32nd Annual Precise Time and Time Interval (PTTI) Meeting

COMMON-VIEW AND MELTING-POT GPS TIME TRANSFER WITH THE UT+

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Abstract

I report results of GPS time transfer relized in France between the BNM-LPTF (Bureau National de Métrologie-Laboratoire Primaire du Temps et des Fréquences) at the Paris Observatory (OP) and Besançon Observatory (OB) using an Oncore UT+ receiver, Motorola's last evolution of precise-time-capable GPS receivers. So-called "melting pot" measurement sessions, where all visible satellites are tracked to produce one average time measurement, were conducted and are reported on. A solution to overcome the poor set of controlling commands of the early versions of the UT+ to lead single-satellite common-view is presented, together with experimental data. The performance reached by the two methods is discussed against their respective constraints. Performance is evaluated by comparisons with data acquired through classical time dedicated GPS receivers (Sercel NRT2 and AO TTR5). An operational solution allowing frequency comparisons to the French national standards at the level of a few 10^{-14} over a 1-day averaging time, based on UT+ melting-pot measurements, is presented.

INTRODUCTION

For several years now, the Observatory of Besancon has been operating GPS links to national time standards, for both academic and industrial laboratories. Two different categories of hardware are involved in the realizations of these links :

- time dedicated "classical" receivers;
- all-purpose, small format, cheap receivers, but with comparable metrological perfomances.

Among the last category, Motorola's Oncore receivers have been shown to exhibit surprising metrological qualities [1] that have triggered the interest of the time & frequency community. The VP oncore has been the most achieved realization and it has been tested and utilized by a certain number or teams throughout the world for the past years.

One of the reasons for its success was, apart from its good time capabilities, a very complete internal software command set offering a wide control over the behavior of the receiver, and the availability of raw navigation and timing data allowing for example multichannel operations [2], testing of ionospheric models [3],or quality time services [4].

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Unfortunately, the VP has been discontinued and replaced by the UT+. If the intrinsic timing capabilities of the UT+ seem to be at least as good as the VP's, the same cannot be said about the internal software. Only a reduced command set is available and it excludes all raw navigation and timing data ; with the early released units (internal software version prior to 3.0, July 1998) it was even impossible to assign a given satellite to a given channel; thus,following a schedule as BIPM's was impossible. So before 3.0 units appear, a method to overcome these weaknesses has been developed and is presented here.

COMMON-VIEW TIME TRANSFER

Workarounds to UT+ Reduced Command Set

Receiver with a software version 3.0 and on

Common-view time transfer with the UT+ looks impossible, since this unit lacks the *commands controlling satellite ID-to-channel assignment*. Fortunately, latest versions of the receiver internal software (software version 3.0 and on) have support for an «ignore satellite" command that allows the user to set an ignore list; ignoring all but the desired SV allow easy following of a standard common-view schedule.

Receivers with a software version prior to 3.0

Even receivers with an older software version can be under certain conditions used in common-view conditions: : in this case, it is possible to achieve these kind of measurements between two stations by using one of the rare feature provided by the unit, that is to set a satellite elevation mask angle that allows only those satellites with an elevation above this mask angle to be tracked. By choosing an appropriate mask angle, it is sometimes possible to have the receiver track only one satellite (the highest satellite in view, of course). Provided the second station is not too far away, there are some periods of time during which one and the same satellite is the highest visible satellite at both sites and then can be tracked in common-view at both locations.

Scheduling in this case implies that each site has the ability to predict satellite elevations with a precision below 1 degree. This can be achieved using the satellite ephemeris set contained in the almanac data, that the UT+ can provide on demand.

Of course there are a number of situations where such scheduling gives no solutions, the constraints on the scheduling process are the following:

- The granularity of the mask angle that can be specified to the UT+ is 1 degree
- The satellite elevation output by the receiver (and that serves to decide whether or not a satellite is above the mask angle and, hence, whether or not it will be tracked) can eventually show a somewhat bizarre behavior (for example for a rising satellite, the elevation output may happen to be successively 29, 30, 29, 30, 31,.. degrees) that can lead to no satellite being tracked if the mask angle has been set at 30 degrees.
- The duration of a common-view session (which has been set to a standard 13 minutes); this duration is the time during which the highest satellite in view must remain the same at both sites. Of course, the probability that this condition can be fullfilled decreases as the length of the session increases.

