Effect of sand and dust storms on microwave propagation signals in southern Libya

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Abstract—The propagation of Electromagnetic waves in millimeter band is severely affected by rain and dust particles in terms of attenuation and de-polarization. There is a growing interest in the effect of dust particles on the propagation of microwaves. This is brought by the increasing number of terrestrial and satellite links in those regions that encounter dust and/or sand storms. Computations of these effects require knowledge of electrical properties of the scattering particles and climate conditions of the studied region.

Libya has a large area and it is counted as a country having desertification climatic. Wireless communication networks and microwaves systems has been installed in the southern part of Libya, where there are dust and sand storms that may affect the microwave signal propagation. When microwaves and millimeter waves pass through a medium containing precipitations like sand and dust particles, the signals get attenuated through absorption and scattering of energy out of beam by the sand and dust particles. The main object of this paper is to study the effect of sand and dust storms on wireless communication, such as microwave links, in the southern region of Libya (Sebha, Ashati, Obari, Morzok, Ghat) by determining the attenuation. The result should that there are some consideration that has to be taken into account in the communication power budget.

Keywords—Attenuation; Scattering; Transmission Loss

I. INTRODUCTION

In the course of increasing data transformation of wireless communication systems, embodied in Microwave links surroundings. These systems are actually influenced by climate circumstances. The performance of service of many applications, for example cellular telephones, public service radio, pagers, broadcast television, radio stations, and differential GPS transmitters, CDMA and WiMax networks, that require RF or microwave propagation from point to point very near the earth’s surface, depends on many factors such as area of coverage, and climate conditions. The millimeter waves bands are in the short wavelengths range; unfortunately, the shorter the wavelength the more attenuation will be induced by absorption and scattering due to rain drops, dust and sand particles in the radio path. The attenuation caused by sand and dust particles is one of the major problems in the utilization of microwave and millimeter wave bands for terrestrial and space communication.

The attenuation and phase shift constants 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 orientation relative to the wave polarization, also the attenuation of electromagnetic waves due to dust is predominantly function of the moisture content of the particles.

Libya is considered as desertification country, in the last few years many problems in wireless communication networks have been recorded in windy and sandy days in the southern part of Libya; No scientific reason has been given for these problems. Wind storms may last for days, reducing visibility to just tens of meters or as little as few meters.

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 southern region of Libya (Sebha, Ashati, Obari, Morzok), where the effect of the dust and sand on the microwave links in this area has not been studied before, neither the effect of the humidity on the complex permittivity nor the antenna height on the visibility, whereby its effect on both attenuation and cross-polarization constants in this region.

II. THE DIELECTRIC CONSTANT OF DUST AND SAND

Knowledge of the dielectric constant of particles suspending or precipitating in the atmosphere is of importance in radio communication and radio meteorology. In desert and semi-desert regions dust and sand storms are frequently encountered and it is therefore of interest to investigate the dielectric constant properties of these particles [1].

A number of models are available to estimate the dielectric constant of a sand and dust samples. Where dielectric constant of mixture \(\varepsilon_m\) depends on the complex dielectric of the
substance \((\varepsilon_i)\) and its relative volume \((\bar{V}_i)\). We can calculate the complex permittivity of the composite component by using the Looyenga equation as given by \([2]\).

\[
\varepsilon_m^{1/3} = \sum_{i=1}^{n} \bar{V}_i \varepsilon_i^{1/3} \quad ............ (1)
\]

Where: \(C_m\) is the complex dielectric constant of the mixture. \(\varepsilon_i\) is the complex dielectric constant of the \(i^{th}\) substance. \(\bar{V}\) is the relative volume of the \(i^{th}\) sample from the volume of the total sample. The permittivity of materials at microwave frequencies is \(\varepsilon = \varepsilon' - j\varepsilon''\), where \(\varepsilon'\) is referred to the dielectric constant and \(\varepsilon''\) is the dielectric loss factor. The complex permittivity also depends on frequency of operation and moisture content. In general, the moisture cause increase of both real and imaginary parts of the complex permittivity which depend on chemical composition of dry soil samples \([3]\).

