Prediction of Attenuation coefficient of X band microwave Signal under different atmospheric chaos (particles) .

Abstract: In this paper an attempt has been made for estimation of attenuation coefficient of microwave signals at different atmospheric chaos. The entire length of atmosphere has been considered as number of layer of sand, silt and clay particles in cascade form. The expression for attenuation coefficient of sand, silt and clay particles have been developed and depends on frequency, angle of incidence, visibility, permittivity, permeability. It is found that attenuation coefficient of microwave signal increases with frequency, decreases with angle of incidence and visibilities.

INDEX WORDS: ATTENUATION COEFFICENT, ANGLE OF INCIDENCE, X BAND MICROWAVE FREQUENCY, VISIBILTY.

1 INTRODUCTION:

The attenuation caused by sand and dust particles is one of the major problems in the utilization of microwave / millimeter wave bands for terrestrial and space communication. When microwave and millimeter waves pass through the medium containing precipitations like sand and dust particles, signals gets attenuated due to [1-3]

(i) Absorption of energy by these particles and its conversion into heat, and
(ii) Scattering of energy out of the beam by these particles.

Under the influence of incident wave, dust particles oscillate as ions and radiate energy in all directions. This results in appreciable amount of attenuation depending on size and concentration of particles. The theory of attenuation coefficients can be explained in terms of scattering and absorption cross-sections of a single particle. Different phenomena, such as, reflection, scattering, absorption and polarization cause considerable changes affection both phase and amplitude of the signal to a great extent [4].

In the present paper, a theoretical investigation has been carried out considering the layers of three main constituents i.e., sand, silt and clay of the storms to quantify the extinction cross-section and attenuation. The developed theoretical model has been used to determine the attenuation in terms of frequency, visibility, particles size and incidence angle.

2 THEORETICAL CONSIDERATIONS:

2.1. GEOMETRY OF PROBLEMS:

In order to consider the attenuation of main constituents of sand and dust storms, such as sand silt and clay, the profile structure of these constituents in atmosphere must be taken into accounts. The geometry of layers of different dust particles in storm is shown in **Figure .1.** The length of communication link is assumed to be L, which contain the layers of different constituents of storms blown to the height of the link due to dust storms. As the storms are assumed to contain three constituents, the entire section is represented in the form of three layers in cascade.

Further, the layer with sand particles extends form Z = 0 to Z = L, layer with silt particles extends from Z= L_1, to L_2 layer with clay particles extends from Z= L_2, to Z= L_3. If ε and α denote the permittivity and attenuation coefficients of microwave signal of sand silt and clay, respectively, then

