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Rain attenuation using Ka and Ku band frequency beacons at Delhi Earth Station

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Quantitative analysis and prediction of radio signal attenuation is necessary in order to improve the reliability of satellite-earth communication links and for economically efficient design. The Ka band suffers large attenuation due to rain and as most of the parts of India are situated in the tropical region, the impact of rain on Ka band propagation is severe. None of the existing ITU-R models is validated for prediction of rain attenuation over India and only a few over the tropical region and hence, it calls for a propagation experiment to validate the existing models. In this paper, study on the effect of rain attenuation on the propagation of satellite signals in Ka band has been carried out by receiving signal of frequency 20.199 GHz from the IPSTAR (Thaicom-4 Satellite) and a Ku band beacon signal of frequency 11.698 GHz from GSAT-8 satellite at Delhi Earth Station of ISRO. It has been observed that the difference between the ITU-R predicted rain attenuations and the observed rain attenuations for Ka band varies from 1.5 to 4.5 dB and that for Ku band from 2.1 to 3.7 dB. The long-term probability distribution of fade slope for any definite base value of attenuation is symmetric on both positive and negative sides and this feature is independent of frequency. This observation corroborates earlier findings.

Keywords: Rain attenuation, Fade slope, Radio signal attenuation, Satellite signal propagation

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1 Introduction

The radio frequency in Ka band offers three advantages for satellite communication over the low frequencies of C and Ku bands in terms of spectrum availability, reduced interference potential and reduced equipment size. However, these benefits are not without a cost. Satellite signals inevitably confront propagation impairments during signal transmissions between the satellite and earth stations. The Ka band is more susceptible to tropospheric impairments than lower frequencies, which can severely degrade service quality. Rain, ice, hail, fog, clouds and moist air affect communication links in different ways. If estimation of such impairments can be done, proper mitigation techniques can be implemented to improve the quality of service[1].

At frequencies above 10 GHz, rain is the dominant propagation phenomena on satellite links. The impairment of signal due to rain depends on rain rate, size of raindrops, rain drop density, etc. As most of the parts of India is located in the tropical region, the high frequency signals in this region is very prone to these tropospheric impairments[2]. Therefore, although satellite communication in Ka band has already started in both Europe and USA on commercial basis[3], frequencies above Ku band are still not commercially used in India. However, the nation is about to move to the next higher band between 20 and 30 GHz. The knowledge about the fade margin is necessary to design the system in a way to overcome the losses in the signal strength due to rain and to provide a given percentage of link availability. So, estimation of such impairments is required and mitigation techniques need to be developed for this region to get the required service quality.

The impairments estimation can be either statistical or deterministic. Generally, statistical models, like ITU-R recommendations, are quite well suited for the design purposes for establishing the necessary static margin. However, the large attenuation and other impairments expected in this region cannot be catered only by static margin of the transmitted signals. To combat the effect of earth atmosphere on 20-30 GHz frequencies, not only the performance of these statistical models, over a region of interest needs to be accurate with lowest error margin but some adaptive techniques are also required to be employed on the ground system.

None of the existing ITU-R models is validated for prediction of rain attenuation over India and only a few over the tropical region and hence, it calls for a propagation experiment to validate the existing models. To achieve this, extensive experiment needs to be conducted which will provide the necessary data for improving the statistical model for the region and establishing the adaptive techniques[4]. So, a Ka Band propagation experiment is conducted by ISRO using beacon signals from the geostationary satellites. This experiment involves the simultaneous measurement of beacon amplitude along with the associated meteorological parameters, including rain rate. This experiment, in its first phase has been carried out using beacon signal onboard Thaicomm-4. Due to restricted availability of the beacon signal at only one location, the experiment has been carried out with limited scope at its Delhi Earth Station. Collected data were analyzed to understand the effect of rain on Ka band frequency. This will provide an input to the fade mitigation models and will help in understanding the fade characteristics on the chosen frequencies in similar Indian regions. Further, it will also provide necessary insight and comprehension for the next phase of experiment to be carried out using GSAT-14 satellite over a number of ground stations. Simultaneous measurement of Ku band signal from the same site are also done to compare the fading effect of Ka and Ku band frequencies.

