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School of Applied Sciences and Engineering
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Effects of Suspended Dust Particles in Air During Sand Storms on Microwave Links Case Study Al-Joufrah Region

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ ۖ

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Abstract

Microwave communication in southern parts of Libya may be affected by dust and sand storms. AL-Joufrah region is located at mid south of Libya has high wind speed, and has too frequent dust storms. Microwave signals in this area may suffer some attenuation and depolarization due to the presence of any carried particles in air. The effect of the dust particles on the microwave links in this area has not been studied previously and this is the first to study it.

The study of electromagnetic signals propagation in microwave band through dust storm, requires knowledge of some of the electrical properties of the dust particles and climate conditions at the studied region. This required to collecting of samples of sand and dust particles, measure their concentration, particle size distribution and chemical analysis which essential to calculate the complex permittivity of samples.

In this Dissertation we will study the effect of dust and sand storms on microwave link taking in account the effect of humidity on complex permittivity of soil samples and the effect of the height of towers on attenuation, phase shift. and cross depolarization.

The main object of this Dissertation is to study the effect of sand and dust storms on microwave communication links, in the AL-Joufrah region by determining the attenuation, phase shift. and cross depolarization. The result showed that there is some consideration that has to be taken into account in the microwave communication link.

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CHAPTER 1

Introduction

1.1.Introduction:

Many radio communication applications require RF or microwave propagation from point to point very near the earth's surface examples of such applications include cellular telephones, pagers, broadcast television, radio stations, and differential GPS transmitters. The performance of service depends on many factors such as area of coverage, and climate conditions.

Radio relay links and satellite communication systems are used to convey voice, data, and/or image signals all over the country, due to the large area of the country and most of her is desert, where microwave links will be extended over a large desert areas, to serve the scattered population, radio wave propagation is affected by the climatic conditions, and the signals may suffer some attenuation and/or depolarization due to the presence of any carried particles in air, e.g. dust, sand and rain drops. If the excess attenuation exceeds the available fade margin, the result is service interruption.

Propagation of microwave signal may suffer attenuation and cross polarization by the suspended particles such as dust, rain, snow, etc. The propagation of microwave signals in dust/sand storms found considerable interest recently, due the increasing number of terrestrial and satellite links established in the regions that frequently encounter dust or sand storms as well as many radar applications at high frequencies. The attenuation of the microwave signals in dusty media may arise from two physical mechanisms, (i) absorption and (ii) scattering of energy by the suspended dust particles. The centimeter 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.

In desert, the effects of dust particles 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.

AL-Joufrah region which is located at the mid north of Libya has high wind speed, desert climate, and has too frequent dust and sand storms, such storms may last for days, reducing visibility to hundreds of meters or as little as few meters. The effect of the dust and sand on the microwave links in this area has not been studied, neither the effect of the humidity on the complex permittivity whereby its effect on both attenuation and cross-polarization constants in this region, and also the effect of the height (height of towers) on the visibility whereby its effect on both the attenuation and the cross-polarization constants in this region and due to the importance of this region for the Libyan microwave communication, where it links north Libya by its south and east by west. Beside the expectation of different chemical analysis of the dust and sand, we have chosen this region for study.

1.2. Related Previous Works:

The effects of sand and/or dust storms on the propagation have been considered by only few investigators in Sudan, Iraq, Saudi Arabia and recently in Libya. This is because most of the developed countries do not face sand dust storms, and they have completely different problems due to rain and snow.

1.2.1. Related Work in Libya:

A study carried out by Hassan Aldeeb [1] in the east part of Libya along the microwave link Agedabia to Jalo between longitude (20.13 to 21.40N) and latitude (30.45 to 29.10 E) in spring of 2006. The analysis of the samples showed that the average of the complex permittivity for the studded area is $\epsilon_r = 4.71965 - j0.08195$.

From size analysis (Particle Size Distribution) of the samples it was classified to two types, sand if it has radius 150 micrometer and higher, and it is dust if the radius is lower than 150 micrometer. The average measured density of the samples collected in the studied area is 1.5067 gm/cm^3 .

The measurements have shown that an average attenuation constant of dry samples is 0.00597 db/km at 3GHz, so the attenuation to signal that results from the dust and/or sand storms is negligible, this is based on the average attenuation per unit length and the maximum distance between stations which is 55km (total attenuation 0.328 dB).

The relation between attenuation and visibility in Agedabia – Jalo region is shown in figure (1.1).

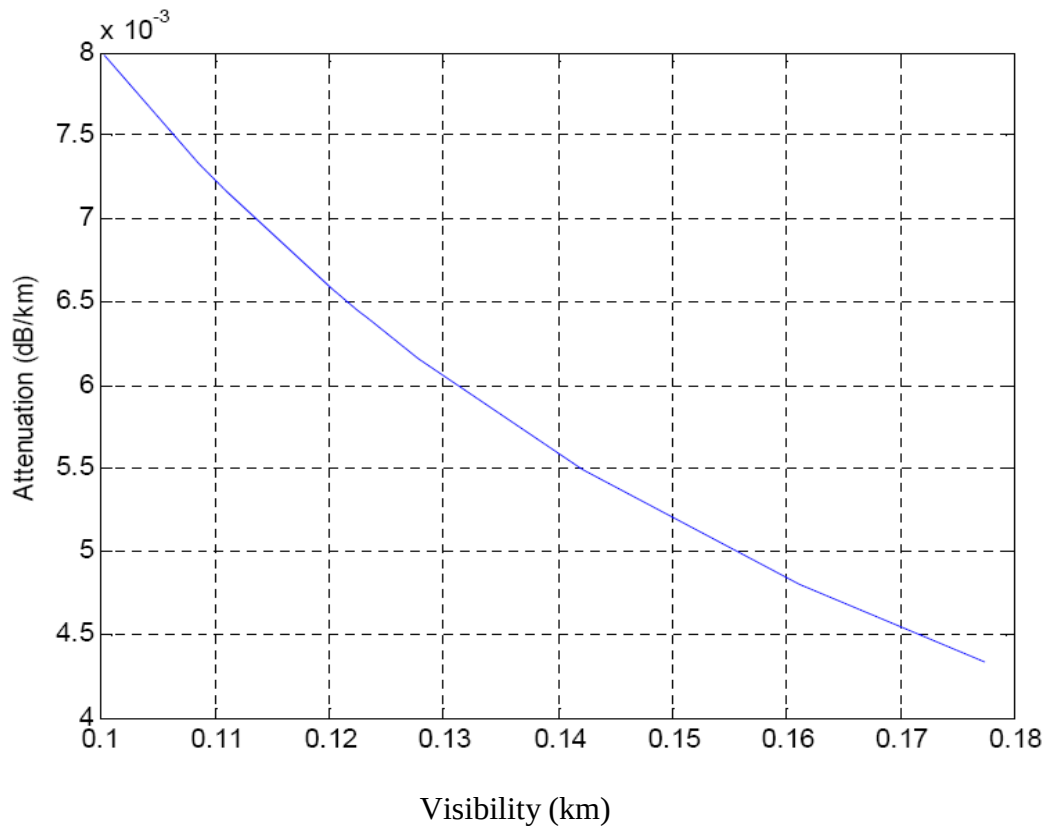


Fig.(1.1):-The Relation Between Attenuation and Visibility [1]

A following study carried out by Nafati Abasallam [2], covered the north part of Libya along the microwave link Abo-Njeem between longitude (15.15 to 15.56N), and latitude (31.7 to 29.07E) in spring of 2008. The analysis of the samples showed that the average of the complex permittivity for the studded area is $\epsilon_r = 5.6344 - j0.1060$, The average of density of samples in Abo-Njeem region is equal to 2.478 gm/cm^3 .

From size analysis (Particle Size Distribution) of the samples, about 87% of the samples have diameter between (125-150 μm), therefore the dominant grain size is a fine sand size.

The attenuation of signal due to dust storms in study area in Libya with visibility equal 5m at a humidity of 0%, humidity of 58.3 %, and 100% is serious at any height, this is based on the attenuation per unit length and the maximum distance between stations which is 51 km (total attenuation 0.3978dB, 1.718dB and 2.8254dB respectively).[2].

The relation between attenuation and visibility in Abo-Njeem region is shown in figure (1.2).

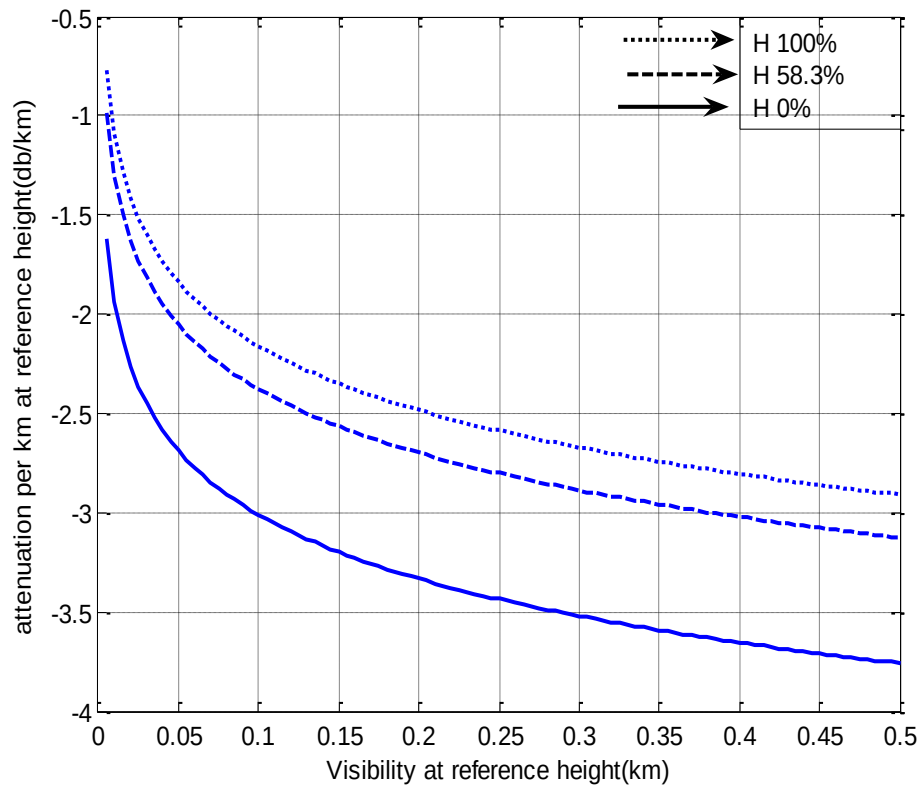


Fig.(1.2):-Attenuation per km at Height=2m and for H=0%, 58.3% and100%.[2]

A following study carried out by Jumaa.O.A.Mesbhy [3], under the supervisor of Dr. Saeh Elhabash covered the south west part of Libya along the microwave link Wadi-ALshati between longitude (14 31 17 to 13 55 31 N) and latitude (27 26 27 to 27 44 52E) in spring of 2009. The analysis of the samples showed that the average of the complex permittivity for the studded area is $\epsilon_r = 5.6309 - j0.2033$. The average of density of samples in Wadi-ALshati region is equal to 1.442 gm/cm^3 , the attenuation of signal due to dust storms with visibility equal 6m at a humidity of 0 % is negligible at any height, this is based on the attenuation per unit length and the maximum distance between stations which is 85 km (total attenuation 0.0923 dB).

The relation between attenuation and visibility in Wadi-ALshati region is shown in figure (1.3).

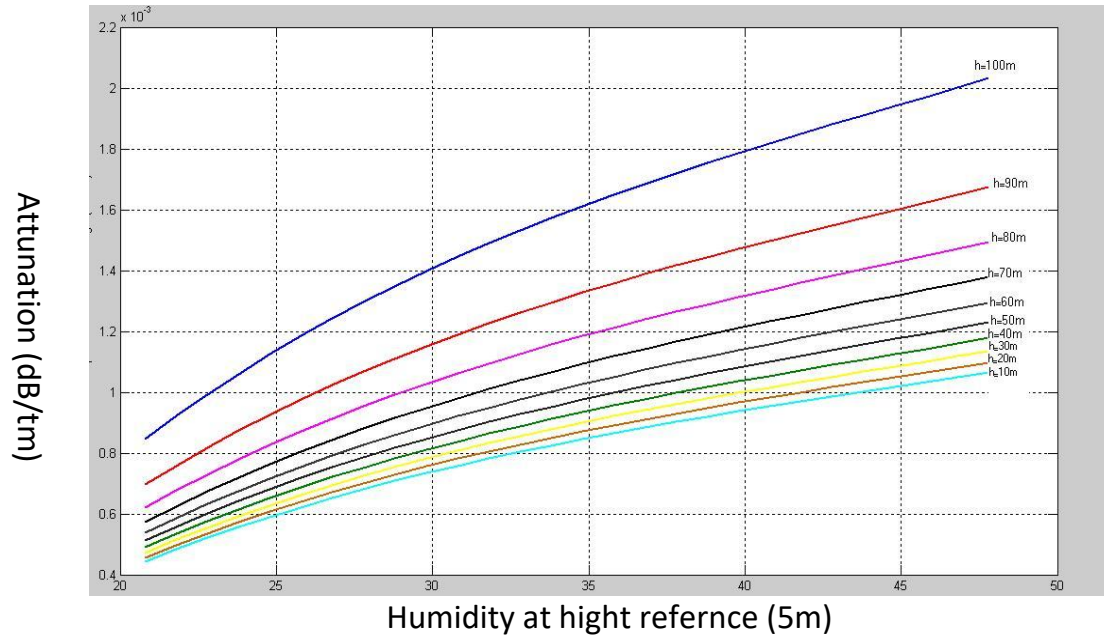


Fig.(1.3) Attenuation per km at reference Humidity and for Difference Heights [3].

A following study carried out by I.M. Saleh and E.M. Abuhdima [4] covered, the Southern Libya in spring of 2010. The analysis of the samples showed that the average of the complex permittivity for the studded area is $\epsilon_r = 6.3485 - j0.0929$, the average of density of samples is equal to 2.5764 gm/cm^3 . and the attenuation constant of the region of study is equal to 0.2412 dB/km . The attenuation due to dust storm in the study region is shown in figure (1.4).

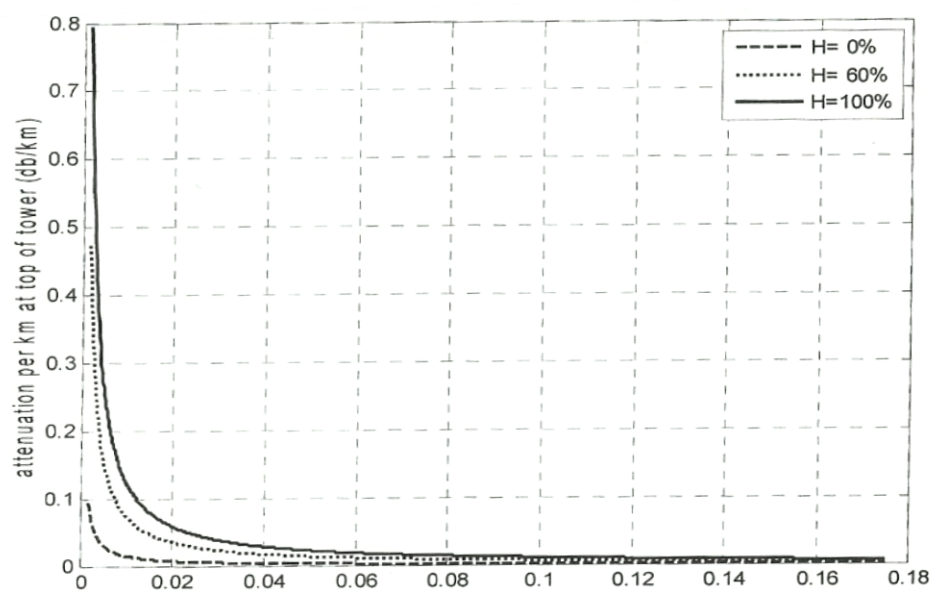


Fig.(1.4) Attenuation per km for $f = 20 \text{ GHz}$. [4]

The main difference between previous studies which is conducted in parts of Libya and our study in the region is different than that of other parts area.

The estimation of the effect of the air relative humidity on complex permittivity, and height of towers on visibility, their effects on both attenuation and cross polarization constants, and assumed the shape of scattering dust particles to be ellipsoids with axes ratios equal to $r_1:r_2:r_3 = 1:0.71:0.53$, [5] and the estimation of their effects on attenuation, phase constant and cross polarization constants (XPD).

1.2.2. Related Work in Saudi Arabia:

A. Ali presented a procedure for obtaining the optimum hop length for millimeter wave radio links operating in arid and semi-arid regions, [6] the procedure is based on long-term meteorological data for Saudi Arabia, a typical arid land, and a set of actual field measurements from a millimeter-wave radio network, his results were based on a study of the meteorological data obtained include a 25-year rain and sand storm record from 137 recording stations in Saudi Arabia.

The study involved the operation and monitoring of radio links in the millimeter wave and infrared parts of the spectrum. Meteorological stations and related test equipment were also operated and monitored. The experimental system comprised of:

- A set of three radio links: two millimeter waves (40GHz) and one near infrared (0.88 m) with path distances of 14km and 0.75m respectively.
- Meteorological instrumentation including dust passive collectors, high volume samples and a dust particle-size analyzer.

Predicting attenuation and phase shift caused by sand or dust storms requires knowledge of pertinent storm parameters affecting propagation. Such parameters include particle shape, size distribution, refractive index, concentration and composition. A record of all sand and dust storm events which occurred in Saudi Arabia over 20 years from 1968 was obtained from the Meteorological & Environmental Protection Administration (MEPA). It includes the dates and durations when the optical visibility was reduced due to storm events. An analysis of propagation reliability for millimeter wave radio links operating in an arid climate has been presented. Using the results of actual measurements of excess attenuation due to rain, sandstorms and fading at 40GHz in Riyadh. The results are presented in the form of design charts depicting link reliability against fade margin at various hop lengths. The

frequency band from 30 to 70GHz was covered in 10GHz increments. Sand particle sizes of 0.07 and 0.15mm were considered with moisture contents of 0%, 5% and 10%. Different design charts were given for various geographical regions of Saudi Arabia. It is believed that the analysis will be used by radio engineers designing radio links operating at millimeter wavelengths in an arid climate. [6]

1.2.3. Related Work in Sudan:

A study was carried out by S. I. Ghobrial and S. M. Sharief [5] the area selected in Sudan is located between longitude (10 to 20N) and latitude (30 to 35 E). The particle-size distribution (PSD) of dust samples collected in Sudan is carried by Hydrometer and Pipette methods, it was indicated that dust particles have an equivalent diameter in the range of 0.1 to 300 micron and with mean diameter less than 50 micron, also microscopic investigation revealed that the average axes ratios for the best fit ellipsoid are 1:0.71:0.53, and the average measured density of samples collected in Khartoum, is given by $\rho = 2.44\text{gm/cm}^3$, the measurements have shown that an average dielectric constant of dry dust samples is $5.5-j0.16$ at 8.5GHz, while it is $8.1-j0.90$ for samples with approximately 4.8% moisture content by weigh at 8.3GHz.

The effects of storms on microwave propagation were investigated; it was found that for linear polarization the effect of dust storms is almost negligible except for very dense storms. For circular polarization, cross polarization can be serious when visibilities fall below 100m over about 10 km of path, or below 10m over about 1 km of path. The attenuation and the cross-polarization discrimination were computed for different visibilities and distances (d), the results are given in table (1.1).

Table (1.1): Loss and XPD in dB.[5]

	d=75Km		d=50Km		d=25Km	
V(km)	XPD	Loss	XPD	Loss	XPD	Loss
0.001	1.3	31.96	3.1	22.33	7.7	11.84
0.010	19.1	3.17	22.6	2.13	28.6	1.07
0.100	40.5	0.27	44.0	0.18	50.0	0.09
1.000	61.9	0.02	65.4	0.02	71.4	0.01

1.2.4.Related Work in Iraq:

Shakir and H.M. Al-Rizzo[7] in their work several wind blown and dust fall samples were collected in the spring, summer and autumn of 1984 at a height of 20m above the ground surface during severe sand and dust storms over the city of Baghdad. The particle-size distribution (PSD) of the samples was determined using five different measurement techniques (hydrometer, pipette, sedimentation balance, optical microscope and coulter counter). The results showed that the cumulative weight techniques yield almost identical results for all the samples tested. The mode of the number distribution was found to occur at around 2 and 3.5 μm for the blowing and falling dust samples, respectively.

A computer program was developed to describe the measured distributions by some analytical functions. It was found that the cumulative distributions can be well described by a third degree polynomial and log-normal functions for particle diameters ranging from 1 to 100 μm . An attempt has been made to estimate the attenuation (α) and phase shift (β) for a microwave signal for up to 37GHz utilizing the measured PSD and for different particle moisture contents. It was concluded that at 37GHz and for 10m visibility, the upper bound for (α) and (β) were 0.7dB/km and 26.5degree/km for 20 percent particle moisture content.[7]

1.3.Dissertation Contributions:

The main aim of this research is summarized in the flowing points:-

- Finding the spatial dimensions of the sand or dust particles and evaluate the complex dielectric constant.
- Computing the attenuation loss and phase change due to the effect of sand and dust storms as will as the effect of humidity on microwave link in AL-Joufrah region.
- Computing the Cross-Polarization (XPD) change per unit length due to the effect of dust particles on microwave link in AL-Joufrah region.

1.4 General outline of the Dissertation:

The aim of this dissertation is to evaluate the attenuation constant, phase constant and cross polarization discrimination of circularly polarized waves due to dust particles on microwave links in AL-Joufrah region, and this have required:

1-Collecting samples for the suspended dust from the towers sites for microwave links.

2-Collecting information about the sites as height of tower and distance between repeaters

stations.

3-Making chemical and size analysis.

4-Using the chemical results to estimate the complex dielectric constant and complex permittivity.

5-Using the results of complex permittivity to estimate the attenuation, cross polarization discrimination (XPD), and phase shift per unit length.

6-Study the effect of visibility and humidity on the attenuation and cross polarization discrimination.

1.5 Dissertation Organization:

This dissertation consists of five chapters:

- Chapter 1 "**introduction**" This chapter include the general introduction, Related Previous Works, aim and General outline of the dissertation.

Chapter 2 " **Microwave Signals Propagation**" This chapter explains Properties of RF and Microwaves signals, types of microwave signals Propagation, RF/ microwave applications, Propagation Factors and study the effect of suspending dust particles on microwave signals propagation for study region.

- Chapter 3 " **Site Description and Analysis**" This chapter includes the general description of Study Region and Microwave link, dust and sand data, wind speed, visibility, and humidity are obtained from the national weather center in Tripoli, and presenting the Chemical composition and the dimensions analysis for samples at the petroleum institute center in Tripoli.
- Chapter 4 "**Practical Results and Discussion**" This chapter contains the analysis of the data presented in chapter 3. Investigation and Analysis of the Experimental Results, estimate the complex permittivity, and estimate of air relative humidity effect from the will find the attenuation and cross polarization discrimination (XPD) to the microwave signal of the microwave link.
- Chapter 5 "**Conclusion and Recommendations**" This chapter include the main conclusions of this Dissertation and suggest some points as a future work.

CHAPTER 2

Microwave Signals Propagation



2.1. Introduction:

Propagation mechanisms are very complex and diverse. First, because of the separation between the receiver and the transmitter, attenuation (reduction or loss) of the signal strength occurs, in addition, the signal propagates in different manners, known as diffraction, scattering, reflection, transmission, and refraction.

This chapter covers the fundamentals of wave propagation and the physical factors that affect propagation and many of the principles, and include too principles of dusty medium and effect of sand storms on microwave signals.

2.2. Microwave Signals:

radio waves at frequencies ranging from 1GHz to 300GHz are generally known as microwaves. Signals at these frequencies have wavelengths that range from 30 cm (at 1 GHz) to 1 millimeter (at 300 GHz) [15]. In some texts, the range 300 MHz to 300 GHz is considered the microwave frequency range.[8]

When the frequency of operation starts to increase toward approximately 1GHz and above, a whole set of new phenomena occurs that is not present at lower frequencies

The microwave frequency range (Microwave Band) consisting of three main commercial frequency bands (UHF, SHF, and EHF), as shown in table (2-1), and can further be subdivided into several specific frequency ranges, each with its own band designation. This band subdivision and designation facilitate the use of microwave signals for specific purposes and applications.

Table (2-1) Radio frequency range and band designator.

FREQUENCY RANGE		BAND DESIGNATOR
3-30	kilohertz (kHz)	very low frequency (VLF)
30-300	kHz	low frequency (LF)
300-3000	kHz	medium frequency (MF)
3-30	megahertz (MHz)	high frequency (HF)
30-300	MHz	very high frequency (VHF)
300-3000	MHz	ultra high frequency (UHF)
3-30	gigahertz (GHz)	super high frequency (SHF)
30-300	GHz	extremely high frequency (EHF)

2.3. Properties of Microwave Signals:

An important property of signals at RF, and particularly at higher microwave frequencies, is their great capacity to carry information. This is due to the large bandwidth is available at these high frequencies. For example, a 10 percent bandwidth at 60MHz carrier signal is 6MHz, which is approximately one TV channel of information; on the other hand 10 percent of a microwave carrier signal at 60GHz is 6GHz, which is equivalent to 1000 TV channels.

