Measurement of Effective Path Length and Specific Attenuation on Slant Path in Ku-band Satellite Channels at Three Different Locations in Kyushu Island, Japan

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https://doi.org/10.15017/1515808

出版情報：九州大学大学院システム情報科学紀要. 8 (1), pp.7-12, 2003-03-26. 九州大学大学院システム情報科学研究院

九州大学大学院
システム情報科学紀要
第8巻 第1号 平成15年3月

Research Reports on Information Science and
Electrical Engineering of Kyushu University
Vol.8, No.1, March 2002

Measurement of Effective Path Length and Specific Attenuation on Slant Path in Ku-band Satellite Channels at Three Different Locations in Kyushu Island, Japan

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(Received December 13, 2002)

Abstract: This paper presents the recent experimental results concerning rain attenuation on radiowave propagation in Ku-band satellite channels at different locations about 100 km far away from each other in Kyushu Island, Japan. We utilize the JCSAT-1B satellite and several VSATs installed at three locations, Oita University at Oita, Kumamoto University at Kumamoto and Kyushu University at Fukuoka, respectively. Rain attenuation is measured using those VSATs at uplink, downlink and total link paths. The relation of rain attenuation and rain intensity is discussed at those links and is compared with the estimation by ITU-R. Characteristics in the wave propagation such as effective path length and specific attenuation based on experimental data are derived and discussed. These experimental results suggest the necessities of detailed study on rain attenuation at local points and of presentation of a method for predicting bit errors, when using effectively Ka-band satellite systems with multispot-beams.

Keywords: Ku-band, VSAT, Rain attenuation, Rain intensity, Effective path length, Specific attenuation

1. Introduction

Satellite communication services incorporating small antennas such as very small aperture terminals (VSAT) and ultra small aperture terminals (USAT) are expected to be used steadily in the coming years. These terminals are economic and useful for various situations because of the small in size, ease of installation, and low-cost. Congestion in the 1–10 GHz region has forced these services to look at Ku(14/12 GHz)-band frequency. However, we have to overcome the impact of rainfall, which is considered as a main factor that limits the effective use of this frequency band and the use of VSAT and USAT. In the future, more attractive Ka(30/20 GHz)-band will be used widely since this band offers several advantages over the Ku-band such as wider bandwidth and large data capacity, allowing small component sizes, and smaller satellite footprints[1]. The use of Ka-band with multispot-beam satellite systems will be considered to illuminate small area with individual spot beam while its rain attenuation is more serious than that of Ku-band.

The theoretical and experimental studies of rain attenuation have been done by many researchers [2)−6)]. However, the measured rain attenuation data is still insufficient [7)−11)] in order to estimate the link within the individual spot beam. Therefore, we are conducting the experiment to study the effect of rainfall by using several VSATs installed at three different locations in Kyushu, Japan, i.e., Oita University at Oita, Kumamoto University at Kumamoto and Kyushu University at Fukuoka for radiowave propagation in popularly used Ku-band.

In this paper, the relations between rain attenuation and rain intensity on radiowave propagation along uplink, downlink and total link in Ku-band are shown through experimental measurement and are compared with the estimation by ITU-R. Characteristics in the wave propagation such as the effective path length and the specific attenuation are derived and discussed from our experimental results.

2. Experimental System

The experimental system at our laboratory incorporates a 1.8 m diameter offset parabolic antenna. This VSAT antenna was installed at the top of a building at Kyushu University for approximately 50 meters above sea level on the point of

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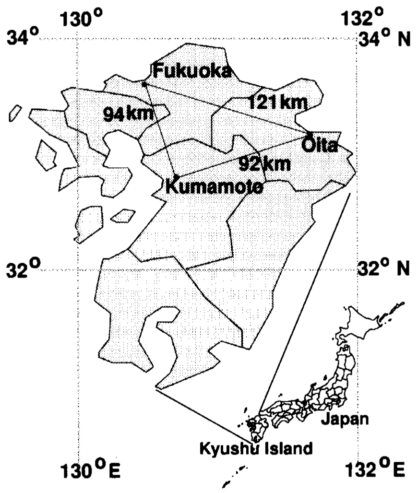
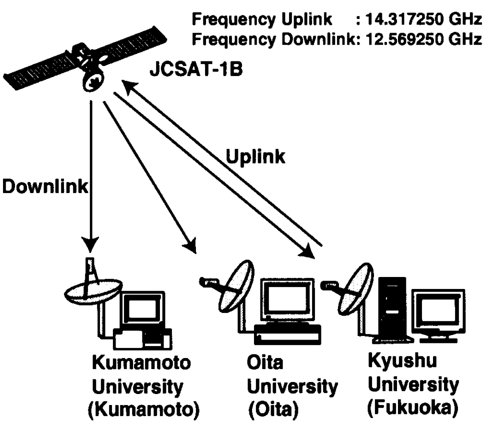


