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Modelling of ionospheric scintillation at high and low latitudes as an input in explaining its different characteristics between these regions.

Hal J. Strangeways

School of Electronic and Electrical Engineering, University of Leeds, Woodhouse Lane,

Leeds LS2 9JT, UK.
(E-mail:h.j.strangeways@leeds.ac.uk)

ABSTRACT

It is well known that it is usual for ground based receivers at high latitudes to see significantly larger phase than amplitude scintillation for transionospherically VHF/UHF signals from satellites whereas the opposite of larger amplitude than phase scintillation is generally seen at low or near equatorial latitudes. There could be a number of reasons for this including geometrical, lower cut-off frequency, detrending and Fresnel filtering effects or a combination of two or more of these or other effects such as different properties and/or heights of the irregularities in the two regions. In order to determine the relative importance of all these effects, in this paper the ratio of the S4 index to the phase scintillation index will be determined to see which factors or parameters have the greatest effect in altering it, looking in particular for an effect that will minimise this ratio at low latitudes and maximise it at high latitudes and including variation with elevation, dip and irregularity properties.

1. Introduction

Scintillation is a problem for global satellite systems such as GPS or Galileo as it can degrade the positioning, cause cycle slips, or result, in the worst case scenario of strong scintillation, in the loss of lock of the receiver PLL. This problem is important for low latitudes (particularly in the equatorial anomaly regions) and at high (particularly polar and auroral) latitudes. Understanding the physical mechanisms of scintillation better and their effect on GNSS receivers should lead to improved mitigation strategies which to be optimum may well vary between low and high latitude applications. It is well known that ground based receivers at high latitudes see significantly larger phase than amplitude scintillation for transionospherically propagated VHF/UHF signals whereas the opposite of larger amplitude than phase scintillation is generally seen at low or near equatorial latitudes. It is desirable to be able to understand this but there are a number of possible reasons. Firstly, scintillation indices are larger for satellite to receiver path aligned close to the geomagnetic field direction as the irregularities causing scintillation are commonly aligned in this direction. This is a then a geometric effect [1]. Secondly it has been seen how much the low cut-off employed in the receiver or by the detrending or determined by the length of the data set, can alter the value of the phase scintillation index [2]. Another factor could also be different properties of the irregularities or in the mesoscale structures in which they are embedded (e.g. plasma bubbles or polar patches) between the two regions. In order to determine the comparative importance of all these effects, in this paper the ratio of the S4 index to the phase scintillation index will be determined for a variety of different scenarios to see which factors or parameters have the greatest effect in altering this ratio, looking in particular for an effect that will minimise this ratio at low latitudes and maximise it at high latitudes. Two different methods will be used to determine the scintillation indices σ_φ and S4; the phase screen method of Rino [3] and the Hybrid method of Gherm et al [4]. Employing two different methods will ensure that the calculation are not too scintillation determination method specific. The method of Rino [3] finds the fluctuations of both the phase and amplitude of the field below a phase screen which represents the diffracting effect of the entire ionosphere and is normally place near or a little above the height of the F region and commonly at 350 km altitude at least when this is not known. The Hybrid Scintillation Propagation Model (HPSM) method [4] uses the complex phase method in combination with the random screen technique. The parameters of the random screen (situated below the ionosphere) are determined as the result of a rigorous solution to the problem of propagation inside the ionosphere using the complex phase method. The random two-dimensional spatial spectrum at the screen is then transferred down to the Earth’s surface employing the rigorous relationships of the random screen theory.

2. Theoretical formulations employed: *this section omitted here*

3. Determination of the scintillation index ratios

The ratio of the amplitude (S4) to phase scintillation indices for the 2 methods was determined for a number of different parameters. When fixed, parameters took the following values: variance of the irregularity electron density: σ_N^2 : 0.001 (which is assumed here to be height independent); the irregularities cross-field aspect ratio: 1 and longitudinal aspect ratio: (the length of the irregularities compared with their diameter) 10; their outer scale (Lo): 10 km, their velocity East-West: 500m/s; the power law of the irregularity anisotropic spatial spectrum: 3.7 (then the slope of the received phase psd on log log axes for weak/moderate scintillation is 2.7); transmission frequency: 1575 MHz; azimuth of path :180 °; path elevation: 45° and geomagnetic field dip: 60°. The vertical electron density profile used for these calculations had a maximum of $4.63\text{x}10^{11}$ el m^{-3} at an altitude of 285 km and a TEC of 14.78.

