

## Analysis of rain fade slope for terrestrial links

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### Article Info

#### Article history:

Received Jun 10, 2019

Revised Sep 12, 2019

Accepted Sep 26, 2019

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#### Keywords:

Rain attenuation

Rain fade

Rain fade dynamics

Rain fade slope

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### ABSTRACT

Rainfall can cause severe degradation to the operation of microwave links working with frequencies above 10 GHz. Many studies have investigated this problem, and one of the factors that attract the attention of researcher is rain fade slope which is the rate of change of rain attenuation. The focus of this study is on rain fade slope for terrestrial links and it is based on measurement conducted in Malaysia. This paper investigates the characteristics of the measured rain fade slope distribution for various attenuation levels. Then, the ITU-R model for rain fade slope is compared with the corresponding statistics obtained from the measured data. Significant discrepancies have been observed since the ITU-R prediction model does not fit the measured fade slope distribution for many attenuation levels. It is recommended to modify the expression of the standard deviation in the ITU-R model when implemented in tropical regions.

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## 1. INTRODUCTION

In recent years, the demand for wireless services has increased tremendously leading to congestion in the frequency spectrum. This necessitates the use of frequencies above 10 GHz. However at such frequencies, the performance of microwave system can be degraded severely by rainfall which causes fading of the propagating signals [1]. The study of rain fade dynamics can help finding new fade mitigation techniques that can improve the quality and reliability of any telecommunication system during rainfall time [2]. Fading is defined as any time varying of phase, polarization, and/or level of a received signal [1], and the term dynamics describes the signal variation with time. When fade dynamics is discussed, three features are generally mentioned: fade duration, interfade duration, and fade slope. These features depend on climatic characteristics such as rain type, wind speed and drop size distribution. It depends also on link parameters such as length of the link, frequency and elevation angle. The fade durations are used in finding the outage time for a wireless communication system. Whereas rain fade slope can be used in determining the power margin of a wireless communication system and the tracking speed of the fade mitigation techniques. This paper focuses on the study of rain fade slope statistics based on rain attenuation data measured in Malaysia. In the last few years, many studies were published on fade slope. However, most of these studies were either conducted in temperate regions [3-7] or dealing with earth to satellite links only [8-12].

Matricciani had studied the rate of change of attenuation at 11.6 GHz based on data collected with the 32° slant link between the Gera Lario station in Italy and the Satellite Sirio [13]. He calculated the rate of change in rain attenuation for different threshold values. He found that the distributions for negative and positive rate were similar and the threshold values do not affect the distribution. Similar results were obtained by Dentelmann [14]. Sweeney and Bostian examined the dynamics of rain-induced fades on radio links and they found that there is no unique relationship between rain fade slope and rain rate [15]. Nelson and

Stutzman studied rain fade dynamics including fade slope statistics for one year of atmospheric propagation data collected and analysed at Blacksburg-USA, using the Olympus satellite beacons [16]. Their measured results have demonstrated that fade slope increases with frequency for a fixed occurrence level. They have also found that, as the attenuation level increases, the occurrence of large fade slope magnitudes increases. The same result is confirmed by Ruker [17]. Furthermore, Miranda et al has analyzed fade slope data collected from three sites in Brazil [18]. He found that the distribution is almost symmetric and that the attenuation events tend to increase quickly and decrease slowly. Van de Kamp made use of the previous results and came up with a new model in [3] which was adopted by the ITU-R. In this study, data collected from terrestrial microwave links are analyzed and the measured rain fade slope distributions are compared with the ITU-R model.

The rest of this paper is organized as follows. The next section presents the ITU-R model. In Section 3, the collected data and the experimental setup are described. Section 4 discusses the statistics obtained from the measured rain fade slope data and then compares it with the ITU-R model. Finally, the paper is concluded in Section 5.

