# THE USE OF THE AOA TTR-4P GPS RECEIVER IN OPERATION AT THE BIPM FOR REAL-TIME RESTITUTION OF GPS TIME

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## Abstract

*The Global Positioning System is an outstanding tool for the dissemination of time. Using mono-channel C/A-code GPS time receivers, the restitution of GPS time through the satellite constellation presents a peak-to-peak discrepancy of several tens of nanoseconds without SA but may be as high as several hundreds of nanoseconds with SA. As a consequence, civil users are more and more interested in implementing hardware and software methods for efficient restitution of GPS time, especially in the framework of the project of a real-time prediction of UTC, UTCp, which could be available in the form of time differences [UTCp - GPS time].*

*Previous work, for improving the real-time restitution of GPS time with SA, to the level obtained without SA, focused on the implementation of a Kalman filtering based on past data and updated at each new observation. An alternative solution relies upon the statistical features of the noise brought about by SA: it has already been shown that the SA noise is efficiently reduced by averaging data from numerous satellites observed simultaneously over a sufficiently long time.*

*This method has been successfully applied to data from a GPS time receiver, model AOA TTR-4P, connected to the caesium clock kept at the BIPM. This device, a multi-channel, dual-frequency, P-code GPS time receiver, is one of the first TTR-4P units in operation in a civil laboratory. Preliminary comparative studies of this new equipment with conventional GPS time receivers are described in this paper. The results of an experimental restitution of GPS time, obtained in June 1993, are also detailed: 3 to 6 satellites were observed simultaneously with a sample interval of 15 s, a efficient smoothing of SA noise was realised by averaging data on all observed satellites over more than 1 hour. When the GPS system is complete in 1994, 8 satellites will be observable continuously from anywhere in the world and the same level of uncertainty will be obtained using a shorter averaging time.*

## INTRODUCTION

The NAVSTAR Global Positioning System, GPS, is a military satellite navigation system based on satellite ranging using on-board atomic clocks. It can also be used as a time distribution system for a user who has a known position and who tracks at least one satellite. The time scale, GPS time, distributed by the GPS satellites is a continuous time, maintained in agreement with UTC(USNO) to within 100 ns [1].

Observational data delivered by GPS time receivers represent time differences between the 1pps (1 pulse-per-second) of the user's local clock and GPS time, as deduced from the received signal of a given GPS satellite. Such timing-data may be used for time transfer purposes by the common-view method [2]. The principal feature of this method is that satellite clock error contributes nothing, as GPS time disappears in the difference. This is of utmost interest during implementation of Selective Availability (SA) [3]. The ultimate accuracy of the common-view mode is a few nanoseconds [4].

The GPS timing data may also be exploited for access to the time scale GPS time and hence to reference time scales such as UTC(USNO) or a even a real-time prediction of UTC [5]. The

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precision of access to GPS time depends on local conditions 'of observation, mainly on the quality of the receiver antenna coordinates. Generally, the realization of GPS time through the constellation shows a peak-to-peak discrepancy, at a given instant, of up to 30 ns. However, this performance is largely degraded by implementation of Selective Availability. The real-time restitution of GPS time from Block II satellites then suffers peak-to-peak discrepancies up to several hundreds of nanoseconds as shown in Section 1 of this paper.

Previous studies have been carried out for real-time processing of local GPS timing data with the aim of improving the restitution of GPS time, in the case of SA, to a level comparable with that obtained without SA. One possible solution relies upon Kalman filter theory [6]. This method, which provides a real-time access to GPS time from filtered past data and from present observations, is efficient even if little data is available but is rather heavy to put in operation. A much simpler solution can be used when a greater amount of data is available. This relies upon the statistical features of the noise brought about by SA [7,8]: it is shown in Section 2 that, for an averaging time of a few hundreds of seconds, the SA noise is white and corresponds to an uncertainty (1σ) of about 85 ns. It follows that an average of data from numerous Block II satellites, observed simultaneously, greatly decreases the impact of SA. This method has been successfully applied to data from a GPS time receiver, model AOA TTR-4P, connected to the caesium clock kept at the BIPM. This device, a multi-channel, dual-frequency, P-Code GPS time receiver, is one of the first TTR-4P units in operation in a civil laboratory. Preliminary comparative studies of this new equipment with conventional GPS time receivers are given in Section 3, together with results of the test of restitution of GPS time.

## 1. REAL-TIME ACCESS TO GPS TIME FROM THE OBSERVATION OF ONE GPS SATELLITE

Data from a GPS time receiver take the form of time differences [Local Clock - GPS time (SV)](t) as obtained through observation of satellite SV over a time interval centred on date t. Quantitative information on the precision of real-time access to GPS time at date t, may be obtained by comparison of this raw observation with a deferred-time estimation of [Local Clock - GPS time](t), achieved through the application of a smoothing technique on a set of data from Block I satellites not affected by SA.

Such estimates are regularly made at the BIPM, which publishes values of [UTC - GPS time] in its monthly bulletin, *Circular T.* An example is shown in Fig. 1.a. for the two-month period February-March 1992, with data following the international GPS common-view schedule. The precision of GPS time restitution can be expressed in terms of the root mean square, r, of the residuals to the smoothed values; here r = 7,3 ns. This value, deduced from Block I satellite data only, reflects the impact of systematic errors due to conditions of observation:

    i. residual errors in local antenna coordinates, in general very small for national timing centres contributing to TAI [9],

    ii. errors in estimating the ionospheric delay of GPS signals, here negligible as measured ionospheric delays are used [10],

    iii. errors in ephemeride parameters broadcast by the satellite [11],

    iv. other minor error sources such as multipath effects and the sensitivity of the local receiver to external temperature [12]).

