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Full Length Research Paper

Extracting of tropospheric scintillation propagation data from Ku-Band satellite beacon

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Satellite beacon measurements at 12.255 GHz with an elevation angle of 40.1° during concurrent rain attenuation and tropospheric scintillation are analyzed. The power spectra density of the beacon signal is presented and scintillation are extracted from the raw propagation beacon data using a high pass filter with a cutoff frequency ranging from 2 to 500 mHz. It was observed at low frequency (2 mHz) the presence of rain attenuation in the scintillation time series that was absent at high frequency 850 mHz.

Key words: Tropospheric Scintillation, satellite communication, ku-band.

INTRODUCTION

Another signal degradation factor for frequency above 10 GHz is tropospheric scintillation. At millimeter-wave frequencies, scintillation may seriously affect satellite-earth links where it yields random fades and enhancements of the received signal particularly at low elevation angles (Mandeep, 2009; Mandeep et al., 2010; Mandeep and Yun, 2010). Therefore, accurate estimates of signal degradation due to this effect must be included in the design of satellite communication systems (Mandeep et al., 2011). During clear-sky conditions as well as in the presence of rain, fluctuations in the received signal have been often observed on satellite link. They are usually caused by a superposition of the direct wave and a contribution due to scattering from tropospheric inhomogenetics knows as scintillation (Ortgies et al., 1998). Scintillation is fast fading process that depends on meteorological information such as long term mean temperature and humidity at ground level and also system parameters such as frequency, elevation angle and antenna diameter. Before using the measured raw beacon data, the propagation factors such as rain, atmospheric, clouds, etc., must be excluded as these will contribute to the data fluctuations for the scintillation studies. These data can be separated by passing the raw data through a high pass filter at a suitable cutoff frequency f_c. The value of the cutoff frequency must be chosen appropriately as if f_c is too low, then non-scintillation effects are included in the signal enhancements and fades about the mean level.

DATA ANALYSIS

The scintillation amplitude was calculated for each valid day of the 15 months from the same time series of signal magnitude (1st January, 2010 to 31st March, 2011) at University Sains Malaysia (USM) at an elevation angle of 40.1° and a sampling rate of 1 Hz using a horizontal antenna with a diameter of 2.4 m. The scintillation amplitude calculation was done during clear sky (absent of rain and spurious spikes) spurious and invalid data have been eliminated by visual inspection of all data sequences. The raw data was converted from quantization levels to relative signal level, A in dB using a fifth-order calibration polynomial. The power spectral density (psd), dB^2 /Hz, of each signal was computed on a block of 4096 samples by breaking the block into seven half-overlapping segments of 1024 samples, removing the mean from each segment before multiplying by a Hanning window and finally averaging the periodograms (square magnitude FFT) of the modified segments. The psd was then smoothed using a third-order median filtering (Mandeep et al., 2006, Otung et al., 1998). To examine the effect on scintillation statistics of the cutoff frequency fc, used for data filtering, 15 different values of fc between 2 to 500 mHz were used.

