SIMPLE METHODS FOR THE ESTIMATION OF THE SHORT-TERM STABILITY OF GNSS ON-BOARD CLOCKS

Jérôme Delporte, Cyrille Boulanger, and Flavien Mercier
CNES, French Space Agency
18, avenue Edouard Belin, 31401 Toulouse cedex 9, France
jerome.delporte@cnes.fr

Abstract

The estimation of GNSS on-board clocks behavior is generally a complex task requiring a large ground infrastructure (a global network of ground stations) and an intense computation (the so-called ODTS, Orbit Determination and Time Synchronization). Here, we propose two alternative methods that allow one to easily estimate the short-term stability of GNSS on-board clocks with respect to a given ground station on a pass. In the first method, we simply consider the phase measurements of the RINEX observation files provided by the ground station on which we apply a high-order polynomial fitting. Thus, we keep the high-frequency part of the measurement, which is expected to be representative of the clock difference. In the second method, we carry out a residuals computation on a given pass using precise ephemerides. The ground station phase measurements are considered. We compute the transmission dates and the satellites' position by interpolation of these dates. Then we compute the theoretical pseudo-distance using the satellites' position and the measurements; the vertical troposphere delay is adjusted. The difference between the measurements and the theoretical pseudo-distance provides an estimation of the clock difference. With these two methods, we can compute the stability of a GNSS on-board clock for each phase observable and for the iono-free phase combination. Obviously, this requires that the stability of the ground station clock is better than the stability of the GNSS on-board clock that we want to estimate. The estimation obtained of the on-board clock has the same sampling rate as the input RINEX phase measurements. For GPS on-board clocks, the results of these two methods using 1 Hz ground stations measurements have been compared to the IGS COD clock products that have a sampling rate of 5 seconds. We obtain a very good agreement up to 1000 seconds. These methods are considered to be simple, fast, and efficient ways to characterize the behavior of GNSS on-board clocks on a given pass.

INTRODUCTION

Global Navigation Satellite Systems embark atomic frequency standards, the characteristics of which have a direct impact on the overall positioning performance. Therefore, the general monitoring and the performance assessment of these on-board frequency standards are of utmost importance. For instance, the performance assessment of the GPS on-board clocks is carried out on a regular basis [1,2]. Similarly,

the on-board clocks of the experimental Galileo satellites (GIOVE) are also assessed by the Europeans **[3]**.

This on-board clock assessment is generally a complex task requiring a global network of ground stations to collect the GNSS measurements on a continuous basis. These station measurements are then merged through an infrastructure and processed together by a dedicated facility. This facility computes the clock of each ground station and the orbits and clocks for each GNSS space vehicle. The clocks are estimated with respect to the GNSS reference time scale (DoD Master Clock for GPS, EGST for GIOVE).

The aim of this work is to propose two alternative methods that allow to estimate the behavior of GNSS on-board clocks with respect to a given ground station. This estimation (which can be validated against IGS products when available) is, therefore, limited to the pass duration, but, on the other hand, provides data at the rate of the station measurements, thus allowing the assessment of the short-term stability of the GNSS on-board clock. These methods are, therefore, considered as complementary to the usual method, while being much simpler and, for at least the polynomial method, available in nearly real time.

DESCRIPTION OF THE METHODS

The two alternative methods developed here use the phase measurements of a given ground station. The first method, called the polynomial method, consists in applying a high-order polynomial fitting to these measurements. Thus, we keep the high-frequency part of the measurement which is expected to be representative of the clock difference. The second method, called the residuals method, consists of carrying out a residuals computation on a given pass using precise ephemerides. The computed theoretical pseudo-distance is compared to the measurements and this provides an estimation of the clock difference.

In both cases, this obviously requires that the stability of the ground station clock is better than the stability of the GNSS on-board clock that we want to estimate.

THE POLYNOMIAL METHOD

This straightforward method is based on the use of raw phase measurements (in RINEX format) coming from a GNSS receiver connected to an atomic clock. Basically, the GNSS measurements represent the clock difference between the transmitter and the receiver. The idea is to exploit that feature in a very simple way. The raw phase measurements and their iono-free combination for a given satellite pass is merely adjusted by a polynomial of high order (typically 24). Thus, we keep the high-frequency part of the measurement, which is expected to be representative of the clock difference. We then compute the Allan deviation, excluding end segments that are generally noisier.

