GPS triple-frequency statistical study of ionospheric amplitude scintillation at low latitude

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Introduction

The ionosphere around Brazilian territory, more specifically over the peak of the equatorial ionization anomaly, represents a treat for navigation systems based on GNSS. Ionospheric scintillation creates a great vulnerability for GPS receiver tracking performance. It is responsible for significant degradation in the accuracy of navigation and positioning. Amplitude fades accompanied by significant phase shifts degrades the signal-to-noise ratio of the received signal to levels below the operational minimal signal strength. Strong scintillations make the GNSS receiver tracking loops difficult to recover the phase and code replicas which may affect availability and positioning. Users of the well known new civil signals will be more susceptible to the effects of the ionosphere in low latitudes. This work investigates how much the users of these new signals will be more affected by scintillation.

GPS triple-frequency scintillation comparison

Example of S_4 and σ_ϕ estimates at the L1, L2C, and L5 signals transmitted by PRN 25 on the night of November 13, 2014. The relative Total Electron Content (TEC) for this example is also shown. It is important to note the strong gradients during the period of scintillation occurrence.

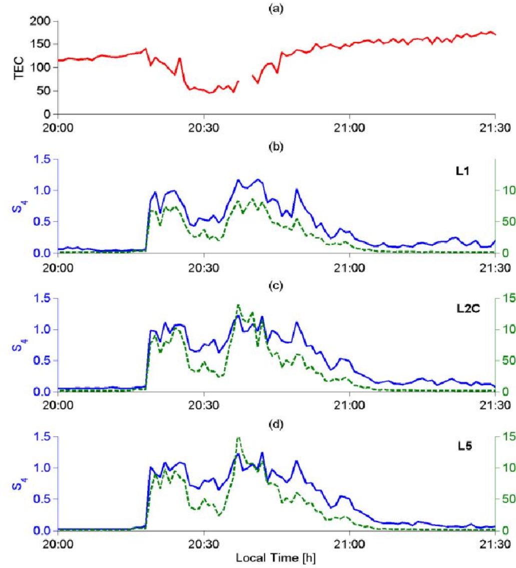

Figure 1: Corresponding S4 and σϕ indices for the L1, L2C, and L5 signals, using the combinations (blue lines, left vertical axes) and (green lines, right vertical axes).

Fading depth and dip variation of scintillation

The present work analyzes GPS L1, L2C and L5 amplitude scintillation data collected during 150 nights from November 2014 to March 2015. In the study we used data obtained from four GNSS stations located in the Brazilian territory. The observatories were from Salvador, Incofidentes, Presidente Prudente, São José dos Campos and Porto Alegre stations.

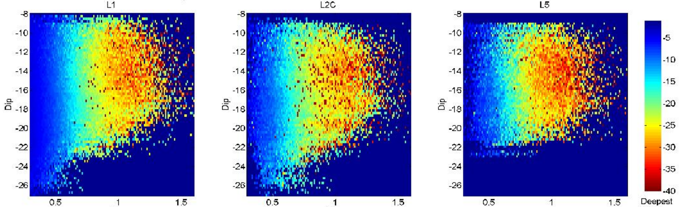

Figure 2: Maximum fading depth recorded as function of dip latitude and S4 highlighting that the users of new civil signals will be more susceptible to deeper fades.

Validation and preliminar results

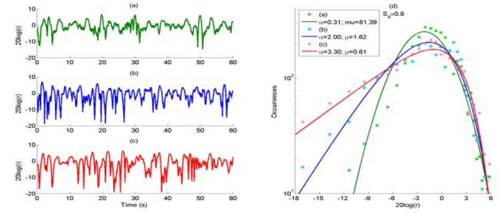

Figure 3: Three cases illustrating different scintillation patterns with almost the same scintillation index S4 (≈ 0.80). (d) Empirical distribution and calculated α-μ model.

