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BUREAU INTERNATIONAL DES POIDS ET MESURES

DETERMINATION OF THE DIFFERENTIAL TIME CORRECTION BETWEEN GPS TIME EQUIPMENT LOCATED AT THE OBSERVATOIRE DE PARIS, PARIS, FRANCE, AND THE UNITED STATES NAVAL OBSERVATORY, WASHINGTON D.C., USA

by

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Abstract

The method of clock comparisons using GPS satellites can now reach an accuracy of several nanoseconds. Poor calibration of GPS time receiving equipment is one of the limiting factors to this accuracy. One method which permits removal of calibration errors is the comparison of remote GPS equipment by transporting a portable receiver from one location to another. We reported here the results of a comparison of the GPS equipment located at the Observatoire de Paris, Paris, France, and at the United States Naval Observatory, Washington D.C., USA. This comparison was effected by means of a portable AOA-TTR6 GPS time receiver and covered a period of one year.

Resumé

La méthode de comparaison des horloges en utilisant les satellites du GPS peut, à ce jour, atteindre une exactitude de quelques nanosecondes. Un mauvais étalonnage des équipements du temps du GPS constitue l'un des facteurs limitant cette exactitude. Une méthode qui permet d'éliminer les erreurs d'étalonnage consiste à comparer des équipements GPS distants par transport d'un récepteur GPS portable. Nous rapportons ici les résultats d'un étalonnage des équipements GPS situés à Paris, France et à l'Observatoire naval des Etats-Unis, Washington D.C., Etats-Unis d'Amérique. Cet étalonnage qui couvre une année d'observations a été effectué à l'aide d'un récepteur de temps du GPS portable modèle AOA-TTR6.

INTRODUCTION

The method of time transfer between remote locations using GPS satellites in common view has now achieved an accuracy of several nanoseconds [1]. Calibration errors in GPS time equipment (for example, receiver and antenna delays, cable delays, 1 pps distribution) limit this accuracy. One method which permits the removal of calibration errors is the comparison of remote GPS time equipment using a portable GPS time receiving equipment. Such calibrations were initiated in 1984 by the Naval Research Laboratory (NRL) with the support of the United States Naval Observatory (USNO) [2]. Since then a number of comparisons of remote GPS time receivers have taken place [3, 4].

The reproducibility of the comparisons from such exercises is a few nanoseconds, but our experience with the long-term stability of GPS time receiving equipment is still limited; drifts or steps of several tens of nanoseconds can occur without being noticed. Some types of GPS time receivers have been shown to be sensitive to external temperature [5, 6]. For these reasons, frequent comparisons of GPS equipment are required.

We report here the results of a calibration exercise organized under the auspices of the BIPM. Comparison of the receivers located at the Observatoire de Paris (OP), Paris, France, and the United States Naval Observatory, Washington D.C., USA, 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 the OP after a visit of 11 months to the USNO.

EQUIPMENT

The present comparison involves the USNO STel 502, the OP TTR5 051 and the portable TTR6 277 receiver belonging to the BIPM and designated BIPM3. The three receivers are single-channel, C/A code receivers. Their principal characteristics are:

Portable receiver: BIPM3	Maker: Allen Osborne Associates, Type: TTR6, Ser. No: 277, Adopted receiver internal delay + antenna cable delay: 290 ns,
OP:	Maker: Allen Osborne Associates, Type: TTR5, Ser. No: 051, Antenna cable length 33,00 m, Adopted receiver internal delay: 54 ns.

USNO: Maker: Stanford Telecommunications Inc.,
Type: STel 502,
Ser. No: 011,
Antenna cable length 30,48 m,
Adopted receiver internal delay: 135 ns.

The OP receiver serves as reference for many international comparisons of GPS time equipment. It has been compared 9 times in the last 12 years with the NIST 'on line', absolutely calibrated GPS time receiver. The differences between these two receivers have always been within a few nanoseconds.

Comparisons at short distances allow cancellation of a number of errors. If the software of the receivers compared is identical, no error should arise from satellite broadcast ephemerides, antenna coordinates or imperfect modelling of the ionosphere and troposphere.

Unfortunately, differences have been found in the software receivers of different type [1, 7]. The *Group on GPS Time Transfer Standards*, operating under the auspices of the permanent CCDS Working Group on TAI, has recently issued standards to be adopted by receiver designers and users concerned with the use of GPS time receivers for common-view time transfer [8]. These standards will soon be implemented in most GPS time receivers.

According to present information, the software in the two types of receivers involved in this exercise is identical except for the tropospheric model. Differences between the "AOA tropospheric model" and the "STel tropospheric model" are, however, small, less than 1 ns [9, 10], and have no impact on this comparison.

When the local time reference produces a pulse of poor shape, differences of trigger level between the receivers can produce a differential delay. The AOA receivers use a trigger level of 0,5 V and the STel receiver a trigger level of 0,8 V. At both locations, the rise time of local references is sharp, 4 ns at the OP and less than 1 ns at the USNO. The difference in trigger level therefore has no effect on this comparison.

