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Tropospheric Scintillation with Rain Attenuation of Ku Band at Tropical Region

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Abstract

Tropospheric scintillation can become a significant impairment in satellite communication systems, especially in tropical regions with frequencies higher than 10 GHz, the attenuation is dramatically affecting the scintillation. This work concentrates on those aspects in equatorial Johor Bahru, Malaysia, based on a one-year Ku-band propagation measurement campaign, utilizing the equipment of Direct Broadcast Receiver (DBR) and Automatic Weather Station (AWS). This study investigates the relationship between wet scintillation and rain attenuation using experimental measurement and concentrate on the probability density function (PDF) of different scintillation parameters. From the results, it is concluded that wet scintillation intensity increases with rain attenuation. Thus, the relationship can be phrased by linear equations or power-law. The PDFs of wet scintillation intensity, adapted to a given rain attenuation level, are found lognormally distributed, leading to selection of method for determining the relation between conditional PDFs and rain attenuation.

Keywords: *rain attenuation, tropospheric scintillation, ku-band, satellite communication*

1. Introduction

Satellite communication systems operating at frequencies above 10 GHz are often heavily influenced by atmospheric effects, mainly due to the scintillation and rain attenuation. In order to efficiently use 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 [1].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 [2-5], there are only limited experimental results of wet scintillation in equatorial and tropical regions [6-9]. Therefore, it is worthwhile to further investigate and estimate the natural characteristics of wet scintillation in Malaysia with respect to the experimental database available and relationships between wet scintillation and rain attenuation models from the established literature.

Furthermore, this study has been a focus to analyze the probability density function (PDF) of both scintillation intensity and scintillation amplitude. Therefore, this study intends to explore those statistics in an equatorial site by exploiting the propagation measurements carried out at Universiti Teknologi Malaysia (UTM) in Johor Bahru, Malaysia. This work will be a helping hand in providing knowledge for characterizing wet scintillation, by investigating the relationship between wet scintillation and rain attenuation. A description of the measurement setup and data analysis procedures, is given in Section 2 and Section 3. Results and discussions about wet scintillation intensity are presented in Section 4 and Section 5. The main statistics of scintillation amplitude are processed with in Section 6. Conclusions are given in Section 7.

2. Experimental Setup

The experimental station installed in the premises of Universiti Teknologi Malaysia, Johor Bahru, situated at 103.64˚ E and 1.55˚ N consist of one direct broadcast receiving

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antenna with a diameter of 90 cm, pointed toward MEASAT-3, broadcasting satellite at the elevation angle of 75.61°. The broadcasting signal at 12.2 GHz is monitored and recorded through spectrum analyzer and data logger. The experimental data was collected for one year (January 2013 to December 2013). Automatic Weather Station (AWS) is also located equipped with various sensors to provide 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.

3. Rain Attenuation and Wet Scintillation Data Analysis

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 as in [5]. A quality inspection was performed on all data to detect any false and invalid data behavior of the received signal. A total of 140 rain events between January and December 2013 were collected and analyzed, totaling more than 280 hours. This data set is considered in this paper analysis.

The separation of wet scintillation effects and rain attenuation was achieved by using a fifth-order Butterworth filter. Consequently, 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. The cut-off frequency f_c used in this study was $0.02\ Hz$, which determined from the power spectrum of signal variations as the power spectra of rain attenuation and scintillation, had different log-slopes [3]. Figure 1 clearly evidenced that rain attenuation had a slope of $-20\ dB/decade$ 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 $0.5\ Hz$.