The r value can as large as 10 ns when measured ionospheric delays are not available [8].

In Fig. 1.b. are shown the smoothed values [UTC - GPS time] of Fig. 1.a., together with raw data obtained from a selection of Block II satellites. The impact of SA may be expressed quantitatively as r equal to 48 ns, which is much larger than the value 7,3 ns obtained from Block I. It follows that with reasonable conditions of observation, the real-time reading of the quantity [Local Clock - GPS time] presents discrepancies up to 30 ns from Block I

satellites and up to 150 ns from Block II satellites. It is thus essential to design and implement hardware and software solutions for efficient real-time restitution of GPS time.

## 2. REAL-TIME ACCESS TO GPS TIME FROM THE SIMULTANEOUS OBSERVATION OF A NUMBER OF BLOCK II SATELLITES

If real-time access to GPS time is degraded to the level of 150 ns from the observation of one single Block II satellite, one could imagine that further information, from the simultaneous tracking of several Block II satellites, would permit a lower value to be obtained. To develop a procedure based on this idea, it is first necessary to have a good knowledge of the statistical properties of the SA noise.

For this purpose, timing data from different Block II satellites have been analysed at the BIPM. They correspond to 15 s data sequentially recorded with a one-channel C/A-code receiver at the BIPM on 10, 11 and 12 February 1993. Four different Block II satellites (SV 16, 19, 26, 27) and one Block I satellite (SV 12) were observed for several hours (from rising up to going down).

Figure 2.a. shows a plot of 15 s raw data recorded for satellite 26 over more than 4 consecutive hours. The Allan deviation computed with this timing data is reported in Fig. 2.b. together with the Allan deviation values obtained with 15 s data from SV 12. Timing data from SV 12 shows white phase noise, the level of which is about 15 s, for all averaging times. It corresponds to observational noise, as detailed in Section 1. The same noise is apparent on Block II data for the very short term, up to $\tau = 30$ s. In the longer term, the SA degradation brings additional noise, characterized by the typical Allan deviation 'bump', which corresponds to sinusoidal variations of timing data with a half-period of order 150 s. For larger $\tau$ (240 s to about 2000 s), the predominant noise is white phase noise, corresponding to a level of about 85 ns. White phase noise can be reduced by using simple averages. Figure 2.c. shows the timing data from SV 26, after smoothing out of both of the short-term and long-term white phase noise. The corresponding Allan deviation values are added in Fig. 2.b.: they show the efficiency of the smoothing procedure. Figure 2.c. clearly indicates the presence of residual sinusoidal variations with periods of order some hundreds of seconds.

The same analysis has been performed with observational data from different Block II satellites. The corresponding Allan deviations are reported in Fig. 3. for four of them. This demonstrates that the SA noise has the same statistical features in each of the four examples, though the corresponding satellites were not tracked simultaneously. One can thus reasonably make the hypothesis that all Block II satellites are affected by white phase noise of comparable level, 85 ns (1σ), over averaging times longer than 240 s. For the usual 780 s tracks, the SA noise is thus reduced by a factor $\sqrt{780}/\sqrt{240}$. It gives a residual SA noise equal to 47 ns (1σ), a value which corresponds to what is reported in Section 1.

The statistical analysis of the noise brought about SA on timing data has very important consequences. With all Block II satellites affected by white phase noise of comparable level, 85 ns (1σ), over averaging times longer than 240 s, it is sufficient, to reduce SA effects, to observe simultaneously a number of Block II satellites over long averaging times and to compute a mean of the individual satellite results. For example, observation of 8 satellites with a multi-channel receiver for a 2000 s track-length reduces the level of the SA white noise to about 10 ns. This is comparable with the usual observational noise. In addition, the result of the mean may be obtained immediately after data recording, thus providing access to GPS time in near real-time. This method was tested using data from an AOA TTR-4P unit in operation at the BIPM.

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## 3. USE OF THE AOA TTR-4P AT THE BIPM FOR REAL-TIME ACCESS TO GPS TIME

### 3.1. Brief Description of the AOA TTR-4P

The Allen-Osborne-Associates TTR-4P is a GPS receiver adapted to high accuracy time measurements. This device is issued from the largely digital Turbo-Rogue geodesic receiver. As is usual in GPS time receivers, it accepts the 1pps, delivered by a local caesium clock, as input together with a stable 5 MHz or 10 MHz signal. It operates with a multidirectional antenna mounted on a choke-ring plane in order to minimize the effects of multi-path propagation. The technical characteristics of the AOA TTR-4P can be obtained from the manufacturer. From our experience the device cannot yet be considered as fully operational but is has practical characteristics of utmost interest for civil users of the timing community. The principal advantages of the AOA TTR-4P are as follows.
- It decodes the P-code, so that it operates with a much higher precision than conventional C/A-code receivers.
- It receives both of the GPS frequencies, so that it delivers timing data directly corrected for measured ionospheric delays.
- In case of Anti-Spoofing (AS), it uses a special cross-correlation mode, so that results are still corrected for measured ionospheric delays. The precision of the results is not as good as that obtained by decoding the P-code but is much better than that obtained with conventional C/A code receivers.
- It has 8 physical channels which makes it possible to observe up to 8 satellite simultaneously.
- Theoretically it can operate with sample interval from 1 s to 30 s with 1 second increments, and from 30 s to 3600 s with 30 seconds increments. In its specific cross-correlation mode, 10 s is the minimum update rate.