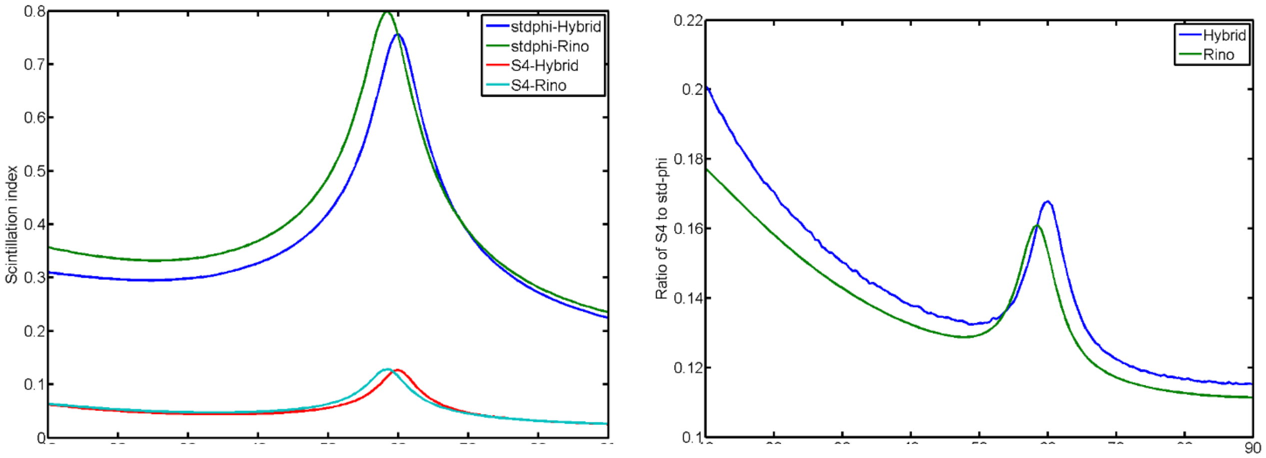

Figure 1(a) (left) shows the scintillation indices for the two methods and 1(b) (right) the corresponding scintillation ratio of S4 to σ_φ plotted against elevation angle in the geomagnetic meridian.

The signal was considered to be transmitted from an altitude of 20,000 km as from a GPS satellite. It is clear that both determination methods give fairly similar results and that the scintillation ratio varies significantly between high and low elevation angles (by a factor of about 0.6) and also increases by about 20% when the path elevation and dip angle are aligned. This would mean that where field aligned paths occur, the S4 index would be larger with respect to the phase index than for non-aligned paths. This might explain why the strongest scintillation occurs at low latitudes as here the scintillation index can be increased both by the low elevation of the path and a propagation direction aligned with the irregularities since these can both occur together whereas at high latitudes, only higher elevation paths could be field-aligned. The scintillation is is also be increased when the aspect ratio of the irregularities is larger. For example, increasing the aspect ratio from 10 to 20 increases the scintillation by a factor of about 1.5. This then could also introduce differences in scintillation between the two regions if the irregularity aspect ratios in one are rather larger than in the other.

The variation the scintillation indices and their ration with both outer scale and detrending cut-off frequency treated in this section is omitted here.

4 Consideration of phase and amplitude psds*:* *this section which show how the difference between the two scintillation indices can best be understood with reference to the idealized psds for phase and amplitude is omitted here.*

5 Conclusions

Three factors have been found which will tend to increase the ratio of S4 to σ_ϕ; lower values of the irregularity drift velocity and higher values of the altitude of the irregularities which both increase the Fresnel frequency and also lower values of the outer scale of the turbulence. The former conditions serve to increase S4 at low latitudes and correlate with lower latitude conditions while the latter condition reduces σ_ϕ. For this to serve as one possible explanation for lower σ_ϕ at low/equatorial latitudes it would necessarily need to be shown that the scale of the turbulence is typically much smaller in this region than at auroral or polar latitude. However, it should be noted that the important ratio of ν_{eff}/Lo will be smaller at low latitudes even for similar values of the outer scale because ν_{eff} depends on the irregularity drift velocity which will generally be considerable smaller at low/equatorial than high latitudes. Further investigation is also required of the possibility of refractive scattering which occurs off irregularity structures with larger scales than the Fresnel scale so that the long wave cut-off in the spectrum of amplitude fluctuations then occurs, not at the Fresnel scale but at a larger scale that increases as the percentage fluctuation of ionization density increases.

Key words: Ionosphere, Satellite, Scintillation, phase, amplitude, S4

6 References

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