Characterization of concurrent Ku band tropospheric scintillation and rain attenuation in Malaysia

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Article Info

Article history:

Received Aug 15, 2018
Revised Dec 12, 2018
Accepted Jan 22, 2019

Keywords:

Equatorial region
Power spectral analysis
Rain attenuation
Satellite communication
Tropospheric scintillation

ABSTRACT

Tropospheric scintillation in satellite communication systems operating at frequencies over 10 GHz is a significant impairment, especially in tropical regions, as attenuation affects scintillation dramatically. This work concentrates on tropospheric scintillation in equatorial Johor Bahru, Malaysia, based on a one-year Ku-band propagation measurement study utilising a direct broadcast receiver and an automatic weather station. This study aimed to investigate the relationship between wet scintillation and rain attenuation using experimental measurements. The power spectral analysis has been carried out to determine required cut-off frequency of filtering to separate out rain attenuation and scintillation effects. The results can provide significant information on the fluctuations of wet scintillation at Ku-band earth space link in tropical regions.

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1. INTRODUCTION

Satellite communication systems operating at frequencies above 10 GHz are heavily influenced by atmospheric effects, mainly rain attenuation. In order to efficiently use the channel capacity of a satellite, the amount of signal drop caused by the concurrent occurrence of wet scintillation and rain attenuation should be estimated. The rapid fluctuation of the received signal amplitude can range up to several decibels. The intensity of the fluctuations in the refractive index can produce significant impairments, as the margin of the communications systems decreases. This is common in places having frequencies above 10 GHz, particularly in tropical and equatorial regions, which has uniform temperature, high humidity and heavy rainfall [1, 2].

In order to efficiently using the channel capacity, the estimation of the amount of signal drop due to the concurrent occurrence of the rain attenuation and wet scintillations is significant [3]. This is prominent, especially in tropical and equatorial regions where convective rain is most frequent, although there have been some studies to understand and estimate the relationship between wet scintillation and rain attenuation in the temperate region [4-7]. However, there are only limited experimental results of wet scintillation in equatorial and tropical regions [8-12]. Therefore, it is worthwhile to further investigate and estimate the natural characteristics of wet scintillation and rain attenuation in tropical region.

Rain attenuation and scintillation are generally recognized by observing a change of spectrum slope in power spectral density of signal variation [4-6, 13, 14]. In general, the effect of rain attenuation only exists at a much lower frequency, while the scintillation tends to appear towards higher frequencies [15, 16].

According to several studies, a few types of filters were used to separate the scintillation and the attenuation effect. Initially, [15] it was suggested that, in order to filter out the scintillation effect, the

2-minute moving average technique must be applied. Later, [17] it was reported that although the moving average was a remarkably good smoothing filter, it was an exceptionally bad low-pass filter especially in the action of a frequency domain. This is because the filter's roll-off was very slow and ripples existed at the stop band attenuation. Hence, the moving average filter was unable to separate one band of frequencies from another. Subsequently, the employment of the fifth-order Butterworth low-pass filter to eliminate the majority of the scintillation power [4-6]. It was reported that 0.025 of the cutoff frequency was used in low-pass filtering, in which the tropospheric scintillation appeared. In contrast, to remove the rain attenuation effect, a high pass filter with cutoff frequency 0.025 Hz [7, 11] or Band-pass filter in the bandwidth 0.025–0.5 Hz [4-6] was used.

Furthermore, this study has been a focus to separate wet scintillation and rain attenuation as much as possible, by filtering the time series of signal. Therefore, this study intends to explore those statistics in an equatorial site by exploiting the propagation measurements carried out in tropical region. This work will be a helping hand in providing knowledge for characterizing wet scintillation and rain attenuation.

A description of the measurement setup is given in Section 2. Data analysis procedures and discussions about wet scintillation and rain attenuation are presented in Section 3 and Section 4. Conclusions are given in Section 5.

