The Impact of Ionospheric Scintillation on the GNSS Receiver Signal Tracking Performance and Measurement Accuracy

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Abstract

The GNSS modernization provides new signal frequencies and satellites which can allow for more accurate methods of monitoring, modeling and mitigating the ionospheric effects on the GNSS applications. In this work, part of the *Innovative Navigation using new GNSS SIGnals with Hybridized Technologies* (iNsight) project funded by the UK Engineering and Physical Sciences Research Council (EPSRC), the ionospheric scintillation effects (abrupt power fades and phase variations in the received signals) are investigated regarding the GNSS modernization. Analysis of the scintillation effects is done through a simulation-based approach using the Spirent GSS8000 GNSS signal simulator where the signals are perturbed using the Cornell Scintillation Model (CSM). The receiver signal tracking performance is evaluated based on the variance of the code and carrier tracking loop errors using the scintillation-sensitive tracking models [1, 2]. Preliminary results on the User Equivalent Range Error (UERE) on particular receiver-satellite links are investigated to understand the effect of scintillation on the (code-based) range measurements.

1. Introduction

In general, the ionosphere affects the GNSS signals through refraction and diffraction. The former affects the signal propagation due to the electron density levels in the ionosphere, leading to errors in the range measurements and the latter occurs in general due to the plasma density irregularities and causes what is known as the ionospheric scintillation, abrupt power fades and rapid phase variations in the received GNSS signal. Regarding the new GNSS signals, which are not yet constellation-broadcast, a simulation-based approach is taken to in this work. Using the Cornell Scintillation Model (CSM) [3], the emulated signals are perturbed and tracked with a scintillation-specific multi-frequency receiver. The receiver logged data, which includes the scintillation indices (amplitude and phase scintillation indices, S4 and $\sigma\phi$, respectively) and spectral parameters (spectral slope and strength parameters, p and T, respectively), is then used to estimate the variance of the tracking error (jitter) at the output of the code and carrier tracking loops using the scintillation-sensitive tracking models of [1] and [2]. These models are however limited to weak-to-moderate levels of scintillation, thus alternative or complementary methods of evaluating the receiver performance are also investigated at a preliminary stage in this paper. Finally, the investigation taken in this work continues with an accuracy assessment of the code-based measurements on particular receiver-satellite signal links that are exposed to scintillation effects on the L1 band.

2. Methodology

The scintillation effects are obtained from the CSM which generates a time series of signal intensity fluctuations (dB) and carrier phase range variations (m) according to the input parameters S4 (60s standard deviation of the normalized intensity fluctuations) and $\tau 0$ (decorrelation time parameter in seconds). The scintillation effects are implemented to start as of the 5th minute and terminate at the 35th minute of the 40-minute long simulation. The CSM outputs for GPS L1 carrier frequency were scaled to be used for the L2 frequency according to [1]. A similar scaling was also applied for the L5 carrier frequency. In the simulation scenarios any other ionospheric and tropospheric effects

were excluded and the scintillation effects were implemented on all of the line-of-sight (LoS) signal links but analyzed for GPS SV11 (for GPS L1, L2C and L5) and Gal SV18 (for Gal L1).

The impact of scintillation on the receiver performance was investigated at the signal tracking level for which the receiver tracking loop parameters were considered in order to understand how they can be configured to provide an optimum tracking performance during different levels of scintillation. For the carrier tracking loop, the jitter variance at the output of the phase-locked loop (PLL), and for the code tracking loop that at the output of the delay-locked loop (DLL) were estimated using the formulae of [1] for the GPS L1 signal. The same formulae were also applied for the Gal L1 signal and for the coded tracking of the GPS L2C signal with appropriate values in the formulae. The PLL and DLL bandwidths were set to different values to configure the receiver for each simulation: sim.1 with 10 Hz PLL and 0.25 Hz DLL; sim.2 with 10Hz PLL and 0.10Hz DLL and sim.3 with 15Hz PLL and 0.25Hz DLL bandwidth. The tracking error variance at the PLL and DLL outputs were calculated from the formulae in [1]; and also for GPS L2C and Gal L1 using the appropriate values for each carrier. Considering the GPS L5 signal tracked on the pilot channel, the formulae in [2] were used. These formulae, however, are valid for weak-to-moderate levels of scintillation. As an alternative method the I and Q correlator outputs were considered.

The impact of the scintillation on the GNSS positioning is also considered in this work. It is important to evaluate the degrading effect of scintillation on each receiver-satellite link since it is in general expected that not all signal links are affected by scintillation simultaneously or to the same level of impact.

3. Results

The signal lock performance for each carrier frequency is considered for the three receiver configurations. Figure 1 shows the occurrence of gaps in the signal phase and intensity data for each GNSS signal. Each line corresponds to a 0.02s gap in this high rate data and consecutive lines lead to accumulation of gaps giving long gaps. The durations of such gaps are crucial for determining the spectral parameters (p and T) and scintillation indices.