CONDITIONS OF COMPARISON

For the present comparison, the portable equipment took the form of the receiver, its antenna and a calibrated antenna cable. The laboratories visited supplied 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 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 uncertainties of a few centimetres.

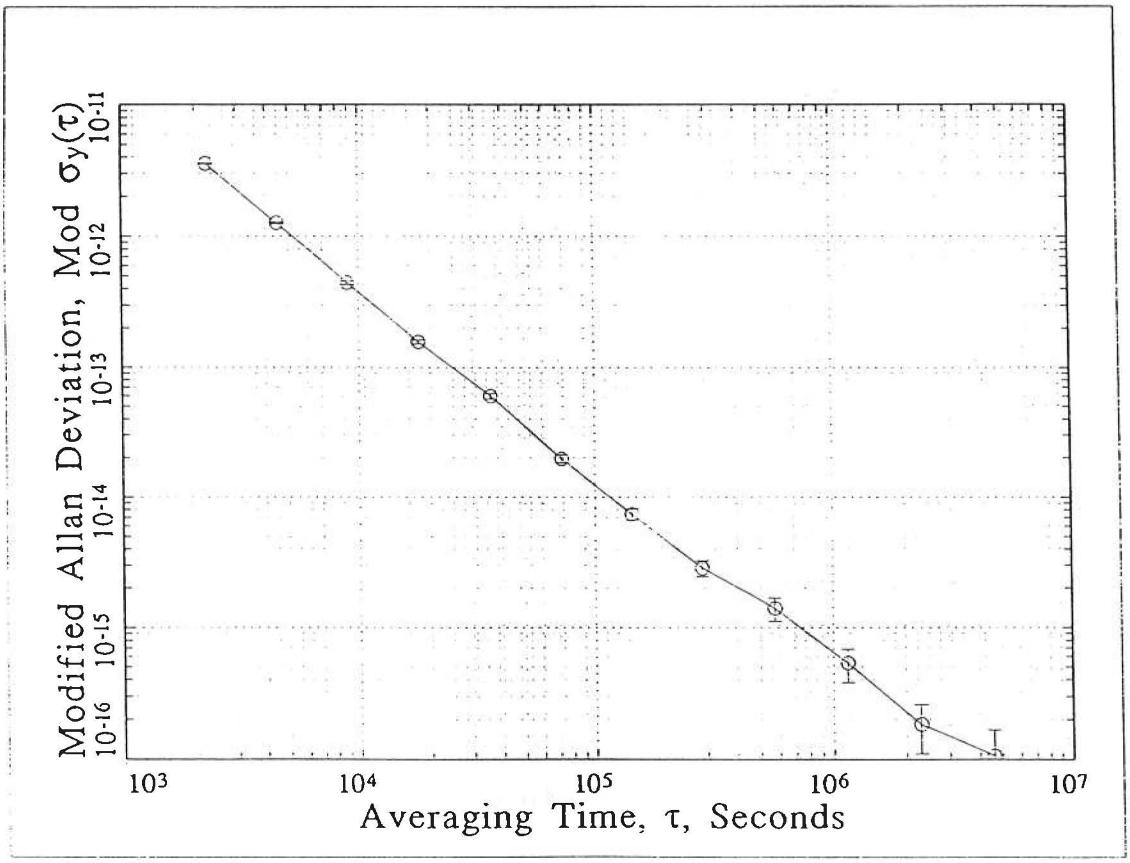
During the comparisons at the Paris Observatory, before and after the visit to Washington DC, the receivers were programmed with 48 tracks of the *BIPM Common-View International Schedules No 25* and *No 27* for Europe. During the comparison at the US Naval Observatory, the receivers were programmed with the *BIPM Common-View International Schedule No 25* and *No 26* for East North America of 42 tracks.

RESULTS

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

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

The noise exhibited by the time series $\mathbf{dt_k}$ is then analysed for the USNO by use of the modified Allan variance. It exhibits white phase noise up to an averaging interval of several tens of days (Figure 1).



τ/d

Figure 1. Square root of the modified Allan variance of the time series $\mathbf{dt_{USNO}}$ for the period July 20, 1995 - January 3, 1996.

This justifies computation of a mean offset for the whole period of comparison and corresponding standard deviations. We adopt the same procedure for each of the visited laboratories. It should be noted that the standard deviation of the mean reflects only the physical conditions during the period of the comparison and gives no indication of the period-to-period reproducibility of the measurements. The results are given in the following table.

