

MILLIMETER WAVE PROPAGATION THROUGH LAYERS OF SAND AND DUST PARTICLES

Mukesh Kumar*

Department of Physics, B. R. A. B. U., Muzaffarpur-842001

* Mailing Address: Trivedi Compound, Mishra Tola, Gannipur,
Muzaffarpur-842001, Ph. No.-(062 I -2244693) (India)

(Received, November 15, 2004)

ABSTRACT

In the present paper theoretical investigation has been carried out to evaluate the effect of the layers of sand, dust particles on the propagation of millimeter wave. For this purpose the layers of sand, silt and clay particles have been considered. The expression for effective propagation constant has been utilized to get the expression for the normalized phase velocity, loss tangent and related attenuation. It has been found that the normalized phase velocity, loss tangent and attenuation, all increase with increasing frequency for different values of fractional volume.- Further the loss tangent first increases with increasing fractional volume and then it starts to decrease with increasing fractional volume.

Key Words:- dust particles, phase velocity, loss tangent, attenuation.

INTRODUCTION

Recently considerable interest has been devoted to estimate the influence of the layers of dust particles on the propagation characteristics of millimeter wave¹⁻³. It may emphasized that while the millimeter waves are allowed to pass through the medium having such layers the phase and amplitude of wave affected by the dust particles, which ultimately cause the attenuation of the wave. In addition that the normalized phase velocity is also effective. Therefore in present paper an attempt has been confined to obtain the expression for the normalized phase velocity and loss tangent of millimeter wave in terms of fractional volume and particle size. The real and imaginary parts of effective propagation constant have been investigated.

Using the expression for loss tangent

the attenuation constant has also been obtained. The detail of entire investigations have been given in following sections of the paper.

air	$Z = 0$
sand	$Z = L_1$
Silt	$Z = L_2$
clay	$Z = L_3$

In order to obtain normalized phase velocity (V_{ph}), effective loss tangent ($\tan\delta_{eff}$) and attenuation constant (α) of millimeter wave from the layers of sand, silt and clay, the profile structure of these constituents in atmosphere must be taken into account, which is shown in fig. 1.

$$V_{ph1}(Z) = V_{ph1} \text{ for } 0 < Z < L_1 \text{ for sand layer}$$

$V_{ph2}(Z) = V_{ph2}$ for $L_1 \leq Z \leq L_2$ for silt layer
 $V_{ph3}(Z) = V_{ph3}$ for $L_2 \leq Z \leq L_3$ for clay layer
 where

$\alpha(Z) = \alpha_1$ for $0 \leq Z \leq L_1$ for sand layer
 α_2 for $L_1 \leq Z \leq L_2$ for silt clay
 α_3 for $L_2 \leq Z \leq L_3$ for clay

And

$L_1 + L_2 + L_3 = L$ the length of communication line.

For low frequency approximation :

Now, the effective propagation constant for low frequency approximation may be given as

$$K_F^2 = K^2 + (3fK^2y/(1-fy)) [1 + i(2/3) K^3 a^3 y (1-f)^4 / (1-fy) (1+2f)^2] \quad (1)$$

where $f = 4\pi a^3 n_0/3$ is the fractional volume

$K = 2\pi/\lambda$ is the propagation constant

a = radius of spherical particles

$y = (\epsilon_c - 1) / (\epsilon_c + 2)$

and n_0 is the number of sand dust particles in the unit volume of atmosphere. Now we have

$$K_F^2 = K^2 + (3fK^2y/(1-fy)) + [i 2 f K^5 y^2 (1-f)^4 / (1-fy) (1+2f)^2] \quad (2)$$

$$K_F^2 = K [K + (3 f K y/(1-fy)) + [i 2 f K^4 y^2 (1-f)^4 / (1-fy) (1+2f)^2]$$

$$K_F^2 = K [1 + (3 f y/(1-fy)) + i 2 f K^4 y^2 (1-f)^4 / (1-fy) (1+2f)^2]$$

$$K_F^2 = K [1 + (3 f y/(1-fy)) + i 2 f K^3 y^2 (1-f)^4 / (1-fy) (1+2f)^2]$$

$$K_F^2 = K [1 + (3 f y/(1-fy)) + i 2 f K^3 y^2 (1-f)^4 / (1-fy)^2 (1+2f)^2]^{1/2} \quad (3)$$

$$= K [1 + (1/2) (3f y/(1-fy)) + (1/2) (i 2f K^3 y^2 (1-f)^4 / (1-fy)^2 (1+2f)^2)] \quad (4)$$

