TIME SERIES GENERATORS TO SIMULATE EARTH SATELLITE LINKS AFFECTED BY SCINTILLATIONS

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Abstract

The earth satellite links may in some cases be affected by signal scintillations due to the propagation through ionosphere and more precisely due to the occurrence of electron density bubbles inside the ionosphere. These signal scintillations affect the navigation systems performance. In order to assess the receiver capabilities to operate in such an environment it is of interest to generate signals exhibiting the same random characteristics for testing receivers testing. The algorithm allowing creating such a signal is the object of this paper.

1 Introduction

The ionosphere signal scintillations are the most important around the magnetic equator (- 20° + 20° magnetic latitude). They were the object of many measurements campaigns mainly in South America and India. In order to assess the capability of a receiver to work under such a scintillation regime, it is of interest to synthesize time series exhibiting the same characteristics. This is the objective of this study.

2 Signal spectrum and synthesis

The scintillation signal has to have an equivalent power spectral density (PSD). The PSD is given by the relationship:

$$\Gamma = \frac{A}{(q + q_0)^{-p}}$$

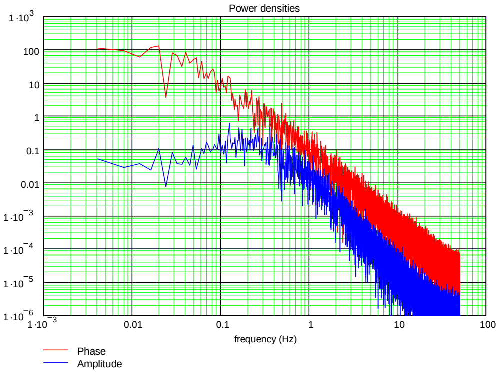


Figure 1: intensity and phase spectrum

It is determined by three parameters:

- The slope p,
- The cut-off frequency $q_0 = \frac{2\pi}{L_0}$, where L0 corresponds to the bubbles correlation distance
- The threshold value A or equivalently the value at 1 Hz

To synthesize the signal we set a value to these three parameters and calculate the PSD using the formula above, depending on the frequency.

In a second step we generate a random signal with a uniform PSD and get its Fourier transform

We then take the product of the second PSD by the square root of the first one and take the inverse Fourier transform of this product. Doing this we get a space domain signal with the required properties. Several successive fluctuating layers (multiple screens) may be considered with specific random characteristics. The signal on the ground is obtained calculating the Fresnel Kirchhoff integral which allows calculating to the signal diffracted by a slot with an arbitrary field distribution.

The time domain signal at the receiver point on the ground is deduced from the space dependent signal, considering in addition the drift velocity at the ground level. The sample duration at the ground level is related to the screen size at the ionosphere level. This last is set in relationship with several parameters: the correlation distances inside the fluctuating medium, the operating frequency and the FFT number of points. To generate signals of any duration, GISM has a loop on the signal generation.

To characterize the scintillation strength at the ground level we use the scintillation ratio S4 which corresponds to the intensity standard variation.

$$S4 = \frac{std(I)}{\langle I \rangle}$$

Due to normalization, S4 is between 0 and 1. A value lower than .2 will correspond to low fluctuations, a value around .5 to medium fluctuations and a value greater than .7 to high fluctuations.

Other parameters of interest are: the phase standard deviation, the probability of fades and the fade duration vs fade depth and the inter fades probability.

The scintillations level is frequency dependent. As a first approximation it increases with the inverse of the frequency. However the relationship is not linear.