2. EXPERIMENTAL SETUP

The experimental station installed in the premises of tropical region [18-19]. The experimental setup was collected for one year, situated at 103.64˚ E and 1.55˚ N consist of one direct broadcast receiving antenna with a diameter of 90 cm, pointed toward MEASAT-3, broadcasting satellite at the elevation angle of 75.61°. The signal of the satellite would reach the parabolic antenna, and then directed into the Low Noise Block (LNB), or simply known as the Radio Frequency (RF) box. The Ku-band signal would be amplified and down-converted into 1 GHz Intermediate Frequency (IF) signal. The broadcasting signal at 12.2 GHz is monitored and recorded through spectrum analyzer and data logger as depicted in Figure 1. Automatic Weather Station (AWS) is also located A meteorological station, equipped with various sensors to provided several surface parameters such as temperature, humidity, and wind speed and direction and a tipping bucket rain gauge, is also located near the receiver antenna.

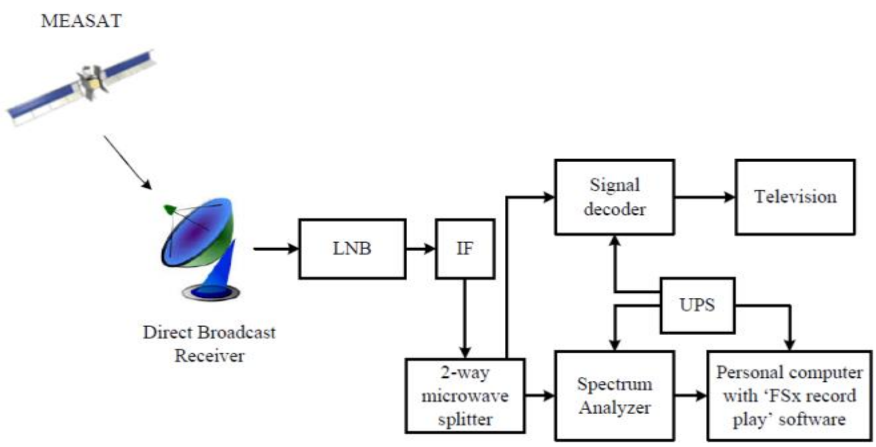


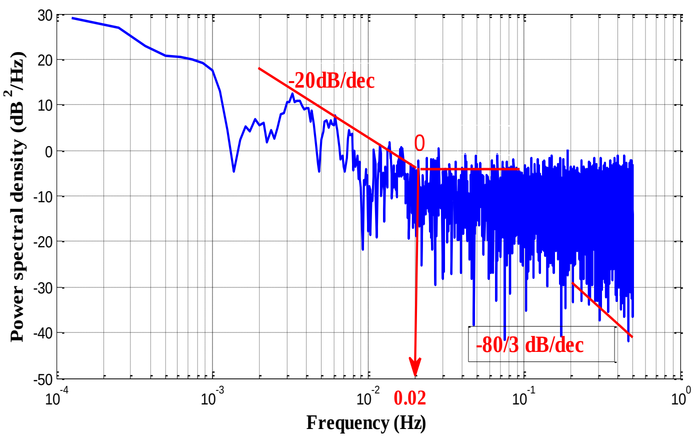
Figure 1. Block diagram of MEASAT satellite receiving system

