Testing the capabilities of GPS receivers for time transfer

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Abstract— **Based on a carrier phase analysis of GPS measurements, we investigate how a geodetic GPS receiver reproduces the variations of the frequency delivered to him by an external clock. For this purpose, two PolaRx2 GPS receivers have been connected to the same antenna, and were driven by two separate Hydrogen Masers. The time and frequency transfer between these two Masers is computed through a combined code and carrier phase GPS data analysis, and the results are compared with the measurements delivered by a phase comparator. The differences between both comparison techniques are of the order of tens of picoseconds for the short-term comparisons. On the long term, 3 weeks in our case, the maximum differences reach 180 picoseconds peak-to-peak (after correction for the day boundary jumps).**

I. Introduction

Frequency and time transfer using a combined analysis of GPS code and carrier phase measurements is now largely spread, and it is the most precise tool presently available for short-term clock comparisons. Longer-term clock comparisons (for averaging times longer than 5 days) are however still produced with the same quality by GPS code measurements or two-way satellite time and frequency transfer [1].

Several error sources degrading GPS time transfer have already been investigated, such as multipath [2], troposphere zenith path delay estimation [3], station position precision[4], or the influence of the GPS data analysis software [5]. This paper will focus on another type of error: it will investigate how well the GPS receiver reproduces the variations of the external frequency delivered to him by an external clock. Indeed, the receiver hardware converts the external frequency in order to generate the frequency needed for the GPS signal measurements and this can cause a deterioration of the original frequency. The experimental setup we used consisted in connecting two GPS receivers to the same antenna and to drive them with two separate atomic frequency standards. The time and frequency transfer results obtained from the GPS code and carrier phase data analysis are then compared with the measurements of a phase comparator connected to the two frequency standards.

Providing different external frequencies to the GPS receivers allows detecting a possible systematic reaction of both receivers to changes in the external frequency. If the same clock would have fed the two receivers, then, an identical reaction of the two receivers to the same external frequency variations would disappear in the differencing process.

II. Setup desription

Two similar geodetic PolaRx2 GPS receivers (Septentrio) have been connected to the same antenna (type Dorne Margolin, ASH701945B_M), and were driven by two separate Hydrogen Masers, one passive (CH1-76) and one active (CH1-75). The time and frequency transfer between these two clocks is computed through a combined code and carrier phase GPS data analysis performed with the Bernese software (V4.2), using the RINEX observations files produced by the two receivers. In parallel, the two clocks are compared using a frequency and phase comparator A7 (Quartzlock). The setup is illustrated in Figure 1. The analysis was performed on a 3-week period (from July 26 to August 15, 2005), using a 30-second sampling rate for the GPS data as well as for the A7 measurements.

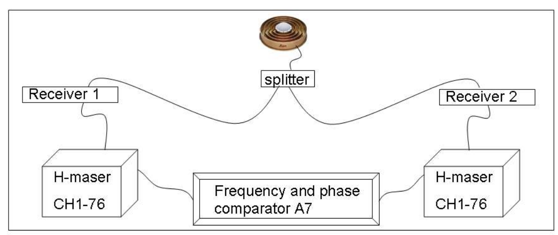

Figure 1. Setup of the experiment

III. GPS analysis vs Phase comparator data

A first comparison performed on a one-day period (Figure 2) shows that the general trend of the clock synchronization errors is well retrieved by the GPS data analysis. However, some of the short-term frequency variations measured by the A7 are not exactly reproduced in the GPS time transfer results, which leads to differences up to 50 picosecond (ps) peak-to-peak as illustrated in Figure 3 which shows the difference between the two curves of Figure 2.

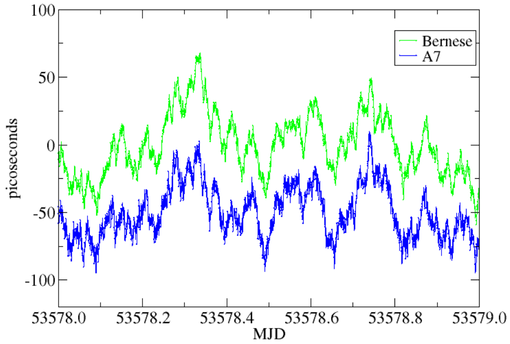

Figure 2. Time transfer between CH1-75 and CH1-76 using either A7 or GPS data analysis for a one-day period.