2 Experimental setup and Measurements

The experimental setup is installed at Delhi Earth Station (28°61'N latitude, 77°18'E longitude and height of 280 m above sea level). The beacon receiver measures the level of Ka band beacon of the IPSTAR (Thaicomm-4) satellite at 20.199 GHz (Ref. 5) using a 2.4 m antenna with an elevation angle of 33.3° and azimuth angle of 117.5°. Another beacon receiver is installed to measure the Ku band beacon at 11.689 GHz from GSAT-8 simultaneously along with Ka band beacon using 4.6 m antenna at an elevation angle of 55° at the same site with an azimuth angle of 220.4°. Both the receivers, sample the data at an interval of 1 second. The rain rate has been recorded on the site using a tipping bucket rain gauge of 0.2 mm resolution. The schematic for the setup and integrated setup is shown in Fig. 1(a and b).

The measurements were made over the days of the years 2012 and 2013. However, considerable attenuations were observed during the rains, which occurred during the monsoon period at the location, between 15 May and 1 October in 2012 and between 6 June and 4 October in 2013. The collected data were pre-processed in which the beacon data and the meteorological data were synchronized and were given common time stamps. Data reduction had been done by removing the partially missing and erroneous data. Scintillations and other measurement noises, such as abrupt variations in the level were removed by central averaging of the data over a predefined period, before processing the data. The instrumental drifts were removed and the attenuation reference level was evaluated using complementary measurements through spectrum analyzer. This was done by monitoring the beacon power level simultaneously using a spectrum analyzer with the help of an application developed in-house along with the beacon receiver measurement. The clear sky reference level of the beacon data was defined from the data after and before rainy days using averaging method.

3 Results and Discussion

With the obtained measurements, the fade temporal distribution probability is first compared with the

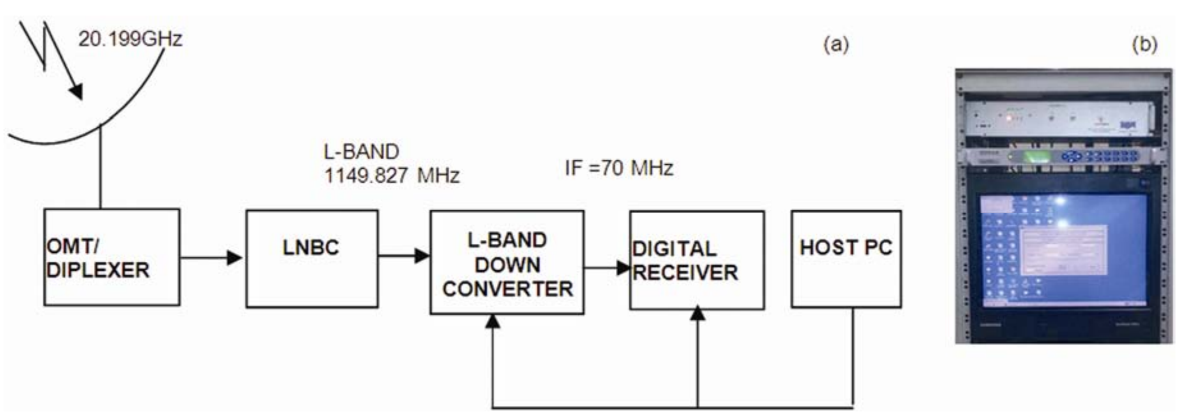

Fig. 1 — (a) Schematic for the set up of the Ka and Ku band beacon receivers at Delhi Erath Station; and (b) Integrated set up

corresponding ITU-R model[6]. The 0.01% of the rain rate exceedence value, required for the purpose is derived from the rain measurement done with a collocated tipping bucket rain gauge installed at the site. From the rain rate time series measurement data thus obtained over the entire period of data collection mentioned above, the rain rate probability distribution and the exceedence distribution of rain rate is derived[7-9]. The exceedence plot is shown as Fig. 2.

From this plot, the 0.01% of rain exceedence ($R_{0.01}$) over a year has been obtained as 49.5 mm h^{-1}. Using this $R_{0.01}$ rain rate value, the statistics of in-excess attenuation have been derived using the mentioned ITU-R model, ITU-R 618.9. According to this model, the attenuation exceedence value for 0.01% of the year, given by $A_{0.01}$, is calculated using equation:

$$A_{0.01} = \gamma_R L_E \qquad \text{(dB)} \qquad \ldots(1)$$

where, L_E, is the effective path length; and γ_R, the specific attenuation.