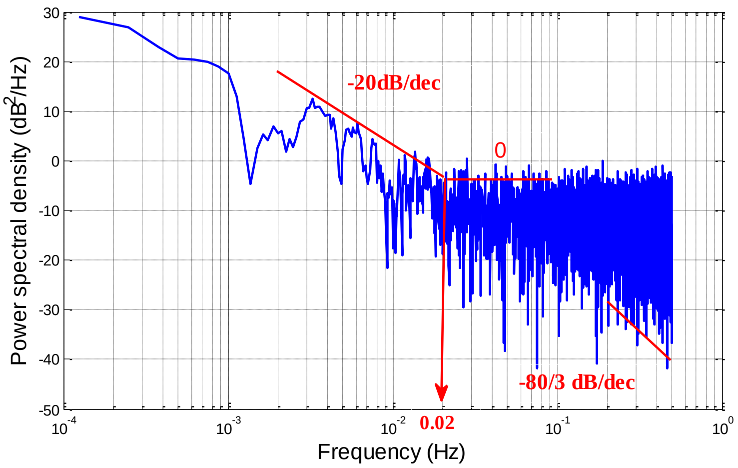


Figure 1. Power spectrum density on 31st December 2013 for MEASAT-3

After the filtering process, the analysis to identify fade and enhancement scintillation proceeded. For the relationship between these phenomena, scintillation intensity σ_x is calculated as the standard deviation of the scintillation amplitude in the one-minute interval. Similarly, the mean value of rain attenuation A is calculated from the original data every minute and related to the value of σ_x in the same minute.

4. Relationship between Attenuation and Scintillation Intensity

Majority of the studies on wet scintillation found that the scintillation intensity and rain attenuation are highly correlated. This is due to the increase in tropospheric turbulence during rain events [5]. The statistical dependence of scintillation standard deviation σ_x on the synchronous rain attenuation A can be modelled to utilize different expressions. The scintillation intensity is related to rain attenuation through a power law [2]. In this study, both Mertens [10] and Van de Kamp [11], works in the Ku and Ka-bands, were used to discover experimentally a linear relationship between these two parameters. Three of the various types of relationships were tested on linear fitting, power-law fitting and the thin layer model to show the relation between scintillation intensity and rain attenuation, as shown in Figure 2.

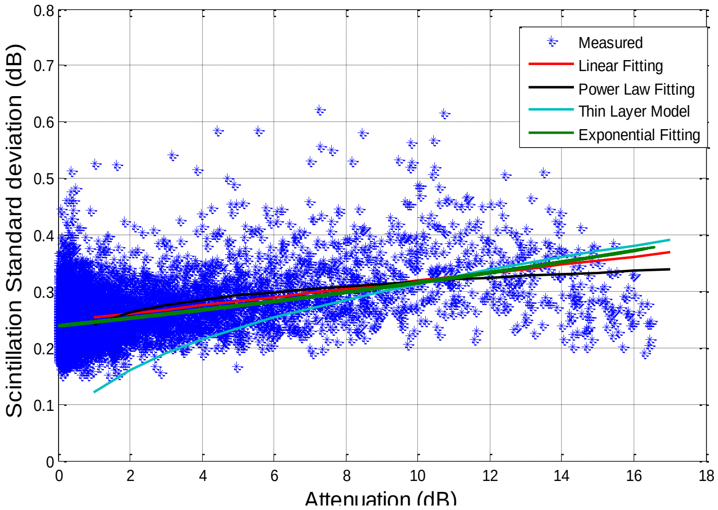


Figure 2. Scatterplot of standard deviation $\sigma_x(dB)$ and rain attenuation $A\ (dB)$ for all data, 1-min intervals, Skudai, Johor. Best fit with a linear relationship, the power law relationship, the thin layer model, and the exponential relationship

A linear relationship between the scintillation intensity and attenuation seemed to be suitable to fit the experimental data, leading to the following equations:

$$\sigma = 0.00721A + 0.2463 \quad dB \tag{1}$$

While, the exponential relation was also assessed through the relationship between the scintillation standard deviation and rain attenuation, as follow

$$\sigma = 0.2388 \cdot e^{0.2771\,A} \quad dB \tag{2}$$

In addition, for power-law expression, a regression line analysis on log-log scales yielded a slope equal to 0.1203 equation (3), where the exponent was not the original 5/12 as considered in [2]. On the other hand, a thin layer model was fit to the measured data, equation (4) with coefficients $\mathrm{k} = 5/12$ and $\mathrm{C} = 0.12$.

$$\sigma = 0.2407 \cdot A^{0.1203} \quad dB \tag{3}$$

$$\sigma = 0.12 \cdot A^{5/12} \quad dB \tag{4}$$

From the expressions in Figure 2, it can be clearly seen that all could be used to evaluate the scintillation intensity for rain attenuation up to 14 dB. However, the linear relationship had better fitting in terms of RMS error, as shown in Table 1.

