GPS RECEIVER PERFORMANCE TEST AT ROA

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Abstract

Real Instituto y Observatorio de la Armada (ROA) carries out daily intercomparisons of time and frequency using the GPS satellite system. For this type of links and for high-precision global comparisons, the use of geodesic GPS receivers is highly recommended, because it provides the solution using code P1/P2 (P3) and also carrier phase (PPP). ROA has been operating two different class of these receivers: PolaRx2 (developed by Septentrio, Belgium) since 2005 and GTR50 (developed by DICOM, Czech Republic) since 2006.

Although the last one was initially developed for time and frequency comparisons using the GPS Common View C/A method, this receiver can perform code and phase measurements and, after the issue of the last software version, it has provided the possibility of solution in carrier phase. In this paper, we present the comparison results of three GTR50 receivers, in two different setups: common clock and zero baseline. Also, comparison with PolaRx2 data are shown and analyzed.

I. INTRODUCTION

GPS Time and Frequency transfer is not only the most useful tool for remote clocks comparison, and the basis for time international timing laboratories contributions to International Atomic Time, but also one of the most accurate techniques in this field. In the case of Precise Point Positioning (PPP), it's almost at the same level of the state-of-the-art technique, two-way satellite time and frequency transfer (TWSTFT).

This last technique has, however, the drawback that it is more expensive than the ones based on GPS, because it requires renting the use of a communication satellite transponder and usually more time for control operations. For all these reasons, it's interesting to develop and study new geodetic GPS receivers, which can perform P3 and PPP solutions in an appropriate and continuous way. Moreover, we are thinking of the new Global Navigation Satellite Systems (GNSS) that are under development and deployment and that will provide time and frequency transfer in a similar way as GPS does.

In the next sections, we will first present the geodetic GTR50 for time and frequency transfer, and the results found during the comparison between three of them and one PolaRx2, in four different setups:

- Common clock of three identical GTR50's
- Common clock and antenna of three identical GTR50's
- Common clock and antenna of two identical GTR50's and one PolaRx2
- Common clock of two identical GTR50's and one PolaRx2.

II. GTR50 RECEIVER

This receiver is basically a Linux PC in a 19-inch chassis together with one GPS receiver (originally it was a Javad GD and currently it is a Javad GGD-112T) and one time-interval counter. The Javad GPS receiver uses its own quartz oscillator, supports both code and phase measurements, and generates one PPS output synchronized to GPS Time.

The difference between this PPS and the PPS input reference is measured by the time-interval counter, that, together with the receiver circuits and the GPS receiver, is located in a thermostatted box (based on thermoelectric Peltier modules) to minimize their delay temperature dependence.

The GTR50 was originally intended only for time and frequency comparisons via GPS common views in C/A code, but new software versions released this year (1.5.3. and later versions), also made possible comparisons with the ionosphere-free code combination P3 and PPP techniques.

III. COMMON CLOCK OF THREE IDENTICAL GTR50'S

In Figure 1, we can see three similar geodetic GTR50 receivers (with denominations GTR1, GTR2, and GTR3), each of which has been connected to its own NovAtel antenna (type GPS-702-GG, with pinwheel technology for multipath rejection and stable phase center), and was driven by the same high-performance cesium frequency standard (type 5071A).