From these constraints, I elaborated the scheduling algorithm whose description follows.

The goal of the algorithm is to output a series of dates representing the beginning of tracking sessions, associated to a pair of mask angles, one for the local site, one for the remote site; the algorithm may be run periodically, e.g. each day at both sites.

The algorithm examines for each minute the constellation of visible satellites and makes some tests to see:

1. Is there a satellite whose elevation is 'really' [1] above the other satellites'
   (a) if yes, is it the same situation at the remote location ?
      i. if yes, will this situation have at least a duration greater than the scheduled track length (i.e. examine what the configuration will be in, say 13 minutes if we adopt that track length) ?
         A. if yes, add the selected date to the schedule.
         B. if no, examine next minute.
      ii. if no, examine next minute.
   (b) if no, examine next minute.

Here is a sample of the output of the algorithm for a given MJD: stations are OP (Observatoire de Paris) and OB (Observatoire de Besançon) 324 km southeast from Paris.

```
SchedBuildSchedule: (SCV) 14 22 09 41 42
SchedBuildSchedule: (SCV) 14 36 09 42 43
SchedBuildSchedule: (SCV) 14 51 09 43 44
...
SchedBuildSchedule: (SCV) 22 38 03 66 44
SchedBuildSchedule: (SCV) 22 53 03 67 44
SchedBuildSchedule: (SCV) 23 07 03 68 44
```

First 2 numbers are the time UTC of the beginning of the track; next is the satellite PRN, then an index, and finally the index of the next scheduled track. The index shows that 68 tracks can be scheduled in 1 day (this number does not significantly change over time for a given pair of stations).

Other tests have given similar results between

1. OP and a station located 700 km south (average of 56 daily tracks);
2. OP and a station located 500 km west (average of 61 daily tracks).

Single common view experimental results

Figure 1 shows 2 sets of data: one acquired with classical GPS receivers (AO TTR5

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[1] By really, I mean without ambiguity considering the constraints mentioned above about the 'granularity' of the mask and the uncertainty on the satellite elevation as output by the receiver. In practice, 'really' means that the elevation difference between the highest satellite and the one whose elevation is immediately below is at least 2 degrees.

at OP and Sercel NRT2 at OB) following BIPM's standard schedule; the second set of data was acquired using 2 UT+ units following the above described common-view schedule. Each point represent a 13-minute tracking processed as recommended by the CCDS. All the UT+ receivers that were used have a software version 2.2, and do not support the "satellite ignore" command, making standard common-view scheduling impossible. Of course, the acquisition dates have no reason to match between the 2 sets. The two sets are in good agreement. The average slope is -2.35 ns/day with the TTR5/NRT2 receivers and -2.42 ns/day with the UT+ receivers. The latter are a little bit more noisy, with an rms of 7.8 ns versus 5.6 ns for the TTR5/NRT2. These data have been recorded before removal of the SA, but it has negligible influence on such short baseline links when operating in common-view. These results confirm that the UT+ timing capabilities are very similar to those of the VP oncore unit [3].

MELTING-POT TIME TRANSFER

Receiver Setup

The different receivers used where:

- at the BNM-LPTF (OP): 1 Allen Osborne TTR5 GPS receiver (ttr5op), 1 motorola UT+ GPS receiver (ut+op)
- at Observatory of Besançon (OB): 1 Sercel NRT2 GPS receiver (nrt2ob) and 3 motorola GPS receivers (ut+ob1, ut+ob2, ut+ob3)

The time reference at the BNM-LPTF is UTC(OP), realized by a HP5071A, and Cs172(OB) at OB, both being realized by HP5071A-001 cesium clocks. Data acquisition with the ttr5op, nrt2ob receivers of course follow the BIPM standard common-view schedule, extended to 86 daily tracks. On the UT+, data acquisition was scheduled at the same dates in order to provide simultaneous measurement results, thus simplifying postprocessing.

