A study of Ka-Band Signal Attenuation at Umiam, Meghalaya with ISRO's GSAT-14 Satellite

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Abstract: ***A study at NE-SAC, Umiam of Rain Attenuation to Ka-Band signals has been made with ISRO's GSAT-14 Satellite carrying two Ka-Band beacons at 20.2 Ghz and 30.5 Ghz and with the help of instruments like High Gain receiving antennas; Humidity Profiler Radiometer, Tipping Bucket Rain Gauge , GPS antenna etc.. The study has been a joint collaboration of ISRO and CNES/ONERA, the French Aerospace Lab. The study comprises simultaneous signal attenuation and rainfall recording of a time period ranging from Pre-Monsoon to Post –Monsoon season at Umiam, from March to October for the year 2016.***

Keywords: Ka-band**,**GSAT-14,Scattering**,** Rain intensity**,** Attenuation

1. Introduction

The millimeter wavelength radio signals are subjected to attenuation due to molecular absorption and scattering by various atmospheric entities, like various gas molecules (Oxygen) or precipitation (water vapour, rain, melting snow, hail, sleet) due to the polar nature of the molecules**[1].** While the single and multiple scatterings can be modelled using the generalized Mie Solution to the Maxwell's equations**[2]** and using the Rayleigh Approximation to suitable cases, the mixed absorption and scattering phenomenon can be expressed using the Radiative Transfer theory**[3]**. In tropical region though, where generally the elevation angle to the satellites in use lies above 20-30 degrees and ice depolarization and effect of snow and sleet is negligible, the principle cause of signal attenuation is rain. In Earth-Space Satellite Communication, communication occurs employing microwave signals mostly in the C (4/6 GHz), Ku (12/18 GHz) and Ka (20/30GHz) bands. Communication satellites are mostly placed at a great distance of 36,000Kms from the earth surface. So, the signals received are already highly attenuated and path loss can be as high as 200 dB. Additional losses due to rain cannot exceed 20-30 dB but it increases with frequency. While European and American countries which typically experience dry monsoon season, use these high frequencies quite successfully taking benefit of high percentage bandwidth and smaller, low cost receiving terminals, tropical countries suffer from the high attenuation due to rain.

2. Methodology

2.1 General Methodology

The general trend in rain attenuation measurement is finding the actual signal level through a satellite beacon receiver and correlating the fall in signal level with the actual rainfall data from measuring instruments and sensor which can be as simple as Rain Gauges giving rain rate, Disdrometers giving rain drop size distribution or sophisticated radiometers which can give lot many information about the atmosphere within its scanning zone. The parameters of utmost interest in this process are the specific attenuation and rain path length. For calculation of specific attenuation, or as mentioned in **[4]**, the extinction cross section per unit volume, assumptions primarily are that the rain drops and cloud particles are homogenous and spherical of uniform size and suspended in the space according to a Poisson distribution process. With these assumptions, scattered field from each raindrop may be calculated and then summed up to find the specific attenuation. Mie Theory is used for frequencies above around 2 Ghz.

2.2 Numerical Rainfall Attenuation Model

The numerical modeling of Rainfall induced signal attenuation is basically due to ITU-R **[5]**. It is based on the assumption that rain is uniformly distributed in a certain distance of path , which is only a small fraction of the Satellite to receiving antenna line of sight distance. This path length is called the actual Rainy Path Length (Le, in Km) and the specific Attenuation due to Rain (Υ, in dB/Km) is calculated. Then, the total Rain Attenuation(A, in dB) can be calculated as

$$A = \Upsilon Le \qquad (1)$$

The Specific Attenuation is related to the Point Rainfall Rate(R, in mm\Hr.) exceeded for a certain percentage of year as follows

$$\Upsilon = \kappa R^{\alpha} \quad (2)$$

Where κ and α are parameters of the semi-empirical model, which are dependent on the signal frequency (f in GHz), angle of elevation (E) of the receiving antenna and polarization tilt (τ) of the antenna with respect to horizontal. These can be calculated from formulas and tables given in **[5]**. Next, the Rain Rate exceeded for a certain percent of time of year has to be calculated. This is an indication of the maximum average rainfall at a certain location. This is done to find the maximum value of attenuation **[6]**.According to ITU-R**[7]**, these values were calculated for the station location through the use of bilinear interpolation method with available data sets. Important results have been given in table below.

I TABLE 1: FREQUENCY DEPENDENT SEMI- EMPERICAL MODEL PARAMETER VALUES AT 20 AND 30 GHZ

f(Ghz)	κ_H	κ_V	κ	α_H	α_V	α
20.2	0.0916	0.0961	0.0931	1.0568	0.9847	1.0317
30.5	0.2403	0.2291	0.2347	0.9485	0.9129	0.931
E = 55 degrees for GSAT-14 at Umiam						
τ = 0° for 20.2 GHz beacon (Horizontal Polarization), 90° for 30.5 GHz beacon (Vertical Polarization).						