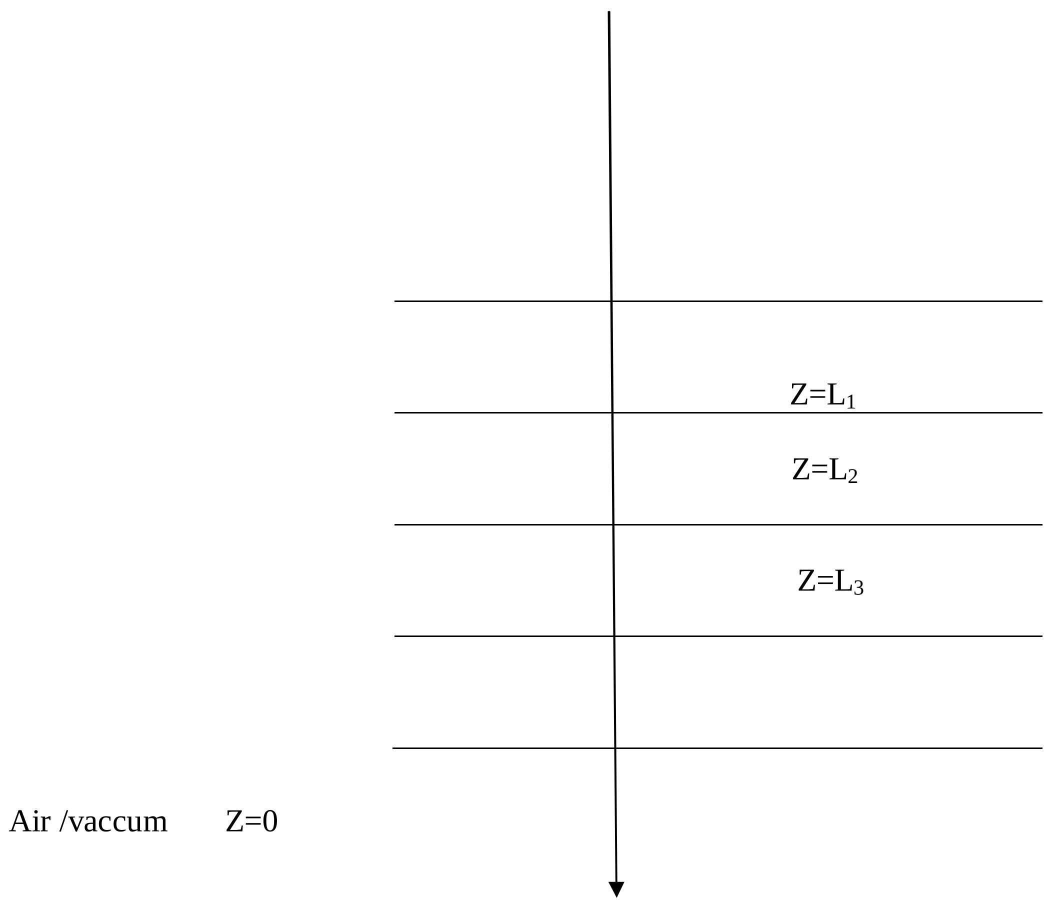

Fig 1 shows that Geometry of the layers of different dust particles.

$$\alpha_1(z) = 0 \le z \le L_1$$
$$\alpha(z) = \alpha_2(z) = L_1 \le z \le L_2$$
$$\alpha_3(z) = L_2 \le z \le L_3$$
$$where L = L_1 + L_2 + L_3$$

.3 ATTENUATION MODEL FOR DUST PARTICLES:

In order to consider the attenuation behavior of the dust particles, which are considered to be dielectric spheres, the concept of energy balance over the surface of sphere surrounding the scattering volume is utilized. If E (θ, ϕ) and H (θ, ϕ) denote the electric and magnetic fields, then field equation for dust particles can be written as ;[5]

$$E_\theta = H_\phi = \left(\frac{\partial P}{\partial \theta} + \cos ec\theta \frac{\partial P'}{\partial \phi}\right)\frac{e^{ikr}}{R}$$

(1)

$$E_\phi = H_\theta = \left(\frac{\partial P}{\partial \theta} - \cos ec\theta \frac{\partial P'}{\partial \phi}\right)\frac{e^{ikr}}{R} \quad . \quad (2)$$

Where,
$$P = k^2(K\alpha + L\beta + M\gamma)_-\left(\frac{1}{30}\right)\left(a^2\alpha^2 + b^2\beta^2 + c^2\gamma^2\right)$$
$$P' = k^2(K'\alpha + L'\beta + M'\gamma)_-\left(\frac{1}{30}\right)\left(a^2\alpha^2 + b^2\beta^2 + c^2\gamma^2\right)$$

.

(3)

$$K = \frac{2}{3}(\varepsilon - 1)F(\varepsilon) : L = \frac{1}{15}(\varepsilon - 1)\frac{1}{3}(6a^2 - b^2 - c^2)F(\varepsilon) :$$
$$M = \frac{1}{6}(\mu - 1)(b^2 - c^2)F(\varepsilon)$$

(4)

$$K' = \frac{2}{3}(\varepsilon - 1)F'(\varepsilon) : L = \frac{1}{15}(\varepsilon - 1)\frac{1}{3}(6a^2 - b^2 - c^2)F'(\varepsilon) :$$
$$M = \frac{1}{6}(\mu - 1)(b^2 - c^2)F'(\varepsilon)$$

. (5)

Where (R, θ, ϕ) are polar co-ordinates (α, β, γ) are direction cosines. Here Z axis is taken as the polar axis and is defined as

α = sin θ cos ϕ: β = sin θ sin ϕ: γ = cos θ

Combining equations .3, .4 and .5 with .1 and .2

$$E_{\theta}=-H_{\phi}=\begin{bmatrix}\left(\frac{\varepsilon-1}{\varepsilon-2}\right)\cos\theta+\left\{\left(\frac{\mu-1}{\mu-2}\right)\right\}+F(\varepsilon)\cos\theta+\left\{\left(\frac{\varepsilon-1}{6(2\varepsilon+3)}\right)\right\}\\ \cos 2\theta F'(\varepsilon)+\left\{\left(\frac{\mu-1}{6(2\mu+3)}\right)\right\}\cos\theta\end{bmatrix}\cos\phi\frac{e^{ikR}}{R}$$