Melting-Pot Experimental Results

Figure 2 allows comparisons between UT+ melting-pot time transfer and common-view data obtained with classical time-dedicated GPS receivers. Figure 2 shows three sets of data, all being measurements of the difference between UTC(OP) and Cs172(OB) (HP5071A-001); data from the upper plot have been obtained through the pair of receivers (ut+op, ut+ob1), while the lower plot was obtained with (ut+op, ut+ob3); the third plot has been derived from data obtained via (ttr5op, nrt2ob).

For each set of data the standard deviation is indicated for each period of 24 hours. It ranges from roughly 4 to 6 ns for (ut+op,ut+ob1); it is a little lower for (ut+op,ut+ob3) around 4 ns and still lower around 2.5 ns for the time dedicated receivers. The next 2 figures show the Allan deviation (together with a multivariance fit and the associated confidence interval) for (ut+op,ut+ob1) and (ttr5op,nrt2ob); the lesson of these plots is that the UT+ is suitable to perform frequency transfer at the level of 10^{-13} or better for an averaging time of 1 day.

OPERATIONAL CONSIDERATIONS

A system based on common-view GPS measurements with low-cost receivers has been operational at the Observatory of Besançon since 1998: laboratories can link their frequency reference to the national standards at the BNM-LPTF, under the control of the french standards authority BNM (Bureau National de Metrologie) and COFRAC (COmite FRAncais d'accreditation). The original system (still in operation) uses the VP oncore and the BIPM common-view schedule. In the new version, the VP is replaced by the UT+ and melting pot operations where data acquisition are synchronized to the BIPM schedule, simplifying possible comparisons with other common-view data sets. The supporting operating system MSDOS has been replaced by a Linux platform, (see annex for details), which provides much more flexible operations. From the final user point of view, operations can now be virtually completely automated. Data can be sent to the reference laboratory on a regular basis (a periodicity of one week seems reasonable) either through a direct modem line or through (permanent or on-demand) IP connectivity. Data are then processed and linked to the national standards and results can then be downloaded by the user using the same link. An official certificate is then issued on a monthly basis.

CONCLUSION

We have shown that the UT+ can be used to compare frequencies at the level of a few 10^{-14} for a one day averaging time. Common-view and melting-pot operations have been shown to have roughly the same performances. In the latter case, the BIPM schedule can be discarded, even if, for compatibility considerations, tracking times are still derived from it. A way of linking one's frequency to the French national standards has been built around this hardware and requesting laboratories will install the first operational systems in December 2000. Important software evolutions and new opportunities have permitted to offer to the final user highly simplified procedures ensuring proper data processing and a more user-friendly graphic interface together with enhanced monitoring capabilities.

ACKNOWLEDGMENTS

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[3] W. Lewandowski, P. Moussay, P. Guerin, F. Meyer, and M. Vincent 1997, *"Testing Motorola Oncore GPS receiver for time metrology,'* Proceedings of the 11th European Time and Frequency Forum (EFTF), 4-7 March 1997, Neuchâtel, Switzerland, pp. 493-497.

[4] P. T. H. Fisk, R. B. Washington, M. A. Lawn, and M. J. Wouters 2000, *"Time and frequency activities at the CSIRO National Measurement Laboratory, Sydney, Australia,'* Proceedings of the 31st Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 7-9 December 1999, Dana Point, California, USA, pp. 211-218.

ANNEX Some considerations about software solutions to operate one (or more) UT+ and a GPIB board under Linux

Operating system and language

As mentioned in the paper, the early version of the system runs under MSDOS. MSDOS is reliable for what it can do, but is now kind of a Jurassic OS: not multitask, not multiuser and all the consequences. From MSWindows and Linux, we choose the latter for reliability, flexibility, and free access. Programming language is C.

User interface

The graphic user interface was developed using *glade (http //glade pn org)*; glade is basically a graphic frontend to ease graphic interfaces creation. It outputs a bunch of boring C code, that it is still possible to manually modify in case of problems.

The controlling software that was obtained allow remote control of the unit, provided IP connectivity exists to the remote unit. This is a very valuable and time sparing option when testing units at different sites.