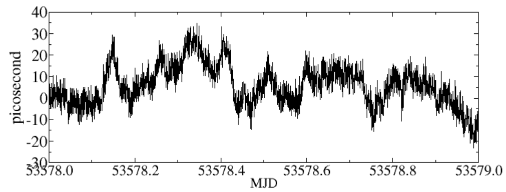

Figure 3. Differences between the GPS data analysis results and the A7 measurements presented in Figure 2.

Figure 4 presents, for the whole period studied, the differences between the time comparison results obtained from GPS data analysis and from the phase comparator. One can observe that the maximum amplitude of the differences is 360 ps peak-to-peak. After correction of the day boundary jumps (typical for GPS-based time transfer) using a single connection of the one-day batches, the difference falls down to 180 ps.

One important phenomenon is observed at MJD=53586.7. At that epoch, the relative frequency change between the two external clocks seems to be enhanced by the receivers, leading to a rapid increase of 75 ps (see Figure 5) in the GPS time and frequency transfer results with respect to the A7 measurements. It is however the only occurrence, during the 3-week period investigated, of such a large deviation of the GPS time and frequency transfer results with respect to the direct comparison made by the A7. The origin of this variation is however unknown; it can be due to a variation of the hardware carrier phase delay due to some internal temperature variation in the receivers. In any case, no external temperature variation was observed at that time.

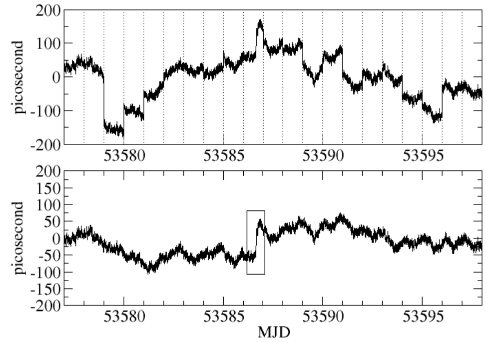

Figure 4. Differences between the GPS data analysis results and the A7 measurements for the whole3 week period studied. Upper part : direct comparison of the results; Lower part: after correction for the day boundary jumps.

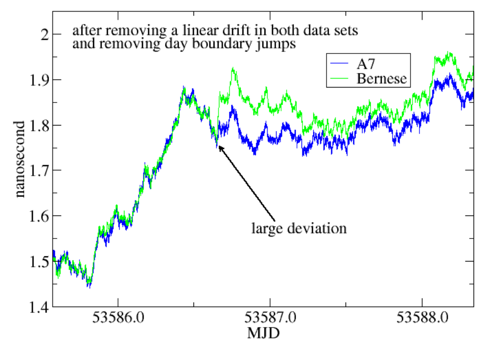

Figure 5. Time transfer between CH1-75 and CH1-76 using either A7 or GPS data analysis, focus on the large deviation in the Bernese results with respect to the A7 measurements.

Figure 6 shows the Allan deviation of both the GPS time transfer results and the A7 measurements. These curves confirm the fact that on the short term GPS has a higher performance than the A7. However, when comparing the GPS timing results with the expected Allan deviation of the passive H-maser and of the A7 (i.e. as announced by the manufacturer), we can see that the GPS time transfer results show a higher short-term stability than the stability of the original external clock. This confirms the idea that the GPS time and frequency transfer technique smooth the rapid frequency variations. This is also confirmed by the Modified Allan deviation which shows, for the A7 measurements, a white phase noise for averaging times shorter than 10 minutes (slope -3/2), while for the GPS data analysis results we get only white frequency noise (slope -1/2), as illustrated in Figure 7. For averaging times longer than 10 minutes, the GPS technique and the phase comparator provide equivalent results, with a white frequency noise up to an averaging time of one day.