(6)

$$E_{\phi}=-H_{\theta}=\begin{bmatrix}\left(\frac{\varepsilon-1}{\varepsilon-2}\right)\cos\phi+\left\{\left(\frac{\mu-1}{\mu-2}\right)\right\}+F(\varepsilon)\cos\varphi+\left\{\left(\frac{\varepsilon-1}{6(2\varepsilon+3)}\right)\right\}\\ c\text{ os }2\phi F'(\varepsilon)+\left\{\left(\frac{\mu-1}{6(2\mu+3)}\right)\right\}\cos\phi\end{bmatrix}\cos\theta\frac{e^{ikR}}{R}$$

(7)

For dust particles, the permittivity value is taken as μ = 1, so equation .6 and equation .7 can be written as;

$$E_{\theta}=-H_{\phi}=\left[\left(\frac{\varepsilon-1}{\varepsilon-2}\right)\cos\theta+F(\varepsilon)\cos\theta+\left\{\left(\frac{\varepsilon-1}{6(2\varepsilon+3)}\right)\right\}\cos 2\theta F'(\varepsilon)+\cos\theta\right]$$
$$\cos\phi\frac{e^{ikR}}{R}$$

(8)

$$E_{\phi}=-H_{\theta}=\left[\left(\frac{\varepsilon-1}{\varepsilon-2}\right)\cos\phi+F(\varepsilon)\cos\varphi+\left\{\left(\frac{\varepsilon-1}{6(2\varepsilon+3)}\right)\right\}\cos 2\phi F'(\varepsilon)+\cos\phi\right]$$
$$\cos\theta\frac{e^{ikR}}{R}$$

(9)

Where F (ε) and F ‘(ε) are scattering amplitudes depending on the size of particles, different for spherical and non-spherical particles. [6].As the problem is concerned with the flow of energy, Pontying vector must be used. In this case only the radial component of Pontying vector actually crosses the surface of the sphere. In spherical co-ordinate system, if E(θ , ϕ) and H(θ , ϕ) denote the electric and magnetic fields, then radial component of the average Pontying vector will be in the radial direction, the value of which is given as;[4]

$$S_R=\frac{1}{2}\mathrm{Re}(E_{\theta}H*_{\phi}-E_{\phi}H*_{\theta})$$

$$S_R=\frac{1}{2}\mathrm{Re}\quad(E_{\theta inc}H*_{\phi inc}-E_{\phi inc}H*_{\theta inc})+(E_{\theta sca}H*_{\phi sca}-E_{\phi sac}H*_{\theta sca})+$$
$$(E_{\theta inc}H*_{\phi sca}-E_{\phi inc}H*_{\theta sca})+(E_{\phi inc}H*_{\phi sca}-E_{\phi inc}H*_{\theta sca})$$

(10)

The t0otal energy scattered out of the surface of dust particles is the sum of the absorbed and scattered powers. The total extinction cross-section will be the ratio of scattered power to incident power given as; [7]

$$\sigma_{ext} = (-\frac{1}{2}) \mathrm{Re} \int\int \left[\frac{1}{2} \mathrm{Re}(E_\theta H^*_\phi - E_\phi H^*_\theta) \right] R^2 \sin d\theta\, d\phi$$

. (11)

During the passage of microwave and millimeter waves through the medium containing sand and dust particles, the waves will be attenuated as consequence of two phenomena i.e., scattering and absorption. Let N(s) ds be the number of dust particles per unit volume of storm with radii in the interval s to (s + ds), s= (a, b, c). If σ be the extinction cross-section of dust particles, then total power removed from the wave with incident Pontying vector S_R by dust particles in volume element of unit cross-sectional area and thickness dl is given as ;[6]

$$\frac{dS_R}{dI} = -S_R \int \sigma_{ext} N(a) da \qquad (12)$$

Denoting the integral in the equation by σ (attenuation)

$$\alpha = \int \sigma_{ext} N(a) da$$

The attenuation for spherical dust particles is ; $\alpha = \int \sigma_{ext} a^3 N(a) da$ (13)

