Study of satellite dependency of phase biases between-receivers and between-signals

Martin Håkansson
Lantmäteriet & KTH, Sweden
martin.hakansson@lm.se

Introduction

Phase biases induced in GNSS hardware have a potential to degrade the accuracy in precise positioning if not handled properly [1]. The existence of a satellite dependency of the biases is extra problematic, as the biases in this case no longer are absorbed by the receiver clock error term alone.

This poster presents results from two studies with the purpose to investigate whether satellite dependencies exist for two cases of relative phase biases.

In the first study, relative receiver phase biases were estimated from receivers of different types in a zero-baseline setup. All of the receivers were also connected to a common external oscillator. In this setup, it is possible to separate the relative receiver phase biases from most other error terms. However, extra care must be taken when handling the remaining error sources, such as potential multipath residuals between the receiver types. As an extra precaution against this type of error, the experiment was performed at two different sites: a main site at the headquarters of Lantmäteriet in Gävle; and a secondary site in Mårtsbo, approximately 10 km from the main site. Photos of the antennas together with the corresponding diagrams of the zero-baseline setups are depicted in Figures 1 and 2 for the sites in Gävle and Mårtsbo respectively.

The second study investigated whether there exists a satellite dependency of between-signals phase biases (e.g. biases between the carrier phases derived from C/A-code and P-code tracking on L1).

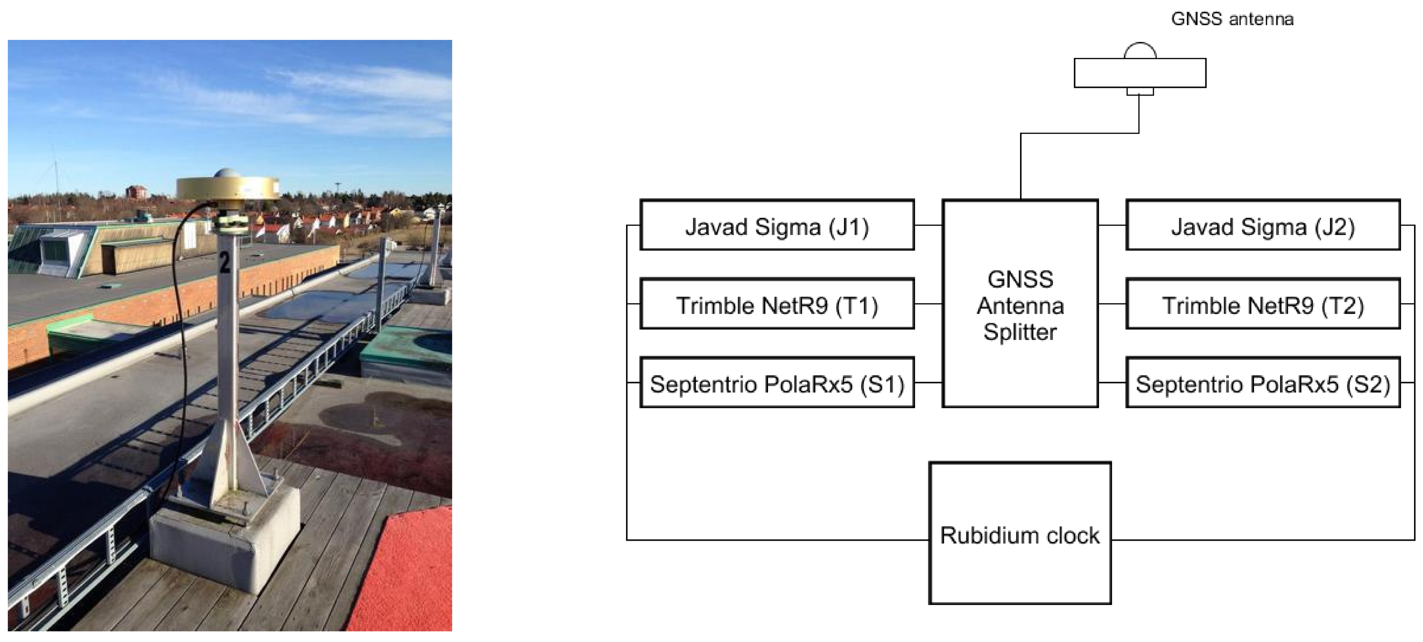

Fig. 1 Photo of the antenna site in Gävle and diagram of the corresponding zero-baseline setup