Separating real and imaginary parts of the propagation constant, one has

$$K_{IF} = K[1 + (1/2) (3fy/(1-fy))] \quad (5)$$

$$K_{iF} = K[(1/2) i2 + K^4 y^2 (1-f)^4 / (1-fy)^2 (1+2f)^2] = fK^4 y^2 (1-f)^4 / (1-fy)^2 (1+2f)^2 \quad (6)$$

Now the normalized phase velocity V_{Ph} is given by

$$V_{Ph} = K / K_{IF} \quad (7)$$

Similarly the effective loss tangent may be obtained as

$$\tan \delta_{eff} = 2 K_{iF} / K_{IF} \quad (8)$$

Comparing equations (5), (6), (7),*(8) one has

$$\begin{aligned} V_{ph} &= K / K [1 + (1/2) (3fy/(1-fy))] \\ &= 1 / [1 + (1/2) (3fy / (1-fy))] \\ \text{and} \\ \tan \delta_{eff} &= 2 f K^4 y^2 (1-f)^4 / K (1 + (1/2) (3 fy / (1-fy))) \\ &= 2 f K^4 y^2 (1-f)^4 / K (1 + (1/2) (3 fy / (1-fy))) \\ &= 2 f K^4 y^2 (1-f)^4 / K (1 + (3/2) (fy / (1-fy))) \\ &= 2 f K^3 y^2 (1-f)^4 / (1 + (3/2) (fy / (1-fy))) \quad (9) \end{aligned}$$

For high frequency approximation :

In this case the expression for normalised phase velocity and effective loss tangent can be obtained from the relation given as,

$$K_F = K - (\pi i n_0 / K^2) \sum_{n=1}^{\infty} (2n+1) (T_n^{(M)} + T_n^{(N)}) \quad (10)$$

where $T_1^{(M)}$ and $T_1^{(N)}$ are the coefficient the amplitude of the field distribution on spherical dust particles. Further $T_1^{(M)}$ and $T_1^{(N)}$ are proportional to the amplitude of magnetic and electric multipoles, which are induced by incident wave, then

$$T_1^{(M)} = -(i/45)((\epsilon_c - 1)\rho^5 \quad (11)$$

$$T_1^{(N)} = -(i/45)(2/3)((\epsilon_0 - 1)/(\epsilon_0 + 2))\rho^3 \quad (12)$$

$$[(1 + (3\epsilon_c - 2)/(5\epsilon_c + 2))\rho^2]$$

Where

$$\rho = (2\pi a/\lambda)$$

Now, for small value of ρ and finite ϵ_c only the first term of equation (12) is important.

$$T_1^{(N)} = [-i(2/3)((\epsilon_c - 1)/(\epsilon_c + 2))]\rho^3 \quad (13)$$

Putting the values of $T_1^{(M)}$ and $T_1^{(N)}$ in eq. (10) one has

$$K_F = K - (3\pi n_0/K^2) \{-i(2/3)((\epsilon_c - 1)/(\epsilon_c + 2))\rho^3 + (-i/45)(\epsilon_c - 1)\rho^5\}$$

$$K_F = K - (3\pi n_0/K^2) \{-i(2/3)((\epsilon_c - 1)/(\epsilon_c + 2))\rho^3 + (-i/45)(\epsilon_c - 1)\rho^5 \quad (14)$$

$$K_F = K - (2\pi n_0/K^2) \{(\epsilon_c - 1)/(\epsilon_c - 2)\rho^3 - (\pi n_0/15K^2)(\epsilon_c - 1)\rho^5 \quad (15)$$

where $\epsilon_c = \epsilon_1 - i\epsilon_2$

Putting the value of ϵ_c in equation (15) one has

$$K_F = K - (2\pi n_0/K^2) \{(\epsilon_1 - i\epsilon_2 - 1)/(\epsilon_1 - i\epsilon_2 + 2)\rho^3 + (\pi n_0/15K^2)(\epsilon_1 - i\epsilon_2 - 1)\rho^5 \quad (16)$$