Where N is the number of particles in unit volume of storm in radii a to a+da.
Similarly, for non-spherical dust particles,

$$\alpha = \int \sigma_{ext} abcN(a) da \qquad (14)$$

Where‘s’ denotes the parameter a, b and c. The number of particles N per unit volume of storm is given by Sami and Ghobrial[46]

$$N = \frac{9.43\times10^{-9}}{V^\gamma \left(\frac{4}{3}\pi a^3\right)} \quad and \quad for \quad non \quad spherical \quad dust \quad particle \frac{9.43\times10^{-9}}{V^\gamma \left(\frac{4}{3}\pi abc\right)}$$

(15)

Where V is the visibility, Km; a the radius of dust particle and γ = 1.07
The attenuation coefficients can be calculated using equations .8, .9, .10, .13, .14 and .15 as

The attenuation coefficient for spherical dust particle (sand, silt and clay particles) of microwave signal are written as ;

$$\alpha = \left(\frac{9.43\times10^{-9}}{V^{\gamma}\left(\frac{4}{3}\pi a^{3}\right)} \right) \left[\left(\frac{\varepsilon-1}{\varepsilon-2}\right)\cos\theta + F(\varepsilon)\cos\theta + \left\{\left(\frac{\varepsilon-1}{(\varepsilon+2)(2\varepsilon+3)}\right)\right\}\cos 2\theta F'(\varepsilon) \right] \frac{\cos\theta\cos 2\phi}{R} \qquad (16)$$

The attenuation coefficients for non spherical dust (sand, silt and clay particles) of microwave signal is written as

$$\alpha = \left(\frac{9.43\times10^{-9}}{V^{\gamma}\left(\frac{4}{3}\pi abc\right)} \right) \left[\left(\frac{\varepsilon-1}{\varepsilon-2}\right)\cos\theta + F(\varepsilon)\cos\theta + \left\{\left(\frac{\varepsilon-1}{(\varepsilon+2)(2\varepsilon+3)}\right)\right\}\cos 2\theta F'(\varepsilon) \right] \frac{\cos\theta\cos 2\phi}{R} \qquad (16.1)$$

The attenuation coefficient for spherical dust particles) of microwave signal is written as ;

FOR SAND

$$\alpha_{sand} = \left(\frac{9.43\times10^{-9}}{V^{\gamma}\left(\frac{4}{3}\pi a^{3}\right)} \right) \left[\left(\frac{\varepsilon_{sand}-1}{\varepsilon_{sand}-2}\right)\cos\theta + F(\varepsilon)\cos\theta + \left\{\left(\frac{\varepsilon_{sand}-1}{(\varepsilon_{sand}+2)(2\varepsilon_{sand}+3)}\right)\right\} \cos 2\theta F'(\varepsilon) \right] \frac{\cos\theta\cos 2\phi}{R} \qquad 4.17$$

FOR SILT

$$\alpha_{silt} = \left(\frac{9.43\times10^{-9}}{V^{\gamma}\left(\frac{4}{3}\pi a^{3}\right)} \right) \left[\left(\frac{\varepsilon_{silt}-1}{\varepsilon_{silt}-2}\right)\cos\theta + F(\varepsilon)\cos\theta + \left\{\left(\frac{\varepsilon_{silt}-1}{(\varepsilon_{silt}+2)(2\varepsilon_{silt}+3)}\right)\right\} \cos 2\theta F'(\varepsilon) \right] \frac{\cos\theta\cos 2\phi}{R} \qquad (18)$$

FOR CLAY

$$\alpha_{clay} = \left(\frac{9.43\times10^{-9}}{V^{\gamma}\left(\frac{4}{3}\pi a^{3}\right)} \right) \left[\begin{matrix} \left(\frac{\varepsilon_{clay}-1}{\varepsilon_{clay}-2}\right)\cos\theta + F(\varepsilon)\cos\theta + \left\{ \left(\frac{\varepsilon_{clay}-1}{(\varepsilon_{clay}+2)(2\varepsilon_{clay}+3)} \right) \right\} \\ \cos 2\theta F'(\varepsilon) \end{matrix} \right] \frac{\cos\theta\cos 2\phi}{R} \quad .(19)$$

The attenuation coefficient for non spherical dust particles of microwave signal is written as ;

