

## Improvement of Fade Slope Model Based on Observed Received Signal Level at 12 GHz in Kyushu Island, Japan

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### 1 Introduction

The prediction of rain fade slope on satellite link is currently an essential parameter used by system designers for the development of communication power control and error-correction schemes, which minimize effects of the link outages for their systems[1, 2]. It is also useful for the implementation of computer generated received signal for primary experiments. Due to its time variation and dependence on the rain type and characteristics, it will be useful to develop an efficient model that fits the fade slope evaluated from the link.

Many programs have been achieved by ESA and NASA in order to efficiently characterize the satellite link for reliable services and many works are being done for this purpose[3-5]. Although the proposed models have observed the basic dynamics and dependencies of the fade slope, some climatic dependence and characteristics are still unknown. Moreover, most of the measurement stored in databases during these campaigns had been made in temperate zones of the Northern Hemisphere where rainfall outages are minimal and some approaches used for the evaluation of the fade slope yield to misestimate the physical aspect of the propagation medium[6, 7]. Then, the obtained models do not match with results from our experiments.

This paper aims to present and discuss an efficient approach to evaluate the fade slope of the received signal level. This approach is applied to experimental data from four stations located in a region of about 12 km in diameter in Fukuoka, Kyushu island, Japan. From our analysis, an improved fade slope model is proposed.

### 2 Experimental System and Fade Distributions

Kyushu University is situated between the ITU-R rain regions M and K. Since Kyushu is located in southern Japan, typhoons frequently cross this area, bringing a lot of rain. Our experimental system used for the data acquisition operates in Ku-band(14/12 GHz) and consists of 4 Very Small Aperture Terminals (VSATs) of 1.8 m diameter directed toward JCSAT-1B communication satellite at the geostationary orbit of longitude 150°E. The elevation angle is 45.6° for these stations. These VSATs are located as shown in Fig. 1. The experimental system observes the received signal level every 0.2 second. During experiments, one of these VSATs is used for data transmission to the satellite and all of them receive the returned signal. The modulation mode is the QPSK with coding rate  $r = 1/2$  and the transmission rate is 64 Kbps. Our system is being used to conduct several experiments for earth-satellite link clarification in Ku-band since 1997.

In this paper, these stations are called: Station II, Station III, Station Z, and Station C. In order to contain as much rain events as possible, based on rainfall data, received signal level data have been collected within June and September in 3 years (2000-2002). We can see from the distribution of rain attenuation presented in Fig. 2 that the attenuation characteristic is almost the same as those observed in tropical region. These results could be helpful in order to estimate the behavior fade slope in tropical regions.

### 3 Definition and Evaluation Approach

By definition, the fade slope is the measurement of the attenuation rate with respect to time[3]. Let the received signal level be a continuous time random function defined by:

$$Sl(t) = Sl_0(t) + m(t) \tag{1}$$

where  $m(t)$  is a zero-mean random process and  $Sl_0(t)$  the filtered received signal. To obtain  $Sl_0(t)$ , a 30 s moving average filter was applied[8].

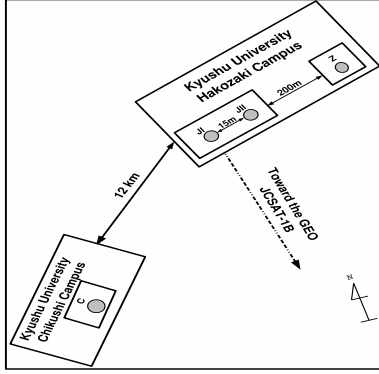


Figure 1: The location of Kyushu University VSATs experimental stations.

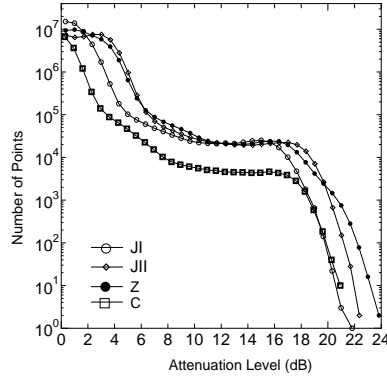


Figure 2: Number of data points collected for each for each VSATs station.

