Temperature Effect on Extinction Cross-Section for Specific Rain Attenuation Calculation

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Abstract- The need of exploration of millimeter wave radio frequency spectrum in order to fulfill the ever increasing demand of high data rate. But, the radio wave operating in millimeter wave frequency bands is severely affected due to rain. Attenuation induced by rain is major limitation and can be havoc especially in tropical countries. India being a tropical country experiences a heavy rainfall thus knowledge of rain attenuation is extremely required for reliable communication system. A lot of researches have been done on rain attenuation which depends mainly on rainfall intensity, rain drop size distribution and the operating frequency while keeping temperature constant or taking it around 20^0C.In fact, temperature is important factor and its effect is quite significant. Although there is large variation in temperature across the country so it is of great need to know temperature variation on specific attenuation calculations. In this paper effect of temperature considered in detail, has contributed the necessary correction factor for rain attenuation.

Index Terms- Millimeter-wave propagation, extinction cross-section, specific rain attenuation, power law coefficient

1. INTRODUCTION

Nowadays Ka band becomes the band of choice for various communication and multimedia applications due to its increasing capacity, availability and its applicability for broadband services. New Ka band come onto the market promises to deliver greater throughput than Ku Band offerings as the Ka band (30 GHz uplink and 20GHz downlink) is approximately twice the Ku band (14 GHz uplink and 12GHz downlink).Thus the utilization of (30/20 GHz) band provides higher quality, better performance and faster speed services.

But, the downside to use Ka band is that adverse weather condition influence it most. The electromagnetic radiations at millimeter wave frequencies are severely attenuated as they pass through the atmosphere due to the presence of hydrometeors such as ice, rain, snow, hail etc. Beside all, rain is the most dominant factor above 10 GHz [1-3].Attenuation due to other hydrometeors are concluded as secondary cause that affects radio wave propagation [4]. The severity of rain impairment increases with frequency. In general higher the frequency more a signal is susceptible to the rain fade. The Communication system experiences an extreme of signal due to rain induced attenuation which makes the system temporarily unavailable for use. The attenuation by the rain is mainly caused due to the scattering and absorption by water droplets causing a large variation in received signal power, and the amount of it is signify by specific rain attenuation in dB/km. For energy absorption part of its is absorbed by rain droplets and transformed into heat, increase molecular energy and corresponding to slight increase in temperature resulting loss of signal energy. While the scattering diffuses the signal may introduce unwanted and interfering signal that masks the desired signal leading to signal attenuation and reduction of the system availability and reliability [5] [6].The calculation for specific rain attenuation (reduction of power per unit length) considerably depends on radio link operating frequency and on rain drop size distribution [7].The latter depends on geographical choices of area in which radio link is applicable. For DSD, Lognormal distribution has been found to be best fit for India [8]. Apart from dependence of rain attenuation on frequency and DSD, a special attention is also paid to the qualitative evaluations considering change of temperature [9]. A forward scattered electromagnetic wave of rain drop influenced by water drop temperature. Moreover it also depends on complex refractive index which depends on permittivity, a function of temperature and frequency that affects attenuation property.

As the Indian subcontinent experiences a large variation in the average temperature along the length and breadth because of varying geographical conditions the ambient temperature varies from sub zero in northern regions to more than 50 degrees in Rajasthan. About 80% of rain observed in monsoon season and the temperature of rainy medium is taken to be 10^0C to 30^0C which is appropriate for tropical Indian region. So it is important to consider temperature induced variations over a wide variety of realistic drop size distributions, for designing a communication system at Ka band in the Indian regions.

To understand the specific rain attenuation characteristics Mie scattering theory is used. Whereas for different temperatures in tropical regions, complex refractive index of water, that is a function of temperature is used to get Mie coefficients. The single scattering considered for the entire rain drops. The rain drops ranging 0.1795mm to 2.6865mm in radius has been taken from Integrated DSD Model [10].

2. FORWARD SCATTERING AMPLITUDE OF RAINDROPS

When the incident electromagnetic wave hits spherical rain drop a scattered wave is generated. The forward scattering in the incident wave propagation direction is considered assuming the shape of rain drops is spherical.