FOR SAND

$$\alpha_{sand} = \left(\frac{9.43\times10^{-9}}{V^{\gamma}\left(\frac{4}{3}\pi abc\right)} \right) \left[\begin{matrix} \left(\frac{\varepsilon_{sand}-1}{\varepsilon_{sand}-2}\right)\cos\theta + F(\varepsilon)\cos\theta + \left\{ \left(\frac{\varepsilon_{sand}-1}{(\varepsilon_{sand}+2)(2\varepsilon_{sand}+3)} \right) \right\} \\ \cos 2\theta F'(\varepsilon) \end{matrix} \right] \frac{\cos\theta\cos 2\phi}{R} \quad . \quad (20)$$

FOR SILT

$$\alpha_{silt} = \left(\frac{9.43\times10^{-9}}{V^{\gamma}\left(\frac{4}{3}\pi abc\right)} \right) \left[\begin{matrix} \left(\frac{\varepsilon_{silt}-1}{\varepsilon_{silt}-2}\right)\cos\theta + F(\varepsilon)\cos\theta + \left\{ \left(\frac{\varepsilon_{silt}-1}{(\varepsilon_{silt}+2)(2\varepsilon_{silt}+3)} \right) \right\} \\ \cos 2\theta F'(\varepsilon) \end{matrix} \right] \frac{\cos\theta\cos 2\phi}{R} \quad (21)$$

FOR CLAY

$$\alpha_{clay} = \left(\frac{9.43\times10^{-9}}{V^{\gamma}\left(\frac{4}{3}\pi abc\right)} \right) \left[\begin{matrix} \left(\frac{\varepsilon_{clay}-1}{\varepsilon_{clay}-2}\right)\cos\theta + F(\varepsilon)\cos\theta + \left\{ \left(\frac{\varepsilon_{clay}-1}{(\varepsilon_{clay}+2)(2\varepsilon_{clay}+3)} \right) \right\} \\ \cos 2\theta F'(\varepsilon) \end{matrix} \right] \frac{\cos\theta\cos 2\phi}{R} \quad . \quad (22)$$

Therefore, the average attenuation coefficients caused by spherical dust particles of microwave signal are written as

$$\alpha_{av}(sp) = \frac{\alpha_{sand} + \alpha_{silt} + \alpha_{clay}}{3} \qquad (.23)$$

Where α_{sand} is attenuation due to sand particle.

α_{silt} is attenuation due to silt particle

α_{clay} is attenuation due to clay particle

The average attenuation coefficients caused by non spherical dust particles of microwave signal are written

$$\alpha_{av}(non-sp) = \frac{\alpha_{sand} + \alpha_{silt} + \alpha_{clay}}{3} \qquad 24$$

The scattering amplitude F (ϵ) and for dust particles are calculated as [8]

$$F(\varepsilon) = \left(K^2 \frac{ab^2}{3}\right)\left[\left(\frac{(\varepsilon - 1)}{1 + (\varepsilon - 1)}\right) A_1\right]$$

$$F'(\varepsilon) = \left(K^2 \frac{ab^2}{3}\right)\left[\left(\frac{(\varepsilon - 1)}{1 + (\varepsilon - 1)}\right) A_1\right] + \left[\left(\frac{(\varepsilon - 1)}{1 + (\varepsilon - 1)}\right) A_2\right] \qquad .25$$

Where the modified geometrical factors A_1 and A_2 are different for probate dust particle's which are given as [8-9].

For probate dust particles

$$A_1 = [\{a^4 / 2b(b^2 - a^2)(b^2 - a^2)^{\frac{1}{2}}\}\tan^{-1}\{(a^2 - b^2)^{\frac{1}{2}} - a)/a\}] \qquad .26$$

$$A_2 = [a\{a^2 - b^2) - 1)/2b(b^2 - a^2)(a^2 - b^2)^{\frac{1}{2}}\}\tan^{-1}\{(a^2 - b^2)^{\frac{1}{2}} - b)/b\}] \qquad .27$$

.4 NUMERICAL COMPUTATIONS:

In order to calculate attenuation coefficient for spherical and non spherical particles for this equation .17 to .29 .The numerical values of permittivity of dry and moist dust particles are tabulated in **Table .1**

S.No	Types of particle	Dielectric constant for dry particle	Dielectric constant for moist particle