**2. ITU-R MODEL FOR FADE SLOPE**

ITU-R model was proposed by the International Telecommunication Union (ITU) in 2003 to calculate the statistics of fade slope due to attenuation on Earth-space paths [2]. It was found that the fade slope probability distribution depends on climatic parameters, drop size distribution, attenuation level A(t), time interval length Δt and rain type. It also depends on the 3 dB cut-off frequency of the low-pass filter which is used to remove tropospheric scintillation and rapid variations of rain attenuation from the signal. Furthermore, it is also concluded that the expected fade slope at a given attenuation level was likely to decrease as path length increased due to the smoothing effect of summing different rain contributions. Moreover, the measured fade slope is influenced by dynamic parameters of the receiving system. A receiver with longer integration time reduces the instantaneous fade change and spreads it over a longer time period. In the ITU-R model, the fade slope ζ at a certain point in time is defined from the filtered data as:

$$\xi(i) = \frac{A(i+0.5 \Delta t) - A(i-0.5 \Delta t)}{\Delta t} , (dB/s) \tag{1}$$

This model is valid for frequencies from 10 to 30 GHz, and elevation angles from 10° to 50°. The following parameters are required as input to the model:

- A : attenuation level (dB) which varies from 0 to 20 dB
- f<sub>B</sub>: 3 dB cut-off frequency of the low pass filter (Hz) which ranges from 0.001 to 1 Hz
- Δt : time interval length over which fade slope is calculated and it is ranging from 2 to 200 seconds.

The step-by-step calculation of the fade slope distribution is as follows:

Step 1: Calculate the function F which gives the dependence on the time interval length Δt and the 3 dB cut-off frequency of the low pass filter f<sub>B</sub> as given below

$$F(f_B, \Delta t) = \sqrt{\frac{2\pi^2}{(f_B^{-b} + (2\Delta t)^b)^{1/b}}} \tag{2}$$

Step 2: Calculate the standard deviation σ<sub>ξ</sub> of the conditional fade slope at a given attenuation level as in

$$\sigma_\xi = s F(f_B, \Delta t) A \tag{3}$$

Step 3: Calculate the probability density p of fade slope ζ at a given attenuation value from the following expression:

$$p(\xi|A) = \frac{4}{\pi \sigma_\xi^2 \left(1 + \left(\frac{\xi}{\sigma_\xi}\right)^2\right)^2} \tag{4}$$

The ITU-R model was tested on data at 12.5 GHz, 20 GHz and 30 GHz data from other sites in the UK, France, Belgium, Italy, and the US [4, 16]. The results showed a good match to the shape of the fade slope distribution as well as its variation with attenuation threshold A, interval length Δt and 3 dB cut-off

frequency,  $f_b$ , of the low pass filter. In this study, the performance of the the ITU-R model is tested with the measured distributions.

### 3. FADE SLOPE DATA

The measured data considered in this paper were obtained from four three experimental microwave links installed at the University of Technology Malaysia (UTM) campus in Johor Bahru, Malaysia. All the links are set up between Radio Science Lab and the Celcom tower, the distance of which is close to 300 meter. Table 1 summarizes the links parameters. The fade slope of the measured data was determined for several attenuation levels from (1). The fade slope data is analyzed and discussed in the next section.

Table 1. Microwave Links Specifications Details

Link	Frequency (GHz)	Polarisation.	Length (km)	Measurement Periods
UTM1 Skudai	15	H	0.3	Jan. 1999 – April 2000
UTM2 Skudai	23	H	0.3	Jan. 1999 – April 2000
UTM4 Skudai	38	H	0.3	Jan. 1999 – April 2000

### 4. RESULTS AND ANALYSIS

The conditional probability density function (CPDF) of the fade slope distribution is computed from the measured data. The conditional distributions at attenuation level  $A$  (in dB) is determined based on attenuation values  $A(t)$  that satisfy the following inequality:

$$A - 0.5 < A(t) \leq A + 0.5 \quad (5)$$

where  $A = 1, 2, 3, 4, \dots$  dB. For example, the 2 dB distribution is obtained considering all fade slopes calculated for attenuation  $A(t)$  between 1.5 and 2.5 dB [7, 19]. Figure 1 shows the CPDF at selected attenuation levels of 1, 3, 5, 10 and 15 dB for the microwave links operating at 15, 23 and 38 GHz. It is observed that the fade slope data are always distributed and symmetric around 0 dB/s. In addition, these distributions spread further as the attenuation level increases. These characteristics are similar for all the three links irrespective of their different frequencies. These results confirm the findings of other researchers [4-5, 15, 20-25].