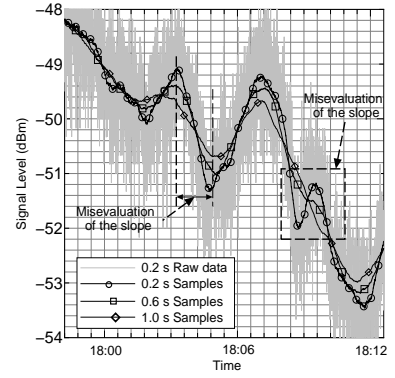


Figure 3: Variation of sampled data according to the received signal level for 0.2, 0.6 and 1.0 s sampling period.

Although the received signal level is continuous, it is always collected after a certain period of time and therefore the collected data are not often continuous. It is then important to define the discrete fade slope as follows:

$$\zeta_{\Delta t}(t_i) = \frac{Sl_0(t_i + \Delta t/2) - Sl_0(t_i - \Delta t/2)}{\Delta t} \quad (2)$$

This difference process is perfectly defined for any fixed  $\Delta t > 0$  and in some sense,  $\zeta_{\Delta t}(t)$  should converge to the desired  $\zeta(t)$  as  $\Delta t \rightarrow 0$ . Many methods have been developed for the fade slope estimation. However, they used a long data-sampling period. Some of the popular methods such as the ESA's method and the Van de Kamp's method used 1.0 s as data sampling period and a differential step ( $\Delta t/2$ ) of 5.0 s and 1.0 s respectively[7, 9]. Although the fade slope evaluates the slow varying rain attenuation rather than the fast-varying scintillation, as mentioned above, we believe that it is reasonable to apply a strict filtering process rather than to use a long sampling period which could lead to a reduction of the fade slope's range and therefore could give a false fade slope estimation. Figure 3 depicts the variation of the signal according to the sampling period and compare to the raw data curve. To obtain these curves, the raw data collected at 0.2 s period is resampled and filtered with a 30 s moving average[3, 8, 10]. We can see from these graphs that by changing the sampling rate the obtained curve could completely miss the variation of the real signal and therefore lead to a false estimation of the fade slope (e.g. case 0.6 to 1.0 s sampling rate in Fig. 3).

#### 4 Fade Slope Analysis Results and Proposed Model

We made several analyzes, principally on the absolute fade slope, the total fade slope and the standard variation of the fade slope for each station and sampling period of 0.2 s, 0.4 s, 0.6 s, 0.8 s and 1.0 s. From these analyzes, the dependence on filter bandwidth and time interval was verified. We observed that for the absolute fade slope at  $0.01 \text{ (dB/s)}^{-1}$  conditional probability density and 0 dB reference signal attenuation, the obtained curves were almost the same. However, from 3 dB of attenuation level, the difference was about 0.15 dB/s and was found to increase with attenuation. Moreover, we observed from our data that the shape of the distribution, as a function of the attenuation, has a return point between 7 and 8 dB in all our stations as shown in Figs. 4(a)-(d). The observed return point appears to be independent of the sampling period as presented in Fig. 5. This is a characteristic not yet observed in other local stations in the world[5, 7]. This observation is verified in Fig. 5 with the appearance of a maximum of standard deviation of the fade slope between 7 and 8 dB for all stations. Since the ITU-R and Van de Kamp show this standard deviation as a linear function of the attenuation level, it appears that this record model could not be applied to our local area[4]. Therefore, it seems important to modify the existing model or propose another model for global use.

If  $A_f(t)$ <sup>1</sup> is the attenuation obtained from the filtered time dependent received signal  $Sl_0(t)$ , the fade slope  $\zeta(t)$  is obtained by differentiating  $A_f(t)$  over the time  $\Delta t$ . From the analysis, the symmetry of the

<sup>1</sup>We note that  $A_f(t) = Sl_{\text{ref}} - Sl_0(t)$  where  $Sl_{\text{ref}}$  is the mean of the received signal  $Sl$  during clair sky.