III. VISIBILITY DURING DUST STORMS

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 \([1]\).

\[
M = \frac{C}{V} \quad ............ (2)
\]

where \(M\) is the mass of dust in kilograms, \(V\) is the visibility in kilometres, and \(C\) and \(\gamma\) are constants that depend on the distance from the point of origin of the storm, type of soil and climatic conditions at the origin. The following values are applicable to conditions in Libya: 

\(C = 2.3 \times 10^{-5}\) and \(\gamma = 1.07\)

From measurements of dust concentration and visibility the following empirical relationship between visibility \(V\) (in km) and mass density \(\rho\) (in gm/cm\(^3\)) has been obtained \([1]\):

\[
\rho = \frac{C}{V^{\gamma}} \quad ............ (3)
\]

Where \(\bar{V}\) 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, \([4]\), arrived at the following empirical relation for the variation of dust or/and sand mass concentration (M, kg/m\(^3\)) with height(h, meter).

\[
M = \frac{a}{h^b} \quad ............ (4)
\]

Where \((a)\) and \((b)\) are constants that vary a little from one year to another. They depend on the climatic conditions, meteorological factors and particle size distribution of the dust and sand \([13]\).

By substituting for \(M\) from eq. \((2)\) into eq. \((4)\), then visibility can be written as:

\[
V^{\gamma} = C \times h^b \frac{a}{h^b} \quad ............ (5)
\]

Let the visibility at some reference height \(h_o\) to be \(V_o\), thus \((3-5)\) yields

\[
V^{\gamma} = V_o^{\gamma} \left[ \frac{h}{h_o} \right]^b \quad ............ (6)
\]

IV. MEASUREMENTS AND ANALYSIS

The Southern part of Libya was chosen as the study region of measuring the impact of dust and/or sand storms on the wireless communication systems such as mobile phone and microwave links, because the region is famous as desert climate and fast wind filled with dust from time to time. Climate information for the region of study, was obtained from weather stations, and more information was obtained from people living in the area, they cleared that frequent interruption and fluctuation in mobile phone signals occurs during strong wind. From data recorded by the surveillance system of GSM during dust storms, it turned out that locations which get fluctuations sometimes experience signal link disconnections between stations or low coverage signals. Nine places were chosen for collecting the sand and dust they are (Albeder, Dleame, Labide, Sebha Air port, Ramlat Zelaf, Bergen, Agar, Gota, Algorda ), which covers the area of study. The collected samples have to be analyzed and compared with the climate conditions to estimate the factors which are needed for calculating the effect of dust storms on microwave links. In this work all the samples are collected at the nine sites, during different times of the year, on the roofs of the building near the communication towers or from plastic cans which were placed in the towers at a height of 13m.

A. Meteorological data for the regional study

The region of study is located between three meteorological stations namely Sebha, Obari and Ghat; we refer to the Libyan centre of metrology for getting the meteorological data of the site selected. The collected meteorological data obtained for a period of 30-years (from 1971 up to the end of 2000) from three recording stations, the monthly average relative humidity, Max. Temp.(C), Min. Temp.(C), Wind Speed Km/h and Rainfall Q.mm. From the data mention above the following summary can be pointed out:

1) The highest average temperature recorded from 20 to 40 C degrees.
2) The highest average percentage of humidity was recorded from 20 to 51%.
3) The wind speed recorded from 10 to 22 km/h.
4) The proportion of rainfall recorded from 0 to 3.4 mm.
5) The maximum temperature recorded 45 C degrees.
6) The maximum rate of humidity was recorded about 60%.
B. Analysis of the samples

For this study we need to do some analysis for samples such as particle size distribution, average density and chemical composition, which are used to compute the dielectric constant and attenuation factors. After we made a search on Libyan laboratories and labs, we found two laboratories are available to carry out the analysis of the samples (Industrial Research Centre and Libyan Petroleum Institute in Tripoli), where the results as shown in table I, and table II as follows:

<table>
<thead>
<tr>
<th>S No.</th>
<th>SiO₂</th>
<th>Fe₂O₃</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.14</td>
<td>0.76</td>
<td>0.32</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>2</td>
<td>1.14</td>
<td>0.76</td>
<td>0.32</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>3</td>
<td>1.14</td>
<td>0.76</td>
<td>0.32</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>4</td>
<td>1.14</td>
<td>0.76</td>
<td>0.32</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>5</td>
<td>1.14</td>
<td>0.76</td>
<td>0.32</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>6</td>
<td>1.14</td>
<td>0.76</td>
<td>0.32</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>7</td>
<td>1.14</td>
<td>0.76</td>
<td>0.32</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>8</td>
<td>1.14</td>
<td>0.76</td>
<td>0.32</td>
<td>0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>9</td>
<td>1.14</td>
<td>0.76</td>
<td>0.32</td>
<td>0.14</td>
<td>0.02</td>
</tr>
</tbody>
</table>

