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Radiometric Measurements of Ka-Band Attenuation during Rain Events at a Tropical Location

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Abstract

Reliable modeling of atmospheric attenuation is needed for optimum design of satellite communication links. In the view of upcoming satellite communications in this region, it is necessary to study the atmospheric attenuation at Ka-band during rain events. In this paper, attenuation estimation at Ka-band obtained from radiometric brightness temperatures (T_b) at Kolkata, India ($22^0$34'E, $88^0$22'N) have been presented. The contribution of water vapor is examined in determining the behavior of attenuation during rain at frequencies 22.24 GHz, 26.24 GHz and 31.4 GHz. It is observed that though the attenuation at 31.4 GHz is the highest, the attenuation at 22.24 GHz is higher than that at 26.24 GHz due to water vapor absorption under low to moderate raining conditions. The attenuation data obtained from ITU-R and Millimeter Wave Propagation (MPM) model are compared with the radiometric data to understand the limitation of radiometric measurements.

1. Introduction

In recent years, propagation studies have been carried out at Ku-band over Kolkata region [1-6]. Earth-space radio wave propagation is highly susceptible to signal degradation due to various meteorological phenomena like rain, cloud and water vapor at Ka-band and higher frequencies. Atmospheric attenuation is sparsely studied in the tropical region like Kolkata. Water vapor is a contributor to total attenuation near 22 GHz due to water vapor absorption. Formation of cloud is governed by transport of water vapor, and the water vapor transportation, in turn, is controlled by atmospheric temperature and pressure variations. Consequently, the study of atmospheric parameters like temperature, humidity, integrated water vapor (IWV), liquid water path (LWP) and atmospheric attenuation is important for understanding the underlying processes associated with precipitation, particularly in the tropical region where distinguishable raining conditions prevail during the pre-monsoon and monsoon periods. Simultaneous and continuous measurements of all such parameters are possible by means of a ground-based radiometer.

In the present work, atmospheric attenuation using radiometric measurements has been studied at 22.24 GHz (water vapor absorption line), 26.24 GHz and 31.4 GHz frequencies for pre-monsoon, monsoon and post-monsoon season. The water vapor plays a major role for atmospheric attenuation before the rain starts as well as at low rain rates. The experimental results have been validated with MPM and ITU-R model [7-8] generated data.

2. Instrumentation

The experimental observations with a ground-based microwave radiometer at Kolkata ($22^0$34'E, $88^0$22'N), India, a tropical location, have been utilized in the present study. The multi-frequency radiometer (RPG-HATPRO) measures brightness temperatures (BRT) at 14 different frequency channels spreading over two frequency bands, namely, at 22-31 GHz and 51-59 GHz. The lower 7 channel frequency band is utilized to study the humidity profile and the higher band monitors the temperature profile. Different atmospheric parameters like IWV, LWP and atmospheric attenuation are derived from BRT measurements by means of a retrieval algorithm based on linear and non-linear regression technique. A collocated disdrometer is also used for the measurement of rain events. For this study the data of the period 2010-2012 have been used.

3. Analysis

The Radiometric observations related to different rain events have been examined to understand the physical process involved in evolution of rain in the current tropical atmosphere. Radiometer provides attenuation time series data at 14 frequency bands. Here, attenuation measurements for only three frequencies, namely, 22.24 GHz, 26.24 GHz and 31.4 GHz have been considered for observations. Effective radiometric temperature (T_m) is one of the essential parameters in deducing atmospheric attenuation, τ_0 (θ), from observed brightness temperature T_b in accordance with the following expression [9-11]:

$\tau_0(\theta) = 4.34 \ln [(T_c - T_m)/(T_b(\theta) - T_m)]$ dB (1)

where T_b (θ) is the brightness temperature, θ is the elevation angle, and T_c is the cosmic noise temperature (approximately equal to 2.7 K). T_m is taken to be 300 K as reported earlier [11].

4. Results and Discussions

4.1 Variation with elevation angle

The atmospheric attenuation over an earth-space path with different elevation angles has been shown in Fig. 1. There is clear evidence of increase of attenuation with decreasing elevation angle [12]. It is due to the fact that, as the elevation angle is decreases, the path length through the troposphere increases, and the resultant total attenuation increases. Atmospheric attenuation is quite significant (more than 10 dB) in lower elevation angles (10°).