The operation of one TTR-4P unit at the BIPM began in November 1992. To our knowledge, this was the sole unit, until late 1993, operating in a civil timing laboratory. Since November 1993, another unit has been installed at the NPL, Teddington, UK. The results of comparisons between two TTR-4P units, on the same site or through GPS strict common-views, are not yet available.

As is generally the case for C/A-code time receivers, our TTR-4P unit was delivered by the manufacturer without previous absolute calibration. In addition, no information is given on its long-term stability and in particular, on possible changes of its internal delay with the external temperature. We were thus very interested to compare this new device with receivers having well known characteristics. The results given here concern preliminary studies of comparisons between the TTR-4P unit and other multi- or mono-channel C/A-code receivers in operation at the BIPM. The TTR-4P unit is operated with a 1 s or 15 s sample interval according to the purpose of the experiments. Since our TTR-4P unit has no flash card for data storing, timing data is dumped directly into an outside microcomputer before treatment.
In case of a 1 s sample interval, the treatment is applied in real-time. This corresponds to short-term data processing as described in the Technical Directives for Standardization of GPS Time Receiver Software [13]: timing data are referenced to UTC, quadratic fits are applied on 1 s measurements over 15 s periods, and linear fits on the results of 52 successive quadratic fits. This makes it possible to recover timing data corresponding to the usual 780 s tracks, in particular those programmed in the international GPS tracking schedule as issued by the BIPM. We must add that we had many difficulties in making our TTR-4P unit operate correctly in the 1 s mode. The manufacturer delivered the appropriate software version only after 6 months of unsuccessful trials at the BIPM. In addition, because of the opacity of the

operator's manual, we discovered the mode for real-time dumping of 1 s data only on 18 October 1993.

Data obtained with 15 s sample interval have sometimes been saved with no immediate treatment and then used to test methods for GPS time restitution [Section 2.3.]. On an operational basis, the corresponding treatment would be implemented in real-time. The 15 s data can also be treated through linear fits in order to recover 780 s tracks. This data processing is in fact very close to the one suggested in [13] as the TTR-4P 15 s data are probably much less noisy than the 15 s data resulting from quadratic fits on 1 s measurements issued from a C/A- code receiver.

### 3.2. Preliminary results of comparison of the TTR-4P with other receivers in operation at the BIPM

The conditions of comparison are as follows.

- Two C/A code GPS time receivers are compared with our TTR-4P unit: one 4-channel SERCEL NRT2 unit and one single channel AOA TTR6 unit. Highly accurate antenna coordinates are entered in each receiver. The common local time reference is the clock installed at the BIPM.

- The comparison lasted 23 days, from 9 to 27 October 1993. From 7 to 18 October, the TTR-4P was operated with 15 s sample, and from 19 October with 1 s sample.

- About 190 tracks, each of them of 780 s duration, were recovered every day from the short-term TTR-4P data. About 40 of these correspond to the international GPS tracking schedule No 21, programmed in the TTR6 unit and in one channel of the SERCEL unit. The 150 tracks left were chosen from Block II satellites and were scheduled in the three remaining channels of the SERCEL unit. The 4 channels of the SERCEL unit were differentially calibrated before the experiment.

- The SERCEL and TTR6 units use modelled ionospheric delays while the TTR-4P unit uses measured delays. For an efficient comparison it is thus necessary to recover timing data which are not corrected for ionospheric delays. It is also necessary to correct the TTR-4P data using the $L_1$-$L_2$ correction [13]. After these diverse corrections are applied, one computes, for each track, the difference between the timing data, referenced to the same clock, obtained with two receivers:

$$\delta t = [\text{Local Clock - GPS time}]\text{Rec1} - [\text{Local Clock - GPS time}]\text{Rec2}.$$

Values given in Table 1 and reported in Figure 4 correspond to daily averages $\Delta t$ of $\delta t$. All residual errors arising from the conditions of observation are smoothed out in the average and the values obtained correspond roughly to the differences of the internal delays of the two receivers. This comparison is thus denoted [Rec2 - Rec1].

A daily value $\Delta t$ reported in Table 1, for a particular date, is characterized by the standard deviation, $\sigma$, of one measurement on that date, and by the number, n, of common tracks between two receivers also on that date. It may be seen that the $\sigma$ values are always inferior to 4 ns: on average 3,0 ns for [TTR-4P - SERCEL] and slightly smaller, 2,5 ns, for [TTR-4P - TTR6]. These $\sigma$ values can be considered as very good: they are of the same order of magnitude as that usually observed when comparing, for instance, one AOA TTR6 unit and one AOA TTR5A unit [14]. In addition, for the comparison [TTR-4P - SERCEL], the number of daily common tracks is much larger than usually done [14]. One can thus conclude that the comparison noise is mainly brought about by the C/A-code receivers, SERCEL and TTR6, and probably not by the TTR-4P. In addition, the change from 15 s to 1 s sample interval on 18 October for the TTR-4P unit was not followed by a decrease of $\sigma$ values, which seems to indicate that, even with short-term data taken every 15 s, the TTR-4P is better than the C/A-code receivers.

In Figure 4, are plotted daily averages Δt for the comparisons [TTR-4P - SERCEL] and [TTR-4P - TTR6], together with the daily average of the outside temperature. One may see a strong variation with temperature of [TTR-4P - SERCEL], but not of [TTR-4P - TTR6]. The SERCEL unit has already been found sensitive with outside temperature [12], which is not the case for this particular TTR6 unit, so the observed phenomenon is probably not due to the TTR-4P unit. We are continuing comparison studies to confirm this result. For the period 15 October to 29 October, for which the outside temperature was stable, the average differences of internal delays are (-19,7 ± 0,5) ns for [TTR-4P - SERCEL] and (-24,7 ± 0,7) ns for [TTR-4P - TTR6].