Another property of microwaves is that they travel by line of sight, very much like the traveling of light rays. Furthermore, unlike lower-frequency signals, microwave signals are not bent by the ionosphere. Thus use of line-of-sight communication towers or links on the

ground and orbiting satellites around the globe are a necessity for local or global communications.

Microwave frequency is the ideal signal band for radar applications, another important advantage of use of microwaves in radars is the availability of higher antenna gains as the frequency is increased for a given physical antenna size. This is because the antenna gain being proportional to the electrical size of the antenna, becomes larger as frequency is increased in the microwave band.

The key factor in all this is that microwave signal wavelengths in radars are comparable to the physical size of the transmitting antenna as well as the target, and there are many other Properties as; wider bandwidths due to higher frequency, Smaller component size leading to smaller systems, more available and less crowded frequency spectrum, lower interference due to lower signal crowding, higher speed of operation, and higher antenna gain possible in a smaller space.[8]

2.4. Microwave Applications:

The major applications of RF/microwave signals can be categorized as the following:

1.Communication:

This application includes satellite, space, long-distance telephone, cellular communication, Bluetooth, mobile phone, aircraft, and among others. Two important subcategories of applications need to be considered: TV and radio broadcast, and optical communications.

- **TV and Radio Broadcast.** In this application, RF/microwaves are used as the carrier signal for audio and video signals. An example is the Direct Broadcast System (DBS), which is designed to link satellites directly to home users.
- **Optical Communications.** In this application, a microwave modulator is used in the transmitting side of a low-loss optical fiber with a microwave demodulator at the other end. The microwave signal acts as a modulating signal with the optical signal as the carrier. Optical communication is useful in cases where a much larger number of frequency channels and less interference from outside electromagnetic radiation are desired. Current applications include telephone cables, computer network links, low-noise transmission lines, and so on.

2. Radar:

This application includes air defense, aircraft/ship guidance, smart weapons, police, weather, collision avoidance, and imaging.

3. Navigation:

This application is used for orientation and guidance of aircraft, ships, and land vehicles. Particular applications in this area are as follows:

- Microwave Landing System (MLS), used to guide aircraft to land safely at airports.
- Global Positioning System (GPS), used to find one's exact coordinates on the globe.

4. Remote Sensing:

In this application, many satellites are used to monitor the globe constantly for weather conditions, meteorology, and other factors such as monitoring and exploration of natural resources.

2.5. Propagation Factors:

Radio propagation is the behavior of radio waves when they are transmitted, or propagated from one point on the Earth to another, or into various parts of the atmosphere, the microwave signals are affected by the phenomena of, reflection, refraction, diffraction, absorption, polarization and scattering.

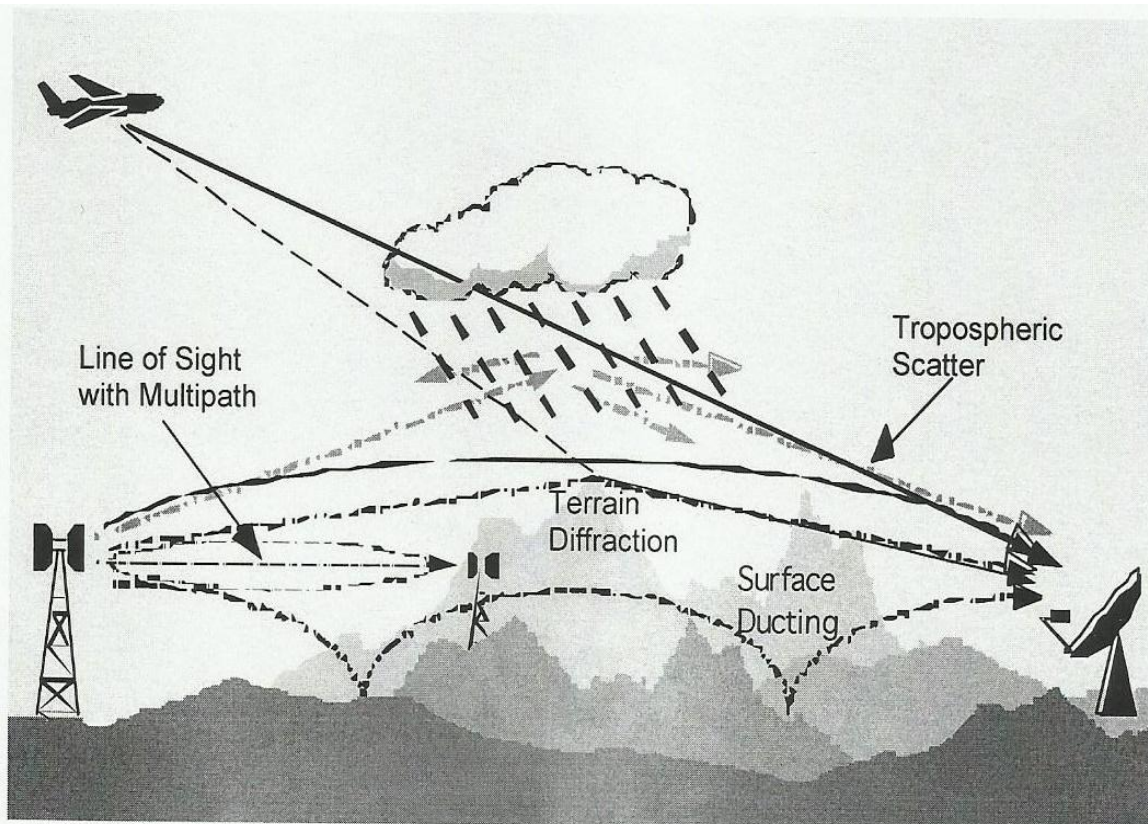
Figure(2.1), shown the microwave propagation mechanisms and scenarios, the Line Of Sight propagation, ducting (surface and elevated), terrain diffraction, and troposcatter. These modes can be used for an unstable telecommunication during a small percentage of the time and they may generate unwanted interference signals.

2.5.1. Diffraction:

Diffraction is the bending of the wave path when the waves meet an obstruction. Diffraction occurs when direct Line-Of-Sight (LOS) propagation between the transmitter and the receiver is obstructed by an opaque obstacle whose dimensions are considerably smaller than the signal wavelength, and the amount of diffraction depends on the wavelength of the wave.

The diffraction occurs at the obstacle edges where the radio waves are scattered and, as a result, they are additionally attenuated. The diffraction mechanism often allows the reception of weakened radio signals when the LOS conditions are not satisfied, whether in urban or rural environments. Sometimes, effects of diffraction help to receive radio waves in areas

located in the "shadow" of obstacles like behind a hill, signals will be weak but still detectable.[9]



Fig(2.1):- Microwave Propagation Mechanisms.

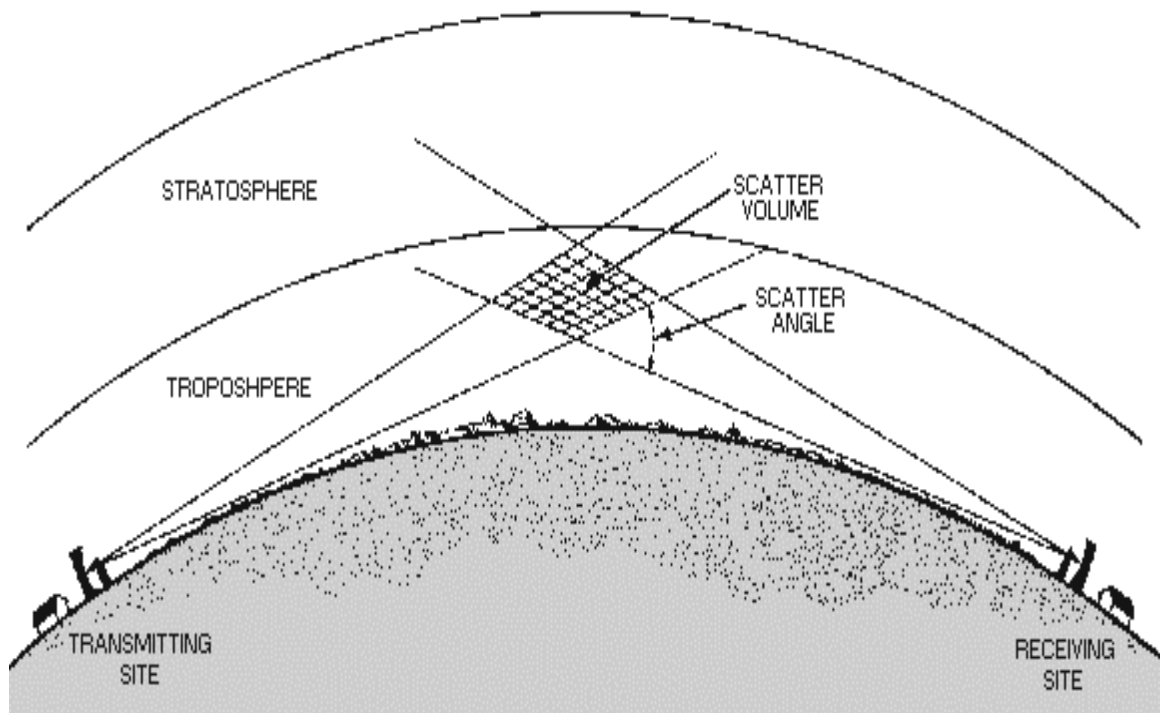
2.5.2. Scattering:

Scattering occurs when the propagation path contains the obstacles whose dimensions are comparable to the wavelength. The nature of this phenomenon is similar to diffraction, except that the radio waves are scattered in a greater number of directions, of all the mentioned effects, scattering is the most difficult to predict.

Scattering can happen in two different ways. The first type of scatter is on a smaller level and has a lesser effect on the signal quality and strength. This type of scatter may manifest itself when the RF signal moves through a substance and the individual electromagnetic waves are reflected off the minute particles within the medium. Smog in our atmosphere and sandstorms in the desert can cause this type of scattering, as shown in figure (2.2).

The second type of scattering occurs when an microwave signal encounters some type of uneven surface and is reflected into multiple directions. Chain link fences, tree foliage, and rocky terrain commonly cause this type of scattering. When striking the uneven

surface, the main signal dissipates into multiple reflected signals, which can cause substantial signal downgrade and even cause a loss of the received signal.



Fig(2.2):-Tropospheric Scattering Propagation.[9]

2.5.3. Reflection:

Microwave signal may be reflected from various substances or objects they meet during travel between the transmitting and receiving sites. The amount of reflection depends on the reflecting material. Smooth metal surfaces of good electrical conductivity are efficient reflectors of radio waves. The surface of the Earth itself is a fairly good reflector. The radio wave is not reflected from a single point on the reflector but rather from an area on its surface. The size of the area required for reflection to take place depends on the wavelength of the radio wave and the angle at which the wave strikes the reflecting substance. [8]

Reflection appears when a wave makes contact with a surface more or less thick or dense (having electric properties different from these for the region from it starting). A reflection can either decrease or increase the signal level at the reception point. At locations where many reflected waves exist, the received signal level tends to be very unstable. This phenomenon is commonly referred to as multipath fading, and the signal is often Rayleigh distributed.

2.5.4. Refraction:

Microwave signals passing through the atmosphere are affected by certain factors, such as temperature, pressure, humidity, and density. These factors can cause the microwave signal to be refracted. When a wave passes from one medium into another medium that has a different velocity of propagation, a change in the direction of the wave will occur. This changing of direction as the wave enters the second medium is called refraction.

Refraction is very important in macrocell (bigger scale, usually consists of many smaller cells) radio system design. Due to the change in refractive index of the atmosphere. However, as a result of the fluctuations of the atmosphere parameters, the received signal strength level fluctuates widely as well.

2.5.5. Fading:

Fading is a general term applied to the reduction in signal strength at the input of a receiver. The term fading applies to propagation variables in the physical radio path which affect changes in the path loss between the transmitter at one station and its normal receiver at other station. The path changes are associated with both atmosphere conditions and the geometry of the path itself i.e. the relative position of the antenna with respect to the ground and other surrounding terrain.

2.5.6. Scintillation and Multipath:

A change in the direction of propagation of a radio wave, caused by refractive index changes in the transmission path. Relatively slow fading due to beam bending caused by large-scale changes in refractive index; more rapid fading and variations in angle of arrival, due to small-scale variations in refractive index.

These refractive index variations are the result of temperature, humidity and pressure irregularities called atmospheric turbulence. The rain scintillations are proportional to path length and inversely proportional to antenna gain.

Multipath is when waves arrive simultaneously at a receiving antenna via several propagation paths and, by interfering with each other, give rise to fading, also called frequency-selective fading. This effect is more significant for decreasing elevation angles due to increase of portion of the propagation path and earth proximity. The high frequency scintillations, due to fast change of refractive index, can affect the attenuation measurements significantly.

Multipath fading consists of phase interference between signals arriving over more than one path which are diffracted, reflected or refracted by changing atmospheric effects over each path. An important type of multipath fading is the fading from rain because of appreciable Doppler shift in the reflected signals which causes distortion as well as attenuation of a broadband signal.

Depending on the nature of the radio propagation environment, there are different models describing the statistical behavior of the multipath fading envelope. The Rayleigh distribution is frequently used to model multipath fading with no direct line-of-sight (LOS) path. The Raleigh fading model therefore has an AF equal to 1, and typically agrees very well with experimental data for mobile systems where no LOS path exists between the transmitter and receiver antennas. It also applies to the propagation of reflected and refracted paths through the troposphere and ionosphere, and to ship-to-ship radio links.

2.5.7. Free-Space path Loss:

Free-space path loss is defined as the loss incurred by an electromagnetic wave as it propagates in a straight line through a vacuum with no absorption or reflection of energy from nearby objective. Free-space path loss is frequency dependent and increase with distance, as shown in fig (2-3). The free-space path loss is given by:[10]

$$L_p = \left(\frac{4\pi D}{\lambda} \right)^2 = \left(\frac{4\pi f D}{c} \right)^2 \dots\dots\dots(2-1)$$

Where:

L_p = free space path loss (unitless).

f = frequency (Hz).

C = Velocity of light in free space (3×10^8 m/s).

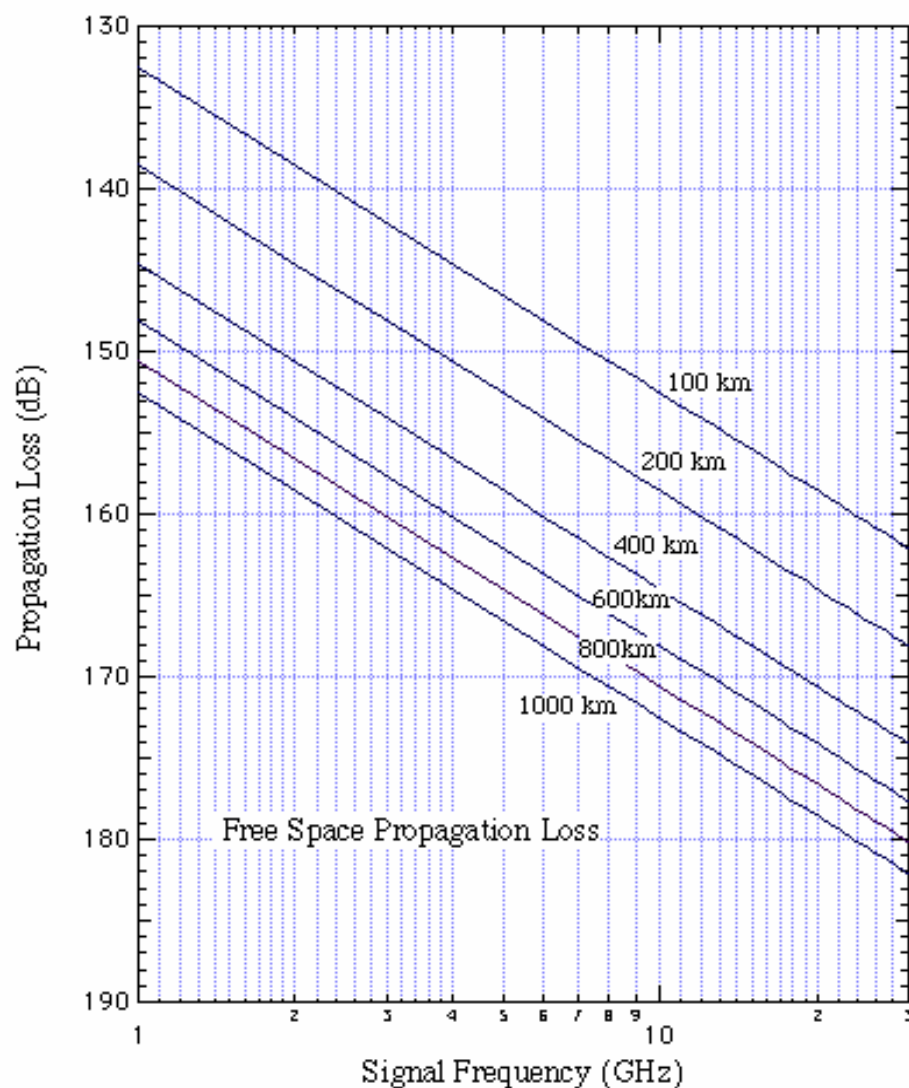
λ = Wavelength (m).

D = Distance (m).

Many types of propagation effects produce attenuation or distortion of a radio signal, they include the physical phenomena of divergence, absorption, diffraction, reflection, and refraction. The attenuation of microwave signals over Line-Of-Sight paths can be classified in terms of constant and time-varying losses (fading). Understanding of these losses will

contribute toward making reasonably accurate path loss estimation. Some components of path loss are relatively constant, examples are those due to the divergence of radiation from an antenna (which varies directly with the square of the distance), certain types of atmospheric absorption, some types of terrain reflections, and beam blockage near the antennas.

Time-varying losses include power fading and multipath fading (phase interference due to differences in component path delays). Within the classification of power fading rain attenuation, water vapor absorption, beam deflection away from the desired antenna because of atmospheric reflection or refraction, and the terrain blockage associated with beam deflection caused by atmospheric refractivity changes.



Fig(2.3):- Free Space Loss as a Function of Frequency for Different Distance.[10]

2.6. Effects of Weather on Propagation:

As the frequency increases, radio degradation effects become more significant due to atmospheric and weather changes. Dominantly responsible for additional losses to the free space loss become atmospheric absorption, clouds, fog, and precipitation, as well as scintillation multipath at low elevation angles.[11]

Radio systems using frequencies above 300MHz experience another loss that must be accounted for when planning the system atmospheric absorption. Relay links that are may experience outages during periods of heavy rainfall and dust storms.

Attenuation is the reduction of signal strength during transmission. It is just the opposite of amplification. Its unit is dB (decibel) or more generally it is measured in dB/km. during the transmission, the signal gets attenuated exponentially.

Attenuation is an inherent characteristic of RF (radio frequency) signal and also is very important in the design aspect. So it should be taken into consideration while designing and calculating the RSL (Receive Signal Level) of the RF signal between two stations.

Attenuation is directly proportional to the frequency. That means the RF signal gets significantly attenuated at higher frequencies and there is less effect of attenuation at lower frequencies, all of these losses to the atmosphere at the microwave frequency range cannot be neglected.

2.6.1. Effect of Rain:

The important source of microwave signal attenuation is rain. When the rain rate intensity is high, then the microwave signal gets significantly attenuated. For example, it is observed that at high rain intensity (150mm/hr), the fading of RF signal at 2.4GHz reached the value 0.02dB/km. So even if the transmission distance is near and the transmitted power is large enough, the signal will be attenuated in a very significant amount due to heavy rain that the link between the two stations may break down. The attenuation becomes significant at higher frequencies and more precisely saying at frequencies greater than 10GHz. At higher frequencies, the signal can get attenuated up to 1dBm/km due to heavy rain fall. The attenuation of radio waves by suspended water droplets and rain often exceeds the effects of combined oxygen and water vapor absorption. Water droplets in fog or rain will scatter radio waves in all directions whether the drops are small compared to the wavelength or comparable to the wavelength, in the latter case, raindrops trap and absorb some of the radio

wave energy; accordingly, rain attenuation is much more serious at millimeter wavelengths (frequencies above about 10GHz) than at lower frequencies.

The attenuation effects of rain, while small in the lower microwave region become more important at frequencies above 10GHz. In Japan, for example, at 15.4GHz, a uniform rain falling at the rate of 100mm/hr has been observed to produce an excess attenuation of about 7dB/km. In the United States, over 4.7km path at 14.4GHz, as much as 48 dB attenuation was observed at a time when the average rainfall rate was 137mm/hr. Also in the United States, a uniform rain, falling at the rate of 100mm/hr was observed to produce an excess attenuation of about 9dB/km at 18GHz.

Under these conditions, it is obviously impossible to maintain transmission over paths longer than a few kilometers. However, recent investigations have shown that the temporal and spatial distributions of such severe rain storms are highly restricted.

To estimate time distributions of rain attenuation fading for a path in a given area, it is necessary to know three parameters: first, the attenuation per kilometer as a function of rainfall rate as figure (2.4), second, the time distribution of rainfall rates for the geographic area, and third, the spatial distribution of rain rates.[8]

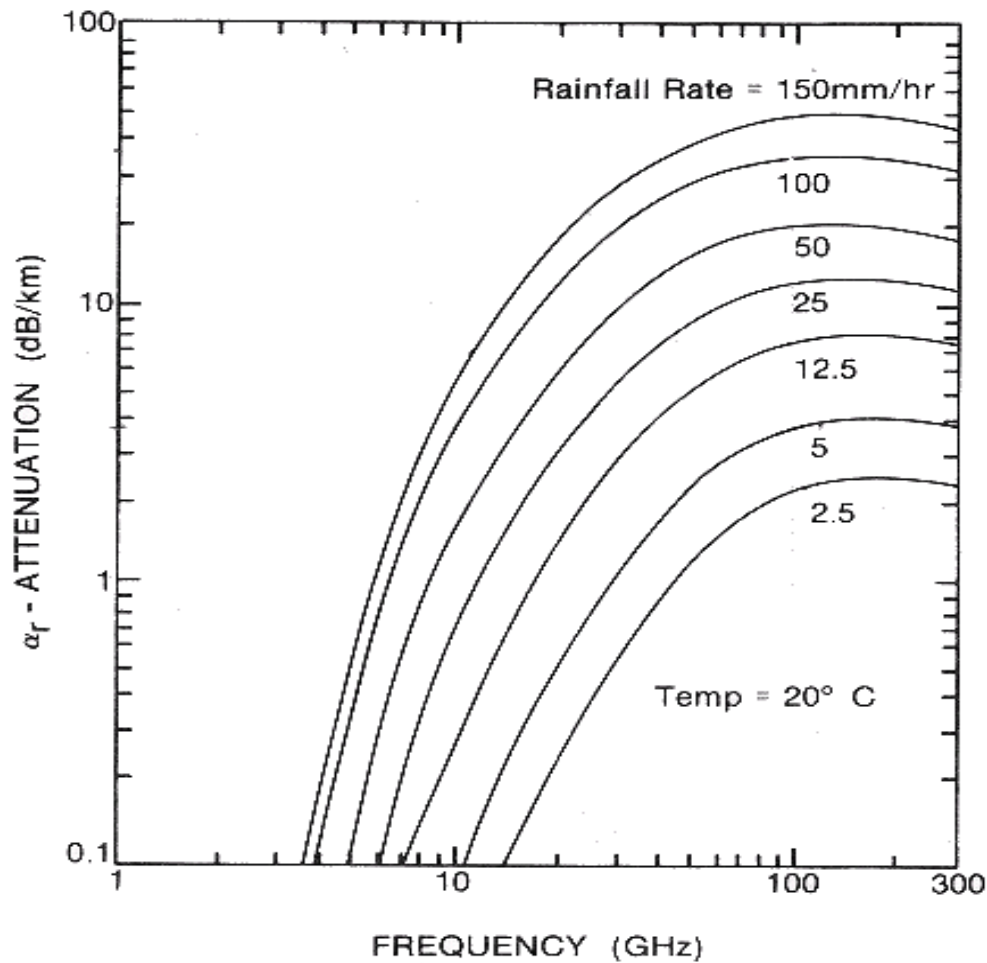
$$\alpha_r = aR^b \dots\dots\dots (2.2)$$

where:

α_r — Attenuation (dB/km),

R – Rain rate (mm/hr),

a, b – Coefficients dependent on frequency and temperature.



Fig(2.4): Theoretical Rainfall Attenuation as a Function of Frequency for Different Rainfall.

2.6.2. Effect of Cloud and Fog:

Fog is basically supersaturated air which some of the water has precipitated to form some water droplets whose sizes are smaller than 0.1mm in diameter. The thickness of the fog layer is usually of the order of hundred meters.

The attenuation due to clouds depends on the path length of the microwave signal through the clouds, which in turn is a function of elevation angle and thickness of the clouds. The main difficulties are about the uncertain values of the liquid water content in a given cloud and the conversion of inadequate information on coverage and type of clouds to readily applicable figures.

