Phase Difference between Horizontally and Vertically Polarized Microwave Signals During Sand Storms.

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Abstract: This paper presents Some of the electrical and mechanical properties of sand and dust particles (SDP) are discussed. An expression for optical visibility during storms is given in terms of the relative volume occupied by dust. Expressions for attenuation and phase shift constants for a medium with precipitating dust particles are derived in terms of visibility and wavelength for both vertical and horizontal polarizations. Estimate phase difference between horizontal and vertical polarization which are needed to estimate the attenuation and cross polarization of circularly polarized waves . Computations show that linearly polarized waves suffer but little effect. Circularly polarized waves on the other band are significantly cross polarized. In extremely severe dust conditions at frequencies around 8-12 GHz, phase difference between horizontal and vertical polarizations increases rapidly with decreasing visibility.

Keywords - vertical polarization, horizontal polarization, Cross polarization, Phase shift, Circular Polarization.

I. Introduction

In desert, the effects of sand and dust particles (SDP) on microwave propagation have received some interest, and the knowledge of the complex permittivity of particles suspending or precipitating in the atmosphere is of importance in radio communication and radio meteorology. The attenuation, phase shift constants and cross polarization for a medium with dust or sand particles depends on the frequency, visibility, maximum particles-size, complex permittivity, shape of the scattering particles, concentration, and their orientation relative to the wave polarization, also the attenuation of electromagnetic waves due to dust is predominantly a function of the moisture content of the particles.

The wave propagating in a non-spherical particle along a propagation path changes its polarization as it progresses [5], [10]. This results in cross-polar interference, a situation where a part of the propagated energy or power emitted in one polarization interferes with the orthogonally polarized signal. Depolarization changes a part of signal with a given polarization to a different polarization. When a left-hand circular polarization is depolarized, a small amount of the left-hand circular polarization wave energy interferes with the right-hand circular polarization wave energy. While the wanted polarization, i.e. left-hand circular polarization, is known as the co-polarization, the unwanted polarization i.e. right-hand circular polarization is known as the cross polarization (XP). Thus, a major problem posed by depolarization to dual polarization frequency reuse communication link is the drop in cross polarization isolation (XPI) and the cross polarization interference along the propagation path. Another limiting factor to performance of communication systems is the cross talk between channels i.e. unwanted signal in the channel. Cross talk is a form of interference which depends on the isolation or discrimination between two polarizations. Thus, XPI or cross polarization discrimination (XPD) is a parameter for quantifying dual polarization frequency reuse link performance. The XPD is the ratio of energy levels of the wanted co-polarization signal to that of the unwanted XP signal. While the XPI appears to be frequently used in system design, the XPD is commonly used in propagation experiments.

In this paper. A few dust parameters such as permittivity of dust particles, particle shape and sizes etc. are used as inputs to estimate phase difference between horizontal and vertical

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polarization polarized which are needed to estimate the attenuation and cross polarization XPD of circularly polarized waves to evaluate the effects of dust storms on microwave propagation.

The study of the effect on wireless communication networks due to dust and sand storms has been carried out by many researchers in countries like Libya [1, 2, 4, 6], Sudan [5, 10], Saudi Arabia [7] and Iraq [9]. The main object of this paper is to study the effect of dust and sand storms on wireless communication such as microwave links in the mid- south region of Libya (Hon – Zillah). The effect of the humidity on the complex permittivity where by its effect on both Phase shift between horizontal and vertical polarization polarized and cross-polarization constants in this region, and also the effect of the height (height of towers) on the visibility where by its effect on both the attenuation for a circularly polarization and the cross-polarization constants.

II. PARTICLES SHAPES

To study the effect of sand and dust storms on microwave links we must review some important properties of particles, shape of the scattering particles, particles-size distribution, and their orientation relative to the wave polarization.

