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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 VAN SWINDEN LABORATORIUM, DELFT, THE NETHERLANDS

by

W. Lewandowski

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Pavillon de Breteuil, F-92312 SEVRES Cedex

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 Van Swinden Laboratorium, Delft, the Netherlands. 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 au Van Swinden Laboratorium, Delft, Pays-Bas. 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 Van Swinden Laboratorium, Delft (VSL), 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 VSL.

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.
VSL:	Maker: VSL, Type: NBS/TTR5, Receiver Ser. No: 01.

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).

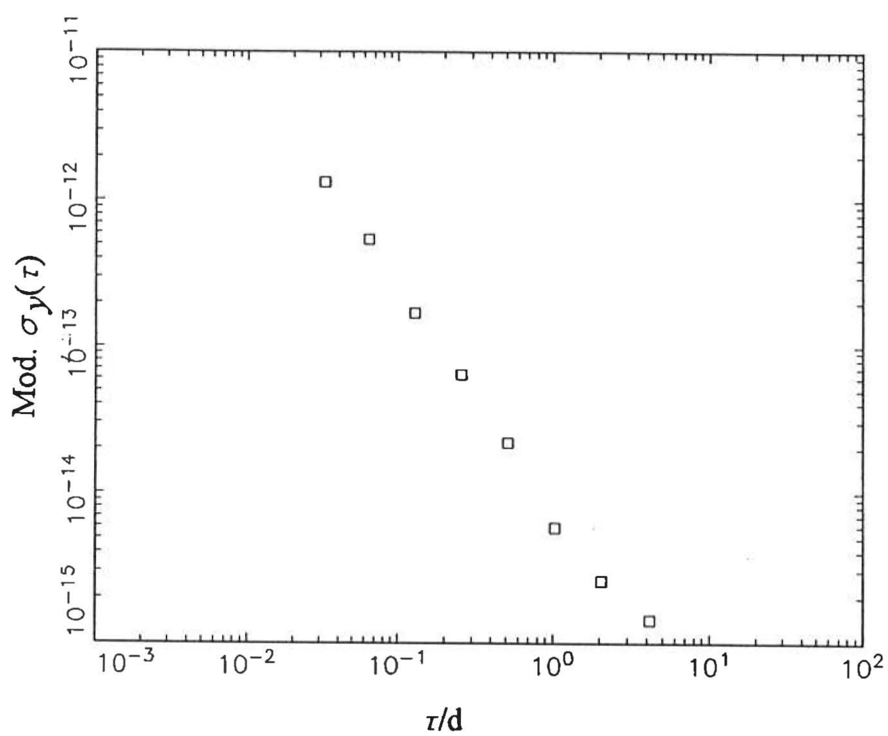

Figure 1. Square root of the modified Allan variance of the time series $\mathbf{dt_{OP}}$ for the period June 6-25, 1995.

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	Apr 24	15	-5,25	2,70	0,70
	Apr 25	36	-5,05	2,50	0,42
	Apr 26	35	-5,08	3,16	0,53
	Apr 27	35	-5,89	2,83	0,48
	Apr 28	35	-6,50	2,24	0,38
	Apr 29	33	-5,79	1,97	0,34
	Apr 30	35	-6,20	2,67	0,45
	May 1	34	-6,70	2,03	0,35
	May 2	34	-5,38	2,43	0,42
	May 3	34	-5,12	2,65	0,45
	May 4	32	-6,45	1,99	0,35
	May 5	34	-5,03	2,04	0,35
	May 6	33	-4,70	1,70	0,30
	May 7	25	-4,69	2,82	0,56
	May 8	34	-4,51	2,47	0,42
	May 9	30	-4,57	2,36	0,43
	May 10	35	-5,00	2,44	0,41
	May 11	34	-4,55	2,42	0,42
	May 12	33	-4,08	2,85	0,50
	May 13	33	-4,18	2,25	0,39
	May 14	35	-4,77	2,99	0,51
VSL	May 22	26	-0,08	2,70	0,53
	May 23	39	-0,68	2,64	0,45
	May 24	30	0,49	2,58	0,44
	May 25	36	0,89	2,46	0,42
	May 26	36	-0,12	3,03	0,52
	May 27	31	-0,66	2,38	0,43
	May 28	36	-0,63	2,86	0,48
	May 29	34	-0,04	2,79	0,48