As the frequency increases, the effect of clouds becomes steadily more important. However, recent measurements show that in some types of cloud (e.g. Stratocumulus) the additional attenuation produced at vertical incidence is no more than 0.5 to 1dB. On the

other hand, clouds with high liquid-water content, such as Cumulonimbus, can cause an additional attenuation of about 4 to 5dB.[12]

2.6.3. Effect of Atmospheric gases:

The atmosphere is comprised of gases, which absorb electromagnetic energy at various frequencies. Atmospheric attenuation due to gaseous absorption should not be confused with multipath or rain fades; it is a different mechanism. The gases of primary concern for microwave and millimeter wave systems are oxygen and water vapor. Similar to refraction, atmospheric losses also depend upon pressure, temperature, and water vapor content for this reason, the effects can vary considerably with location, altitude, and the path slant angle. The atmosphere can be thought of as being comprised of horizontal layers at different altitudes, each having different water vapor and oxygen densities. Therefore, terrestrial links and earth-to-space/air links experience different atmospheric effects and must be modeled differently.

For frequencies between 1 and 10GHz, an estimate of 0.01dB per kilometer path length is a reasonable allowance for the total atmospheric absorption. Between 10 and 40GHz the values of figure (2.5) are added together and then multiplied by the path length to estimate the value of the average atmospheric absorption. For paths located at high terrain elevations, or for paths with elevation angles greater than 0.5 degrees, such an estimate will be slightly too large. For a first estimate, the values from figure (2.5) will generally be sufficient even though the losses will vary with humidity and air.

For terrestrial links where both terminals are at or near the same altitude, the atmosphere can be treated as constant over the path. In this case it makes sense to characterize the absorption as a specific attenuation value in dB/km, which can be applied to the path distance to determine the total attenuation. The expression for the total loss due to atmospheric absorption on a terrestrial path is:[8]

$$A = \gamma_a d \dots\dots\dots(2.3) \text{ (dB)}$$

Where:

d : is the line-of-sight distance between the terminals in km

γ_a : is the specific attenuation of the atmosphere in dB/km.

The specific attenuation of the atmosphere is given by the sum of the specific attenuation due to water vapor and that due to oxygen.

While the ITU gives formulas for these parameters [11], they are very long and tedious to evaluate. Instead of calculating the specific attenuation, it is common practice to use values extracted from a plot like Figure:(2.5).

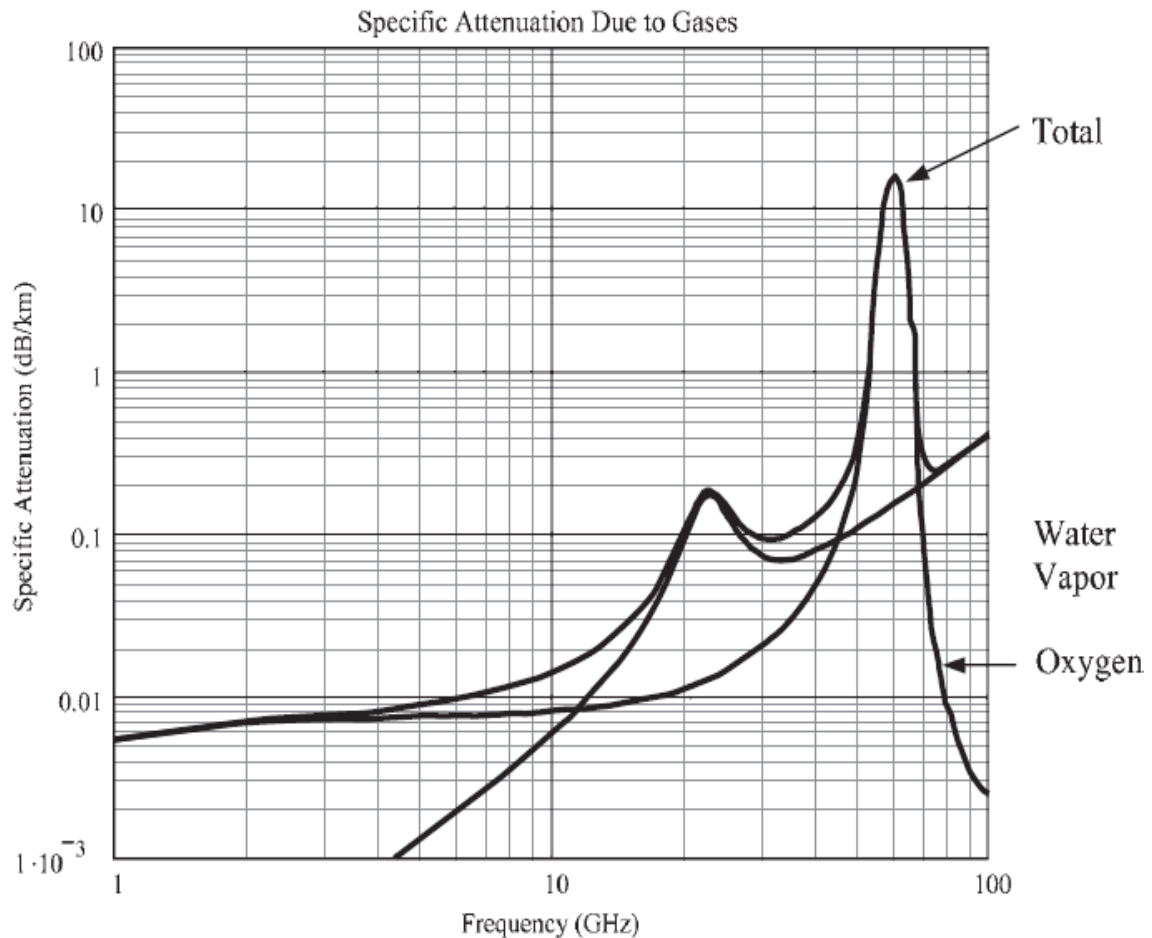


Fig.(2.5):-The Attenuation due to Oxygen and Water Vapor. [11]

2.6.4. Effect of Sand and Dust Storm:

The atmosphere contains a variety of solid particles in suspension. These particles range in size from aerosols (up to $50\mu\text{m}$) to coarse dust, sometimes known as sand (about 1mm [Miller and Anthes, 1981]). The larger the size of the particles, the quicker they fall out of suspension. While aerosols can remain suspending for days, and sometimes years, coarse dust will rapidly descend to the ground once the impelling force, such as a violent wind storm, has subsided. In a like manner, aerosols can be carried high up into the stratosphere in

even a slight updraft while the larger particles, such as coarse dust, generally remain within a few meters of the surface of the earth. Aerosols and small solid particles do not significantly affect the transmission of electromagnetic waves until the optical frequencies are approached and their extinction cross-section becomes appreciable. The effect of fine dust and coarse dust on radio wave transmissions can be noticeable at much lower frequencies, however, although the impact is often difficult to separate from the meteorological phenomena that often accompany the dust storms.

For terrestrial sand or dust storms, the visibility V is often used to describe the distance at which a mark disappears against the background. Storms usually have a visibility of 10m or less, with a minimum of 3m, and can reach a height of 1 km or more [9]. Dust particles have an average size of 10 to 20 μm , with the largest in a range of 80–300 μm . For an extreme case, with a particle number density, N_t , of $10^8/\text{m}^3$, and dust material mass density, ρ , $2.6 \times 10^6 \text{ g/m}^3$, mass loading can reach 40–60 g/m^3 . At S-band (10^a cm wavelength), over a 20-km one-way path, attenuation can be as great as 13dB. X-band (10GHz) attenuation can reach 44dB over the same path. Thus, in desert areas, sand storms can cause a problem for domestic-satellite services [13], have summarized the studies of the effects of Earth dust storms on radio wave propagation. The microwave attenuation (α) is given by:

$$\alpha = 189 \frac{r}{\lambda V} \left[\frac{3\epsilon''}{(\epsilon' + 2)^2 + \epsilon''^2} \right] \dots\dots\dots (2.4) \text{ dB/km}$$

Where:

V : is visibility in kilometers, r is particle radius in meters.

λ : is wavelength in meters.

ϵ' , ϵ'' : the real and imaginary parts of the mean permittivity of dust or sand particles.[5]

2.7. Properties of Dusty Medium:

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

2.7.1. Definition of Sand and Dust Particles:

A dust storm is a meteorological phenomenon common in desert and semi-desert regions and arises when a gust front passes or when the wind force exceeds the threshold value where loose sand and dust are removed from the dry surface.

Particles are transported by saltation and suspension, causing soil erosion from one place and deposition in another. In soil mechanics, particles with radii less than 60 micron are termed clay or silt, depending on their size. Particles with radii greater than 60 micron are called sand. [14, 15]

2.7.2. Dusty Medium Permittivity:

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. [16]

Dust and sand particles are soil particles removed from the earth surface as a result of wind erosion under certain climatic, meteorological and soil conditions. It is well known that the earth surface is composed of a large number of minerals in homogeneous mixture form. The dust and sand particles are expected to have similar composition. The mixture percentage depends on the mineral composition of the parent soil.

In order to predict the dielectric constant for dust and sand particles from its mineral and /or chemical composition values, the following points should be considered:

- 1- The chemical and mineral composition of the dust and the sand.
- 2- The dielectric of each constituent.
- 3- Model for the mixture dielectric constant.

The chemical composition of a sand sample may or may not come close to that of a dust samples. This depends on the origin of sand and dust samples. One should not expect a change in the dielectric constant with particle size. The chemical analysis carried out in Sudan showed that the major constituents of dust are SiO_2 , Al_2O_3 and Fe_2O_3 . [17]

A number of models are available to estimate the dielectric constant of a sand and dust samples. Where dielectric constant of mixture (ϵ_m) depends on the complex dielectric of the substance (ϵ_i) and its relative volume (v_i). [18]

$$\epsilon_m^{1/3} = \sum_{i=1}^n v_i \epsilon_i^{1/3} \quad \text{Looyenga model..... (2.5)}$$

The permittivity of materials at microwave frequencies is $\epsilon = \epsilon' - j\epsilon''$; where ϵ' is referred to as the dielectric constant and ϵ'' is the dielectric loss factor.

The complex permittivity also depends on frequency of operation and moisture content. In general, moisture causes increase both real and imaginary parts of the complex permittivity depending on chemical composition of dry soil samples. [16]

To study the effect of suspending particles 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. [15]

$$\epsilon_i = \epsilon_a \left(1 + v \frac{\epsilon - \epsilon_a}{\epsilon_a + A_i (\epsilon - \epsilon_a)} \right), \quad i=1, 2, 3.....(2.6)$$

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 : the depolarization factor along the a_i axis as illustrate in figure (2.6).

For air with suspending dust and/or sand particles, eq. (2.6)reduces to[5,18].

$$\epsilon_i = \left(1 + v \frac{\epsilon - 1}{1 + A_i (\epsilon - 1)} \right)(2.7)$$

2.7.3. Methodology of Particles:

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 not 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, [19] as shown in Figure.(2.6).

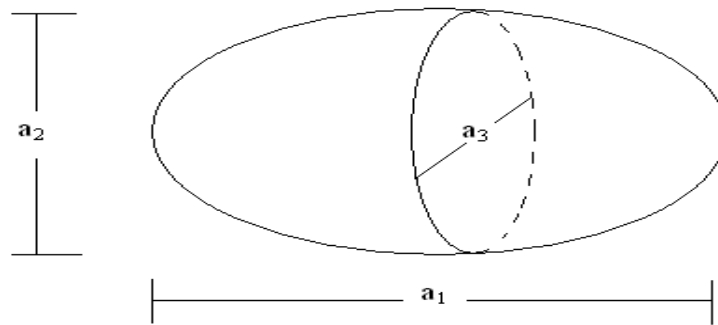


Fig.(2.6):- Dust Particle Geometry Approximation.[19]

The average ratio of the axes is given by $1:r_2:r_3 = 1:0.71:0.53$; where $r_2 = a_2/a_1$, $r_3 = a_3/a_2$. [5, 15].

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 (2.7), 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. [14]

- 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.

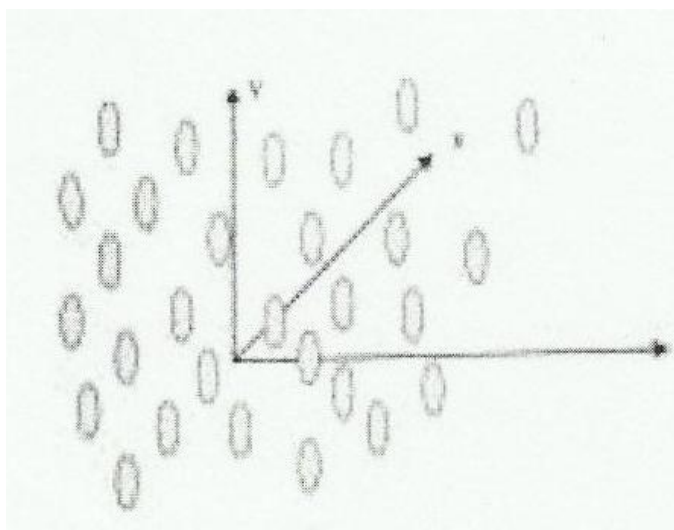


Fig.(2.7):- Dusty Medium Model.

2.7.4. Dusty Media Depolarization Factor:

Consider the ellipsoid geometry shown in Fig (2.6), 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 A_i along the a_i axis is defined by:[5]

$$A_i = \frac{a_1 a_2 a_3}{2} \int_{s=0}^{\infty} \frac{ds}{\left((s + a_i^2) \left[(s + a_1^2)(s + a_2^2)(s + a_3^2) \right]^{1/2} \right)}, \quad i = 1, 2, 3 \dots \dots \dots (2-8)$$

Integrating (2.8) we get:

The depolarization factor in the 1 and 3 directions are obtained as follows:

$$A_1 = \frac{r_2 r_3}{\sqrt{(1-r_3^2)(1-r_2^2)}} [F(x, m) - E(x, m)] \dots \dots \dots (2-9)$$

$$A_3 = \frac{r_2}{(r_2^2 - r_3^2)} \left[r_2 - \frac{r_3}{\sqrt{1-r_3^2}} * E(x, m) \right] \dots \dots \dots (2-10)$$

Where: $F(x, m)$, $E(x, m)$ are elliptic integral of the first kind and of the second kind respectively.

The depolarization factor in the 2 direction is obtained immediately as:

$$A_2 = 1 - (A_1 + A_3) \dots \dots \dots (2-11)$$

Figures, (2-8.a) and (2-8.b), show plots of the Elliptic integral of the first kind and of the second kind showing the different ellipsoid axial ratio r_2 and r_3 . The above expression used to determine the depolarization factor for dusty medium, i.e. ellipsoid dust particles suspended in air. The results shown in Figures. (2-9.a) and (2-9.b) for A_1 and A_3 . [15]

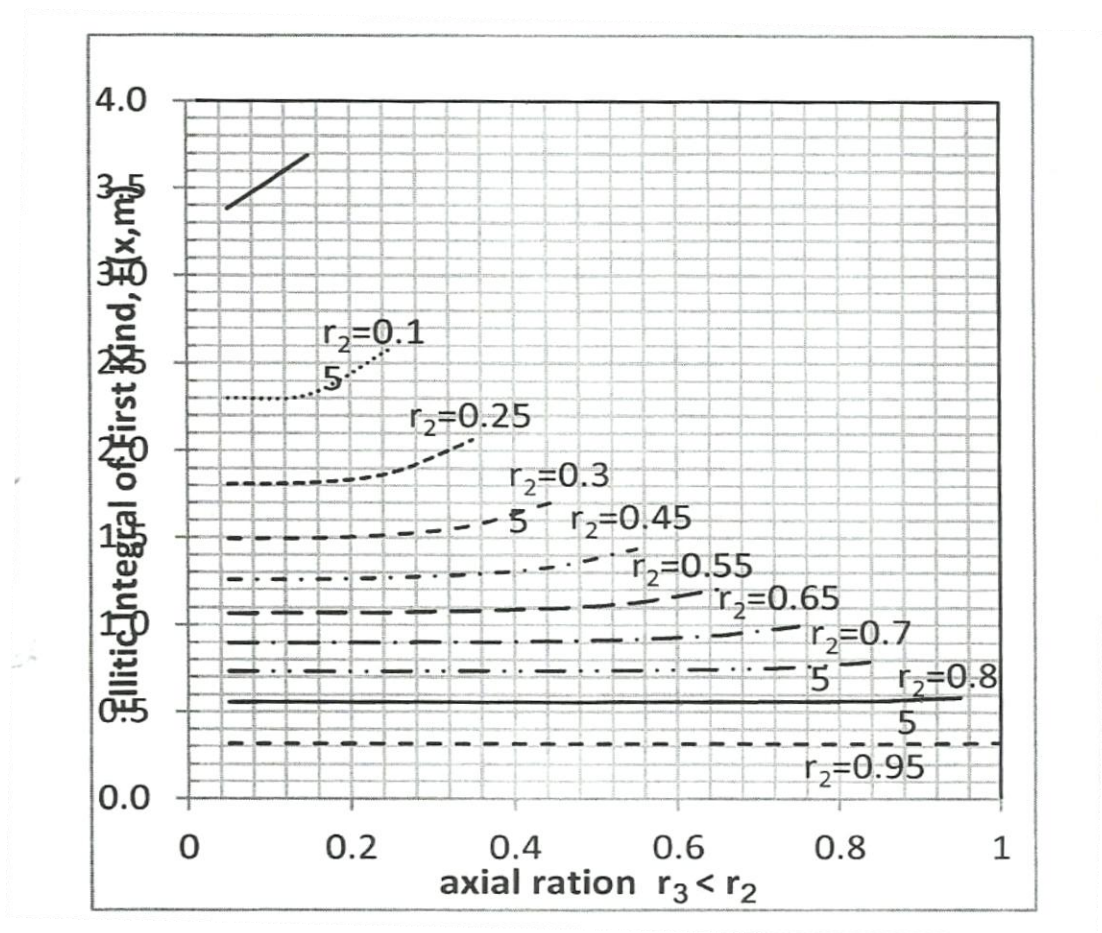


Fig.(2.8a):- Solution of Elliptic Integral of First Kind.

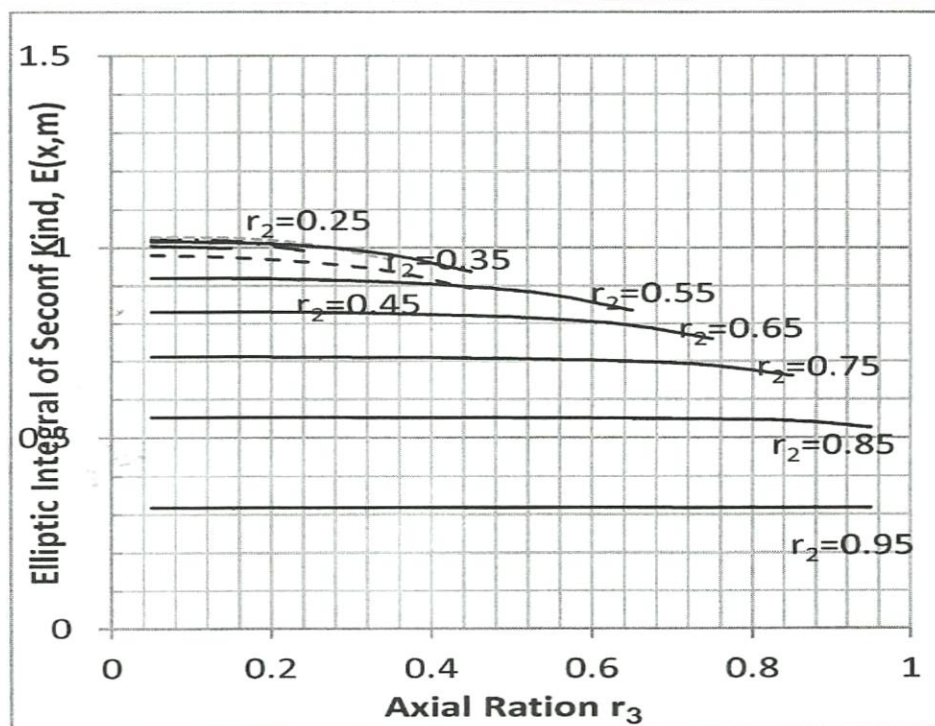


Fig.(2.8b):- Solution of Elliptic Integral of Second Kind.

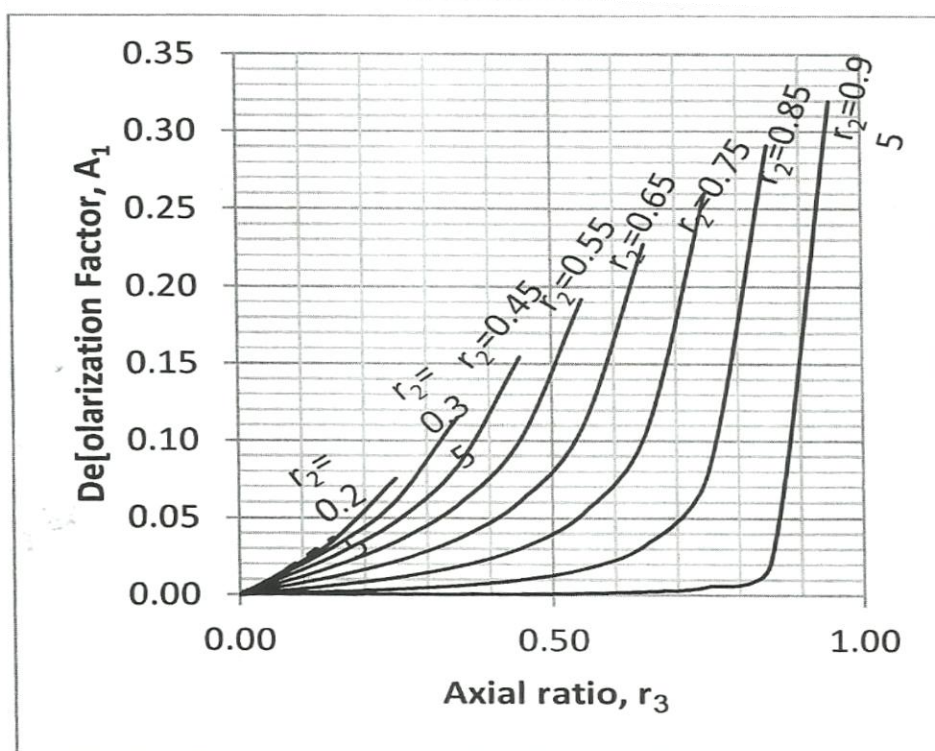


Fig.(2.9a):- Dusty Medium Depolarization factor in the direction 1.

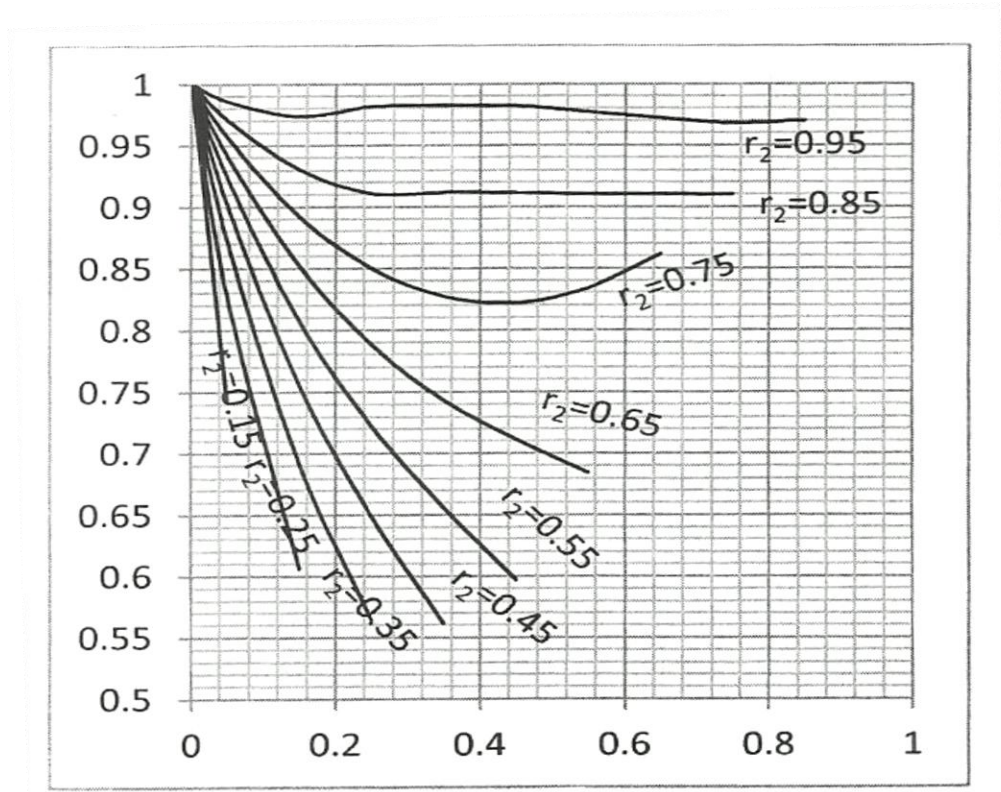


Fig.(2.9b):- Dusty Medium Depolarization factor in the direction 3.