To conclude, the preliminary results of comparison of our TTR-4P unit with two C/A-code receivers is satisfactory. For now, this device does not appear to be sensitive to outside temperature, and, in addition, it is convenient to operate it with 15 s sample interval, which facilitates the task. We continue to test this device in particular, through multi-channel common-views with a remote TTR-4P unit.

### 3.3. Experimental results of real-time restitution of GPS time

Data from the TTR-4P unit, which were taken over a 10 hour period on 15 June 1993, include 15 s observations of all available Block I and Block II satellites. Observations corresponding to very low satellite elevation were not retained in the data set. In addition, a hill close to the BIPM, and lying in a western direction from it, constitutes a mask, so that, for the period under study, data from only 3 to 6 satellites were observable simultaneously. Among them, data from 1 or 2 Block I satellites were available for some hours of the experiment. A deferred-time smoothing was applied to this Block I data and the corresponding values, reported in Figures 5.a. and 5.b., can be considered, to some extent, as reference values for [Local Clock - GPS time].

The 15 s data from all Block II satellites observed simultaneously are averaged and reported on Figure 5.a.: the SA noise is still evident. This Block II data is then treated through a moving average over a time interval chosen as a multiple of 240 s, the duration 240 s corresponding to the shortest time for which the SA noise is white (see Figure 3.). The result of the moving average is assigned to the mid-date of the averaging time interval and constitutes the restored value of [Local Clock - GPS time] at this date.

Results are reported on Figure 5.b. for a time interval of 3840 s (16 times 240 s). The SA noise can be treated as being white for this averaging time, as shown on Figure 3. Figure 5.b. indicates that the moving average performs a smoothing of Block II data. With, on average, 4 satellites observed simultaneously over a time period of 16x240 s, the SA noise, 85 ns (1σ), is reduced by a factor $\sqrt{16}x\sqrt{4}$ and has an estimated value of 11 ns (1σ). This verifies approximately the value obtained from the computation of an Allan standard deviation on these values. A part from a residual noise, the restored values present biases relative to smoothed Block I data: the largest discrepancy is about 16 ns. Such biases may come from both Block I and Block II satellites:

- from Block I satellites, because they are at the end of their life and present biases of up to 20 ns between them [15],
- from Block II satellites, because it has already been shown that the SA noise can also cause long-term drift [8]. With 6 satellites observed simultaneously, a bias of 80 ns for one of them results in a bias of only 13 ns on the average.

To improve yet these results, it is necessary to observe more satellites, for preference 8 of them when the constellation is complete, and to control long-term drifts. In the above experiment, the restitution of GPS time is carried out with a delay less than half an hour. Observation of a greater number of satellites would reduce this delay further.

## CONCLUSIONS

The precision of the real-time restitution of GPS time from the occasional observation of one single Block II satellite is degraded to the level of several hundreds of nanoseconds because of SA. In theory, this effect can be reduced if simultaneous observations of Block II satellites are continuously performed through the use of a multi-channel GPS time receiver.

This method was tested using data from a multi-channel, dual-frequency, GPS time receiver, model AOA TTR-4P, which decodes the P-code and is in operation at the BIPM. Some comparative studies between this newly designed device and conventional C/A-code GPS time receivers have been performed. Preliminary results confirm the stated performances of the TTR-4P model, though it cannot yet be considered as fully operational.

The experiment on the restitution of GPS time, performed at the BIPM, shows that the implementation of a moving average on a sufficient long period of simultaneous observations of Block II satellites helps to smooth out the SA noise. The delay of access to restored values can be of order half an hour. This is an important result, which must be still studied as part of the project of dissemination of a real-time prediction of UTC [5].