1	Sand	3.776-j0.255	6.786-j0.321
2	Silt	4.031-j0.214	8.26-j0.221
3	Clay	4.495 –j0.255	9.206-j0.221

5 RESULT AND DISCUSSION

Attenuation coefficient of microwave signal in sand and dust storm condition for spherical and non spherical can be calculated by using equation in terms of frequency, visibility, angle of incidence and particle radii. The results are tabulated in table .2 to table .6 and their variations are shown in fig .2 to .6. The attenuation coefficient for sand, silt and clay dust particle observed in this model are similar to observation made by S. Singh et. al [1996].[8] The attenuation coefficient for spherical and non spherical can be calculated from equation .17 to equation .25 and their results are tabulated below. In order to calculate the attenuation coefficient for spherical and non spherical dust particles, the numerical value of complex permittivity are taken as 3.776-j0.255 for dry sand, 6.786-j0.321 for moist sand particles, 4.031-j0.214 for dry silt particles, 8.26-j0.221 for moist silt particles, 4.495-j0.255 for dry clay particles, 9.26-j0.221 for moist clay particle respectively. It is observed the attenuation coefficient (dB) is calculated with respect to frequency as well as visibility. The frequency varies from 30 GHz to 140 GHz and visibilities from 0.001 Km 1 Km.

Table : 2 **Variation of Attenuation coefficient (dB) for spherical particles with frequency at visibility 0.1 Km**

Sr. No.	Freq (GHz)	PRESENT STUDY			SINGH STUDY et.al (1996)		
		Attenuation coefficients (dB) **at visibility 0.1 Km**			Attenuation coefficients (dB) **at visibility 0.1 Km**		
		Sand	Silt	Clay	Sand	Silt	Clay
01	30	1.31	1.42	1.51	1.73	1.92	2.31
02	60	2.12	2.32	2.51	2.33	2.38	2.42
03	90	2.98	3.12	3.34	3.21	3.9	4.12
04	120	3.53	4.12	5.63	3.73	4.12	4.33
05	140	3.97	4.33	5.12	3.83	4.53	4.77

Table : .3 Variation of Attenuation coefficient (dB) for non-spherical particles with frequency at visibility 0.1 Km

Sr. No.	Frequency (GHz)	PRESENT STUDY			SINGH STUDY et .al (1996)		
		Attenuation coefficients (dB) **at visibility 0.1 Km**			Attenuation coefficients (dB) **at visibility 0.1 Km**		
		Sand	Silt	Clay	Sand	Silt	Clay
01	30	1.41	1.62	1.64	1.93	2.12	2.51
02	60	2.22	2.52	2.53	2.53	2.58	2.62
03	90	3.01	3.22	3.54	3.41	4.09	4.32
04	120	3.63	4.22	4.83	3.93	4.32	4.53
05	140	4.07	4.53	5.32	4.17	4.73	4.93

Table : 4 Variation of Attenuation coefficient (dB) for spherical and non-spherical particles with visibility in different frequencies.

Sr. No.	Visibility Km	Attenuation coefficients for spherical particle (dB)			Attenuation coefficients for non-spherical particle (dB)		
		40 GHz	60 GHz	80 GHz	40 GHz	60 GHz	80 GHz
01	0.001	3.98	4.31	4.51	4.12	4.27	4.97
02	0.01	3.23	4.23	4.32	3.96	4.19	4.89
03	0.1	2.64	3.72	4.13	3.2	4.08	4.68
04	1	2.03	2.98	3.4	2.5	2.5	4.09

TABLE 5

Variation of Attenuation coefficient (dB) with particle size for spherical and non-spherical particles at visibility at 0.1K.M. at 40 GHz in case of sand, silt, clay particles.

Sr. No.	Particle size (mm.)	Attenuation coefficients for spherical particle (dB)			Attenuation Coefficients for non-spherical particle (dB)		
		Sand	Silt	Clay	Sand	Silt	Clay
01	0.1	0.7	1.1	1.32	0.9	1.21	1.4
02	0.2	1.33	1.5	1.68	1.47	1.58	1.7
03	0.3	1.47	1.89	2.32	1.69	2.01	2.7
04	0.4	1.76	2.21	2.51	2.01	2.42	2.9

Table : .6 **Variation of Attenuation coefficient (dB) for spherical and non-spherical particles with angle of incidence in degree.**

Sr. No.	Angle of incidence (in degree)	Attenuation coefficients for spherical particle (dB)			Attenuation coefficients for non-spherical particle (dB)		
		40 GHz	60 GHz	2.48	40 GHz	60 GHz	80 GHz
01	30^0	1.49	1.68	2.01	1.58	2.48	3.48
02	60^0	1.33	1.59	1.64	1.46	2.01	3.01
03	75^0	0.9	1.43	1.33	1.21	1.64	2.64
04	90^0	0.52	0.72	1.33	0.61	1.33	2.33