3. RAIN ATTENUATION AND WET SCINTILLATION DATA ANALYSIS

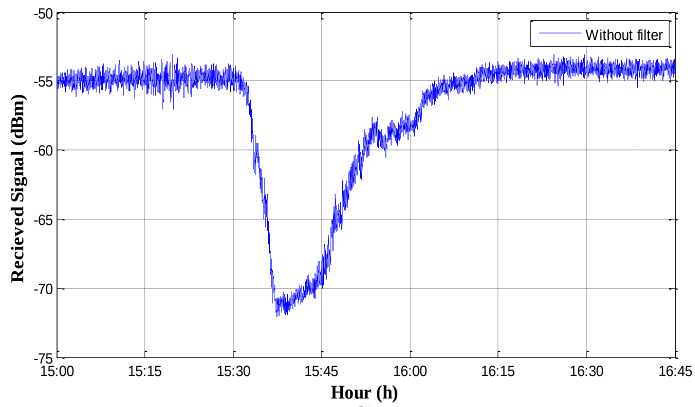
In order to recognize between the rain attenuation (signal fluctuations due to scattering and absorption of hydrometeors) and scintillation (signal fluctuations due to air turbulence), the two effects must be separated as much as possible, by filtering the time series of signal [15].

The experimental data set was divided into rain periods and clear sky periods. The start and end of a rain event were manually identified from the observation of the rain rate time series, concurrently collected from the rain gauge [7]. A quality inspection was performed on all data to achieve to detect any false and invalid data behaviour of the received signal. In spite of the fact that this phenomenon is not always true for all rain events, sometimes the signal level may be affected by the presence of the rain along a slant propagation path while the rain intensity is measured only based on onsite reception signal.

The time series of the received signal would need to be low-pass filtered to remove rapid fluctuation, and high-pass filtered to take off rain attenuation. In this work, the separation of scintillation effects and rain attenuation was achieved by using a fifth-order Butterworth filter. Butterworth filter is considered as a very popular filter because of its best approximation to the ideal filter in the sense of maximal flatness in the filter passband. Also, the fifth order of the filter is used as the magnitude characteristics approach to the ideal filter [20]. The cut-off frequency used in this study was 0.02 Hz as shown in Figure 2(a) for convective rain event from MEASAT-3. Such cutoff frequency, determined from the power spectrum of signal variations as the power spectra of rain attenuation and scintillation, had different log-slopes [5]. For instance, rain attenuation had a slope of -20 dB/decade, whereas scintillation had a slope of -80/3 dB/decade. This is clearly evidenced in Figure 2(a), when the two decades on the Y-axis are equivalent to -20 dB/decade slope up to 0.02 Hz, followed by a typical tropospheric scintillation power spectrum with -80/3 dB/decade slope, extended up to Nyquist frequency at 0.5 Hz for MEASAT-3 [4].



(a)



(b)

Figure 2. (a) Power spectral density, (b) corresponding time series of received signal on 31st December 2013 for MEASAT-3

4. RESULTS AND DISCUSSION

The impact of the two phenomena can be assessed from the power spectra of the high- and low-pass filtered signal level data having different slopes. The received signal was filtered using low pass filter with $f_c = 0.2$, to obtain rain attenuation. Meanwhile, High- pass filtered scintillations with $f_c = 0.2$ for MEASAT-3 satellite. Figure 3(a) and (b) show low-pass filtered rain attenuation and high-pass filtered scintillations, respectively for the rain event, as illustrated in Figure 2(b).

