An Experimental Study of Rain Attenuation at Ku Band Frequencies for an Earth Space Path over Chennai

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ABSTRACT
In this paper, rainfall attenuation suffered by a Ku band signal was measured with a receiver located at Anna University's MIT campus and used to verify the accuracy of the ITU R model in the Chennai region. The rainfall statistics were applied to the appropriate ITU R model and the differences between the experimental and observed results for the attenuation suffered by the system have been documented and tabulated.

Keywords:
Rain attenuation, Ku-Band, DTH, ITU-R model, Chennai.

1. INTRODUCTION
With the advent of DVB television systems and advancements in satellite communication, there has been a tremendous growth in the use of Ku band frequencies as a means of broadcasting television signals. Ku band is very useful for this purpose simply because it is relatively congestion free. The natural consequence of this is the mushrooming of several satellite TV service providers trying to enter the market today to utilize this spectrum on a commercial scale. This increased interest in this part of the spectrum calls for a need to study the atmospheric impairments suffered by such a communication system. Amongst all forms of atmospheric attenuation, attenuation caused by rain is one of the most important factors responsible for link outages of systems at Ku band frequencies [2]. There are several schemes which model this attenuation and give a theoretical estimate of this attenuation [1], [3], [4]. Such models have been used in several studies such as Maitra et al [6], Alnutt et al [7] to predict the attenuation characteristics of several regions theoretically. However, there is a need to verify the accuracy of these models with the actual attenuation suffered by a Ku band signal in a specific earth station. In this paper, an effort has been made to calculate rainfall attenuation experimentally over an earth space path in Chennai in order to compare and offer improvements specific to this region to the theoretical ITU-R model [1] .The results obtained in this study can be used for more efficient link designs in the Chennai region.

2. RAIN ATTENUATION MODELLING
Before experimentally calculating rainfall attenuation data, efforts were made to study the several rain attenuation models available in the literature. Rain attenuation modeling has been performed since 1980 with Crane [4] suggesting the earliest models. Rainfall modeling is a relatively complex process and involves the evaluation of specific attenuation, effective path length and rainfall intensity. In this paper, ITU recommendations [1], [5] were used to theoretically estimate rainfall attenuation over the Chennai region. Calculation of the rain rate, which is essential for attenuation measurement, was done with the Rice Holmberg model [8]. According to Bhattacharya et al [2], the process of rain modeling can be approached in two ways – one utilizing large number of attenuation statistics at different frequencies, locations and path geometries. The other method is to synthesize attenuation data available from metrological data and this approach is followed in this paper. The metrological data required was readily obtained from several sources over the internet such as the Indian Metrological Department [11]. Several codes required for calculation of rain attenuation as per the ITU-R model were developed on Matlab® and utilized to obtain the theoretical attenuation values for the rainfall events. Figures 1 and 2 are plots obtained from two such events.

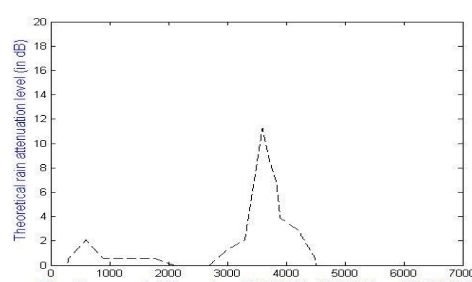

Figure 1: Theoretical estimate plot for rain attenuation on 17/8/2010

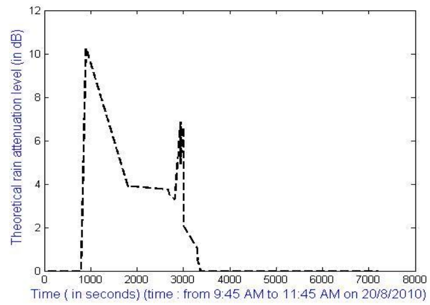

Figure 2: Theoretical estimate plot for rain attenuation on 20/8/2010

3. EXPERIMENTAL SETUP

Figure 3 describes the experiment set up used in the measurement process. The exact co-ordinates of Chennai are 13^0 N, 80^0 E. To receive Ku band signals, a typical satellite receiver was used. The satellite receiver receives intermediate frequency (IF) signal (Frequency range .95 to 2.05 GHz) from an LNB, which is connected to a dish placed at an elevation angle of 68.29^0.The dish antenna receives signals from the INSAT 4B satellite which is at 93.5^0 East longitude .The IF signal is taken from satellite receiver loop out and fed to a spectrum analyzer which gives the spectrum shown in figure 4(a) during clear sky conditions. An Agilent E4402B, 3 GHz spectrum analyzer was used to record samples of the viewed spectrum over finite periods of time. The set up is then used to obtain data for signal power during events of rainfall. The corresponding rain statistics are obtained from the Indian Metrological Department website [11] and are used to run the theoretical models.