Dust and sand particles are random in shape and can't be classified as spheres, ellipsoid or otherwise. However, since computation of the effects of dust storms on wave propagation can be not easily carried out for the case of random shaped particles one needs to assume some suitable geometry. The nearest geometry that approximate particles are ellipsoid or sphere. This geometry has three degrees of freedom, and it gives good approximation to the shape of realistic dust particles, [10] as shown in Figure.1.

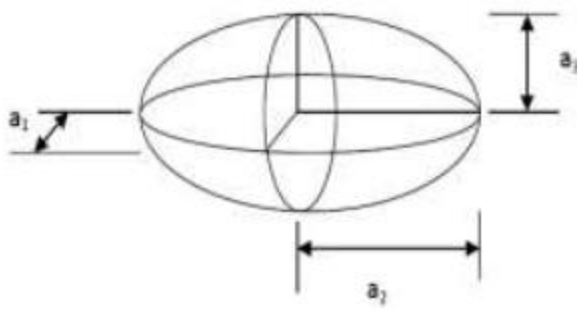

Figure 1 Dust Particle Geometry Approximation.

The average ratio of the axes is given by 1: r_2: r_3 = 1:0.71:0.53; where $r_2 = a_2 / a_1$, $r_3 = a_3/a_2$. [10], [5], In stationary air condition, particles, which assumed ellipsoid shape, fell with the shortest axis vertical and the two other axis are randomly oriented in the horizontal plane, However, it is well known that turbulent air flow is present during dust and sand storms, this situation results in random orientation of the dust particles, Figure .2 shows the dusty medium model used in this study.

In this model the electromagnetic wave is propagated in the positive z direction, there are two important factors to estimate cross polarization discrimination change due to the effect of elliptical particles on microwave links. [16]

1- Orientation of the particle relative to the propagation field, determination of the orientation of particles during storms is difficult because this depends on the motion of air surrounding the particle.

2- The axes ratio a_1: a_2: a_3, the probability distributions of the a_2/a_1 and a_3/a_2 ratios are of interest and use in estimate attenuation and phase constants for ellipsoid particles.

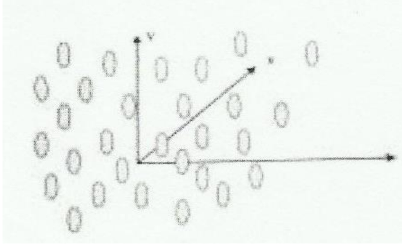

Figure 2. Dusty Medium Model

III. DEPOLARIZATION FACTOR

on microwave propagation it will be assumed that the medium (air with suspending particles) is homogeneous and uniform. The dielectric constant of the medium (this will be referred to by the term storm) depends on the intensity of dust particles per unit volume of air, the polarization of the wave relative to the particles axes, etc. The dielectric constant of the medium with suspending ellipsoids is given by [10].

$$\varepsilon_i = \varepsilon_a \left(1 + v \frac{\varepsilon - \varepsilon_a}{\varepsilon_a + A_i (\varepsilon - \varepsilon_a)}\right) \quad i = 1,2,3 \qquad (1)$$

Where: ε_i is the dielectric of the medium with suspending ellipsoids, ε is the dielectric constant of the ellipsoids material, (dust or/and sand particles), ε_a is the dielectric constant of the medium in which ellipsoids are suspending(in our case air), v is the relative volume occupied by particles, A_i is the depolarization factor along the a_i axis as explained in Figure1, and is defined by using the following equation:

$$A_i = \frac{a_1 a_2 a_3}{2} \int_{-\infty}^{\infty} \frac{ds}{(s + a_i^2)[(s + a_1^2)(s + a_2^2)(s + a_3^2)]^{1/2}} \qquad i = 1,2,3 \qquad (2)$$

For air with suspending dust and/or sand particles, Eq. (1) reduces to [5], [15].

$$\varepsilon_i = \left(1 + v \frac{\varepsilon - 1}{\varepsilon_a + A_i (\varepsilon - 1)}\right) \quad i = 1,2,3 \qquad (3)$$