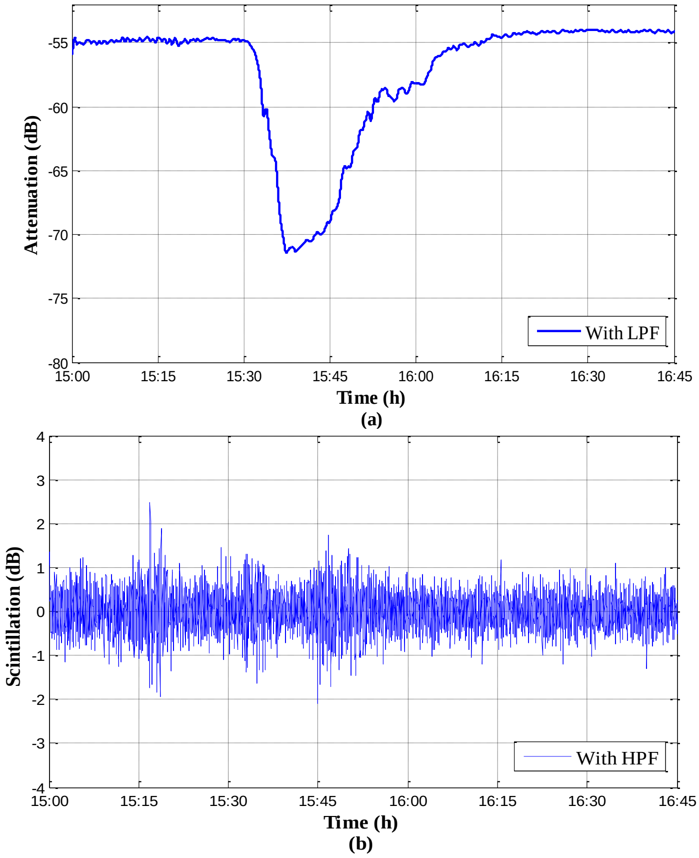


Figure 3. MEASAT-3 received signal level (a) With LPF, (b) With HPF

The complementary cumulative distribution functions (CCDFs) of wet scintillation amplitude statistic from the measurements at Johor Bahru relative to the one-year period. Figure 4 shows that fade scintillation is higher than enhancement scintillation. The figure also shows the CCDF of scintillation fades at 0.01% of the time was 0.96 dB, and approximately 0.95 dB of scintillation enhancements. Furthermore, there was about 1.45 dB scintillation fades at 0.001% of the time, and approximately 1.4 dB scintillation enhancements.

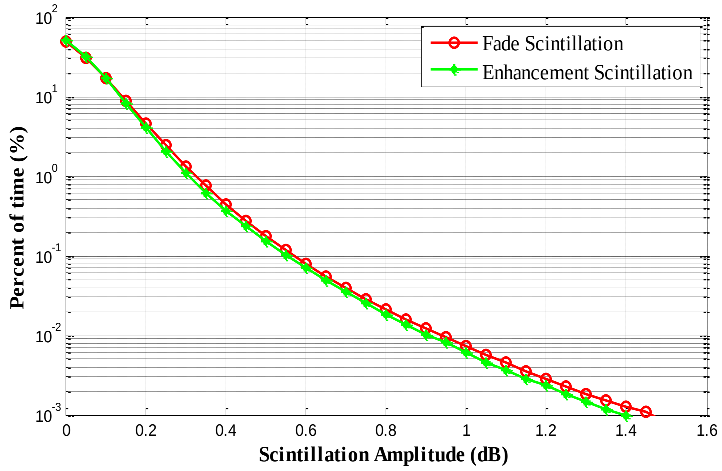


Figure 4. Complementary cumulative distribution function (CCDF) of the measured scintillation fade and enhancement in equatorial Johor Bahru

5. CONCLUSION

Wet scintillation characteristics in tropical and equatorial regions were intensively investigated. The raw data collected from a measurement campaign carried out in tropical region needed to be processed carefully before any analysis was performed. Besides, the collected signal was processed and separated into clear-sky and rainy events based on rain rate data from a rain gauge located near the receiving antenna. Similarly, for rainy events, a signal quality assessment to eliminate anomalous signals was necessary. The results showed that the fifth-order Butterworth low pass filter with 0.02 cutoff frequency was eliminate the majority of the scintillation power. In contrast, the fifth-order Butterworth high pass filter with 0.02 cutoff frequency was used to remove the rain attenuation effect. Furthermore, the results clearly pointed out that CCDF of wet scintillation amplitude of one year measurement data shows a higher scintillation fade compared with scintillation enhancement. Such findings provide information is of great interest for the system designers to appropriately design fade margin.

ACKNOWLEDGEMENTS

This work has been funded by Ministry of Education Malaysia and UTM under “FRGS” Vot. No. R.J.130000.7823.4F958, and UTHM Tier 1 Grant Vot. No. H160.

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