Microwave Attenuation and Phase Shift in Sand and Dust Storms

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Abstract—**Based on the forward scattering amplitude function for sand particle under the Rayleigh approximation, the calculation models of microwave attenuation and phase shift due to sand and dust particles is given in terms of lognormal size distribution. The model shows that attenuation and phase shift are found to be dependent on visibility, frequency and complex dielectric constant. Obtained results show that moisture content of particle has significant impact on the attenuation and phase shift, and the higher frequency is, the greater are the influence on attenuation and phase shift. The attenuation and phase shift increase with the increase of moisture content.**

I. INTRODUCTION

The theory of microwave propagation in sand storms has received much attention in the literature owing to the importance of radio relay, communication and remote sensing. Usually, when sandstorms occur, sand particles can rise to such heights above ground level that these particles interfere with microwave or millimeter-wave radio. Consequently, the absorption and scattering effect happens which causes loss in signal energy and additional phase shift. This would greatly affect the coverage, quality of Communication and can even interrupt the local area communications [1].

A number of papers have addressed the problem of prediction of the amount of attenuation and phase shift in sand storms[2]-[11]. These investigators concluded that attenuation by dust storms is not serious except for very dense storms. For different size distribution of sand storms, millimeter propagation has been analyzed by Ahmed [12] and Ali [13]. Based on the Maxwell-Garnett equation [14], millimeter attenuation through sand storms has been investigated by Ruike [15]. Goldhirsh and Bashir obtained the formulas of wave attenuation induced by sand and dust storms in terms of mass of dust per unit volume of air. Dazhang [16] And Zhou [17] also calculated microwave attenuation in sand and dust storms with lognormal size distribution, the models require data for the number of dust particles N or dust concentration, which statistically is difficult to measure accurately.

In this paper, using the relationship of the number of dust particles and optical visibility, the number of dust particles for lognormal size distribution is obtained. The formulas of attenuation and phase shift are presented for microwave propagation in storms, suitable for different frequency. The effects of different frequency and moisture content of particle on microwave attenuation are discussed.

II. PARTICLE DISTRIBUTION IN SAND AND DUST STORMS

Ahmed et al. [12] indicated that log-normal functions fit more adequately than power law or exponential functions for modeling particle size distributions. Analysis of particle sizes carried out in Tengger Desert and Yellow River Beach in China [16] indicates that the particle radii fit log-normal distribution. The log-normal distribution may expressed by

$$N(a) = N_0 p(a) \tag{1}$$

$$p(a) = \frac{1}{\sqrt{2\pi}\sigma a}\exp\left(-\frac{(\ln a - m)^2}{2\sigma^2}\right) \tag{2}$$

where a is particle radius, N_0 is the mean number density of particles of all sizes, $p(a)$ is the function of size distribution. m is the mean of $\ln a$, σ is the variance of $\ln a$.

III. MICROWAVE ATTENUATION AND PHASE SHIFT IN SAND AND DUST PARTICLES

The complex refractive index of a scattering medium given by Van De Hulst [19] can

$$n_e = 1 - i2\pi k_0^{-3}\int_0^\infty S(0)N(a)\,da \tag{3}$$

$$k_0 n_e = \alpha + j\beta' \tag{4}$$

where k_0 is the propagation constant in free-space, $S(0)$ is the is the forward scattering amplitude and N(a)=N_0P(a) is the particle size distribution per unit volume (cm^3) having radii in the region $a \to a + da$. The attenuation and phase shift can then be determined directly as

$$\alpha = 8.686\times10^3\,\frac{2\pi}{k_0^2}\int_0^\infty \mathrm{Re}\left[S(0)\right]N(a)\,da \tag{5}$$

$$\beta = 57.296\times10^3\,\frac{2\pi}{k_0^2}\int_0^\infty \mathrm{Im}\left[S(0)\right]N(a)\,da \tag{6}$$

As the sand particle size is relatively small and the frequency is not too high, i.e. $ka << 1$, using the Rayleigh approximation, the forward scattering amplitude of the sand [3] is

$$S(0) = jk_0^3 \left(\frac{\varepsilon_m^* - 1}{\varepsilon_m^* + 2} \right) a^3 \qquad (7)$$

where a is the radius of sand particle, ε_m^* is the dielectric constant of sand particle, $\varepsilon_m^* = \varepsilon' - j\varepsilon''$.