THE RESIDUALS METHOD

For this method, we carry out a residuals computation on a given pass using precise ephemerides. The computation is carried out as follows:

•   the precise ephemerides and RINEX observation files are turned into sparse format
•   the transmission dates are computed on these measurements
•   the satellites' positions are computed by interpolation at these dates

- the theoretical pseudo-distance is computed using the satellites' positions and the measurements; the vertical troposphere delay is adjusted.

We then compute the stability of the on-board clock for each phase observable and for the iono-free phase combination.

RESULTS ON GPS ON-BOARD CLOCKS

For GPS on-board clocks, we can compare to IGS products [4] that provide clock products at the sampling rate of 30 seconds. We preferred to compare to the COD clock products that have a sampling rate of 5 seconds. This can be considered as a validation of the methods.

We used the measurements of the GIEN ground station (GIEN is a station of the GIOVE network located in Torino, Italy). This station provides GPS and GIOVE measurements at the rate if 1 Hz and is driven by a hydrogen maser which is also the E-GST (Experimental Galileo System Time).

GPS PRN 3 CESIUM CLOCK

The following graph shows the stability of GPS PRN 3 (SVN 33) on-board clock (Cesium II/IIA) obtained with both methods and compared to the COD clock solution in the very same period. The stability obtained with the polynomial method (in blue) is very close to the one obtained with the residuals method (in red). Both results are consistent with the COD clock solution between 10 seconds and 1000 seconds.
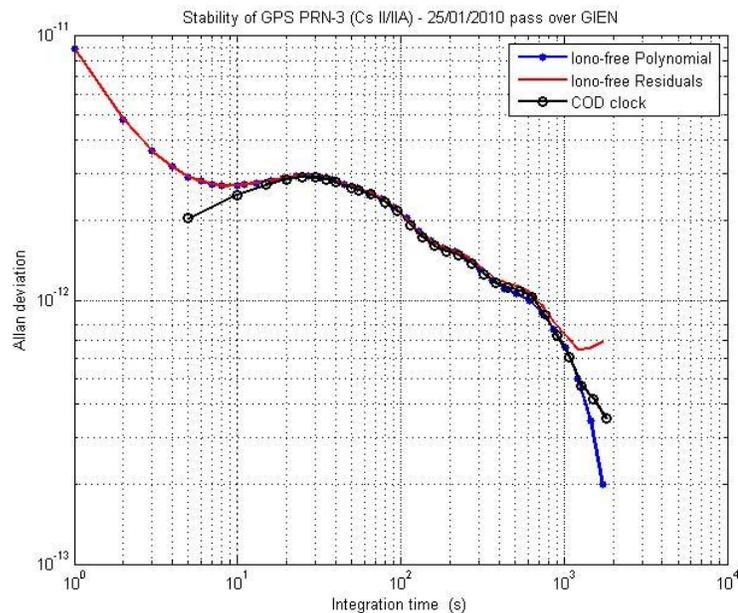

Figure 1. Stability of GPS PRN-3 Cesium II/IIA using both methods on the iono-free combination.

It is clear that the stability is limited in the very short term (between 1 and 10 seconds) by the noise of the iono-free phase observables.

The following figure shows the same stabilities computed with the polynomial method only, but with each phase observable (L1 and L2). Similar results are obtained with the residuals method (the short-term stability is the same for a given observable in the two methods).
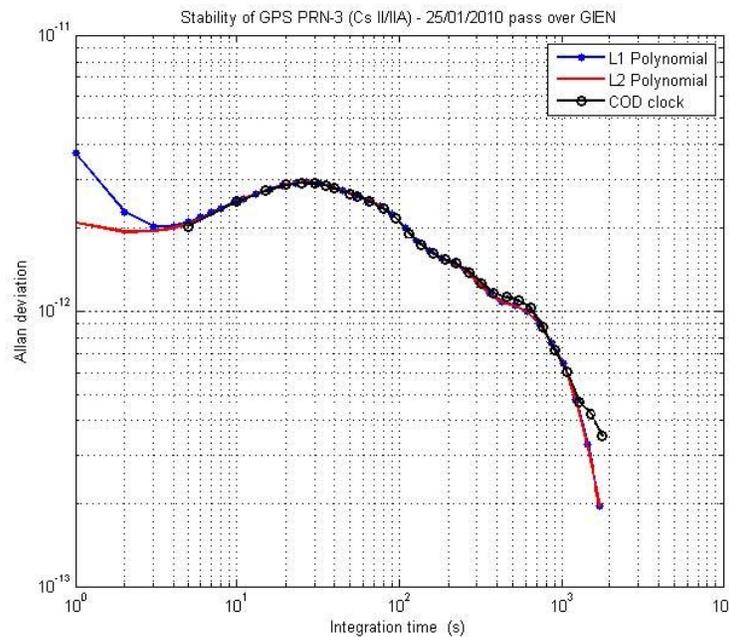