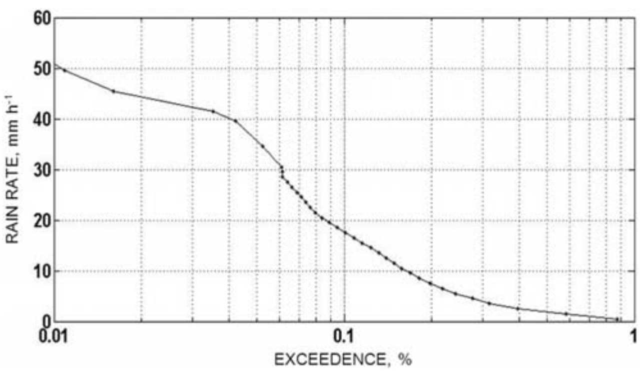

Fig. 2 — Exceedence plot of rain rate

$$\gamma_R = k\,(R_{0.01})\alpha \qquad (\text{dB km}^{-1}) \qquad \ldots(2)$$

where, k and α, are frequency dependent constants. The values of ‘k’ and ‘a’ are 0.0916 and 1.056, respectively for 20.199 GHz frequency. These values are 0.0177 and 1.214, respectively for 11.689 GHz (Ref. 10). Using the value of $A_{0.01}$, the predicted attenuation of other percentage of the year are calculated as given in model ITU-R 618.9.

The predicted value for 0.01% exceedence value of the attenuation ($A_{0.01}$) for Ka band is found to be 24.6 dB and the same for Ku band is 8.7 dB. From these values, attenuation for different percentage exceedences are derived.

The occurrence probability distribution of the attenuation is also obtained from the pragmatic data and the exceedence probability curve is also derived from this for both Ku and Ka bands. The model derived exceedence probability curve and the exceedence probabaility curve derived from measured data has been simultaneously plotted for both Ka and Ku bands. The comparative plot of the equiprobable predicted and measured attenuation of both Ka band and Ku band frequency are shown in Figs 3(a and b).

It has been found that for both the cases of Ku and Ka bands, the measured attenuation exceeds the ITU-R model predicted values for almost the entire range. Only for very low exceedence probabilities, the measured values show a tendency of saturation and eventually fall below the predictions. This nature of the curve arises due to the limited dynamic range of the beacon receiver. Owing to this fact, the receiver sometimes fail to record the higher side of the

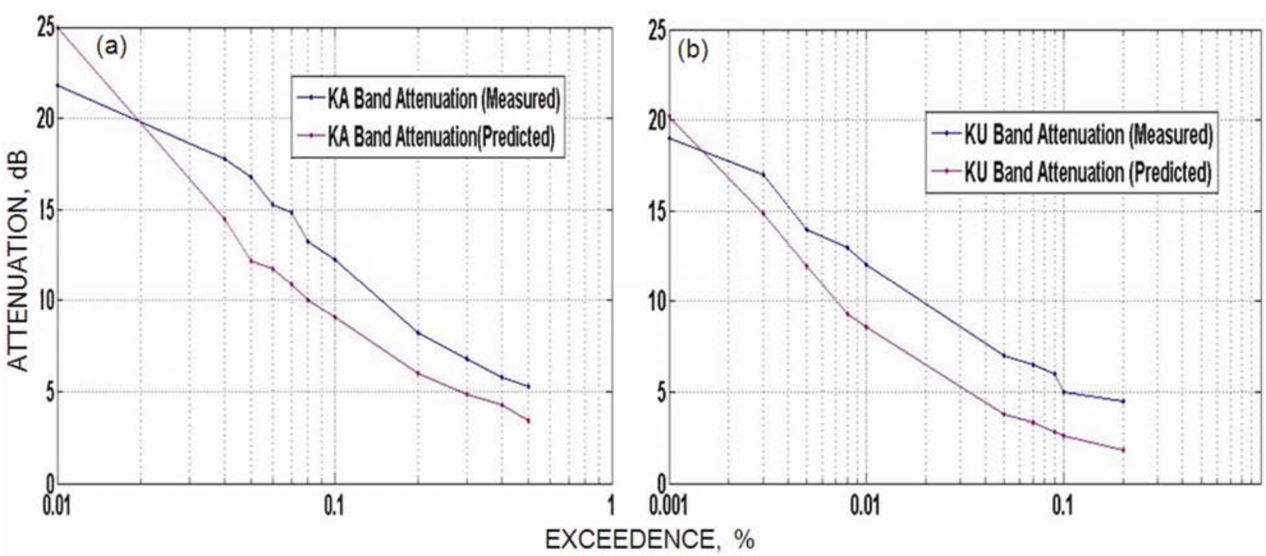

Fig. 3 — Comparative plot of attenuation exceedence derived from the model and measurement for: (a) Ka band; and (b) Ku band

excursion of the attenuation values, which is typically large for the tropical locations. Hence, the statistics at these higher values are under populated and exhibit this tendency of saturation.