Consider the ellipsoid geometry shown in Figure 1, with the semi axes fall in the order $a_1 > a_2 > a_3$, (a_1,a_2 and a_3 are orthogonal directions). The depolarization factor in the I direction is given by Eq.(2), and by integration we get: [5], [10]

$$A_1 = \frac{r_1 r_3}{\sqrt{(1 - r_3^2)(1 - r_2^2)}}[f(x,m) - E(x,m)] \qquad (4)$$

$$A_3 = \frac{r_2^2}{r_2^2 r_3^2}[r_2 \frac{r_3}{\sqrt{1 - r_3^2}} - E(x,m)] \qquad (5)$$

Where: $f(x,m)$ the Elliptic integral of the first kind and $E(x,m)$ the second kind, the Solution of Elliptic Integral of First Kind and the second kind given by. [10]

IV. DUST MASS DENSITY AND VISIBILITY

The number of particles suspended per unit volume of air (mass concentration), is one of the important parameters needed to compute the medium propagation constants.

A measure of severity of a dust storm that is used in meteorology is visibility; needless to mention that visibility decreases with increasing intensity of dust in a storm. It is found that visibility is related to the mass of dust per cubic meter of air by. [4]

$$M = {}^{C}/_{V^{\gamma}} \quad (6)$$

Where: M is the dust or sand mass in Kg/cubic meter of air, V is the visibility in Km, C and γ are constants that depend on the type of land from which the storm originated as well as the climatic conditions. The following values are applicable to conditions in Libya C = 2.3*10-5and γ= 1.07. [10]

As is well known visibility decreases with increasing number of particles in the atmosphere. As we saw previously by Eq. (6), the mass of suspending dust per unit volume of air is related to visibility. From measurements of dust concentration and visibility the following empirical relationship between visibility V (in km) and mass density ρ (in gm/cm3) has been obtained. [17]

$$\rho = {}^{C}/_{v \times V^{\gamma}} \quad (7)$$

Where: v is the relative volume occupied by particles (m^3 of particles /m^3 of air).The visibility during dust and/or sand storms increases as the height is increased. Chepil and Woodruff [11], arrived at the following empirical relation for the variation of dust or/and sand mass concentration (M, kg/m^3) with height (h, m).

$$M = {}^{a}/_{h^{b}} \quad (8)$$

Where: a and b are constants that vary a little from one year to another. They depend on the climatic conditions, meteorological factors and the particle size distribution of the dust and the sand. [16]

By substituting for M from Eq. (7) into Eq. (8), then visibility can be written as:

$$V^{\gamma} = {}^{C \times h^{b}}/_{a} \quad (9)$$

V. ANALYSIS

A. Dust Complex Dielectric Constant.

From the values of the complex permittivity and the relative volume of all substances, we can calculate the complex permittivity of the composite component by using the Looyenga equation as given by. [15],[3]

$$\varepsilon_m^{1/3} = \sum_{i=1}^{n} \varepsilon_i^{1/3} v_i \quad (10)$$

Where ε_m is the complex dielectric constant of the mixture, ε_i is the complex dielectric constant of the i^{th} substance.[5], v_i is the relative volume of the i^{th} sample from the volume of the total sample.

The average concentration density of sand and dust particles in study area is equal to 2.3275 gm/cm^3, and the average of complex permittivity of samples equal to ε_m =6.0891-j0.1656. [6]

B. Estimate of Air Relative Humidity.

The complex permittivity depends on moisture contents in samples. Sharief [5-16] arrived at the empirical relation for the variation of complex permittivity with relative humidity. The effect of relative humidity on the complex permittivity in the studied area given by. [6]

$$\acute{\varepsilon} = 6.0891 + 0.04H - 7.78 * 10^{-4}H^2 + 5.56 * 10^{-6}H^3 \quad (11)$$

$$\ddot{\varepsilon} = 0.1656 + 0.02H - 3.71 * 10^{-4}H^2 + 2.76 * 10^{-6}H^3 \quad (12)$$