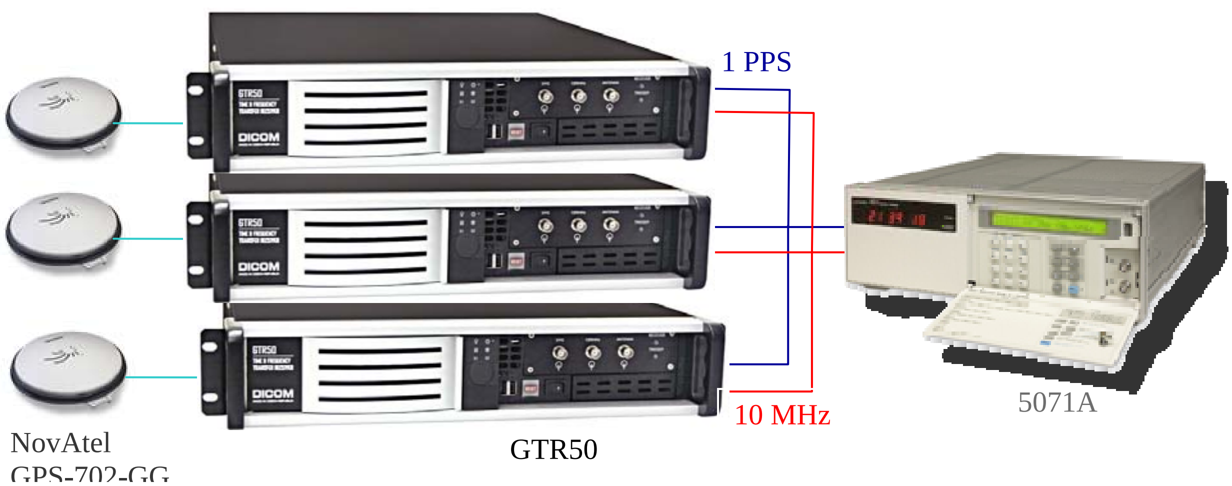

Figure 1. First setup of three identical GTR50's in common-clock.

The time and frequency transfer between these receivers has been computed initially in code, by the "common view" (CV) method, using the CGGTTS C/A and P3 daily files generated automatically by each receiver. In Figure 2, we can see the CV results from day of year (DOY) 118 to 135 of the pair GTR1-GTR3, where we can observe a standard deviation of resulting data differences of 160 ps and a correlation with the external temperature that rounds to 0.04 ns/ºC (Figure 3). The same number is found for the GTR2-GTR3 pair, but it goes down to 0.009 ns/ºC for the last possible combination GTR1-GTR2. The effect of environmental conditions on antenna electronics in GPS time receivers is well documented **[1]**, and can also be detected clearly in terms of Modified Allan variance.

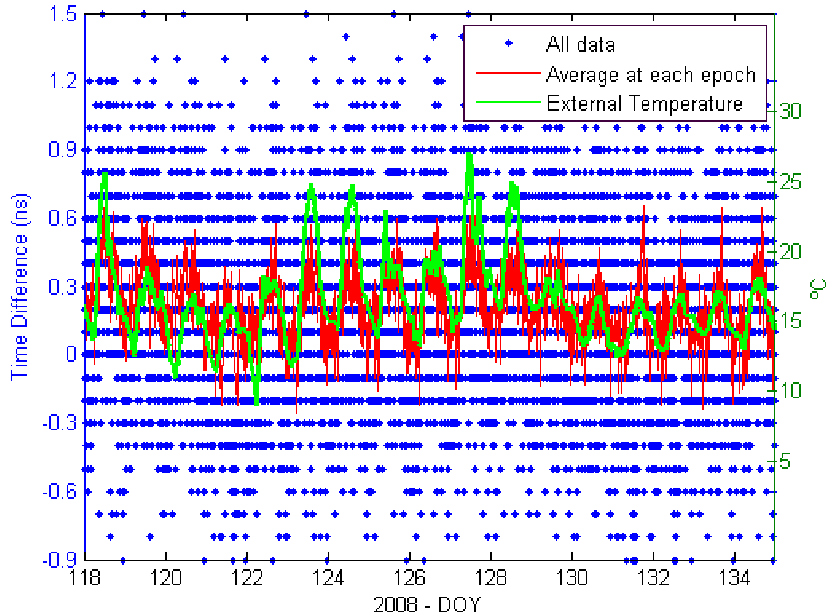

Figure 2. CV CGGTTS C/A GTR1-GTR3 and external temperature.

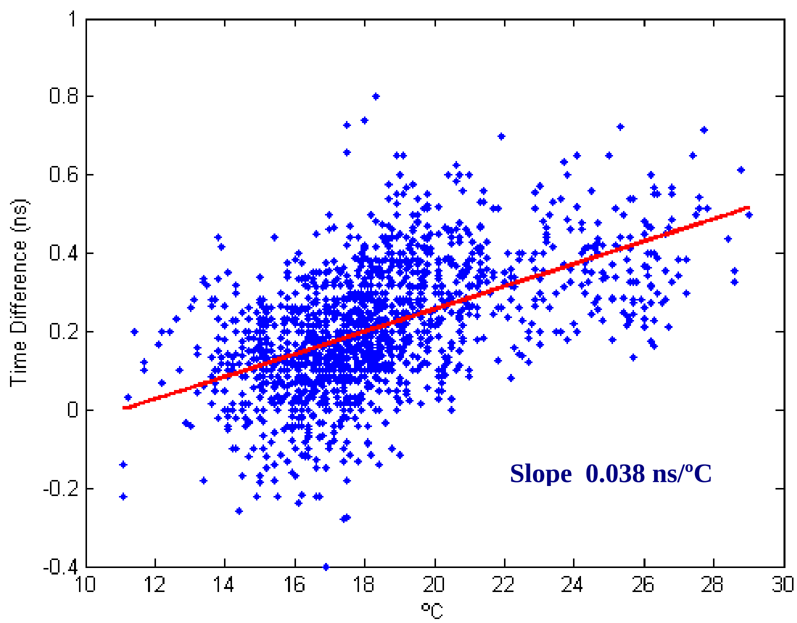

Figure 3. Temperature sensitivity coefficient for the data of Figure 2.