The second order statistics of fade slope is also determined using the same data. Fade slope analysis and fade slope predictions are very important to develop the fade mitigation algorithms, like the uplink power control and other similar techniques to minimize the effects of link outage due to rain fade. Fade slope is defined as a measurement of attenuation rate of change with respect to time and has the unit of decibels per second. To quantify this, after the fast variations due to scintillation and other noises are removed, the first derivative of attenuation with respect to time is calculated.

To obtain the fade slope at a sampling instant, n, a window of 5 samples about the nth sample, i.e. samples at instants n-2, n-1, n, n+1 and n+2, have been taken and a least square fit is obtained using fourth order regression equation. From the first derivative of the fit equation, the value of the derivative at the middle point, i.e. at instant n is obtained. Finally, conditional probability densities of fade slope with attenuation are generated for Ka and Ku band beacon signal. The plots for the fade slope in Ka and Ku bands are shown in Figs 4(a and b), respectively.

The distribution of the conditional probability density of the fade slope, ς, given by $P(\varsigma|A)$ for different base attenuation (A) can also be derived using the ITU-R model ITU-R P.1623, which can be expressed as[11,12]:

$$P(\varsigma|A) = 2/\pi\sigma_\varsigma\,(1+(\varsigma/\sigma_\varsigma))^2)^2 \qquad (\text{dB s}^{-1}) \qquad \ldots(4)$$

where, σ_ς, is the standard deviation of the conditional fade slope and is a function of the base attenuation level (A) and the measurement interval of the attenuation values. This value for different attenuation is obtained using the expression given in the said model.

The model indicates a distribution of the rain fade slope, which is symmetrical about a zero mean. It also expects the distribution to have a longer ledge and higher peaks of the distribution with a peak value of $2/\pi\sigma_\varsigma$ as compared to a Gaussian distribution with the same standard deviation.

From the measured fade values, the conditional probability distribution of the fade slope in Ka and Ku bands are also found to show similar variations. The fade slope is found to be distributed symmetrically about 0 dB s^{-1} with similar extensions along the positive and negative sides of the slopes. The same nature is exhibited for all base attenuation values. In order to check this quantitatively, some parameters were calculated from the distributions, like the median slope values and average positive and negative slopes. No substantial variation of these values from zero is found.

The absolute fade slope values are found to extend from –0.1 to 0.1 dBs^{-1} for different attenuations. The spread of this fade slope is also found to increases with the base attenuation, corroborating the model. Furthermore, the distribution is nearly similar for both beacons, even though the samples are very differently distributed over the attenuation bins for the two frequencies. This is indicative of the conditional