Since the ITU-R [2] has adopted the Van de Kamp model [4] for the prediction of fade slope, this study investigates the performance of this model when applied to the measured data. The CPDFs of the measured fade slope data at 15 GHz was compared with the ITU-R's predictions for different attenuation levels of 1, 2, 3, 5, 8, and 10 dB as illustrated in Figure 2. The results show that the CPDFs of the predicted ITU-R model are generally different than the measured ones. Figure 2 shows also that most of the ITU-R distributions are less spread specially for attenuation values less than 5 dB. This problem is mainly due to the lower values of the standard deviation used by the ITU-R curves in comparison with those of the measured data. Similar behavior is also observed for the other two links. However, these observations are not good enough to reject the ITU-R model since we should take into considerations the uncertainty in the measured data. For this reason, the ITU-R model should be checked with the well known chi-square goodness of fit test.

The chi-square goodness-of-fit test determines if the predicted CPDF fits the measured distribution using hypothesis testing for a given significance level of 0.05 [26]. First, the null hypothesis ( $H_0$ ) and the alternative hypothesis ( $H_a$ ) are defined as follows:

$H_0$ : There is no significant difference between the measured and the predicted values.

$H_a$ : There is a significant difference between the measured and the predicted values.

Then the chi-square test is calculated using [26]