(a)



(b)

Fig.1 Experimental Locations and Illustration.

Lat. 33°37′N and Long. 130°26′E, and is directed toward the JCSAT-1B on the geostationary orbit of Long. 150°E. The elevation angle between earth station and satellite is 45.6°. On the other hand, the same VSATs were set up at Oita and Kumamoto Universities. Oita University is located on the point of Lat. 33°10′N and Long. 131°36′E with the elevation angle of 46.6° and Kumamoto University is on the point of Lat. 32°48′N and Long. 130°43′E with the elevation angle of 46.6°. The distance from Fukuoka to Kumamoto is 94 km, Fukuoka to Oita is 121 km, and Oita to Kumamoto is 92 km. See **Fig. 1(a)**.

In this experiment, VSAT at Kyushu University transmits data to the JCSAT-1B communication satellite and VSATs at Oita University, Kumamoto University and Kyushu University simultaneously receive those returned from the JCSAT-1B as shown in **Fig. 1(b)**.

3. Experimental Results and Discussion

3.1 Link Analysis

As illustrated in **Fig. 1**, several VSATs at different locations are used in this experiment. We provide the following requirements for link analysis:

- A reference level is obtained by averaging the entire received signal level data on each month and at each place during no rain term. Rain attenuation is obtained by subtracting reference level from the measured received signal level.
- Rain attenuation at the downlink paths both at Oita University and Kumamoto University are obtained by taking into consideration that no rain falls at the uplink path from Kyushu University while it is rainy at the downlink path.
- Rain attenuation at the uplink path is obtained by taking into consideration that no rain falls at the downlink path to Oita University or Kumamoto University while it is rainy at the uplink path from Kyushu University. Rain attenuation at the uplink path can be read at the receiving terminal at Oita University or Kumamoto University.
- Rain attenuation at the downlink path to the receiving terminal at Kyushu University is obtained by subtracting the rain attenuation at the uplink path obtained from the above requirement from the rain attenuation at the total link path.
- Rain attenuation at the total link paths at Oita University and Kumamoto University are obtained by taking into consideration that rain falls both at the uplink path from Kyushu University and at the downlink path or at one of those link paths, i.e., at the uplink path or downlink path. The results can be read at the receiving terminal at those locations.
- Rain attenuation at the total link path at Kyushu University can be read at the receiving terminal at Kyushu University, because Kyushu University acted also as the transmitting terminal.

The above is summarized in **Table 1**, where A_{OU}, A_{KU} and A_{QU} are the total rain attenuation at Oita University, Kumamoto University and Kyushu University, respectively.

Table 1 Link analysis schema.

Link	OU	KU	QU	Attenuation
DL at OU	R	-	NR	A_{OU}
DL at KU	-	R	NR	A_{KU}
UL at QU	NR	-	R	A_{OU}
	-	NR	R	A_{KU}
DL at QU	NR	-	R	$A_{QU}-A_{OU}$
	-	NR	R	$A_{QU}-A_{KU}$
TL at QU	-	-	R	A_{QU}

DL: Downlink; UL: Uplink; TL: Total link;
OU: Oita University; KU: Kumamoto University
QU: Kyushu University; R: rain; NR: no rain.

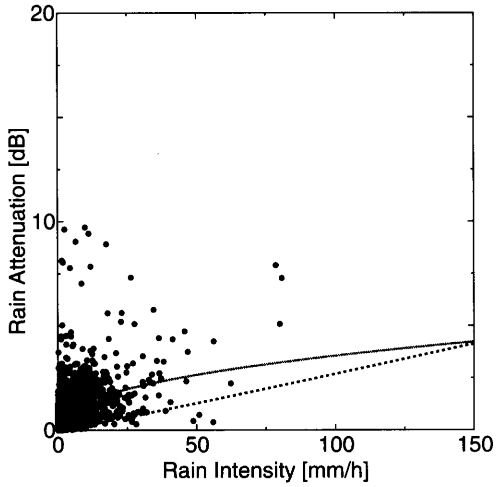


Fig.2 The relation between rain attenuation and rain intensity for downlink to Oita University.

