

# Improvement of Communication Capacity of a Satellite with Ku-, Ka-Band and Millimeter-Wave Frequencies during Rain Attenuation

#Naresh Tripathi<sup>1</sup>, Wataru Chujo<sup>1</sup>, Takeshi Manabe<sup>2</sup> and Sin-ichi Yamamoto<sup>3</sup>

<sup>1</sup>Department of Electrical and Electronic Engineering, Meijo University  
1-501 Shiogamaguchi, Tempaku-ku, Nagoya, 468-8502 Japan, 113433015@ccalumni.meijo-u.ac.jp

<sup>2</sup>Department of Aerospace Engineering, Osaka Prefecture University  
1-1 Gakuen-cho, Naka-ku Sakai, Osaka, 599-8531, Japan

<sup>3</sup>Kashima Space Technology Center, NICT  
893-1 Hirai, Kashima, Ibaraki, 314-8501, Japan

## 1. Introduction

Atmospheric effects play a major role in the design of satellite to earth links when operating at higher frequencies above 10 GHz. Raindrops absorb and scatter radio signal which leads to signal attenuation and reduction of the system availability and communication capacity of a satellite. Therefore to overcome the rain attenuation, various countermeasure techniques such as site diversity, frequency diversity [1], orbital diversity [2] etc. are developed. In this paper we are concerned in frequency diversity as a recovery technique against the rainfall attenuation occurred between satellites to earth links. Our target is to improve the communication capacity of a satellite with the simultaneous use of Ku, Ka-band and millimeter-wave frequencies (40 GHz).

For the effective application of frequency diversity, we have compared the communication capacity of satellites with two different cases that are millimeter-wave frequency diversity and dual frequency use. First case, the millimeter-wave frequency is used for clear day only, while Ku or Ka band is operated for rainy day [3]. Second case, for clear day both the Ku- or Ka-band and millimeter-wave frequencies are operated and Ku- or Ka-band frequency is functioned for rainy day which leads to further increment in the communication capacity.

## 2. Estimation of attenuations for millimeter-wave frequencies

Our measurement system is located at Kashima Space Technology Center in Ibaraki Prefecture, Japan and which is illustrated as in Fig. 1 below. In the first step, we have measured and analysed different received signal strengths and attenuation levels of both 12.65 GHz from Ku-band JCSAT2A and 18.9 GHz from Ka-band WINDS satellites when the rainfall intensity is over 10 mm/hr from November 2009 to October 2011 for two years. The received signals from both satellites are sampled at intervals of 1 second. The received signal level of a clear day is used as reference signal for the rainy day attenuated signal. The attenuation level of a Ka-band satellite from the Ku-band satellite can be estimated by referring to ITU-R rain attenuation model [4] as in the following equation:

$$A_{mmw} = K_{mmw} \left( \frac{A_K}{K_K L} \right)^{\frac{\alpha_{mmw}}{\alpha_K}} L \quad (1)$$

where,  $A_K$  represents the attenuations of the Ku- or Ka-band satellites, and  $K_K$ ,  $\alpha_K$  are the frequency-dependent coefficients for the Ku- or Ka-bands.  $L$  is the propagation length. We can calculate attenuations for millimeter-wave frequencies,  $A_{mmw}$  from Ku or Ka-band satellites by the equation (1).

The attenuation of Ka-band satellite is also estimated from Ku-band satellite and compared with the Ka-band measured attenuations. They coincide with each other [3]. Although the locations of JCSAT2A and WINDS are slightly different by azimuth angle of 17.8 degree, both measured Ku- and Ka-band data are available for frequency diversity analysis. Next, we have calculated attenuations for millimeter-wave frequencies from both measured time-series attenuations of Ku and Ka band. Figure 2 (a) shows the rainfall intensity on 18<sup>th</sup> February 2011 and Fig. 2 (b) shows the measured attenuations of Ku- and Ka-band satellites and calculated attenuations of 40 GHz from Ku- and Ka-band ones. We have examined the calculated attenuations of millimeter-wave frequencies from the Ku- and Ka-band for two years which are synchronized and coincide well with each other.

