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SATELLITE-TO-EARTH MICROWAVE LINK PERFORMANCE DUE TO RAIN FADE IN INDIA

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ABSTRACT

In tropical regions, rain is the dominant source of attenuation at higher frequency bands in Satellite Links. Rain degrades the system performance with increased Path Loss. Knowledge of rain fade performance is essential in order to optimize system capacity, quality and reliability. The rain intensity data is derived from140 years measured annual rainfall data worldwide. The converted rain intensity data is used to estimate rain fades at C, X and Ku-bands using ITU-R recommendations. Noise generated, carrier-to-noise ratios during rains are estimated and compared for all the mentioned three bands. This paper presents the effects of satellite to earth link on the performance of receiving system due to rain fades operating in tropical country like India. Currently in India C and Ku-band frequencies are being used for commercial satellite communications.

Keywords: rainfall data, rain fade, link budget, satellite-to- earth and CNR.

INTRODUCTION

Rain causes attenuation in electromagnetic spectrum through the process of absorption and scattering. This rain attenuation depends on the rainfall rate and frequency which results in increasing path loss, limiting the coverage area, and consequently degrading the system performance. Attenuation in radio link communication increases with rain rate and has adverse effect at microwave frequencies [12]. Rain can cause uncontrolled variations in signal amplitude, phase, polarization and angle of arrival, which result in a reduction in the quality of analog transmissions and an increase in the bit error rate of digital transmissions. Three major effects of rain on the transmission of an electromagnetic signal are:

a) Attenuation of the signal
b) Increase in the system noise temperature
c) Change of polarization

Maintaining good quality economical designs, present and future operational frequency selection, site planning, multilevel systems reliability and optimizing the system capacity are the important factors for designing an efficient communication system [1]. Overcoming the outage problem is one of the most critical factors in satellite link design. Attenuation due to rain at frequencies above 10 GHz in temperate and above 7 GHz in tropics mainly leads to outages that compromise the availability and quality of service, making this one of the most critical factors in satellite link design.

In the design of a radio communication system, one of the major concerns is to assess system unavailability, also called outage time. Outage time is the amount of time during which the system's performance will be below threshold level or the system is not usable. For designing a reliable system, the amount of outage time has to be kept low. In microwave systems outages can occur either due to equipment failure or due to propagation effects. In modern systems, the equipment outage time can be controlled using redundant equipment and automatic protection switching systems. The practical way of achieving a reliable radio system at those frequencies is to design the system in such a way that the expected amount of rain outage time is kept at minimum [2].

For a reliable communication system, unavailability time during a year has to be kept at 0.01 percent. This corresponds to availability time of 99.99 percent during a year. Rainfall with one-minute integration time is very important parameter for predicting attenuation at 0.01% of time. For 99.5% of availability at a BER of 5E-7 or better the link availability threshold margins have to be determined [15]. The non-homogeneous rain structure can lead to different specific attenuation in real time. Rain drops can assume various shapes, i.e. spherical for small size cells, oblate spheroid for medium and oblate distorted for large size rain drops. This information is needed to indicate the best distribution model of rain falls within tropical climate in the rain attenuation model simulation [8].The measured rain rate data is converted from measured long term annual rainfall data from the deviation curves. With the increase of system reliability, deviation between predicted attenuation of measured maximum and minimum $R_{0.01}$ and ITU-R predicted attenuation increases [4]. For higher frequencies, rain rates attenuation becomes large above a critical value [5]. With the modified ITU-R model, statistical methods attenuation exceeded for other percentages of time were calculated from the data obtained from the Tropical Rainfall Measuring Mission (TRMM) 3B43 V6 and Nig ComSat-1 satellite for 37 stations in Nigeria [8]. Indian rain rate distribution of six rainfall homogeneous regions was estimated using global sets of TRMM and Global Precipitation Climatology Project (GPCP).The estimated rain rate distributions are compared with the standard ITU-R P837-5 for different frequencies [6]. For tropical regions the following modifications are made:

The accumulation time factor at the breakpoint is an invariant

For elevation angles $<60^0$, at high rain rates multiple rain cells intersect the slant path.

