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MEASUREMENT OF RAIN ATTENUATION FOR KU BAND SATELLITE SIGNAL IN TROPICAL ENVIRONMENT USING DAH, SAM MODELS

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ABSTRACT

Nowadays Telecommunications and broadcasting services are in a rapid phase of expansion. There is an increasing demand for the multimedia services such as high-speed internet, on demand digital TV services, video conferencing and tele-education etc., which need high-speed data rates to cope with the demand whilst guaranteeing a high quality of service. The current microwave frequency spectrum allocated for telecommunication and broadcast services has become packed as the proposed broadband systems requires higher bandwidths. However, the attenuation due to atmospheric gases, clouds and rain increases significantly, for the frequencies above Ku- band. Though the attenuation is due to clouds and gases frequently, it is rain that causes the largest attenuation. In this paper three sophisticated models (ITU-R, DAH and SAM) have been explained to calculate rain attenuation. ITU-R model is the most widely accepted model by the international propagation community and is used for estimating long term statistics of rain attenuation at high frequencies in most of the regions. DAH stands for Dissanayake-Allnutt-Haidara Model. This is similar to and an extension of the ITU-R model. This model is also used at high frequencies. SAM stands for Simple Attenuation Model, which is suitable for tropical climate and heavy rainfall regions to calculate attenuation at point rainfall.

Keywords: specific attenuation, percentage exceedance, rain rate, attenuation.

INTRODUCTION

Generally satellite communication requires high band of frequencies i.e., ultra-high frequencies. At present, C, Ku band is used for satellite communication. It has band of frequencies in between 10-14 GHZ. But increasing the frequency range will also bring conflicts along with benefits. This is due to several factors like rain, snow, atmospheric gases etc. Among them, the major factor that leads the world of attenuation is RAIN. It is one of the most important factors which cause degradation of satellite signals in high frequency bands. Rain affects the transmitting signal in three ways; (1) It attenuates the signal; (2) It increase system noise temperature; and (3) It changes the polarization [1, 2].

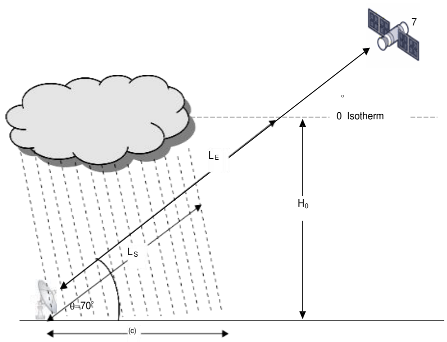

Figure-1. Schematic diagram of earth-space communication affected by slant path rain.

To predict the attenuation caused by rain, three refined models were explained namely **SAM, ITU-R, DAH.**

EXPERIMENTAL SET UP AND LOCATION DETAILS

To study the Ku band attenuation over Indian region experimental setup was placed at K.L. University (Latitude-16.44'N, Longitude 80.62'E).Parabolic dish with size 96cm pointing towards INSAT 4A, GSAT-10 satellite for Rain attenuation studies. Received KU-band signal is given to down converter by using LNBF (9.5GHZ to 10.0GHZ) 950KHZ 2150 KHZ i.e., monitored by using spectrum analyzer, with the help of Data logging module (Lab-View(VI)), GPIB cable data a logged in to the PC with 10 sec interval. Simultaneously parallel experimental setup using OTT Percival disdrometer for recorded rain events with same 10 sec interval [10].

SAM: SAM is the Simple Attenuation model for predicting attenuation due to rain. This model utilizes the point rainfall rate for calculating attenuation. Simple Attenuation Model has been improved from an earlier version and now includes the effect of wave polarization. The model is for the prediction of rain attenuation statistics on earth-space communication links operating in the Ku and Ka band frequencies. Simple calculations produce attenuation values as a function of average rain rate. These together with rain rate statistics (either measured or predicted) can be used to predict annual rain attenuation statistics in region.

