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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.

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 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 visit to the USNO.

This exercise is associated with a *field trial*, an international Two-Way Satellite Time Transfer (TWSTT) experiment through the satellite INTELSAT (VA-F13) located at 307° E, involving European and North-American time laboratories [7, 8, 9].

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, 10]. 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 [11]. 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 [12, 13], 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 Schedule No 24* for Europe. During the comparison at the US Naval Observatory, the receivers were programmed with the *BIPM Common-View International Schedule No 24* for East North America of 42 tracks plus 6 additional tracks. The number of programmed tracks was limited to the number allowed by the software of the AOA receivers.

RESULTS

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

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

The noise exhibited by the time series $\mathbf{dt_k}$ is then analysed for each laboratory by use of the modified Allan variance. For the comparisons at the OP, at the USNO and again at the OP, the time series $\mathbf{dt_k}$ exhibit white phase noise up to an averaging interval of one day (Figures 1, 2, 3).

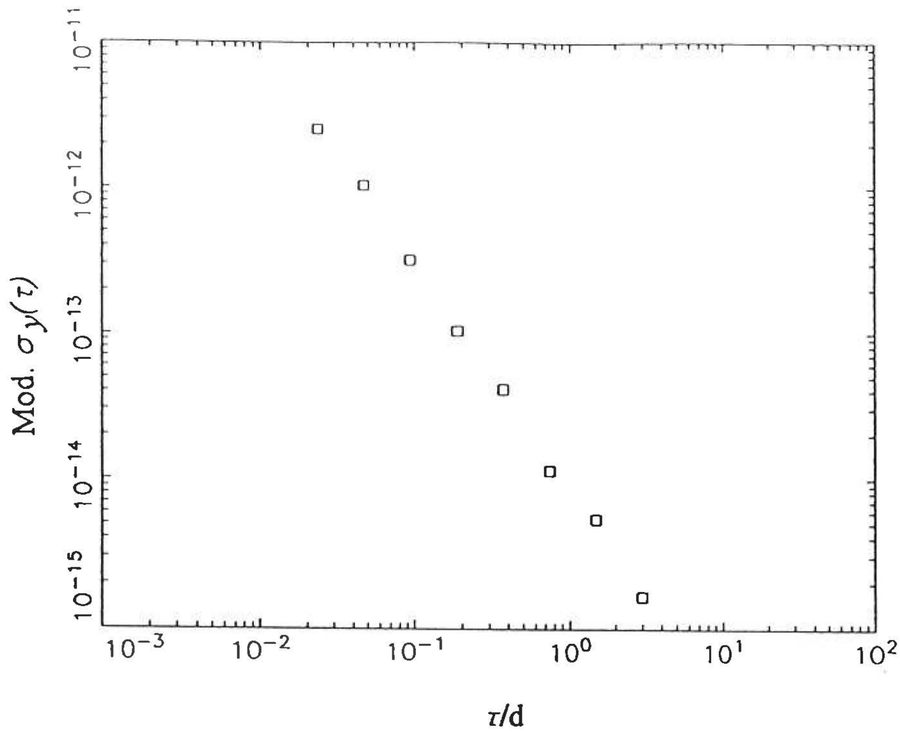

Figure 1. Square root of the modified Allan variance of the time series $\mathbf{dt_{OP}}$ for the period February 9-28, 1995.