For the same period, the CV P3 differences results are higher (all the setups' computed values are reported in Section VII) and again two pairs are affected by temperature (GTR1-GTR2 and GTR2-GTR3), with a temperature sensitivity on the same order as for the C/A code.

Finally, we processed the resulting daily RINEX files using two different sets of PPP software. First, we used GIPSY 5.0 provided by the Jet Propulsion Laboratory, California Institute of Technology, released last summer, which includes new models for the troposphere mapping function, Earth orientation models, and the capability to model second-order ionosphere effects. Then we used the NRCan 1087 software, provided by the Geodetic Survey Division (GSD) of Natural Resources, Canada. Both analyses have shown that the best performance has values of standard deviation less than 100 ps. A comparison of three time transfer techniques in terms of frequency stability is shown in Figure 4.

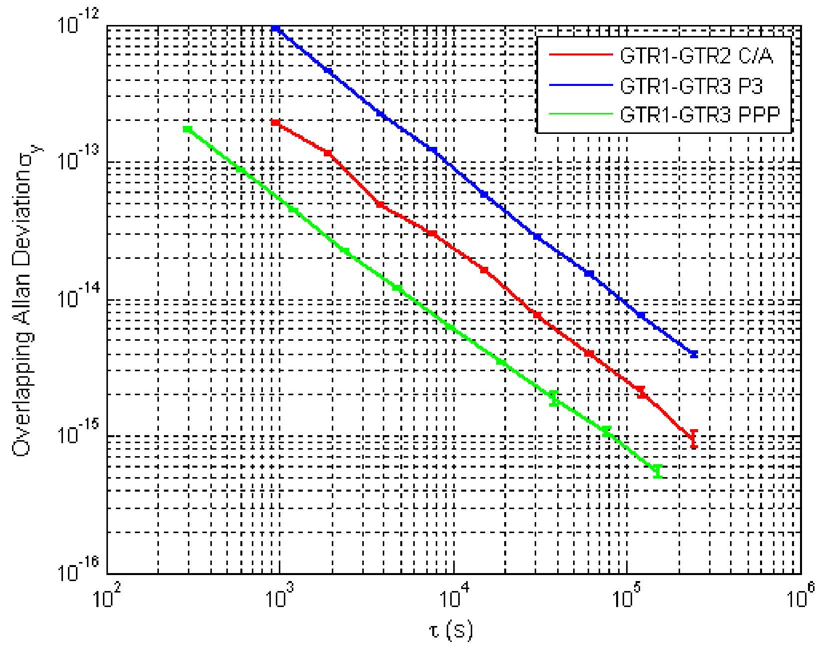

Figure 4. Frequency stability of three different techniques for time and frequency transfer in a common-clock configuration.

IV. COMMON CLOCK AND ANTENNA OF THREE IDENTICAL GTR50

For this setup, we have the same distribution of Figure 1, except for using only one Choke Ring Sensor Systems antenna (type SEN67157596+CR) that is normally used as the antenna input of one GPS Networking Rack Mount Amplified GPS Splitter (type RMALDCBS1X16) and that finally provides the GPS signal to each receiver (see Figure 8.). In this configuration, we avoid the noise contribution of each antenna and we can really check the receiver's noise. Although we can't recognize any sensitivity temperature in C/A results for any GTR50 combination, we recognize a daily phase variation in two of three combinations, which must be more closely studied.

In Figure 5, we can see the frequency stability of results from DOY 136 to 141, where the C/A and P3 values have reduced significantly, remaining constant for PPP, with respect to the previous setup. Figure

6 shows the residuals of difference between GIPSY solution and the one obtained with a 5-day rinex batch using NRCan software in backward smoothed mode.