2.7.5. Particle Size Distribution (PSD):

Analysis of particulate samples is done to find the particle size and distribution from a representative sample. A particle size distribution can be displayed either in tabular form or graphically, and either as a cumulative distribution or as a differential distribution. For a sphere, the size is the diameter (or radius) of the sphere. For a real particle of arbitrary shape, the commonly acceptable size for 3-dimensional measurement techniques such as laser diffraction and counter principle is defined as the volume equivalent sphere diameter. Because it is impractical to measure every particle in a bulk sample, especially for small particles, correct sampling, to ensure statistical representation of measured particles to the bulk samples, and correct particle dispersion, to ensure all particles are measured individually, are key steps in any particle size analysis experiment.

The particle size distribution (PSD) has great importance in the effect of sand and dust on microwave communication links. Much work has been carried out to measure PSD under different conditions in different locations. The size of sediment particles can be measured by visual estimation or by use a set of sieves.

Particle size distribution was studied by a number of researcher's. The results obtained for the Sudan have indicated that dust particles may have an equivalent diameter in the range $0.1 < D < 300$ micron. [14]

2.7.6. Dust Concentration 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. [15]

$$M = \frac{C}{V^\gamma} \dots\dots\dots(2-12)$$

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,

$$C = 2.3 \times 10^{-5} \text{ and } \gamma = 1.07. [5]$$

As is well known visibility decreases with increasing number of particles in the atmosphere. As we saw previously by eq. (2-12), 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. [20]

$$\rho = \frac{56 \times 10^{-9}}{V^{1.25}} \dots\dots\dots(2-13)$$

Where: ν is the relative volume occupied by particles (m³ of particles /m³ of air).

The visibility during dust and/or sand storms increases as the height is increased. Chepil and Woodruff [21], arrived at the following empirical relation for the variation of dust or/sand mass concentration (M , kg/m³) with height(h , m).

$$M = a/h^b \quad \dots\dots\dots (2-14)$$

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. [5]

By substituting for M from eq. (2-12) into eq. (2-14), then visibility can be written as:

$$V^\gamma = C h^{b/a} \quad \dots\dots\dots (2-15)$$

Let the visibility at some reference height h_0 to be V_0 , thus (2.15) yields:

$$V^\gamma = V_0^\gamma [h/h_0]^b \quad \dots\dots\dots (2-16)$$

2.8. Microwave Signal Attenuation through Dust Storms:

Signal attenuation caused by dust storm is one of the major problems in utilization of microwave bands for terrestrial and space communication especially at desert and semi desert area. Signal attenuation is an important parameter in telecommunications applications because of its importance in determining signal strength as a function of distance. A major cause of this phenomenon is atmospheric particles which can seriously limit the performance of telecommunication system especially at microwave level. The propagation constant of the storm is given by: [15]

$$\gamma_i = \alpha_i + j\beta_i = j\frac{\omega}{c} \sqrt{\epsilon_i} = j\frac{2\pi}{\lambda} \sqrt{\epsilon_i} = j\frac{2\pi}{\lambda} \sqrt{1 + v \frac{\epsilon - 1}{1 + A_i(\epsilon - 1)}} \quad \dots\dots\dots (2-17)$$

Hence:

$$\alpha_i \approx -\frac{\pi}{\lambda} \text{Im} \frac{v(\epsilon - 1)}{1 + A_i(\epsilon - 1)} \quad \dots\dots\dots (2-18)$$

$$\beta_i \approx \frac{2\pi}{\lambda} \left[1 + \frac{1}{2} \operatorname{Re} \left(\frac{v(\varepsilon - 1)}{A_i(\varepsilon - 1)} \right) \right] \dots\dots\dots(2-19)$$

The phase shift per unit length relative to a wave traveling in air is obtained from eq.(2.19) immediately as:

$$\phi_i = \frac{\pi}{\lambda} \operatorname{Re} \frac{v}{A_i + \frac{1}{(\varepsilon - 1)}} \dots\dots\dots(2-20)$$

If particles have random orientations relative to the wave polarization then the attenuation and phase shift constants are obtained as the average of all ϕ_i and α_i , respectively, thus:

$$\alpha = -\frac{\pi}{3\lambda} \sum_i \operatorname{Im} \frac{v}{A_i + \frac{1}{(\varepsilon - 1)}} \dots\dots\dots(2-21.a)$$

$$\phi = \frac{\pi}{3\lambda} \sum_i \operatorname{Re} \frac{v}{A_i + \frac{1}{(\varepsilon - 1)}} \dots\dots\dots(2-21.b)$$

Equations (2.18) and (2.20) may be used to determine the attenuation and phase shift when a wave of known polarization propagates through a storm. Evaluation of these equations requires, however, knowledge of the orientation of particles relative to the wave polarization. McEwan and Bashir argued [22], that dust particles fall with the longest dimension vertical. The orientation of particles in the horizontal plane is, however, random with all directions equally likely to be encountered. It should be observed that the above hypothesis is valid only when particles are precipitating under the effect of gravity in the absence of wind. During the storm orientation of particles is expected to be different; the actual orientation depends on many factors including direction of wind, its speed etc.

2.8.1. Attenuation and Phase Constants for Vertical Polarization:

For a vertically polarized wave, the direction of the electric field is parallel to the shortest axis of the dust particles in air. using eq.(2.18) and eq.(2.20) the expression for the attenuation and phase shift constants are as follows:

$$\alpha_3 = -\frac{\pi}{\lambda} \operatorname{Im} \frac{v}{A_3 + \frac{1}{\epsilon - 1}} \dots\dots\dots(2.22-a)$$

and

$$\varphi_3 = \frac{\pi}{\lambda} \operatorname{Re} \frac{v}{A_3 + \frac{1}{\epsilon - 1}} \dots\dots\dots(2.22-b)$$

Since A_3 depends on the ellipsoids' axes ratios and since particles have different ratios, A_3 is not constant and the above equations need to be modified to taken into account the variations in the a_2/a_1 and a_3/a_2 ratios. Let the probability of finding particles with a_2/a_1 ratio in the range $R_{i-1} < R < R_{i+1}$ be $P_i(R)$. Also if $P_j(r)$ is the probability of finding particles with a_3/a_2 in the range $r_{j-1} < r < r_{j+1}$ then the probability of finding particles with a_2/a_1 and a_3/a_2 within the indicated range is $P_i(R) P_j(r)$, here $\mathbf{R}$ and $\mathbf{r}$ are ratios a_2/a_1 and a_3/a_2 , respectively. The above joint probability is valid if the random variables R and r are statistically independent which is assumed, there is no reason to believe otherwise. [5]

If the volume occupied by dust per unit volume of air is v , then the volume occupied by particles with the axes ratios in the selected ranges is $v P_i P_j$. Also for these particles the depolarization factor can be designated by A_{3ij} . The attenuation and phase constants due to the presence of these particles can be written as:

$$\alpha_{3ij} = -\frac{\pi}{\lambda} \operatorname{Im} \frac{v P_i P_j}{A_{3ij} + \frac{1}{\epsilon - 1}} \dots\dots\dots(2.23-a)$$

$$\varphi_{3ij} = \frac{\pi}{\lambda} \operatorname{Re} \frac{v P_i P_j}{A_{3ij} + \frac{1}{\epsilon - 1}} \dots\dots\dots(2.23-b)$$

The total attenuation and phase constants of a vertical polarized wave due to all particles is obtained as:

$$\alpha_v = -\frac{\pi}{\lambda} \text{Im} \sum_l \sum_j \frac{v P_l P_j}{A_{3lj} + \frac{1}{\epsilon-1}} \dots\dots\dots(2-24.a)$$

$$\phi_v = \frac{\pi}{\lambda} \text{Re} \sum_l \sum_j \frac{v P_l P_j}{A_{3lj} + \frac{1}{\epsilon-1}} \dots\dots\dots(2-24.b)$$

2.8.2. Attenuation and Phase Constants for Horizontal Polarization:

The propagation constants for horizontal polarization are obtained following the same analysis as for vertical polarization. However, in this case the subscript 3 is replaced by 1 or 2. Since particles have no particular orientation in the horizontal plane the attenuation and phase shift constants are obtained as:[20]

$$\alpha_h = (\alpha_1 + \alpha_2)/2 \dots\dots\dots(2-25.a)$$

$$\phi_h = (\phi_1 + \phi_2)/2 \dots\dots\dots(2-25.b)$$

Hence, the attenuation and phase shift constants of a horizontally polarized wave is given by:

$$\alpha_h = -\frac{\pi}{2\lambda} \text{Im} \sum_l \sum_j v P_l P_j \left[\frac{1}{A_{2lj} + \frac{1}{\epsilon-1}} + \frac{1}{A_{1lj} + \frac{1}{\epsilon-1}} \right] \dots\dots\dots(2-26.a)$$

$$\phi_h = \frac{\pi}{2\lambda} \text{Re} \sum_l \sum_j v P_l P_j \left[\frac{1}{A_{2lj} + \frac{1}{\epsilon-1}} + \frac{1}{A_{1lj} + \frac{1}{\epsilon-1}} \right] \dots\dots\dots(2-26.b)$$

2.8.3. Attenuation and Cross Polarization of Circular Polarization:

A circular polarized wave may be resolved into two linearly polarized waves of equal magnitudes but with their polarizations orthogonal and 90° 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.[15, 17]

$$\text{XPD} = 10 \log_{10} \left| \frac{1 + 2m \cos \phi + m^2}{1 - 2m \cos \phi + m^2} \right| \text{ dB} \dots\dots\dots(2-27)$$

Where: m is the ratio of the amplitudes of the two linearly polarized waves producing circular polarization; and ϕ is the phase difference between them.

If $m = 1$ and $\phi = 90^\circ$, then the wave is truly circularly polarized and XPD becomes infinite.

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

$$m = e^{-|\alpha_h - \alpha_v|D} \dots\dots\dots(2-28.a)$$

$$\phi = (\phi_h - \phi_v)D \dots\dots\dots(2-28.b)$$

Where:

D is the propagation path length in storm.

Attenuation of the circular polarized wave is brought about by two mechanisms:

- 1) Absorption of energy in the propagation medium.
- 2) Change in polarization.

It can be readily shown that the attenuation of a circularly polarized wave due to the above two effects is given by:[5]

$$\text{att(dB)} = -20 \log_{10} \sqrt{\frac{1 + 2m \cos \phi + m^2}{4}} e^{-\alpha_v D} \dots\dots\dots(2-29)$$

2.8.4. Attenuation and Phase Shift for spherical particles:

It has been demonstrated by Chu [20], that the attenuation coefficient from dust or sand storms at centimeter wavelengths may be expressed for a monodispersive medium (equal particle radii) by:

$$\alpha = 12.6 \frac{\alpha_o r}{\lambda} \left[\frac{3\epsilon''}{(\epsilon' + 2)^2 + \epsilon''^2} \right] \text{ dB/Km} \dots\dots\dots(2-30)$$

Where: α_o is the optical attenuation coefficient (dB/Km), r is the particle radius (m)

The total number of particles per unit volume (N_T) is given by:

$$N_T = 3.67 \times 10^{-5} \frac{\alpha_o}{r^2} \dots\dots\dots(2-31)$$

Solving for α_o in eq.(2-31) and substituting the resultant expression into eq. (2-30), we get

$$\alpha = 3.43 \times 10^5 \frac{r^3 N_T}{\lambda} \frac{3\epsilon''}{(\epsilon' + 2)^2 + \epsilon''^2} \dots\dots\dots(2-32)$$

If we assume a more realistic condition that a distribution of particle sizes exists (polydispersive case), the eq.(2-32) may alternately be expressed.

$$\alpha = \frac{1.029 \times 10^6 \times \epsilon''}{[(\epsilon' + 2)^2 + \epsilon''^2] \lambda} \sum_i N_i r_i^3 \dots\dots\dots(2-33)$$

Where: N_i is the number of particles with radii between r_i and $r_i + \Delta r_i$ per m^3 . Multiplying and dividing eq. (2-33) by the total particle density N_T , we arrive at the alternate expression.[20]

$$\alpha = \frac{1.029 \times 10^6 \times \epsilon'' N_T}{[(\epsilon' + 2)^2 + \epsilon''^2] \lambda} \sum_i P_i r_i^3 \dots\dots\dots(2-34)$$

Where P_i is the probability that r_i lies between r_i and $r_i + \Delta r_i$, and it is given by

$$P_i = \frac{N_i}{N_T} \dots\dots\dots(2-35)$$

CHAPTER 3

Site Description and Analysis

3.1. Introduction:

This chapter will be devoted to presenting the collection of the sand and dust samples, the humidity, the wind speed, and the visibility data in study region. The sand and dust samples will be collected from seven positions for the microwave stations towers, the rest of the data, wind speed, visibility, and humidity are obtained from the national weather center in Tripoli. The samples will be analyzed for the Chemical composition and the dimensions at the petroleum institute center in Tripoli, and the Lebda Plant in EL-Khoms.

3.2. Study Region Description:

The region of this study was chosen where there is a high potential of sand and dust storms, and a place where there are many microwave networks, one of such region is located at the mid south of Libya between longitude (29:46:30 to 28:20:30 N) and latitude (16:29:P10 to 17:45:15 E).

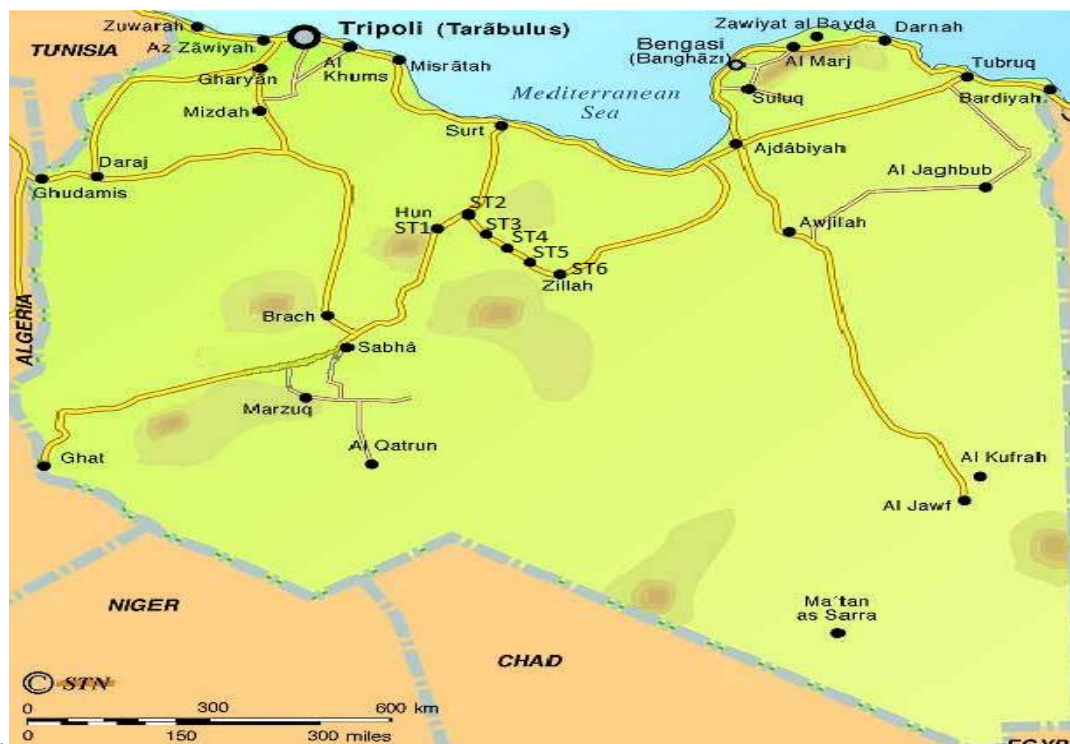


Fig (3.1):-Map Showing the Location of microwave links

Then this region has high wind speed, desert climate, and has too frequent dust and sand storms, the region is an important for the Libyan microwave communication N.W, where it links north Libya by its south and east by its west.

The microwave link has six stations from Hun region (Station 1) to Zillah region(station 6),and operating at a frequency of 6-7GHz located in the region is an analog system, the heights of towers and the latitude and longitude locations of towers in studied region [Appendix (C)],showing in table (3.1).

Table(3.1): Location of Station and Height of Towers.

Station	Height of Tower(m)	(E)longitude	(N) Latitude	Distance between station (km)
Hun	65	16:30:13	29:47:33	-
Woadan	90	16:28:27	29:29:58	33
WZ1	85	16:18:45	29:19:34	58
WZ2	90	16:34:27	28:52:30	55
WZ3	120	16:55:47	28:42:11	40
Zillah	65	17:40:04	28:24:36	45

3.3.The Meteorological Data:

The region of study is located between Hun and Zillah, we refer to the Libyan center of metrology for getting the metrological of the region selected.

Collected meteorological data obtained for a period of 10-years (from 2000 up to the end of 2010) from Hun city[Appendix (C)], table(3.2) give the average relative humidity and wind speed from the meteorological stations.

Table(3-2): Relative Humidity and Wind Speed for Hoon.

Month	R.Humidity (%)	Wind speed(knots)
JAN.	58.5	10.3
FEB.	53.2	11.4
MAR.	21.3	8.9
APR.	38.1	8.9
MAY.	37.5	11.8
JUN.	38.8	12.7
JUL.	44.5	10.0
AUG.	42.1	12.9
SEP.	42.5	10.6
OCT.	48.3	8.5
NOV.	51.8	7.4
DEC.	71.8	10.5.
Yearly Average	45.70	10.24

From table (3-2) we get the average humidity for AL-Joufrah region collected through more the ten years (2000-2010) equal **45.70 %** and average wind speed equal **10.24** knots.

3.4.Samples Collection:

In this work the samples were collected in the spring of 2013 at seven sites, during different times of the year, on the roofs of the communication towers or from the roofs of the building near the towers at a height of 6m, along the microwave link in AL-Joufrah region.

- Sample 1 from Hun region..
- Sample 2 to the south east of sample 1 about 33Km.
- Sample 3 and Sample 4 to the south east of sample 2 about 58Km.
- Sample 5to the south of sample 3 about 55Km .
- Sample 6 to the south of sample 4 about 40 Km.
- Sample 7 to the south east of sample 6 about 45km

3.5. Analysis of the Samples:

For this study we need to do some analysis for samples such as chemical composition, particle size distribution and average density, which are used to compute the dielectric constant and attenuation constant. The Libyan Petroleum Institute in Tripoli have equipments that are capable to carry out the required analysis. And the Lebda Plant in EL-Khoms City have an equipments that is capable to carry the chemical composition, size analysis and density test equipments.

3.5.1. Chemical Composition of Samples:

The compounds and its percentage in samples can be estimated by chemical analysis. The chemical composition of all samples as determined by the Libyan Petroleum Institute and Lebda Plant [Appendix (A)], are given in tables (3-3) to (3-9).

Table (3-3):Chemical Analysis of Sample (1).

Oxide	Mass %
SiO ₂	49.71
CaO	25.36
Al ₂ O ₃	5.11
MgO	2.78
Fe ₂ O ₃	2.08
K ₂ O	1.32
SO ₃	0.341
Na ₂ O	0.201
MnO	0.221
C1	0.431
TiO ₂	0.0039
ZrO ₂	0.0975
ZnO	0.0672
P ₂ O ₅	0.0543
LOI	11.47

Chemical analysis of sample (1), showed that the major constituents of the sample are SiO₂, CaO, Al₂O₃ and MgO about 83% by weight of the sample.

Table (3-4) Chemical Analysis of Sample (2).

Oxide	Mass %
SiO ₂	55.86
CaO	14.87
Al ₂ O ₃	8.87
MgO	2.91
Fe ₂ O ₃	1.43
K ₂ O	2.41
SO ₃	0.363
Na ₂ O	0.276
MnO	0.141
Cl	0.344
TiO ₂	0.0728
P ₂ O ₅	0.185
ZrO ₂	0.0984
ZnO	0.179
NOi	0.0196
LOI	10.92

Chemical analysis of sample (2) showed that the major constituents of the sample are SiO₂, CaO, Al₂O₃, and MgO, about 82% by weight of the sample.

Table (3-5):Chemical Analysis of Sample (3).

Oxide	Mass %
SiO ₂	58.84
CaO	17.08
Al ₂ O ₃	8.42
MgO	1.76
Fe ₂ O ₃	1.86
K ₂ O	1.71
SO ₃	0.401
Na ₂ O	0.188
MnO	0.256
Cl	0.435
TiO ₂	0.0874
P ₂ O ₅	0.245
ZrO ₂	0.0914
ZnO	0.1257
LOI	7.13

Chemical analysis of sample (3) showed that the major constituents of the sample are SiO₂, CaO, Al₂O₃, and Fe₂O₃ 86% by weight of the sample.

Table (3-6):Chemical Analysis of Sample (4).

Oxide	Mass %
SiO ₂	62.17
CaO	15.32
Al ₂ O ₃	8.98
MgO	2.03
Fe ₂ O ₃	1.63
K ₂ O	1.17
SO ₃	0.241
Na ₂ O	0.345
MnO	0.229
Cl	0.243
TiO ₂	0.0614
P ₂ O ₅	0.0602
ZrO ₂	0.0587
ZnO	0.0474
LOI	6.84

Chemical analysis of sample (4) showed that the major constituents of the sample are SiO₂, CaO, Al₂O₃, and MgO, about 89% by weight of the sample.

Table (3-7) Chemical Analysis of Sample (5).

Oxide	weight %
SiO ₂	51.80
CaO	18.97
Al ₂ O ₃	7.56
MgO	4.76
Fe ₂ O ₃	3.97
K ₂ O	0.734
Na ₂ O	0.352
SO ₃	0.424
MnO	0.223
Cl	0.732
TiO ₂	0.0135
ZnO	0.0182
ZrO ₂	0.0529
P ₂ O ₅	0.0692
Noi	0.0087
LOI	9.64

Chemical analysis of sample (5) showed that the major constituents of the sample are SiO₂, CaO, Al₂O₃, and MgO, about 83% by weight of the sample.

Table (3-8) Chemical Analysis of Sample (6).

Oxide	weight %
SiO ₂	56.41
CaO	16.45
Al ₂ O ₃	9.37
MgO	1.53
Fe ₂ O ₃	2.43
K ₂ O	0.763
SO ₃	1.41
Na ₂ O	0.246
MnO	0.128
C1	0.641
P ₂ O ₅	0.694
TiO ₂	0.0412
NiO	0.0823
ZrO ₂	0.0072
LOI	9.71

Chemical analysis of sample (6) showed that the major constituents of the sample are SiO₂, CaO, Al₂O₃, and Fe₂O₃ about 85% by weight of the sample.

Table (3-9):Chemical Analysis of Sample (7).

Oxide	weight %
SiO ₂	48.72
CaO	17.12
Al ₂ O ₃	13.94
MgO	2.32
Fe ₂ O ₃	4.53
K ₂ O	1.14
SO ₃	0.876
Na ₂ O	0.134
MnO	0.352
C1	0.827
TiO	0.0234
ZrO ₂	0.792
NiO	0.0042
LOI	8.47

Chemical analysis of sample (7) showed that the major constituents of the sample are SiO₂, CaO, Al₂O₃, and MgO, and about 85% by weight of the sample.

The density of all samples as determined by the Libyan Petroleum Institute [Appendix (A)], and results are given in table (3-10).

Table (3-10): Density of Samples.

Sample No.	Density (g/cm ³)
1	2.51
2	1.99
3	2.36
4	2.45
5	2.67
6	2.24
7	2.30

3.5.2. Size Analysis of Samples:

Size of the samples in this work is measured by sieving. The basic principle of this technique is as follows. A sand sample of known weight is passed through a set of sieves of known mesh sizes. The sieves are arranged in downward decreasing mesh diameters. The sieves are mechanically vibrated for a fixed period of time. The weight of sediment retained on each sieve is measured and converted into a percentage of the total sediment sample. This method is quick and sufficiently accurate for most purposes.

The Particle- Size Distribution (PSD) of all samples as determined by the Libyan Petroleum Institute laboratory [Appendix (A)], are given in tables (3-11) to (3-17).

Table (3-11): PSD of Sample (1).

Sample weight	197.41g		
Screen opening (μm)	Weight (g)	Weight %	Cumulative weight (g)
600	1.978	1.001975584	1.978
425	3.980	2.016108606	5.958
300	9.230	4.675548351	15.19
180	15.58	7.890177803	30.76
106	95.22	48.23463857	125.98
75	61.74	31.27501142	187.72
32	9.686	4.906539689	197.41

The sieving analysis showed that the major grain size of the of sample ranges from 75μm to 180μm. Where about 87% of the sample consists of grains of diameters that range from 75μm to 180μm.

Table (3-12): PSD of Sample (2)

Sample weight	211.336 g		
Screen opening (μm)	Weight (g)	Weight %	Cumulative weight (g)
600	0.597	0.282488549	0.597
425	4.168	1.972214862	4.765
300	5.542	2.622364387	10.31
180	13.75	6.506227051	24.06
106	91.23	43.16822501	115.29
75	78.27	37.03581027	193.56
32	17.77	8.412669872	211.33

The sieving analysis showed that the major grain size of the of sample ranges from 32μm to 106μm. Where about 89% of the sample consists of grains of diameters that range from 32μm to 106μm.