II. TABLE 2 : RAINFALL RATES CALCULATED AT UMIAM

R0.01(mm)	R0.1(mm)
78.2	29.2

Also, the effective path length Le is given as

$$Le = lr \quad (4)$$

Where, l is actual rainy path length, r is horizontal reduction factor having the form given as:

$$r = 1 / (1+Cl^{m}) \quad (5)$$ **[8]**

Where, C depends on the relevant percent(P) of the year for which data is available and m depends on both the actual path length as well as signal frequency. Moupfouma**[9]** gives,

$$r = \frac{1}{1+0.03(\frac{P}{0.01})^{-\beta} l^{m}} \quad (6)$$

Where,

III. TABLE 3 : VALUES OF β AT DIFFERENT P

P	β
0.01	0.45
0.1	0.6

$$m = 1 + 1.4 \times 10^{-4} f^{1.76} \log_e l \quad (7)$$

Where f is signal frequency. Also l which is the rainy path length is given by

$$l = l_s \cos E \quad (8)$$

Where l_s is slant path length given by

$$l_s = (H_r - H_s)/\sin E \quad (9)$$

Where, H_r is Effective Rain Height above MSL and H_s is Station Height above MSL in Kilometre.

H_r is given by,

$$H_r = H_o + 0.36 \quad (10)$$

Where, H_o is 0° isotherm height at the station location.

The following table gives station specific parameters

IV. TABLE 4: STATION RELATED PARAMETERS

H_0	H_s	H_r	l
4.7573	1.05	5.1173	3.583

According to ITU-R data, at the station location, H_o is 4.7573 Km through bilinear transformation as mentioned in **[10].** Based on these calculations, the following table is obtained.

V. TABLE 5: GEOMETRIC PARAMETER VALUES

f(GHz)	r0.01	r0.01	$Le_{0.01}$	$Le_{0.1}$
20.2	0.9	0.973	3.225	3.49
30.5	0.897	0.971	3.213	3.48

Then, taking ITU-R values for $R_{0.01}$, $R_{0.1}$, the following table is obtained

VI. TABLE 6: ATTENUATION PARAMETER VALUES

f(GHz)	A0.01(dB)	A0.1(dB)
20.2	26.968	10.562
30.5	26.868	10.532

2.3 Instrument and utilities Used:

The following set of instrument were used for data acquisition:

2.3.1 ***RPG HUMPRO G4 Radiometer****:* The Radiometer scans the atmosphere in Line of Sight and Zenith direction and gives atmospheric brightness temperatures at 7 frequency bands, from 22.24 GHz to 31.84 GHz, Integrated Water Vapour in the scan path, Liquid Water Path in the scan area. It also gives raw atmospheric parameters through its associated mini-AWS like Humidity, Temperature , Wind Pressure, Wind Velocity, Wind Direction and Relative Humidity Value at ground level through integrated Weather Station.

2.3.2 ***Tipping Bucket Rain Gauge****:* The critical instrument for rain rate determination is the tipping bucket rain gauge that gives rainfall resolution of

0.01 mm. From this, rainfall rate can be determined using the formula :

$$R = (0.1x3600) / T$$

2.3.3 ***Beacon Receiver*** : Two Beacon Receivers with Fixed Polarization VSAT antennas and data recording platform at 20.2 GHz and 30.5 GHz, provided by ONERA.

2.3.4 All required Software for Data Acquisition.

3. Results :

Based on the parameters of numerical Rainfall Attenuation model, a plot of Attenuation values at the two frequencies due to various rainfall rates was prepared.

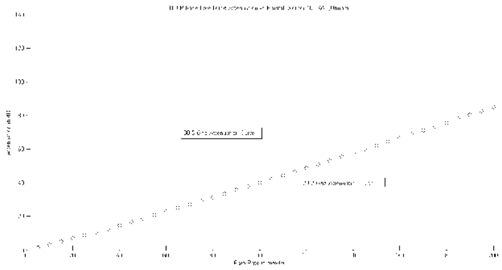

Figure 1 : ITU-R based predicted attenuation at NESAC

Now, a database was created from all the available sensors at NE-SAC Ka-Band Propagation Experiment Set-up. This comprises of regular data from Radiometer, Beacon Receivers and Rain Gauges. The raw data from each of these sensors were processed with MATLAB software to generate plots of atmospheric profiles and signal levels. Following is an example:

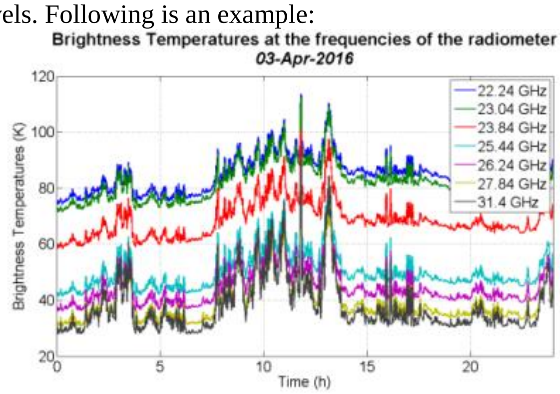

Figure 2: Brightness Temperatures of Radiometer

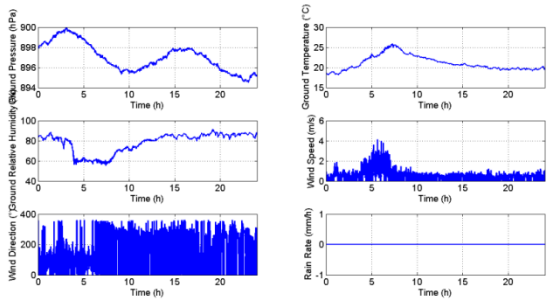

Figure 3 : Various Meteorological parameters obtained from the Radiometer

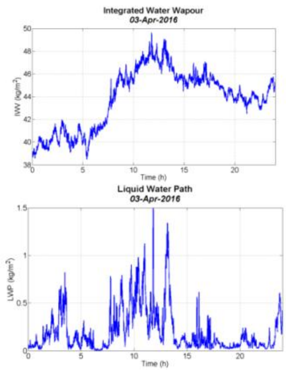

Figure 4: Integrated Water Vapour and Liquid Water Path retrieved from Radiometer

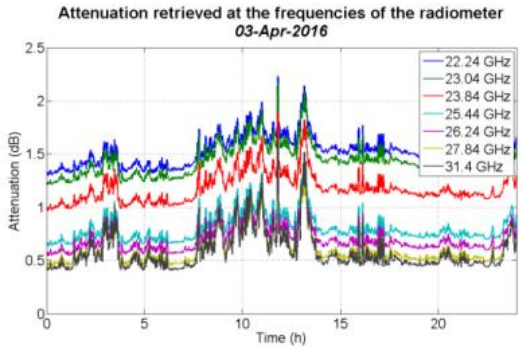

Figure 5: Total Attenuation of different frequency channels of Radiomter

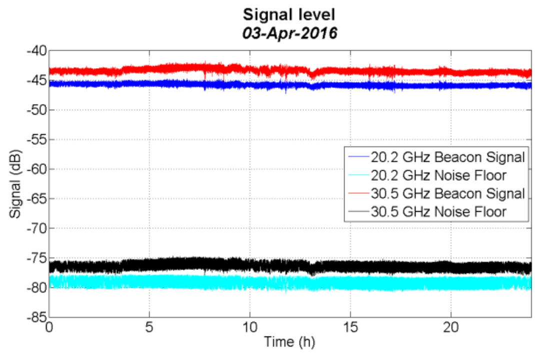

Figure 6: Beacon Receiver outputs of signal strength on a non-rainy day

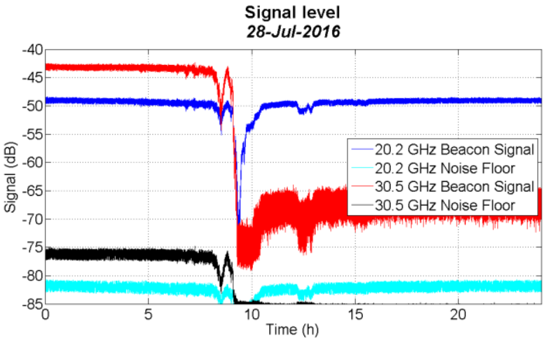

Figure 7 : Beacon Receiver outputs of signal strength on a rainy day with single rain event

Then, a data analysis was carried out with all the available data to plot real attenuation versus rainfall rate at NE-SAC. The following resulting curves were obtained.

1) Received Attenuation at 20.2 GHz frequency versus model rainfall(ITU-Model)
2) Received Attenuation at 20.2 GHz frequency versus Actual Rainfall

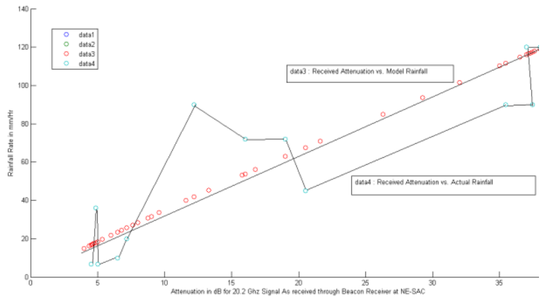

Figure 8 : Attenuation(dB) as received through beacon receiver at NE-SAC

4. Discussion :

As can be seen from the plots, the data matches pretty well at the higher end of signal attenuation but does not match that well towards the lower end. The scarcity of actual rainfall data due to unavailability of Rain Gauge data from other sources to verify and non-working of radiometer for a long period reduced the scope for field validation. However, the data matches pretty well with ITU-R predicted rainfall model at the higher end of Attenuation. So, it can be safely deduced that when the rainfall is high, the attenuation is mostly due to Raindrop scattering only but when the attenuation and rainfall is low, the attenuation can not be solely ascribed to rainfall scattering but cloud absorption or depolarization effects can become stronger. Also, as a general trend, it can be said that the rainfall rate predicted by ITU-R model generally exceeds the actual rainfall in the lower end of attenuation values but it generally matches well with high values of attenuation.

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