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The modified prediction model (for tropics) gives remarkable agreement with the measured Ku-band. The rain attenuation exceedance is predicted by two expressions

- Lower rain rate less than break point
- Higher rain rate greater than breakpoint [13].

This paper presents the model for prediction of signal loss due to rain rate to adopt necessary fade correction technique for the Ka band satellite communications over Indian Sub-Continent. The work also suggests an improvement in the rain rate suggested by global ITU-R model [16].

This paper presents the cumulative rainfall data collected for 140 years from six different regions of India. The long-term annual rainfall data has been converted to rain intensity data by using Chebil conversion model. The rain intensity proposed by International Telecommunication Union (ITU-R) and converted data are used to predict the rain fade for satellite-to- earth at C, X and Ku-Bands. In this paper rain attenuation calculated theoretically as well as experimentally using ITU-R model for Ku, Ka bands and instrumental for developing a new model.

ANNUAL RAIN STATISTICS

India's latitude and longitude zones are 22° 00' N and 77° 00'E (North). Some places in India experience excessive rainfall throughout the year and rainfall rate varies within small distances. Majority Regions in India can be regarded as climatically tropical. India experience two types of climates:

- Tropical monsoon climate (tropical wet) and
- Tropical Dry climate

The most humid is the tropical wet climate or tropical monsoon climate. It covers a strip of south western lowlands like the Malabar Coast, the Western Ghats, southern Assam and two island territories like Lakshadweep and the Andaman and Nicobar Islands. The consequence of this monsoon is moderate to high temperatures occurring even in the foothills and rainfall is seasonal but heavy typically above 2,000 mm (79in) per year.

Tropical dry areas annual rainfall averages between 750-1, 500 mm (30-59 in) across the region. It covers most part of inland peninsular India except for a semiarid rain shadow east of the Western Ghats.

India receives the heavy average precipitation in distinct regions such as North, East, South and West. The annual rainfall data collected for India from1870 AD to 2010AD is shown in Figure1. The mean annual rainfall for North East is 2070.52, Central North is 1200.28 mm, North West is 544.39 mm, West Central is 1073.04 mm and Peninsular is 1159.31 mm [14].