$$\chi_c^2 = \sum_{i=1}^N \frac{(O_i - E_i)^2}{E_i} \quad (6)$$

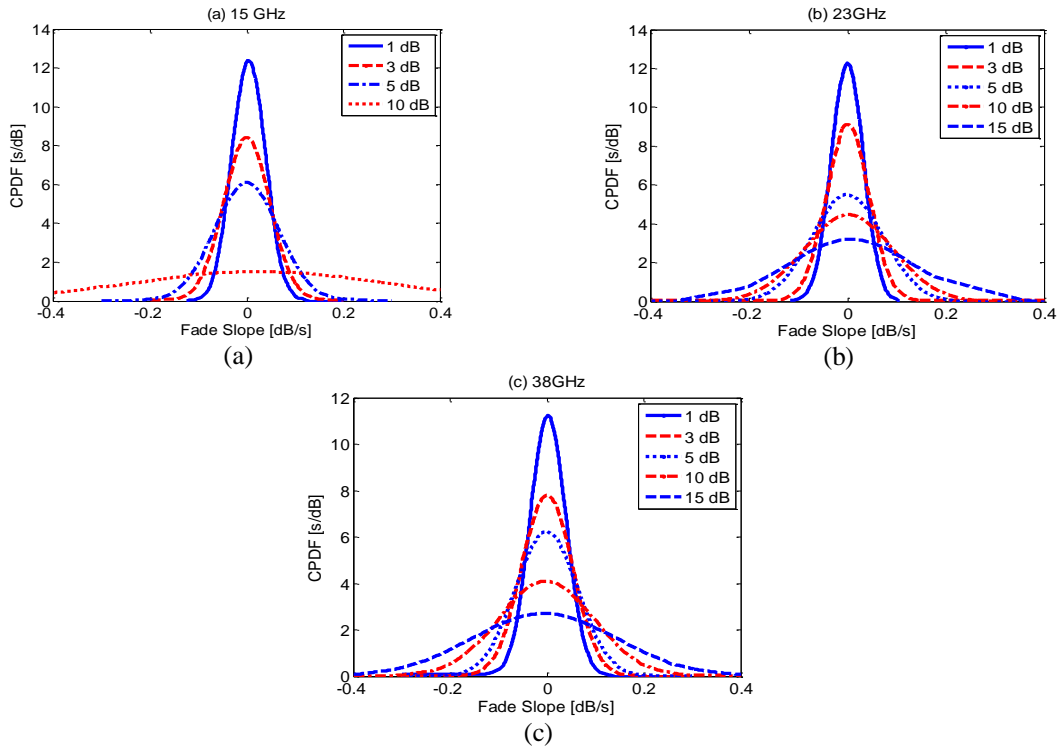


Figure 1. The CPDF of the measured fade slope data for selected attenuation values at (a) 15 GHz, (b) 23 GHz and (c) 38 GHz

where  $\chi_c^2$  represents the computed chi-square value,  $O_i$  is the observed or the measured value,  $E_i$  is the predicted value, and  $N$  is the number of samples. The computed values for  $\chi_c^2$  along with the theoretical chi-square value,  $\chi_{th}^2$ , are shown in Table 2 for the three types of measured data.  $\chi_{th}^2$  is determined for a significance level of 0.05.

Table 2. The Computed ( $\chi_c^2$ ) and the Theoretical ( $\chi_{th}^2$ ) Chi Square Values for a Significance Level of 0.05 are Presented for the Three Microwave Links

Attenuation level (dB)	15 GHz		23 GHz		38 GHz	
	$\chi_c^2$	$\chi_{th}^2$	$\chi_c^2$	$\chi_{th}^2$	$\chi_c^2$	$\chi_{th}^2$
1	$2.18 \cdot 10^5$	51302	$1.45 \cdot 10^5$	69550	$3.10 \cdot 10^5$	36157
2	48655	59304	40482	52055	79850	29909
3	17197	31216	18527	34558	22809	42367
5	9405	4661	12245	8026	7915	20312
8	4094	72	4046	2031	3762	7009
10	45856	18.3	1783	658	2714	6689
15	-	-	2168	108	2827	1214

Form Table 2, it is noted that  $\chi_c^2$  is less than  $\chi_{th}^2$  only when the attenuation levels are equals to 2 and 3 dB for the 15 and 25 GHz links. On the otherhand, the attenuation levels are between 3 and 8 dB for the 38 GHz link. For such cases, the null hypothesis  $H_0$  is accepted. This means there is no significant difference between the predicted ITU-R values and the measured values for the specified range of attenuation levels with 95% confidence. However,  $\chi_c^2$  is higher than  $\chi_{th}^2$  for attenuations levels lower than 1 dB and higher than 5 dB for the 15 and 25 GHz links, whereas, the attenuation levels are lower than 2 dB and higher than 10 dB for the 38 GHz link. In such conditions, the null hypothesis  $H_0$  is rejected which indicates there is significant difference between the predicted ITU-R values and the measured values for the specified range of attenuation levels. It can be concluded that the ITU-R model fits the measured data only for certain attenuation levels which is not good enough. Therefore, there is need to improve the model so that it will be valid for all desired attenuation levels. It is suggested to modify the expression of its standard deviation in order to improve the model.