Most meteorological observations of sand and dust storms are made in terms of optical visibility rather than concentration. It is further useful to adopt the optical attenuation coefficient α_0, which is inversely proportional to visibility [13]

$$V_b = 15/\alpha_0 \qquad (8)$$

where α_0 is measured in decibels per kilometre and is related to the concentration via [18]

$$N_0 = 5.5\times10^{-4} \frac{1}{V_b a_e^2} \qquad (9)$$

$$a_e = \left[\int_0^\infty a^2 p(a) da \right]^{\frac{1}{3}} \qquad (10)$$

where a_e is the equivalent particle radius.

Substituted (2) into (9), the value of N_0 (number of particles of dust) is given as

$$N_0 = 5.5\times10^{-4} \frac{1}{V_b \exp\left[2m + 2\sigma^2\right]} \qquad (11)$$

Substituted (6), (7), (11) into (3), and the attenuation coefficient can then be expressed as

$$\alpha = 1.88 \cdot \frac{F}{V_b} \cdot \frac{\varepsilon''}{(\varepsilon'+2)^2 + \varepsilon''^2} \cdot \exp\left(m + 1.5\sigma^2\right) \qquad (12)$$

Similarly, the phase shift coefficient can be shown that

$$\beta = 4.154 \cdot \frac{F}{V_b} \cdot \frac{(\varepsilon'-1)(\varepsilon'+2) + \varepsilon''^2}{(\varepsilon'+2)^2 + \varepsilon''^2} \cdot \exp\left(m + 1.5\sigma^2\right) \qquad (13)$$

where F is the frequency (GHz), V_b is the visibility (km).

IV. Calculations and Results

Microwave attenuation and phase shift with different moisture content at 14, 24 GHz are calculated using (12), (13). The following parameters [3] are ε_m^* =2.8-j0.035, ε_m^* =3.9-j0.62, ε_m^* =5.5-j1.3 at 0.3% , 5.0%, 10.0% moisture content for 14 GHz, and ε_m^* =2.5-j0.028, ε_m^* =3.6-j0.65, ε_m^* =5.1-j1.4 at 0.3% , 5.0%, 10.0% moisture content for 24 GHz, respectively.

Results are obtained for 0.3%, 5.0%, 10.0% moisture content as shown in Fig. 1 and Fig. 2. From Figs.1-2, moisture content has a significant impact on the wave attenuation. Increase in attenuation is observed at higher moisture content. It is because that the sand particle will absorb moisture in the atmosphere and acts as a water vapor the more humidity in the atmospheric the more condensation nucleus. This induces the significant changes of the dielectric constant of sand particles and causes higher attenuation. So sandstorms with a high humidity have a greater attenuation and signal fading. And the