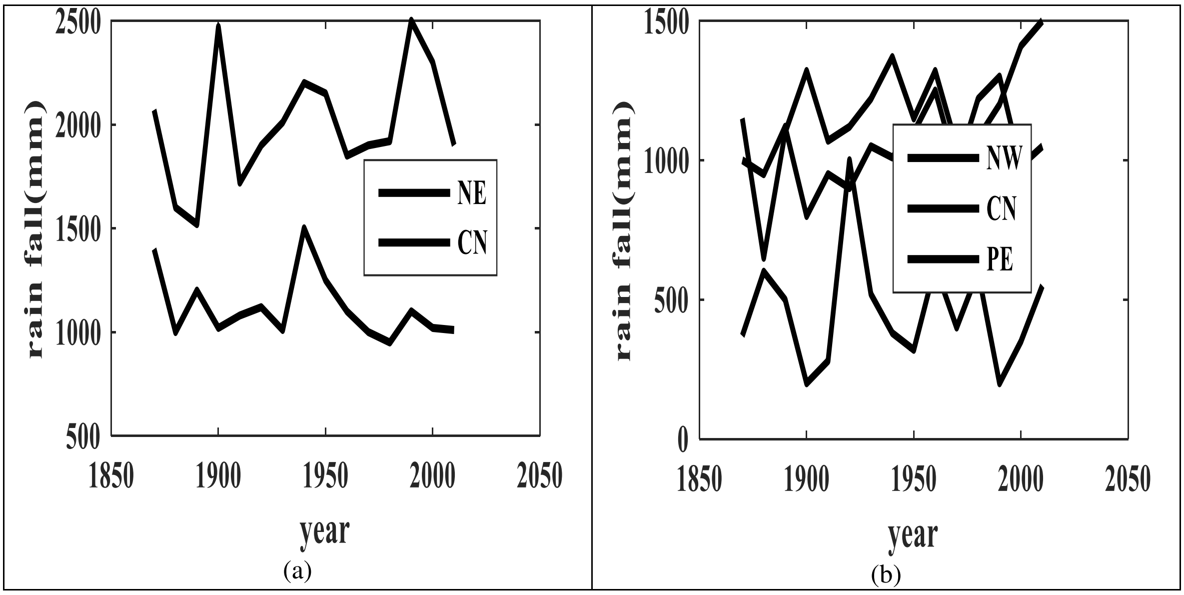

Figure-1. Temporal variation of annual rainfall for (a) North East, Central North (b) North West, West Central and Peninsular.

CONVERSION OF RAIN STATISTICS TO RAIN INTENSITIES

Conversion of the available rainfall data into the equivalent 1-min rain rate cumulative distribution is highly beneficial for radio engineers. Here, 1- min rain rate CD can be estimated by the use of Chebil model and long-term mean annual rainfall data [3]. This model is expressed as follows:

$$R_{0.01} = \alpha M^{\beta} \quad (1)$$

Where and α, β are regression coefficients and defined as

α = 12.2903 and β = 0.2973

M = measured value of rainfall

This method gives the best estimates of the measured data as shown in Table-1.

Table-1. Measured mean annual rainfall and converted corresponding rain intensity at different regions of India.

Name of the region	Measured Mean Annual Rainfall (mm)	Converted Rainfall Rate $R_{0.01}$(mm/hr)
North East	2070.52	118.97
Central North	1200.28	101.67
North West	544.39	79.97
West Central	1073.34	97.86
Peninsular	1159.31	100.13
ITU-R	-	95

The highest rain intensity is observed at North East region of India at 118.97mm/hr and lowest is North West with 79.97 mm/hr. The rain intensity recommended by ITU-R map is around 95 mm/hr for India [6]

RAIN ATTENUATION STATISTIC FROM RAINFALL RATE

ITU-R is an organization with standardized rules for prediction of rain attenuation in telecommunication radio links. The International Telecommunication Union - Radio Communication Sector (ITU-R) model is most widely used for conformity and reliability, in the absence of measured data [7] [8]

This method is for estimating the slant-path rain attenuation for the location to the frequencies up to 55 GHz is given in the following steps. The parameters are as shown in Figure-2.

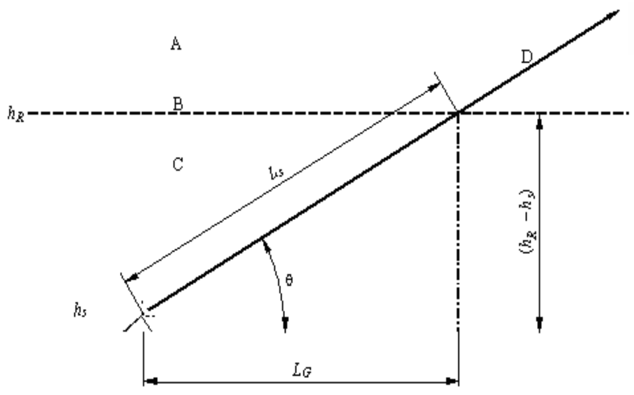

Figure-2. Schematic presentation of an earth-space path.

A = frozen precipitation
B = rain height
C = liquid precipitation
D = Earth-space path

The parameters are:

$R_{0.01}$: 0.01% point rainfall rate of an average year (mm/h)
h_s: height above mean sea level (km)
θ: elevation angle (degrees)
ψ: latitude of the earth station (degrees)
f: frequency (GHz)
R_e: effective radius of the Earth (8,500 km).