Figure 3: The experimental setup used to measure attenuation

4. EXPERIMENT METHODOLOGY

The entire study was carried out at Anna University, MIT campus where the above set-up was placed in order to study the event. The average received IF signal at 1.27 GHz level was around -43.79dBm during clear sky conditions. This was taken as reference power level to measure the extent of rain attenuation during the time of a rain event.

Figures 4(a) and (b) give an indication of signal levels during clear sky and heavy rain conditions as seen on the spectrum analyzer.

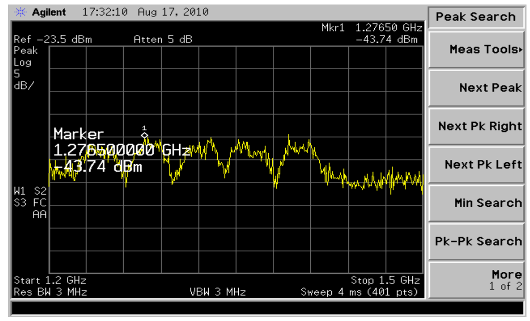

Figure 4 (a): Satellite IF signal during clear sky conditions.

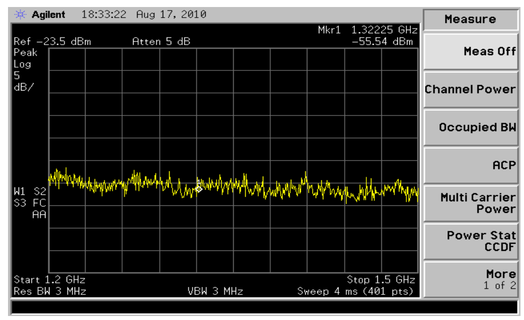

Figure 4 (b): Satellite IF signal during typical rain event.

With the experimental setup described above, a number of readings were taken whenever a rainfall event was observed in the region. For each rainfall event, the attenuation suffered was noted and correspondingly, the rainfall rate at that instant was noted. The rainfall rate was then utilized to estimate the theoretical rainfall attenuation suffered by the signal as per the ITU-R global model for attenuation.

The ITU-R model [1] calculates specific attenuation based on the equation:

$$\gamma = \kappa * R^{\alpha} \qquad (1)$$

Where γ, the specific attenuation due to rainfall, is dependent on R, the rainrate (mm/hr) in the given region. Also, κ and α are regression coefficients dependant on frequency, temperature, drop spectral density and polarization of radio wave. Apart from the specific attenuation, the model also requires calculation of effective path length $L_{(effective)}$; which is calculated from the equation:

$$L_{(\text{effective})} = L_r * v \qquad (2)$$

Where

$$L_r = (L_g * r_p)/\cos(\theta) \quad (3)$$

In which

$$L_g = L_s * \cos(\theta) \quad (4)$$

Where;

L_s = slant path length

r = rain rate exceeded for p% time

θ = elevation angle (in degrees)

v = vertical adjustment factor

The slant path is itself calculated from the rain height with the help of ITU-R recommendation 839.1 [9]. With the above formulae, the expression for rain attenuation as a function of rain exceedence is also given in the ITU-R recommendation and calculated as:

$$A_{.01} = \gamma * L_{effective} \quad (5)$$

Where:

$A_{0.01}$= Attenuation exceeded for 0.01 % time in an average year.

Using the recommendation and subsequent formulas, attenuation for different exceedence percentages can be obtained. A code was developed for this on Matlab® and the typical rain exceedence curve for Chennai region is seen in figure 5.

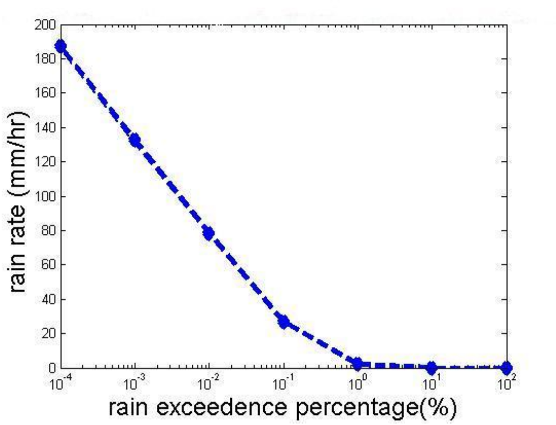

Figure 5: Year-round Rain exceedence curve for Chennai region as calculated by use of ITU-R recommendation

As it can clearly be seen, higher rain rates are pretty rare and hardly account for 0.01% to 0.001% of an entire year. It is during such times of the year maximum attenuation due to rainfall can be studied best. Tabulated below are the comparisons of the actual rainfall attenuation suffered by the Ku band signal on two days i.e., 17/8/2010 and 20/8/2010 and the ITU-R theoretical estimate. The attenuation is calculated by subtracting the clear sky signal power (-43.74dBm) from the measured value at that instant of time.