### References
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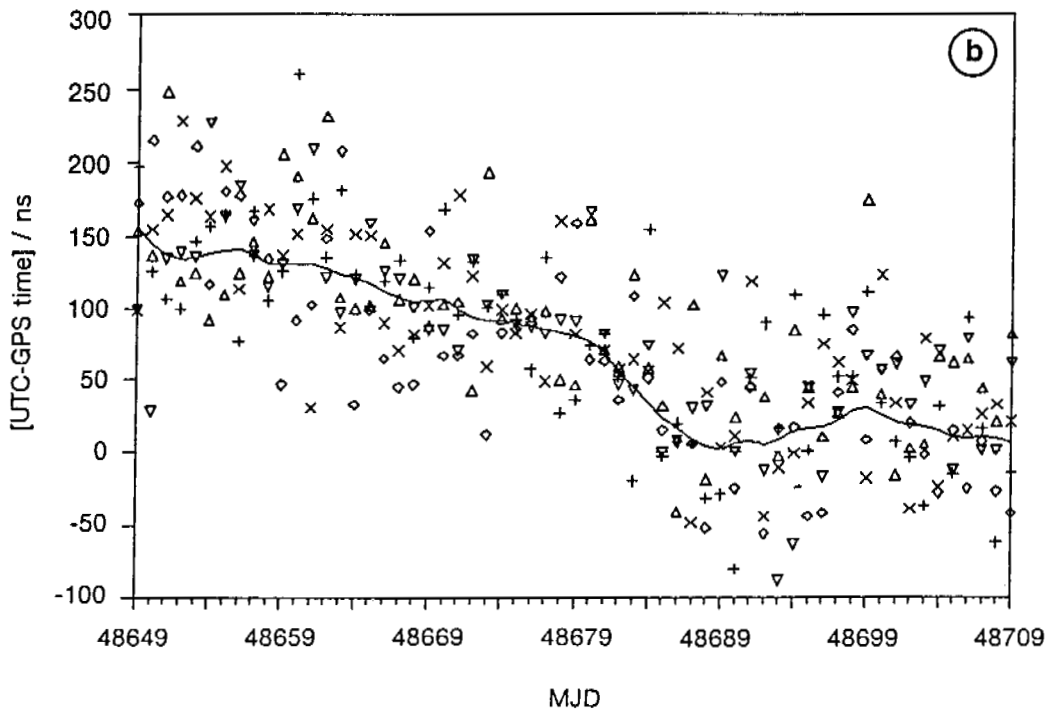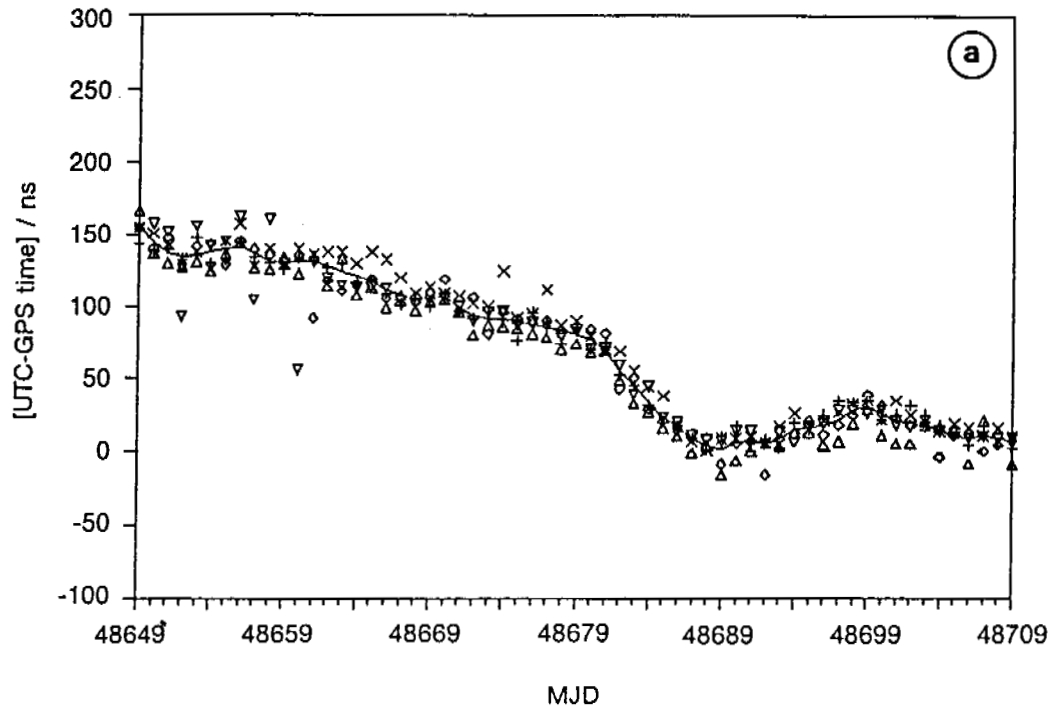15. For example, BIPM *Circular T 67*, *BIPM Publications*, 1993.

**Figure 1.** Restitution of [UTC - GPS time] in deferred-time.
Measured ionospheric delays are used to correct raw GPS data.
1.a. Data from Block I tracks and corresponding smoothed values (———).
1.b. Data from Block II tracks and smoothed values of Fig. 1.a.
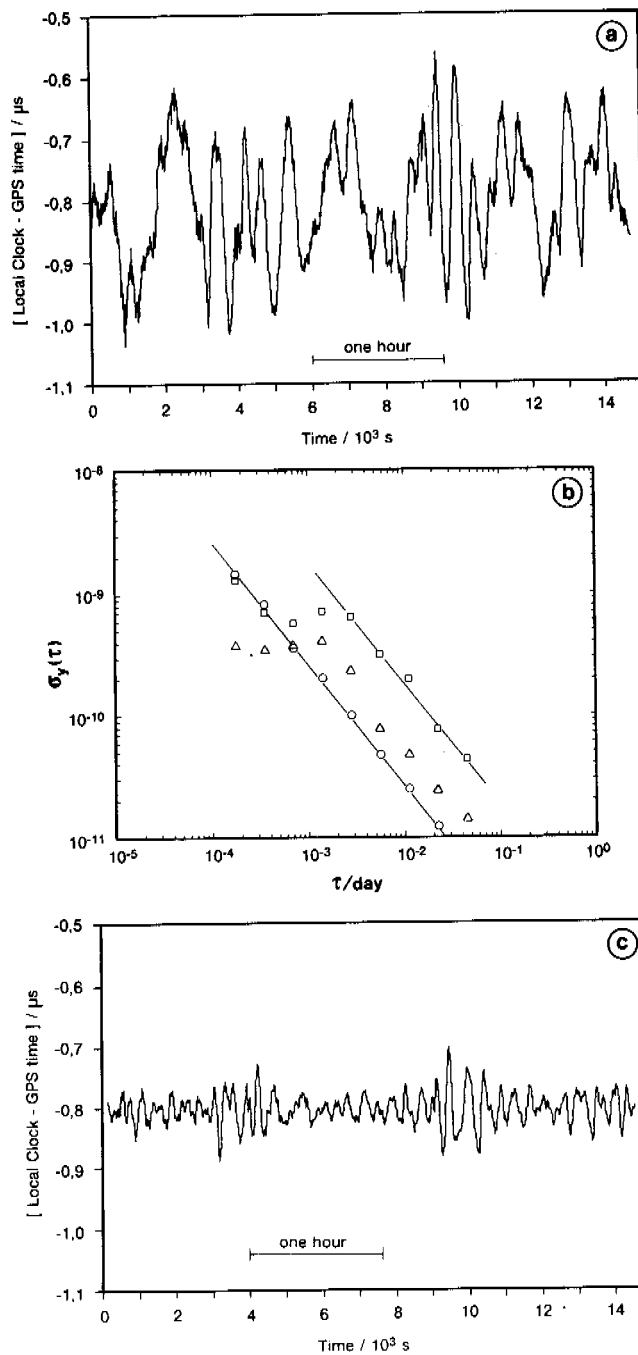
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Figure 2. Study of data from satellite 26, taken for more than 4 consecutive hours.