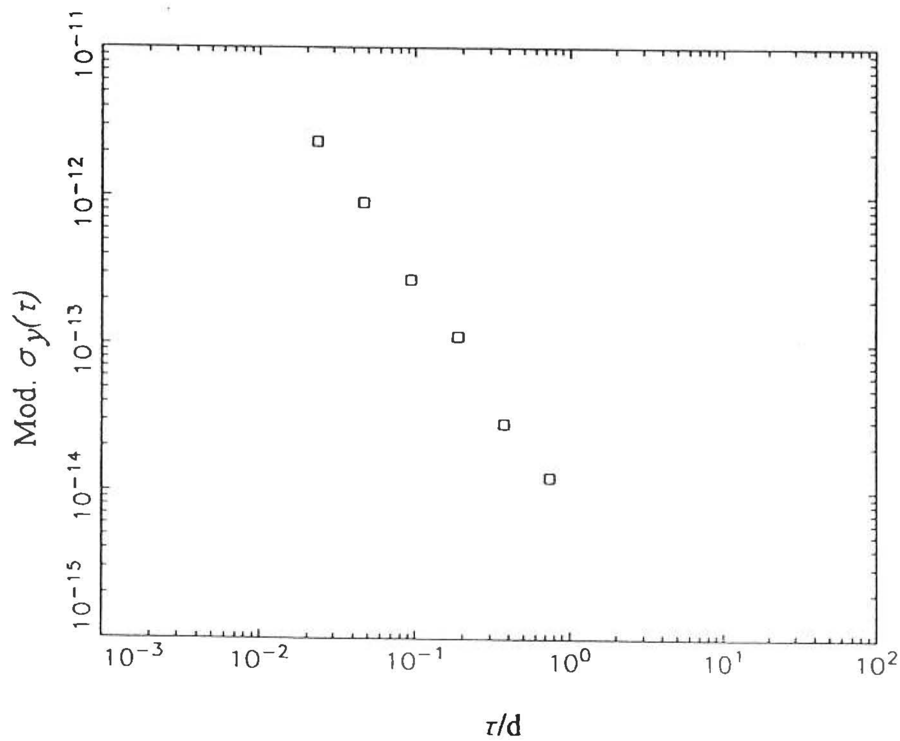

Figure 2. Square root of the modified Allan variance of the time series $\mathbf{dt_{USNO}}$ for the period March 1-5, 1995.

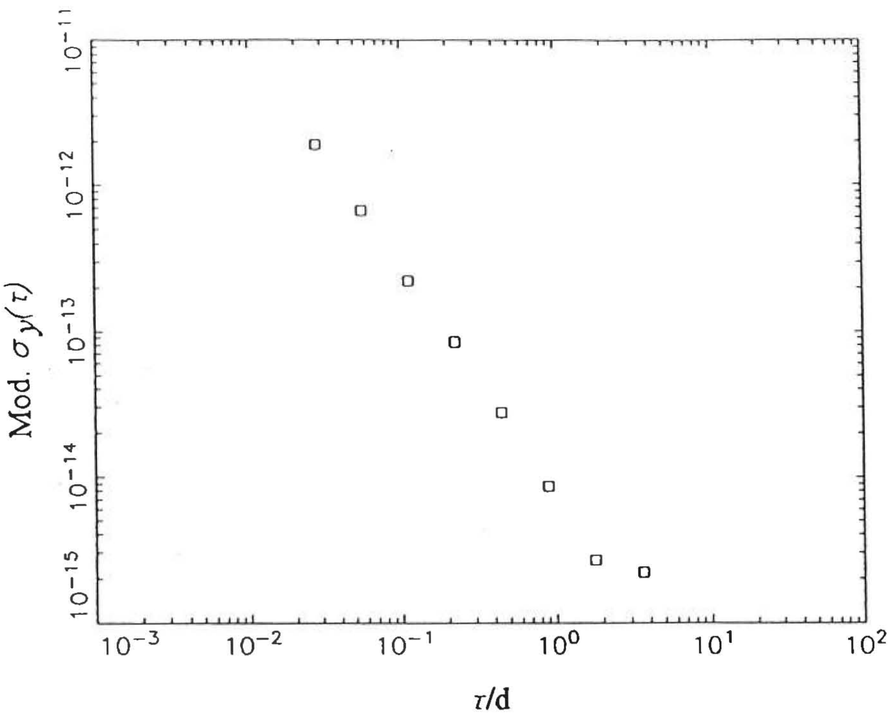

Figure 3. Square root of the modified Allan variance of the time series $\mathbf{dt_{OP}}$ for the period March 7-April 3, 1995.

This justifies computation of a mean offset for one-day periods and the use of the standard deviation of the mean as an expression of confidence in the mean. It should be noted that the standard deviation of the mean reflects only the physical conditions during the one-day period of the comparison and gives no indication of the day-to-day reproducibility of the measurements.