3.2 Relation between Rain Attenuation and Rain Intensity

Data of signal level and rain intensity during propagation and communication time were collected and analyzed within the period of January 2000 to December 2000. Rain attenuation is obtained by subtracting a reference level from the measured received signal level. The reference level is obtained by averaging the entire received signal level data on each month and at each place during no rain term. Here the rain intensity and the rain attenuation were averaged over every one minute.

Figures 2–6 show the relation of rain attenuation and rain intensity for each link. In these figures the dots are obtained by directly plotting rain attenuation versus rain intensity and the solid line is the best fit curve obtained by fitting rain attenuation versus rain intensity with the least mean square method using the following equation;

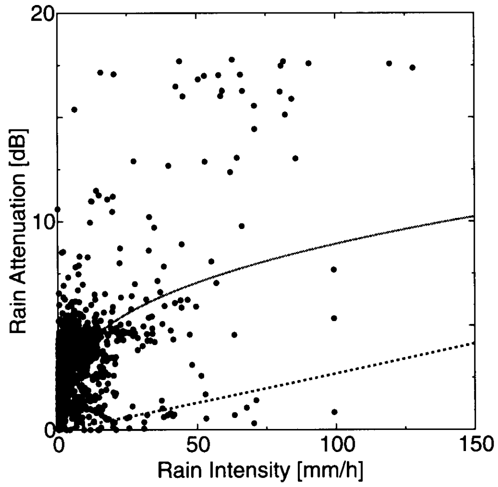


Fig.3 As **Fig. 2** but to Kumamoto University.

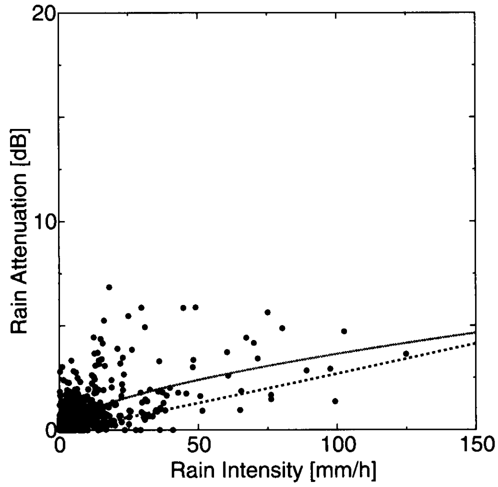


Fig.4 As **Fig. 2** but to Kyushu University.

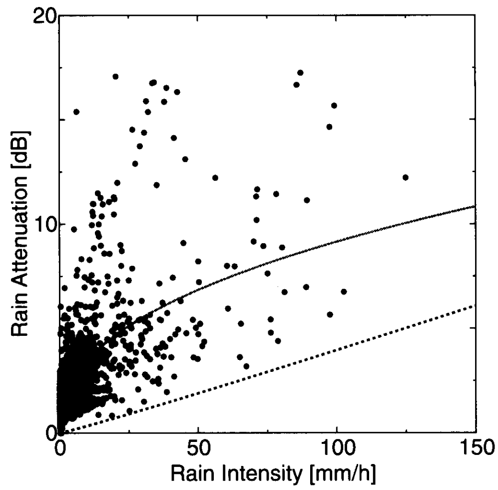


Fig.5 As **Fig. 2** but for uplink from Kyushu University.