For each scintillation data set (obtained using a particular value of

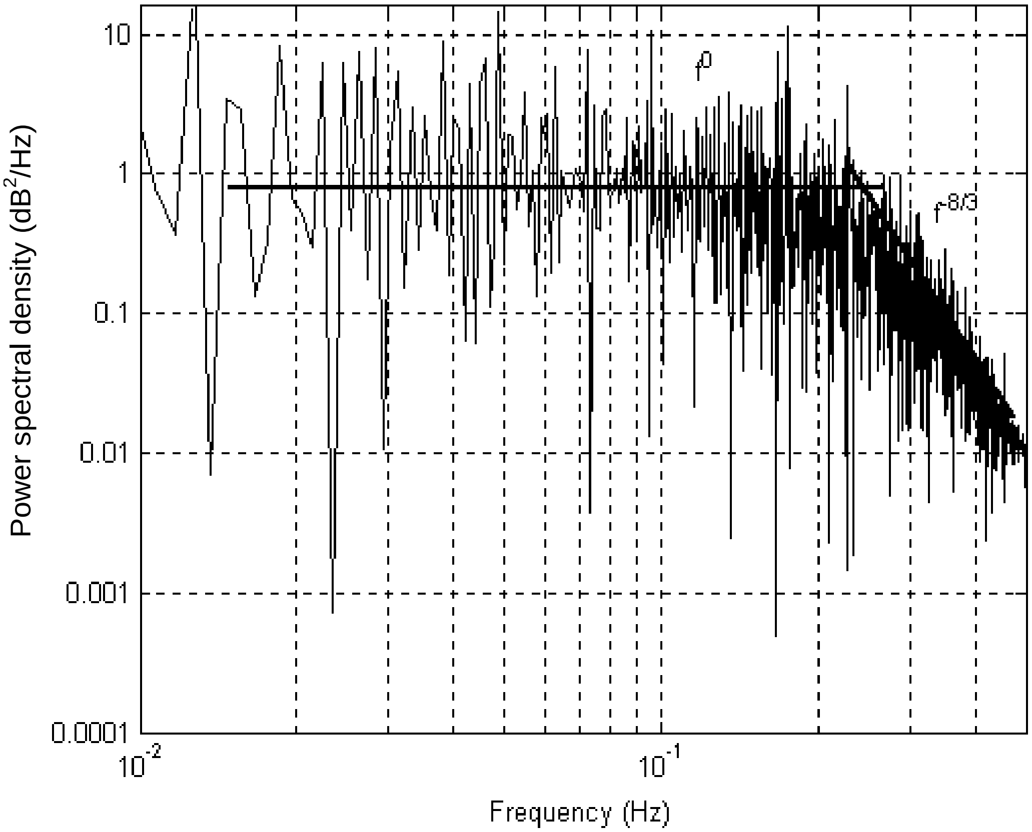

Figure 1. Power spectral density signal variations during the occurrences of rain attenuation and scintillation simultaneously.

f_c) a goodness of fit test were performed to determine whether the 1 min distribution of the scintillation amplitude followed a Gaussian pdf ((Mandeep et al., 2006; Otung et al., 1998).

RESULTS AND DISCUSSION

Power spectral densities (PSDs) of the time series for the concurrent scintillations and rain attenuations, are usually found to have different slopes. Figure 1 shows the power spectral density of signal fluctuations observed on December 12, 2010 during 45 min of simultaneous scintillation and rain attenuation. The shape of the spectra is very similar to Kolmogorov Spectrum (Tatarskii, 1961) wave propagation in turbulent medium characteristic. The flat portion occurs from 2 mHz to 0.85 Hz followed by a slope - above 0.85 Hz. The slopes of the spectrum have been identified by a 0 dB/decade and then by a −80/3 dB/decade ($f^{-8/3}$) roll-off, indicating scintillation effects.

The corner frequency of the scintillation spectrum is defined as the frequency above which the power of all the Fourier components falls at least 3 dB below the maximum amplitude Fourier component present in the flat region of the spectrum. Figures 2, 3 and 4, shows how the cutoff frequency, f_c, influences the scintillation statistics on the satellite link. Different sets of f_c, of 5, 50 and 500 mHz time series extracted from measured beacon data were chosen. At 5 mHz, there is noticeable presence of rain attenuation in the scintillation time series that is absent in 50 and 500 mHz. However, at 500 mHz, the amplitude scintillation is reduced since legitimate contributions to scintillation energy at lower Fourier components are obviously excluded by choosing such a high value of cutoff frequency (Otung et al., 1998). The corner frequency can be calculated by using the equation that was recommended by Vilar and Haddon (1984).

$$\omega_c = 1.43\,\omega_o \quad \text{rad/s} \qquad (1)$$

where, ω_o is called the Fresnel frequency and is given by

$$\omega_o = v_t \sqrt{k/L} \quad \text{rad/s} \qquad (2)$$

The typical low-pass filter shape with a flat session, with a density $W_0(w)$ for the lower frequencies and a roll-off section density $W_\infty(w)$ towards higher frequency were