Table 1. Mean and RMS Errors of Fitting Expressions (1), (2), (3), and (4)

Fitting equation	Mean error (dB)	RMS error (dB)
Power law	5.087×10^{-5}	4.97×10^{-2}
Thin layer	7.36×10^{-2}	9.84×10^{-2}
Linear fit	4.49×10^{-6}	3.74×10^{-2}
Exponential fit	5.7732×10^{-5}	3.986×10^{-2}

5. Long-Term Distribution of Scintillation Intensity

Wet Scintillation statistics are generated from the rain attenuation events. Two different distributions can be calculated for scintillation fade. The first is CCDF (or the probability) of occurrence of scintillation fade during rain attenuation. Figure 3 exhibits the cumulative distribution of scintillation fade plotted as a function of attenuation in intervals of 2 dB wide, except for the higher attenuation interval, due to the lack of data. As can be seen, with higher rain attenuation, the scintillation fade became higher.

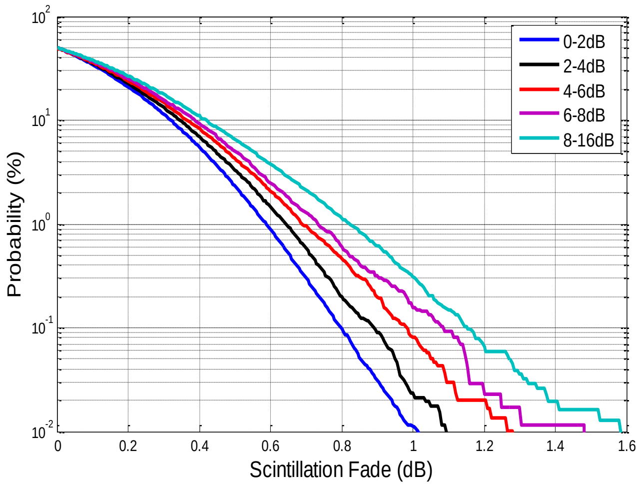
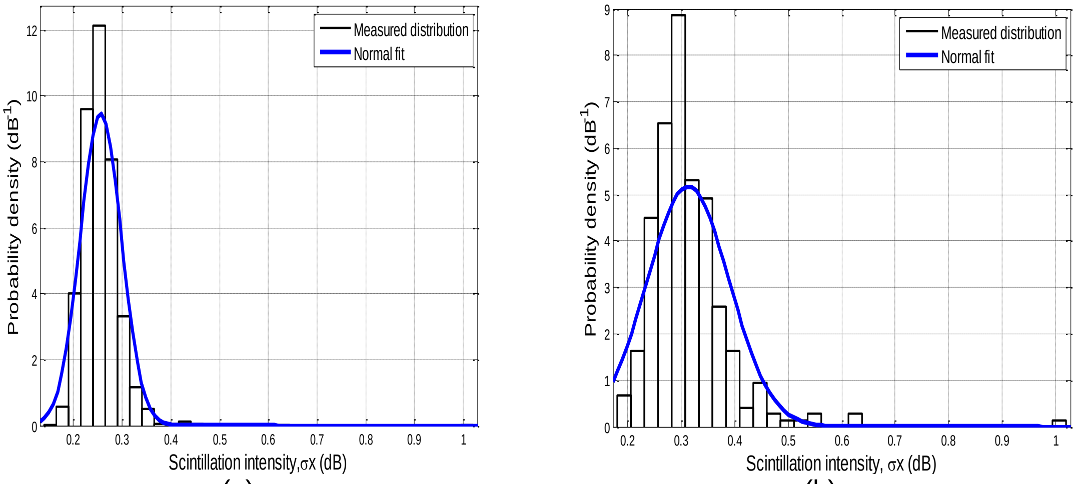


Figure 3. Conditional distributions of scintillation fade (dB) as a function of rain attenuation, from 0–2 dB to 8–16 dB

Karasawa posited that Gamma distribution provides a good performance to model the dry scintillation [12]. Furthermore, this study has been a focus to determine and model the PDF of scintillation intensity for wet scintillation. Figure 4 displays two samples of the probability density function (pdf) of rain attenuation between 2 and 4 dB, and for rain attenuation between 6 and 8 dB. It was found that the lognormal distributions were symmetric to the data for both cases; which could be extended to all other attenuation ranges.