C. Estimation of the Attenuation and phase Shift for Non- spherical Particles.

The propagation constant of the Dust storm is given by: [10], [12]

$$\gamma_i = \alpha_i + j\varphi_i \quad (13)$$

The attenuation and phase shift constants are obtained as the average of all α_i and , φ_i respectively, thus:

$$\alpha = -\frac{\pi}{3\lambda}\sum_i Im \frac{v}{A_i + {}^1/_{(\varepsilon-1)}} \quad (14)$$

$$\varphi = \frac{\pi}{3\lambda}\sum_i Re \frac{v}{A_i + {}^1/_{(\varepsilon-1)}} \quad (15)$$

Equations (14) and (15) may be used to determine the attenuation and phase shift when a wave of known polarization propagates through a storm.

A circular polarized wave may be resolved into two linearly polarized waves of equal magnitudes but with their polarizations orthogonal and 90^o out of phase. Since the attenuation and phase constants for vertical and horizontal polarizations in a storm are not the same, cross polarization is induced. It is known that the cross-polar discrimination (XPD) for a circular polarized wave is given by. [13], [8]

$$XPD = 10 \log\_10 |(1 + 2m \cos\varphi + m\hat{}2) / (1 - 2m \cos\varphi + m\hat{}2)| \quad (16)$$

The quantities *m* and φ can be determined for a wave propagating in a storm immediately as follows:

$$m = e^{|\alpha_h - \alpha_v|D} \quad (17)$$

$$\varphi = (\varphi_h - \varphi_v)D \quad (18)$$

Where: D is the path length in the storm in kilometers.

The attenuation of a circularly polarized wave given by: [10]

$$att(dB) = -20\log \sqrt{\frac{1 + 2m\cos\varphi + m^2}{4}}\ e^{-\alpha_v D} \quad (19)$$

Assumed all dust particles to be ellipsoids with axes ratios equal to the average axes ratios $a_1 : a_2 : a_3 = 1 : 0.71 : 0.53$. of some 500 particles that were studied using microscopic measurements.

These ratios are in good agreement with the results obtained by McEwan and Bashir. [17], [10]. We can use the equations obtained by S.I. Ghobrial and S. M Sharief [5]. To estimate the attenuation and phase constants for vertical and horizontal polarization.

To evaluate the attenuation and phase constants for vertical and horizontal polarization the quantity x defined by:

$$x_i = \sum_i \frac{1}{A_i + {}^{1}/_{(\varepsilon - 1)}} \qquad i = 1,2,3 \qquad (20)$$

Was evaluated for two values of ε these are the dielectric constant of dust with relative humidity 21% and 72%. Table: I gives the outcome of these computations. The values of A_1, A_2, and A_3 were taken from Eq. (4), and (5).

Table I: Dielectric Constant of Dust with relative humidity 21% and 72%

dielectric constant (ε)	X_1	X_2	X_3
6.638-j0.448	4.3325-j0.2636	2.8032-j0.1101	1.0606-j0.0157
7.011-j0.713	4.5563-j0.4069	2.898-j0.1638	1.0743-j0.0225

From equations obtained by S.I. Ghobrial and S. M Sharief [5], [10], the attenuation and phase constants for vertical polarization and horizontal polarization can be written as:

$$\alpha_V = -\frac{\pi}{\lambda}\, v\, Im\, x_3 \qquad (21a)$$

$$\varphi_V = \frac{\pi}{\lambda}\, v\, Re\, x_3 \qquad (21b)$$

$$\alpha_h = -\frac{\pi}{2\lambda}\, v\, Im(x_1 + x_2) \qquad (22a)$$

$$\varphi_h = -\frac{\pi}{2\lambda}\, v\, Re(x_1 + x_2) \qquad (22b)$$

Using Equations.(7), (11), (12), (14), (15), and (20), and values of 'x_i' given in Table :I, the following expression for attenuation and phase constants were obtained in terms of visibility *V*, wavelength λ, and path length *D* in the storm:

For relative Humidity (H=21%): ε = 6.638-j0.448:

$$\alpha_v = 4.2464 * 10^{-4} D/(\lambda V^{\gamma}) \qquad (23a)$$

$$\Phi_v = 0.1878 * D/(\lambda V^{\gamma}) \qquad (23b)$$

$$\alpha_h = 5.0 * 10^{-3} D/(\lambda V^{\gamma}) \qquad (24a)$$

$$\Phi_h = 0.6348 * D/(\lambda V^{\gamma}) \qquad (24b)$$

For relative Humidity (H=72%): ε = 7.011-j0.713:

$$\alpha_v = 6.0552 * 10^{-4} D/(\lambda V^{\gamma}) \qquad (25a)$$

$$\Phi_v = 0.1911 * D/(\lambda V^{\gamma}) \qquad (25b)$$

$$\alpha_h = 7.7 * 10^{-3} D/(\lambda V^{\gamma}) \qquad (26a)$$

$$\Phi_h = 0.6631 * D/(\lambda V^{\gamma}) \qquad (26b)$$

In the above expressions λ is the wavelength in centimeter, *V* is the visibility in kilometers, *D* is the path length in the storm in kilometers.

We will be using Equations. (17), (18), (19), and (23-26) to calculate the attenuation for a circularly polarized wave, and calculate the phase difference between horizontally and vertically polarized waves as a function of visibility for a path length of 1 km, and we can use the Eq. (16), to estimate the cross polarization discrimination for values of path length. By using Computer Program (Matlab), the results are shown in Table II, III, and Figure 3, 4.

Table II: Attenuation per km for two types of dust at height=10m

Visibility(km)	**α (dB/km) at ε = 6.8190-j0.4507**	**α (dB/km) at ε = 7.1927 - j0.7157**
0.008	*0.0951*	*0.1281*
0.048	*0.0091*	*0.0135*
0.088	*0.0046*	*0.0068*
0.128	*0.0030*	*0.0045*
0. 168	*0.0022*	*0.0033*
0.208	*0.0018*	*0.0027*
0.248	*0.0015*	*0.0022*
0.288	*0.0012*	*0.0019*

Table III: Phase difference between Horizontal and Vertical polarizations at height=70.

Visibility(km)	**Φ(degree) at ε = 6.8190-j0.4507**	**Φ(degree) at ε = 7.1927 - j0.7157**
0.004	*22.78*	*23.99*
0.024	*3.349*	*3.528*
0.044	*1.751*	*1.845*
0.064	*1.173*	*1.235*
0.084	*0.877*	*0.923*
0.104	*0.697*	*0.735*
0.124	*0.578*	*0.609*

D. Estimation of the Cross Polarization Constant (XPD):

For circular polarization and dust particles are not spherical, cross polarization can be serious. We can use the equations (16) to estimate the cross polarization discrimination for values of path length (D). the results are given in figures.5.

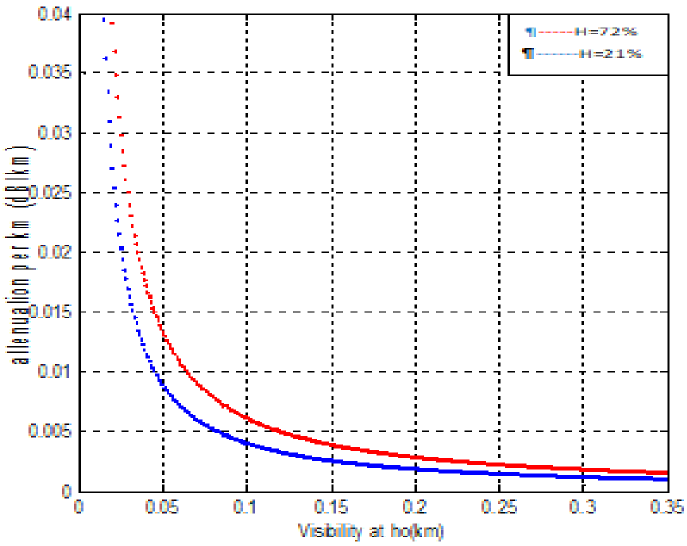

Figure.3 Attenuation per km at height= 10m and for for two types of dust.