The forward scattering amplitude S(0) of the spherical rain drop can be written as [11] [12]

$$S(0)=\frac{1}{2}\sum_{n=1}^{\infty}(2n+1)(a_n+b_n) \tag{1}$$

The infinite series of summation n in Eq.1 can be truncated after n max terms given by the value if

$$n_{\max}=\alpha+4\alpha^{1/3}+2$$

where $\alpha=2\pi\alpha/\lambda$, and λ is wavelength equals 10mm, 'a' is radius of rain drop, a_n, b_n are the Mie coefficients.

The Mie theory is applicable for a region containing rain drops. The key parameters a_n, b_n for Mie calculations to compute the amplitudes of scattered field.

Therefore the Mie coefficients a_n and b_n can be described as

$$a_n(m,\alpha)=\frac{m^2 j_n(m\alpha)[\alpha j_n(\alpha)]'-j_n(\alpha)[m\alpha j_n(m\alpha)]'}{m^2 j_n(m\alpha)[\alpha h_n^{(1)}(\alpha)]'-h_n^{(1)}(\alpha)[m\alpha j_n(m\alpha)]'} \tag{2}$$

$$b_n(m,\alpha)=\frac{j_n(\alpha)[m\alpha j_n(m\alpha)]'-j_n(m\alpha)[\alpha j_n(\alpha)]'}{h_n^{(1)}(\alpha)[m\alpha j(m\alpha)]'-j_n(m\alpha)[\alpha h_n^{(1)}(\alpha)]'} \tag{3}$$

Where m is the complex refractive index of water drops which is a function of temperature and frequency m (T, F) and α=ka where a is the sphere radius and k is the wave number. The key parameters for Mie calculations are the Mie coefficients to compute the amplitudes of the scattered field. The computation of these parameters has been the most challenging part in Mie computations due to the involvement of spherical Bessel functions [13] [14].

Apart from size information, Mie theory needs complex refractive index taking into account the temperature dependence of water refractive index on frequency. The refractive index m equals to the square root of complex dielectric permittivity.

Mathematically $m = \sqrt{\varepsilon}$

Where $\varepsilon = \varepsilon' - \varepsilon''$

The real part of permittivity ε' the dielectric constant is a parameter to describe how the electric field polarizes matter while the imaginary part ε'' for loss factor describes how much signal absorbed [15][16]. Thus the refractive index,

$$m = n + ik \tag{4}$$

is calculated by using Eq.4 for n using Eq.5 and the complex part k using Eq.6.While the values of ε' and ε'' has been taken from the Table(1) at different temperatures viz 10^0C, 20^0C, 25^0C and 30^0C [17].

$$n = \sqrt{\frac{\sqrt{\varepsilon'^2+\varepsilon''^2}+\varepsilon'}{2}} \tag{5}$$

$$k = \sqrt{\frac{\sqrt{\varepsilon'^2+\varepsilon''^2}-\varepsilon'}{2}} \tag{6}$$

Table 1 Refractive Index

Temperature(^{0}C)	ε'	ε''	**Refractive index (m)**
10^0C	17.17	27.86	4.9948+2.7889i
20^0C	23.76	32.00	5.6398+2.8368i
25^0C	26.12	32.55	5.8247+2.7941i
30^0C	29.76	33.78	6.1251+2.3617i

Taking the values of complex refractive index,m from Table(1) and put into Eq. (2)(3) to computes a_n and b_n using MATLAB software These values now put in Eq.1 to calculate S(0).

Table 2 Forward Scattering Amplitude

Rain Radius (mm)	**Forward Scattering Amplitudes at all Temperatures**			
	10^0C	***20^0C***	***25^0C***	***30^0C***
0.1795	1.257e-004	1.051e-004	9.910e-005	8.411e-005
0.2275	2.843e-004	2.463e-004	2.350e-004	2.019e-004

Rain Radius (mm)	Forward Scattering Amplitudes at all Temperatures			
	10^0C	20^0C	25^0C	30^0C
0.2755	5.709e-004	5.142e-004	4.969e-004	4.338e-004
0.3280	0.0011	0.0011	0.0010	9.198e-004
0.3855	0.0022	0.0021	0.0021	0.0020
0.4565	0.0046	0.0047	0.0048	0.0046
0.5580	0.0062	0.0126	0 .0131	0.0135
0.6655	0.0115	0.0293	0.0304	0.0337
0.7530	0.0256	0.0498	0.0511	0.0569
0.8325	0.0719	0.0740	0.0749	0.0809
0.9560	0.1257	0.1260	0.1258	0.1305
1.1295	0.2513	0.2429	0.2407	0.2425
1.2920	0.4156	0.3987	0.3941	0.3890
1.4345	0.5789	0.5586	0.5533	0.5457
1.5990	0.7660	0.7474	0.7426	0.7368
1.7720	0.9464	0.9295	0.9247	0.9194
1.9850	1.1232	1.1050	1.0996	1.0924
2.1750	1.3310	1.3090	1.3028	1.2952
2.4295	1.6220	1.5929	1.5851	1.5770
2.6865	1.9929	1.9549	1.9445	1.9322

