Rapport BIPM-91/6

BUREAU INTERNATIONAL DES POIDS ET MESURES

DETERMINATION OF DIFFERENTIAL TIME CORRECTIONS BETWEEN THE GPS TIME RECEIVERS LOCATED AT THE OBSERVATOIRE DE PARIS, THE OBSERVATOIRE DE LA COTE D'AZUR AND THE TECHNICAL UNIVERSITY OF GRAZ

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Abstract

Time comparisons by GPS satellite *common-view* method are performed on an operational basis with an accuracy of about 10 ns, which can be further improved with some precautions such as using measured ionospheric delays and precise satellite ephemerides. However one of the limiting factors to accuracy can be wrong calibration of the GPS time receivers involved in time transfer operations. The determination of differential time corrections for pairs of laboratories permits partial removal of calibration errors. This can be achieved by comparison of on-site receivers with a portable receiver successively in operation at one location then another. We report here the results of such a campaign organized under the auspices of the BIPM in April and May 1991. The comparison of the GPS receivers located at the Observatoire de Paris (Paris, France), the Observatoire de la Côte d'Azur (Grasse, France) and the Technical University of Graz (Graz, Austria) was effected by means of a portable GPS receiver belonging to the BIPM.

Résumé

Les comparaisons horaires utilisant les satellites du GPS en *vues simultanées* sont réalisées d'une manière opérationnelle avec une exactitude de l'ordre de 10 ns. Cette performance peut encore être améliorée avec quelques précautions telles que l'utilisation de retards ionosphériques mesurés et d'éphémérides précises de satellites. Cependant l'un des facteurs limitatifs en exactitude peut être le mauvais étalonnage des récepteurs de temps du GPS utilisés pour les comparaisons horaires. La détermination de corrections différentielles en temps pour chaque paire de laboratoires permet de réduire partiellement ces erreurs d'étalonnage. Ceci peut être réalisé pratiquement par comparaison des récepteurs locaux avec un récepteur portable mis en fonctionnement successivement à un site puis à l'autre. Nous donnons ici les résultats d'une campagne de ce type organisée par le BIPM en avril et mai 1991. La comparaison des récepteurs du GPS situés à l'Observatoire de Paris (Paris, France), à l'Observatoire de la Côte d'Azur (Grasse, France) et à l'Université Technique de Graz (Graz, Autriche) a été effectuée au moyen d'un récepteur du GPS portable appartenant au BIPM.

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 is of order 10 ns on an operational basis and can reach the level of a few nanoseconds with the use of measured ionospheric delays and post-processed precise satellite ephemerides [2].

Wrong calibration of GPS time receivers (instrumental delay, antenna cable, connection to the local clock) is one of the limiting factors to this accuracy. One possible method for some removal of calibration errors is the comparison of remote receivers by transfer of a portable receiver from one location to another [3] in order to determine differential time corrections. In the past, several campaigns for the comparison of GPS time receivers have been organized. Particularly notable were those of the U.S Naval Research Laboratory in December 1984 [4] and the BIPM and the NBS in October 1986 [3]. However, only a few of the receivers have been checked. Some received a single visit [5], but very few received two or more visits.

During such a campaign the reproducibility of the comparisons is of order 2 ns, but our experience concerning the long-term stability of receivers is limited, and drifts or steps of several tens of nanoseconds could occur without being noticed. Recently a sensitivity to the external temperature of one type of GPS time receiver was discovered [6]. For these reasons more frequent comparisons of receivers are required.

We report here the results of a campaign organized under the auspices of the BIPM. The comparison of the receivers located at the Observatoire de Paris (OP, Paris, France), the Observatoire de la Côte d'Azur (OCA, Grasse, France) and the Technical University of Graz (TUG, Graz, Austria) was effected by means of a portable GPS time receiver belonging to the BIPM here designated "BIPM2".

This campaign was associated with a separate experiment for the comparison of time transfers between the OCA and the TUG using both the *two-way* technique and the GPS *common-view* method.

INVOLVED RECEIVERS

In the comparisons of GPS receivers, as well as in current GPS time transfers, the receiver software, the adopted reference frames and the constants should be identical. Unfortunately, differences have been found in the software of receivers of different type [1,7,8]. A *Group of Experts on GPS Standardization* is now being set up under auspices of the CCDS Working Group on TAI [9]. Its task will be to prepare standards which can be adopted by receiver designers and users.

Fortunately for the present campaign all the receivers involved were of a single NBS design. They are single channel, C/A code receivers. Although they were constructed at different times, the essential features of these receivers were 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. All receivers involved in this campaign used a single trigger level of 0.5 V.

Principal characteristics of the receivers are listed below:

Portable receiver BIPM2:	Maker - Allen Osborne, Type - NBS/TTR6, Ser. Nr - S/N0262.
OP:	Maker - Allen Osborne, Type - NBS/TTR5, Ser. Nr - S/N051.
OCA:	Maker - Allen Osborne, Type - NBS, Ser. Nr - S/N053.
TUG:	Maker - NBS, Type - NBS, Ser. Nr - 03.