3 Analysis of synthesized signals

Two examples corresponding to medium scintillations are reproduced below for the phase and intensity

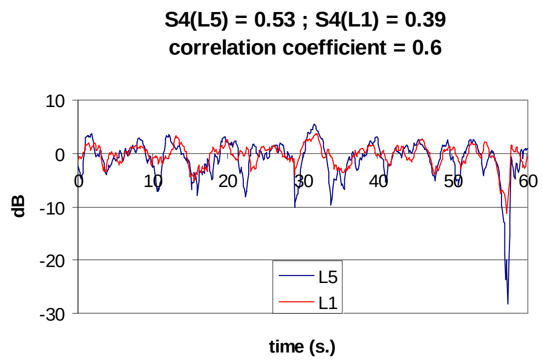


Figure 2: intensity fluctuations (medium scintillations)

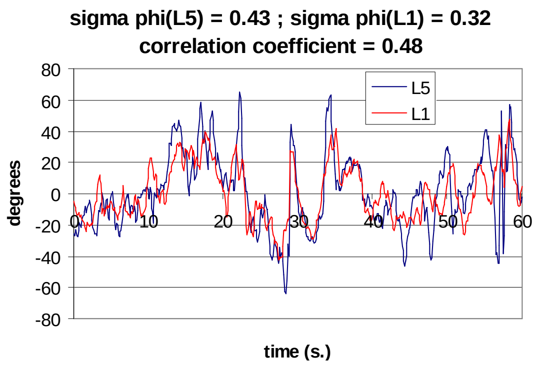


Figure 3: phase fluctuations (medium scintillations)

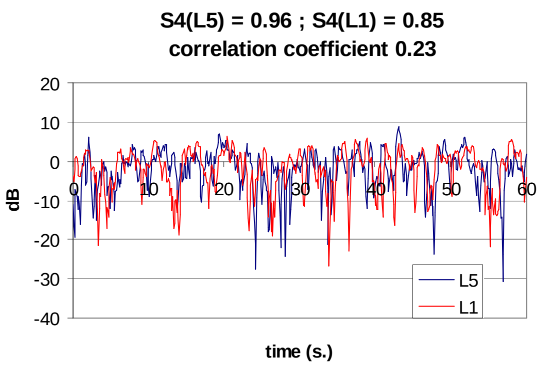


Figure 4: intensity fluctuations (strong scintillations)

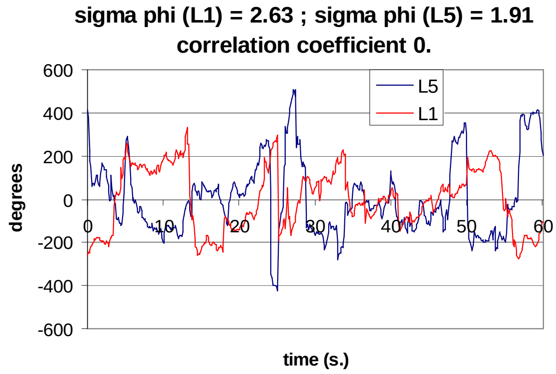


Figure 5: phase fluctuations (strong scintillations)

The simulations presented figures 2 to 5 have been obtained using the same seed for the random generator. The medium is consequently the same for the two frequencies.

The following plots present the correlation coefficient between the two frequencies and the dependency of the correlation coefficient on the frequency.

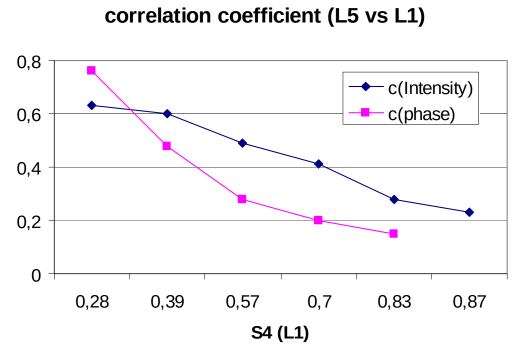


Figure 7: correlation coefficient

The phase correlation coefficient drops significantly with the scintillations level. This is due to phase jumps which appear as the scintillation ratio increases.