The Virginia Polytechnic Institute and State University Blacksburg, VA, has been engaged for several years in the development of rain attenuation models and related measurement programs. Several iterations of a quasi-physical model of rain attenuation on a slant path have been provided. Earliest versions of a comprehensive rain attenuation prediction model was the - Piecewise

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Uniform Rain Rate Model. The Piecewise Uniform Model was later extended with an expanded global data base to an exponential shaped rain rake profile, and was called the Simple Attenuation Model (SAM).The simple attenuation model (SAM), incorporates the individual characteristics of stratiform and convective type of rainfall and utilizes the point rainfall rate at the ground to calculate the attenuation time series

$$A = A1 * L,$$
$$L = (He - Ho)/sin(\theta)$$
$$a = 4.21 * 10^{-5} * f^{2.42}$$

$$b = 1.41 * f^{-0.0779}$$

H_e = Effective rain height.

H_o = Isothermal height from sea level.

L = Slant path length.

Θ = Elevation angle (degrees).

A1 = Specific attenuation.

Rain attenuation.

a,b = Empirical constants.

The SAM is a semi empirical model that describes the spatial rainfall along a slant path length L.Simple Attenuation Model has been improved from an earlier version and now includes the effect of wave polarization. The model is for the prediction of rain attenuation statistics on earth-space communication links operating in the Ku and Ka band frequencies. Calculations produce attenuation values as a function of average rain rate. These together with rain rate statistics (either measured or predicted) can be used to predict annual rain attenuation statistics in K.L. University.

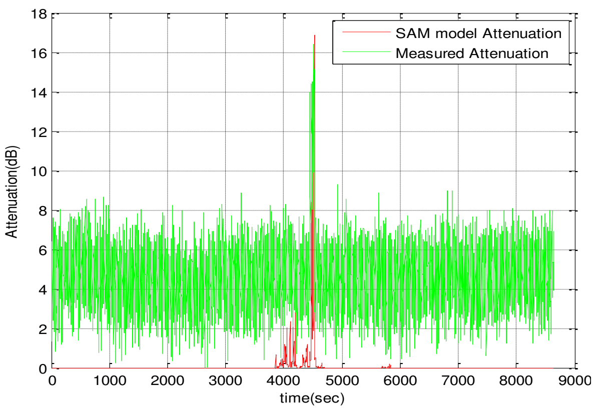


Figure-2. Kuband attenuation plot of February 16, 2014.

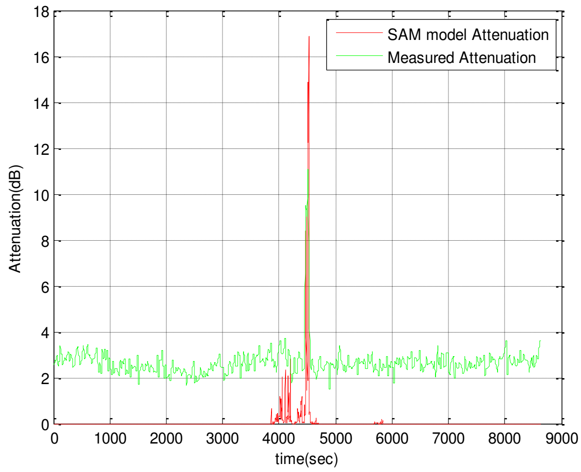


Figure-3. Kuband attenuation plot on February 16,2014 with curve fitting.