CONDITIONS OF COMPARISONS

The portable equipment consisted of the receiver, its antenna and a calibrated antenna cable. The individual laboratories supplied a) a 5 MHZ reference signal, b) a series of 1 s pulses from the local reference, UTC(lab), via a cable of known delay. The portable receiver in each laboratory was connected to the same clock as the local receiver, and the antenna of the portable receiver was placed close to the local antenna (less than 10 meters away). The differential coordinates of the antenna phase centres at each site were known with uncertainties of a few centimetres.

The receivers were programmed with a schedule of 48 tracks which included the *BIPM Common-View International Schedule No 16* of 35 tracks plus 13 additional tracks. About 40 common views were available for the comparisons at each site, including 5 Block I satellites and 5 Block II satellites. All common views were subjected to the following conditions: 240 s common-view tolerance, 780 s minimum duration of the track, 21° minimum elevation for satellites, 20 ns maximum RMS for 13-min track. As the Block II satellites during this campaign were free of Selective Availability, non strict common views were allowed.

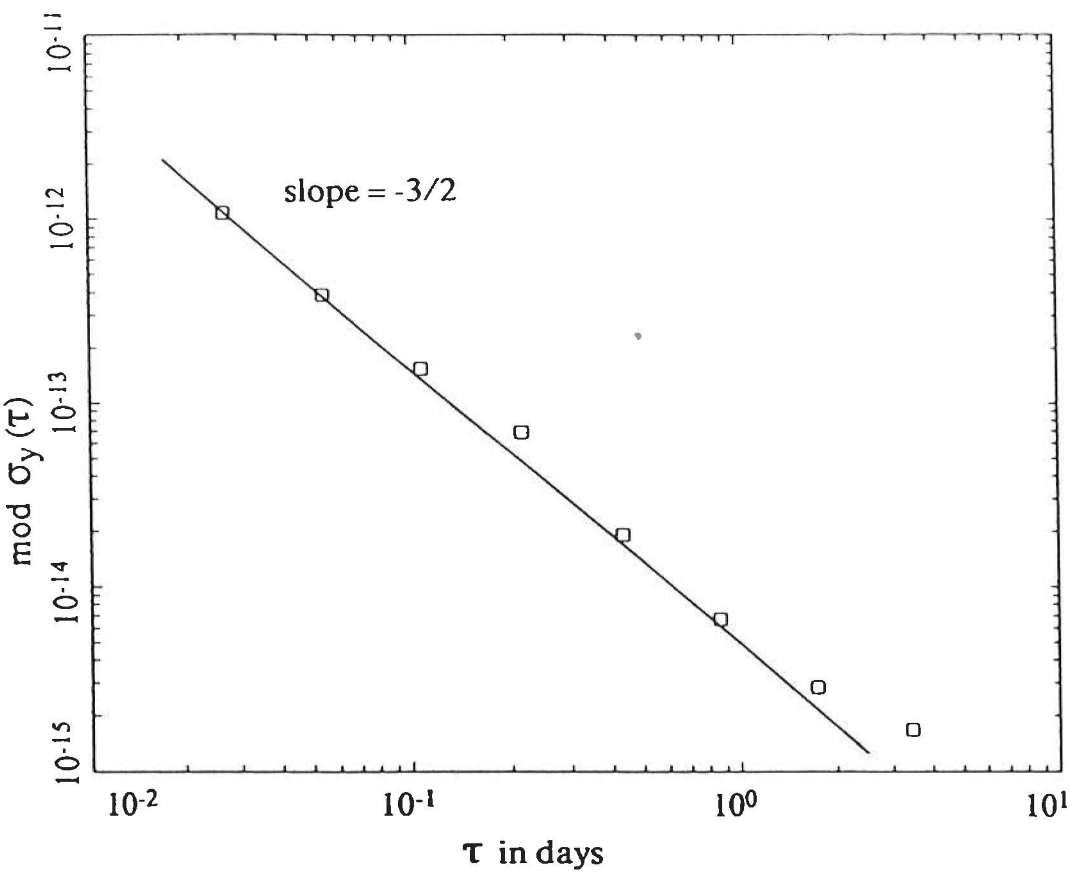
The comparison of two GPS receivers located on the same site is performed in conditions where time transfer errors due to satellite ephemeris errors and imperfect modelling of ionosphere are cancelled. In addition errors due to relative antenna coordinates are negligible. As all the receivers involved in this campaign are of the same type, software anomalies are cancelled. The comparison results are mainly perturbed by differences in measurements due to multipath reception and instabilities of receiver hardware.

RESULTS

The time differences $dt(i)_{loc.rec.}$ obtained at each laboratory for each track i are defined as:

$$dt(i)_{loc.rec.} = [UTC(lab) - GPS\ time(i)]_{BIPM2} - [UTC(lab) - GPS\ time(i)]_{loc.rec.}$$

They are analysed through the computation of modified Allan variances. As illustrated for the comparison at the OCA during the period May 1 - May 12, 1991 in figure below, the values $dt(i)_{loc.rec.}$ are affected of white phase noise up to one-day averaging interval.