I. CONCLUSION:

Some of the properties of (SDP) were reviewed. and its effects on microwave propagation were. It was found that for linear polarization the effect of dust storms is almost negligible except for very dense storms; i.e., storms with visibilities less than a few meters. Cross polarization in terrestrial link is not expected since particles precipitate with one axis parallel to the vertical. For circular polarization, cross polarization can be serious when visibilities fall below 100 m over about 10 km of path. Or below 10m over about 1 km of path. It is theoretically possible for circular polarized signal to be cross polarized as to cause an apparent signal loss, but this would require extremely severe dust conditions at frequencies around 8-12 GHz. Simple expressions for attenuation and phase shifts of linearly polarized waves were derived in terms of the path length, wavelength, and visibility in study area. The attenuation for non-spherical particles with visibility equal 8m (worst case) at a humidity 21% and 72% at any height, equal (0.0729dB/km and 0.1004dB/km respectively), and For visibilities less than 50m, phase difference between horizontal and vertical polarizations increases rapidly with decreasing visibility. The effect of dust humidity on phase difference and cross polarization is not significant for different visibilities.

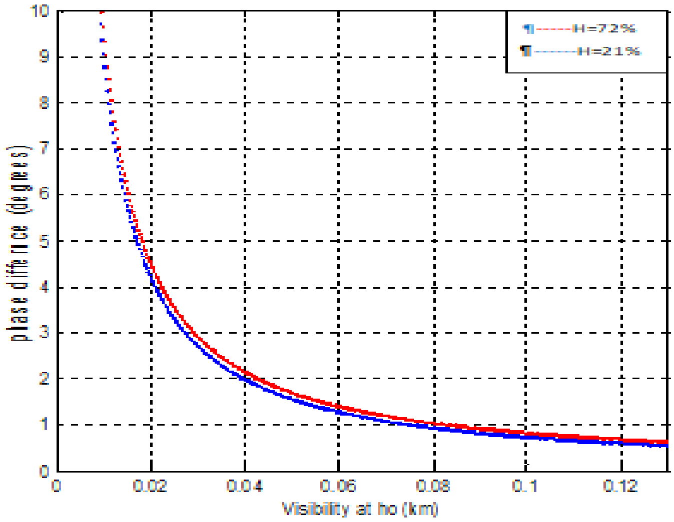

Figure.4. Phase difference(degree) at height=10m.

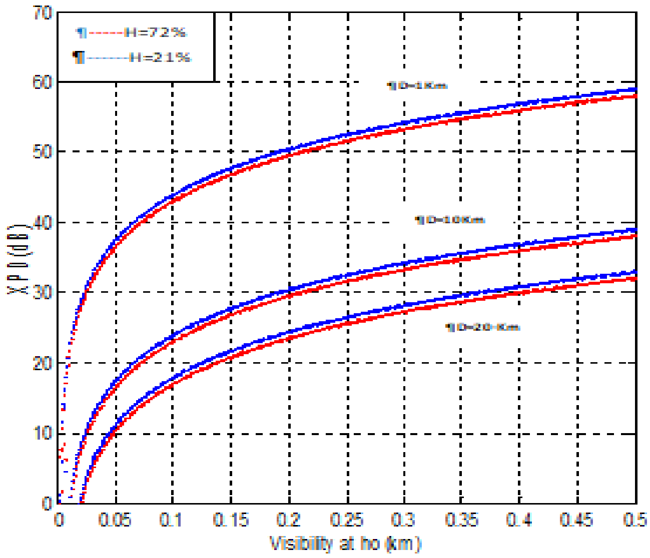

Figure.5.Cross Polarization Discrimination (dB) at height= 10m.

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