Step 1: From the ITU-R P.839 Recommendation, rain height h_R has been calculated

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

$$L_s = \frac{h_R - h_S}{\sin\theta} \quad \text{Km} \tag{2}$$

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

$$L_s = \frac{2(h_R - h_S)}{\left(\frac{\sin^2\theta + 2(h_R - h_S)}{R_e}\right)^{0.5}} \quad \text{Km} \tag{3}$$

Step 3: Calculate the horizontal projection L_G as

$$L_G = L_s \cos\theta \ \text{ Km} \tag{4}$$

Step 4: Obtain the rainfall rate $R_{0.01}$, exceeded for 0.01% of an average year (with an integration time of 1min). In the absence of local data statistics, Recommendation ITU-R P.837 [10] and rain fall data maps can be used. 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: Specific attenuation, γ_R, can be obtained using from the Recommendation of ITU-R P.838 [11] and the rainfall rate $R_{0.01}$, by using:

$$\gamma_R = k(R_{0.01})^{\alpha} \ \text{dB/km} \tag{5}$$

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

$$r_{0.01} = \frac{1}{(1+0.78\sqrt{\left(\frac{L_G\gamma_R}{f}\right)} - 0.38(1-\exp(-2LG))} \tag{6}$$

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

$$\zeta = \frac{\tan^{-1}(h_R - h_s)}{L_G r_{0.01}} \ \text{degrees}$$

For $\zeta > 0$, $L_R = \frac{L_G R_{0.01}}{\cos\theta}$ km

If $|\psi| < 36^0$, $\chi = 36 - |\psi|$ degrees

Else $\chi = 0$ degrees

$$v_{0.01} = \frac{1}{1+\sqrt{\sin\theta(31\left(1-e^{\frac{\theta}{1+\chi}}\right)*(\frac{L_R\gamma_R}{f^2} - 0.45)}} \tag{7}$$

Step 8: The effective path length is:

$$L_E = L_R v_{0.01} \ \text{ Km} \tag{8}$$

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

$$A_{0.01} = \gamma_R L_E \text{ dB} \quad (9)$$

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

If $p \geq 1\%$ or $|\phi| \geq 36°$: $\beta = 0$
If $p < 1\%$ and $|\phi| < 36°$and $\theta \geq 25°$: $\beta = -0.005(|\phi| - 36)$
Otherwise: $\beta = -0.005(|\phi| - 36) + 1.8 - 4.25 \sin\theta$

$$A_P = A_{0.01}\left(\frac{p}{0.01}\right)^{-(0.65+0.03\ln(p)-0.04\ln(A0.01) - \beta(1-p)\sin\theta)} \quad (10)$$

This method provides an estimate of the long term statistics of attenuation due to rain. By, taking the data from the IRNSS lookup angle, the elevation angle considered is 31.8°. Using above methodology from step1 to step10 and the rain rates derived in Table-1, rain fades have been estimated for all regions and as well as those recommended by ITU-R and presented in Figure-3 and Figure-4. All cases the signals are assumed as circularly polarized and the regression coefficients are given in Table-2.

Table-2. Regression Coefficients for Estimating Specification Attenuation.

Circular	**C-band (4 GHz)**	**X-band (10 GHz)**	**Ku-band (15 GHz)**
α	1.0991	1.2695	0.0353
k	0.000621	0.0095	1.1418