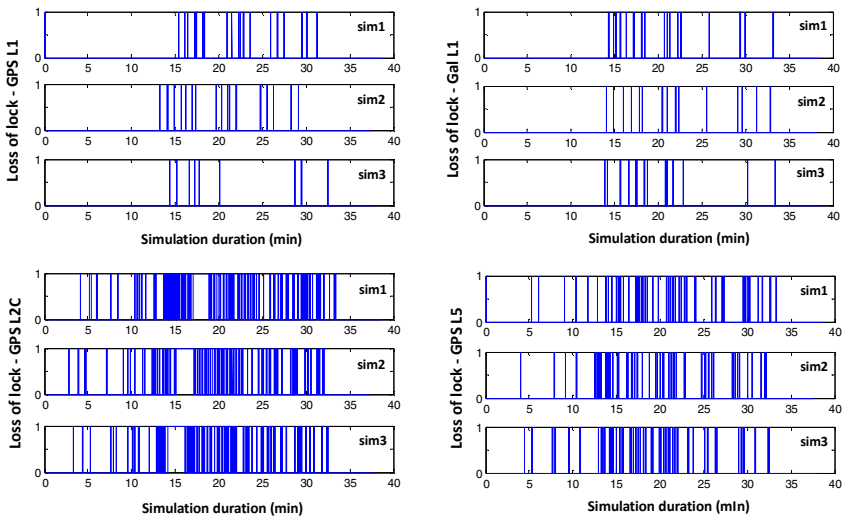

Figure 1. Occurrence of losses of lock throughout the simulations for all four GNSS signals; y-axis value of 1 corresponds to a gap in the high rate (50Hz) sampled data.

Considering the L1 band signals, the moderate level of scintillation (when S4 is about 0.5 between 5-15 minutes) does not challenge the signal tracking as much as the later periods of higher levels of scintillation. A wider PLL bandwidth of 15Hz (sim.3) can help maintain the signal lock better for both GPS L1 and Gal L1 signals as can be understood from the less number of lines populating between the minutes 20-35 compared to the same period in sim.1 and sim.2 for both carriers. As for the GPS L2C and L5 signals, many gaps occur in the high rate data. The lower transmission power and carrier frequency of GPS L2C may cause such gaps during high levels of scintillation.

The receiver tracking performance is investigated following [1] and the preliminary results of analyzing the I and Q correlator outputs are presented. The thermal noise contribution can be estimated when S4<0.707. For the GPS L2

and L5, this threshold is almost always exceeded thus such an estimation of the jitter variance from is not possible. Fig.2 shows the jitter variance for GPS L1 and Gal L1 between 5-15 minutes; during moderate levels of scintillation estimating the PLL jitter according to [1] can be possible.

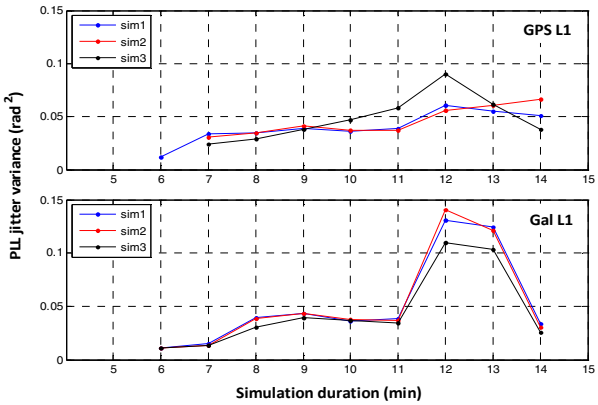

Figure 2. Jitter variance [1] between 5-15th minutes for the L1 band signals.

With the I and Q correlator outputs, the occurrence of navigation data bit errors and the carrier phase discriminator output are analyzed. The latter is important for evaluating the receiver tracking performance which can be limited to weak-to-moderate levels of scintillation regarding the formulae in [1, 2]. Both analyses are performed with comparison to the non-scintillation case in order to observe the impact of scintillation on both concepts. It was observed that during scintillation navigation data bit errors are more likely to occur (not shown here). Moreover, it was observed that during times of scintillation the loop estimate of the phase becomes less precise and accurate leading to an increase in the tracking error at the PLL output (also not shown here).

Further analysis of the carrier phase error at the PLL discriminator output can be achieved through the std of this error. As can be seen in Fig.3, the std of this error changes significantly (note the different scales of the plots) due to scintillation. The carrier tracking performance can be quantified/qualified with the std of the phase error which can be computed for all levels of scintillation throughout the simulation and be used to mitigate the impact of scintillation on these signal links in the GNSS positioning solution [6].