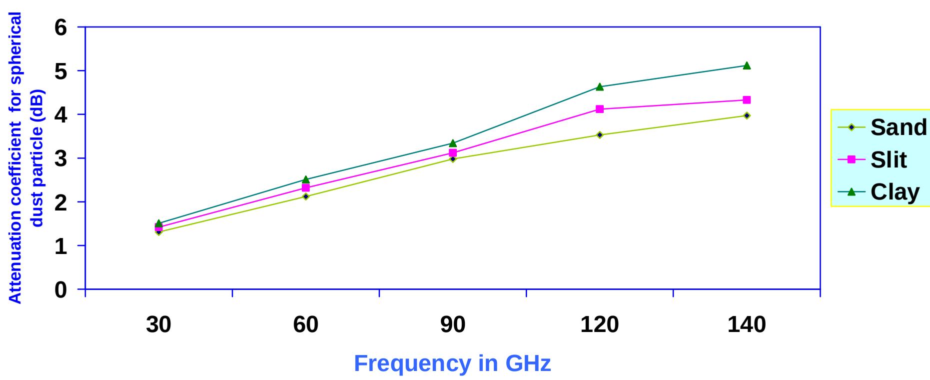

Fig 2 Variation of Attenuation coefficient for spherical dust particle (sand, silt and clay) with frequency at visibility at 0.1 Km

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(NOTE -Bold line shows spherical particle
Dashed line shows that non spherical particle).

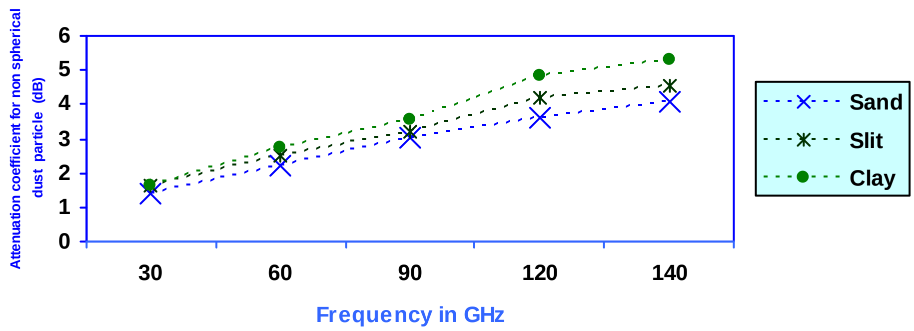

Fig .3 Variation of Attenuation Coefficient for non spherical dust particle (sand silt and clay) with frequency at visibility at 0.1 Km.

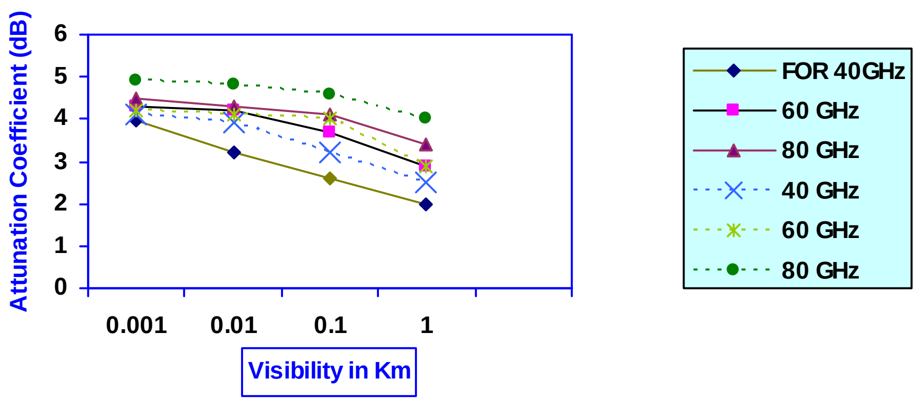

Fig .4 Variation of Attenuation Coefficient with visibility in Km at different frequencies.