2.a. Raw 15 s measurements.

2.b. Allan deviation of:

☐  15 s raw measurements from satellite 26.

○  15 s raw measurements from satellite 12.

△  15 s smoothed measurements from satellite 26.

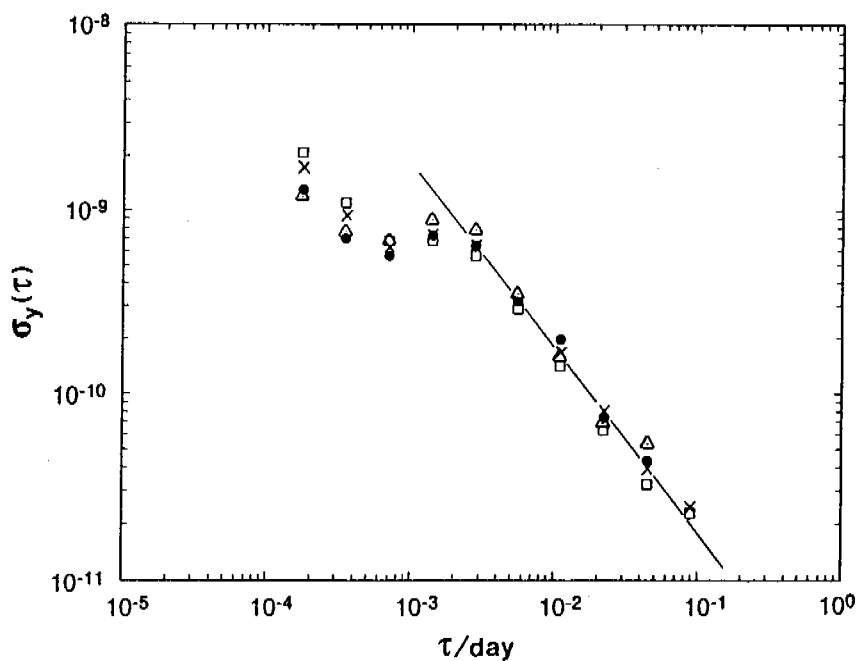2.c. Data from satellite 26, smoothed for short-term and long-term white noise.

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**_Figure 3_. Allan deviation of 15 s data from 4 Block II satellites. Satellite 26, ● , 19,□ , 27, ✕ , and 16, △ .**

| date 1993 | [TTR-4P - SERCEL] | | | [TTR-4P - TTR6] | | |
|---|---|---|---|---|---|---|
| | Δt/ns | σ/ns | n | Δt/ns | σ/ns | n |
| 07 Oct | -14.7 | 3.6 | 179 | -25.1 | 4.7 | 34 |
| 08 Oct | -15.0 | 3.6 | 179 | -25.5 | 3.6 | 32 |
| 09 Oct | -15.6 | 3.2 | 172 | -26.0 | 2.9 | 33 |
| 10 Oct | -14.6 | 3.1 | 180 | -24.8 | 2.8 | 35 |
| 11 Oct | -14.2 | 3.7 | 185 | -24.7 | 3.4 | 35 |
| 12 Oct | -14.2 | 3.2 | 188 | -25.0 | 2.8 | 34 |
| 13 Oct | -14.4 | 3.2 | 180 | -23.3 | 3.5 | 35 |
| 14 Oct | -15.8 | 4.0 | 177 | -24.2 | 3.3 | 33 |
| 15 Oct | -19.0 | 2.7 | 145 | -23.5 | 1.7 | 32 |
| 16 Oct | -19.4 | 2.8 | 167 | -24.1 | 3.9 | 35 |
| 17 Oct | -19.5 | 2.5 | 181 | -24.5 | 2.6 | 35 |
| 18 Oct | -19.9 | 2.6 | 176 | -24.7 | 2.4 | 34 |
| 19 Oct | -19.6 | 2.6 | 182 | -25.0 | 2.1 | 36 |
| 20 Oct | -20.1 | 3.1 | 182 | -25.3 | 2.4 | 35 |
| 21 Oct | -19.3 | 3.0 | 182 | -24.1 | 2.3 | 34 |
| 22 Oct | -19.2 | 2.8 | 178 | -24.2 | 1.8 | 33 |
| 23 Oct | -19.9 | 2.6 | 187 | -25.0 | 2.6 | 35 |
| 24 Oct | -19.3 | 2.7 | 184 | -24.1 | 2.0 | 35 |
| 25 Oct | -19.6 | 2.9 | 193 | -24.9 | 1.8 | 34 |
| 26 Oct | -20.9 | 2.5 | 185 | -26.3 | 2.4 | 35 |
| 27 Oct | -20.2 | 2.4 | 180 | -25.0 | 1.6 | 33 |
| 28 Oct | -19.4 | 3.3 | 183 | -25.0 | 2.4 | 34 |
| 29 Oct | -20.0 | 3.0 | 149 | -25.5 | 2.3 | 27 |

