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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 ISTITUTO ELETTROTECNICO NAZIONALE GALILEO FERRARIS, TORINO, ITALY

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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 report here the results of a comparison of the GPS equipment located at the Observatoire de Paris and at the Istituto Elettrotecnico Nazionale Galileo Ferraris, Torino, Italy. This comparison was effected by means of a portable AOA-TTR6 GPS time receiver.

Resumé

La méthode de comparaison des horloges qui utilise les satellites du GPS peut, à ce jour, atteindre une exactitude de quelques nanosecondes. Un mauvais étalonnage des equipements 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 equipements GPS distants par transport d'un récepteur GPS portable. Nous rapportons ici les résultats d'un étalonnage des equipements GPS situés à l'Observatoire de Paris, Paris, France et à l'Istituto Elettrotecnico Nazionale Galileo Ferraris, Turin, Italy. Cet étalonnage a été effectué à l'aide du récepteur du temps du GPS portable 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 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 receiver 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 calibration exercise organized under the auspices of the BIPM. Comparison of the receivers located at the Observatoire de Paris (OP), Paris, France and the Istituto Elettrotecnico Nazionale Galileo Ferraris (IEN), 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 IEN.

EQUIPMENT

All three receivers involved in this comparison are single-channel, C/A code receivers. Their principal characteristics are:

Portable receiver: BIPM3	Maker: Allen Osborne Associates, Type: NBS/TTR6, Ser. No: 277.
OP:	Maker: Allen Osborne Associates, Type: NBS/TTR5, Receiver Ser. No: 051.
IEN:	Maker: Allen Osborne Associates, Type: NBS/TTR5, Receiver Ser. No: 031.

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. This is the case for this comparison, where all involved receivers are of the NBS type.

Unfortunately, differences have been found in the software receivers of different type [1,8,9]. 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 [10]. These standards will soon be implemented in most GPS time receivers.

When the local time reference produces a pulse of poor shape, differences of trigger level between the receivers can produce a differential delay. Receivers involved in this exercise used a single trigger level of 0,5 V.

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 the receivers were programmed with the *BIPM Common-View International Schedule No 24* for Europe.

During this exercise the Block II satellites were subjected to Selective Availability (SA), so strict common views were required. All common views retained for the comparison fulfilled the following conditions: 15 s common-view tolerance, 765 s minimum duration of the track, 25° minimum elevation angle for satellites. The 15 s tolerance for common views is necessitated by a default in the AOA TTR receivers which begin observations 15 s later than scheduled. Values of the common views were computed for the midpoints of the 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)-GPS time]$_{BIPM3,i}$-[UTC(k)-GPS time]$_{k,i}$.