Lab	Period	Total number of common views	Mean offset /ns	Standard deviation of individual common view /ns	Standard deviation of the mean /ns
OP	6-29 June 1995	697	-5,1	2,5	0,1
USNO	20 July 1995-26 June 1996	10254	-15,7	4,6	0,1
OP	3-25 July 1996	826	-0,9	3,3	0,1

Two repeated measurement at the OP give indication of the reproducibility of the comparisons. At the beginning and at the end of this exercise they show offsets of -5,1 ns and -0,9 ns (Table above and Figure 2). In between, the portable receiver experienced packing and unpacking, with associated vibrations and temperature changes. The possibility of changes of the delays of the local receivers is not completely excluded. It is now well documented and generally admitted that GPS time equipment is sensitive to external temperature [5,6]. A more detailed discussion of the possible impact of the external temperature on the USNO GPS time equipment is given in [13]. It can be seen that a correlation with external temperature was detected over short periods. The effect can sometimes hit about 5 ns peak to peak over a period of several days. No seasonal effect is evident, Figure 2.

From the preceding table, it can be seen that a differential time correction should be added to GPS comparisons of the time scales kept by the laboratories visited.

$UTC(k_1)-UTC(k_2)$	Differential time correction to be added to $UTC(k_1)-UTC(k_2)$ /ns	Estimated uncertainty for the period of comparison /ns
UTC(USNO)-UTC(OP)	-14	2 (1σ)

Uncertainties given in this table are conservative estimates which rely mainly on results of repeated comparisons at the OP.

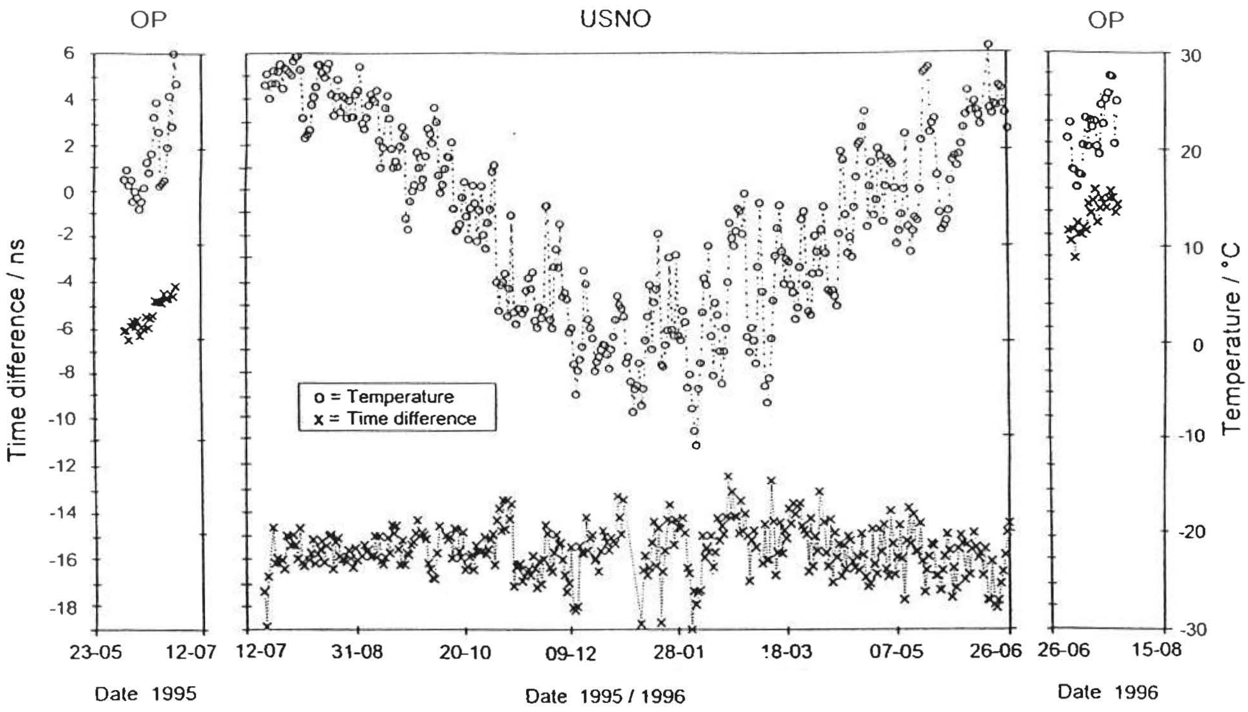


Figure 2. Daily averages of external temperature and daily averages of $\mathbf{dt_{OP}}$ and $\mathbf{dt_{USNO}}$.

CONCLUSION

This new determination of the differential time correction between GPS time receivers located at the USNO and at the OP of -14 ns differs from the -20 ns found in June 1995 [12] but agrees with -13 ns found in March 1994 [11]. This agrees also with the result of an absolute calibration of the STel 502 receiver by the Naval Research Laboratory in 1991 [14]. According to this calibration, the internal delay of the STel 502 receiver should be increased by 14 ns.

The offset found between the two sets of GPS time receiving equipment involved in this comparison exceeds the estimated uncertainty for the period of this comparison. It also exceeds the impact of other errors expected in GPS time transfer, linked for example to the quality of tropospheric and ionospheric models, satellite ephemerides, antenna coordinates,...[1]. For this reason the offset of 14 ns is significant and should be taken into account.

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