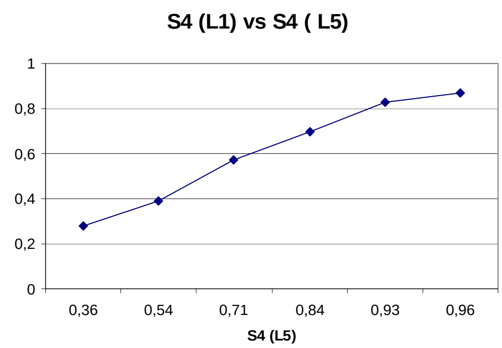


Figure 8: frequency correlation

The frequency correlation exhibits a linear relationship for medium scintillations. Both values peak to 1 in the case of strong scintillations.

The fade duration vs fade depth has been plotted on figure 9. In the case of deep fades, the fade duration is much larger than the pre-detection integration time of a GPS receiver. Consequently as regards the receiver operation a deep fade can be seen as a decrease in the signal to noise ratio by the fade level.

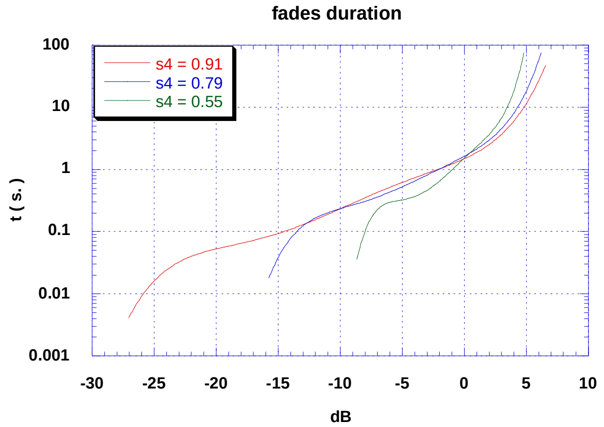


Figure 9: fade duration vs fade depth

4 Phase jumps

High fluctuating signals will lead to deep fades and correlatively to phase jumps. This can be noticed on figure 10.

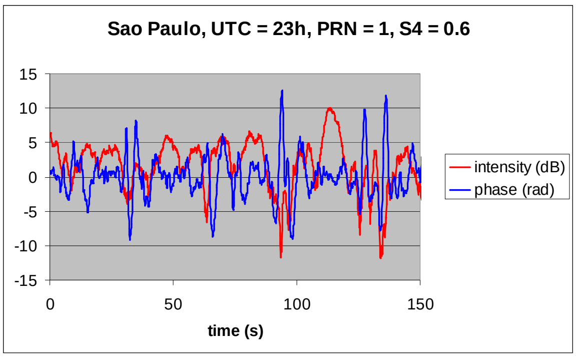
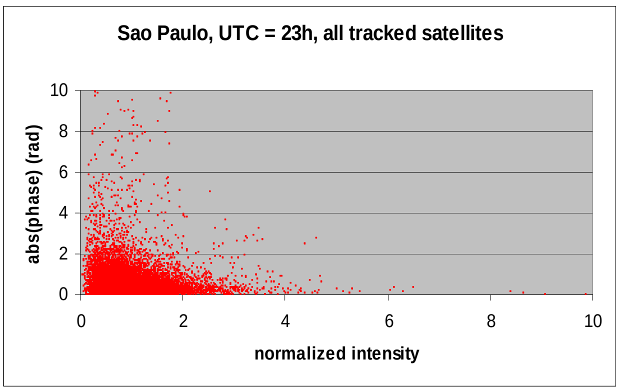


Figure 10: occurrence of deep fades and phase peaks

Such an analysis has been made extensively using both the signal and its derivative on GPS signals measurements in Brazil. This is reported on Figures 11 & 12.