### 3. Availability of millimeter-wave frequencies

Since the estimated attenuations of 40 GHz from the Ku- and Ka-band are identical, the calculated 40 GHz attenuations is applied to find the availability percentage of millimeter-wave satellite by

$$A = \left( \frac{AT}{AT + UT} \right) \quad (2)$$

where,  $A$ ,  $AT$  and  $UT$  are satellite availability percentage, available and unavailable time of the satellite. We have verified that the calculated attenuations of 40 GHz from the Ku- and Ka-bands are identical, which can be applied to calculate the availability of a millimeter-wave satellite. Figure 3 (a) shows the measured availability percentage of Ku-band and calculated availability percentage of millimeter-wave 40 GHz from Ku- band. Measured availability percentage of Ka-band and calculated availability percentage of millimeter-wave frequencies is illustrated by Fig. 3 (b). The millimeter-wave satellite availability can be increased by use of the frequency diversity or dual frequency use. Also, from Fig 3(a) and (b), the availability percentage of millimeter-wave frequencies from Ku and Ka band are similar to each other. Therefore, we can apply availability percentage of 40 GHz for frequency diversity techniques to increase the communication capacity of a satellite.

### 4. Improvement of communication capacity using frequency diversity and dual frequency use

The satellite availability is applied to frequency diversity and dual frequency use to increase the communication capacity of a satellite. The communication capacity  $C_{div}$  for millimeter-wave frequency with Ku and Ka band and  $C_{dual}$  that for dual frequency use can be determined by the following equations:

$$C_{div} = C_{mmw} \cdot P_{Ammw} + C_K \cdot P_{Ummw} \cdot P_{div}, \quad (3)$$

$$C_{dual} = C_{mmw} \cdot P_{Ammw} + C_K \quad (4)$$

where,  $C_K$ ,  $C_{mmw}$ ,  $C_{div}$  and  $C_{dual}$  are communication capacities of the Ku- or Ka-band, millimeter-wave frequency 40 GHz, frequency diversity and dual frequency use,  $P_{Ammw}$  and  $P_{Ummw}$  are the availability and unavailability percentage of millimeter-wave frequencies, and  $P_{div}$  is the availability percentage for Ku or Ka bands when the millimeter-wave frequency is unavailable. The communication capacity of Ku-band is assumed to be half of Ka-band and millimeter-wave capacity is considered to be twice of Ka-band.

We have estimated satellite availability for Ku- or Ka-band while millimeter-wave frequencies is unavailable and calculated equivalent communication capacity using satellite frequency diversity. We have compared the communication capacity of satellites with frequency

diversity and dual frequency use. Figure 4 shows the communication capacity ratio  $C_{div}/C_K$  of the frequency diversity and  $C_{dual}/C_K$  of the dual frequency use. In Fig. 4 the abscissa shows the millimeter-wave threshold level and the clear day signal is supposed to be 0 dB. We compare communication capacity of a satellite for low threshold level that is -10 dB. Fig. 4 (a) shows the communication capacity ratio when the Ku-band and Millimeter-wave frequencies are used. At higher threshold level less than -20 dB,  $C_{dual}$  is close to 1.25 times the  $C_{div}$ . On the other hand, at lower threshold level -10 dB, the communication capacity from frequency diversity is 106 percent while the dual frequency use of Ku-band and millimeter-wave satellite enlarge the communication capacity up to 126 percent i.e. 20% increment in communication capacity is achieved. Figure 4 (b) presents the communication capacity with frequency diversity and dual frequency use when the Ka-band and millimeter-wave frequencies are used. At higher threshold level less than -20 dB,  $C_{dual}$  is close to 1.5 times the  $C_{div}$ . At -10 dB threshold, the communication capacity from frequency diversity with Ka-band and millimeter-wave frequency is 150 percent. However, Ka-band and millimeter-wave dual frequencies used at the same time increases communication capacity up to 200 percent i.e. 50% maximization in communication capacity is acquired.