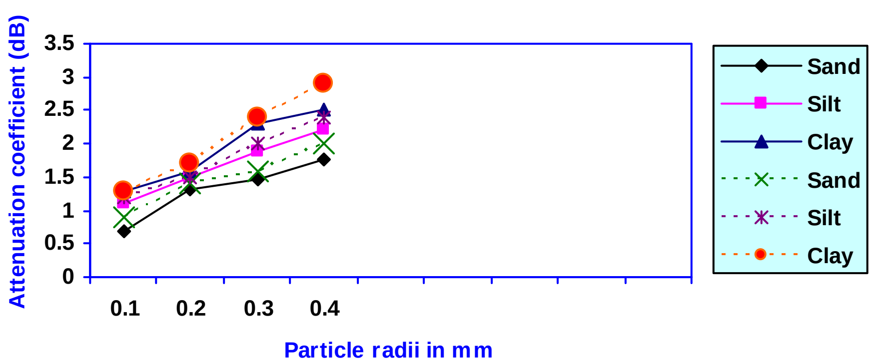

Fig .5 Variation of Attenuation Coefficient with particle radii in mm for different particle.

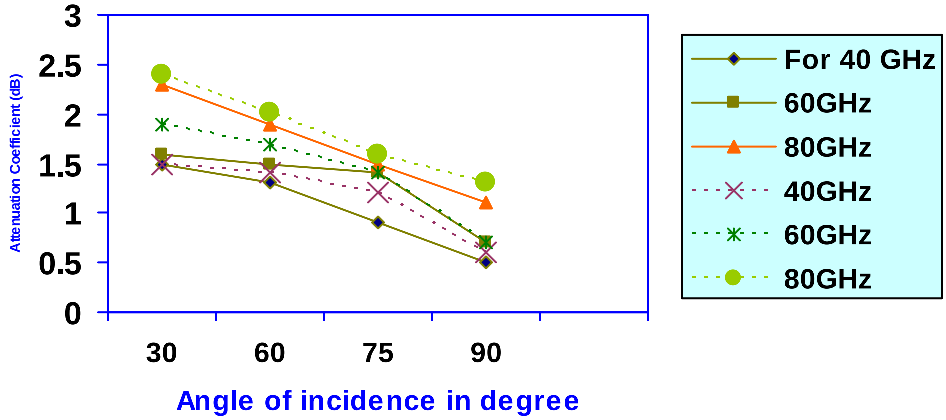

Fig 6 Variation of Attenuation Coefficient with angle of incidence in degree at different frequencies.

From above discussion it is concluded that attenuation coefficient of microwave signal depend upon frequency, visibility, and particle radii. Attenuation coefficient of microwave signal increases with frequency due to increase in, for zero visibility the medium is almost completely packed with sand, dust particles. Any lossy dielectric medium will have a complex permittivity

$$\varepsilon^* = \varepsilon(1 - j\sigma / \omega\varepsilon) .$$

The imaginary part of which is function of conductivity and frequency. There are two types of loss which attenuate the wave in addition to the loss of reflection loss. First conductivity of the dielectric contributes to the loss of energy in form of heat. Secondly the dipoles created due to polarization process experience certain amount of friction (damping force) when they flip back and forth in alternating an electromagnetic field. Consequently these dipoles extract energy from the impressed field which is dissipated in form of heat. Since the losses due to dielectric conductivity and polarization damping force in form of heat it is logical to represent the two losses in terms of conductivity. These equation shows increasing frequency enhance conductivity and loss tangent of the medium. These in turn raise the effective absorption loss with reflection in the reflection in the system. Thus absorption loss increases with frequency. It may concluded that it may, therefore be concluded that it is the polarization damping force that predominately controls the loss in the medium, when frequency of the propagating signal is increased. The attenuation coefficient of microwave signal increases with particle radii and decreases with increases with visibilities and increases with angle of incidence according to Brewster's Phenomena. Attenuation coefficients for Non-spherical dust particle are large value than spherical dust particle. Therefore it can be predicted that non-spherical dust particle passes higher value of attenuation than spherical dust particle. Clay particle passes large dielectric constant in comparison to sand and silt particle.

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Authors

Dr. Megha Persai Bhatt presently, worked in Agriculture university, Raipur, CG, India, as visiting faculty, Astt . Professor in LNCT –S Engg . College, Bhopal MP, India. She has done his Ph.D in GuruGhasi Das Central university, Bilaspur, CG, under Dr. S.K Srivastav, HOD of Physics Deptt, Ambikapur , CG under topic Study of effect of microwave signal under dust storm condition and Remote Sensing . . She is also Gold Medalist in MSc 20077 from PT .R S U , University , Raipur CG