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

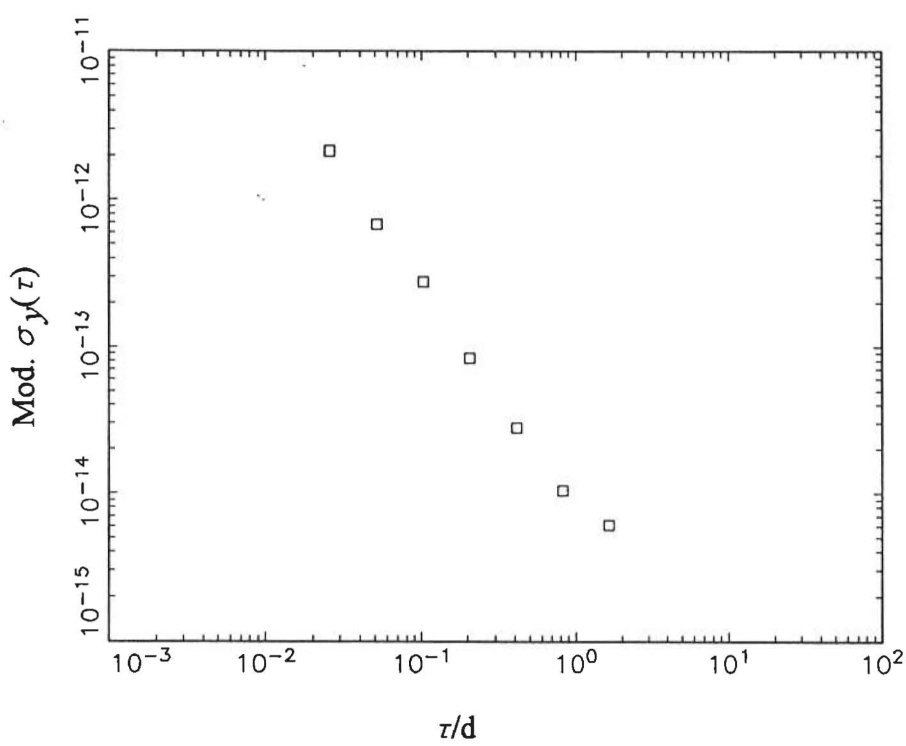

Figure 1. Square root of the modified Allan variance of the time series $\mathbf{dt_{OP}}$ for the period January 10-22, 1995.

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 of the mean. 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 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	Jan 10	17	-4,30	2,35	0,57
	Jan 11	41	-4,16	2,78	0,43
	Jan 12	40	-3,60	2,34	0,37
	Jan 13	39	-3,76	2,23	0,36
	Jan 14	39	-3,91	2,44	0,39
	Jan 15	36	-3,38	2,14	0,36
	Jan 16	41	-3,55	2,35	0,37
	Jan 17	39	-3,45	2,46	0,39
	Jan 18	41	-2,58	2,56	0,40
	Jan 19	39	-3,94	2,34	0,37
	Jan 20	30	-5,10	2,48	0,45
	Jan 21	36	-4,73	2,64	0,44
	Jan 22	36	-4,26	2,31	0,39
IEN	Jan 27	21	-25,78	2,53	0,55
	Jan 28	40	-25,84	2,13	0,39
	Jan 29	27	-25,79	2,46	0,47
	Jan 30	34	-25,98	2,37	0,41
	Jan 31	33	-24,94	2,14	0,37
	Feb 1	39	-25,77	2,01	0,32
	Feb 2	38	-25,08	2,23	0,36
	Feb 3	39	-25,60	2,22	0,36
	Feb 4	20	-25,85	2,97	0,66

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
	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

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	Jan 10-22	474	-3,9	0,6
IEN	Jan 27-Feb 4	291	-25,6	0,4
OP	Feb 9-28	699	-6,6	0,3

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 -3,9 ns and -6,6 ns. 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 has been shown that some GPS receivers are sensitive to the external temperature [5, 6], and humidity or ageing of electronic components could also be possible causes of delay changes.

The practical purpose of such a comparison is to estimate a differential correction to be applied to the pair of involved laboratories. The following differential correction should be added to the GPS comparison values between the time scales of the two visited laboratories:

$UTC(k_1)$-$UTC(k_2)$	Differential time correction to be added to $UTC(k_1)$-$UTC(k_2)$ /ns	Estimated uncertainty for the period of comparison /ns
UTC(IEN)-UTC(OP)	-20	2 (1 σ)

Uncertainty given in this table is conservative estimate which relies mainly on usual results obtained with repeated comparisons at the OP.

CONCLUSION

The results of the determination of differential time correction between the GPS time receivers located at the OP and at the IEN are useful to check the accuracy of time transfer between these two laboratories. The offset of -20 ns agrees, within the involved uncertainties, with the offset of -18 ns found in October 1986 between the same two receivers, NBS31 at the IEN and NBS51 at the OP [3].

Two repeated comparisons at the OP exhibited a change in the delays of the receivers. The conditions of travel suggest that the portable receiver probably changed its internal delay. It remains that changes in environmental conditions such as temperature, humidity and multipath reflections, should also be investigated in each location.

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