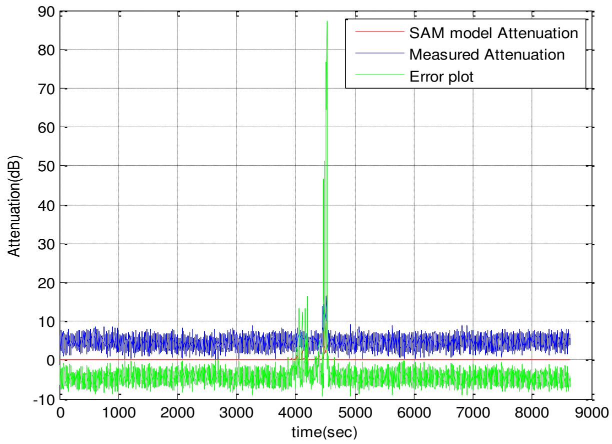
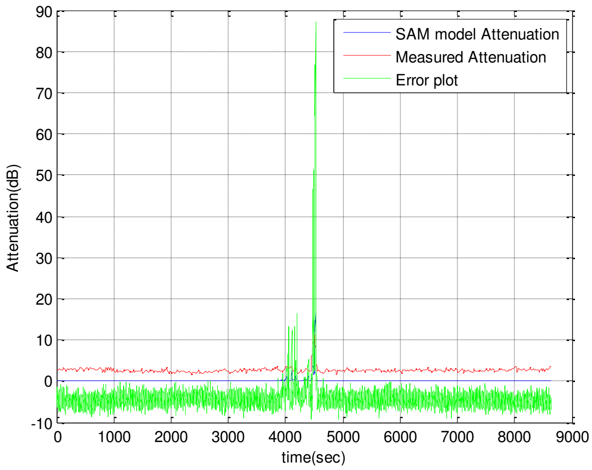


Figure-4.Attenuation error between practically measured value and measured using SAM model with out curve fitting.



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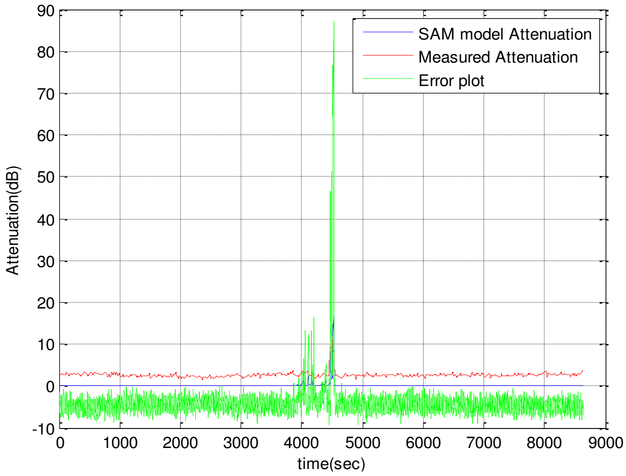

Figure-5. Attenuation error between practically measured value and measured using SAM model with curve fitting.

Figures from 2 to 5 shows the attenuation measurment on february 16th 2014 using practically recorded beacon data and with the mathematical model SAM in Figure-2 shows the measured and calculated attenuation using SAM model, at anytime measured attenuation is deaviating from the attenuation measured using mathematical model, this is because of some cable losses, and practically equipment deviates from its ideal version.and also the measured attenuation fluctuates very frequently .to optmize those variotions curve fitting was used and also cable looses are considered as2dB.

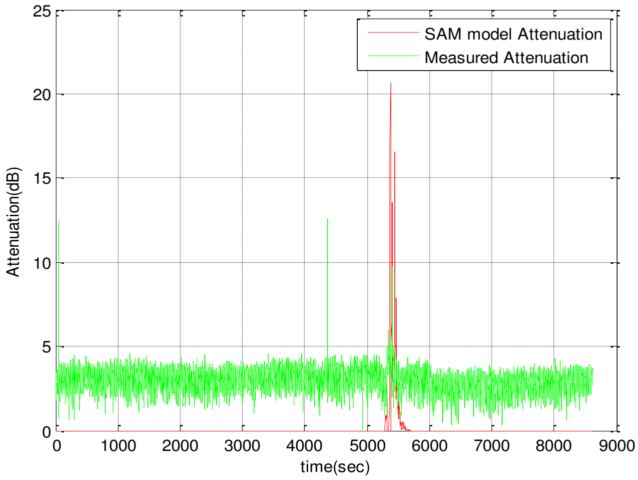

Figure-6. Kuband attenuation plot of October 3, 2014.