The daily results of the comparisons are as follows:

Lab	Date 1995	Number of individual common views	Mean offset /ns	Standard deviation of individual common view /ns	Standard deviation of the mean /ns
OP	Feb 9	15	-7,06	1,60	0,41
	Feb 10	37	-6,66	2,37	0,37
	Feb 11	37	-6,78	1,88	0,31
	Feb 12	37	-6,36	2,68	0,44
	Feb 13	36	-6,30	2,36	0,36

Lab	Date 1995	Number of individual common views	Mean offset /ns	Standard deviation of individual common view /ns	Standard deviation of the mean /ns
OP	Feb 14	38	-6,07	3,06	0,50
	Feb 15	39	-6,58	2,94	0,47
	Feb 16	39	-6,99	3,18	0,51
	Feb 17	37	-6,21	3,02	0,50
	Feb 18	37	-6,34	3,06	0,50
	Feb 19	37	-6,34	3,03	0,50
	Feb 20	38	-6,02	3,36	0,55
	Feb 21	38	-6,52	2,93	0,47
	Feb 22	38	-6,77	3,19	0,52
	Feb 23	38	-6,20	2,54	0,41
	Feb 24	37	-6,63	3,56	0,58
	Feb 25	38	-7,01	2,75	0,45
	Feb 26	32	-6,91	2,76	0,49
	Feb 27	38	-7,11	3,32	0,54
	Feb 28	13	-6,54	2,62	0,73
USNO	Mar 1	10	-26,44	2,70	0,85
	Mar 2	45	-26,51	3,15	0,47
	Mar 3	37	-26,82	2,53	0,42
	Mar 4	41	-26,05	2,96	0,46
	Mar 5	43	-26,32	2,89	0,44
OP	Mar 7	17	-6,20	2,59	0,63
	Mar 8	38	-6,00	2,66	0,43
	Mar 9	38	-6,62	3,05	0,50
	Mar 10	38	-6,02	2,74	0,44
	Mar 11	39	-6,15	3,23	0,52
	Mar 12	39	-6,40	3,27	0,52
	Mar 13	39	-5,80	3,09	0,50
	Mar 14	39	-6,22	3,54	0,57
	Mar 15	36	-6,03	3,07	0,51
	Mar 16	39	-5,62	2,98	0,48
	Mar 17	34	-5,75	2,77	0,48
	Mar 18	37	-5,70	2,17	0,36
	Mar 19	39	-6,37	2,58	0,41
	Mar 20	36	-6,29	1,44	0,24
	Mar 21	37	-5,93	2,33	0,38

Lab	Date 1995	Number of individual common views	Mean offset /ns	Standard deviation of individual common view /ns	Standard deviation of the mean /ns
OP	Mar 22	38	-5,73	2,17	0,35
	Mar 23	36	-4,96	2,67	0,44
	Mar 24	37	-5,71	2,95	0,49
	Mar 25	37	-5,75	2,52	0,41
	Mar 26	35	-5,64	2,94	0,50
	Mar 27	28	-6,52	2,34	0,44
	Mar 28	37	-6,95	1,96	0,32
	Mar 29	38	-6,21	2,53	0,41
	Mar 30	35	-6,36	2,38	0,40
	Mar 31	36	-5,19	1,73	0,29
	Apr 1	36	-5,51	2,67	0,45
	Apr 2	35	-5,16	2,97	0,50
	Apr 3	37	-4,55	3,35	0,55

The following table gives averages, and corresponding standard deviations, of the daily mean offsets for the whole period of comparison at each location.

Lab	Period 1995	Total number of common views	Mean offset /ns	Estimated uncertainty /ns
OP	Feb 9-28	699	-6,6	0,3
USNO	Mar 1-5	176	-26,4	0,3
OP	Mar 7-Apr 3	1010	-5,9	0,5

It is noticeable that the two measurements carried out at the OP, before and after the trip to the USNO, agree to within 1 ns.

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)	-20	2 (1σ)

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

CONCLUSION

This new determination of the differential time correction between GPS time receivers located at the OP and at the USNO is useful as a check of the delay stability of these two receivers. The offset of -20 ns differs from the offset of -13 ns found in June 1994 between the same receivers, STel 502 at the USNO and TTR5 051 at the OP [14]. A temperature dependence of the STel 502 receiver of roughly 0,5 ns/°C could be the explanation of this difference. As the mean temperature in Washington D.C. between beginning of March and beginning of June differs by roughly 15°C, the change found in the receiver delay is in reasonable agreement with this estimation. Further investigation of the behaviour of the receivers involved in this exercise is necessary.

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