TABLE II PSD AND DENSITY OF SAMPLES

<table>
<thead>
<tr>
<th>S No.</th>
<th>PSD</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>sand</td>
<td>2.5426</td>
</tr>
<tr>
<td>2</td>
<td>sand</td>
<td>2.5685</td>
</tr>
<tr>
<td>3</td>
<td>dust</td>
<td>2.6138</td>
</tr>
<tr>
<td>4</td>
<td>sand</td>
<td>2.62714</td>
</tr>
<tr>
<td>5</td>
<td>dust</td>
<td>2.4202</td>
</tr>
<tr>
<td>6</td>
<td>dust</td>
<td>2.9232</td>
</tr>
<tr>
<td>7</td>
<td>dust</td>
<td>2.4732</td>
</tr>
<tr>
<td>8</td>
<td>dust</td>
<td>2.5425</td>
</tr>
<tr>
<td>9</td>
<td>dust</td>
<td>2.4764</td>
</tr>
</tbody>
</table>

C. Calculation of the Complex Permittivity for Samples

By using the results presented in table I, and table II, which represent the relative volume of the i-th sample from the volume of the total sample. The complex permittivity of each substance is given in table III and equation (1) can be used to estimate the complex permittivity of each sample [2], by using computer program, where the results are given in table IV.

<table>
<thead>
<tr>
<th>Compound</th>
<th>ε&quot;' - jε&quot;''</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>4.43-j0.04</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>12.66-j1.31</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>16.58-j0.93</td>
</tr>
<tr>
<td>CaCO₃</td>
<td>8.22-j0.12</td>
</tr>
<tr>
<td>MgCO₃</td>
<td>5.03-j0.17</td>
</tr>
<tr>
<td>CaSO₄</td>
<td>5.01-j0.08</td>
</tr>
</tbody>
</table>

Where the average density of all samples equal to 2.5764 g/m³.

D. Estimate of Air Relative Humidity

The complex permittivity depends on moisture contents in samples, S. M. Sharief [5] arrived at the following empirical relation for the variation of complex permittivity with relative humidity.

\[ \varepsilon' = 6.3485 \times 10^{-4} H^2 + 5.56 \times 10^{-3} H^3 \] (7)

\[ \varepsilon'' = 0.0929 \times 10^{-2} H^2 + 2.76 \times 10^{-6} H^3 \] (8)

Where H is the air relative humidity (percentage).

E. Calculate the attenuation Constant

In this study, we will use exactly the same expression obtained by Samir I. Ghobrial [1] using an analysis based on the work of Maxwell Garnett. Also the effect of the height (height of towers) on the visibility thereby its effect on both the attenuation constants in this region as follows:

\[ \alpha = \frac{2.46 \times 10^5 \times \nu \times \frac{C}{\rho \times \nu + \gamma}}{\lambda \times \left( \frac{h}{2} \right)^2 + \varepsilon''} \] (9)

\[ \nu = \frac{C}{\rho \times \nu + \gamma} \] (10)

Where \( \nu \) is the relative volume occupied by particles (m³ of particles /m³ of air) C and \( \gamma \) are constants that depend on the distance from the point of origin of the storm,
type of soil and climatic conditions at the origin. The following values are applicable to conditions in Libya, $C=2.3 \times 10^{-5}$, $\gamma = 1.07$

Where: $\lambda$ is the wavelength (in meters), $V_o$ is the visibility at $h_0$; its minimum value about 4m, $h_0 = 2m$ is the reference height, $C$ & $C''$ are the values obtained from the average complex permittivity of the samples collected in the studied region is equal to 6.3485 and 0.0929 respectively and $\rho$ is the average measured density of the samples collected in the studied region is 2.5764 gm/m$^3$, where the results are as follows:

Figures (1) showing the relation between attenuation per km and visibility at $h=12m$ in the region of study for humidity 0%, 60% and 100%.

Figures (2) showing the relation between attenuation per km and visibility at $h=17m$ in the region of study for humidity 0%, 60% and 100%.

Figures (3) showing the relation between attenuation per km and visibility at $h=20m$ in the region of study for humidity 0%, 60% and 100%.

CONCLUSION

The effect of dust and sand storms on microwave signal propagation in southern part of Libya were investigated.

It was found that the major constituents of sample are SiO$_2$, CaO, Al$_2$O$_3$, and Fe$_2$O$_3$. Where the Silicon dioxide has the major influence on the real part of the permittivity of dust. On the other hand aluminium oxide has the greatest effect on the imaginary part.

It was also calculate that the average of density and complex permittivity of samples in Southern region are equal to 2.5764 gm/m$^3$, 6.3485-j0.0929 respectively and the attenuation constant of the region of study is equal to 0.2412 dB/km. Where the microwave signal attenuation, due to dust storms with visibility equal 4m (worst case), and with a humidity equal to 0 %, 60% and 100% is serious at any height.

REFERENCES