Table (3-13): PSD of Sample (3)

Sample weight	230.657 g		
Screen opening (μm)	Weight (g)	Weight %	Cumulative weight (g)
600	0.654	0.283532977	0.654
425	3.168	1.373444145	3.822
300	9.839	4.265567218	13.66
180	19.31	8.373327090	32.97
106	99.65	43.20192837	132.62
75	88.35	38.30296409	220.97
32	9.686	4.199236108	230.657

The sieving analysis showed that the major grain size of the of sample ranges from 75μm to 180μm. Where about 90% of the sample consists of grains of diameters that range from 75μm to 180μm.

Table (3-14): PSD of Sample (4)

Sample weight	188.48 g		
Screen opening (μm)	Weight(g)	Weight %	Cumulative weight (g)
600	1.332	0.706706281	1.332
425	2.521	1.337542445	3.853
300	4.445	2.358340407	8.298
180	9.751	5.173493209	18.049
106	94.39	50.07958404	112.44
75	71.26	37.80772496	183.69
32	4.781	2.536608659	188.48

The sieving analysis showed that the major grain size of the of sample ranges from 75μm to 180μm. Where about 93% of the sample consists of grains of diameters that range from 75μm to 180μm.

Table (3-15): PSD of Sample (5)

Sample weight	193.955 g		
Screen opening (μm)	Weight(g)	Weight %	Cumulative weight (g)
600	13.49	6.955221572	13.49
425	38.42	19.80871852	51.91
300	63.97	32.98187724	115.88
180	12.29	6.336521358	128.17
106	40.38	20.81926220	168.55
75	18.24	9.404243252	186.79
32	7.165	3.694155861	193.95

The sieving analysis showed that the major grain size of the of sample ranges from (106 to 425μm). Where about 80% of the sample consists of grains of diameters that range from 106μm to 425μm.

Table (3-16) PSD of Sample (6)

Sample weight	238.94 g		
Screen opening (μm)	Weight(g)	Weight %	Cumulative weight (g)
600	13.51	5.654139114	13.51
425	36.71	15.36368963	50.22
300	50.75	21.23964175	100.97
180	37.48	15.68594626	128.45
106	73.98	30.96174772	202.43
75	26.54	11.10739098	228.97
32	9.970	4.172595631	238.94

The sieving analysis showed that the major grain size of the of sample ranges from 106μm to 425 μm. Where about 79 % of the sample consists of grains of diameters that range from 106 μm to 425 μm.

Table (3-17): PSD of Sample (7).

Sample weight	177.79 g		
Screen opening (μm)	Weight(g)	Weight %	Cumulative weight (g)
600	1.654	0.930336337	1.654
425	4.213	2.369782878	5.867
300	9.272	5.215434807	15.14
180	6.327	3.558893014	21.47
106	79.29	44.60006750	100.76
75	61.71	34.71144111	162.47
32	15.32	8.617392271	177.79

The sieving analysis showed that the major grain size of the of sample ranges from 32 μm to 106 μm . Where about 88% of the sample consists of grains of diameters that range from 32 μm to 106 μm .

CHAPTER4

Practical Results and Discussion

4.1. Introduction:

In this chapter, the analysis presented in chapter three will be analyzed and discussed, by finding the average complex permittivity of mixture, the average density of samples and estimating the different effects on the microwave signals such as the attenuation, cross polarization constants and phase change.

4.2. Calculation of the Dust Complex Permittivity:

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. [17]

$$\epsilon_m^{1/3} = \sum_{i=1}^n \epsilon_i^{1/3} v_i \dots\dots\dots(4-1)$$

Where: ϵ_m : is the complex dielectric constant of the mixture.

ϵ_i : is the complex dielectric constant of the i^{th} substance as shown in table (4-1).[5]

v_i : is the relative volume of the i^{th} sample from the volume of the total sample.

The complex permittivity of oxides in our samples is not known, for this reason, we processes data to obtain compounds that have complex permittivity that is available. The percentage of the SiO_2 , Al_2O_3 , Fe_2O_3 and MnO_2 are taken to be equal to these compounds appearing in the chemical compositions. The percentage of the MgCO_3 is calculated from the percentage of the MgO . The percentage of the CaSO_4 is calculated from sulphate appearing in the chemical composition. To calculate the CaCO_3 percentage, first the percentage of CaO allocated to the CaSO_4 is obtained; the rest of the CaO is used to calculate the percentage of CaCO_3 . The percentage of the NaCl is calculated from Sodium appearing in the chemical composition. Recently to calculate the KCl percentage, first the percentage of Cl allocated to the NaCl is obtained; the rest of the Cl and the percentage of the Potassium in the chemical composition are used to calculate the percentage of KCl . In all above calculations the molecular weight has been used, table (4-1) gives the chemical compositions of samples calculated using this procedure.

Table (4-1) Chemical Composition (model)

Compound	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7
SiO ₂	49.71	55.86	58.84	62.17	51.80	56.41	49.72
CaCO ₃	36.76	26.52	25.89	22.59	26.39	25.52	26.29
Al ₂ O ₃	5.11	8.80	8.42	8.98	7.56	9.37	13.94
MgCO ₃	4.73	6.10	3.134	3.52	7.776	2.935	4.339
Fe ₂ O ₃	2.08	1.43	1.86	1.63	3.97	2.43	2.32
CaSO ₄	0.581	0.618	0.783	0.410	0.909	1.998	1.488
MnO ₂	0.221	0.142	0.256	0.229	0.225	0.128	0.352
KCl	0.453	0.358	0.456	0.261	0.767	0.675	0.868
NaCl	0.355	0.282	0.358	0.206	0.603	0.529	0.682

In the previous table we ignored (ZrO₂, ZnO, TiO₂, P₂O₅ and NiO) due to the lack of information about their permittivity (the volume of the ignored items about 0.482).

By using the results presented in table (4-1) which represents 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 (4-2) and equation (4-1) can be used to estimate the complex permittivity of each sample (program (1) in Appendix (B)), the results are given in tables (4-3) to (4-10).

Table (4-2): Complex Permittivity of Substances.

complex permittivity	Compound
4.43-j0.04	SiO ₂
12.66-j1.31	Al ₂ O ₃
16.58-j0.93	Fe ₂ O ₃
8.22-j0.12	CaCO ₃
5.03-j0.17	MgCO ₃
5.01-j0.08	CaSO ₄
75.74-j26.29	MnO ₂
4.70-j0.05	KCl
5.70-j0.09	NaCl

Table (4-3). The Complex Permittivity of Sample 1.

Compound	$\varepsilon' + j\varepsilon''$	ν	$\varepsilon^{1/3}\nu$
SiO ₂	4.43-j0.04	0.4971	0.8164 -j0.0025
CacO ₃	8.22-j0.12	0.3678	0.7423 -j0.0036
Al ₂ O ₃	12.66-j1.31	0.0511	0.1192 -j0.0041
MgCO ₃	5.03-j0.17	0.0473	0.0811 -j0.0009
Fe ₂ O ₃	16.58-j0.93	0.0208	0.0531 -j0.0010
CaSO ₄	5.01-j0.08	0.00581	0.0099 -j0.0001
MnO ₂	75.74-j26.29	0.00221	0.0095 -j0.0011
KCl	4.70-j0.05	0.00453	0.0076 -j0.0001
NaCl	5.70-j0.09	0.00355	0.0063 -j0.0001

From the above table and equation (4-1) the complex dielectric constant of the mixture is $\epsilon_m = 6.2837 - j 0.1353$.

Table (4-4). The Complex Permittivity of Sample 2.

Compound	$\varepsilon' + j\varepsilon''$	ν	$\varepsilon^{1/3}\nu$
SiO ₂	4.43-j0.04	0.5586	0.9156 -j0.0028
CacO ₃	8.22-j0.12	0.2652	0.5352 -j0.0026
Al ₂ O ₃	12.66-j1.31	0.0880	0.2053 -j0.0071
MgCO ₃	5.03-j0.17	0.0610	0.1045 -j0.0012
Fe ₂ O ₃	16.58-j0.93	0.0143	0.0365 -j0.0007
CaSO ₄	5.01-j0.08	0.00618	0.0106 -j0.0001
MnO ₂	75.74-j26.29	0.00142	0.0061 -j0.0007
KCl	4.70-j0.05	0.00358	0.0060 -j0.0001
NaCl	5.70-j0.09	0.00282	0.0050 -j0.0001

From the above table and equation (4-1) the complex dielectric constant of the mixture is $\epsilon_m = 6.0761 - j0.1505$.

Table (4-5). The Complex Permittivity of Sample 3.

Compound	$\varepsilon' + j\varepsilon''$	ν	$\varepsilon^{1/3}\nu$
SiO ₂	4.43-j0.04	0.5884	0.9664 -j0.0029
CaCO ₃	8.22-j0.12	0.2589	0.5225 -j0.0025
Al ₂ O ₃	12.66-j1.31	0.0842	0.1965 -j0.0068
MgCO ₃	5.03-j0.17	0.03134	0.0537 -j0.0006
Fe ₂ O ₃	16.58-j0.93	0.0186	0.0474 -j0.0009
CaSO ₄	5.01-j0.08	0.00783	0.0134 -j0.0001
MnO ₂	75.74-j26.29	0.00256	0.0110 -j0.0012
KCl	4.70-j0.05	0.00456	0.0076 -j0.0001
NaCl	5.70-j0.09	0.00358	0.0064 -j0.0001

From the above table and equation (4-1) the complex dielectric constant of the mixture is $\epsilon_m = 6.0763 - j0.1504$.

Table (4-6). The Complex Permittivity of Sample 4.

Compound	$\varepsilon' + j\varepsilon''$	ν	$\varepsilon^{1/3}\nu$
SiO ₂	4.43-j0.04	0.6217	1.0211 -j0.0031
CaCO ₃	8.22-j0.12	0.2259	0.4559 -j0.0022
Al ₂ O ₃	12.66-j1.31	0.0898	0.2095 -j0.0072
MgCO ₃	5.03-j0.17	0.0352	0.0603 -j0.0007
Fe ₂ O ₃	16.58-j0.93	0.0163	0.0416 -j0.0008
CaSO ₄	5.01-j0.08	0.00410	0.0070 -j0.0001
MnO ₂	75.74-j26.29	0.00229	0.0098 -j0.0011
KCl	4.70-j0.05	0.00261	0.0044 -j0.0001
NaCl	5.70-j0.09	0.00206	0.0037 -j0.0000

From the above table and equation (4-1) the complex dielectric constant of the mixture is $\epsilon_m = 5.9610 - j0.1492$.

Table (4-7). The Complex Permittivity of Sample 5.

Compound	$\varepsilon' + j\varepsilon''$	ν	$\varepsilon^{1/3}\nu$
SiO ₂	4.43-j0.04	0.5180	0.8507 - 0.0026
CaCO ₃	8.22-j0.12	0.2639	0.5326 - 0.0026
Al ₂ O ₃	12.66-j1.31	0.0756	0.1764 - 0.0061
MgCO ₃	5.03-j0.17	0.0778	0.1333 - 0.0015
Fe ₂ O ₃	16.58-j0.93	0.0397	0.1013 - 0.0019
CaSO ₄	5.01-j0.08	0.00909	0.0156 - 0.0001
MnO ₂	75.74-j26.29	0.00223	0.0096 - 0.0011
KCl	4.70-j0.05	0.00767	0.0128 - 0.0000
NaCl	5.70-j0.09	0.00603	0.0108 - 0.0001

From the above table and equation (4-1) the complex dielectric constant of the mixture is $\epsilon_m = 6.2600 - j0.1618$.

Table (4-8).The Complex Permittivity of Sample 6.

Compound	$\varepsilon' + j\varepsilon''$	ν	$\varepsilon^{1/3}\nu$
SiO ₂	4.43-j0.04	0.5641	0.9265 -j0.0028
CaCO ₃	8.22-j0.12	0.2552	0.5150 -j0.0025
Al ₂ O ₃	12.66-j1.31	0.0937	0.2186 -j0.0075
MgCO ₃	5.03-j0.17	0.0294	0.0503 -j0.0006
Fe ₂ O ₃	16.58-j0.93	0.0243	0.0620 -j0.0012
CaSO ₄	5.01-j0.08	0.01998	0.0342 -j0.0002
MnO ₂	75.74-j26.29	0.00128	0.0549 -j0.0061
KCl	4.70-j0.05	0.00675	0.0113 -j0.0000
NaCl	5.70-j0.09	0.00529	0.0094 -j0.0001

From the above table and equation (4.1) the complex dielectric constant of the mixture is $\epsilon_m = 6.6659 - j0.2226$.

Table (4-9). The Complex Permittivity of Sample 7.

Compound	$\varepsilon' + j\varepsilon''$	ν	$\varepsilon^{1/3}\nu$
SiO ₂	4.43-j0.04	0.4872	0.8166 -j0.0025
CaCO ₃	8.22-j0.12	0.2629	0.5306 -j0.0026
Al ₂ O ₃	12.66-j1.31	0.1394	0.3253 -j0.0112
MgCO ₃	5.03-j0.17	0.0434	0.0744 -j0.0008
Fe ₂ O ₃	16.58-j0.93	0.0232	0.0592 -j0.0011
CaSO ₄	5.01-j0.08	0.01488	0.0255 -j0.0001
MnO ₂	75.74-j26.29	0.00352	0.0151 -j0.0017
KCl	4.70-j0.05	0.00868	0.0145 -j0.0001
NaCl	5.70-j0.09	0.00682	0.0122 -j0.0001

From the above table and equation (4-1), the complex dielectric constant of the mixture is $\epsilon_m = 6.5713 - j0.2116$.

Results of complex dielectric constant of each sample, as shown in the following table.

Table (4-10). The Complex Permittivity of each Sample.

Samples No.	complex permittivity
1	6.2837 -j 0.1353.
2	6.0761 -j0.1505
3	6.0763 -j0.1504
4	5.9610 -j0.1492
5	6.2600 -j0.1618
6	6.6659 -j0.2226
7	6.5713 -j0.2116

The average of complex permittivity of samples in table (4-10) equal to $\epsilon_m = 6.2706 - j0.1688$.

4.3. Calculation of the Average Density:

The analysis of these samples was done in laboratories of the Libyan Petroleum Institute and Lebda Plant in AL-Khoms. The average density of all samples from table (3-10) is equal to 2.36 gm/cm^3 .

From the tables (3-3) to(3-10) and (4-3) to(4-9) the following remarks can be pointed out:

- The major constituents of samples are SiO_2 , CaO and AL_2O_3 about 82% by weight of samples.
- The average density of all samples from table (3-10) is equal to **2.36 gm/cm^3** and this could be used as the effective density for the studied area of Libya (AL-Joufrah region)
- The average complex permittivity from table (4-10) is equal to **$6.2706 - j0.1688$** , and this could be used as the effective complex permittivity for the studied area of Libya (AL-Joufrah region).

4.4. Calculation of the Size Distribution Probability:

The analysis of(PSD) of all samples as determined by the Libyan Petroleum Institute laboratory and Lebda Plant in AL-Khoms.

From the results presented in tables (3-11) to (3-17), the distribution probability can be obtained as given in the following tables (4-11) to (4-17) respectively.

Table (4-11):Distribution Probability of Sample (1)

Particle Diameter (μm)	Probability
600	1.001975584
425	2.016108606
300	4.675548351
180	7.890177803
106	48.23463857
75	31.27501142
32	4.906539689

A particle size distribution can be displayed graphically from figure (4.1) showing the relation between diameter of particles and their distribution probabilities.

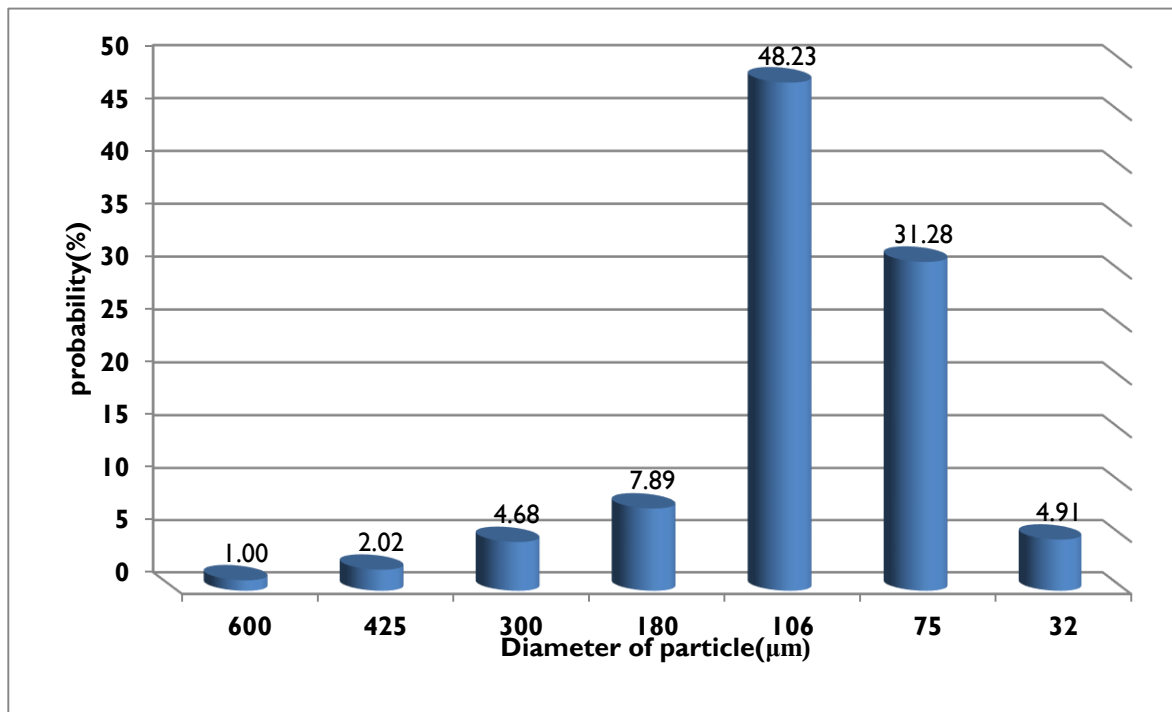


Fig.(4.1) Size Distribution Probability of Sample (1).

From table (4-11), we can note that about 87% of the sample consists of diameters that range from (75-180μm).

Table (4-12):Distribution Probability of Sample (2)

Particle Diameter (μm)	Probability
600	0.282488549
425	1.972214862
300	2.622364387
180	6.506227051
106	43.16822501
75	37.03581027
32	8.412669872

A particle size distribution can be displayed graphically form, figure (4.2) showing the relationship between diameter of the particles and their distribution probabilities.

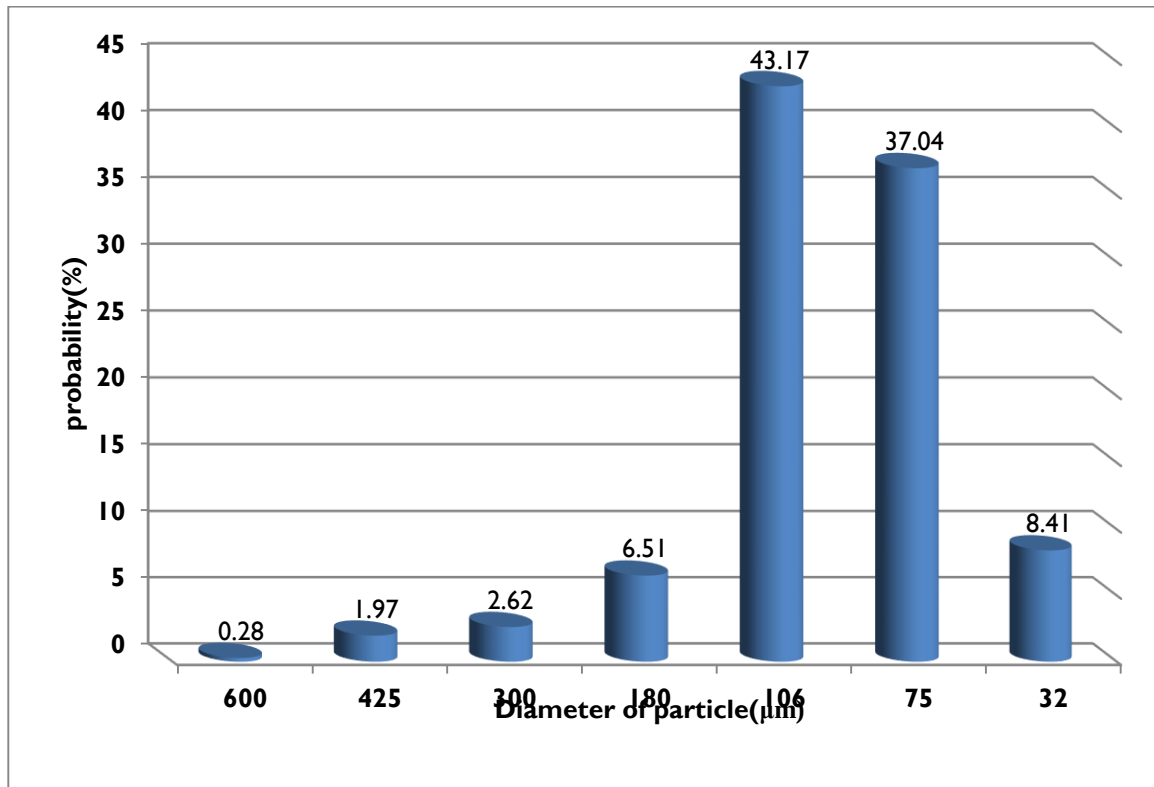


Fig.(4.2) Size Distribution Probability of Sample (2).

From table (4-12), we can note that about 89% of the sample consists of diameters that range from (32-106μm).

Table (4-13):Distribution Probability of Sample (3)

Particle Diameter (μm)	Probability
600	0.283532977
425	1.373444145
300	4.265567218
180	8.373327090
106	43.20192837
75	38.30296409
32	4.199236108

A particle size distribution can be displayed graphically form, figure (4.3) showing the relationship between diameter of the particles and their distribution probabilities.

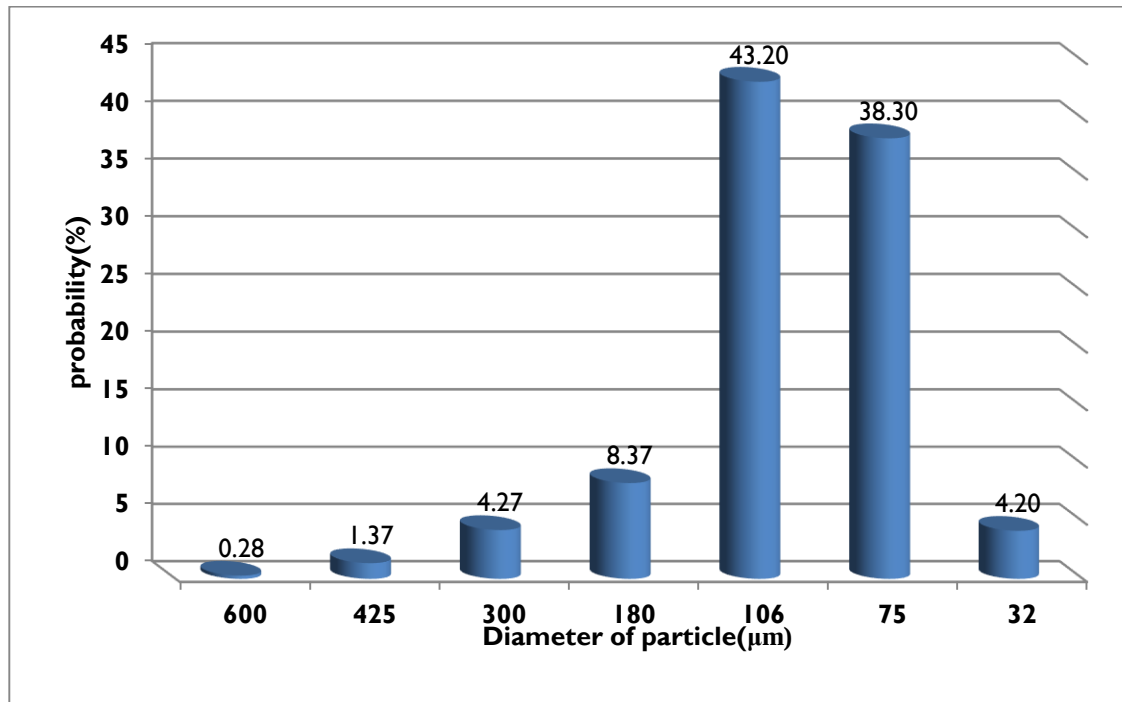


Fig.(4.3) Size Distribution Probability of Sample (3).

From table (4-13), we can note that about 90% of the sample consists of diameters that range from (75-180μm).

Table (4-14):Distribution Probability of Sample (4)

Particle Diameter (μm)	Probability
600	0.706706281
425	1.337542445
300	2.358340407
180	5.173493209
106	50.07958404
75	37.80772496
32	2.536608659

A particle size distribution can be displayed graphically form, figure (4.4) showing the relationship between diameter of the particles and their distribution probabilities.

