL), Hong Kong, 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 SCL.

## 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 (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. |
| OP: | Maker | - Allen Osborne Associates, |
| | Type | - NBS/TTR5, |
| | Serial Number | - S/N051. |
| SCL: | Maker | - Allen Osborne Associates, |
| | Type | - NBS/TTR5A, |
| | Serial Number | - S/N0192. |

**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 is connected to the same clock as the local receiver, 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 20 including 40 tracks for Paris and 33 tracks for Hong Kong. As conditions of reception in Hong Kong are poor during the day six additional common views were added to the night-time schedule.

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.

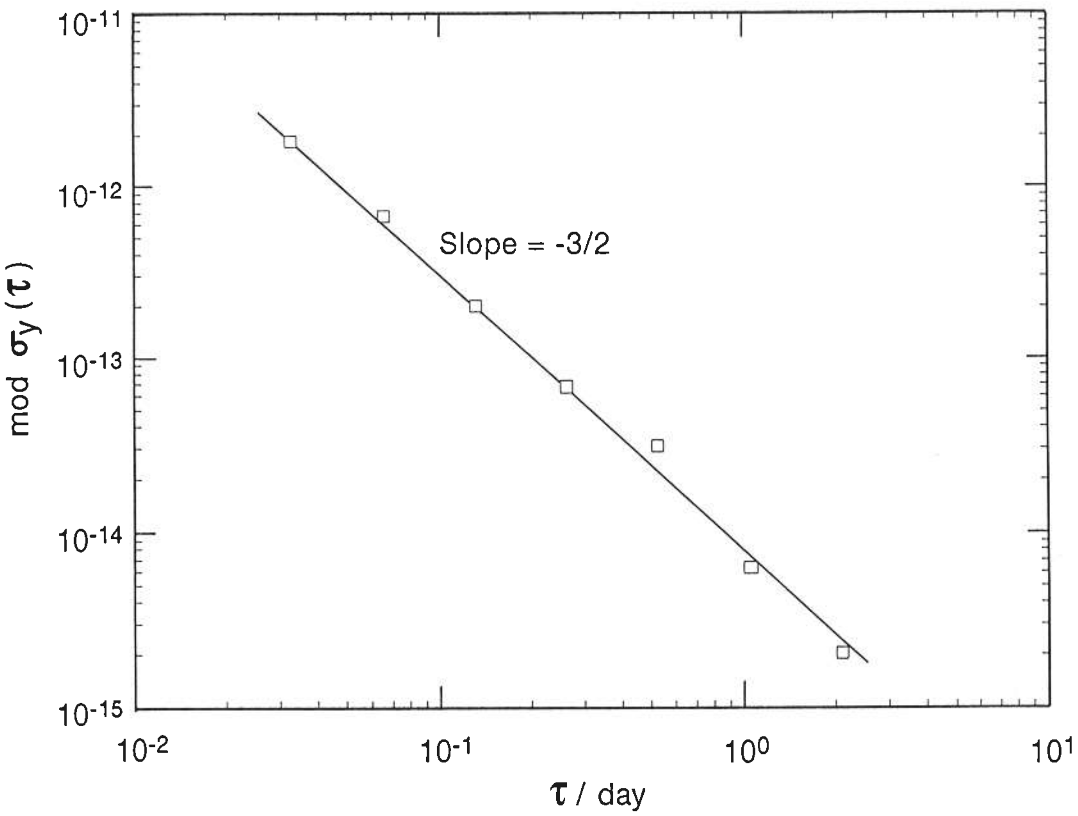
## RESULTS

The processing of the comparison data consists first of the computation, for each track i and for each lab k, of the time differences:

$$dt_{ki} = [UTC(k) - GPS\ time]_{BIPM3} - [UTC(k) - GPS\ time]_k.$$

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 SCL and back to OP, the quantities $dt_k$ exhibit white phase noise for an averaging time of one day. This is illustrated for the comparison at the OP during the period 25 May - 1 June 1993 on the figure below.




*Square root of the modified Allan variance of the quantity $dt_{NBS51}$ for the period 25 May - 1 June 1993.*

This justifies computation of a mean value for one-day periods and of the standard deviation of the mean as an expression of confidence of the mean.

The daily results of the comparisons are then as follows:

| Lab | Date 1993 | Number of individual common views | Mean offset /ns | Standard deviation of individual common views /ns | Standard deviation of the mean /ns |
|---|---|---|---|---|---|
| OP | April 20 | 16 | -3,02 | 2,80 | 0,70 |
| | April 21 | 37 | -3,30 | 3,21 | 0,53 |
| | April 22 | 35 | -2,80 | 2,09 | 0,35 |
| | April 23 | 16 | -2,86 | 2,94 | 0,74 |
| SCL | May 3 | 08 | -4,47 | 2,47 | 0,88 |
| | May 4 | 13 | -4,69 | 1,90 | 0,53 |
| | May 5 | 14 | -4,33 | 1,85 | 0,49 |
| | May 6 | 11 | -5,92 | 2,36 | 0,71 |
| | May 7 | 11 | -3,75 | 1,79 | 0,54 |
| | May 8 | 09 | -5,09 | 2,16 | 0,72 |
| | May 9 | 17 | -5,49 | 2,29 | 0,56 |
| OP | May 25 | 34 | -3,58 | 2,98 | 0,51 |
| | May 26 | 33 | -2,63 | 2,58 | 0,45 |
| | May 27 | 34 | -3,11 | 2,85 | 0,49 |
| | May 28 | 33 | -3,28 | 2,40 | 0,42 |
| | May 29 | 36 | -3,21 | 3,18 | 0,53 |
| | May 30 | 34 | -2,84 | 1,98 | 0,34 |
| | May 31 | 36 | -2,97 | 2,44 | 0,41 |
| | June 1 | 32 | -2,75 | 2,12 | 0,37 |

The following table gives the mean offsets taken over the total number of common views for each period of comparison. The corresponding uncertainties cannot be estimated through computation of the standard deviations of the means, because there is no indication of the presence of white phase noise covering the total duration of the comparisons, but merely a consistency of daily offsets within 1 ns. For this reason the value of 1 ns is chosen as a conservative estimate of the uncertainties.

| Lab | Period 1993 | Total number of common views | Mean offset /ns | Estimated uncertainty /ns |
|---|---|---|---|---|
| OP | 20 Apr - 23 Apr | 104 | -3,1 | 1,0 |
| SCL | 3 May - 9 May | 83 | -4,9 | 1,0 |
| OP | 25 May - 1 June | 272 | -3,0 | 1,0 |

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

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(SCL) | 1,8 | 1,5 |

## CONCLUSIONS

The offset found in the differential calibration exercise between the GPS time receivers located at the Paris Observatory, France, and the Standards and Calibration Laboratory, Hong Kong, is small and of the same order as its estimated uncertainty. In consequence, it is the view of the BIPM that no correction should be applied when GPS time comparisons are made between these laboratories, and to keep without any modification the values of the internal delays introduced in the GPS time receivers at OP and SCL.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