The values a_n and b_n then put in Eq.1 to calculate Forward Scattering Amplitude for entire spherical rain drops at different temperatures as shown in Table 2.

3. Extinction Cross Section

The extinction coefficient is basically a hypothetical area which describes likelihood of energy being scattered by raindrops. Generally it is different from geometrical cross section of rain drop and it also depends on permittivity and wavelength in addition to sizes of rain drops. The combined effect of absorption and scattering is Extinction [14] such that

$$Q_{ext} = Q_{scat} + Q_{abs}$$

From Table2 it is clear that forward scattering amplitude contains both real and imaginary values. Extinction Cross-Section, Q_{ext} is calculated by considering only the real part shown by formula given below [18].

$$\operatorname{Re} Q_{ext} = \frac{4\pi}{k^2} \operatorname{Re} S(0) \tag{7}$$

Where, $k = \frac{2\pi}{\lambda}$

Table 3 Extinction Cross Section (Q_{ext})

Rain Radius (mm)	Calculated Q_{ext} at Different Temperatures			
	10^0C	20^0C	25^0C	30^0C
0.1795	0.0040	0.0033	0.0032	0.0027
0.2275	0.0090	0.0078	0.0075	0.0064
0.2755	0.0182	0.0164	0.0158	0.0138
0.3280	0.0356	0.0335	0.0329	0.0293
0.3855	0.0692	0.0682	0.0679	0.0622
0.4565	0.1450	0.1503	0.1521	0.1459
0.5580	0.3671	0.4013	0.4139	0.4301
0.6655	0.8437	0.9305	0.9637	1.0729
0.7530	1.4820	1.5851	1.6240	1.8111
0.8325	2.2872	2.3538	2.3803	2.5722
0.9560	4.0521	4.0069	4.0033	4.1521
1.1295	7.9942	7.7259	7.6642	7.7140
1.2920	13.2188	12.6813	12.5480	12.3711
1.4345	18.4111	17.7668	17.6130	17.3561
1.5990	24.3621	23.7712	23.6309	23.4345
1.7720	30.1019	29.5646	29.4250	29.2426
1.9850	35.7244	35.1451	34.9884	34.7348
2.1750	42.3334	41.6328	41.4548	41.1952
2.4295	51.5878	50.6636	50.4381	50.1556
2.6865	63.3836	62.1763	61.8752	61.4541

4. Modeling of Q_{ext}

The variation of experimental Q_{ext} (as in Table 3) with rain radius was analyzed using TableCurve2D software. A power law relationship has been considered for such purpose

$$\operatorname{Re} Q_{ext}(a,\lambda,T) = Ka^G \tag{8}$$

Where K, G are extinction coefficients of power law equation. The TableCurve2D of modeled Q_{ext} with rain rate, these constants are determined for different temperatures as shown in Table4.TableCurve2D software is software uses linear fitting procedure based on fast std. option has been used for curve fitting.

Table 4 Values of Coefficients of Specific Attenuation

Temperature(^{0}C)	**K**	**G**
10^{0}C	4.098	3.525
20^{0}C	3.983	3.501
30^{0}C	3.852	3.482
40^{0}C	3.631	3.451

The experimental Q_{ext} from Table 3, corresponding to 20 rain drops at different Temperatures have been plotted over the model derived curves using values of K and G obtained from Table4 against rain radius.The best fit curves between Calculated Q_{ext} and Model Q_{ext} against rain radius at all of the Temperature 10^{0}C, 20^{0}C, 25^{0}C, 30^{0}C were drawn using MATLAB software as shown in Fig.1 (a), (b), (c), (d) respectively.