The dual frequency use of Ku- or Ka-band and millimeter-wave frequencies leads to the improvement of the communication capacity. High communication capacity was achieved when the Ku- or Ka-band and millimeter-wave frequencies are operated simultaneously as compared to the capacity of frequency diversity between them. Especially, when the threshold level is low, we can use small satellite and millimeter-wave frequencies for frequency diversity to pursue increment in the communication capacity of a satellite.

## 5. Conclusion

To investigate the communication capacity of a millimeter-wave satellite we have calculated the attenuations for millimeter-wave frequencies from measured Ku and Ka-band ones and which exactly coincides with each other. The satellite availability for millimeter-wave frequencies was estimated from calculated attenuations of Ku and Ka-bands that are synchronized. We have compared the satellite communication capacity of millimeter-wave frequency diversity with simultaneous operation of Ku- or Ka-band and millimeter-wave frequencies. We improved communication capacity of the satellite for rain attenuation by use of dual frequency with Ku- or Ka-band and millimeter-wave frequencies. The simultaneous use of Ku- or Ka-band and millimeter-wave frequencies increases the communication capacity by 50 percent than the use of frequency diversity. The communication capacity with simultaneous operated Ku- or Ka-band and millimeter-wave frequencies can be increased even though at low threshold level that means small millimeter-wave satellite with less transmission power is adopted.

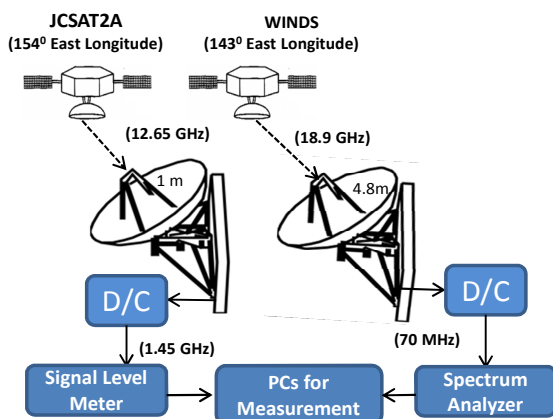


Figure 1: Received signal measurement system of Ku- and Ka-band satellites.

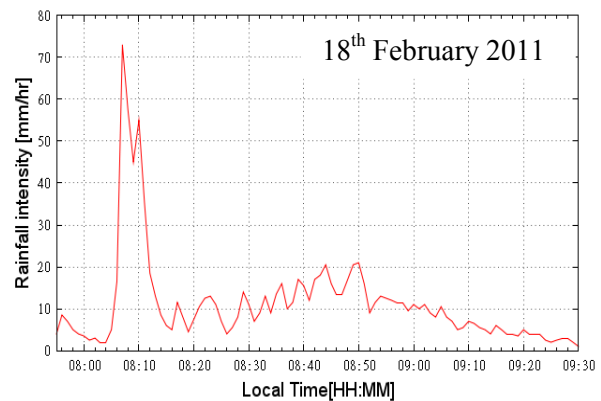


Figure 2 (a): Rainfall intensity on 18<sup>th</sup> February 2011.