Figure 5 shows a screenshot of the user interface; gnuplot, a free plotting software, can be used to continuously and graphically monitors the data being taken, allowing a quick detection of problems.

Time interval counter, GPIB operations

Controlling the time-interval counter often involves the use of the GPIB bus. Unfortunately until recently, GPIB board manufacturers did not offer GPIB drivers for the Linux platform. The only known possibility was the driver developped as part of the Linux Lab project; still it is limited to 2.0 kernel versions and seems to be no longer supported. National Instruments has started the development of a Linux driver for its PCI GPIB card. This driver was used for this experiment. It showed no problem except for the IRQ processing; further tests are needed to check whether or not the driver is the cause of the problem. Anyway, this is not a real concern as far as only one measurement has to be acquired each second.

For now, our software supports Stanford Research SR620 (serial port) and Hewlett-Packard HP53132A time-interval counters, but alternate counter support could be added very easily.

Contact the author for further details.

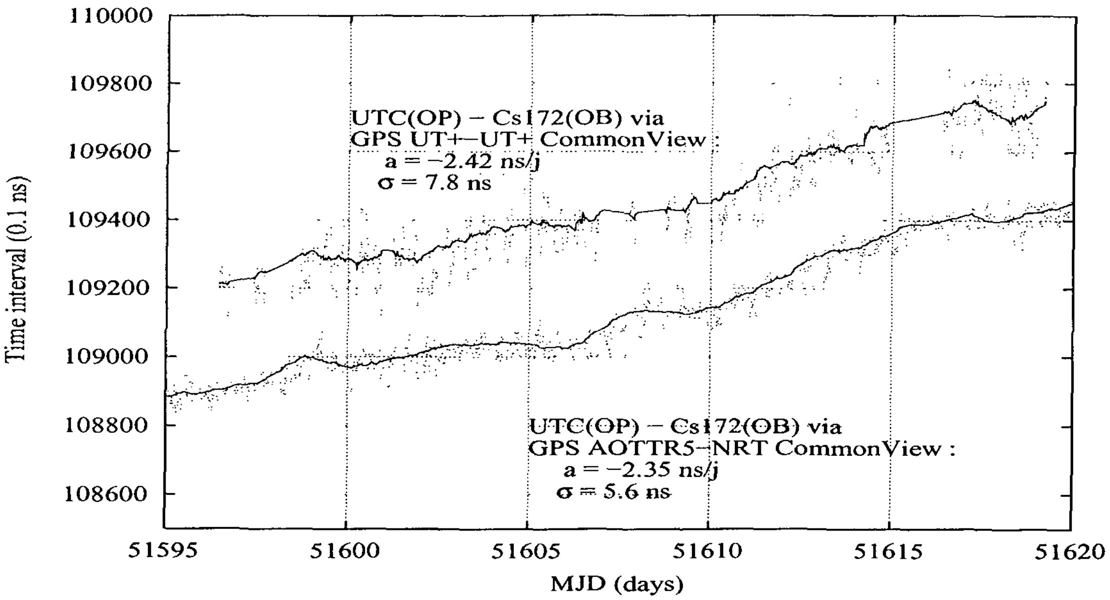


Figure 1: Common-view UT+ measurements compared to common-view NRT2/AOTTR5: plot of UTC(OP) - GPS(ttr5op) - (Cs172(OB) - GPS(nrt2ob)) and UTC(OP) - GPS(ut+op) - (Cs172(OB) - GPS(ut+ob))