Figure 2. Stability of GPS PRN-3 Cesium II/IIA using the polynomial method on L1 and L2.

We notice that the L2 observable is less noisy than L1 in the very short term. We get in this case a better noise than with the iono-free combination simply because of the linear combination. Comparing it to the previous figure, we see that the stability obtained with L1 or L2 is consistent with the stability obtained with COD between 5 and 10 seconds.

We also observe here a "bump" probably due to the servo of the quartz crystal oscillator on the atomic transition that seems to have a time constant of about 30 seconds. For longer integration times, we get the expected -1/2 slope (white frequency noise, typical of a passive frequency standard).

GPS PRN 26 RUBIDIUM II/IIA CLOCK

Here is another example with the GPS PRN 4 (SVN 34) which is a Rb of Block II/IIA:
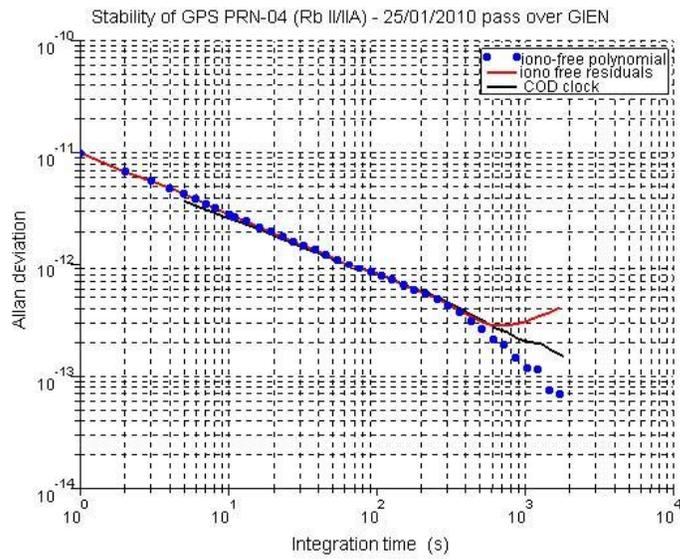
Figure 3. Stability of GPS PRN-4 Rb II/IIA using both methods on the iono-free combination.

Similar conclusions can be drawn with that type of clock.

GPS PRN 20 RUBIDIUM IIR

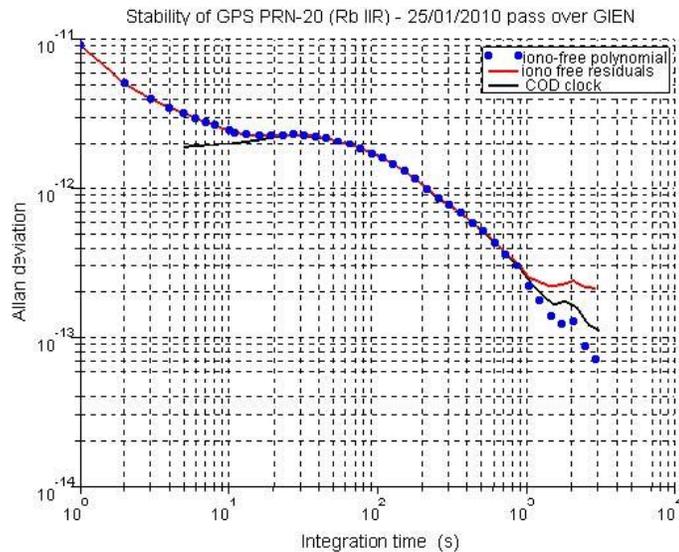Here is another example with the GPS PRN 20 (SVN 51), which is a Rb IIR:

Figure 4. Stability of GPS PRN-20 Rb IIR using both methods on the iono-free combination.