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	June 6	11	-5,88	1,90	0,57
	June 7	33	-6,11	2,02	0,35
	June 8	33	-6,55	2,44	0,42
	June 9	32	-5,95	2,16	0,38
	June 10	32	-5,71	2,27	0,40
	June 11	32	-5,00	2,09	0,37
	June 12	33	-5,66	2,71	0,47
	June 13	31	-6,37	2,15	0,39
	June 14	31	-5,96	3,09	0,55
	June 15	29	-6,09	2,01	0,37
	June 16	32	-5,54	2,99	0,53
	June 17	30	-6,01	2,26	0,41
	June 18	33	-5,60	2,58	0,45
	June 19	29	-5,48	2,99	0,56
	June 20	31	-4,82	2,93	0,53
	June 21	29	-4,91	2,09	0,39
	June 22	31	-4,86	2,18	0,39
	June 23	33	-4,92	2,60	0,45
	June 24	31	-4,51	2,76	0,50
	June 25	34	-4,77	3,01	0,52

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	Apr 24-May 14	684	-5,2	0,8
VSL	May 22-29	268	-0,1	0,6
OP	June 6-25	610	-5,5	0,6

Two repeated measurements at the OP give an indication of the reproducibility of the comparison, which in this case is of 0,3 ns. This value is rather small when compared to the offsets of about 2 ns or 3 ns, usually obtained in such experiments [3, 11].

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(VSL)-UTC(OP)	5	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 VSL are useful to check the accuracy of time transfer between these two laboratories. The offset of 5 ns agrees, within the involved uncertainties, with the offset of 3 ns found in October 1994 between the same two receivers, VSL01 at the VSL and NBS51 at the OP [11].

This kind of comparison should be repeated from time to time in order to check the aging of the receivers. Environmental conditions such as temperature, humidity and multipath reflections, should also be investigated in each location.

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REFERENCES

[1] W. Lewandowski, C. Thomas, "GPS Time Transfer," in Proceedings of *the IEEE Special, Issue on Time and Frequency,* pp. 991-1000, July 1991.

[2] J.A. Buisson, O.J. Oaks, M.J. Lister, "Remote Calibration and Time Synchronization (R-CATS) Between Major European Time Observatories and the US Naval Observatory Using GPS," *Proc. 17th Annual PTTI meeting,* pp. 201-222, 1985.

[3] W. Lewandowski, M. Weiss, D. Davis, "A Calibration of GPS Equipment at Time and Frequency Standards Laboratories in the USA and Europe, *Proc. 18th PTTI,* pp. 265-279, 1986, also in *Metrologia,* **24**, pp 181-186, 1987.

[4] W. Lewandowski, "Determination of differential time correction between the GPS time receivers located at the Observatoire de Paris, the Observatoire de la Côte d'Azur and the Technical University of Graz," *BIPM Report 91/6,* 1991.

[5] W. Lewandowski and R. Tourde, "Sensitivity to the External Temperature of some GPS Time Receivers," *Proc. 22nd PTTI,* pp. 307-316, 1990.

[6] D. Kirchner, H. Ressler, P. Grüdler, F. Baumont, Ch. Veillet, W. Lewandowski, W, Hanson, W. Klepczynski, P. Uhrich, "Comparison of GPS Common-view and Two-Way Satellite Time Transfer Over a Baseline of 800 km," *Metrologia,* **30**, pp. 183-192, 1993.

[7] J.A. Davis, P.R. Pearce, D. Kirchner, H. Ressler, P. Hetzel, A Söring, G. De Jong, F. Baumont, L. Veenstra, "Two-Way Satellite Time Transfer Experiments Between Six European Laboratories Using the INTELSAT (VA-F13) Satellite", *Proc. 8th EFTF,* pp. 296-314, March 94.

[8] W.J. Klepczynski, J.A. Davis, D. Kirchner, H. Ressler, G. de Jong, F. Baumont, P. Hetzel, A. Soering, Ch. Hackman, M. Granveaud, W, Lewandowski, "Some Preliminary Results of the Fast Calibration Trip During the INTELSAT Field Trials ", *Proc. 26th PTTI,* pp. 89-94, 1994.

[9] D. Kirchner, H. Ressler and S. Fassl, "Experience with two collocated C/A code GPS receivers of different type," *Proc. 3rd EFTF,* pp. 94-103, March 1989.

[10] The Group on GPS Time Transfer Standards, "Technical Directives for Standardization of GPS Time Receiver Software," *BIPM Report 93/6,* 1993.

[11] W. Lewandowski and F. Baumont, "Determination of differential time correction between the Observatoire de Paris, Paris, France, the Observatoire de la Côte 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," *BIPM Report 94/12,* 1995.