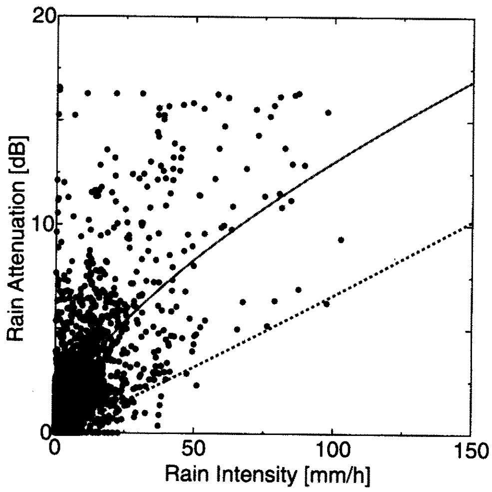


Fig.6 As **Fig. 2** but for total link at Kyushu University.

$$A(R, L_e) = \alpha R^\beta \qquad \text{[dB]} \tag{1}$$

where A, R and L_e are rain attenuation, rain intensity and effective path length, respectively. The fitting does not contain 0 mm/h of rain intensity. Values for α and β are provided in **Table 2**. The dotted line is the estimation by the ITU-R method [12)–14)].

There are two reasons why the tendency of the relation between rain attenuation and rain intensity is erratic as shown by the dot distribution in **Figs. 2–6**. One reason is that the rain intensity measured at the local point is not a representation of the rain intensity profile along the propagation path, which is suffered by rain. The other is that the actual characteristics of rain attenuation along the path are very complex and are influenced by many factors, specifically in addition to the nonuniform rainfall in general meaning, such as the raindrop size distribution and shape, nonuniform rain rates on the path, wind speed and direction, and rain temperature. Considering that, these figures indicate (i) inadequacy of conventional estimation by ITU-R for spot beam links and (ii) necessity of prediction method for rain attenuation distribution at a local point. It is necessary to collect much more data for a long period of time and at locally neighborhood region in order to yield a stable and reliable relationship between rain attenuation and rain intensity. This will be able to compensate inadequacy data and, at once, may be meaningful in developing the prediction method.

Table 2 Values for α and β estimated from the experimental data by Eq. (1).

Location	α	β
DL at OU	0.5012	0.4255
DL at KU	1.8770	0.3385
DL at QU	0.2261	0.6033
DL(ITU-R)	0.0107	1.2056
UL at QU	1.3381	0.4175
UL(ITU-R)	0.0185	1.1666
TL at QU	0.6730	0.6436

3.3 Effective Path Length and Specific Attenuation

One of the difficult parameters of the attenuation model is the effective path length since this parameter strongly depends upon the spatial distribution of rainfall. The authors attempt to calculate it in a way based on the experimental data.

Equation (1) contains

$$\alpha = cL_e(R) \tag{2}$$

where c is function of frequency and rain temperature. By fitting the measured rain attenuation A and the measured rain intensity R from our experimental results using Eq. (1), α and β can be obtained and are provided in **Table 2**.

L_e in Eq. (2) is estimated by the ITU-R independently of R but is known to be deviated due to rainfall event characterized by the rain intensity. Values for α and β for the ITU-R are provided also in **Table 2** based on 12)-14).

The ITU-R [14)] provides a method for calculating L_e from the rain intensity whose measurement time exceeds 0.01% of the total time $R_{0.01}$; according to the method, L_e is given by

$$L_e(R_{0.01}) = \frac{L_s}{\left(1 + \dfrac{L_s \cos\theta}{L_0}\right)} \qquad \text{[km]} \tag{3}$$

where L_s is the slant path length determined by the effective rain height and the elevation angle θ, and L_0 is given by the following formula:

$$L_0(R_{0.01}) = 35\exp(-0.015R_{0.01}) \quad \text{[km]} \tag{4}$$

For $R_{0.01} > 100$ mm/h, use the value 100 mm/h in place of $R_{0.01}$. We assume that the rain height is 4 km as reported by 15) based on the radar measurements on the average over raining days at Wallops

Island, Virginia. Then Eqs. (3) and (4) with the elevation angle stated in Sec. 2 and with the experimental $R_{0.01}$ lead to L_e approximately as 3.7 km at Kyushu University, 3.8 km at Oita University and Kumamoto University.