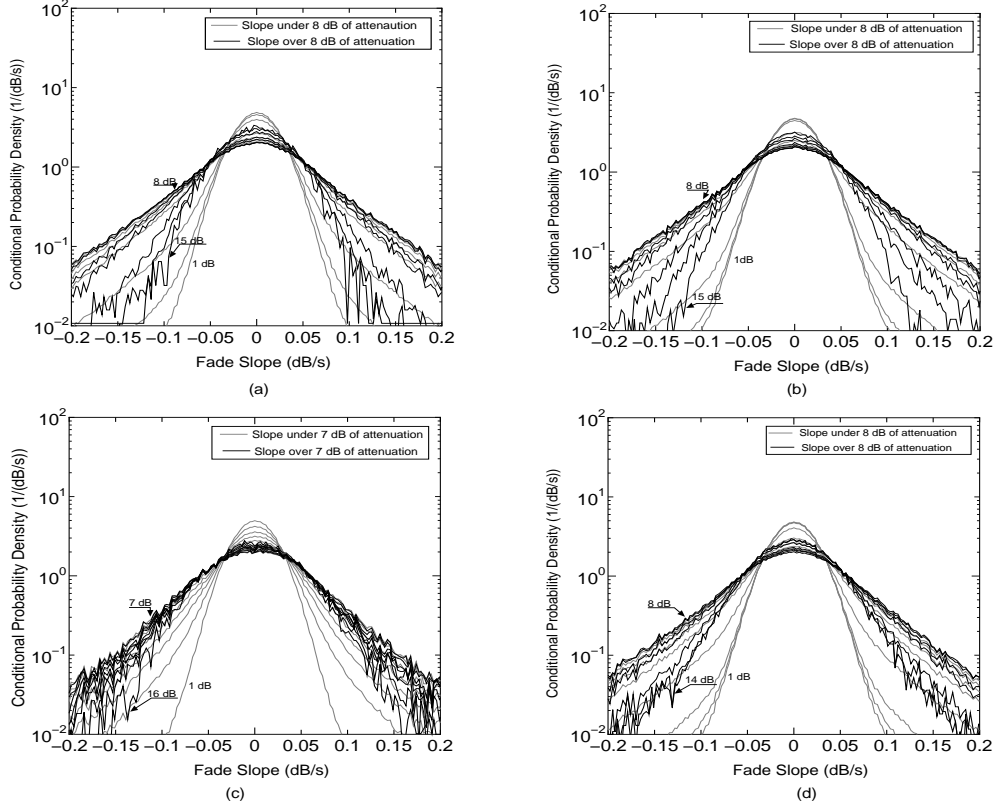


Figure 4: Fade slope observed in our stations above  $0.01 \text{ (dB/s)}^{-1}$  conditional probability density and  $\Delta t = 0.2 \text{ s}$  for: (a) JI, (b) JII, (c) C and (d) Z.

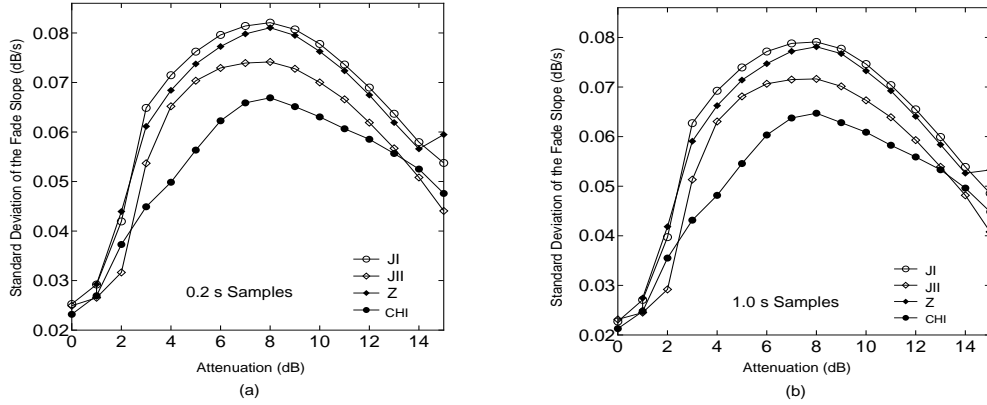


Figure 5: Variation of standard deviation of fade slope at each attenuation level for: (a) 0.2 s sampling period and (b) 1.0 s sampling period.