We also notice a very good consistency between 20 and 1000 seconds. The following figure shows the same stabilities computed with the polynomial method only, but with each phase observable (L1 and L2).
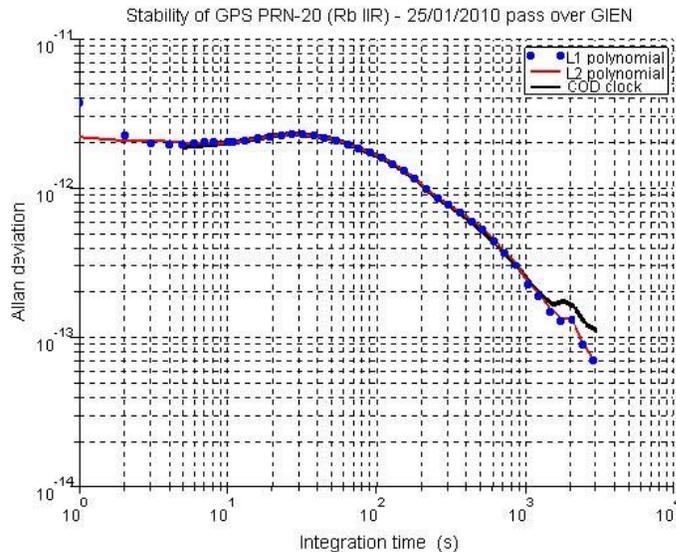

Figure 5. Stability of GPS PRN-20 Rb IIR using the polynomial method on L1 and L2.

The same conclusions can be drawn with that type of clock. Similar results have been obtained with the other GPS on-board clocks and also with the measurements of other ground stations. This allows us to validate these two methods. Another interesting example is the recently launched PRN 25 (IIF).

GPS PRN 25 RUBIDIUM IIF

The GPS PRN 25 (SVN 62) is the first Block IIF satellite; it was launched in May 2010 and embarks two rubidium clocks and one cesium clock. At the time of this experiment, the payload was driven by one of the rubidium clocks.

Figure 6 below shows the stabilities obtained with both methods using the L1/L2 iono-free combination. The COD clock solution exhibited in the period corresponding to the pass over GIEN considered here some nonstationary instabilities. Therefore, for the COD clock solution stability, in Figures 6 and 7, we did not consider the whole pass over GIEN, but a subset of this pass without any such instabilities.

The COD clock solution is consistent with both methods (using the L1/L2 iono-free combination) between 100 and 1000 seconds. The stability obtained at 1000 seconds is about 3.10^{-14}, which is a better order of magnitude than the clocks of previous GPS Blocks. This result is consistent with the in-orbit assessment of **[5]**.
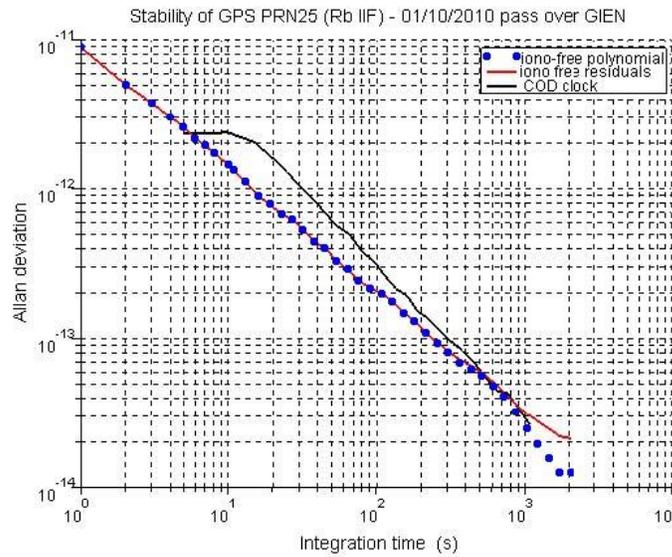
Figure 6. Stability of GPS PRN-25 Rb IIF using both methods on the L1/L2 iono-free combination.
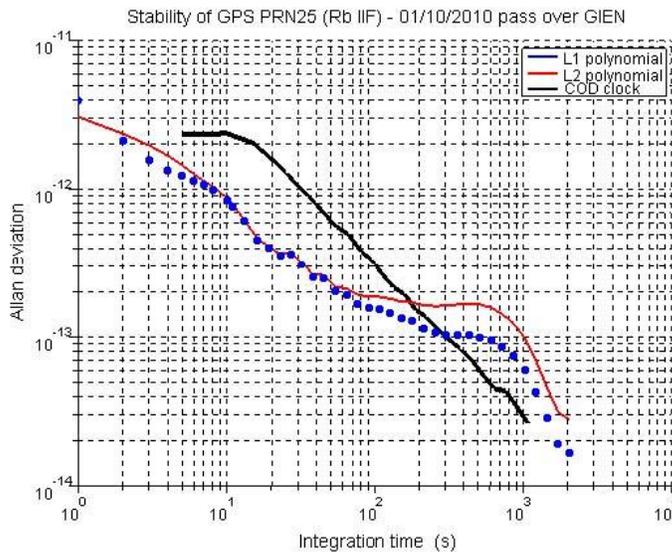