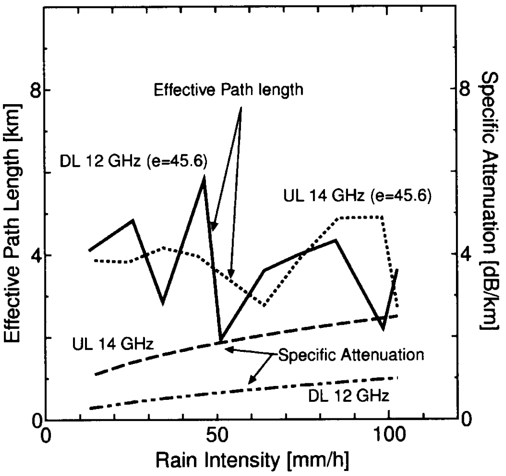
Next we investigate the relation of L_e and R. c of Eq. (2) is obtained from L_e estimated above and α given in **Table 2**, and the values are 0.13 for downlink to Oita University, 0.49 for downlink to Kumamoto University, 0.06 for downlink to Kyushu University and 0.36 for uplink from Kyushu University, respectively. And therefore, we can determine L_e as a function of R using our actual recorded experimental data as follows:

$$L_e(R) = \frac{E(A)}{cE(R)^{\beta}} \quad \text{[km]} \tag{5}$$

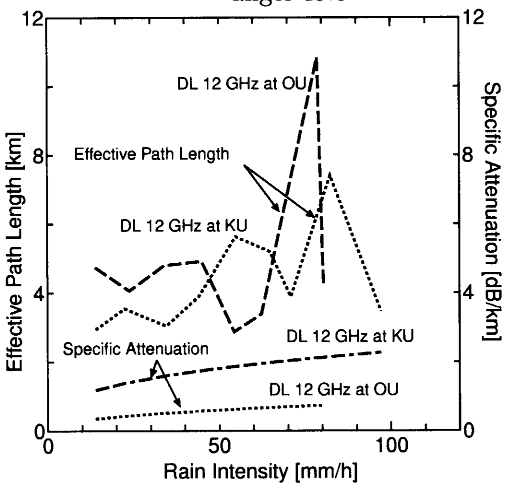
where $E(A)$ and $E(R)$ denote the averaged rain attenuation and the averaged rain intensity, respectively, within the interval 10 mm/h of rain intensity.

Figure 7(a) shows L_e and γ versus R for uplink and downlink at Kyushu University. **Figure 7(b)** shows the same relation for downlink to Oita University and Kumamoto University, respectively. If the cell structure of a storm is taken into account, the path length for low R is longer than for high R. With this in mind, the effective path length decreases with the increase of rain intensity. However, our experimental results have shown fluctuation of the effective path length. The fluctuation of effective path length is strongly related to the dot distribution in **Figs. 2–5**. If the measured rain attenuation indicated by the dot distribution in **Figs. 2–5** is greater than the averaged rain attenuation indicated by the best fit curve within the interval 10 mm/h of R, then the effective path length will increase and vice versa. The effective path length shown in **Fig. 7** is abnormal because theoretically it should increase with decreasing rain intensity. In addition, insufficient data by limited measurement only in the year of 2000 also contributes the fluctuation.

The results on effective path length and specific attenuation are important in deducing rain attenuation along the path which is a major contributing factor accounting for link outages in satellite communication. Such will be needed for the prediction of rain attenuation in multispot-beam propagation of Ka-band and millimeter waves.



(a) at Kyushu University with elevation angel 45.6°



(b) at Oita University and Kumamoto University with elevation angel 46.6°

Fig.7 Specific attenuation and effective path length versus rain intensity.

4. Conclusion

Using experimental data, we analyzed the relation of rain attenuation and rain intensity on radiowave propagation along uplink, downlink and total link in Ku-band by utilizing the JCSAT-1B satellite and several VSATs installed at three different locations in Kyushu Island, Japan. The analysis shows that the effect of rain are quite different even in neighboring regions. Strongly related parameters such as the effective path length and the specific attenuation have been given to illustrate the dynamic characteristics of rainfall. The effective path length has been obtained from the ratio of the rain attenuation to the specific attenuation. In addition, this result promotes studies on propagation experiment and prediction of bit errors for the future system using multispot-beams.

In subsequent work, characteristics of rain attenuation and their relation with rain intensity at those locations will be further investigated through experiment, adding the bit error measurement. After that we will try to study Ka-band propagation using multispot-beams and test an intelligent system based on the prediction of bit errors.

Acknowledgments

The authors would like to thank Prof. H. Ikuno of Kumamoto University, Prof. M. Tanaka of Oita University and their co-workers for conducting this experiment.

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