$$K_F = K - (2\pi n_0/K^2) \{(\epsilon_1^2 + \epsilon_1 - 2 + \epsilon_2^2) + \epsilon_1\epsilon_2 - i\epsilon_2 - 3\epsilon_2\}/((\epsilon_1 + 2)^2 + \epsilon_2^2) \quad (17)$$

$$K_F = K - (2\pi n_0/K^2) \{(\epsilon_1^2 + \epsilon_1 - 2 + \epsilon_2^2)/((\epsilon_1 + 2)^2 + \epsilon_2^2) - (i2\pi n_0/K^2)\{(\epsilon_2/(\epsilon_1 + 2)^2 + \epsilon_2^2)\} \quad (18)$$

Now under this approximation, the expression for $\tan \delta_{eff}$ can be obtained as

$$\tan \delta_{eff} = (2K_{if}/K_{rf}) = [2 \cdot (2\pi n_0/K^2)\{(\epsilon_2/(\epsilon_1 + 2)^2 + \epsilon_2^2)\}/[K - (2\pi n_0/K^2)\{(\epsilon_1^2 + \epsilon_1 - 2 + \epsilon_2^2)/((\epsilon_1 + 2)^2 + \epsilon_2^2)\}]$$

Also the normalised phase velocity can be obtained as

$$V_{ph} = (K/K_{rf}) = \{K/[K - (2\pi n_0/K^2)]\} \{(\epsilon_1^2 + \epsilon_1 - 2 + \epsilon_2^2)/((\epsilon_1 + 2)^2 + \epsilon_2^2)\} = \{K/[K - (2\pi n_0/K^2)]\} \{(\epsilon_1^2 + \epsilon_1 - 2 + \epsilon_2^2)/((\epsilon_1 + 2)^2 + \epsilon_2^2)\} \quad (19)$$

Attenuation constant (a) of millimeter wave

The value of attenuation constant (a) can be evaluated as per this. Let the propagation constant (γ) of wave given by relation

$$\gamma = J\omega\sqrt{\mu\epsilon}\sqrt{1-j(\sigma/\omega\epsilon)} \quad \text{or} \quad \gamma = J\omega\sqrt{\mu\epsilon}(1-j(\sigma/\omega\epsilon)^{1/2})$$

$$\gamma = J\omega\sqrt{\mu\epsilon}[1-j(\sigma/2\omega\epsilon) + (1/8)(\sigma/\omega\epsilon)^2 + \dots] \quad (20)$$

Hence

$$a = J\omega\sqrt{\mu\epsilon}(-j(\sigma/2\omega\epsilon)) = (\sigma/2)\sqrt{(\mu/\epsilon)} \text{ Np/m} \quad (21)$$

Now the attenuation constant is related to loss tangent by relation

$\alpha = (\omega\epsilon/2) \times \text{loss tangent} \sqrt{(\mu/\epsilon)} \text{ Np/m} \quad (22)$ since loss tangent $(-\sigma/\omega\epsilon)$

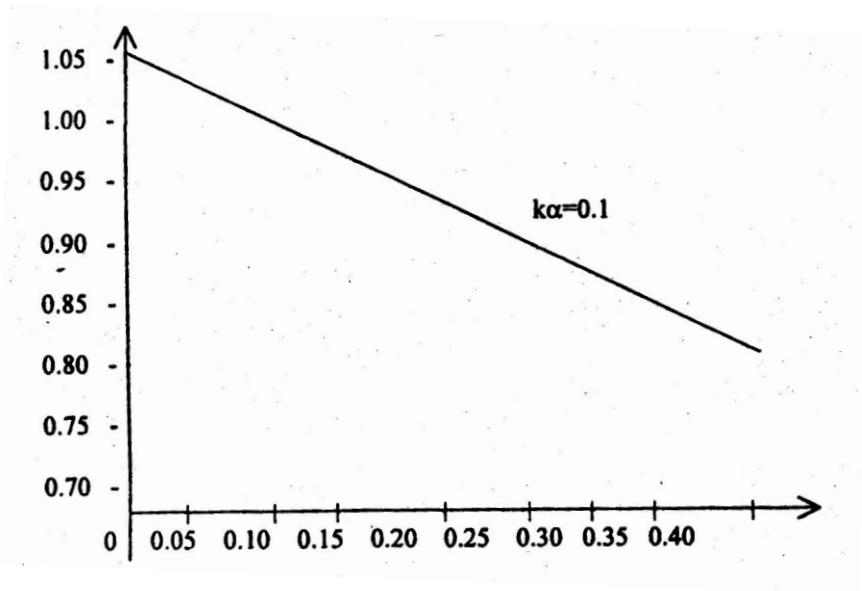


Fig. 1. Variation of normalized phase velocity with frequency for different values of fractional volume.