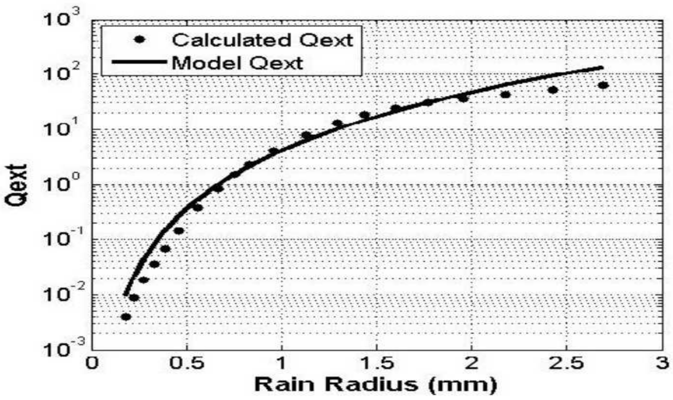

Fig.1 (a) Modeling of extinction cross-section at 10^{o}C

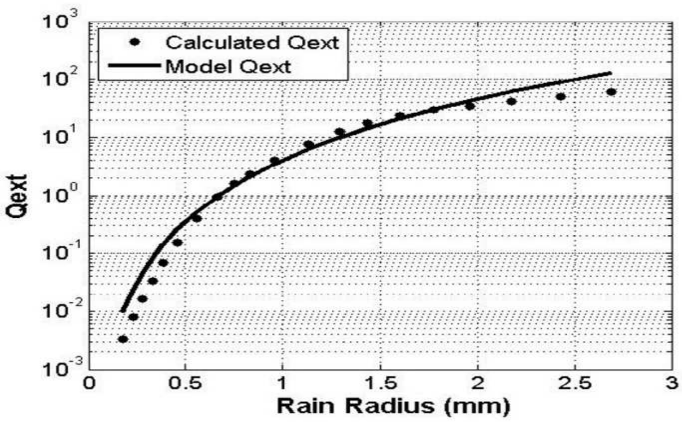

Fig.1 (b) Modeling of extinction cross-section at 20^{o}C

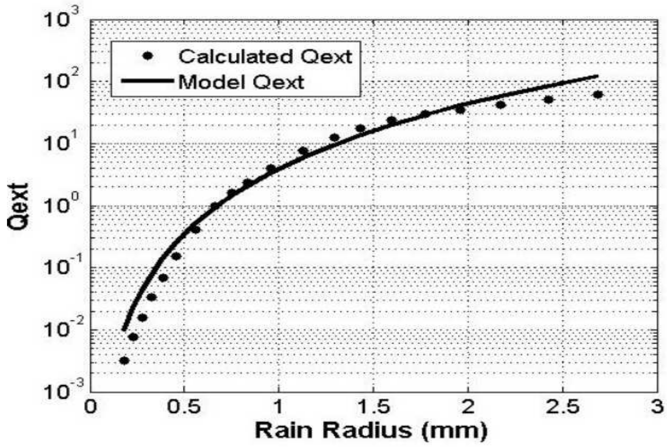

Fig.1(c) Modeling of extinction cross-section at 25^{o}C

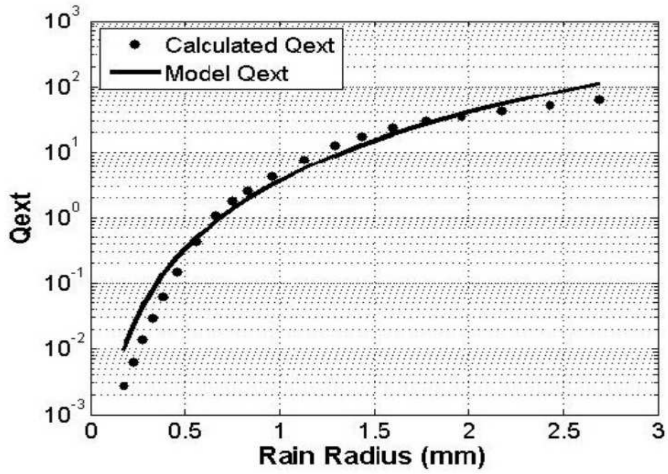

Fig.1(d) Modeling of extinction cross-section at 30^{o}C

In the Fig1 (a)-1(d) modeled Q_{ext} and experimental Q_{ext} for different temperatures in that order with rain radius have been shown. It can be seen that Modeling of Q_{ext} at different temperatures are similar in nature, but not exactly the same. Also, the Model Q_{ext} and Calculated one are approximately overlapping each other at Rain Radius ranging 0.5mm to 2.5mm which is noteworthy because the numbers of rain drops in this range are more that turns out good correlation. The correlation coefficient between model and calculated Q_{ext} at each temperature has been plotted in Fig.2. As shown below. The values of correlation coefficient between the model and the experimental data have been found to be lie between 0.95 and 0.98 which shows a very good correlation.