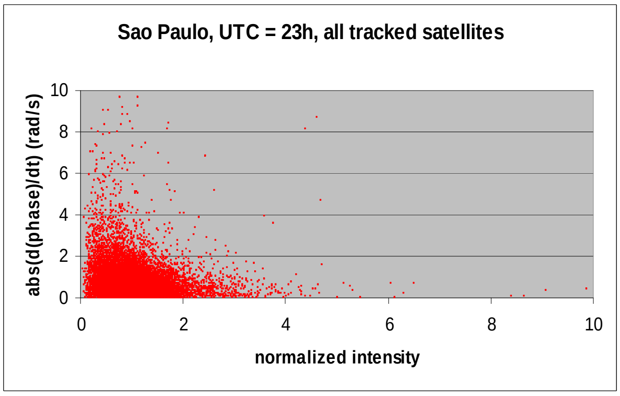


Figure 12: intensity and derivative of the phase

5 Use of time series

The two plots below show a result of a simulation using the generator for testing a GPS receiver. The first plot shows the signal at the generator output and the second one, the corresponding error due to a phase jump.

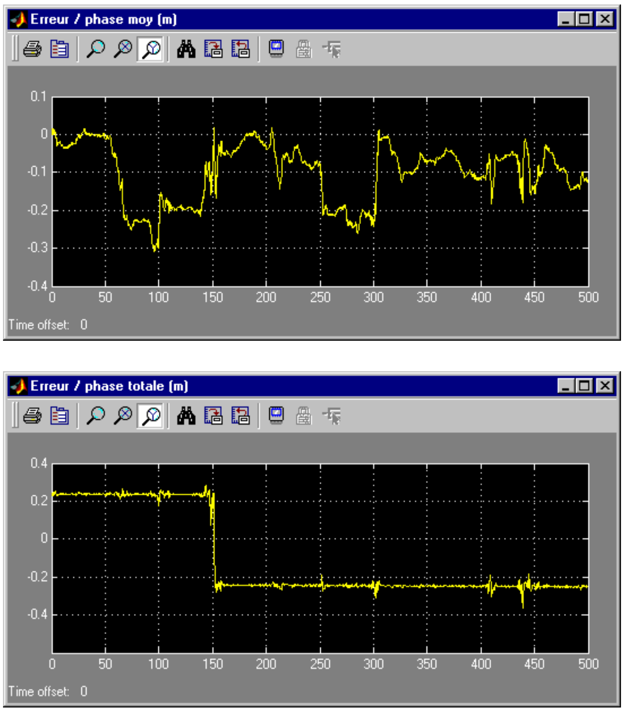


Figure 13: use of time series generator for receiver testing

6 Time series parameters

As stated in section 1, there are three parameters to feed the generator: the spectrum slope, a correlation distance and a signal strength.

For the ionosphere scintillations, these three parameters will be deduced from the results of a measurement campaign in the frame of the PRIS ESA / ESTEC study. The signals are recorded on a permanent basis, processed and stored. The data base is under constitution.

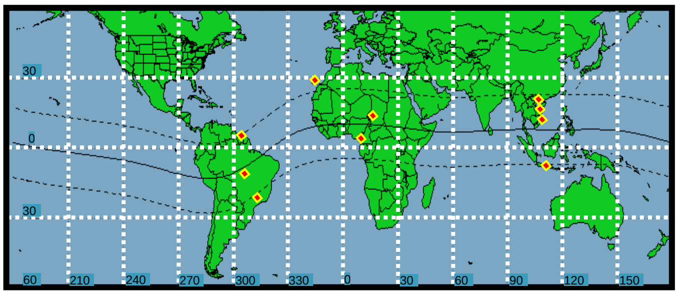


Figure 14: PRIS measurement campaign

The receivers locations are pointed in red. They are mostly located around the magnetic equator corresponding to the highest occurrence of scintillations. This is a 2 years measurement campaign.

7 Conclusion

The algorithm and the main characteristics of a time series generator were presented. The input parameters have been given. For GPS signals and scintillations, there is a measurement campaign on going which will help getting the corresponding values.

We have pointed out the problem of phase jumps in the case of very deep fades. This is of particular interest for testing GPS receivers in a strong fluctuating environment. Additional statistical data would be required however in that case.

References

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