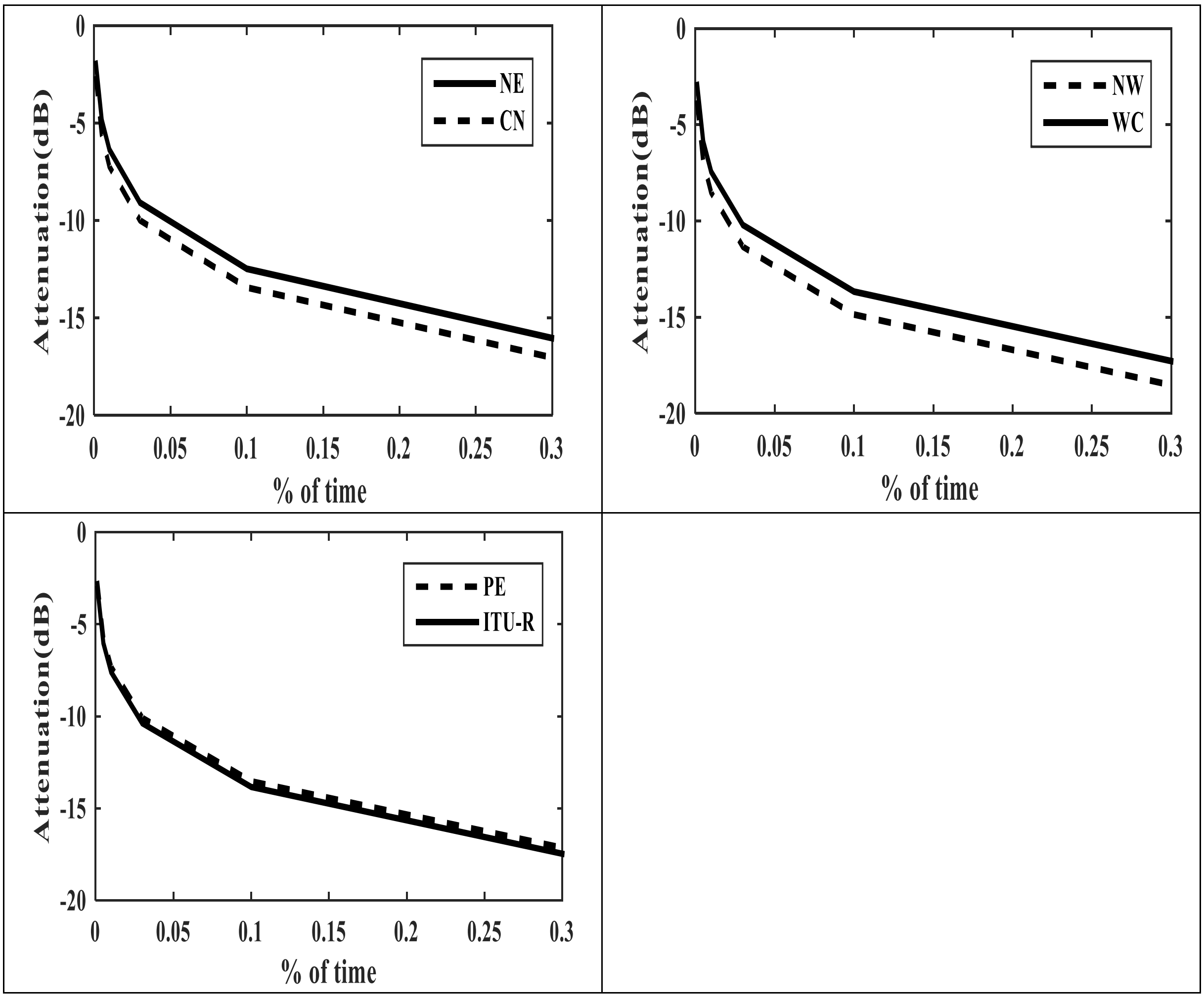

Figure-3. Variations of predicted rain fade for C-Band (a) North East, Central- North (b) North West, West Central (c) Pennisular, ITU-R

At C-band, attenuation due to rain is predicted as -6.36 dB for 0.01% of the time of the year. But the same at X-band and Ku-band are predicted as 6 dB and 8.54 dB respectively for the design of Satellite-to-Earth microwave link with 99.99% reliability. Hence designing reliable earth-to-satellite microwave link is very critical at Ku bands.