distribution has been confirmed as mentioned by other researchers[3, 5]. From our data, we derived the proposed model as described by equations (3) and (4). These equations have been obtained based on reference [4]. Furthermore, by successive fitting of our data these equations have been modified.

$$P(\zeta|A) = \frac{2}{\pi \sigma_\zeta (1 + (\zeta/\sigma_\zeta)^2)^2} \text{ (dB/s)}^{-1} \quad (3)$$

$$\sigma_\zeta = \alpha \cdot F(f_{3\text{dB}}, \Delta t) \cdot A(1 + \lambda \cdot \ln A) \quad (4)$$

where  $F(f_{3\text{dB}}, \Delta t) = \pi \sqrt{\frac{2}{\Delta t}} \left[ f_{3\text{dB}}^{-b} + (2\Delta t)^b \right]^{-1/2b}$   
 $\alpha \approx 4.84 \times 10^{-2}$ ,  $\lambda \approx -3.21 \times 10^{-1}$  and  $b = 2.3$ . The 3 dB cut-off is given by :  $f_{3\text{dB}} = 0.003 \text{ Hz}$  and

$\Delta t = 0.2s$ .

We note that Fig. 6 is obtained by taking  $\lambda = 0$ . Therefore, the parameter  $\lambda$  could be related to the rain region and/or characteristics. Figures 6 and 7, respectively show the simulation of the existing model based on the parameters of our data and the modified model.

## 5 Conclusion

In this paper, we analyzed the fade slope and its dependence on the sampling method. In this paper, we analyzed and presented a fade slope model for satellite link. We remarked that the fade slope distribution in our stations, as a function of attenuation, has a particular variation while remaining symmetric and does not fit the ITU-R recommended model. Moreover, the proposed model is an important step toward a global fade slope model. This paper opens a new perspective on fade slope modelling.

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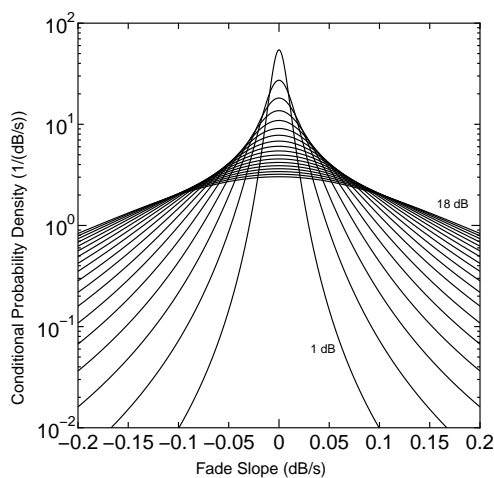


Figure 6: Actual model proposed by the ITU-R recommendation and Van de Kamp above  $0.01 \text{ (dB/s)}^{-1}$  conditional probability density [4, 5].

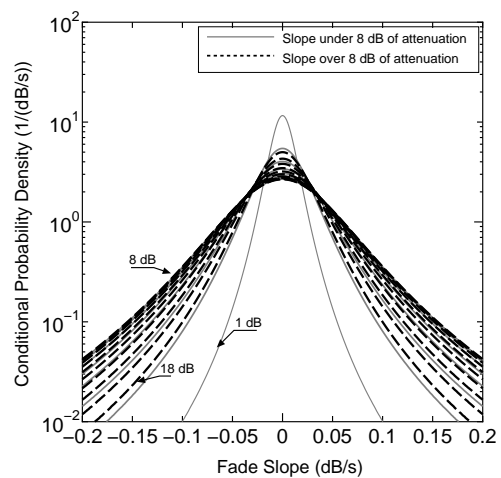


Figure 7: Fade slope simulation result using the model above  $0.01 \text{ (dB/s)}^{-1}$  conditional probability density.