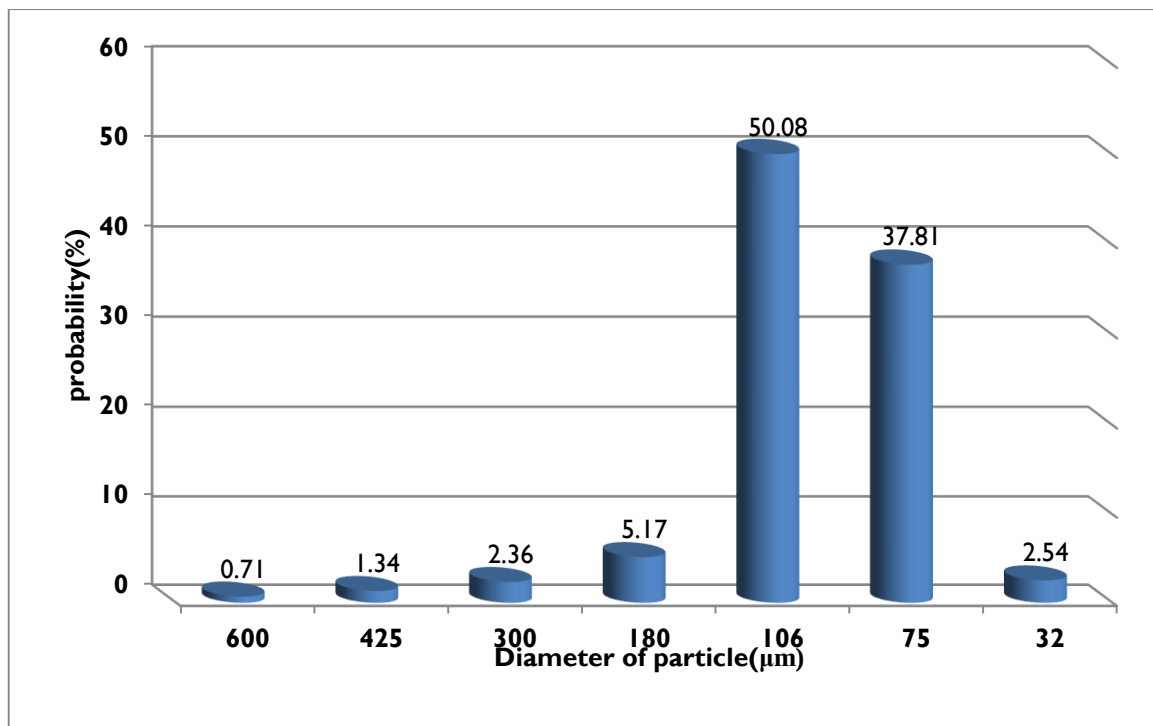


Fig.(4.4) Size Distribution Probability of Sample (4).

From table (4-14), we can note that about 93% of the sample consists of diameters that range from (75-180μm).

Table (4-15):Distribution Probability of Sample (5)

Particle Diameter (μm)	Probability
600	6.955221572
425	19.80871852
300	32.98187724
180	6.336521358
106	20.81926220
75	9.404243252
32	3.694155861

A particle size distribution can be displayed graphically form, figure (4-5) showing the relationship between diameter of the particles and their distribution probabilities.

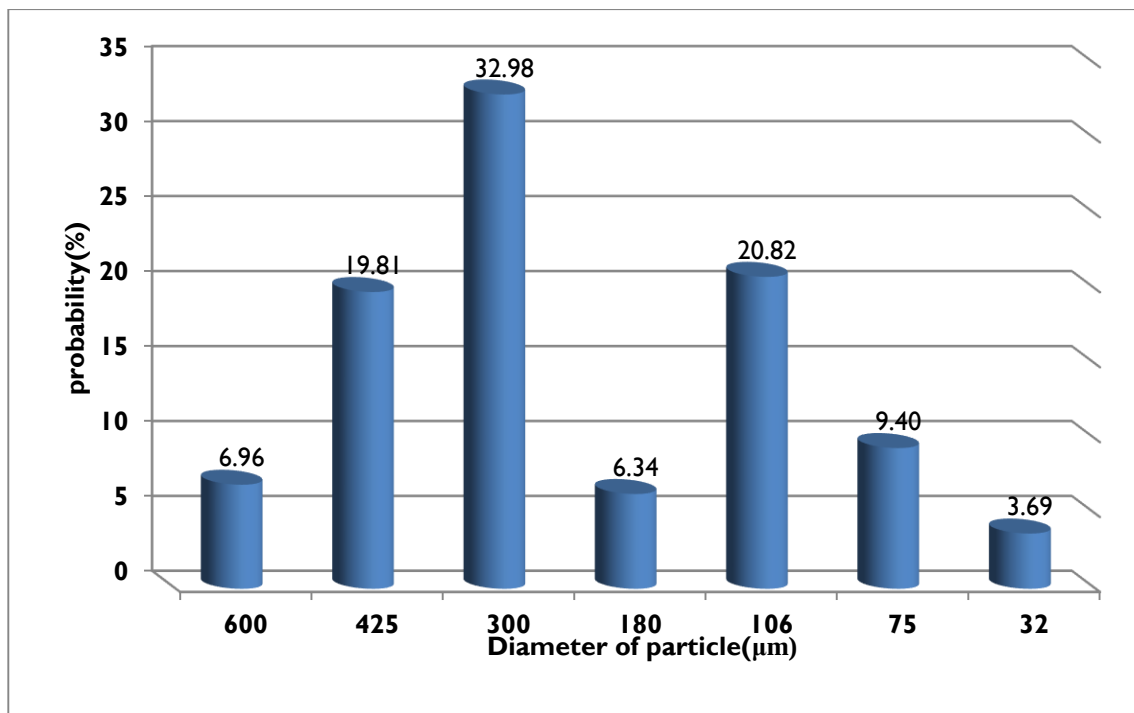


Fig.(4.5) Size Distribution Probability of Sample (5).

From table (4-15), we can note that about 80% of the sample consists of diameters that range from (106-425μm).

Table (4-16):Distribution Probability of Sample (6)

Particle Diameter (μm)	Probability
600	5.654139114
425	15.36368963
300	21.23964175
180	15.68594626
106	30.96174772
75	11.10739098
32	4.172595631

A particle size distribution can be displayed graphically form, figure (4-6) showing the relationship between diameter of the particles and their distribution probabilities.

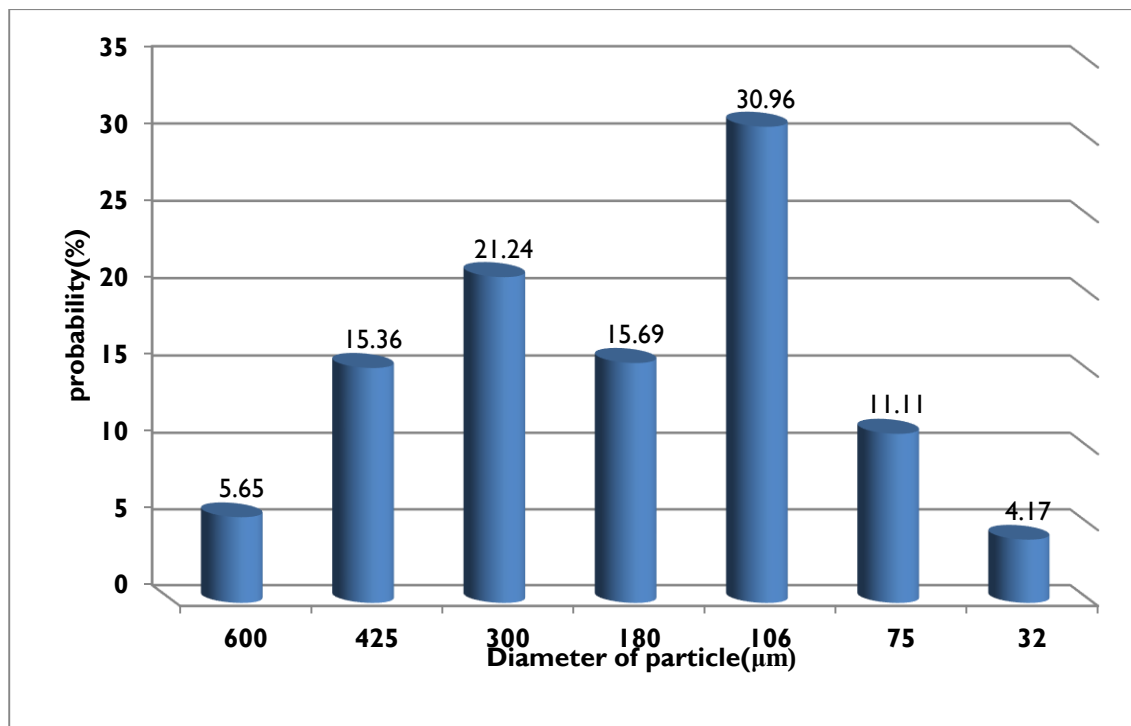


Fig.(4.6) Size Distribution Probability of Sample (6).

From table (4-16), we can note that about 79% of the sample consists of diameters that range from (106-425μm).

Table (4-17): Distribution Probability of Sample (7)

Particle Diameter (μm)	Probability
600	0.930336337
425	2.369782878
300	5.215434807
180	3.558893014
106	44.60006750
75	34.71144111
32	8.617392271

A particle size distribution can be displayed graphically form, figure (4-7) showing the relationship between diameter of the particles and their distribution probabilities.

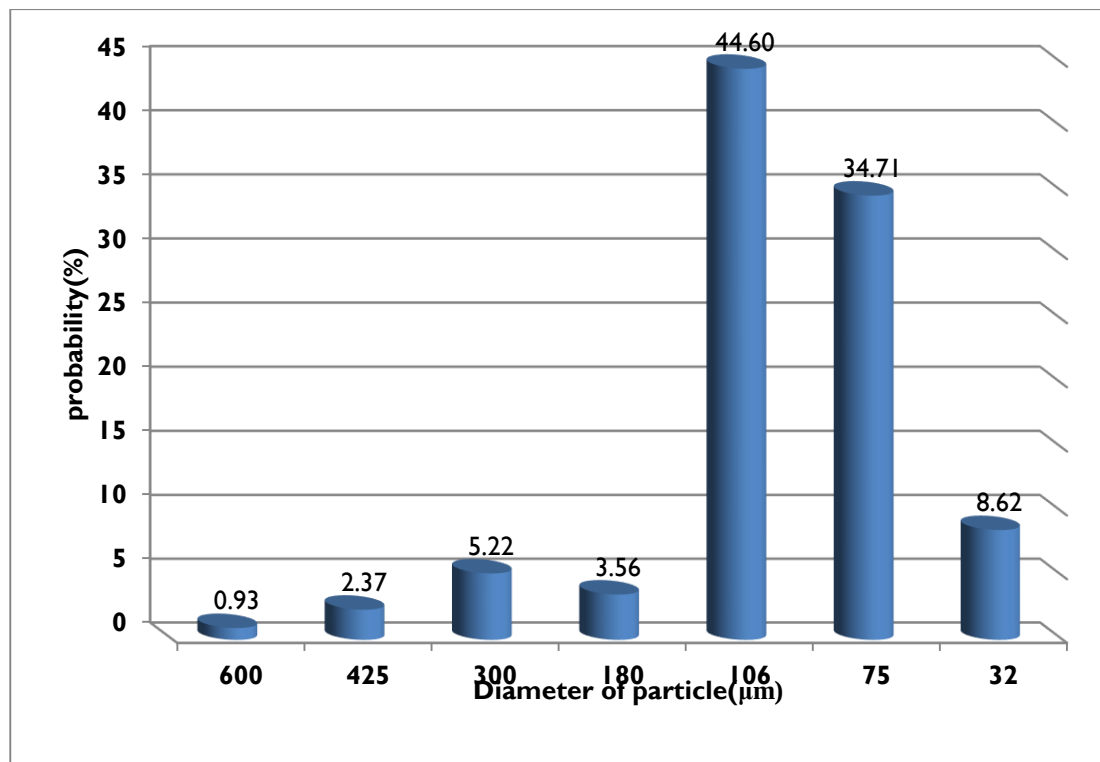


Fig.(4.7) Size Distribution Probability of Sample (7).

From table (4-17), we can note that about 88% of the sample consists of diameters that range from (32-106μm).

From pervious tables the following remarks can be pointed out:

- About 80% of the samples have a diameter between (75-180μm), therefore the dominant grain size is a fine sand size.
- Size of particles depend on site of samples.

4.5. Estimation of Air Relative Humidity:

The complex permittivity depends on moisture content of samples; S. M. Sharif arrived at the following empirical relation for the variation of complex permittivity with relative humidity. [5, 17]

$$\epsilon' = 5.52 + 0.04H - 7.78 * 10^{-4}H^2 + 5.56 * 10^{-6}H^3 \dots\dots\dots(4-2)$$

$$\epsilon'' = 0.16 + 0.02H - 3.71 * 10^{-4}H^2 + 2.76 * 10^{-6}H^3 \dots\dots\dots(4-3)$$

Where: H is the air relative humidity (percentage).

We can use the equations (4-2) & (4-3) to estimate the effect of relative humidity on the complex permittivity in the studied area (AL-Joufrah) region, by changing the first term of both equations of the real part and imaginary part of complex permittivity of dry samples respectively as in equations below .

$$\epsilon' = 6.2706 + 0.04H - 7.78 * 10^{-4}H^2 + 5.56 * 10^{-6}H^3 \dots\dots\dots(4-4)$$

$$\epsilon'' = 0.1688 + 0.02H - 3.71 * 10^{-4}H^2 + 2.76 * 10^{-6}H^3 \dots\dots\dots(4-5)$$

4.6. Estimating the Attenuation and Cross Polarization for spherical particles:

4.6.1. Estimation of the Attenuation Constant:

In this study, two methods for calculating the attenuation constant are used:

▪ First Method:

In this section we will use exactly the same expression obtained by Samir I. Ghobrial [5] using an analysis based on the work of Maxwell Garnett. Also the effect of the height (height of towers) on the visibility there by its effect on both the attenuation and the cross-polarization constants in this region.

$$\alpha = \frac{2.46 * 10^5 * \nu}{\lambda} * \left[\frac{\varepsilon''}{(\varepsilon' + 2)^2 + \varepsilon''^2} \right] \dots\dots\dots(4-6)$$

$$\nu = \frac{C}{\rho * V_o^\gamma \left(\frac{h}{h_o} \right)^b} \dots\dots\dots(4-7)$$

Where:

ν is the relative volume occupied by particles (m^3 of particles / m^3 of air), C and γ 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 believed to be applicable to conditions in Sudan and Saudi Arabia, for this reason and a lack of any information about them, we can use the same values in Libya, it has been used before, $C=2.3 \times 10^{-5}$, $\gamma = 1.07$. [5]

λ is the wavelength (in meters)

V_o is the visibility at h_o ; its minimum value is about 4m.

$h_o = 2\text{m}$ is the reference height

$\varepsilon = 6.2706 - j0.1688$ is the complex permittivity of dry samples

ρ is the average measured density of the samples collected in AL-Joufrah region from table (3-10) is 2.36gm/cm^3 .

By using program (2) in [Appendix (B)], the results are given in tables (4-18), (4-19), and (4-20).

Table (4-18). Attenuation per km at humidity 21% with different heights (dB/km).

Visibility at h_0 (km)	Att.per km at h=10	Att.per km at h=30	Att.per km at h=70
0.008	0.0346	0.0254	0.0201
0.048	0.0051	0.0037	0.0029
0.088	0.0027	0.0020	0.0015
0.128	0.0018	0.0013	0.0010
0.168	0.0013	9.77e-004	7.71e-004
0.208	0.0011	7.78e-004	6.14e-004
0.248	8.77e-004	6.45e-004	5.08e-004
0.288	7.45e-004	5.49e-004	4.33e-004

The relation between attenuation per km and visibility in AL-Joufrah region at humidity 21%, and at height 10,30 and70m are shown in figure (4.8).

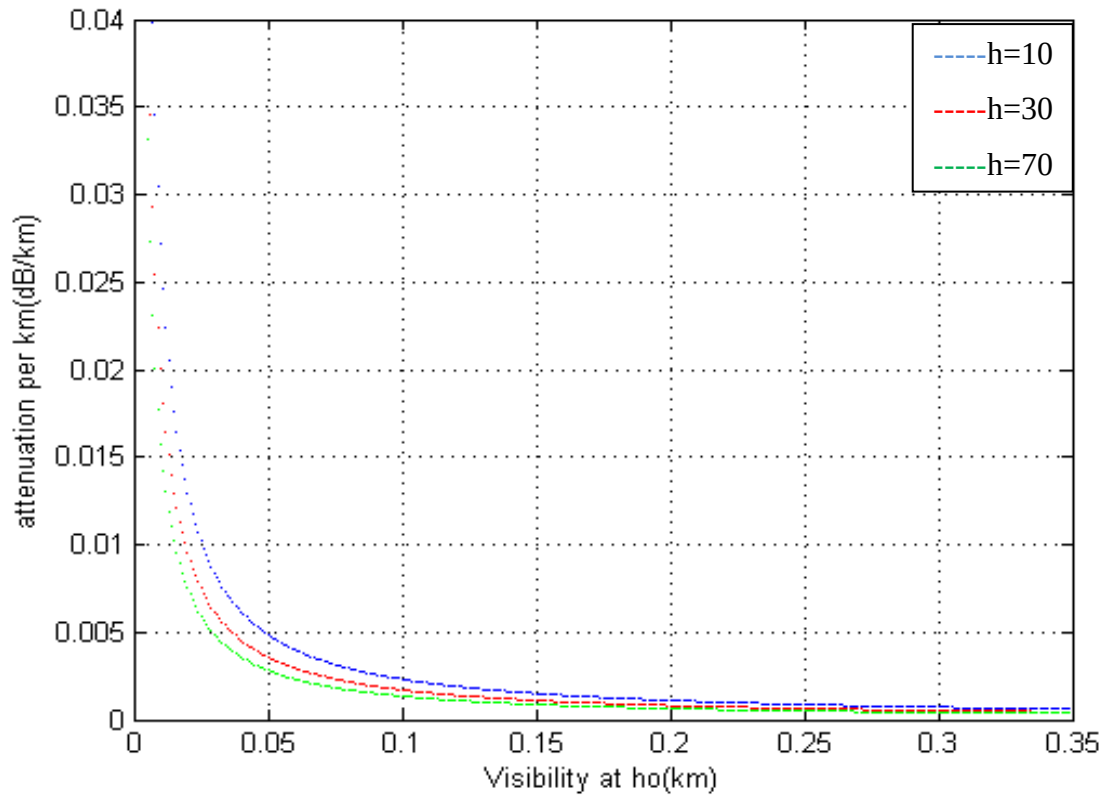


Fig.(4.8):-Attenuation per km at H=21% and for height=10, 30 and70m.

Table (4-19). Attenuation per km at humidity 46% with different heights (dB/km).

Visibility at h_0 (km)	Att.per km at h=10	Att.per km at h=30	Att.per km at h=70
0.008	0.0421	0.0310	0.0244
0.048	0.0062	0.0046	0.0036
0.088	0.0032	0.0024	0.0019
0.128	0.0022	0.0016	0.0013
0.168	0.0016	0.0012	9.40e-004
0.208	0.0013	9.48e-004	7.48e-004
0.248	0.0011	7.85e-004	6.19e-004
0.288	9.086e-004	6.69e-004	5.28e-004

The relation between attenuation per km and visibility in AL-Joufrah region at humidity 46%, and at height 10,30 and 70m are shown in figure (4.9).

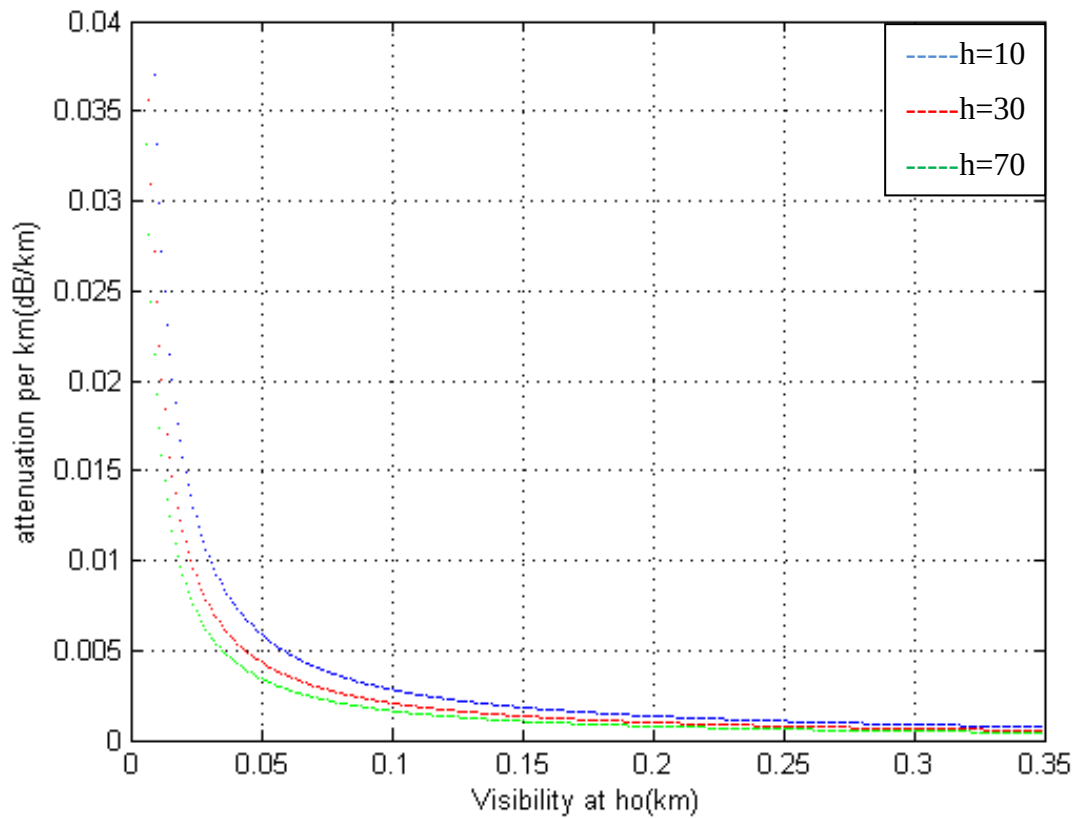


Fig.(4.9):-Attenuation per km at H=46% and for height=10, 30 and70m.

Table (4-20). Attenuation per km at humidity 72% with different heights (dB/km)

Visibility at h_0 (km)	Att.per km at h=10	Att.per km at h=30	Att.per km at h=70
0.008	0.0506	0.0372	0.0293
0.048	0.0074	0.0055	0.0043
0.088	0.0039	0.0029	0.0023
0.128	0.0026	0.0019	0.0015
0.168	0.0019	0.0014	0.0011
0.208	0.0015	0.0011	8.98e-004
0.248	0.0013	9.43e-004	7.44e-004
0.288	0.0011	8.04e-004	6.34e-004

The relation between attenuation per km and visibility in AL-Joufrah region at humidity 72%, and at height 10,30 and 70m are shown in figure (4.10).

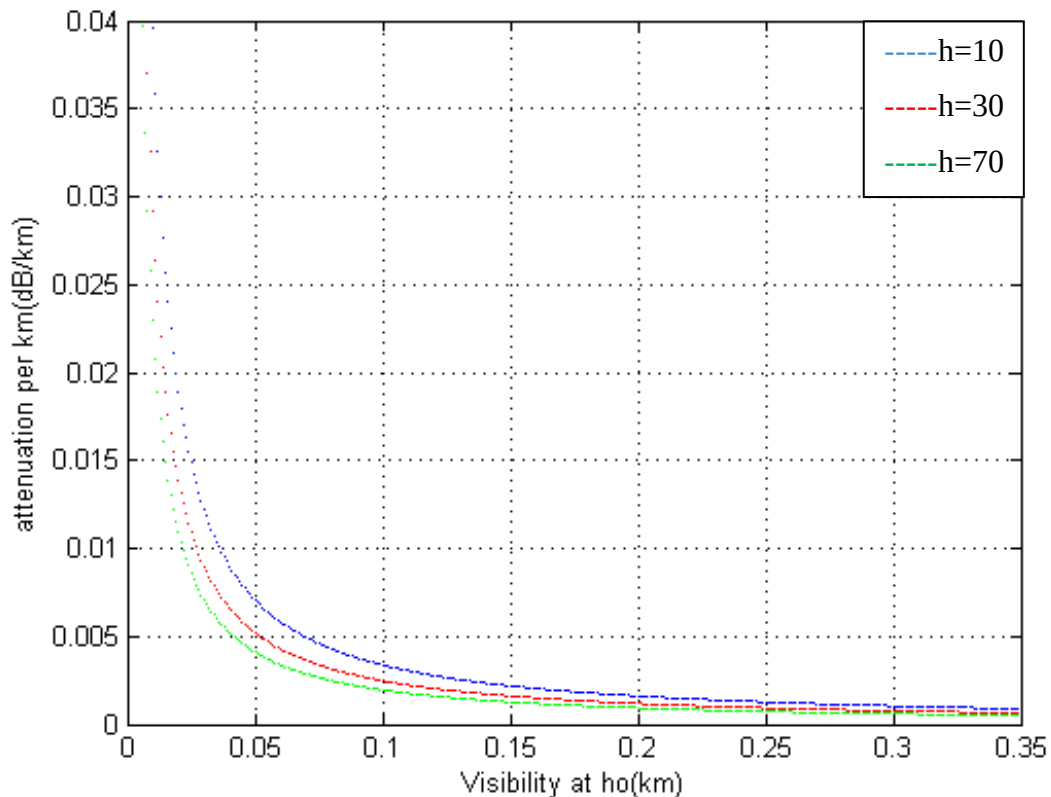


Fig.(4.10):-Attenuation per km at H=72% and for height=10, 30 and 70m.