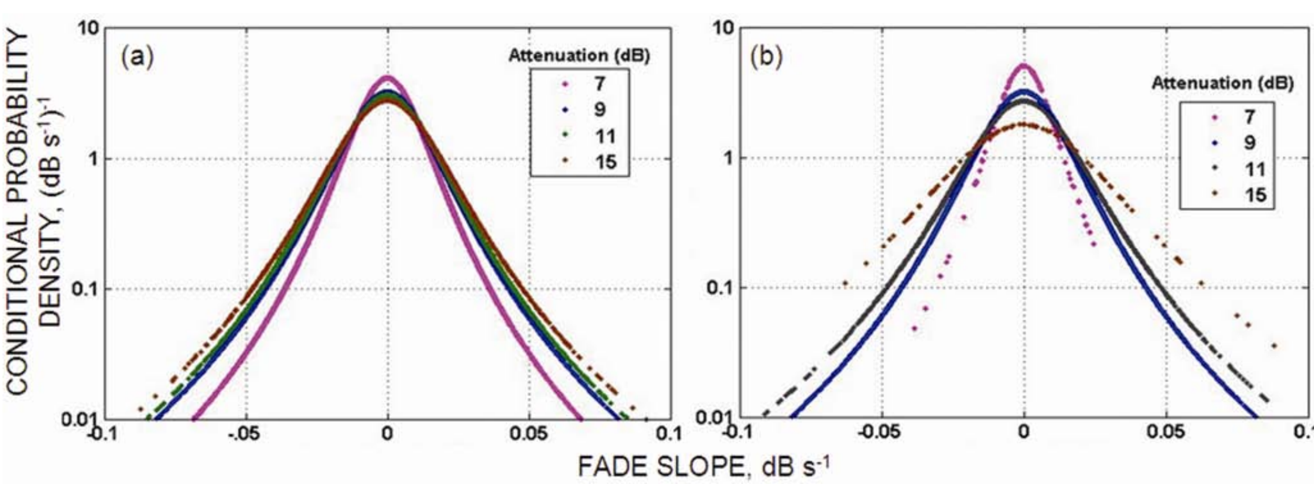

Fig. 4 — Conditional fade slope distributions for: (a) Ka band; and (b) Ku band

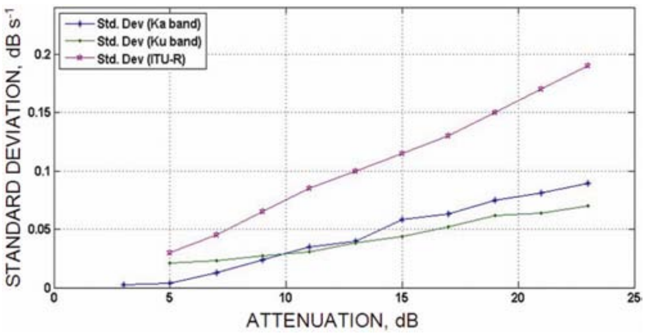

Fig. 5 — Variation of the standard deviation of the fade slope distribution with base attenuation

distribution of ς for a certain value of A to be independent of frequency.

Comparing the fade slope distribution plots, it can be seen that the distribution of fade slope for any fixed base attenuation value can be approximated by conditional probability equation as given in Eq. (4), where σ_ς, is the only characterizing parameter and that it is dependent on A. To find the relation between the standard deviation of fade slope with attenuation, the value of σ_ς is calculated from the pragmatic conditional distribution function of measured fade slope derived at every attenuation level. Measurements from both the beacons at Ka and Ku bands are generated separately. The standard deviation of the distribution is found to increases monotonically with the base attenuation value and the relation varies similarly for the two beacon frequencies. This is evident from the Fig. 5 that illustrates the variation of the standard deviation of the fade slope distribution with base attenuation. The commonality of the nature of the variation indicates its independence with frequency.

The observed variations of the standard deviations with base attenuations are compared with the same from the ITU-R function. The slope of this variation is found to be smaller than that indicated in the ITU model. This is evident from Fig. 5.

4 Conclusion

The rain attenuations, collected over two years in the Ka band from IPSTAR (Thaicom-4 satellite) and Ku band from GSAT-8 were analysed to observe the statistical characteristics. The long term occurrence exceedence variation are obtained and compared with those expected from the ITU-R model using the measured rain rates. The two values of attenuation showed a significant disparity over the entire range. The difference between the predicted and measured exceedence values is found to vary from 1.5 to 4.5 dB in Ka band and 2.1 to 3.7 dB in Ku band. The long-term probability distribution of fade slope for any definite base value of attenuation is found to be symmetric on both sides and independent of frequency. The standard deviation (σ_s) of the observed zero mean distribution is found to be linearly increasing with the base attenuation values (A). However, the slope of the variation of σ_s with A is found to be different than that expected from the ITU-R model.

The study has been conducted with only two seasons of rain data. The results presented here may be moderately revised when the rainfall data for longer period would be analysed in future. However, the gross statistical nature is expected to remain the same. Further, the receiver used for the experiment is having low dynamic range. It has the limitation that pragmatic data cannot be collected beyond certain attenuation values. So, the extreme higher exceedence probabilities cannot be obtained using this setup.

The same methodology of analysis can be adopted for the data to be obtained from propsed Ka band propagation experiment using GSAT-14 onboard beacons at 20.2 and 30.5 GHz that will eventually recommend and develop a technique for attenuation and fading prediction of radio wave propagation in Ka Band over Indian region and develop suitable mitigation techniques.

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