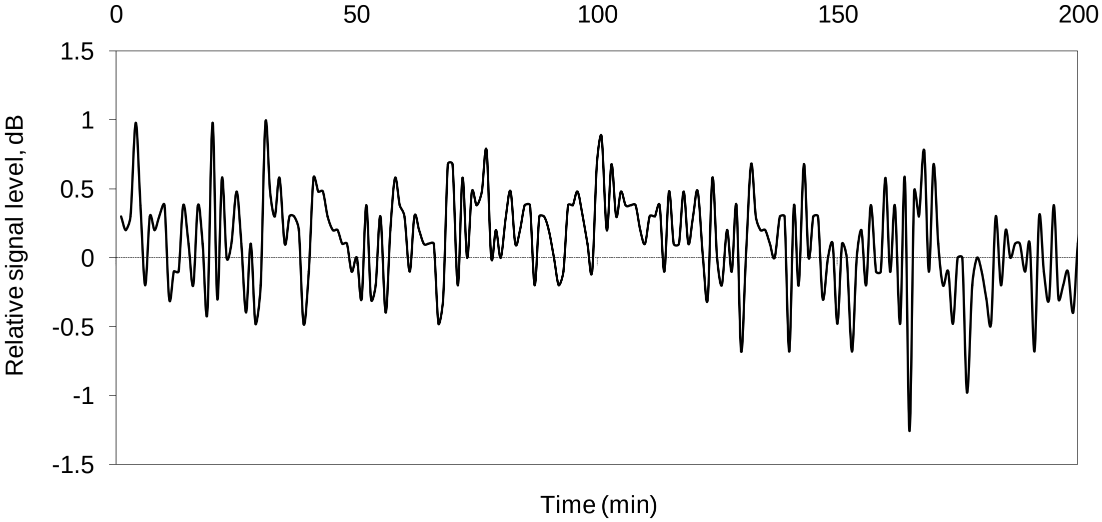

Figure 2. Extraction of scintillation with a cutoff frequency of 5 mHz for 200 min.

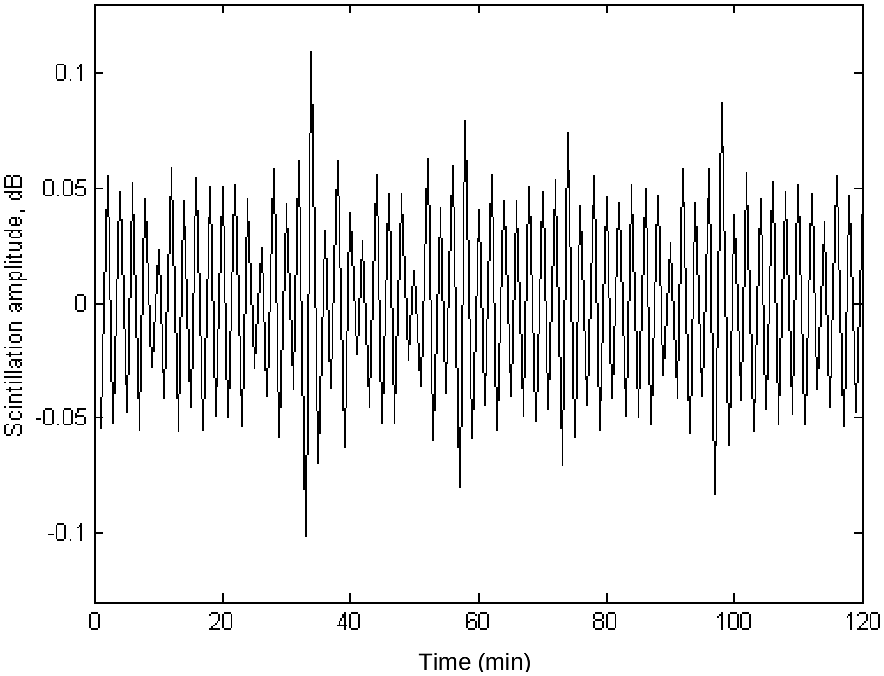

Figure 3. Extraction of scintillation with a cutoff frequency of 50 mHz for 120 min.

calculated from (Ishimaru, 1978).