Table 1:

Comparison of the measured and theoretical attenuation values on 20/8/2010

TIME (PM)	RAIN RATE (mm/hr)	ATTN (measured) (dB)	ATTN (theoretical ,ITU) (dB)
5:25	0	0	0
5:32	0	0	0
5:35	5	1	0.53
5:40	15	2.6	2.06
5:45	5	1.23	0.53
5:50	5	0.49	0.53
5:55	5	0.64	0.53
6:00	0	0	0
6:10	10	1.63	1.25
6:20	15	3.1	2.06
6:30	60	11.94	11.27
6:32	48	9	8.58
6:34	40	6.24	6.85
6:35	25	4.11	3.91
6:40	17	2.25	2.93
6:45	5	0.79	0.53

From the above tabulation, a graph was plotted on Matlab to show the relation between rain attenuation and rainfall intensity (Figure 6). Also, it is clear from this tabulation that the ITU R model seems to underestimate the rainfall attenuation at least in the Chennai region. Another example of this is tabulated in table 2 and this is the rainfall attenuation suffered by Ku band signals on 20/8/2010 between 10 A.M and 11:30 A.M. The calculation of attenuation was done in a similar fashion as that for the previous tabulation.

Table 2:

Comparison of the measured and theoretical attenuation values on 20/8/2010

TIME (AM)	RAIN RATE (mm/hr)	ATTN (measured) (dB)	ATTN (theoretical ,ITU) (dB)
10:00	56	11.4	10.28
10:15	25	4.1	3.91
10:20	23	3.5	3.48
10:22	22	3.05	3.31
10:23	21	3.01	3.11
10:24	30	4.72	4.89
10:27	15	2.61	2.09
10:30	5	0.48	0.53

It is again seen that the ITU R model underestimates the actual attenuation suffered by a Ku band signal in Chennai region. There are several more such calculated data which points to the above fact of which the above samples are a small part. Matlab® files were created to combine and plot rain attenuation vs time and rain rate vs time (Figure 7). The tabulation plots give a clear picture on the relationship of rain attenuation with the rainrate at any given instant of time.

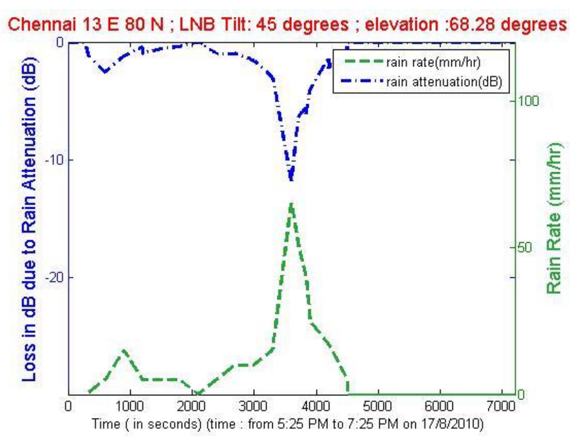

Figure 6: Rain Attenuation and Rainrate vs Time (Table 1)

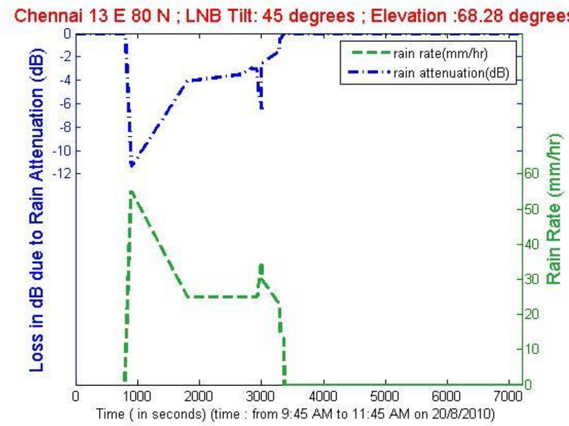

Figure 7: Rain Attenuation and Rainrate vs Time (Table 2)

5. DISCUSSIONS AND CONCLUSIONS

In this paper, data has been furnished to show the inadequacies of the global ITU R model in accurately predicting the magnitude of rainfall attenuation. The model accuracy could be improved by using a more specific value for κ and α, the regression parameters given in the ITU-R model. Data recording was done during the months of June to December – a relatively small period to model a long term effect such as rain attenuation. However, the fact that the global ITU R model underestimates the magnitude of attenuation is very important to note because, with the ever increasing growth of satellite technology, the need to study and improve prediction of atmospheric phenomena such as rain attenuation is bound to become even more important than ever before. Thus, a need arises to offer slight modifications in the ITU-R model itself to improve its prediction capabilities in tropical regions such as Chennai. This paper is an effort to offer experimental evidence on the drawbacks of the existing model in order to aid in the development of more India-specific models in the future.

6. ACKOWLEDGEMENTS

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