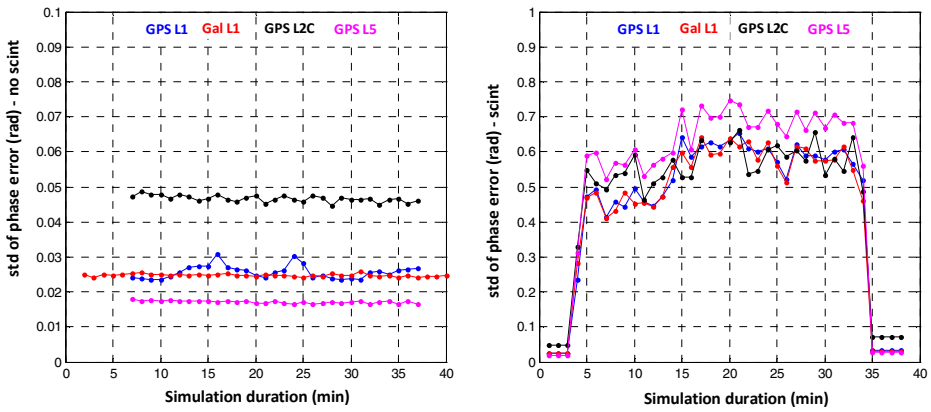

Figure 3. The std of the phase error at the output of the PLL discriminator during the absence and presence of scintillation; results shown for sim.1such that GPS signals are tracked from GPS SV11, and Gal L1 from Gal SV18.

Finally, an analysis of the User Equivalent Range Error (UERE) is done on certain signal links considering the absence and presence of scintillation to show how much the UERE can change between the two conditions [7]. Multiplying the std of the code tracking error with the appropriate code chip length gives UERE on each signal link due to the degrading effects of the scintillation as all the other error sources are neglected in the simulations. During

scintillation, the impact on the UERE values are immediate and significant: in both figures to the right and left of the sky plot in Fig.4 the UERE values during scintillation have a greater mean and variance on these L1 band signals.

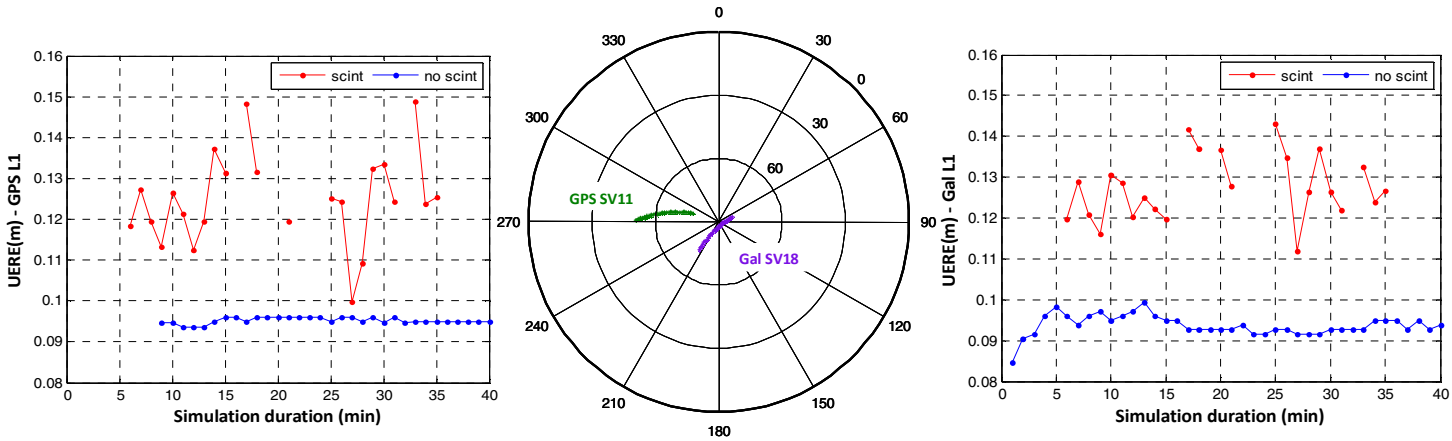

Figure 4. Sky plot showing the GPS SV11 and Gal SV18 both of which ascend in the sky from the start of the simulation onwards. UERE plots are shown for each signal link for the particular carrier frequency.

4. Conclusion

The preliminary results of analyzing the impact of ionospheric scintillation on the GNSS receiver signal tracking performance and the measurement accuracy are presented. Regarding the GNSS modernization which is not yet complete on a constellation level, the scintillation-oriented simulations performed in this work can provide a comprehensive investigation of the effects on the GNSS receiver performance. As shown here, a multi-frequency GNSS receiver can suffer from the degrading effects of amplitude scintillation which can disrupt the receiver's lock on the signal and that it can be possible to maintain the signal lock longer when the tracking loops are configured to some *optimum* settings during such background ionospheric conditions. Future work will focus on improving the research by e.g. investigating how the receiver tracking performance can be continuously monitored during weak-to-strong levels of scintillation and a correlation analysis between the occurrence of navigation data bit errors during scintillation and the positioning solution will also be carried forward. Future work will also look into the impact of scintillation on the positioning accuracy at a greater depth and implement a reliable and accurate mitigation technique to reduce the degrading effects of scintillation prior to the GNSS positioning solution.

5. References

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