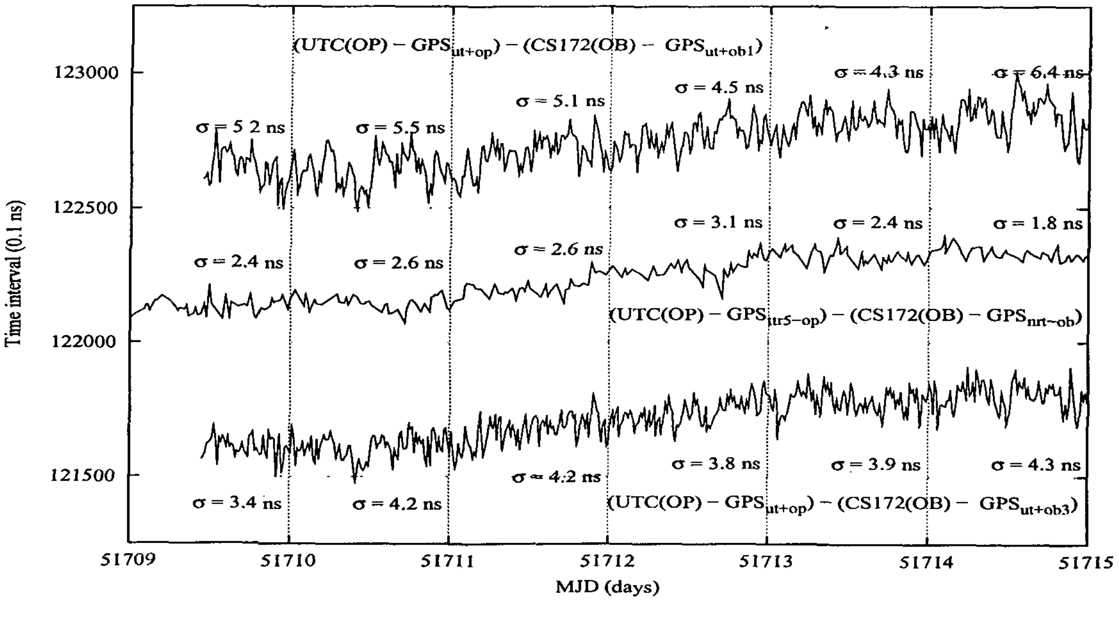


Figure 2: Melting-pot UT+ measurements compared to common-view NRT2/AOTTR5: (2 different UT+ units were used at OB) plot of UTC(OP) - GPS(ttr5op) - (Cs172(OB) - GPS(nrt2ob)) UTC(OP) - GPS(ut+op) - (Cs172(OB) - GPS(ut+ob1)) UTC(OP) - GPS(ut+op) - (Cs172(OB) - GPS(ut+ob3))

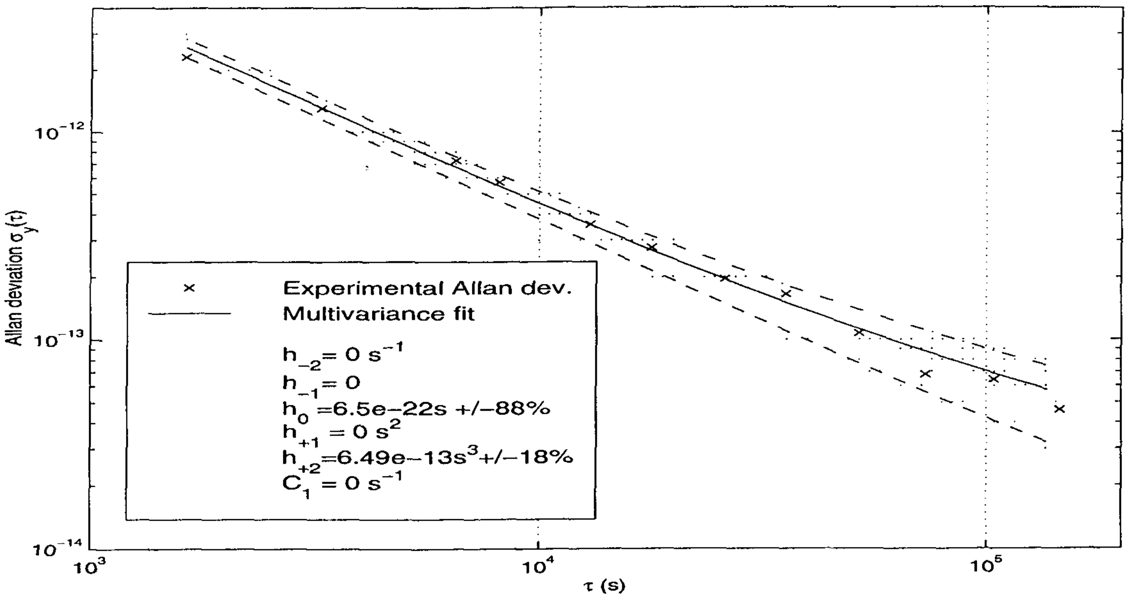


Figure 3: Allan deviation of UTC(OP) - GPS(ttr5op) - (Cs172(OB) - GPS(nrt2ob))