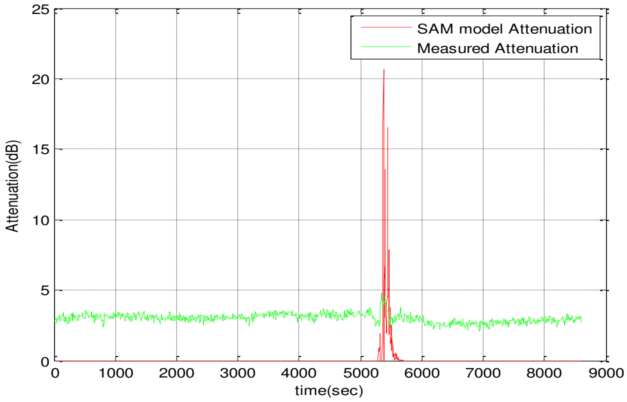

Figure-7. Kuband attenuation plot on October 3, 2014 with curve fitting.

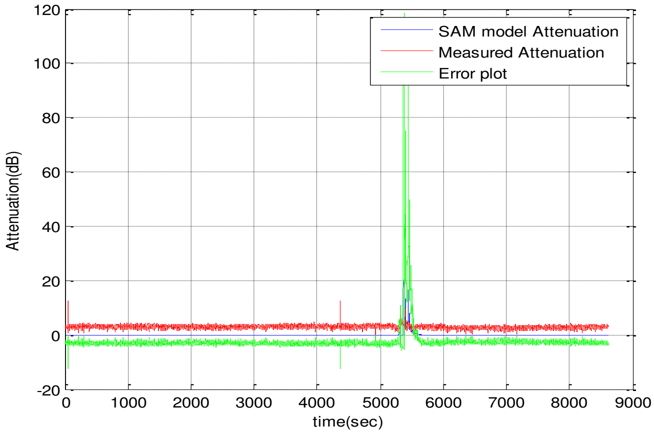

Figure-8. Attenuation error between practically measured value and measured using SAM model with out curve fitting.

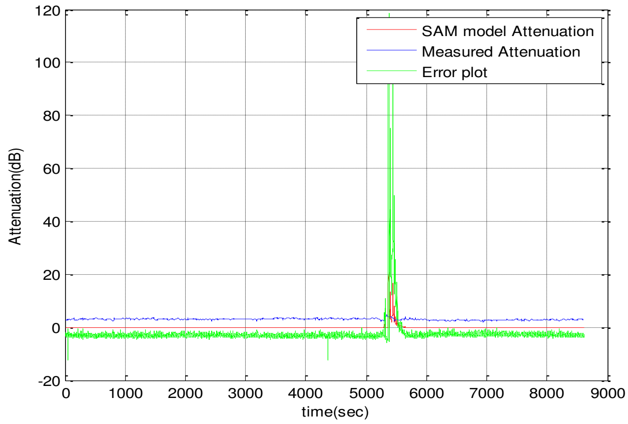

Figure-9. Attenuation error between practically measured value and measured using SAM model with curve fitting.

Figures from 6 to 9 shows the attenuation measurment on october 3rd 2014 using practically recorded beacon data and with the mathematical model SAM. in Figure-6 shows the measured and calculated attenuation using SAM model, at anytime measured attenuation is deaviating from the attenuation measured using mathematical model, this is because of some cable losses, and practically equipment deviates from its ideal

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version.and also the measured attenuation fluctuates very frequently .to optmize those variotions curve fitting was used and also cable looses are considered as 2dB.

PREDICTION MODELS

ITU-R:- Mentioned earlier, it is the most widely accepted model by the international propagation community and is used for estimating long term statistics of rain attenuation at high frequencies in most of the regions. The International Telecommunication Union first adopted a prediction of attenuation caused by rain in 25th Plenary Assembly in Geneva in 1982. The model is continuously updated as rain attenuation modeling is better understood. This gives the rain attenuation calculations required for international planning and coordination meetings and regional and world administrative radio conferences.