Figure 7. Stability of GPS PRN-25 Rb IIF using the polynomial method on L1 and L2.

CONCLUSION

The methods developed here represent alternative ways to characterize the short-term stability of GNSS on-board clocks. These methods have been validated using GPS on-board clocks and COD clock products. The results provided by the two methods are completely consistent with one another and with the COD clock solution.

The outstanding advantage of the polynomial method is that all you need is a ground receiver connected to a clock, the performances of which are better than the space clock. This feature is obviously extremely interesting when a global network of stations is not yet available (e.g., in a GNSS early development phase) or not accessible, or when the ODTS (Orbit Determination and Time Synchronization) process is not available. Moreover, the ODTS often provides a clock solution with a rate of 300 seconds that does not allow one to estimate the short-term behavior of the on-board clock, while the polynomial method provides an estimate of the on-board clock with the rate of the used RINEX observation files.

The polynomial method is considered to provide accurate estimations of the GNSS on-board clock stability up to at least some hundred seconds and then might be slightly too optimistic for longer integration times. The residuals method is thought to provide accurate estimations of the GNSS on-board clocks stability up to at least one thousand seconds (provided the troposphere delay effects are taken into account).

Giving access to the high rate behavior of the GNSS on-board clocks, these methods allow one to identify potential sinusoidal patterns that may not be clearly visible with the ODTS clock solution. These methods are considered to be simple, fast, and efficient ways to characterize the behavior of GNSS on-board clocks on a given pass.

ACKNOWLEDGMENTS

REFERENCES

[1] J. Oaks, M. Largay, W. Reid, and J. Buisson, 2003, *"Global Positioning System Constellation Clock Performance,"* in Proceedings of the 34th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 3-5 December 2002, Reston, Virginia, USA (U.S. Naval Observatory, Washington, D.C.), pp. 77-87.

[2] M. Epstein, T. Dass, J. Rajan, and P. Gilmour, 2008, *"Long Term Clock Behavior of GPS IIR Satellites,"* in Proceedings of the 39th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 27-29 November 2007, Long Beach, California, USA (U.S. Naval Observatory, Washington, D.C.), pp. 59-77.

[3] P. Waller, F. Gonzalez, J. Hahn, S. Binda, R. Piriz, I. Hidalgo, G. Tobias, I. Sesia, P. Tavella, and G. Cerretto, 2009, *"In-orbit Performance Assessment of GIOVE Clocks,"* in Proceedings of the 40th Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 1-4 December 2008, Reston, Virginia, USA (U.S. Naval Observatory, Washington, D.C.), pp. 69-82.

[4] J. M. Dow, R. E. Neilan, and C. Rizos, 2009, *"The International GNSS Service in a changing landscape of Global Navigation Satellite Systems,"* **Journal of Geodesy, 83,** 191-198, DOI: 10.1007/s00190-008-0300-3 (see Erratum, **Journal of Geodesy, 83,** 689, DOI: 10.1007/s00190-009-0315-4).

[5] F. Vannicola, R. Beard, J. White, K. Senior, A. Kubik, and D. Wilson, 2010, *"GPS Block IIF Rubidium Frequency Standard Life Test,"* in Proceedings of the ION GNSS 2010 Meeting, 20-24 September 2010, Portland, Oregon, USA (Institute of Navigation, Alexandria, Virginia).