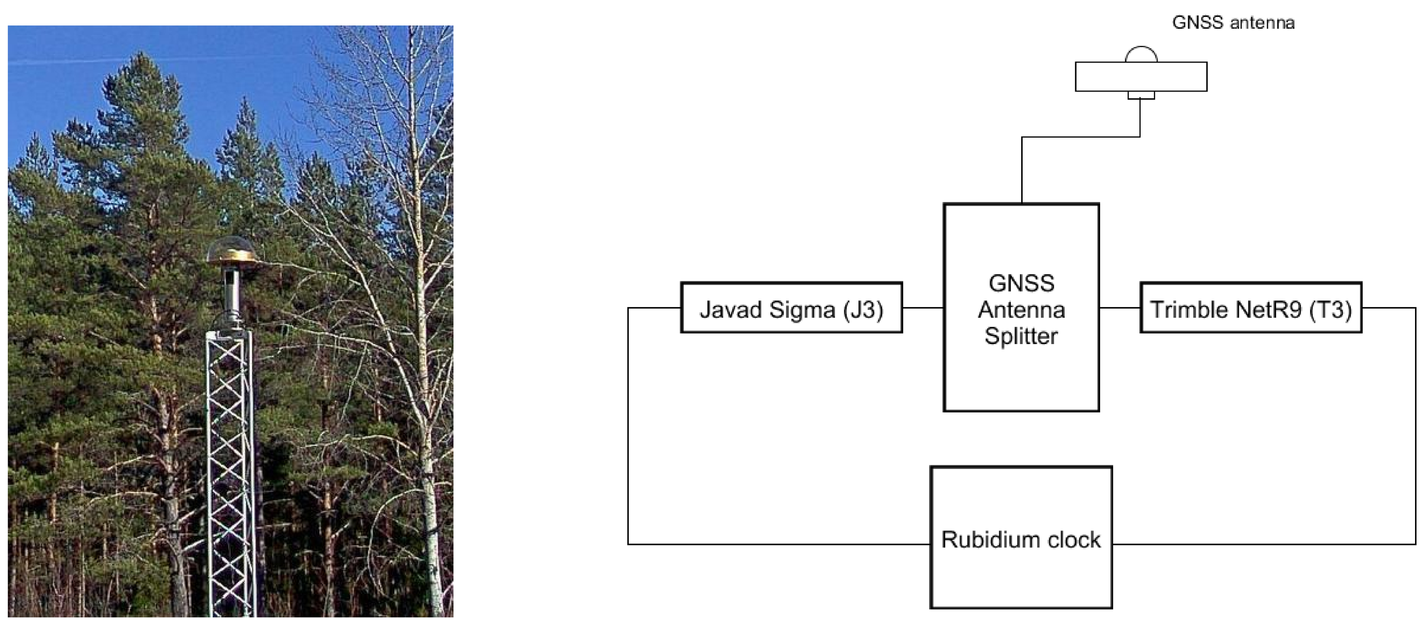

Fig. 2 Photo of the antenna site in Mårtsbo and diagram of the corresponding zero-baseline setup

Between-receivers biases

Most error sources will be common for both receivers in a zero-baseline setup. The single difference phase observation equation for the remaining error sources thus becomes

$$\Phi_{AB}^{s} = f\left(\delta_{AB} + \varphi_{AB} + b_{AB}^{s}\right) + N_{AB}^{s} + \varepsilon_{AB} \qquad (1)$$

where f is the carrier frequency, δ is the relative receiver clock error, φ is relative receiver initial phase, b is the relative receiver phase bias, N is the integer valued phase ambiguity, and ε is the remaining error sources including noise. As can be noted, the receiver phase bias b is here not assumed to be independent on the satellite tracked.

As this equation system is rank deficient, Equation 1 must be reparametrized in order to solve for the bias terms. This was done with the following substitutions

$$\tilde{\Phi}_{AB}^{s} = \tilde{\delta}_{AB} + \tilde{N}_{AB}^{s} + \varepsilon_{AB} \qquad (2)$$

where $\tilde{\delta}_{AB} = f\left(\delta_{AB} + \varphi_{AB} + b_{AB}^{1}\right) + N_{AB}^{1}$ (3)

and $\tilde{N}_{AB}^{s} = f\left(b_{AB}^{s} - b_{AB}^{1}\right) + N_{AB}^{s} - N_{AB}^{1}$ (4)

After the biases were estimated, their common mean value was subtracted so that the biases were centered around zero.

Between-signals biases

Relative between-signals phase biases were estimated from observations from the same receiver and with the same carrier frequency. The observation equation for the remaining error sources in this case becomes

$$\Phi_{S_1 S_2, r}^{s} = f b_{S_1 S_2, r}^{s} + N_{S_1 S_2, r}^{s} + \varepsilon_{S_1 S_2} \qquad (5)$$

With the knowledge that the phase bias b is much smaller than the carrier wavelength, N is easily handled by subtracting the closest integer from Φ so that only the fractional part remains. The formed equation system can then be solved for one or several epochs with least squares adjustment. Also in this case the common mean value was subtracted.