▪ Second Method:

In this section we will use the exact expression obtained by Chu [20]. Attenuation due to dust or sand storms at centimeter wavelengths may be expressed for polydisperse (not equal particle radii) system by:

$$\alpha = \frac{1.029 \cdot 10^6}{\lambda} * \frac{\varepsilon''}{\left[(\varepsilon' + 2)^2 + \varepsilon''^2 \right]} * \sum_i N_i r_i^3 \dots (4-8)$$

$$N_T = \frac{3.C}{4.\pi.\pi.\rho_o \gamma \left(\frac{h}{h_o} \right)^b \sum_i P_i . r_i} \dots (4-9)$$

$$N_i = N_T * P_i$$

Where:

N_T is the total number of particles per unit volume

N_i is the number of particles with radii between r_i and $r_i + \Delta r_i$ per m^3

P_i is the probability that r_i lies between r_i and $r_i + \Delta r_i$

V_o , h_o , λ , ρ , C , γ and ε have been previously defined by method (1); else P_i , N_i and N_T will calculate them from PSD of samples, by using program (2) in [Appendix (B)], the results are given in tables (4-21), (4-22) and (4-23).

Table (4-21). Attenuation per km at humidity 21% with different height (dB/km).

Visibility at h_0 (km)	Att.per km at $h=10$	Att.per km at $h=30$	Att.per km at $h=70$
0.008	0.0345	0.0253	0.0201
0.048	0.0051	0.0037	0.0029
0.088	0.0027	0.0019	0.0015
0.128	0.0018	0.0013	0.0010
0.168	0.0013	9.75e-004	7.69e-004
0.208	0.0011	7.75e-004	6.12e-004
0.248	8.74e-004	6.43e-004	5.07e-004
0.288	7.45e-004	5.47e-004	4.32e-004

The relation between attenuation per km and visibility in AL-Joufrah region at humidity 21%, and at height and 10,30 and70m are shown in figure (4.11).

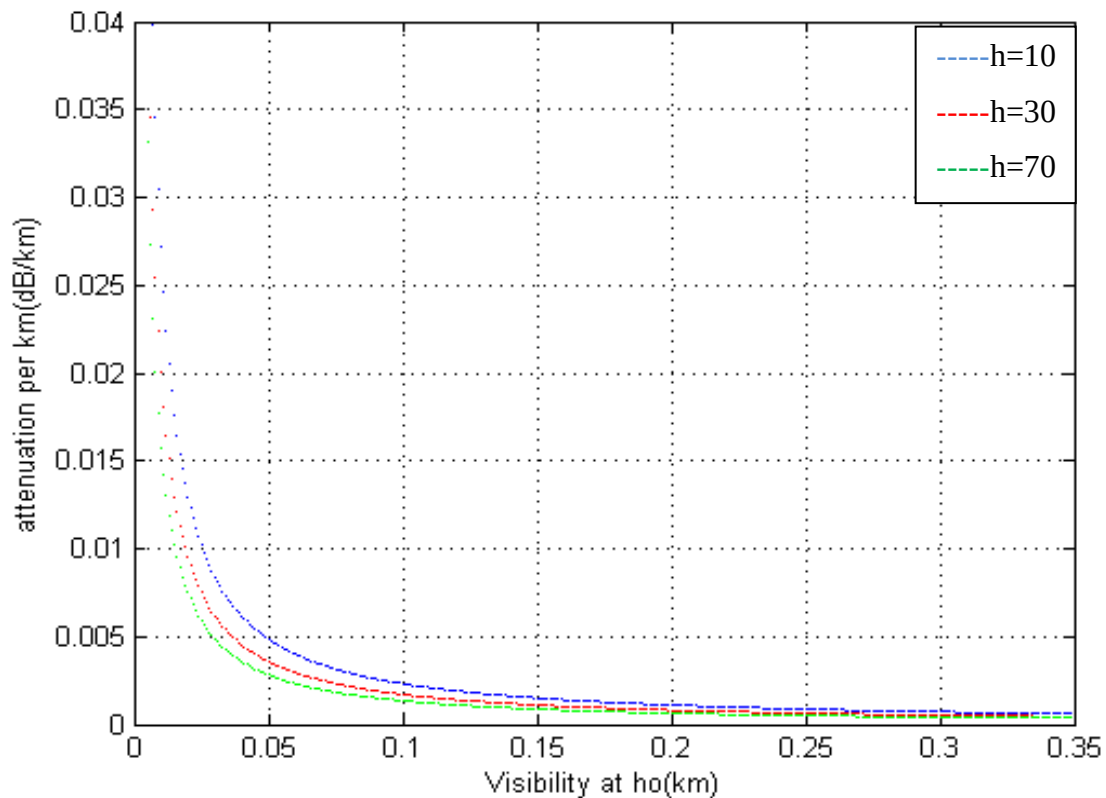


Fig.(4.11):-Attenuation per km at H=21% and for height=10, 30 and70m.

Table (4-22). Attenuation per km at humidity 46% with different heights (dB/km).

Visibility at $h_0(\text{km})$	Att.per km at $h=10$	Att.per km at $h=30$	Att.per km at $h=70$
0.008	0.0421	0.0310	0.0244
0.048	0.0062	0.0046	0.0036
0.088	0.0032	0.0024	0.0019
0.128	0.0022	0.0016	0.0013
0.168	0.0016	0.0012	9.40e-004
0.208	0.0013	9.48e-004	7.48e-004
0.248	0.0011	7.85e-004	6.19e-004
0.288	9.10e-004	6.69e-004	5.28e-004

The relation between attenuation per km and visibility in AL-Joufrah region at humidity 46%, and at height 10,30 and 70m are shown in figure (4.12).

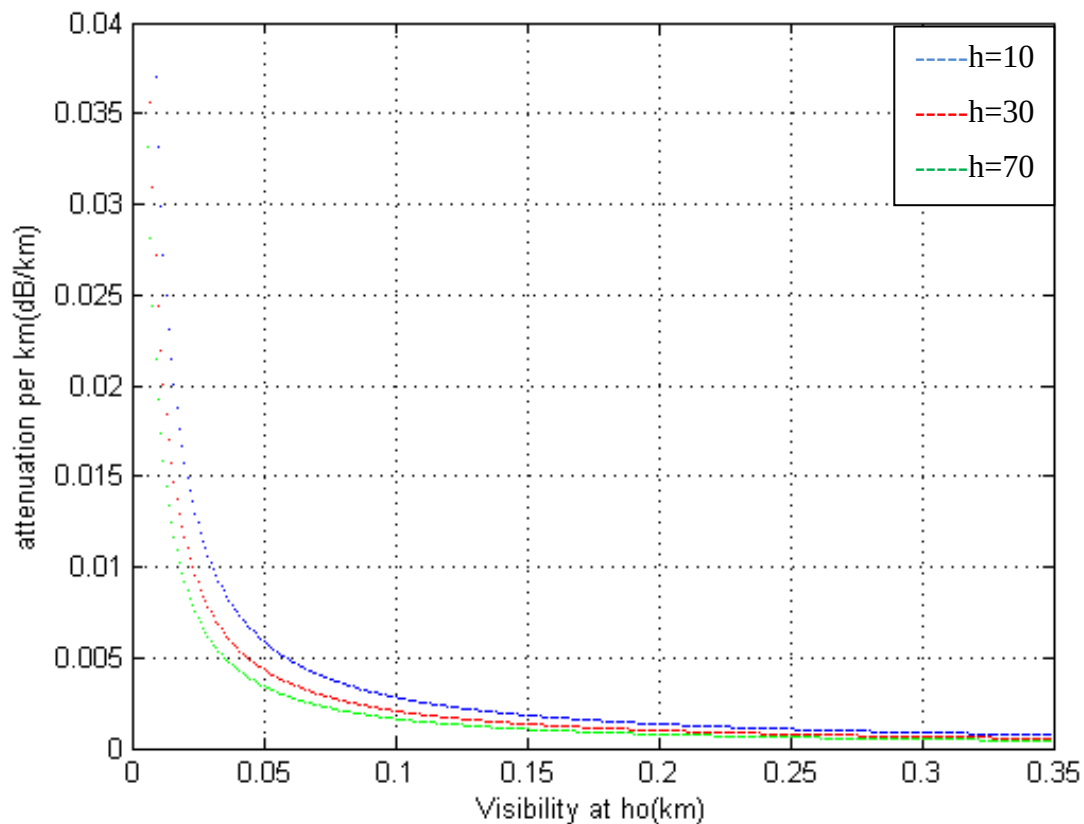


Fig.(4.12):-Attenuation per km at H=46% and for height=10, 30 and 70m.

Table (4-23). Attenuation per km at humidity 72% with different heights (dB/km).

Visibility at h_0 (km)	Att.per km at $h=10$	Att.per km at $h=30$	Att.per km at $h=70$
0.008	0.0506	0.0372	0.0293
0.048	0.0074	0.0055	0.0043
0.088	0.0039	0.0029	0.0023
0.128	0.0026	0.0019	0.0015
0.168	0.0019	0.0014	0.0011
0.208	0.0015	0.0011	8.98e-004
0.248	0.0013	9.43e-004	7.44e-004
0.288	0.0011	8.04e-004	6.34e-004

The relation between attenuation per km and visibility in AL-Joufrah region at humidity 72%, and at height 10,30 and 70m are shown in figure (4.13).

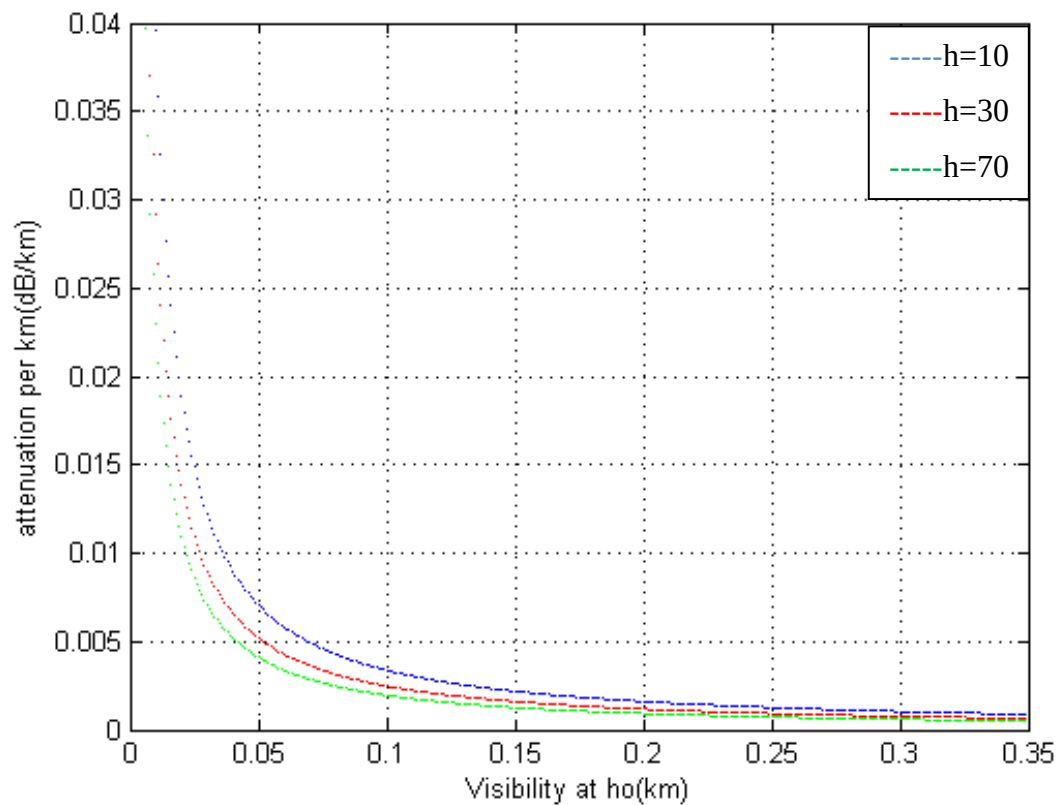


Fig.(4.13):-Attenuation per km at H=72% and for height=10, 30 and 70m.

From the tables (4-18) to(4-23) the following remarks can be pointed out:

- The value of the attenuation constant using method (2) is the same as that found using method (1), where the attenuation of signal due to dust storms with visibility equal 8m (worst case) at humidity 21% at any height, this is based on the attenuation per unit length and the maximum distance between stations which is 58km (total attenuation 1.546dB).
- The attenuation of signal due to dust storms with visibility equal 8m (worst case) at humidity 46 % and 72% is serious at any height, this is based on the attenuation per unit length and the maximum distance between stations which is 58km (total attenuation 1.885dB and 2.264dB respectively).

4.6.2. Estimation of the Cross-Polarization Constant:

For spherical particles the axis ratios of particles are equal, the attenuation and phase shift constants for both vertically polarized waves and horizontal polarized waves are equal, where by cross-polarization "XPD" becomes infinite.

Therefore, we conclude that the cross-polarization is not serious when the shape of dust particles is spherical.

For circular polarization, cross polarization can be serious when dust particles are not spherical.

4.7. Estimating the Attenuation and Cross Polarization for non spherical particles:

4.7.1 Estimation of the Attenuation and Phase Constants:

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. [22,15]

We can use equations (2-21) 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:

$$x_i = \sum_i \frac{1}{A_i + \frac{1}{\epsilon - 1}} \quad i=1,2,3 \dots \dots \dots (4-10)$$

Was evaluated for two values of ' ϵ ' these are the dielectric constant of dust with relative humidity 21% and 72%. Table (4-24) gives the outcome of these computations. The values of A_1 , A_2 and A_3 were taken from equations (2.9), (2.10), (2.11), and Fig (2-8), (2-9).

Table (4-24). Dielectric Constant of Dust with relative humidity 21% and 72% .

dielectric constant (ϵ)	X_1	X_2	X_3
6.8190-j0.4507	4.1060 -j0.2238	2.9909 - j0.1186	1.0684 - j0.0151
7.1927 - j0.7157	4.2952 - j0.3419	3.0921 - j0.1767	1.0814 - j0.0215

From equation (2.22), the attenuation and phase constants for vertical polarization can be written as:

$$\alpha_v = -\frac{\pi}{\lambda} v \operatorname{Im} x_3 \dots \dots \dots (4-11.a)$$

$$\phi_v = -\frac{\pi}{\lambda} v \operatorname{Re} x_3 \dots \dots \dots (4-11.b)$$

Also from (2.26), for horizontal polarization:

$$\alpha_h = -\frac{\pi}{\lambda} v \operatorname{Im}(x_1 + x_2) \dots (4-12.a)$$

$$\phi_h = -\frac{\pi}{\lambda} v \operatorname{Im}(x_1 + x_2) \dots (4-12.b)$$

Using (2.13), (4.11), and (4.12) and values of ' x_i ' given in table (4.24), the following expression for attenuation and phase constants were obtained in terms of visibility, wavelength, and path length D in the storm:

For relative Humidity($H=21\%$): $\varepsilon = 6.8190 - j0.4507$:

$$\alpha_v = 4.017 * 10^{-4} D / (\lambda V^\gamma) \dots (4-13.a)$$

$$\Phi_v = 0.1874 * D / (\lambda V^\gamma) \dots (4-13.b)$$

$$\alpha_h = 4.6 * 10^{-3} D / (\lambda V^\gamma) \dots (4-13.c)$$

$$\Phi_h = 0.6225 * D / (\lambda V^\gamma) \dots (4-13.d)$$

For relative Humidity($H=72\%$): $\varepsilon = 7.1927 - j0.7157$:

$$\alpha_v = 5.7299 * 10^{-4} D / (\lambda V^\gamma) \dots (4-14.a)$$

$$\Phi_v = 0.1897 * D / (\lambda V^\gamma) \dots (4-14.b)$$

$$\alpha_h = 6.9 * 10^{-3} D / (\lambda V^\gamma) \dots (4-14.c)$$

$$\Phi_h = 0.6480 * D / (\lambda V^\gamma) \dots (4-14.d)$$

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; and ' γ ' is a constant equal to 1.07.

We will be using Equations (2.28), (2.29), (4.13) and (4.14) 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 1km, by using program (3) in Appendix (B), the results are given in tables (4-25), (4-26), (4-27).and (4-28).

Table (4-25). Attenuation per km for two types of dust at height=10m.

Visibility(km)	α (dB/km) at $\varepsilon = 6.8190 - j0.4507$	α (dB/km) at $\varepsilon = 7.1927 - j0.7157$
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

Figure (4.14) showing the relation between attenuation per km and visibility in AL-Joufrah region at h=10m and different relative humidity.

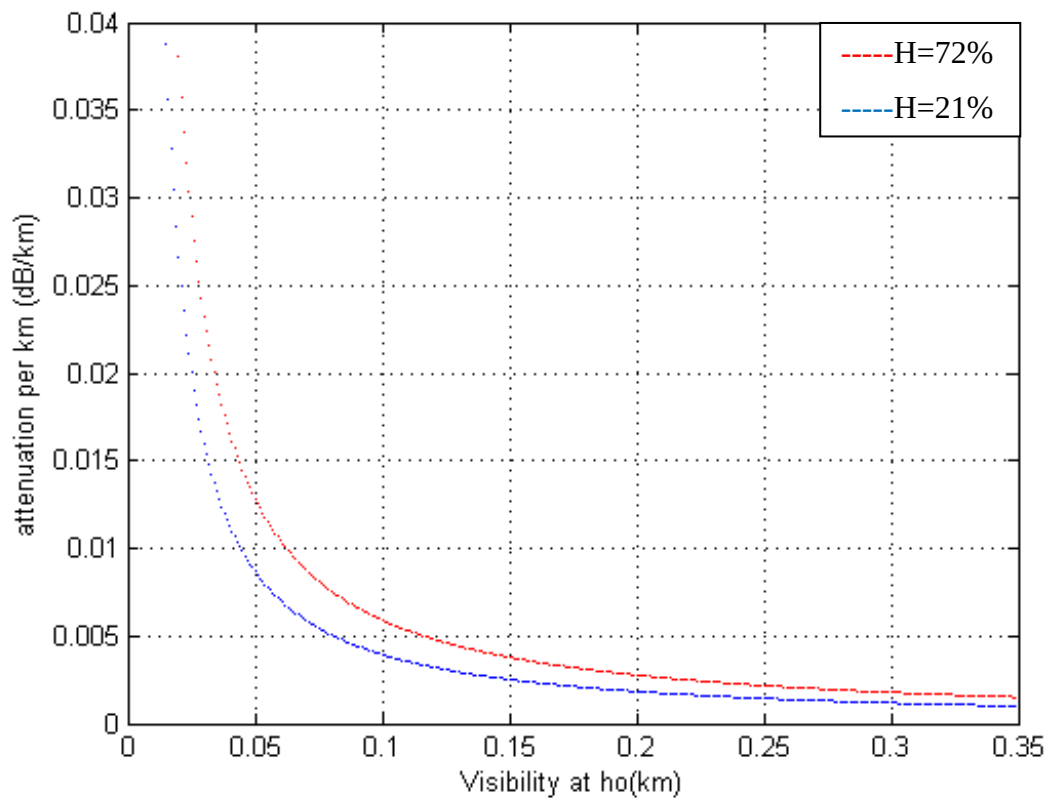


Fig.(4.14):Attenuation per km at height= 10m and for H=21%,72%.

Table (4-26). Attenuation per km for two types of dust at height=70m.

Visibility(km)	α (dB/km) at $\varepsilon = 6.8190 - j0.4507$	α (dB/km) at $\varepsilon = 7.1927 - j0.7157$
0.008	0.0457	0.0638
0.048	0.0051	0.0076
0.088	0.0026	0.0039
0.128	0.0017	0.0026
0.168	0.0013	0.0019
0.208	0.0010	0.0015
0.248	8.3601e-004	0.0013
0.288	7.1135e-004	0.0011

Figure.(4.15) showing the relation between attenuation per km and visibility in AL-Joufrah region at h=70m and at different relative humidity.

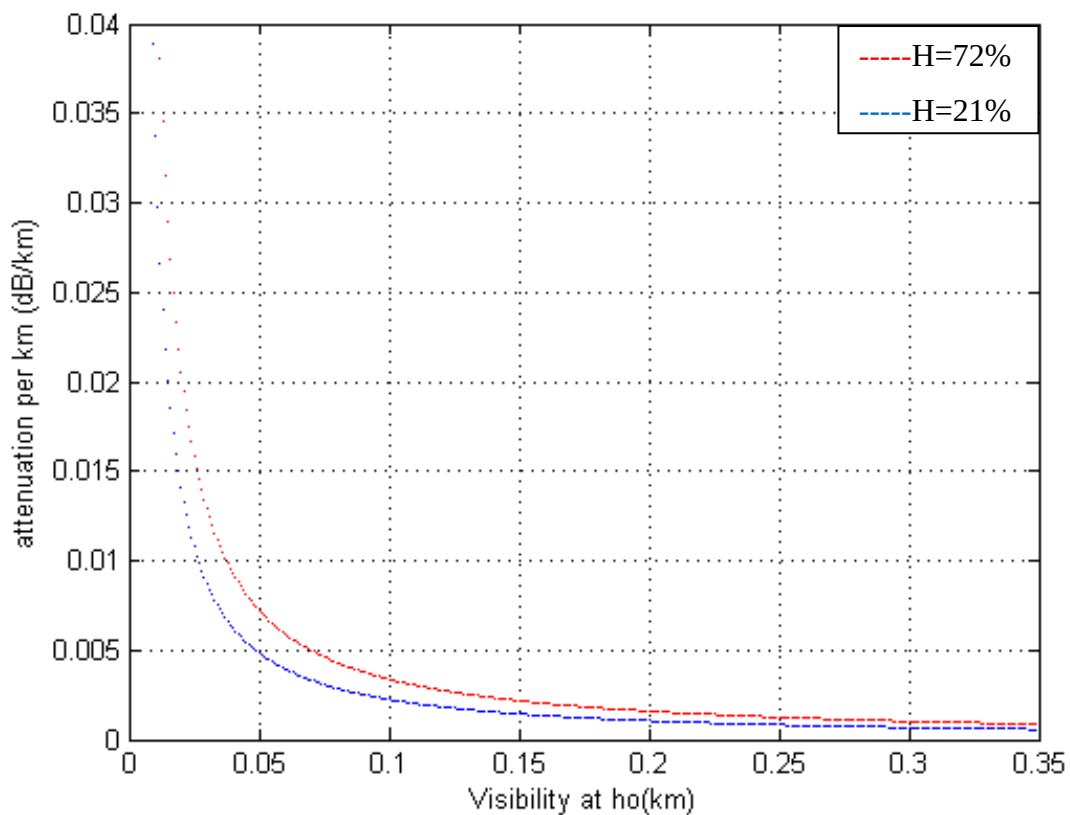


Fig.(4.15):-Attenuation per km at height= 70m and for H=21%,72%.

. Table (4-27) Phase difference between horizontal and vertical polarizations at height=10m.

Visibility(km)	$\Phi(\text{degree})$ at $\varepsilon = 6.8190 - j0.4507$	$\Phi(\text{degree})$ at $\varepsilon = 7.1927 - j0.7157$
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

Figure.(4-16), gives a plot of phase difference between horizontally and vertically polarized waves as a function of visibility for a path length of 1 km.