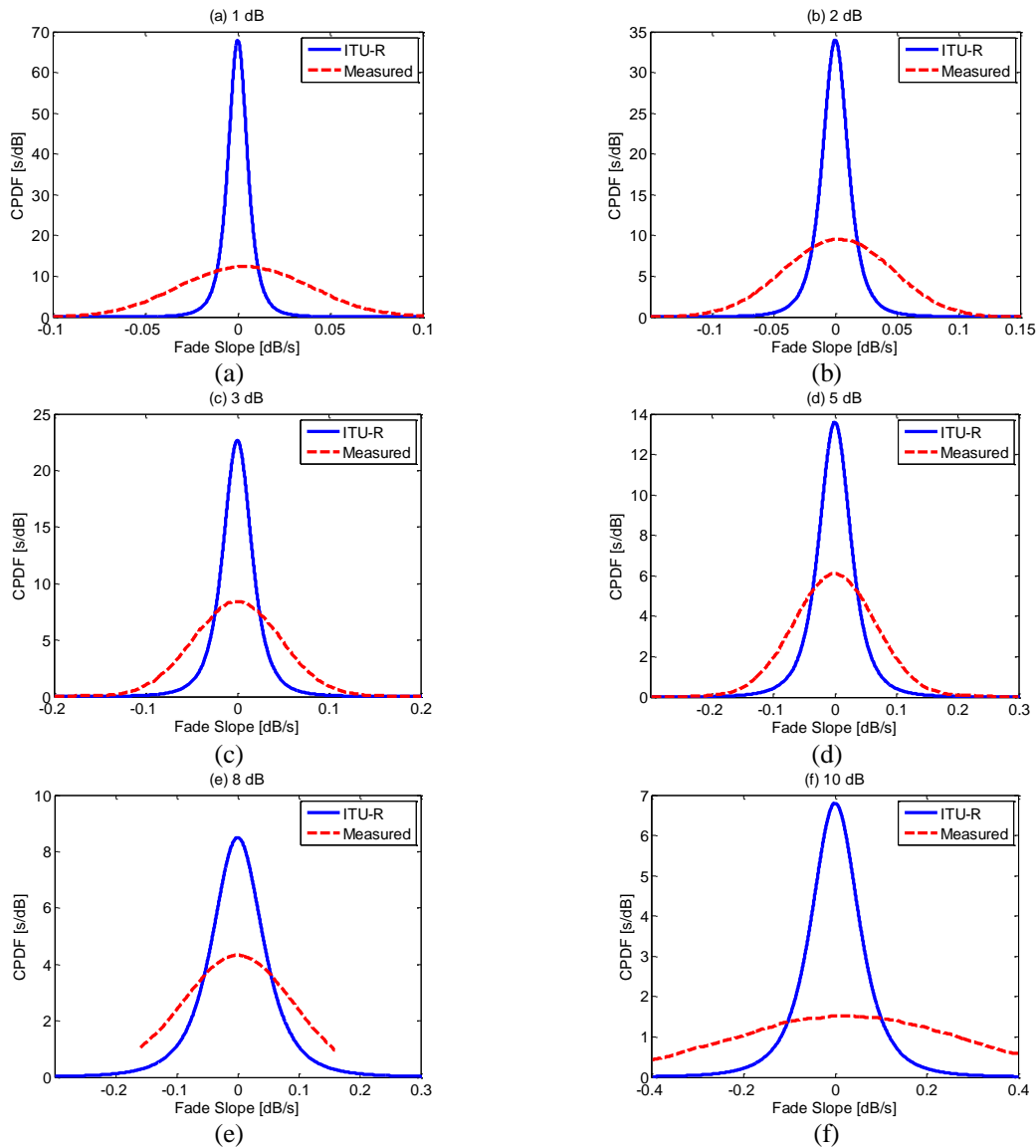


Figure 2. The CPDF of the measured fade slope data at 15 GHz with the predicted ITU-R model for selected attenuation levels at: (a) 1 dB; (b) 2 dB; (c) 3 dB; (d) 5 dB; (e) 8 dB; and (f) 10 dB.

## 5. CONCLUSION

This paper studied the characteristics of rain fade slope based on rain attenuation data collected in Malaysia from three microwave links operating at three different frequencies. It is observed that the fade slope data are always distributed and symmetric around 0 dB/s and it spreads further as the threshold attenuation level increases. In addition, the ITU-R model for rain fade slope is compared with the corresponding measured distributions. It was found that the ITU-R model fits the measured data only for certain attenuation levels and cannot be generalized to all cases. Therefore, it is suggested to modify the ITU-R model in order to be applied in tropical regions.

## ACKNOWLEDGEMENTS

This work was supported by IoT and Wireless Communication Protocols Lab and is partially funded by the International Islamic University Malaysia Publication Research Initiative Grant Scheme number P-RIGS18-003-0003.

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