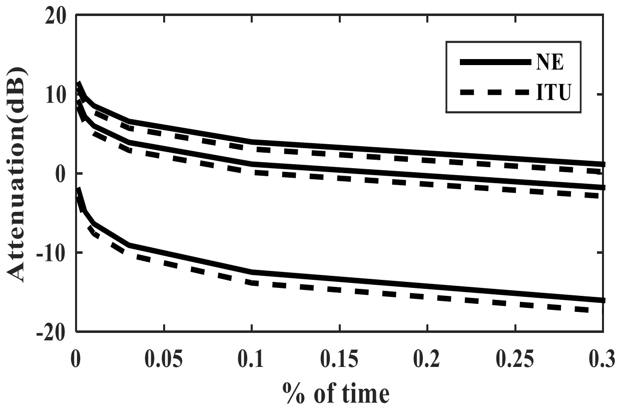

Figure-4. Comparison with ITU-R and worst case in different bands.

All three bands, rain attenuation are also estimated based on ITU-R recommendations. All rain fades at 0.01% are presented in Table-3. It is obvious that ITU-R predicted rain attenuation is much lower than those predicted using measured rain rate in all cases. The differences are 1.24dB at C-band, 0.94 dB at X-band and 0.82dB at Ku-band.

Table-3. Estimated rain fades for all three frequency bands.

	4GHz	10GHz	15GHz
$A_{0.01}$%	dB	dB	dB
ITU-R	-6.36	5.06	7.72
Measured	-7.6	6	8.54

LINK BUDGET AT CLEAR SKY AND DURING RAIN

The atmospheric absorption has been estimated using ITU-R proposed graph for elevation angle 31.8^0 using the Eqn (11) and presented in Table-4.

$$\text{Atmospheric Absorption}[AA] = [\text{AA}]\ 900 * \text{cosec (El)} \quad (11)$$

Table-4. Atmospheric absorption losses at three frequency bands.

Frequency	[AA] dB
4	0.075
10	0.1
15	0.28

Link Budget has been calculated for Satellite-to-Earth downlink at three bands using ITU-R proposed rain rate and converted measured rain rate for India. The receive signal level as well as Carrier-to-noise ratio has been estimated both Clear Sky condition and rain conditions and are tabulated in Table-5. The noise power is calculated using equation (12).

$$N = KT_{sky}B_w \quad (12)$$

K is Boltzmann constant
T_S is sky temperature and is assumed as 140°.
B_w is noise band width and 36 MHz at C, X and Ku-bands.

Noise temperature increase during rain is estimated as follows:

Sky noise temperature due to rain

$$T_{sky.rain} = 273(1 - 10^{\frac{-A}{10}})\ \text{K} \quad (13)$$

Hence, total system noise temperature in rain,

$$T_{s.rain} = T_{LNA} + T_{sky.rain} \quad (14)$$

Finally, increase of noise temperature due to rain in different polarization,

$$N = 10\log(T_{s.rain} * T_s) \quad (15)$$

It is observed that ITU-R recommendation underestimates the rain rate measured in India and consequently the link budget estimation introduces significant errors especially at Ku bands. C/N ratio is 1.5-2.5 dB higher in Ku than C-band during clear sky condition. But during the rains C/N ratios falls to 15.62dB at C-band and 0.8 dB at X and -5.84 dB at Ku bands. These estimations are based on ITU-R recommended rain rates. But the above estimation is done based on converted measured rain rate and C/N ratio is fallen to 0.67 dB at X-band and -4.88dB at Ku-band. These prediction shows that using Ku-band is very challenging and critical in this region. However, the measured rain rate data is converted from measured long term annual rainfall data, it is too preliminary to comment correctly.