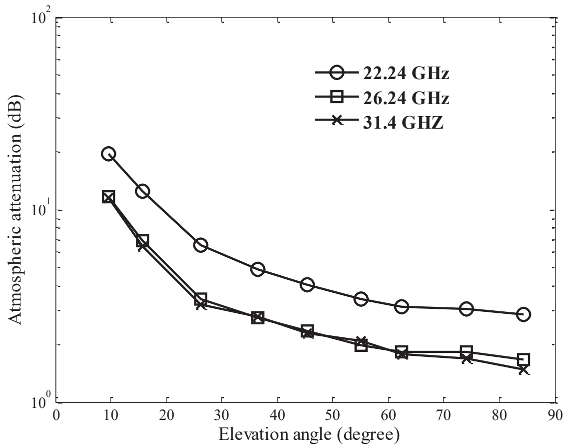

Fig. 1. Variation of atmospheric attenuation with various elevation angles

4.2 Case Study

Fig. 2 compares the attenuation values at 22.24 GHz, 26.24 GHz and 31.4 GHz with rain rate during a rain event recorded on 19 September 2011. From the Fig. 2, it can be noted that the attenuation at 22.24 GHz is higher than that at 26.24 GHz and the attenuation at 31.4 GHz is the highest. Though the rain attenuation should be higher at greater frequency, in the present case, due to the presence of high water vapour content during a rain event in the tropical atmosphere, the attenuation at 22.24 GHz shows higher values compared to that at 26.24 GHz.

4.3 Exceedance Probability

It is often necessary to specify propagation impairments on a statistical basis for optimum design of communication links. The exceedance probability for radiometric attenuation has been plotted for three different seasons, namely, monsoon (June-September), pre-monsoon (April-May), post-monsoon (October-November). The exceedance plot of attenuation values shows higher occurrences at 31.4 GHz than at two other frequencies. The exceedance occurrences of attenuation at 22.24 GHz are higher than that at 26.24 GHz which is due to the presence of the water vapor absorption line. However, before rain, the exceedance probability of attenuation at 22.24 GHz is highest among the three frequencies.

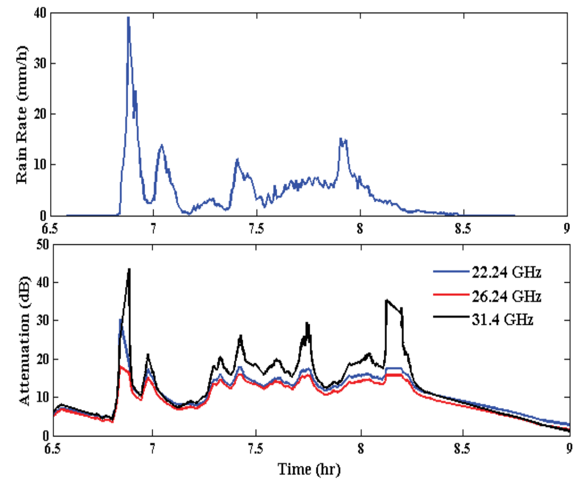

Fig. 2. Variation of (a) rain rate, (b) atmospheric attenuation

From Table 1, it can be inferred that the time exceedance values of rain attenuation is more in monsoon than other two seasons which is quite usual as monsoon season is predominant over this region. The attenuation value exceeding 0.01% of total time at 22.24 GHz is seen to be higher than 26.24 GHz indicating the role of water vapor in determining total attenuation.

Table 1: Attenuation value for 0.01 % of time

ATTENUATION	22.24GHz	26.24GHz	31.4 GHz
Monsoon	37.95	32.79	41.43
Pre-monsoon	24.49	17.41	31.56
Post-monsoon	19.17	15.64	26.21

4.4 Rain attenuation using MPM model

In Fig. 4, the time variation of specific attenuation with rain rate is depicted during the rain event of 18 June 2011. The MPM model is used to calculate the specific attenuation using frequency, humidity, and temperature and rain rate as input to the model. The specific attenuation values calculated from the model are observed to be higher at 31.4 GHz for higher rain rates whereas for lower rain rates these values are higher at 22.24 GHz compared to other frequencies. Relative humidity has varied from 95 % to 100 % (Fig. 4c).