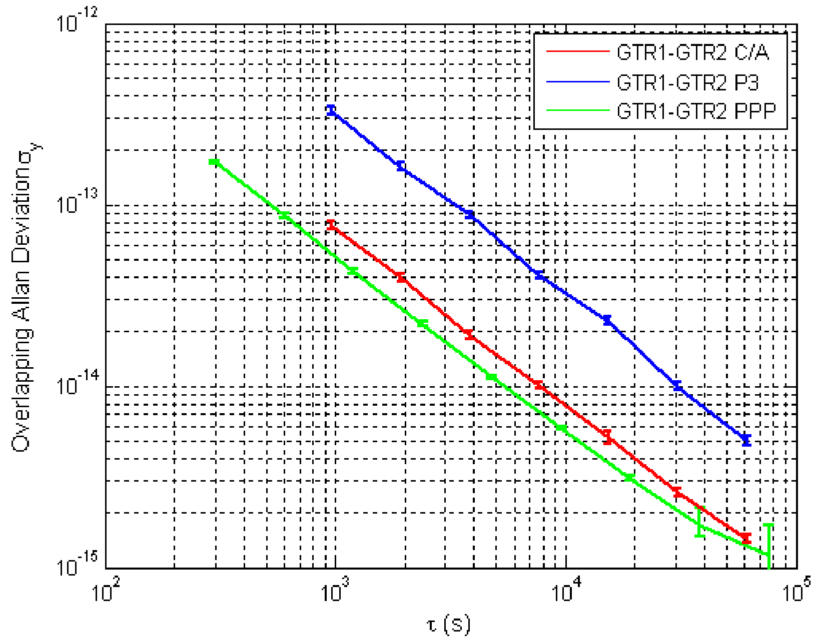

Figure 5. Frequency stability of three different techniques for time and frequency transfer in a common-clock and antenna configuration.

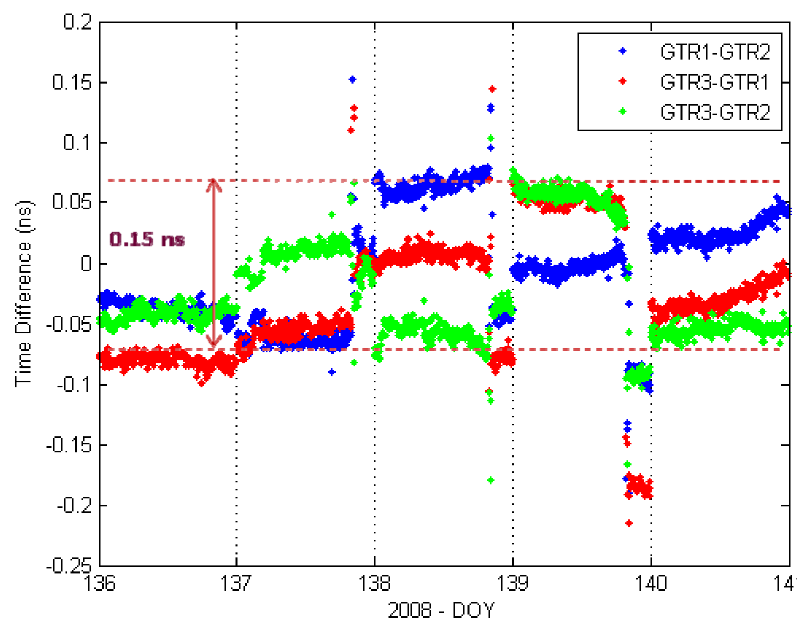

Figure 6. Differences between GIPSY and NRCAN BWD solutions.

In this section, we conclude, remarking the noise type predominant in the three different techniques. While in C/A and P3 code we only observe white phase noise, in PPP carrier and code combination (Figure 7), we recognize white phase noise for averaging times less than 2000 s and flicker phase noise for higher tau values, caused by the typical additive thermal noise of electronic devices **[2]**.