CONCLUSIONS

Rain is a dominant source of attenuation at higher frequencies in tropical regions. Therefore, accurate estimation of rain fade is necessary to design reliable microwave links in such regions. This paper has predicted rain fades in a tropical country like India using rain intensity data derived from 140 years measured annual rainfall data. It is observed that rain fade is not significant at C-band, but is very critical at X and Ku-bands. This paper has also investigated performance of Satellite-to-Earth link due to rain fades. Noise generated during rains is predicted for all three bands and carrier-to-noise ratios are estimated to compare the performances of Satellite-to-Earth link at different frequency bands. From observation, it is found that C/N ratio is 1.5-2.5 dB higher in X and Ku-bands than C-band during Clear Sky condition. But during rains C/N ratios falls to 8.6 dB at C-band, 0.8 dB and -5.84dB at X and at Ku-band respectively. These, estimation are based on ITU-R recommended rain rates. But the C/N ratio falls to 15.57 dB at C-band and 0.67dB,-4.88 dB at Ku-band based on converted measured rain rate. These predictions show that using Ku-band is very

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challenging and critical in this region. However, the measured rain rate data is converted from measured long term annual rainfall data, it is too preliminary to comment. It is recommended to measure rain intensity and raindrop size distribution in the design of reliable microwave link in India.

Table-5. Link Budget Calculation for Satellite-to-Earth downlink at three bands using ITU-R proposed rain rate for India.

	ITU- R		
Downlink power budget	**4GHz**	**10GHz**	**15GHz**
EIRP	50	50	50
Bo = Transponder output back off (typically)	-2	-2	-2
Gr=Receiving antenna gain	33.93	43.47	47.91
[FSL] = Free space path loss	-195.61	-203.57	-207.09
Lant = Edge of beam loss for satellite antenna(typically)	-3	-3	-3
[AA] = Clear Sky atmospheric loss	0.075	0.1	0.28
Lm = Other losses (typically)	-0.5	-0.5	-0.5
Pr = Receive power at receive station (Clear Air)	-115.26	-113.66	-112.76
Rain Attenuation A_{rain}	0.17	3.2	5.92
Pr (due to rain)	-115.43	-126.42	-132.64
Downlink Noise Budget			
k = Boltzmann's constant dBW/K/Hz	-228.6	-228.6	-228.6
Ts = System noise temperature, 140 K	21.46	21.46	21.46
Bn = Noise bandwidth, 36 MHz	75.56	75.56	75.56
N = Receiver noise power (Clear Sky)	-131.58	-131.58	-131.58
Increased due to rain (ΔN)	0.534	4.36	4.78
N = Receiver noise power (due to rain)	-131.05	-127.22	-126.8
C/N = (Clear Sky)	16.32	17.92	18.82
C/N = (due to rain)	15.62	0.8	-5.84

Table-6. Link Budget Calculation for Satellite-to-Earth downlink at three bands using measured rain rate for India.

	North East (worst case)		
Downlink power budget	**4GHz**	**10GHz**	**15GHz**
EIRP	50	50	50
Bo = Transponder output backoff (typically)	-2	-2	-2
Gr = Recieving antenna gain	33.93	43.47	47.91
[FSL] = Free space path loss	-195.61	-203.57	-207.09
Lant = Edge of beam loss for satellite antenna(typically)	-3	-3	-3
[AA] = Clear Sky atmospheric loss	0.075	0.1	0.28
Lm = Other losses (typically)	-0.5	-0.5	-0.5
Pr = Receive power at receive station (ClearAir)	-115.26	-113.66	-112.76
Rain Attenuation A_{rain}	0.23	3.98	7.08
Pr (due to rain)	-115.43	-126.42	-132.64
Downlink Noise Budget			
k = Boltzmann's constant dBW/K/Hz	-228.6	-228.6	-228.6
Ts = System noise temperature, 140 K	21.46	21.46	21.46
Bn = Noise bandwidth, 36 MHz	75.56	75.56	75.56
N = Receiver noise power (Clear Sky)	-131.58	-131.58	-131.58
Increased due to rain (ΔN)	0.58	4.49	4.82
N = Receiver noise power (due to rain)	-131.0	-127.09	-127.76
C/N = (Clear Sky)	16.32	17.92	18.82
C/N = (due to rain)	15.57	0.67	-4.88

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