(a) (b)

Figure 4. Measured probability distributions of scintillation intensity dependent on rain attenuation, and lognormal fits. (a) Rain attenuation: 2–4 dB. (b) Rain attenuation: 6–8 dB

The parameters mean σ_m and standard deviation σ_σ of the associated normal distribution of $\ln(\sigma_x)$ are listed in Table 2. The standard deviation value decreased with attenuation, which was the opposite of the mean value. A relationship between both parameters had been fitted using linear equation. Therefore, a linear fitting of both parameters leads to the following equations:

$$\sigma_m = 0.03308 \cdot A - 1.417 \tag{5}$$

$$\sigma_\sigma = 0.009377 \cdot A - 0.1274 \tag{6}$$

As a result, the RMS errors were equal to 0.0607 and 0.0478 for each relationship, respectively.

Table 2. Parameters of the Lognormal Fit to the Conditional Probability Density Function $\ln(\sigma_x/A)$

Rain attenuation $A\ (dB)$	Mean value of $\ln(\sigma_x)$, σ_m	Standard deviation of $\ln(\sigma_x)$, σ_σ
1-2	-1.386	0.1428
2-3	-1.342	0.1403
3-4	-1.304	0.1483
4-5	-1.272	0.1721
5-6	-1.256	0.1733
6-7	-1.223	0.1762
7-8	-1.174	0.1964
8-9	-1.174	0.1981
9-10	-1.098	0.2134

6. Long-Term PDF of Scintillation Amplitude

A pdf comparison had been made between the scintillation amplitude for attenuation range of 0-2 dB and 8-16 dB. In Figure 5, the first curve refers to the best performance found for a normal distribution. Meanwhile, high rain attenuation exhibited that the Logistic distribution had given a better agreement with the second curve. However, it was interesting to notice that as the attenuation increased, the scintillation amplitude distribution became slightly broader. It means that the rapid fluctuation of the high attenuation was relatively higher than that of low attenuation; which might be due to the presence of heavy rainfall in equatorial Malaysia.

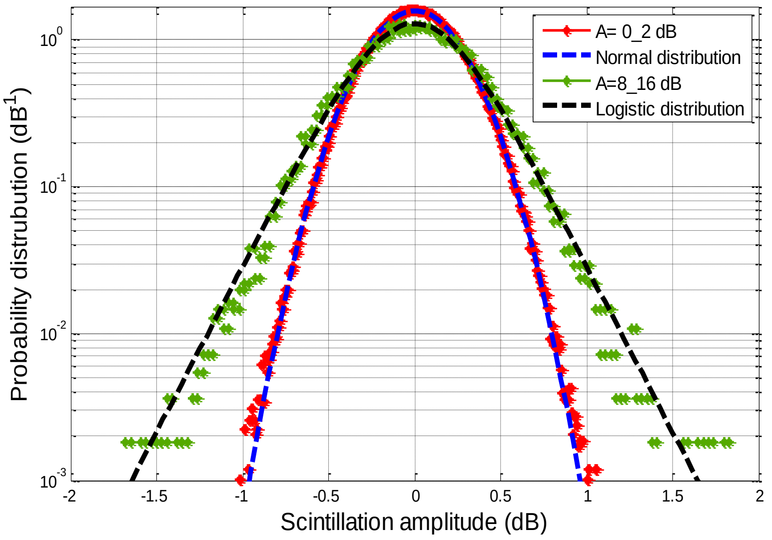


Figure 5. PDF of scintillation amplitude for various attenuation levels. Measured distribution, normal fitting and logistic fitting

7. Conclusion

Wet scintillation characteristics in tropical and equatorial regions were intensively investigated. The relationships between wet scintillation and rain attenuation were obtained using several expressions of relationships such as thin layer model, linear relation and power law. Besides these results, the CCDF of wet scintillation with rain attenuation of 0-2 dB and 6-8 dB in Johor Bahru at 0.01% of the time were 1.015dB and 1.48 dB, respectively. Furthermore, the analysis of scintillation intensity as a function of attenuation suggested that a lognormal distribution is symmetrical to the data to provide a relationship between the standard deviation of $\ln(\sigma_x)$ and attenuation and the relationship between the mean of $\ln(\sigma_x)$ and attenuation. Finally, the PDF of scintillation intensity had also been included as part of the analysis. The results reported that the normal distribution is agreeable with low scintillation intensity. Whereas, for strong intensities, the Logistic distribution had given a better agreement.

Acknowledgment

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