$$W_o(w) = 2.765\ \sigma^2_\chi / \omega_o\ \text{dB}^2 / \text{Hz} \qquad \omega \le \omega_c \qquad (3)$$

where,

$$\sigma^2_\chi = (20\log_{10}(e))^2 0.307 C^2_n k^{7/6} L^{11/6}\ (\text{dB})^2 \qquad (4)$$

$$W_\infty(w) = 7.13\ \sigma^2_\chi / \omega_o\ (\omega_c/\omega_o)^{-8/3}\ \text{dB}^2 / \text{Hz} \qquad (5)$$

where σ^2_χ is the variance of amplitude scintillation, L is the distance on the top of the turbulent layer (m) and C^2_n the structure constant of the refractive index fluctuations ($m^{-2/3}$). For $f > f_c$, the region corresponds to a pure scattering mechanism where in this frequency region, the

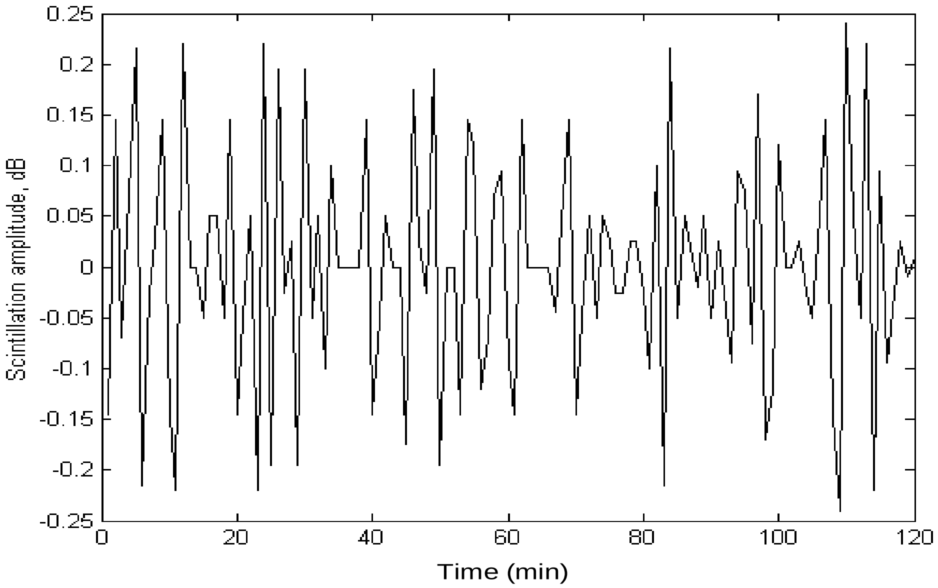

Figure 4. Extraction of scintillation with a cutoff frequency of 500 mHz for 120 min.

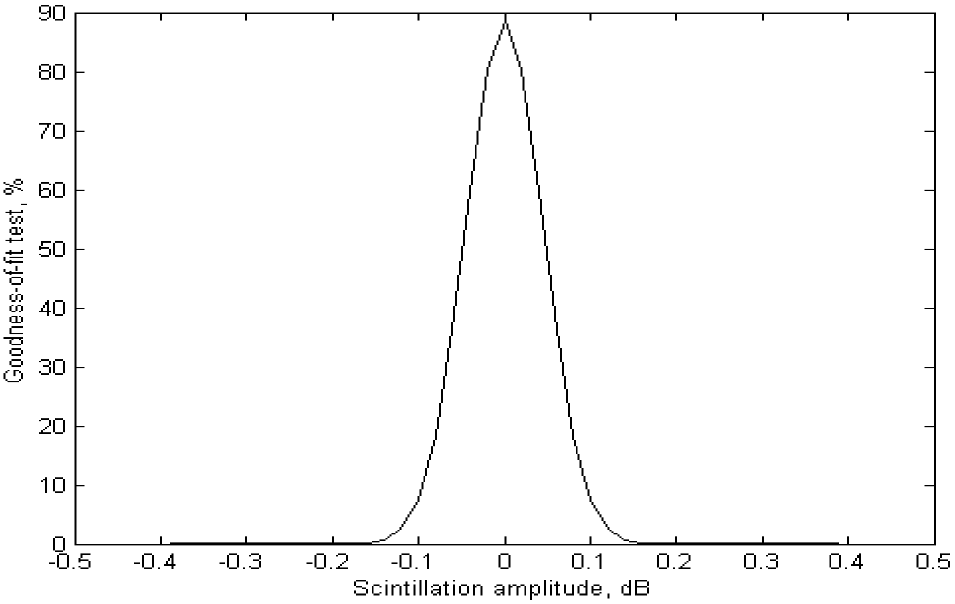

Figure 5. Goodness of fit test for Gaussian pdf scintillation amplitude at f_c = 0.25 Hz.