Square root of the modified Allan variance of the differences
$dt(i)_{NBS53} = [UTC(OCA) - GPS\ time(i)]_{BIPM2} - [UTC(OCA) - GPS\ time(i)]_{NBS53}$
for the period May 1 - May 12, 1991.

This justifies the computation of a mean offset for one-day periods characterized by its standard deviation. It should be noted that this standard deviation of the mean reflects only the physical conditions during the involved one-day period of the comparison and gives no indication of the day-to-day reproducibility of the measurements.

The results of the comparisons are as follows:

Lab	Date 1991	Number of individual tracks	Daily mean offset (ns)	Standard deviation of individual track (ns)	Standard deviation of the mean (ns)
OP	Mar 30	35	-1.14	2.02	0.34
	Mar 31	38	-1.22	2.09	0.34
	Apr 1	38	-0.78	1.85	0.30
	Apr 2	36	-0.57	2.16	0.36
	Apr 3	37	-0.65	2.05	0.34
	Apr 4				
	Apr 5	33	-1.44	2.16	0.38
	Apr 6	38	-0.81	2.56	0.41
	Apr 7	37	-0.86	2.96	0.49
OCA	Apr 12	37	17.55	2.28	0.36
	Apr 13	40	17.59	1.91	0.30
	Apr 14	39	17.88	1.84	0.29
	Apr 15	38	17.47	1.82	0.29
TUG	Apr 23	36	9.85	2.14	0.36
	Apr 24	41	10.73	2.08	0.32
	Apr 25	40	10.26	1.82	0.29
	Apr 26	41	10.25	1.91	0.30
OCA	May 1	40	15.06	1.88	0.30
	May 2	39	15.59	1.35	0.22
	May 3	38	15.96	1.45	0.24
	May 4	37	16.40	1.44	0.24
	May 5	36	16.24	2.01	0.33
	May 6	37	15.90	1.39	0.23
	May 7	38	15.91	1.58	0.26
	May 8	38	15.86	1.42	0.23
	May 9	38	15.71	1.88	0.31
	May 10	33	15.31	1.60	0.28
	May 11	39	15.20	1.46	0.23
	May 12	39	14.97	1.50	0.24
OP	May 17	37	-2.09	2.12	0.35
	May 18	37	-2.03	1.88	0.31
	May 19	37	-1.98	2.60	0.43
	May 20	36	-1.27	2.20	0.37

For the periods of comparison at each laboratory, ranging from 4 to 12 days, daily offsets are consistent to within 1.5 ns. Mean offsets for each of these periods are given below:

Lab	Period 1991	Number of daily comparisons	Mean offset (ns)
OP	Mar 30-Apr 7	8	-0.9
OCA	Apr 12-Apr 15	4	17.6
TUG	Apr 23-Apr 26	4	10.3
OCA	May 1-May 12	12	15.7
OP	May 17-May 20	4	-1.8

Two repeated measurements at the OP and the OCA give indications of the reproducibility of the comparisons. Measurements made at the OP at the beginning and at the end of this campaign show offsets of -0.9 ns and -1.8 ns, and at the OCA, before the trip to the TUG, 17.6 ns and, after the return from the TUG, 15.7 ns. In between, were periods of 37 and 13 days of travel, carrying portable equipment in a car or a plane, packing and unpacking, with associated vibrations and temperature changes. The conditions of travel and the fact that changes in both laboratories occurred in the same direction suggest that the portable receiver changed its delay. The possibility of changes of the delays of the local receivers must also be considered. A recent study has shown some GPS receivers to be sensitive to the external temperature [6]. Other causes of delay changes, such as humidity or ageing of electronic components should also be considered.

The practical purpose of such a campaign is to give differential time corrections for pairs of involved laboratories. The following differential corrections should be added to the GPS comparisons of the time scales of the visited laboratories:

UTC(i)-UTC(j)	Differential time correction to be added to UTC(i)-UTC(j) (ns)	Estimated uncertainty (ns)
UTC(OCA)-UTC(OP)	18.0	1.0
UTC(TUG)-UTC(OP)	11.6	1.0
UTC(OCA)-UTC(TUG)	6.4	1.5

The above corrections were derived from the mean offsets evaluated over the periods of comparisons. Given uncertainties are conservative estimates from the repeated comparisons at the OP and the OCA.

CONCLUSION

The results of this campaign for the comparison of GPS time receivers at three European laboratories should bring a significant improvement to the accuracy of time transfer between them. The offsets measured between these receivers, in one case 18 ns, far exceed the impact of other errors of GPS *common-view* time transfer over several hundreds of km [1].

Two repeated comparisons at the OP and the OCA exhibited a change in the receivers' delays. The conditions of travel and the fact that changes in both laboratories occurred in the same direction suggest that the portable receiver changed its internal delay. The possibility of changes in the delays of the local receivers must also be considered.

This kind of comparison should be repeated from time to time in order to test the influence of ageing on time receivers. Environmental conditions such as temperature, humidity and multipath reflections should also be investigated.

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