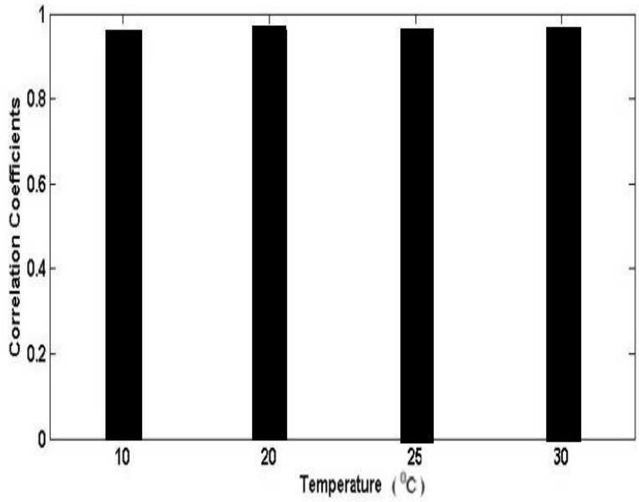

Fig.2 Correlation Coefficients between modeled and experimental Q_{ext} for ifferent temperatures

5. Modeling of Fit Parameters of Coefficients for Specific Attenuation

The values of fit parameters K, G for Q_{ext} have taken from Table 4 at each temperature. The variation of fit parameters K and G with Temperature has been studied using TableCurve2D software and have been plotted in Fig. 3(a) and 3(b). The best fit equations have been found as

$$K = K_0 + K_I T^3 \quad (9)$$

$$G = G_0 + G_1 T^3 \quad (10)$$

Where the coefficients $K_{0,}$ $K_{1,}$ G_0 and G_1 are best fit parameters and T is the temperature. Insertion of Eq.9 and Eq.10 in Eq.11 helps in calculation of specific rain attenuation. These two coefficients are both frequency and temperature dependent the values of coefficients, their correlation coefficient and fit standard error are given as Table 5:

Table 5 Values of Fit Parameters

Fit Parameters	Coefficients	Correlation	Fit Std error
K	K_0= 4.1230699 K_1= 1.7961248e-05	0.9983	0.0098
G	G_O= 3.52337 G_1= -2.695262e-06	0.9971	0.00048