Results

Relative receiver phase biases were estimated from 1-second RINEX 3 observations of GPS L1 C/A-code tracking collected over a time period of 24 hours for the receivers depicted in Figure 1, with their corresponding labels (i.e. J1, J2, T1, T2…). Phase biases were estimated for each one of the hours during this time span – see Figure 3.

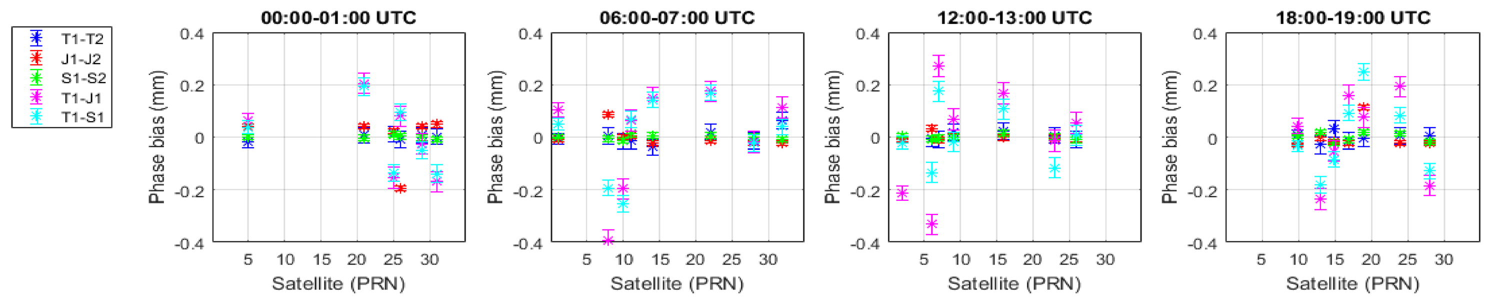

Fig. 3 Estimated relative phase biases for various receiver combinations

Three major observations can be made in Figure 3:

1. The phase bias variations between satellites tend to be small, all variations are below 0.8 mm between the largest and the smallest values. They will thereby have a negligible effect on the position accuracy and can thereby be ignored in most applications.
2. The variations are significantly larger for the mixed receiver combinations T1-J1 and T1-S1. This indicates that a satellite dependency actually exists and that it differs between receivers of different type.
3. Biases estimated from SDs with different receiver types differ between satellite passes (compared relatively between two satellites), i.e. the satellite dependent variations seem to vary over time.

As multipath is a local error source that depends both on the satellite geometry and the surrounding environment, the test was also performed at a secondary site, depicted in Figure 2. Figure 4 shows the estimated phase biases for three pairs of the receiver combination Trimble – Javad, where one of the pairs are located on the secondary site in Mårtsbo. The similarity that can be observed between these bias estimates indicate that multipath has an insignificant effect on all these estimates.

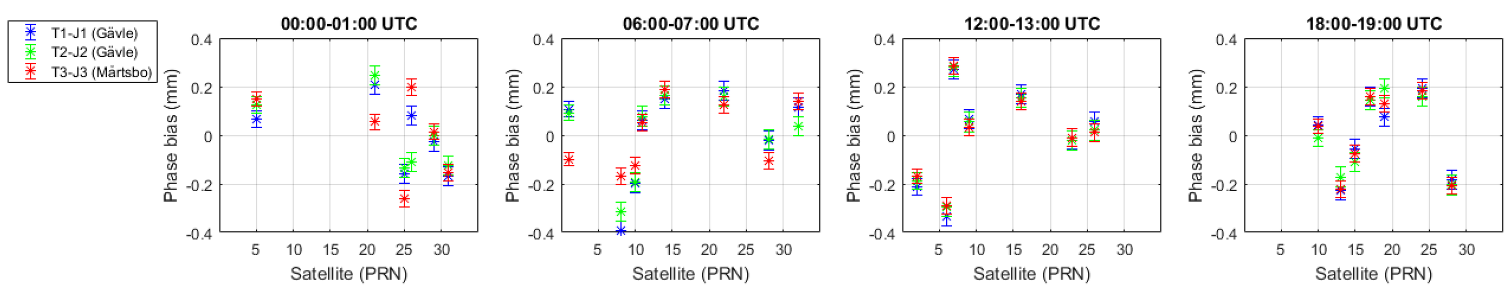

Fig. 4 Estimated relative phase biases for various receiver combinations

Even though the satellite dependent biases tend to vary over time, it was observed that these variations repeat themselves every sidereal day. Figure 5 shows bias estimates for DOY 2, 3 and DOY 76-77, where the last estimate has a separation of 75 sidereal days from the first.

