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IONOSPHERIC SCINTILLATION EFFECTS FROM GPS SIGNALS

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1 INTRODUCTION

The problem of determining tracking jitter error from just time-domain data using both amplitude and phase scintillation indices, as well as an estimated value of the Fresnel frequency, (as proposed by Strangeways[1]) has been investigated using high latitude high frequency rate GPS data. This has been done both using (i) a Fresnel frequency estimated using the amplitude PSD (in order to check the accuracy of the method) and (ii) an assumed value of Fresnel frequency for an hour's data period (for the real situation where contemporaneous frequency spectra are not available). An example is presented here for data (from a receiver at Longyearbyen[2] (78.169ºN, 15.992ºE), for a time period of 1900 – 2000 UT on 7th May 2008). Both of the spectral parameters *p* and *T* calculated using this method give quite good agreement with their determination using a straight line fit to the slope of the phase PSD in dB. There is also good agreement between the *p* and *T* values calculated using the Fresnel frequency determined from the amplitude spectra and the results obtained using a constant estimated Fresnel frequency, 3Hz, as would be avoid obtaining amplitude spectral.

For this data set, it is found that there can be a significance difference in the scintillation level observed on the paths from different satellites received simultaneously at the receiver location. Since Aquino et al.[2] found that the positional accuracy can be improved by use of the tracking jitter variance to weight the measurements from each satellite used in the positioning calculation, this method is tried on this data set in order to quantitatively determine the increase in positional accuracy which can be achieved by using weightings which are derived from the determined tracking jitters for each satellite using the Strangeways[1] method. This has significant advantages for scintillation mitigation since this process can be accomplished in this way, utilizing only time domain measurements, thus obviating the need for continual determination of phase PSDs via FFTs.

2 DETERMINATION THE p AND p FROM THE σϕ AND SPECTRAL MODELS

Strangeways[1] uses the difference between general fading frequency behavior of the amplitude and phase PSD to determine the phase spectral parameter, *p* that will result in given values of σ_ϕ and σ_x by finding zero of the function:

$$\sigma_\phi^2 - \sigma_x^2 - \left(\frac{\sigma_\phi^2 r}{f_u^r - f_c^r}\right)\left[\left(\frac{f_F^r - f_c^r}{r}\right) - \left(\frac{f_F - f_c}{f_F^p}\right)\right] \tag{1}$$

σ_x is equivalent to S2 and $S4 \approx 2\sigma_x$. f_F, f_c and f_u are Fresnel, lower and upper cut-off frequencies respectively. This method has been used to determine the results in Figure 1.

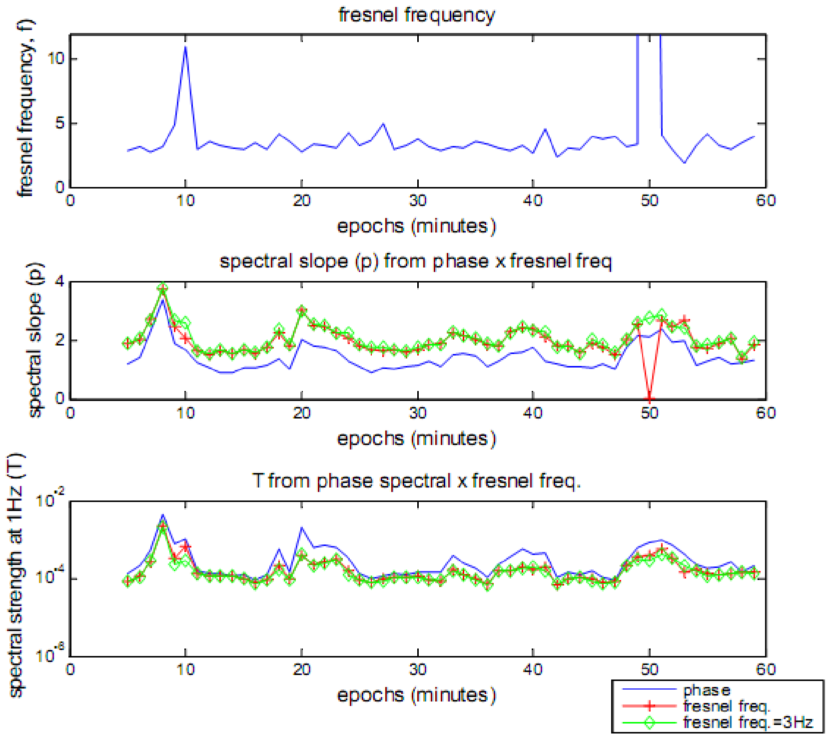

Figure 1 Fresnel frequency (upper) determined from amplitude PSD. Spectral parameters *p* (middle) and *T (lower)* determined using phase PSD, Fresnel frequency (from amplitude PSD) and assumed Fresnel frequency.