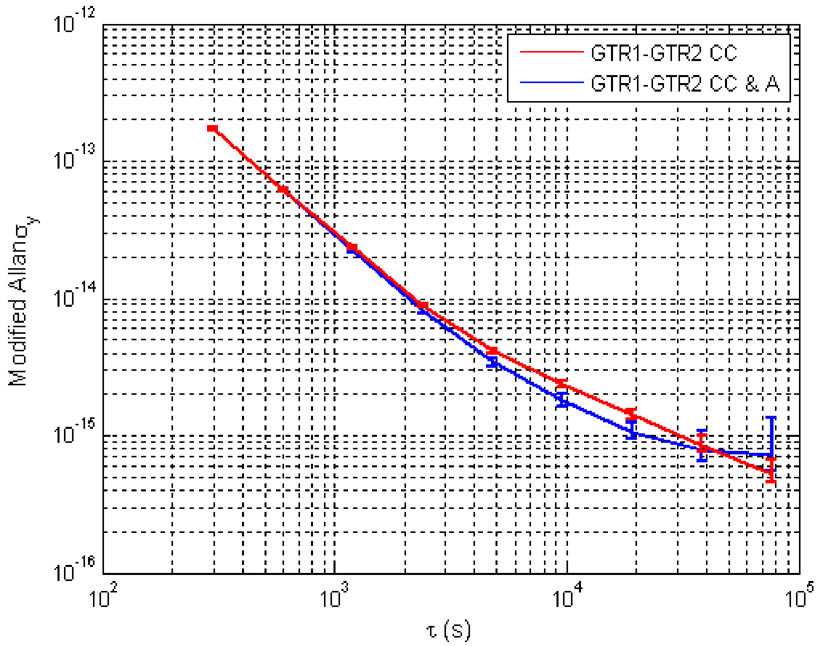

Figure 7. Modified Allan deviation for PPP results in common-clock and in common-clock and antenna configurations.

V. COMMON CLOCK AND ANTENNA OF TWO IDENTICAL GTR50'S AND ONE POLARX2

For this setup, we use the connections diagram showed in Figure 8, with the same antenna signal system mentioned in the preceding section, two GTR50's, one PolaRx2 GPS receiver, and a Symmetricom Active Hydrogen Maser (type MHM 2010) driven by a Symmetricom Auxiliary Output Generator (type AOG-110).

The PolaRx2 GPS receiver, the other type of geodetic receiver available in our laboratory, is characterized by two main features: its internal clock is driven by an external frequency (10 MHz) and it accepts 1PPS input to synchronize its internal clock **[3]**. Currently, this receiver constitutes our second IGS station, with the denomination of ROAP.

In Figure 9, we can see the Time deviation of PPP data processing for each pair of receivers, where the lower noise combination corresponds with the GTR50 pair, according to expectations considering that we are using twin or almost identical receivers.

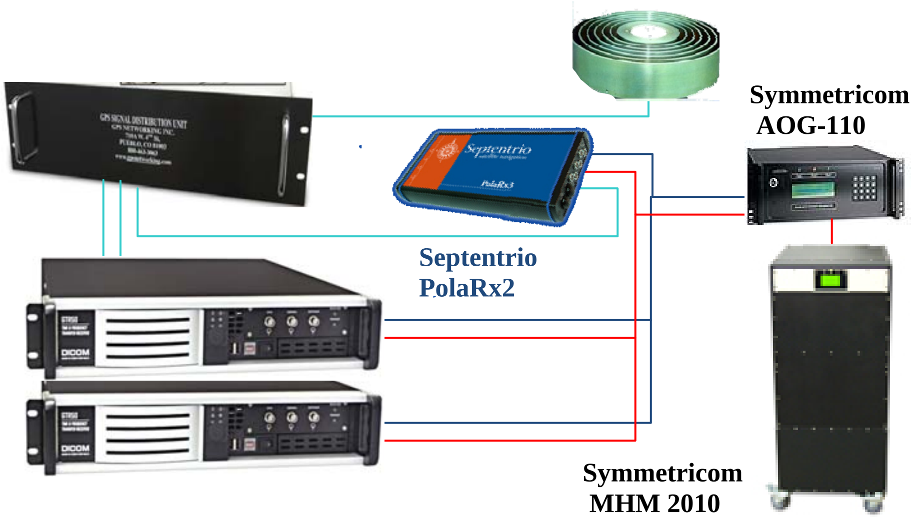

Figure 8. Setup of two identical GTR50's and one PolaRx2 in common-clock and antenna.