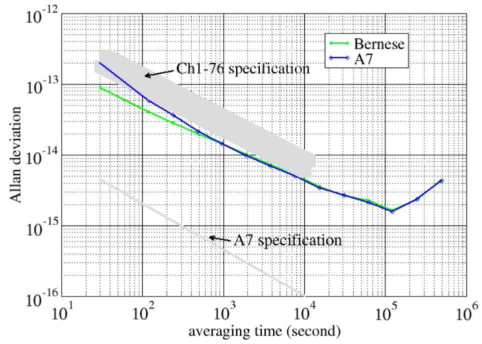

Figure 6. Allan deviation of the Bernese results and of the A7 measurements.

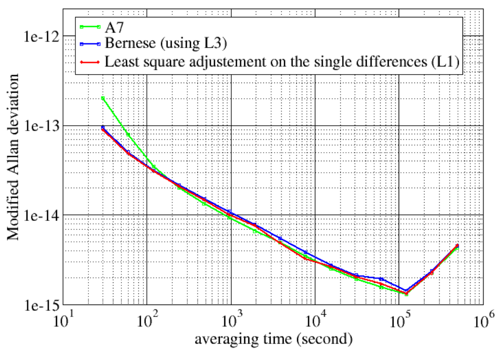

Figure 7. Modified Allan deviation of the Bernese results and of the A7 measurements, as well as of the least square adjustment on L1 GPS measurements.

In order to investigate if this smoothing of the rapid frequency variations is due to the receiver hardware or to the GPS data analysis, we performed, in parallel to the Bernese software, a direct least squares analysis of the GPS single differences on L1 (differences of code and carrier phase observations provided by both receivers) without any atmospheric correction as these receivers are connected to the same antenna. The Modified Allan deviation of the corresponding time transfer results is presented also in Figure 7; there is no significant difference with respect to the Modified Allan deviation of the results provided by the Bernese analysis; the smoothing of the frequency variations is therefore not due to the analysis but rather to the receiver hardware.

IV. Conclusion

This paper aimed at testing the fidelity of GPS receivers to the external frequency standard used to drive them. It presented preliminary results for the comparison between GPS time and frequency transfer results and direct clock comparison obtained with a frequency and phase comparator. The numerical differences obtained in this study are of course related to the receiver type. On the short term, we measured differences of tens of picoseconds between the GPS results and the phase comparator. On the long term, 3 weeks in our case, the maximum differences reached 180 picoseconds peak-to-peak, after correction for the day boundary jumps.

The origin of these differences can be attributed to either the way the GPS receiver reacts to the frequency changes from the external clock, or to the GPS data analysis. This second hypothesis was discarded by using, in parallel to the Bernese software, a least squares analysis of the GPS single differences on the L1 phase measurements (differences of code and carrier phase observations provided by both receivers); the results so-obtained were similar to the Bernese results. Another possibility would be a noise exceeding the specifications of the A7 frequency and phase comparator. However, this is less probable as the Allan deviation of the A7 measurements on the short term corresponds to the expected Allan deviations of the passive H-maser. These differences between the GPS timing results and the phase comparator seem therefore well due to a smoothing of the phase measurements made by the GPS receiver. As they have better short-term stability, the use of two active Hydrogen Masers could reinforce this thesis, and will be the subject of further investigations.

References

[1] Bauch A., Dach R., Davis J., Lorini L., Parker T., Petit G., and Richard J.-Y., 2005, Time and frequency comparisons between four European timing institues and NIST using multiple techniques, Proc. EFTF 2002 (CD-rom).

[2] Ray J. and Senior K., 2003. IGS/BIPM Pilot Project: GPS carrier phase for time/frequency transfer and time scale formation, Metrologia, 40(3), S270-S288.

[3] Hackman C. and Levine J., 2004, Adding water vapor radiometer data to GPS carrier-phase time transfer, Proc. PTTI 2004, (CD-rom).

[4] Dach R., Beutler G., Hugentobler U., Schaer S., Schildknecht T., Springer T., Dudle G., and Prost L., 2003. Time transfer using GPS carrier phase: error propagation and results, J. Geodesy, 77, doi 10.1007/s00190-002-0296-z,1-14.

[5] Bruyninx C., Ray J., Roosbeek F., and Senior K., 2004.Comparison of geodetic clock analysis strategies, presented at the PTTI symposium 2004 (Washington DC).