**_Table 1_. Comparison of three GPS time receivers at the BIPM for a 23-day period. The involved receivers are one AOA TTR-4P unit, one SERCEL NRT2 unit, and one AOA TTR6 unit. The different notations are defined in Section 3.2.**
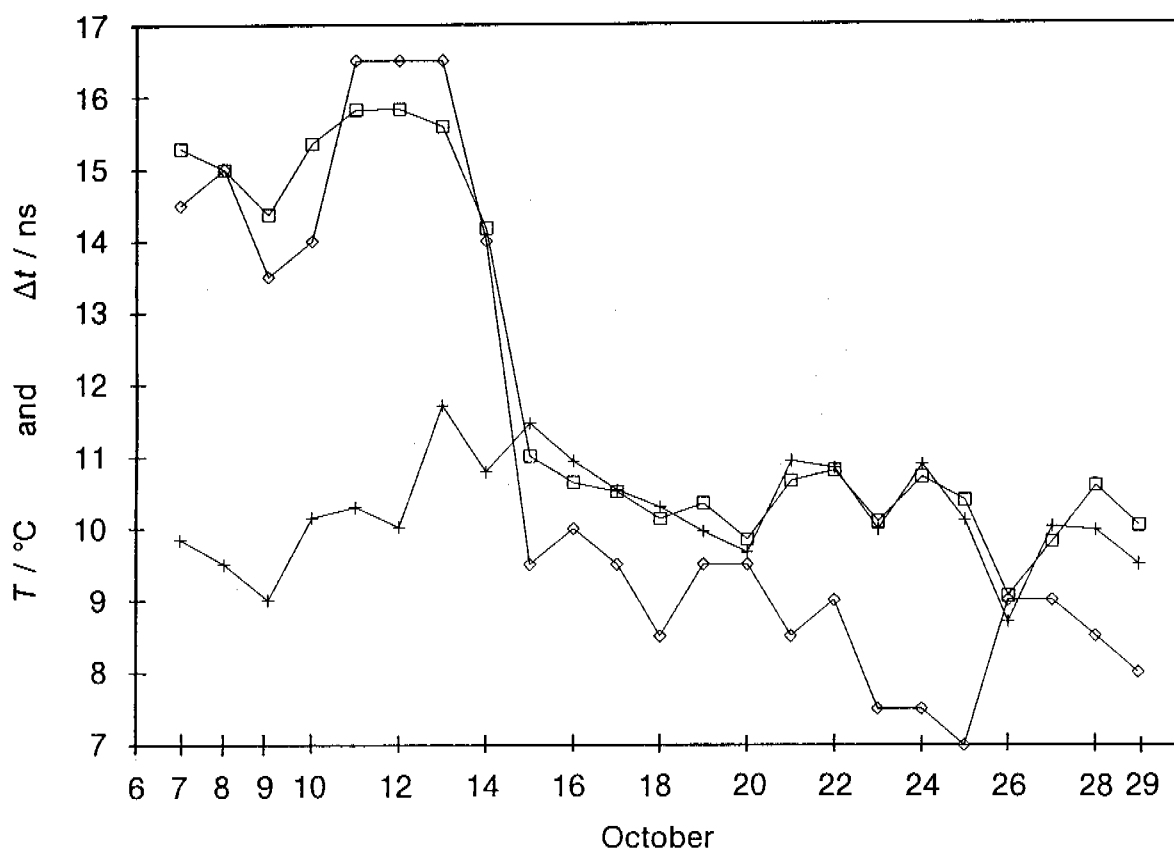
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**Figure 4.** Comparison of three GPS time receivers at the BIPM for a 23-day period. The involved receivers are one AOA TTR-4P unit, one SERCEL NRT2 unit, and one AOA TTR6 unit. The notation Δt is explained in Section 3.2.

◇ Outside temperature T.

□ Δt for [TTR-4P - SERCEL], shifted by +30 ns.