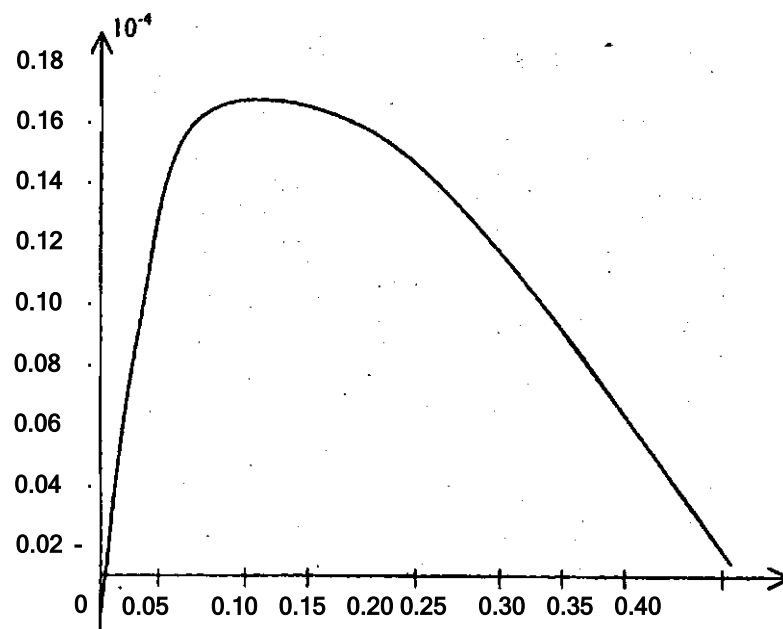


Fig. 2. Variation of normalized phase velocity with fractional volume for different values of frequency.

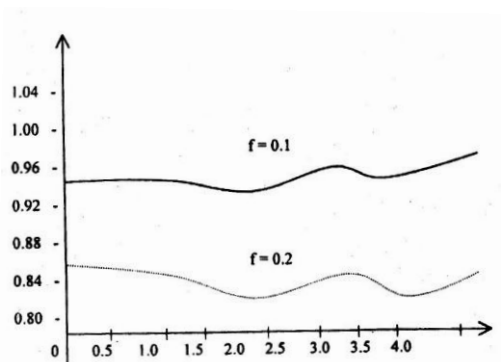


Fig. 3. Variation of loss tangent with frequency for different values of fractional volume.

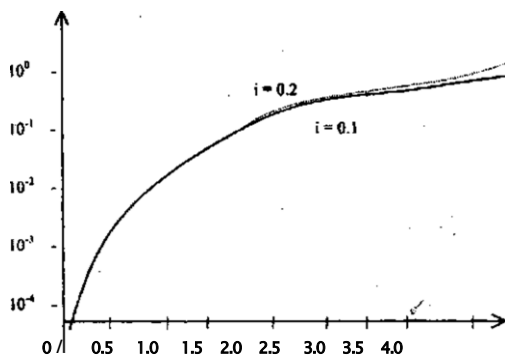


Fig. 4. Variation of loss tangent with fractional volume for different values of frequency.

$$\begin{aligned}
 \text{or } \alpha &= (\omega \mu^{1/2} \epsilon^{1/2} / 2) \tan \delta_{\text{eff}} \\
 \text{or } \alpha &= (\omega / 2c) \tan \delta_{\text{eff}} \\
 &= (2\pi r / 2c) \tan \delta_{\text{eff}} \\
 &= (2\pi r / 2c) \tan \delta_{\text{eff}} \\
 \Rightarrow &= (2\pi / 2\lambda) \tan \delta_{\text{eff}} \\
 &= (\pi / \lambda) \tan \delta_{\text{eff}} N_p / m
 \end{aligned}$$