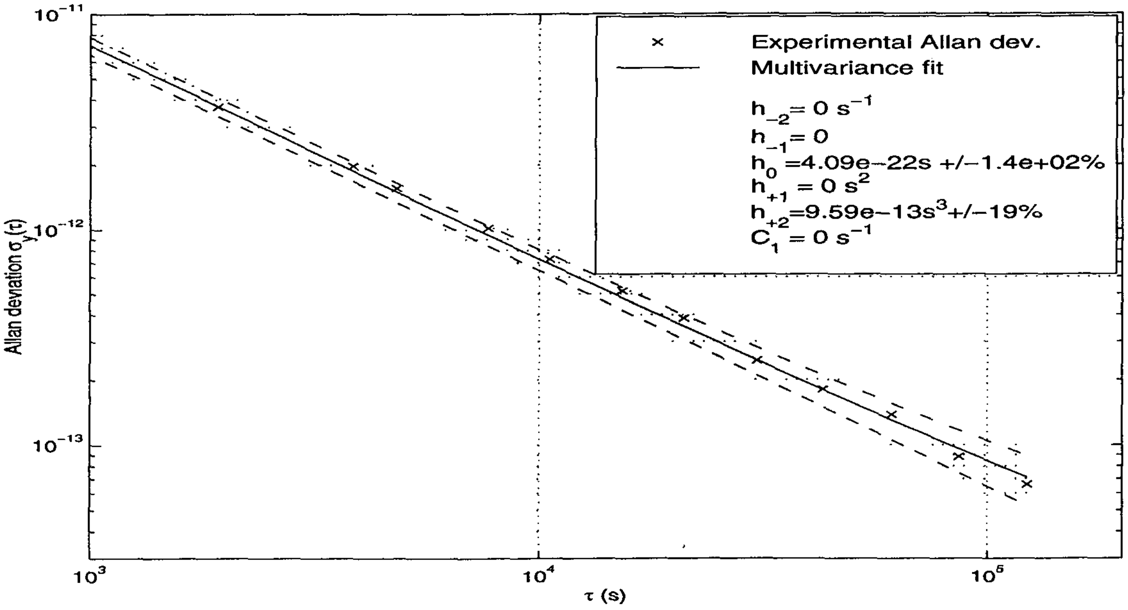
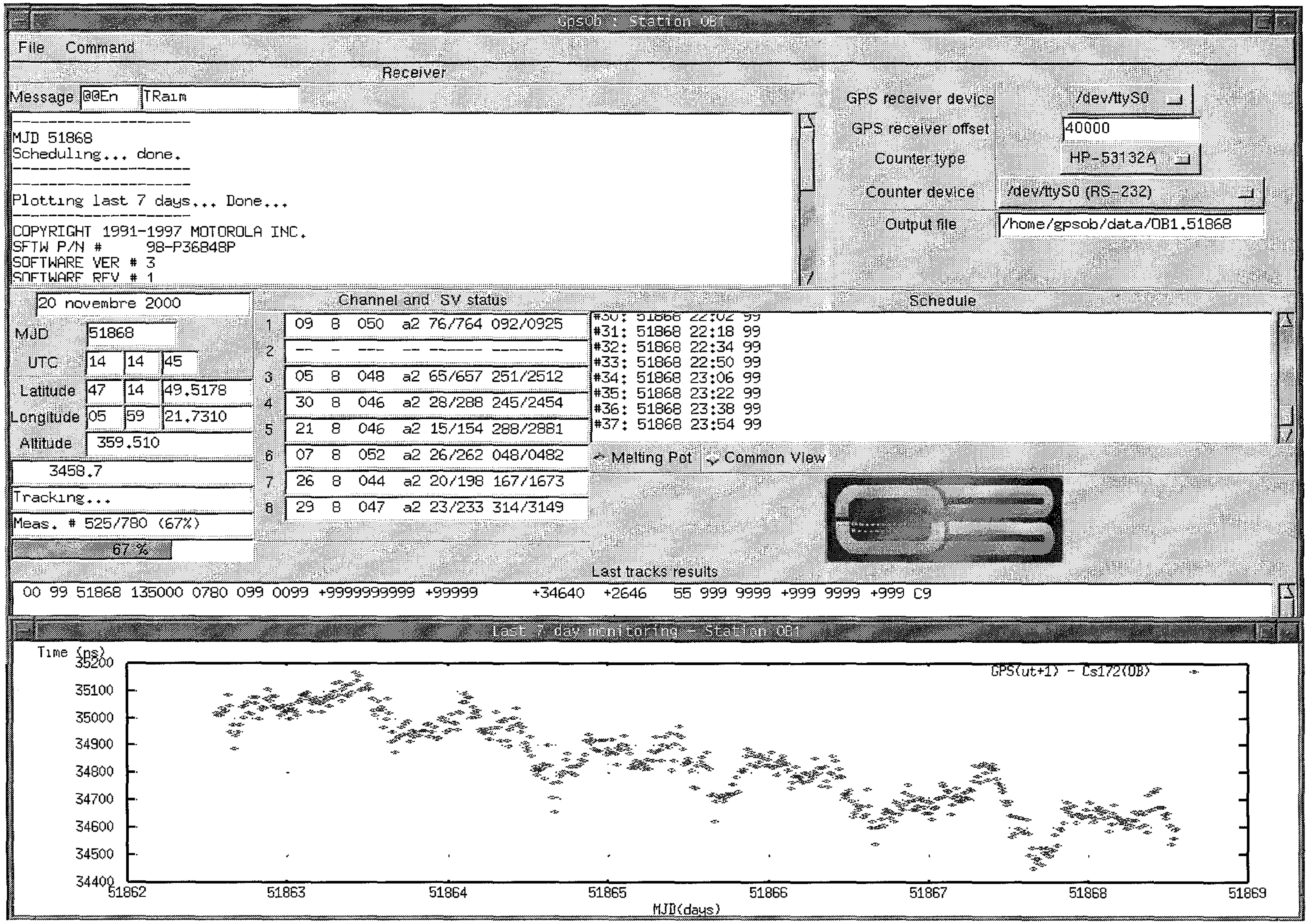