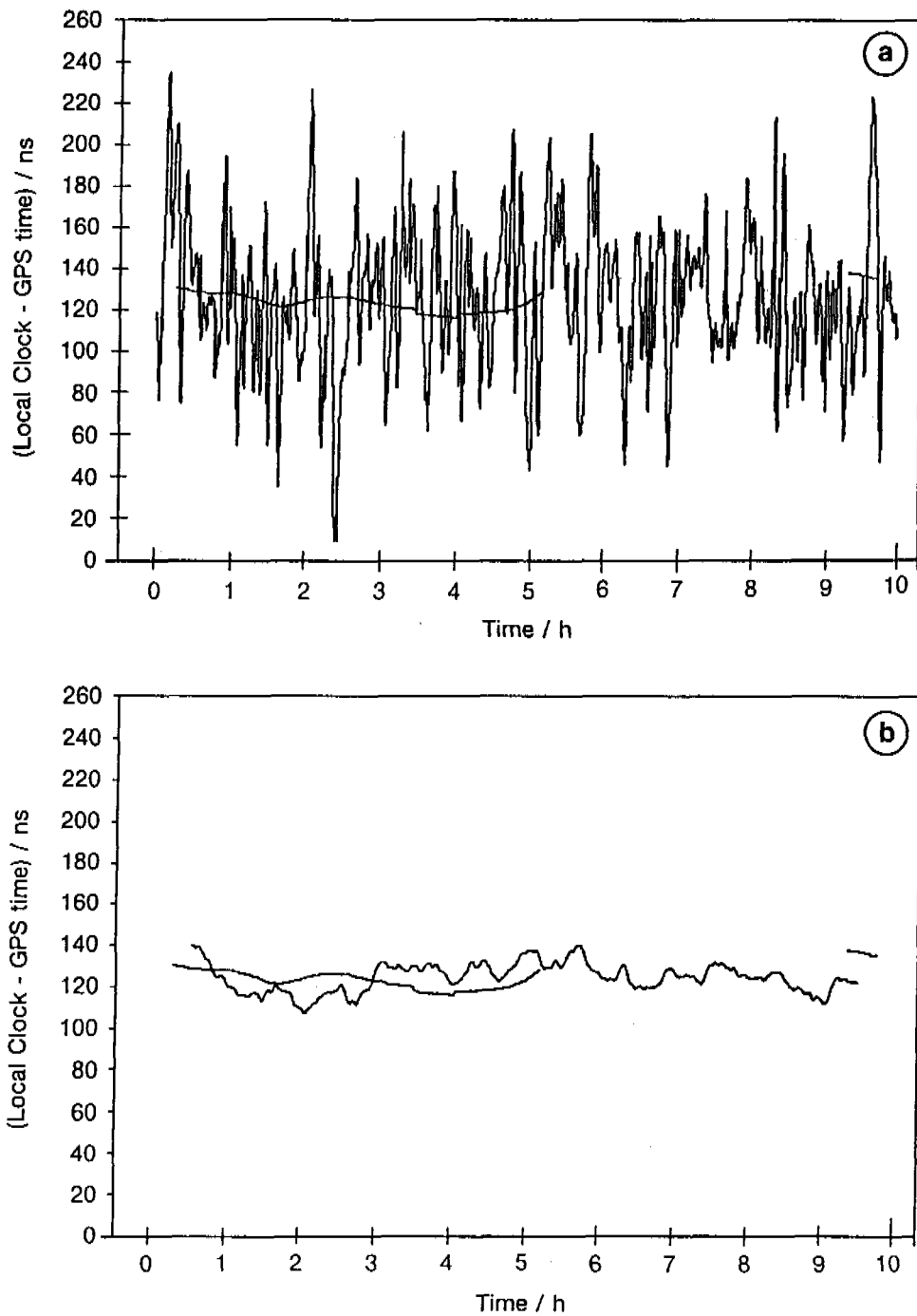+ Δt for [TTR-4P - TTR6], shifted by +35 ns.

*Figure 5.* GPS data taken at the BIPM for 10 hours on 15 June 1993, from the AOA TTR-4P unit operating with a 15 s sample interval.

    *5.a.* Real-time average of data from all observable Block II satellites and smoothed Block I data.

    *5.b.* Smoothed Block II data, through moving average over 3840s, and smoothed Block I data.

# QUESTIONS AND ANSWERS

**Phil Talley, Aerospace Corporation:** If I understood correctly, your plot of the Allan deviation versus time in fractional days, it would appear to me that that is exactly what the clocks on orbit are doing, because that is the transition from the quartz operation with the control loop controlling from the atomic standard. The time interval, as I think I have interpreted it, is exactly what we see when we test the clocks on the ground.

**David Allan, Allan's Time:** You are very observant, Phil. Those curves are coincidentally about at the same point, around 250 seconds. The levels, however, are very significantly different. If you look at the values, the SA value is two orders of magnitude above where the clock noise is. So it is not clock noise, it is actually SA noise, even though it looks similar. So it is coincidental.

**Dr. Winkler, USNO:** I find it interesting to see that there is a change in doctrine from a strict common–view measurement to a robust method, which I have been advocating for years in my robust estimation seminars, where the principle is that you must collect as much data as you can from as many different satellites as you can get. Because if you do that, you obtain two things; you first obtain some kind of robustness; you are not sensitive to a single satellite and its problems. And secondly, you obtain an internal measure of precision on the deviations which you observed. And I am in complete agreement with that. I think that is the most promising one.

There is another side to that and that is that there are quite a few receivers which are coming out, some of them very inexpensive now. For instance, we have had several on test from Magnavox and Motorola, six–channel receivers. And if you just blindly use these receivers, let them select whatever satellites they see; then, in fact, the variance in time is somewhere slightly less than 40 ns if you have a stable reference. And that is not as good as you would expect from your estimates. So there some systematic effects still. But I think the principle which you have mentioned is absolutely correct. You have to make measurements of as many as you can get.

**Claudine Thomas:** I will say that the experiment that I reported here, we have cancelled all data corresponding to low elevation.

**Dr. Winkler:** You also have to remember that we cannot count on a continuing capability of the Block–1 satellites.

**J. Levine, NIST:** What I was going to do is commend you for what I think will be a very significant development in UTC. I think it will help all of us. One of the concerns and one of the points that will have to be watched very carefully is the transient response of your eight

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satellite average when something fails. Because, the system will crash in some funny way and will come back in some funny way. And you are then averaging this funny transient response of all these eight satellites together. And we will have to know what that step response is, "we" being the downstream users. And that is something that will need to be experimented with, I guess.

Claudine Thomas: Yes, that is why I never mentioned doing that as an operational service which will be provided by the BIPM. For now it is only an experiment. The results can be given informally to anyone who wants them, but it is impossible for now to stress about the installation of an operational service which is sure to deliver what is needed.

Dr. Winkler: There is one other point. And that is that I am kind of amazed that there are users who need that information in real time. Because, one of the things which I have observed is that the Observatory has provided that information for the last two years. And there are not more than three or four users who regularly call in. So I am just wondering who is going to need that.