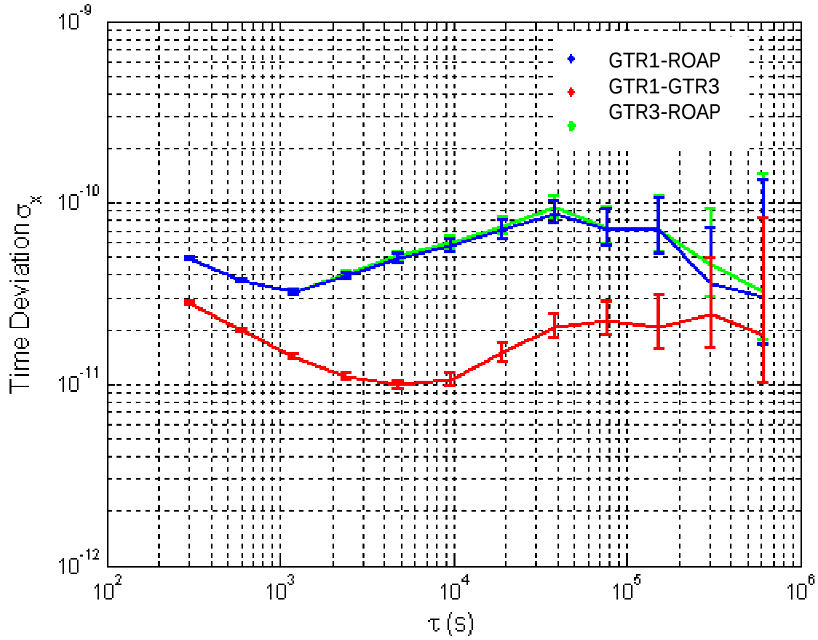

Figure 9. PPP results for the three different combinations in common-clock and antenna.

VI. COMMON CLOCK OF TWO IDENTICAL GTR50'S AND ONE POLARX2

In the last setup, we have the same distribution as Figure 8, except for the fact that ROAP uses the Sensor antenna and each GTR50 its NovAtel antenna. This configuration is the same for GTR50 as it was in the first common-clock setup; therefore, the results are on the same order. The standard deviation of the differences with ROAP is higher, but less than 1 ns, during the 10-day interval.

In this section, instead of looking at the pair differences, we have studied the short-term noise in one GTR50 receiver and in ROAP (Figure 10). For the former, we processed the data using IGS high-rate clock products (30 s), and we have found worse behavior in GTR50 for averaging times less than 1000 s, with predominantly white phase noise, whereas in ROAP, and for these averaging times, we have found predominantly flicker phase noise.

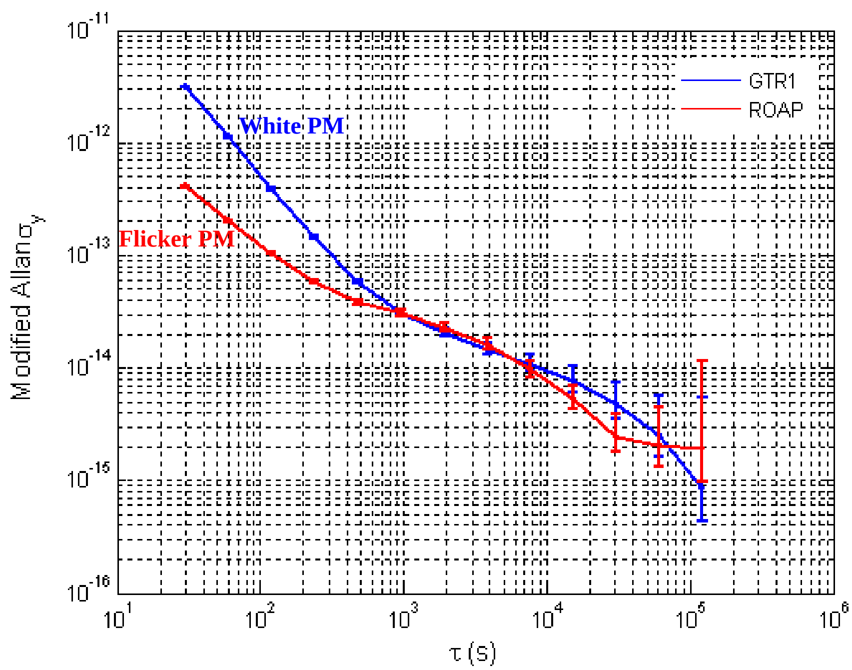

Figure 10. PPP solution, REF Clock (H-maser) – IGST.