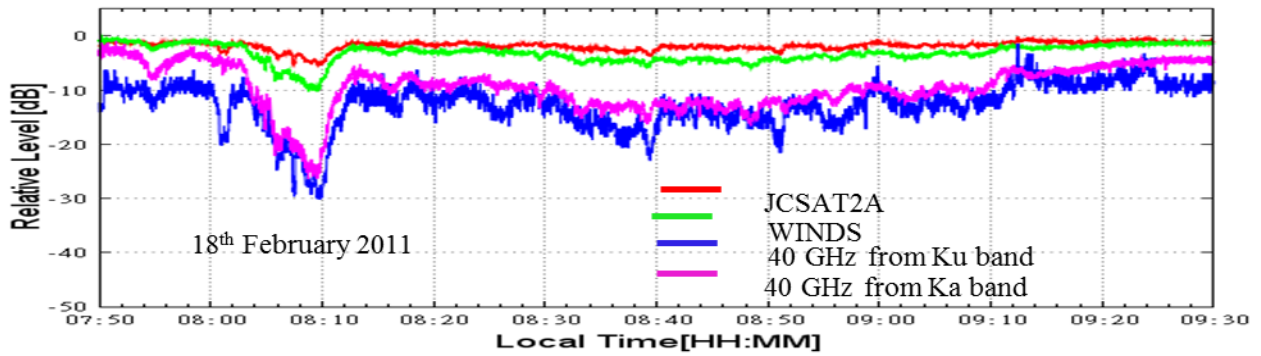
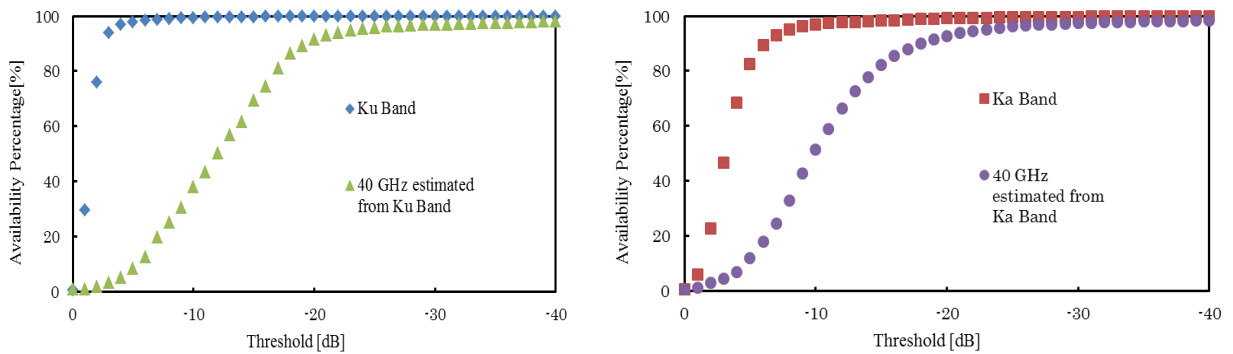


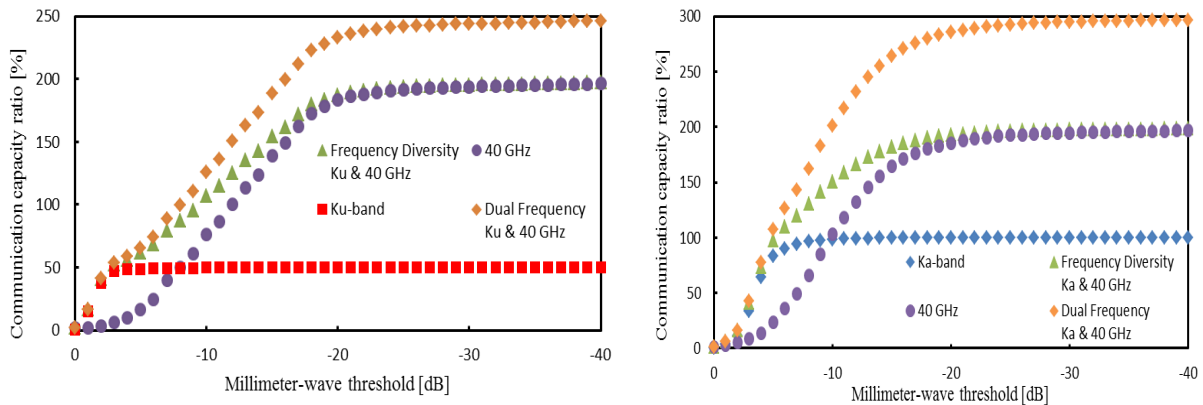
Figure 2 (b): An example of measured attenuations of Ku-, Ka-band and calculated attenuations of 40 GHz from the Ku- and Ka-band on 18<sup>th</sup> February 2011.



(a) Ku-band and 40 GHz

(b) Ka-band and 40 GHz

Figure 3: Availability percentages of Ku-, Ka-band and 40 GHz estimated from 13 days data.



(a) Ku-band and 40 GHz

(b) Ka-band and 40 GHz

Figure 4: Communication capacity ratio of frequency diversity and dual frequency use.

## References

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