4.5 Percentage contribution of water vapor and rain to specific attenuation using MPM model

The contribution of water vapor and rain to specific attenuation has been calculated using MPM model for different rain rates. For low rain rates, the contribution of water vapor is more than rain for all the frequencies as in Fig. 5. It can be seen that as the rain rate increases, atmospheric attenuation due to rain plays more dominant role than water vapor. However at 22.24 GHz, the attenuation due to water vapour is comparable to that due to rain up to 5 mm/h because of the presence of water vapour absorption line at this frequency.

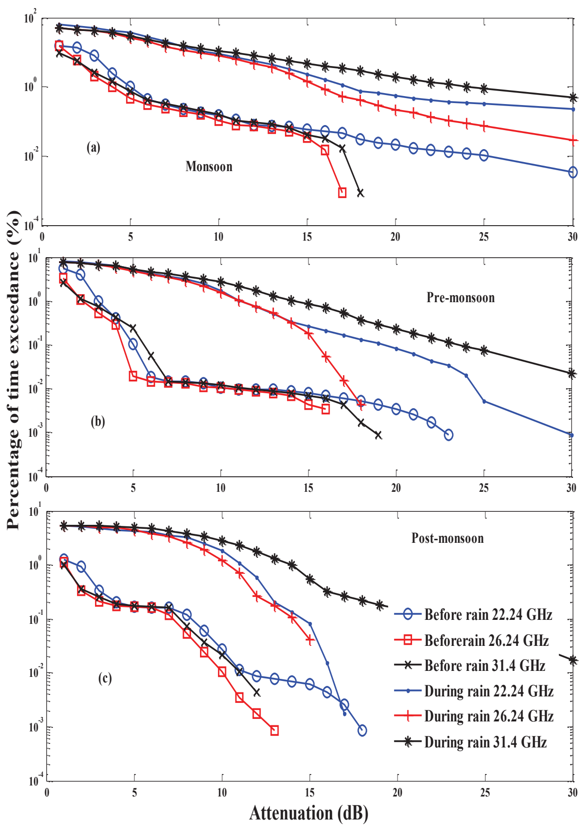

Fig. 3. Percentage of time exceedance of attenuation during (a) monsoon, (b) pre-monsoon, (c) post- monsoon.

4.6 Comparison of Radiometric Attenuation with ITU-R and MPM model

In order to compare the total attenuation measured by the radiometer with specific attenuation obtained from ITU-R and MPM model [7], the effective path length for the present location is estimated utilizing ITU-R model [8]. It is evident that radiometric attenuation data matches reasonably well with the model generated values up to a rain rate of 20 mm/h. At higher rain rates the ITU-R and MPM model both overestimate the attenuation obtained from radiometric measurements.

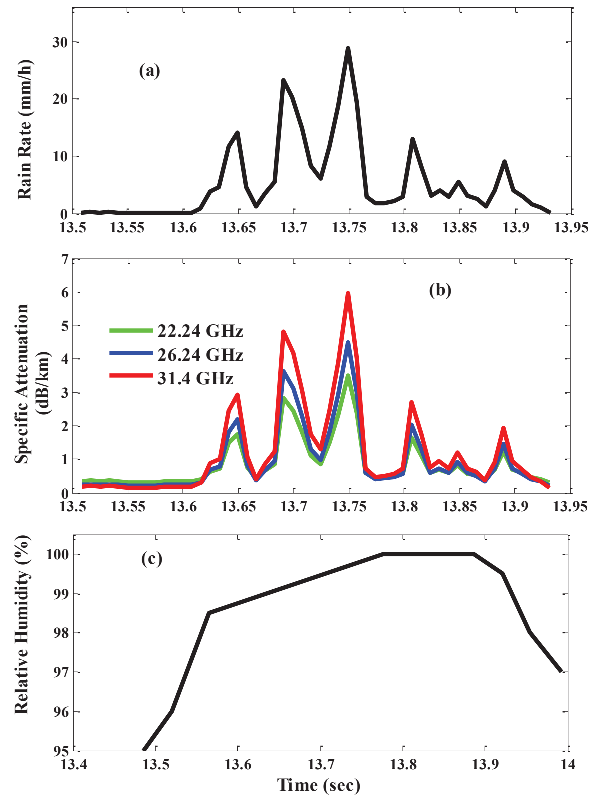

Fig. 4.Variation of (a) rain rate (mm/h), (b) specific attenuation (dB/km), (c) relative humidity (%).