Figure 4: Allan deviation of UTC(OP) - GPS(ut+op) - (Cs172(OB) - GPS(ut+ob3))



Message @@En TRaim

```
--------------------
MJD 51868
Scheduling... done.
--------------------
--------------------
Plotting last 7 days... Done...
--------------------
COPYRIGHT 1991-1997 MOTOROLA INC.
SFTW P/N #     98-P36848P
SOFTWARE VER # 3
SOFTWARE REV # 1
```

GPS receiver device: /dev/ttyS0

GPS receiver offset: 40000

Counter type: HP-53132A

Counter device: /dev/ttyS0 (RS-232)

Output file: /home/gpsob/data/OB1.51868

20 novembre 2000

MJD: 51868

UTC: 14 14 45

Latitude: 47 14 49.5178

Longitude: 05 59 21.7310

Altitude: 359.510

3458.7

Tracking...

Meas. # 525/780 (67%)

67 %

```
1  09  8  050  a2 76/764 092/0925
2  --  -  ---  -- ------ --------
3  05  8  048  a2 65/657 251/2512
4  30  8  046  a2 28/288 245/2454
5  21  8  046  a2 15/154 288/2881
6  07  8  052  a2 26/262 048/0482
7  26  8  044  a2 20/198 167/1673
8  29  8  047  a2 23/233 314/3149
```

```
#30: 51868 22:02 99
#31: 51868 22:18 99
#32: 51868 22:34 99
#33: 51868 22:50 99
#34: 51868 23:06 99
#35: 51868 23:22 99
#36: 51868 23:38 99
#37: 51868 23:54 99
```

```
00 99 51868 135000 0780 099 0099 +9999999999 +99999     +34640  +2646   55 999 9999 +999 9999 +999 C9
```

Figure 5: Screenshot of the graphic user interface of the controlling software and monitoring plot