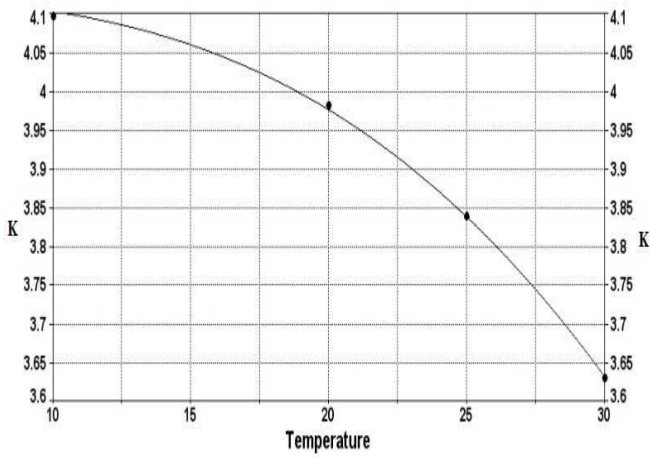

Fig.3 (a) Variation of fit parameter K with Temperature

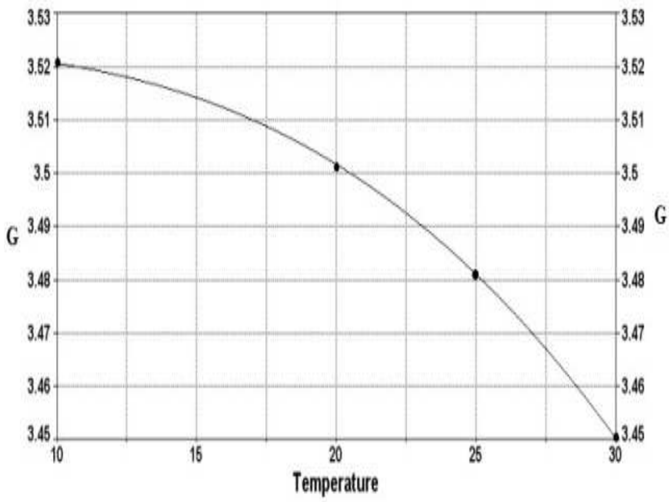

Fig.3 (b) Variation of fit parameter G with Temperature

6. Calculation of Specific Attenuation

To get an idea about the dependency of temperature, the value of specific attenuation at different rain rates have been considered .The specific attenuation, A_{SP} can be calculated as [19]

$$A_{SP} = 4.343 \times 10^{-3} \times \frac{KN_T}{2^G} \exp\left[G\mu + \left(\frac{G\sigma}{\sqrt{2}} \right)^2 \right] \quad (11)$$

where N_T is the total number of drops per unit volume at a particular rain rate, μ is the geometrical mean of the rain drop diameter, σ is standard deviation of drop diameter, and K , G are the best fit coefficients. Moreover the parameters N_T, μ and σ have been taken from Integrated DSD Model [10] and, all these three parameters are Rain dependent. The parameters K and G have been taken from Table.5.

Likewise put the values of all the parameters in to the Eq.11 and calculate the values of specific attenuation at all the Temperature using MATLAB software. It is useful to estimate the direct relationship between Rain rate and the specific rain attenuation.

7. Result and Analysis

In order to observe the effect of Temperature on specific attenuation values against rain rate, a Graph is plotted between Rain Rate and Specific Attenuation values at the Temperature 10^0C, 20^0C,25^0C and 30^0C as shown in Fig.4.The fig. shows the variation of specific rain attenuation with rain rate from lognormal model at different temperatures for frequency 30 GHz.

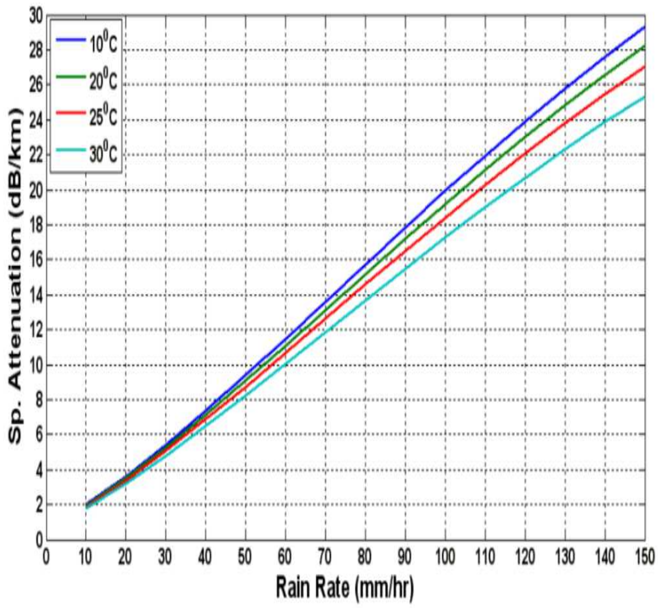

Fig.4 Specific Rain attenuation against Rain rate at different Temperatures for 30 GHz

From the Fig.4 it is clear that for higher rain rates specific rain attenuation values vary significantly. With the probability of 99.95%, the maximum rain rate is approximately 70mm/hr. In view of that for the maximum Temperature here 30^0C, its value is 12dB/km while for that of for the minimum Temperature 10^0C the corresponding Specific Attenuation is 14dB/km. Thus value of Specific Attenuation increases as the Temperature decreases. Hence it is found that Specific attenuation varies significantly at different Temperatures, such that for the minimum and maximum Temperature variation it comes out to be 2dB/km which is substantial to be noticed.

8. Conclusion

In the present analysis specific rain attenuation has been modeled on the basis of data collected on DSD at various places in the country and considering the large variation in temperature at different geographical locations in the country However, from the present study it is evident that Rain Attenuation depends on the Temperature to a great extent. It is observed that specific rain attenuation is less for 30^0C and higher for 10^0C.The results will be helpful in understanding rain attenuation variation. The outcome of the paper will help in estimation of necessary fade margin to be provided during rainy seasons for establishing reliable communication system in the country for achieving desired link availability at mm wave frequencies.

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