Here the name of model is **ITU-R P.618-11.** This gives summarized procédure for the computation of a satellite Path Rain atténuation. The following paramètres are required for calculating atténuation [11].

R0.01: point rainfall rate for the location of 0.01% of average year (mm/h).

hs: height above mean sea level of the earth (km)

θ: elevation angle (degrees)

Φ: latitude of the earth station (degrees)

f: frequency (GHz)

Re: effective radius of the earth (8500 km).

Step-1: Determine the rain height, h_R, as given in Recommendation ITU-R P.839.

Step-2: For $\theta \geq 5°$ compute the slant-path length, L_s, below the rain height from:

$$L_s = \frac{(h_R - h_s)}{\sin\theta} \quad \text{km} \tag{1}$$

For $\theta < 5°$, the following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2\theta + \frac{2(h_R - h_s)}{R_e}\right)^{1/2} + \sin\theta} \quad \text{Km} \tag{2}$$

If $h_R - h_s$ is less than or equal to zero, the predicted rain attenuation for any time percentage is zero and

The following steps are not required.

Step-3: Calculate the horizontal projection, L_G, of the slant-path length from:

$$LG = Ls \cos\theta \quad \text{km} \tag{3}$$

Step-4: Obtain the rainfall rate, $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of 1 min). If

This long-term statistic cannot be obtained from local data sources, an estimate can be obtained from the maps of Rainfall rate given in Recommendation ITU-R P.837. If $R_{0.01}$ is equal to zero, the predicted rain attenuation is zero for any time percentage and the following steps are not required.

Step-5: Obtain the specific attenuation, γ_R, using the frequency-dependent coefficients given in Recommendation ITU-R P.838 and the rainfall rate, $R_{0.01}$, determined from Step 4, by using

$$\gamma R = k\,(R0.01)\alpha \quad \text{dB/km} \tag{4}$$

Step-6: Calculate the horizontal reduction factor, $r_{0.01}$, for 0.01% of the time:

$$r_{0.01} = \frac{1}{1 + 0.78\sqrt{\frac{L_G\,\gamma_R}{f}} - 0.38\left(1 - e^{-2L_G}\right)}$$

Step-7: Calculate the vertical adjustment factor, $v_{0.01}$, for 0.01% of the time:

$$\zeta = \tan^{-1}\left(\frac{h_R - h_s}{L_G\, r_{0.01}}\right) \text{ Degrees}$$

$$\text{For } \zeta > \theta,\quad L_R = \frac{L_G\, r_{0.01}}{\cos\theta} \text{ km}$$

$$\text{Else,}\quad L_R = \frac{(h_R - h_s)}{\sin\theta} \text{ km}$$

If $|\varphi| < 36°$, $\chi = 36 - |\varphi|$ degrees

else, $\chi = 0$ degrees

$$v_{0.01} = \frac{1}{1 + \sqrt{\sin\theta}\left(31\left(1 - e^{-(\theta/(1+\chi))}\right)\frac{\sqrt{L_R\,\gamma_R}}{f^2} - 0.45\right)}$$

Step-8: The effective path length is:

$$L_E = L_R\, v_{0.01} \text{ km} \tag{5}$$

Step-9: The predicted attenuation exceeded for 0.01% of an average year is obtained from:

$$A_{0.01} = \gamma_R\, L_E \quad \text{dB} \tag{6}$$

Step-10: The estimated attenuation to be exceeded for other percentages of an average year, in the range 0.001% to 5%, is determined from the attenuation to be exceeded for 0.01% for an average year:

If $p \geq 1\%$ $|\varphi| \geq 36°$: $\beta = 0$

If $p < 1\%$ or and $|\varphi| < 36°$ and $\theta \geq 25°$

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β =0.005(| φ | – 36)
Otherwise:β = –0.005(| φ | – 36) + 1.8 – 4.25 sin θ

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.655+0.033\ln(p)-0.045\ln(A_{0.01})-\beta(1-p)\sin\theta)} \quad \text{dB}$$

DAH

DAH rain attenuation model was developed by Asoka Dissanayake, Jeremy Allnutt and FatimHaidara. The prediction model is similar to the ITU-R model where the rain related input to the model is the rain intensity at the 0.01% probability level. Inhomogeniety in rain in the horizontal and vertical directions are accounted for in the prediction. The method is applicable across the frequency range 4~35 GHz and percentage probability range from 0.001% to 10% [1,2].