More recent studies have revealed different aspects of the statistics of the amplitude of the received signal. The results indicated that the α-μ model provides a flexible and realistic description of the statistics of amplitude scintillation in comparison with other tested distributions based on conventional indices, due to the additional degree of freedom provided by its two parameters. The α-μ probability density function (pdf) of the amplitude envelope R of the received signal can be expressed in the form

$$f_R(r) = \frac{\alpha\ \mu^{\mu}}{\Gamma(\mu)\tilde{r}}\left(r/\tilde{r}\right)^{\alpha\mu-1}\exp\left[-\mu\left(r/\tilde{r}\right)^{\alpha}\right]$$

In the above expression, $\alpha > 0$ is an arbitrary fading parameter, and $\mu > 0$ is the inverse of the normalized variance of R^{α}. Additionally, $\Gamma(z)$ is the Gamma function of argument z. The present work will estimate the bit error probability Pe of binary DPSK (Differential Phase Shift Keying) transmissions, and consequently the mean time between cycle slips Ts=0.02/Pe. The bit error probability Pe for binary DPSK can be computed by

$$P_e = \frac{\alpha\mu^{\mu}}{4\Gamma(\mu)}\int_0^{\infty} v^{\alpha\mu/2-1} e^{-\left(\mu v^{\alpha/2}+\tilde{s}v\right)} dv$$ where

$$\tilde{r}^2 = \frac{\mu^{2/\alpha}\Gamma(\mu)}{\Gamma(\mu+2/\alpha)} \rightarrow \tilde{s} = \frac{\mu^{2/\alpha}\Gamma(\mu)}{\Gamma(\mu+2/\alpha)}\left(E_b/N_o\right) = \left[\frac{\mu^{2/\alpha}\Gamma(\mu)}{\Gamma(\mu+2/\alpha)}\right] T_b\left(C/N_o\right)$$

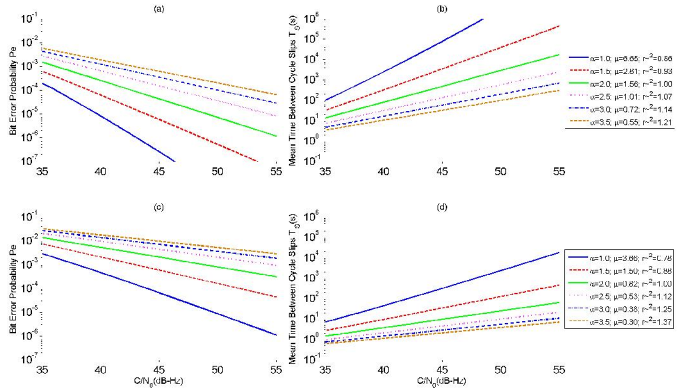

Figure 4: (a)(c) Bit error probability Pe for binary DPSK as a function of C/No, for fixed values of S4 = 0.8 and S4 = 1.1, respectively, and different values of α . 4(b), 4(d) The equivalent mean time between cycle slips Ts for the same values of S4 and α.

Results

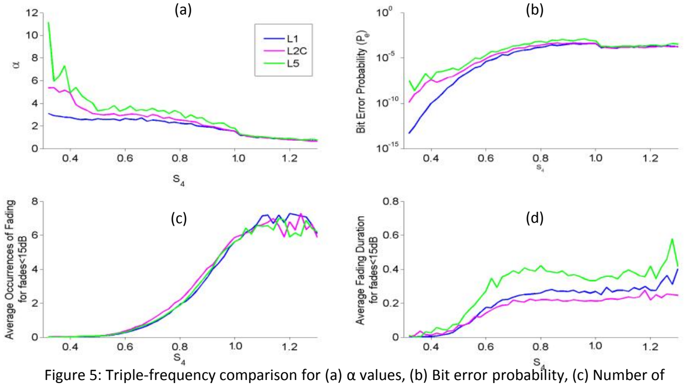

Figure 5: Triple-frequency comparison for (a) α values, (b) Bit error probability, (c) Number of occurrences for fades<-15dB and (d) Average fading duration for fades<-15dB.

The results show that the new civil frequencies are more likely to losses lock occurrences . In addition users should expect the presence of more severe fading in these conditions. Therefore users of systems in these frequencies in low latitudes could have serious problems of positioning performance besides availability.