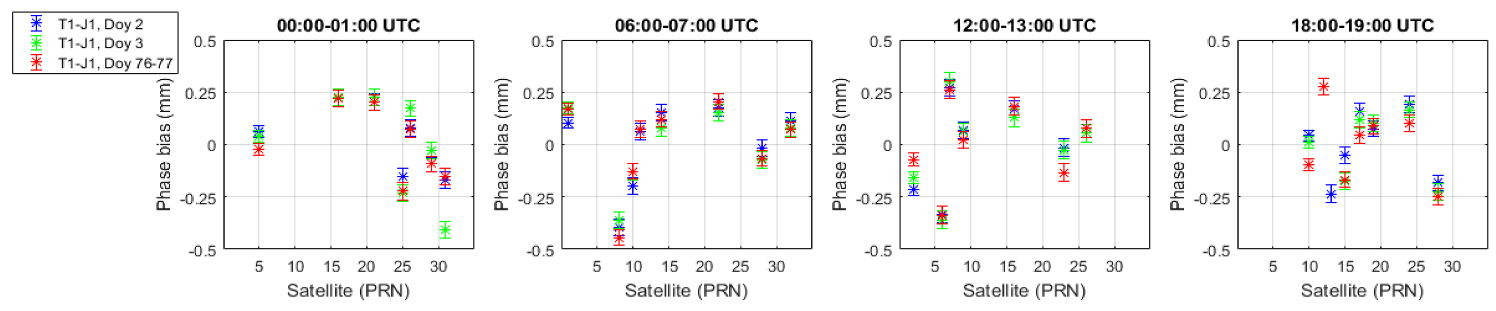

Fig. 5 Estimated relative phase biases on DOY 2, 3 and 76-77

Relative phase biases between signals were estimated between the carrier phases of C/A-code tracking and P-code tracking on L1, and between C-code tracking and P-code tracking on L2 for Javad Sigma and Trimble NetR9, respectively. Figure 6 shows diagrams of the estimated biases. The first diagram shows L1 biases estimated from Javad Sigma observation on the sites Gävle and Mårtsbo. The second diagram shows L2 biases for the sites Gävle and Mårtsbo estimated from both Javad and Trimble observations. In the third diagram L1 biases estimated from Javad observations are compared between two consecutive days. All these diagrams show biases that are similar regardless of site, receiver type, or observation time.

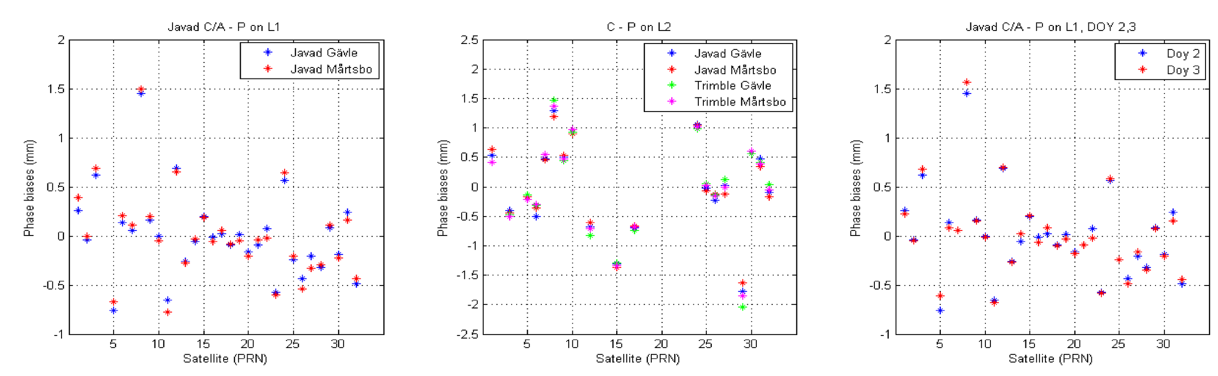

Fig. 6 Relative between-signals phase biases

Conclusions

The results show that a satellite dependency exists for both investigated cases of relative phase biases. In the first case the estimated biases varied periodically, with repetitions every sidereal day. Even though it couldn't be connected with local multipath, it is still likely that the phenomenon is connected with the repetition of the GPS satellite constellation geometry every sidereal day. It is therefore the author's hypothesis that this effect occur as a result of nadir-angle dependent signals distortions. In the second case the biases were shown to be independent both of the receiver type and on the day the GNSS observations were collected. It is here the author's hypothesis that these biases occur due to delays in the signal transmissions from the satellites.

References

[1] Håkansson, M., et al., *Review of code and phase biases in multi-GNSS positioning.* GPS Solutions, 2017. **21**(3): p. 849-860.

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