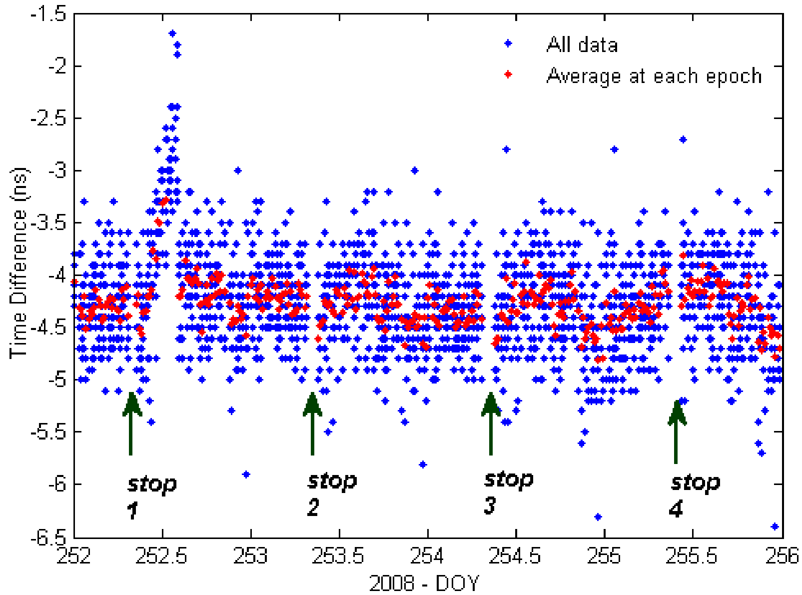

Figure 11. CV CGGTTS C/A GTR1-GTR3 in common-clock configuration.

We also carried out the test showed in Figure 11 in order to study the behavior of GTR50 after a reboot or shutdown. For this scheme, we used a pair of receivers, one continuously running and the other to be switched off and powered on. We ran 1 week, switching off the last receiver for 1 hour on different days, for a total of four shutdowns. We only observed anomalous behavior 1 hour after the first stop, with a maximum difference of about 1 ns from median. Finally, the standard deviation after the last day was 0.18 ns, a similar result to the one obtained in the first setup.

VII. RESULTS

To separate the noise contribution of the three receivers under test (Table 2), with the assumption that these units have similar performance and the behavior is uncorrelated **[4]**, we make use of the so-called "three-cornered" method for data in Table 1.

We begin with these three combinations:

$$\sigma_{12}^2 = \sigma_1^2 + \sigma_2^2$$
$$\sigma_{13}^2 = \sigma_1^2 + \sigma_3^2$$
$$\sigma_{23}^2 = \sigma_2^2 + \sigma_3^2$$

Table 1. Test results of four different setups in common-clock (CC) and in common-antenna (CA).

Setup		$\sigma_{1\text{-}2/POL}$	$\Delta\sigma_{1\text{-}2}$	$\sigma_{1\text{-}3}$	$\Delta\sigma_{1\text{-}3}$	$\sigma_{3\text{-}2/POL}$	$\Delta\sigma_{3\text{-}2}$
CC 3 GTR	C/A	0.14	0.004	0.16	0.004	0.19	0.005
	P3	0.53	0.015	0.52	0.015	0.56	0.016
	PPP	0.06	0.001	0.07	0.001	0.05	0.001
CC & CA 3 GTR	C/A	0.05	0.003	0.05	0.003	0.05	0.003
	P3	0.18	0.009	0.19	0.010	0.20	0.010
	PPP	0.05	0.001	0.04	0.001	0.04	0.001
CC & CA 2 GTR 1 POL	P3	0.53	0.027	0.25	0.013	0.62	0.031
	PPP	0.19	0.002	0.05	0.001	0.22	0.002
CC 2 GTR 1 POL	P3	0.75	0.028	0.58	0.021	0.68	0.025
	PPP	0.19	0.002	0.08	0.001	0.18	0.002

Operating in this equation system, we can easily determine the individual stabilities:

$$\sigma_1^2 = \frac{1}{2}\left(\sigma_{12}^2 + \sigma_{13}^2 - \sigma_{23}^2\right)$$
$$\sigma_2^2 = \frac{1}{2}\left(\sigma_{12}^2 + \sigma_{23}^2 - \sigma_{13}^2\right)$$
$$\sigma_3^2 = \frac{1}{2}\left(\sigma_{23}^2 + \sigma_{13}^2 - \sigma_{12}^2\right)$$