Step-1: Obtain the effective rain height H

H=5.0-0.075(|φ|-23) for φ≥23)

Where φ : the latitude of the earth station (deg)

Step-2: Calculate the slant path length L

L = (H−H 0)/sin (θ) Km for θ≥ 5

Step-3: Calculate the horizontal projection of the slant-path L_g

L_g = L cosθ

Step-4: Determine the specific attenuation ã (dB/km)

Γ=k (R0.01) ^ α

Where k and are the same as ITU-R model, R0.01 is the point rain rate that exceed for 0.01% of a year (mm/h).

In ITU-R model, the expressions of k and are given as follows:

k = [k_H +k_v + (k_H − k_v)) cos(θ)^2cos (2t)] /2

α = [$k_H\alpha_H$+ $k_v\alpha_v$+ ($k_H\alpha_H$ − $k_v\alpha_v$) cos(2θ) cos(2t)] /(2k)

Where t is the polarization tilt angle relative to horizontal

Step-5: Calculate the horizontal path adjustment factor rh0.01 for 0.01% of the time

rh0.001=1/ (1+0.78√(LgY/f)-0.38[1-exp(-2Lr)])

Where f is frequency in GHz.

Step-6: Calculate the adjusted rainy path length Lr (km) through rain

L_r= Lg(rh0.001)/cos(θ) for ζ> θ
Else L_r=(H-H0)/sin(θ)

Step-7: Calculate the vertical adjustment factor rv0.01 for 0.01% of the time

rv0.001=1/(1+31(1-e^(θ/(1+ρ)) √(Lrγ/f^2)-0.45)√(sin(θ)))

Step-8: Calculate the effective path length through rain Le

Le = L_r rv0.01

Step-9: Determine the attenuation exceeded for 0.01% of an average year

A0.01 =γLe dB

Step-10: Determine the attenuation to be exceeded for other percentages of an average year in the range 0.001% ~ 10%

$$A_p = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.655+0.033\ln(p)-0.045\ln(A_{0.01})-z(1-p)\sin\theta)} \quad \text{dB}$$

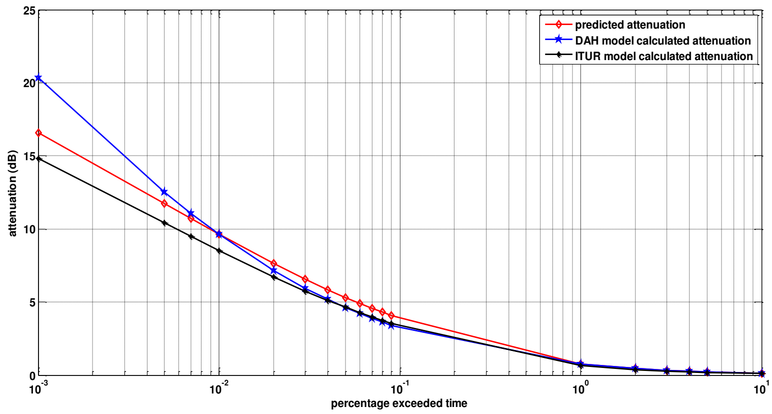

Figure-10. Attenuation verses percentage time exceedance of rain attenuation.

Figure-10 shows the percentage availability of satellite link in one year period by calculating the attenuation verses percentage time rain attenuation exceedance using ITU-R and DAH model .practically predicted attenuation for most of the instances it was closely matched with the DAH model except at lower exceedace cases. At any instant of time ITU-R underestimates the attenuation from the predicted one.

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