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BUREAU INTERNATIONAL DES POIDS ET MESURES

DETERMINATION OF THE DIFFERENTIAL TIME CORRECTIONS BETWEEN GPS TIME EQUIPMENT LOCATED AT THE OBSERVATOIRE DE PARIS, PARIS, FRANCE, THE OBSERVATOIRE DE LA COTE D'AZUR, GRASSE, FRANCE THE NATIONAL PHYSICAL LABORATORY, TEDDINGTON, UNITED KINGDOM, THE VAN SWINDEN LABORATORIUM, DELFT, THE NETHERLANDS, THE PHYSIKALISCH-TECHNISCHE BUNDESANSTALT, BRAUNSCHWEIG, GERMANY, THE FORSCHUNGS-UND TECHNOLOGIEZENTRUM, DARMSTADT, GERMANY, AND THE TECHNICAL UNIVERSITY, GRAZ, AUSTRIA

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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. The calibration exercise reported here took place from 15 September to 6 November 1994. It was coupled to the FAST portable station calibration trip around European time laboratories equipped with Two-Way Satellite Time Transfer stations.

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 le transport d'un récepteur GPS portable. La campagne d'étalonnage rapportée ici a eu lieu du 15 septembre au 6 novembre 1994. Elle était couplée à la campagne d'étalonnage des stations européennes utilisées pour les comparaisons horaires par aller et retour, realisée par transport d'une station portable (FAST station).

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 intercomparisons of GPS equipment are required.

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]. The laboratories, visited with portable TWSTT FAST station and portable GPS time receiver, were: the Observatoire de Paris (OP), Paris, France, the Observatoire de la Côte d'Azur (OCA), Grasse, France, the National Physical Laboratory (NPL), Teddington, United Kingdom, the Van Swinden Laboratorium (VSL), Delft, the Netherlands, the Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany, the Forschungs- und Technologiezentrum (FTZ), Darmstadt, Germany and the Technical University (TUG), Graz, Austria.

EQUIPMENT

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

Portable receiver: BIPM3	Maker: Allen Osborne Associates, Type: NBS/TTR6, Receiver Ser. No: 277.
OP:	Maker: Allen Osborne Associates, Type: NBS/TTR5, Receiver Ser. No: 051.
OCA:	Maker: Allen Osborne Associates, Type: NBS/TTR5, Receiver Ser. No: 053.
NPL:	Maker: Allen Osborne Associates, Type: NBS/TTR5A, Receiver Ser. No: 276.
VSL:	Maker: VSL, Type: NBS/TTR5 Receiver Ser. No: 01.
PTB:	Maker: Rockwell Collins, Type: NBS/TTR5.
FTZ:	Maker: VSL, Type: NBS, Receiver Ser. No: 19.
TUG:	Maker: NBS, Type: NBS, Receiver Ser. No: 03.

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 the same 0,5 V trigger level.

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 23* 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, 11° 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.

At the NPL, the external 5 MHz was accidentally disconnected from the BIPM3 receiver. The receiver automatically switched to its internal quartz oscillator. This is the reason of the noisiness of the NPL data. The time shift due to poor performance of the quartz oscillator was estimated and taken into account.

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).

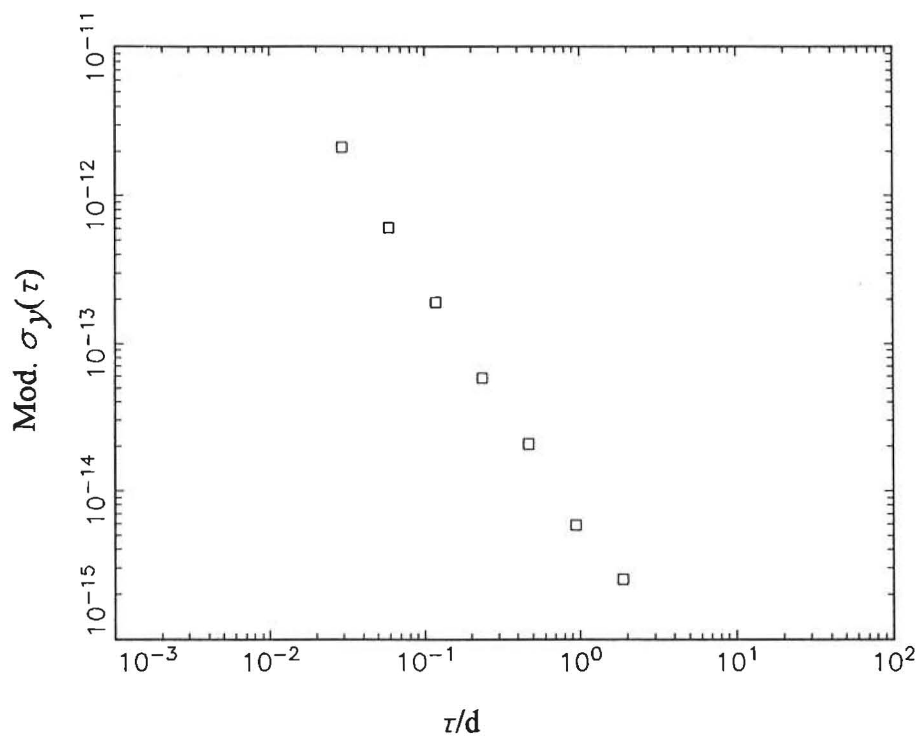

Figure 1. Square root of the modified Allan variance of the time series $\mathbf{dt_{OP}}$ for the period October 29-November 6, 1994.