And applying the law of propagation of uncertainty, we can obtain the associated uncertainties:

$$u_c^2(y) = \sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i)$$

$$u_c(\sigma_1) = \frac{1}{2\sigma_1}\sqrt{\left(c_{12}\, u(\sigma_{12})\right)^2 + \left(c_{13}\, u(\sigma_{13})\right)^2 + \left(c_{23}\, u(\sigma_{23})\right)^2}$$
$$u_c(\sigma_2) = \frac{1}{2\sigma_2}\sqrt{\left(c_{12}\, u(\sigma_{12})\right)^2 + \left(c_{23}\, u(\sigma_{23})\right)^2 + \left(c_{13}\, u(\sigma_{13})\right)^2}$$
$$u_c(\sigma_3) = \frac{1}{2\sigma_3}\sqrt{\left(c_{23}\, u(\sigma_{23})\right)^2 + \left(c_{13}\, u(\sigma_{13})\right)^2 + \left(c_{12}\, u(\sigma_{12})\right)^2}$$

where $c_{12} = \frac{\sigma_{12}}{2\sigma_1}$, $c_{13} = \frac{\sigma_{13}}{2\sigma_1}$ and $c_{23} = -\frac{\sigma_{23}}{2\sigma_1}$ are the sensitivity coefficients.

Table 2. Noise contribution of each individual receiver under test.

Setup		σ_1	$\Delta\sigma_1$	σ_3	$\Delta\sigma_3$	$\sigma_{2/POL}$	$\Delta\sigma_2$
CC 3 GTR	**C/A**	0.07	0.010	0.15	0.005	0.12	0.006
	P3	0.34	0.020	0.39	0.018	0.40	0.017
	PPP	0.05	0.001	0.04	0.001	0.02	0.002
CC & CA 3 GTR	**C/A**	0.04	0.003	0.04	0.003	0.04	0.003
	P3	0.12	0.013	0.15	0.011	0.13	0.012
	PPP	0.04	0.001	0.02	0.002	0.04	0.001
CC & CA 2 GTR 1 POL	**P3**	0.14	0.084	0.29	0.042	0.55	0.022
	PPP	0.07	0.005	0.09	0.004	0.20	0.002
CC 2 GTR 1 POL	**P3**	0.47	0.032	0.34	0.043	0.59	0.025
	PPP	0.07	0.004	0.04	0.007	0.18	0.002

VI. CONCLUSIONS

In this paper, we have studied the behavior and noise contribution of three GTR50 GPS receivers, exploring all different techniques for time and frequency transfer in all possible configurations. Initially, we found a low level noise between all GTR50 pair combinations, with a ceiling noise lower than 150 ps for zero and short baselines for CV C/A mode.

In P3, we have observed a high level of noise, less than 400 ps in the most unfavorable situation. We have also found an external temperature influence for both techniques in common-clock configuration, that can give rise to the value of 0.04 ns/ºC, and it appears in a pair of receivers in C/A code, which doesn't imply that it has to happen with P3 code.

In reference to PPP processing, NRCan 1087 and GIPSY 5.0 software have provided similar results, confirming this technique as the most useful tool for time transfer, bringing less noise even for short and zero baselines. Taking the Allan variance results for common-clock, we will need averaging times higher than 3 hours to have a fractional frequency stability less than 6×10^{-15} and averaging times higher than 1 day for it to be in parts in 10^{-16}.

In regard to the GTR50 versus PolaRx2 comparison, we detected dominant white PM noise in PPP processing for averaging times less than 900 s. This can be due to not using an external frequency reference in the GPS receiver or to the intrinsic noise of the time-interval counter module. Finally, we would also like to emphasize the very stable situation after any shutdown or restart, where we have not detected time jumps and malfunctions just after the restart or during the following days of operation.

ACKNOWLEDGMENTS

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REFERENCES

[1] W. Lewandowski, J. Azoubib, and W. J. Klepczynski, 1999, "*GPS: Primary Tool for Time Transfer,*" **Proceedings of the IEEE, 87,** 163-172.

[2] R. Costa, D. Orgiazzi, V. Pettiti, I. Sesia, and P. Tavella, 2004, "*Performance comparison and stability characterization of timing and geodetic GPS receivers at IEN,*" in Proceedings of the 18th European Frequency and Time Forum (EFTF), 5-7 April 2004, Guildford, UK.

[3] G. Petit, P. Defraigne, B. Warrington, and P. Uhrich, 2006, "*Calibration of Dual Frequency GPS Receivers for TAI,*" in Proceedings of the 20th European Frequency and Time Forum (EFTF), 27-30 March 2006, Braunschweig, Germany, pp. 455-459.

[4] C. R. Ekstrom and P. A. Koppang, 2002, "*Degrees of freedom and three-cornered hats,*" in Proceedings of the 33rd Annual Precise Time and Time Interval (PTTI) Systems and Applications Meeting, 27-29 November 2001, Long Beach, California, USA (U.S. Naval Observatory, Washington, D.C.), pp. 399-405.