spectrum has a –8/3 slope if the refractive index turbulent fluctuations can be considered isotropic and homogeneous (Tatarski, 1961).

Finally, the short-term probability density function (pdf) of each the scintillation amplitude series extracted using a different high pass filter cutoff frequency, f_c was analyzed. It was found that at very small values of f_c, a large majority of the measured pdf's failed a goodness of fit test for Gaussian behavior at 5% significance level. For example when f_c = 0.08 Hz, the goodness of fit test failed, when f_c = 0.2 Hz, only 45% of the 1 min pdf of the scintillation amplitude extracted were Gaussian compared to 90% at f_c = 0.25 Hz. On this basis, therefore, the influence of non-scintillation effects on the data series may be minimized by using a cutoff frequency f_c = 0.25 Hz. This is shown in Figures 5 and 6.

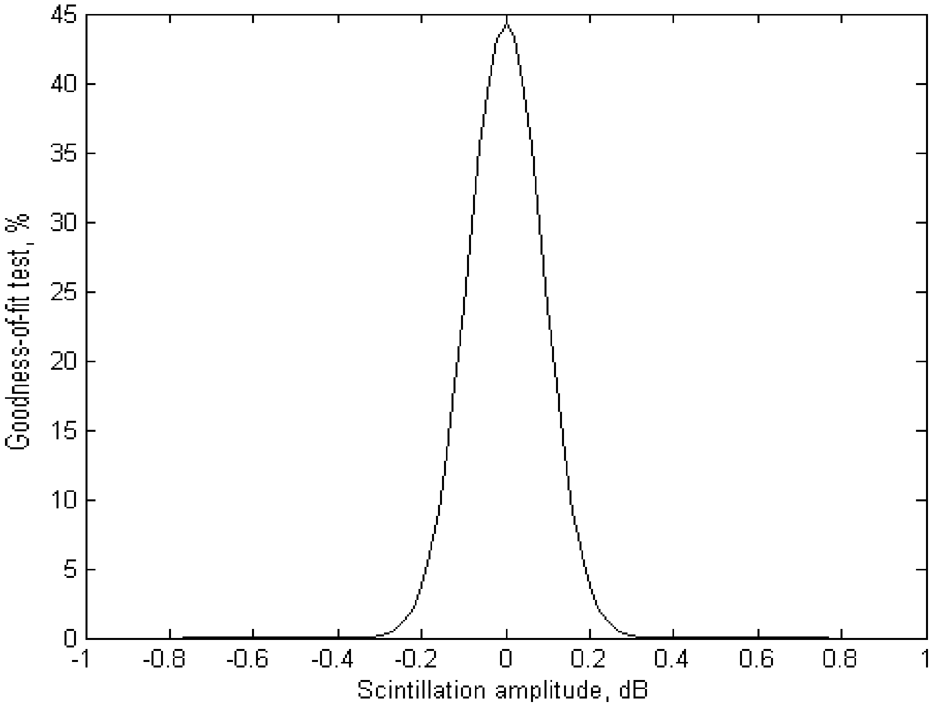

Figure 6. Goodness of fit test for Gaussian pdf scintillation amplitude at f_c = 0.2 Hz.

Conclusion

The presence of non-scintillation effects such as spacecraft maneuver or inadvertent system alteration at earth station during data acquisition which may give rise to abrupt changes in the received signal level and signal spikes generated in the earth station receiver systems if the wrong cutoff frequency was chosen. Absent was rain attenuation was detected at 850 mHz, as this shows that scintillation can be extracted from the measured data by using a high pass filter.

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