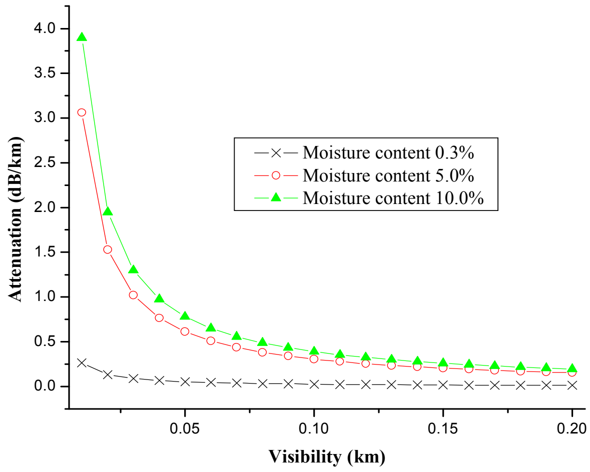

Fig. 1 Variation of attenuation with different moisture content at 14GHz

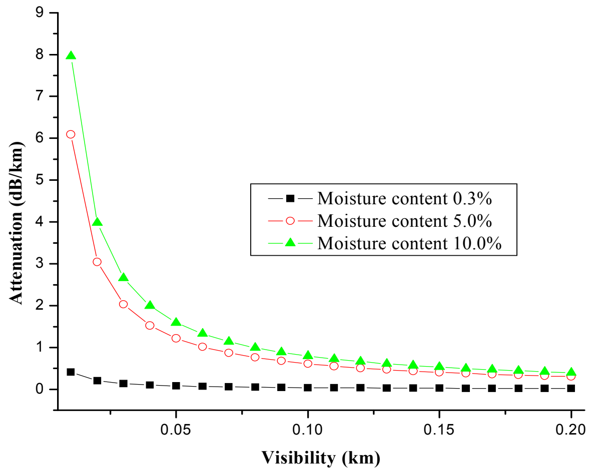

Fig. 2 Variation of attenuation with different moisture content at 24GHz

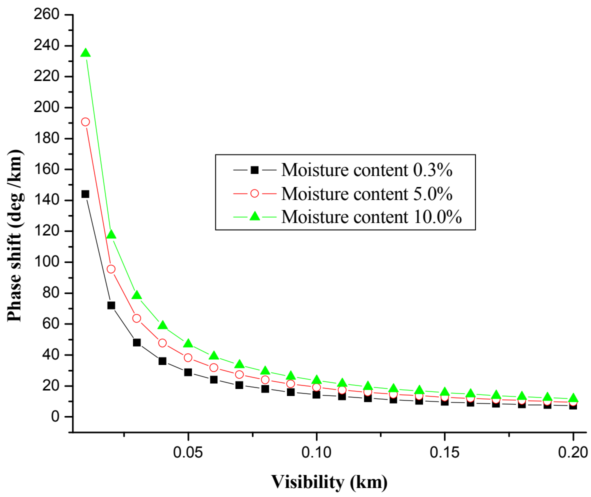

Fig. 3 Variation of phase shift with different moisture content at 14GHz

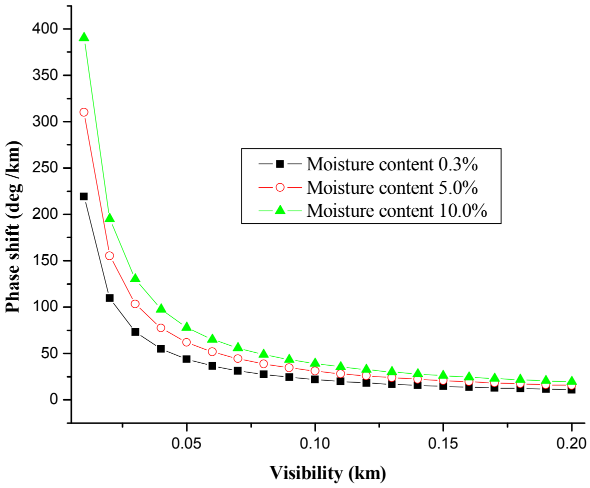

Fig. 4 Variation of phase shift with different moisture content at 24GHz

wave attenuation in sand and dust storms increases as the visibility decreases because wave attenuation is directly proportional to the particle number. Furthermore they have a great influence on the microwave signal for a higher frequency. Figs.3-4 show the relationship between microwave phase shift and visibility under the moisture content 0.3%, 5.0%, 10.0% at 14, 24 GHz.

From Figs.3-4, moisture content has also a significant impact on phase shift. Phase shift increases with the increase of the moisture content; for the same moisture content, the phase shift decreases with the increase of visibility. Under the same moisture content and visibility, the phase shift increases with the increase of frequency.

V. CONCLUSION

This work investigates microwave propagation in dust and dust storms. The mathematical models for evaluating attenuation and the phase shift in dust storms are developed. The proposed model suitable for frequency and different visibility range is based on the method of Rayleigh approximation. The model shows that attenuation and phase shift are found to be dependent on visibility, frequency and complex dielectric constant for the lognormal size distribution. The results of the calculation show that moisture content has a significant impact on the wave attenuation, and microwave attenuation and Phase shift increase with the increase of the moisture content. And the wave attenuation and phase shift in sand and dust storms increase as the visibility decreases because wave attenuation is directly proportional to the particle number. Furthermore they have a great influence on the microwave signal for a higher frequency.

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