Putting this value of $\tan \delta_{\text{eff}}$ in equation (13) one has

$$\begin{aligned}
 \alpha &= (\pi / \lambda) K^3 a^3 y^2 f(1-f)^4 / [(1-f_y)(1+2f)^4] \\
 &\quad [K(1-f_4) + 3 f_4 K] \\
 &= 8.68(\pi / \lambda) [K^3 a^3 y^2 f(1-f)^4 / [(1-f_y)(1+2f)^4]
 \end{aligned}$$

$$[K(1-f_4) + 3 f_4 K] \text{ dB/km} = 8.68 (\pi / \lambda)$$

dB/km Now for the sand particles

$$\alpha_1 = AL_1 \text{ dB}$$

Similarly for silt particles

$$\alpha_2 = AL_2$$

$$\alpha_3 = AL_3$$

where

$$\begin{aligned}
 A &= 8.68(\pi / \lambda) [K^3 a^3 y^2 f(1-f)^4 / \\
 &\quad [(1-f_y)(1+2f)^4] [K(1-f_4) + 3 f_4 K] \text{ dB/km}
 \end{aligned}$$

Numerical Computation :

In order to obtain the value of normalized phase velocity and effective loss tangent for low frequency and high frequency approximation. The computational work has been done using equations (8), (9), (18) and (19) respectively. Further the value of attenuation constant (a) has also been calculated using equation (20). The graphs have been shown by figs. 1, 2, 3 and 4.

DISCUSSION

Using equations (8), (9), (18), (19), the values of normalized phase velocity, effective loss tangent for low frequency and high frequency approximation have been calculated respectively. The obtained results are shown and plotted in the form of graphs Figures 1, 2, 3 and 4.

It has been found from Fig.(1) that the normalized phase velocity first decreases with increasing frequency and then oscillates with increasing frequency. The expression for different values of fractional volume under low approximation and high approximation both, and further it is also observed from figures 3 and 4 that the loss tangent first increases with increasing frequency and then saturates at high frequency in both the cases. For low and high approximation variation of loss tangent and normalized phase velocity with fractional volume been

shown in figure 3 and 4 respectively. The value of effective loss tangent first increases with increasing fractional volume and then starts to decrease with increasing fractional volume.

It is found from figure 4 that the value of normalized phase velocity decreases with increasing fractional value. This is according to the fact that the increasing value of

Fractional volume increases the number of particles in atmosphere, which ultimately decreases the phase velocity.

Further the variation of attenuation constant with frequency has been shown in fig. 4, where it is found that attenuation constant increasing with increasing frequencies.

REFERENCES

1. Bashir, S.O. and McEwan, N.J., "Microwave propagation in sand and dust storm a review, JEE Proc. vol. 133 pt, Hno.3, pp.391-397 (1986).
2. Ali, A. A., "Millimeter wave propagation in arid land the effect of rain and sand storms" Int. J. infrared millimeter wave (USA) vol. 7, no.3, pp.323-327 (1986).
3. Ghobrial, S.J. and Sami M.S., "Microwave attenuation and cross polarization in dust storms", JEEI Trans on Antenna and propagation, vol. Ap 35, no. 4, pp.418-425 (1987).
4. Shakir A. A., Abdulla H. Al, Rizzo, M. and Mona M.C., "Particles size distribution of Iraqi sand and dust storms and their influence on Micro wave communication", JEEE Trans on Antenna and propagation, vol. Ap 36, pp. 114-126 (1988).
5. Qinglin, Ma Ishimary, A and Kuga, Y. Scattering and depolarization of waves incident upon a slab of random medium with refractive undex different form that of the surrounding media, Radio Sci. (USA), Vol. 25, no. 4, pp.419-426 (1990).
6. Al Hafid, H. T., Gupta S. C, Agrawala N. K. and Srinivasan, A., "Effect of sand storms on millimeter electromagnetic wave propagation, ICOMM, pp. 606-610 (1990).
7. Kerr D. E. (Ed.), "Propagation of short radio waves" Peter Peregrinus Ltd. on behalf of the Institution of electTlcal Engineers (UK) pp.675-676 (1987).
8. Leung Trang Jin Aukong and Robert, T. S., Theory of microwave remote sensing, John Wiley & Sons, pp.458-461 (1985).