The Fresnel frequency f_F is determined by a cubic fit to the amplitude PSD every 1 minute over the frequency range 0.2 – 5 Hz, where most of the scintillation power normally exists. Most of the determined Fresnel frequencies during the period were between 3 – 5 Hz. A comparison was made between the spectral parameters p and T calculated (i) from phase spectra, (ii) using a Fresnel frequency determined from the data and (iii) a fixed value of Fresnel frequency of 3 Hz. The result shows a good agreement between these 3 different procedures. It should be mentioned that the Fresnel frequency is only approximately determined by the cubic fit. The amplitude variability with frequency was too large for the 1 minute time samples used to visually see a clear maximum corresponding to the Fresnel frequency in the data so the accuracy with which the Fresnel frequency was determined cannot be estimated. The difference between the results from the phase spectrum and the method of Strangeways1 tends to imply that the Fresnel frequency was under-estimated as the values of p for the latter were always over-estimated.

3 DETERMINATION OF TRACKING JITTER

Conker et al.[3] introduced the model of tracking error variance at the output of the L1 carrier PLL as: $\sigma_\phi^2 = \sigma_{\phi_s}^2 + \sigma_{\phi_T}^2 + \sigma_{\phi_{OSC}}^2$ where, $\sigma_{\phi_s}^2$ $\sigma_{\phi_T}^2$and $\sigma_{\phi_{OSC}}^2$ are the phase scintillation, the thermal noise and the oscillator noise components of the tracking error variance respectively.

$$\sigma_{\phi_T}^2 = \frac{B_n\left[1 + \dfrac{1}{2\eta\left({}^{c}/_{n_0}\right)_{L1-{}^{C}/_{A}}\left(1 - 2S_4^2(L1)\right)}\right]}{\left({}^{c}/_{n_0}\right)_{L1-{}^{C}/_{A}}\left(1 - 2S_4^2(L1)\right)} \tag{2}$$

where B_n is the L1 third-order PLL one-sided bandwidth, (~10 Hz); $(c/n_0)_{L1\text{-}C/A}$ is the SNR and η is the predetection integration time (0.02s for GPS and 0.002s for WAAS). The formula is valid for S4(L1) < 0.707. Then the phase scintillation component of the tracking error variance is given by:

$$\sigma_{\phi_S}^2 = \frac{\pi T}{k f_n^{p-1} sin\left(\dfrac{[2k+1-p]\pi}{2k}\right)} \quad \text{for } 1 < p < 2k \tag{3}$$

where k is the order of the PLL, f_n is the loop natural frequency. For the calculations of tracking jitter presented below k was taken as 3, $(c/n_0)_{L1\text{-}C/A}$ as 30dB and η as 0.02, f_n as 1.91 Hz, B_n as 10 Hz and $\sigma_{\phi_{OSC}}$ was taken to be 0.1 rad. Result shows < 3% differences for the tracking jitter variance calculated using these 3 different methods for the Longyearbyen data.

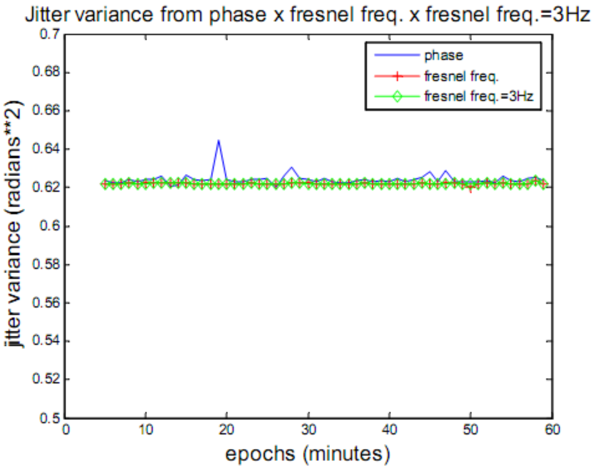

Figure 2 Tracking jitter variance determined using phase PSD, Fresnel frequency(from amplitude PSD) and a presumed value of Fresnel frequency = 3 Hz

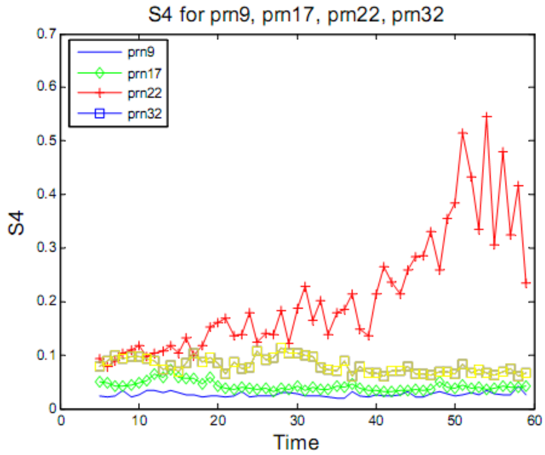

Figure 3 Scintillation level S4 for different simultaneous satellite paths to the Longyearbyen receiver.

4 SCINTILLATION VARIATION WITH DIFFERENT SATELLITE PATHS AND ITS MITIGATION

Figure 3 shows the large variation of scintillation, as measured by the S4 index,that can occur between different simultaneous paths for the same station and time period as above. This illustrates the advantage that can be achieved in positioning accuracy when paths are weighted inversely to the scintillation occurring on them. Then the above-demonstrated method can be used to determine the tracking jitter for each satellite (using just scintillation indices and an estimated Fresnel frequency) and these weights used in the positional calculation. The improved accuracy obtainable in this way for strong scintillation conditions will be discussed further in the presentation of this paper.

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