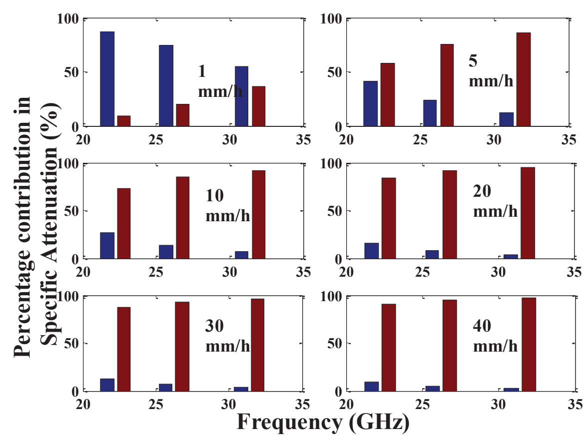

Fig.5. Percentage contribution of water vapor and rain to specific attenuation at three frequencies for different rain rates.

Fig. 7 presents the variation of total attenuation against rain rate from radiometric measurements, ITU-R and MPM model considering all the rain events in the study period. The discrepancy of attenuation values from radiometric measurements with respect to the model generated values is prominent at high rain rates, as radiometric brightness temperature shows significant reduction under intense raining conditions due to darkening effect [13-14].

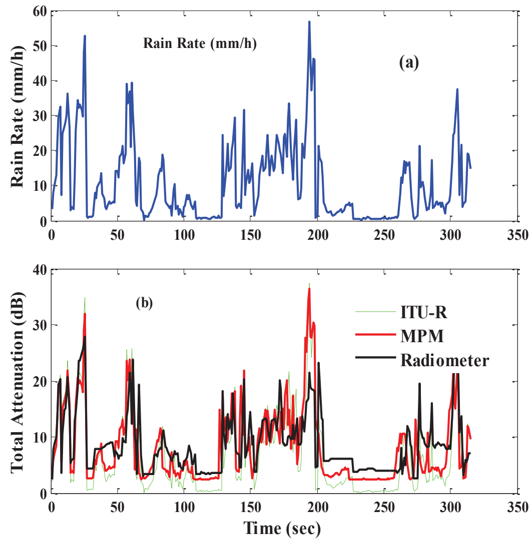

Fig. 6. Variation of (a) rain rate (mm/h), (b) total attenuation (dB).

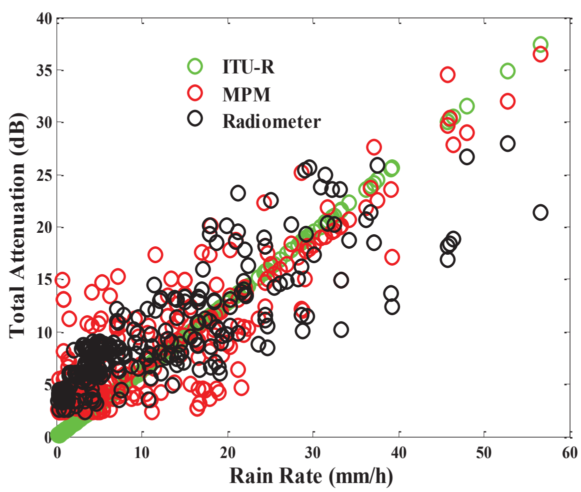

Fig. 7. Variation of total attenuation against rain rate from radiometricmeasurements, and ITU-R and MPM model.

5. Conclusions

Ka Band attenuation has been studied using radiometric measurements at 22.24 GHz, 26.24 GHz and 31.4 GHz at a tropical location. Brightness temperatures at these frequencies are utilized to obtain total attenuation along the earth-space path in vertical direction. Prior to the onset of the rain, water vapour causes significant attenuation at 22.24 GHz compared to the other two frequencies. The exceedance statistics shows that for 0.01% of occurrence, the attenuation is higher at 22.24 GHz than at 26.24 GHZ while it is the highest at 31.4 GHz. A comparison of radiometric measurements with ITU-R and MPM model data shows reasonably good match up to a rain rate of 20 mm/h, beyond which radiometric measurements show lower values, the deviation increasing with rain rate, indicating the darkening effect due to thick raining layer. This study indicates that water vapour has a significant role in determining Ka-band attenuation during and prior to rain events in the tropical region.

6. ACKNOWLEDGMENT

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