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 1994	Number of individual common views	Mean offset /ns	Standard deviation of individual common view /ns	Standard deviation of the mean /ns
OCA	Sept 15	45	3,56	1,65	0,25
	Sept 16	35	3,54	1,49	0,25
	Sept 17	41	3,78	1,82	0,28
	Sept 18	41	4,55	1,60	0,25
OP	Sept 21	21	-2,58	2,28	0,50
	Sept 22	40	-1,85	2,06	0,32
	Sept 23	19	-2,31	2,21	0,51
NPL	Sept 26	10	-1,44	5,67	1,79
	Sept 27	11	-4,20	2,36	0,71
	Sept 28	12	-4,83	4,38	1,26
VSL	Oct 1	28	-0,78	2,36	0,45
	Oct 2	38	-0,37	2,12	0,34
	Oct 3	15	0,41	1,57	0,41
PTB	Oct 5	10	0,77	1,85	0,59
	Oct 6	29	0,96	2,29	0,43
	Oct 7	11	1,71	2,37	0,71
FTZ	Oct 11	16	0,90	3,44	0,86
	Oct 12	21	1,86	2,36	0,51
TUG	Oct 14	13	-0,80	1,24	0,34
	Oct 15	46	-1,42	1,92	0,28
	Oct 16	40	-1,10	1,67	0,26
	Oct 17	42	-1,13	1,42	0,22
OCA	Oct 22	21	1,29	1,90	0,41
	Oct 23	35	2,17	1,62	0,27
	Oct 24	33	2,45	1,56	0,27
	Oct 25	35	2,97	1,93	0,33
	Oct 26	34	2,75	1,57	0,27

Lab	Date 1994	Number of individual common views	Mean offset /ns	Standard deviation of individual common view /ns	Standard deviation of the mean /ns
OP	Oct 29	26	-4,76	1,34	0,26
	Oct 30	35	-4,46	3,10	0,35
	Oct 31	35	-4,25	3,05	0,35
	Nov 1	33	-5,12	2,11	0,33
	Nov 2	33	-4,06	2,68	0,33
	Nov 3	35	-3,69	2,21	0,35
	Nov 4	34	-3,76	2,65	0,34
	Nov 5	33	-2,95	2,48	0,33
	Nov 6	29	-3,92	1,42	0,29

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 1994	Total number of common views	Mean offset /ns	Estimated uncertainty /ns
OCA	Sept 15-18	162	3,9	0,5
OP	Sept 21-23	80	-2,2	0,4
NPL	Sept 26-28	33	-3,7	1,5
VSL	Oct 1-3	81	-0,2	0,6
PTB	Oct 5-7	50	1,1	0,5
FTZ	Oct 11-12	37	1,4 *	0,7
TUG	Oct 14-17	141	-1,1	0,3
OCA	Oct 22-26	158	2,3	0,6
OP	Oct 29-Nov 6	293	-4,1	0,6

*) Before 11 October 1994 15 h UTC: -16 ns.

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 exercise show offsets of -2,2 ns and -4,1 ns, and at the OCA, 3,9 ns and 2,3 ns. In between, the portable receiver travelled for more than one month and experienced packing and unpacking, with associated vibrations and temperature changes. In addition, changes in both laboratories occurred in the same direction. This suggests that the portable receiver probably changed its delay. However, 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 preceding table makes it possible to derive differential time corrections to be added to GPS comparisons of any pair of laboratories. Below are given corrections to be added to GPS comparisons of the time scales kept by the laboratories visited and the time scale UTC(OP).

$UTC(k_1)-UTC(k_2)$	Differential time correction to be added to $UTC(k_1)-UTC(k_2)$ /ns	Estimated uncertainty for the period of comparison /ns
UTC(OCA)-UTC(OP)	6	2 (1 σ)
UTC(NPL)-UTC(OP)	0	3 (1 σ)
UTC(VSL)-UTC(OP)	3	2 (1 σ)
UTC(PTB)-UTC(OP)	4	2 (1 σ)
UTC(FTZ)-UTC(OP)	5 *	2 (1 σ)
UTC(TUG)-UTC(OP)	2	2 (1 σ)

*) Before 11 October 1994 15 h UTC: -12 ns.

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

CONCLUSION

In several cases, the offsets found between the GPS time receiving equipments involved in this exercise exceed the impact of errors usually expected in GPS time transfer, linked for example to the quality of tropospheric and ionospheric models, satellite ephemerides, antenna coordinates,...[1].

Two repeated comparisons at the OP and the OCA exhibited a change in the delays of the receivers. The conditions of travel and the fact that changes in both laboratories occurred in the same direction 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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