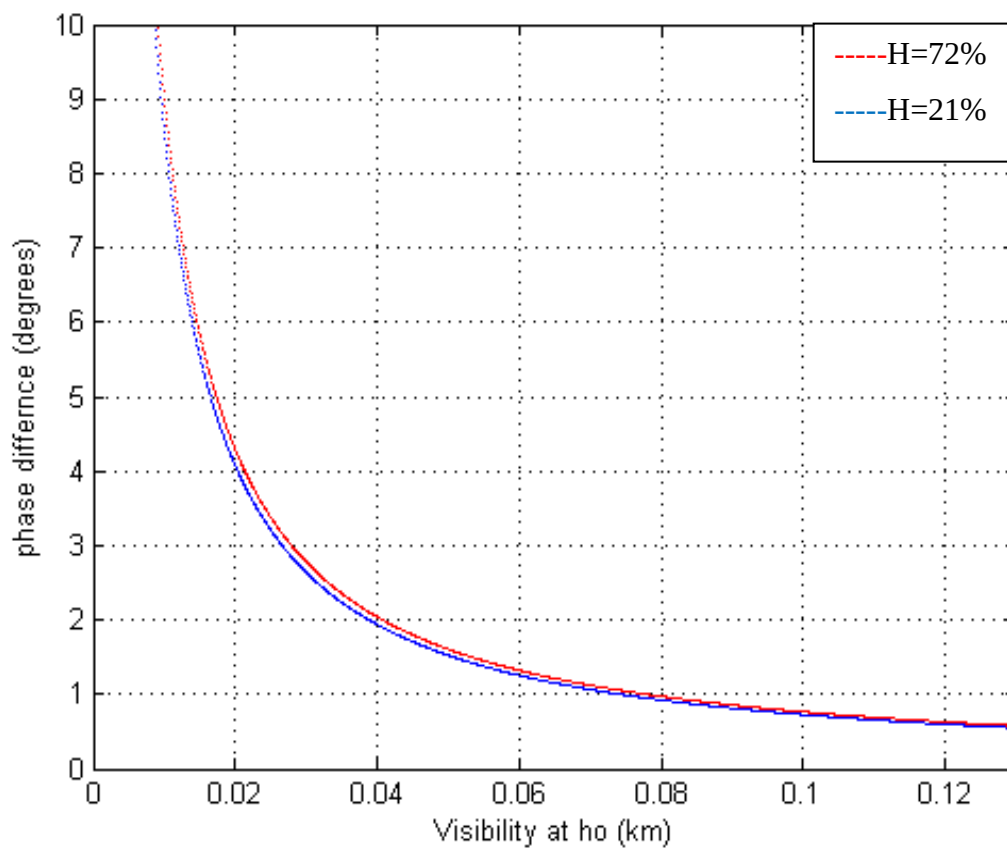


Fig.(4.16) Phase difference(degree) at height=10m.

. Table (4-28) Phase difference between horizontal and vertical polarizations at height=70.

Visibility(km)	$\Phi(\text{degree})$ at $\varepsilon = 6.8190 - j0.4507$	$\Phi(\text{degree})$ at $\varepsilon = 7.1927 - j0.7157$
0.004	13.21	13.916
0.024	1.942	2.046
0.044	1.016	1.069
0.064	0.680	0.716
0.084	0.508	0.536
0.104	0.405	0.426
0.124	0.335	0.353

Figure.(4-17), gives a plot of phase difference between horizontally and vertically polarized waves as a function of visibility for a path length of 1km.

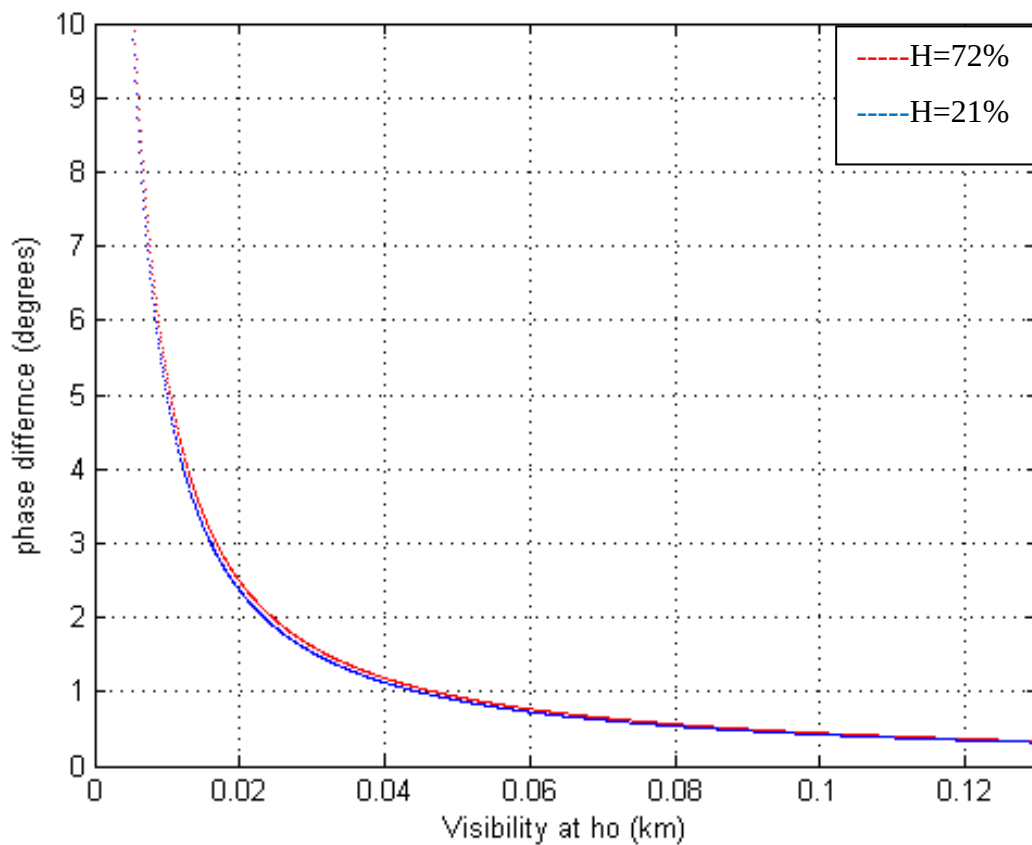


Fig.(4.17) Phase difference(degree) at height= 70m.

From the tables (4-25) to(4-28) the following remarks can be pointed out:

- The value of the attenuation of signal due to dust storms with visibility equal 8m (worst case) at minimum relative humidity 21% and maximum relative humidity 72% for AL-Joufrah region, this is based on the attenuation per unit length and the maximum distance between stations which is 58km (total attenuation 3.083dB and 4.562dB respectively).
- For visibilities less than 40m phase difference between horizontal and vertical polarizations increases rapidly with decreasing visibility.
- The effect of dust humidity on phase difference between horizontal and vertical polarizations is not significant for different visibilities.

4.7.2. Estimation of the Cross Polarization Constant:

For circular polarization and dust particles are not spherical, cross polarization can be serious. We can use the equations (2-27),(2.28),(4.13) and (4.14) to estimate the cross polarization discrimination for values of path length (D).By using program (3) in Appendix (B), the results are given in tables (4-29), and (4-30).

Table (4-29) Cross-Polarization at $\epsilon = 6.8190-j0.4507$, and $h=10$.

Visibility(km)	XPD(dB) at D=1km	XPD(dB) at D=10km	XPD(dB) at D=20km
0.008	20.48	-2.385	-8.996
0.108	44.65	24.64	18.58
0.208	50.74	30.73	24.71
0.308	54.39	34.38	28.36
0.408	56.99	37.01	30.97
0.508	59.03	39.05	33.01
0.608	60.71	40.70	34.68

Table (4-30). Cross-Polarization at $\epsilon = 7.1927 - j0.7157$, and $h=10$.

Visibility(km)	XPD(dB) at D=1km	XPD(dB) at D=10km	XPD(dB) at D=20km
0.008	19.95	-3.729	-8.297
0.108	44.17	24.16	18.11
0.208	50.27	30.26	24.23
0.308	53.91	33.91	27.89
0.408	56.53	36.52	30.50
0.508	58.57	38.56	32.54
0.608	60.23	40.23	34.21

Figure (4-18), gives a plot of cross polarization discrimination of circular polarization wave as a function of visibility for three values of D . These are 1,10 and 20km.

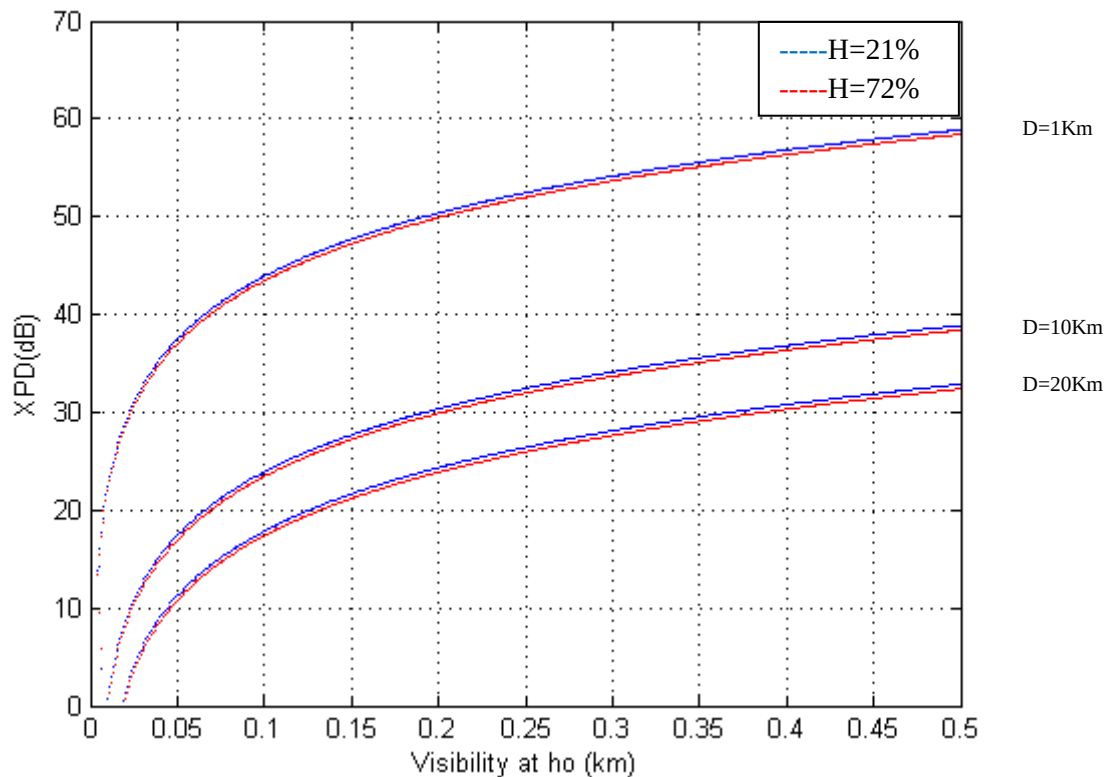


Fig.(4-18).Cross Polarization Discrimination (dB) at height= 10m.

From the tables (4-29),(4-30) and figure (4-18), they are seen that the 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 on microwave link of AL-Joufrah region.

The effect of dust humidity on cross polarization is not significant. A decrease in discrimination of less than (0.5dB) is produced by a change in dust humidity from 21 to 72 percent.

CHAPTER5

Conclusions and Recommendations

5.1. Conclusions:

The dust or sand storms are frequently encountered at southern and central parts of Libya. Microwave communication in these regions may be affected by dust and sand storms. AL-Joufrah region which is located at mid south of Libya has high wind speed, desert climate, and has too frequent dust and sand storms. The effect of the dust and sand on the microwave links in this area has been studied, we estimated the effect of the humidity on the complex permittivity and also the effect of the height of towers on the visibility whereby its effect on the attenuation, phase shift and cross polarization constants in this region.

Soil samples have been collected at different sites over the studied area along microwave link. The chemical and size analyses of these samples were done in the Libyan Petroleum Institute (LPI) in Tripoli and Lebda Plant in AL-Khoms (the chemical composition, the particle size distribution (PSD), and the density).

The meteorological data for the region of this study has been collected from the Libyan Center of Metrology.

Results of chemical and size analysis and some models were used to estimate the effect of dust storms on microwave link in study area. From the results, we concluded that:

- The major constituents of samples are SiO_2 , CaO and Al_2O_3 about 82% by weight of samples.
- The average density of all samples equal to 2.36gm/cm^3 and this could be used as the effective density for the studied area of Libya AL-Joufrah region.
- The average of complex permittivity of dry soil equal to **6.2706 - j0.1688** and equal to **7.1927 - j0.7157** at maximum relative humidity for the studied area of Libya (AL-Joufrah region).
- About 80% of the samples have a equivalent diameter between (75-180 μm), there for the dominant grain size is a fine sand size.
- The attenuation of signal due dust storms for spherical particles in study area in Libya with visibility equal 8m (worst case) at a humidity 21%, 46%, and 72% at any height equal (**0.0267dB/km**, **0.0325dB/km** and **0.039dB/km** respectively).

- The attenuation of signal due dust storms for non spherical particles in study area in Libya with visibility equal 8m (worst case) at a humidity 21% and 72% at any height, equal (**0.0531dB/km** and **0.0768dB/km** respectively).
- For circular polarization, cross polarization can be serious when visibilities fall below 100m over about 10km of path. or below 10m over about 1km of path on microwave link. of AL-Joufrah region.
- For visibilities less than 40m 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.
- Simple expressions for attenuation and phase shifts of linearly polarized waves were derived in terms of the path length, wavelength, and visibility.

From the chemical and size analysis of the collected soil samples in the studied area, we can note that chemical composition and size of particles are different from chemical composition and size of particles of collected samples from other parts of Libya as given in a previous study, so the attenuation constant is different as we expected.

5.2. Recommendations:

- The results of this study should not be drawn for all of Libya, but it is valid for the studied area and any similar part only, for other parts that are not similar, parallel study should be conducted.
- Study the effect of dust storms on performance of earth-satellite links in part of Libya in studied area.
- An experimental study should be conducted by designing and building a special microwave link that takes in account all effects of dust storms.

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Appendix(A)

Chemical and Size Analysis

Libyan Petroleum Institute (LPI) in Tripoli and Lebda Plant in AL-Khoms

I- Chemical Analysis of Samples.

Sample-No.1	
Oxide	weight %
SiO ₂	49.71
CaO	25.36
Al ₂ O ₃	5.11
MgO	2.78
Fe ₂ O ₃	2.08
K ₂ O	1.32
SO ₃	0.341
Na ₂ O	0.201
MnO	0.221
C1	0.431
TiO ₂	0.0039
ZrO ₂	0.0975
ZnO	0.0672
P ₂ O ₅	0.0543
LOI	11.47

Sample-No.2	
Oxide	weight %
SiO ₂	55.86
CaO	14.87
Al ₂ O ₃	8.87
MgO	2.91
Fe ₂ O ₃	1.43
K ₂ O	2.41
SO ₃	0.363
Na ₂ O	0.276
MnO	0.141
C1	0.344
TiO ₂	0.0728
P ₂ O ₅	0.185
ZrO ₂	0.0984
ZnO	0.179
NOi	0.0196
LOI	10.92

Sample-No.3	
Oxide	weight %
SiO ₂	58.84
CaO	17.08
Al ₂ O ₃	8.42
MgO	1.76
Fe ₂ O ₃	1.86
K ₂ O	1.71
SO ₃	0.461
Na ₂ O	0.188
MnO	0.256
C1	0.435
TiO ₂	0.0874
P ₂ O ₅	0.245
ZrO ₂	0.0914
ZnO	0.1257
LOI	7.13

Sample-No.4	
Oxide	weight %
SiO ₂	62.17
CaO	15.32
Al ₂ O ₃	8.98
MgO	2.03
Fe ₂ O ₃	1.63
K ₂ O	1.17
SO ₃	0.241
Na ₂ O	0.345
MnO	0.229
Cl	0.243
TiO ₂	0.0614
P ₂ O ₅	0.0602
ZrO ₂	0.0587
ZnO	0.0474
LOI	6.84

Sample-No.5	
Oxide	weight %
SiO ₂	51.80
CaO	18.97
Al ₂ O ₃	7.56
MgO	4.76
Fe ₂ O ₃	3.97
K ₂ O	0.734
Na ₂ O	0.352
SO ₃	0.424
MnO	0.223
C1	0.732
TiO ₂	0.0135
ZnO	0.0182
ZrO ₂	0.0529
P ₂ O ₅	0.0692
NOi	0.0087
LOI	9.64

Sample-No.6	
Oxide	weight %
SiO ₂	56.41
CaO	16.45
Al ₂ O ₃	9.37
MgO	1.53
Fe ₂ O ₃	2.43
K ₂ O	0.763
SO ₃	1.41
Na ₂ O	0.246
MnO	0.128
C1	0.641
P ₂ O ₅	0.694
TiO ₂	0.0412
NiO	0.0823
ZrO ₂	0.0072
LOI	9.71

Sample-No.7	
Oxide	weight %
SiO ₂	48.72
CaO	17.12
Al ₂ O ₃	13.94
MgO	2.32
Fe ₂ O ₃	4.53
K ₂ O	1.14
SO ₃	0.876
Na ₂ O	0.134
MnO	0.352
Cl	0.827
TiO	0.0234
ZrO ₂	0.792
NiO	0.0042
LOI	8.47

II- Density of Samples

Sample No.	Density (g/cm ³)
1	2.51
2	1.99
3	2.36
4	2.45
5	2.67
6	2.24
7	2.30

III-Size Analysis of Samples.

Sample weight No.1	197.41g		
Screen opening (μm)	Weight (g)	Weight %	Cumulative weight (g)
600	1.978	1.001975584	1.978
425	3.980	2.016108606	5.958
300	9.230	4.675548351	15.19
180	15.58	7.890177803	30.76
106	95.22	48.23463857	125.98
75	61.74	31.27501142	187.72
32	9.686	4.906539689	197.41

Sample weight No.2	211.336 g		
Screen opening (μm)	Weight (g)	Weight %	Cumulative weight (g)
600	0.597	0.282488549	0.597
425	4.168	1.972214862	4.765
300	5.542	2.622364387	10.31
180	13.75	6.506227051	24.06
106	91.23	43.16822501	115.29
75	78.27	37.03581027	193.56
32	17.77	8.412669872	211.33

Sample weight No.3	230.657 g		
Screen opening (μm)	Weight (g)	Weight %	Cumulative weight (g)
600	0.654	0.283532977	0.654
425	3.168	1.373444145	3.822
300	9.839	4.265567218	13.66
180	19.31	8.373327090	32.97
106	99.65	43.20192837	132.62
75	88.35	38.30296409	220.97
32	9.686	4.199236108	230.657

Appendix(A)**Chemical and Size Analysis**

Sample weight No.4	188.48 g		
Screen opening (µm)	Weight(g)	Weight %	Cumulative weight (g)
600	1.332	0.706706281	1.332
425	2.521	1.337542445	3.853
300	4.445	2.358340407	8.298
180	9.751	5.173493209	18.049
106	94.39	50.07958404	112.44
75	71.26	37.80772496	183.69
32	4.781	2.536608659	188.48

Sample weight No.5	193.955 g		
Screen opening (µm)	Weight(g)	Weight %	Cumulative weight (g)
600	13.49	6.955221572	13.49
425	38.42	19.80871852	51.91
300	63.97	32.98187724	115.88
180	12.29	6.336521358	128.17
106	40.38	20.81926220	168.55
75	18.24	9.404243252	186.79
32	7.165	3.694155861	193.95

Sample weight No.6	238.94 g		
Screen opening (µm)	Weight(g)	Weight %	Cumulative weight (g)
600	13.51	5.654139114	13.51
425	36.71	15.36368963	50.22
300	50.75	21.23964175	100.97
180	37.48	15.68594626	128.45
106	73.98	30.96174772	202.43
75	26.54	11.10739098	228.97
32	9.970	4.172595631	238.94

Sample weight No.7	177.79 g		
Screen opening (μm)	Weight(g)	Weight %	Cumulative weight (g)
600	1.654	0.930336337	1.654
425	4.213	2.369782878	5.867
300	9.272	5.215434807	15.14
180	6.327	3.558893014	21.47
106	79.29	44.60006750	100.76
75	61.71	34.71144111	162.47
32	15.32	8.617392271	177.79

Appendix(B)

Computer Program(Matlab)

***** the first and second method to estimate attenuation *****

```

v= input('v=')    %%relative volume occupied by particles.
per= input('per=') %complex permittivity of constituents.
[N,M]=size(v)
for n=1:N
    a=0
    s=0
for m=1:M
    a=v(n,m)*(per(m))^(1/3)
    s=s+v(n,m)*(per(m))^(1/3)
end
perm(n)=s^3
end
averageper =mean(perm) % average permittivity of samples.
h=input ('h=')        % height of tower (km).
H=input ('H=')        % air relative humidity.
S=input('S=')         %Particle Size Distribution of Samples.
F=input(F=)           % GHz
e= real(averageper)+0.04*H-7.78*H^2*(10^-4)+5.56*H^3*(10^-6) %real part
ee=-imag(averageper)+0.02*H-3.71*H^2*(10^-4)+2.76*H^3*(10^-6) %imag part
lamda=(0.3)/f        % m.
c=2.3*(10^-5 )
ho=2                % reference height (m)
segma=2360          % density (kg/m^3)
b=0.28
alpha=1.07
for vis=0.004:0.001:0.35    % Visibility at reference height (km)
    v=c/(segma*(vis^alpha)*(h/ho)^b)
    att=(2.46*v*ee*10^5)/(((e+2)^2+ee^2)*lamda) .....% attenuation per km (dB/km).
    plot(vis,att)
    xlabel('Visibility at ho(km)')
    ylabel('attenuation per km(db/km)'); grid on
end
P=mean(S)
end
For vis=0.004:0.001:0.35    % Visibility at reference height (km)
vn=(vis)*(h/ho)^(b/alpha)
Nt=(3*c)/(4*pi*segma*AvgSr*((vis)^1.07)*(h/ho)^b)
Ni=Nt*P
for n=1:7
    sum=sum+(Ni(n)*(D(n)/2)^3)
end
att=((1.029*(10^6)*ee)/(((e+2)^2+ee^2)*lamda))*sum % attenuation per km (dB/km).
plot(vis,att) plot(vis,att)

```

```

xlabel('Visibility at ho(km)')
ylabel('attenuation per km (dB/km)');grid on
end

```

***** the third method to estimate attenuation *****

```

averageper =input ('av=')    % average permittivity of samples.
h=input ('h=')              % height of tower (km).
H=input ('H=')              % air relative humidity.
D=input ('D=')              % path length (km)
A1=input('A1=)
A3=input('A3=)
F=input(F=)                  % GHz
e= real(averageper)+0.04*H-7.78*H^2*(10^-4)+5.56*H^3*(10^-6) %real part
ee=-imag(averageper)+0.02*H-3.71*H^2*(10^-4)+2.76*H^3*(10^-6) %imag part
sp=e-j*(ee)
lamda=(0.3)/f    % m.
ho=2            % reference height (m).
segma=2360      % density (kg/m^3).
c=2.3*(10^-5 )
x1=((sp-1)/(A1*(sp-1)+1));
x2=((sp-1)/(A2*(sp-1)+1));
x3=((sp-1)/(A3*(sp-1)+1));
b=0.28
alpha=1.07
for vis=.0001:0.001:0.36    % Visibility at reference height (km).
    v=c/(segma*((vis)^alpha*((h/ho)^b)));
    bv=((pi/lamda)*v*real(x3))*1000;    % phase constants for V
    bh=((pi/(2*lamda))*v*real(x1+x2))*1000;    % phase constants for H
    attv=((-pi/lamda)*v*imag(x3))*1000;    % vertical attenuation
    atth=((-pi/(2*lamda))*v*imag(x1+x2))*1000; % horizontal attenuation
    m=exp(-(abs(atth-attv))*D);
    pd=(ph-pv)*D;
    att=-20*log10(sqrt((1+2*m*cos(pd)+(m^2))/4))*(exp(-attv*D)) % attenuation per
km(dB/km).
    plot(vis,att,'-')
xlabel('Visibility at ho(km)')
ylabel('attenuation per km (dB/km)'); grid on
end

```

***** estimate the phase shift and XPD *****

```

averageper =input ('av=')    % average permittivity of samples.
h=input ('h=')              % height of tower (km).
H=input ('H=')              % air relative humidity.
D=input ('D=')              % path length (km)
A1=input('A1=)

```

```

A3=input('A3=)
F=input(F=)           % GHz
e= real(averageper)+0.04*H-7.78*H^2*(10^-4)+5.56*H^3*(10^-6) %real part
ee=-imag(averageper)+0.02*H-3.71*H^2*(10^-4)+2.76*H^3*(10^-6) %imag part
sp=e-j*(ee)
lamda=(30)/f          %cm
c=2.3*(10^-5 )
x1=((sp-1)/(A1*(sp-1)+1))
x2=((sp-1)/(A2*(sp-1)+1))
x3=((sp-1)/(A3*(sp-1)+1))
ho=2
segma=2360
b=0.28
alpha=1.07
for vis=0.0001:0.001:0.13    % Visibility at reference height (km)
    v=c/(segma*((vis)^alpha*((h/ho)^b)));
    bv=((pi/lamda)*v*real(x3))*(180/pi)*100000;    % phase constants for V
    bh=((pi/(2*lamda))*v*real(x1+x2))*(180/pi)*100000;    % phase constants for H
    m=exp(-(abs(atth-attv))*D);
    vh=(bh-bv)*D    % phase difference(degree)
    plot(vis,vh,'r');grid on
    xlabel('Visibility at ho (km)')
    ylabel('phase difference (degrees)'); grid on
    xpd=10*log10(abs((1+2*m*cos(vh)+m^2)/(1-2*m*cos(vh)+m^2)))
    plot(vis,xpd,'-');grid on
    xlabel('Visibility at ho (km)')
    ylabel('XPD(dB)'); grid on
end

end

```

Appendix (C)

Stations reading

I-Center Post in Hoon:

location of towers of microwave link between Hoon and Zillah .

Station	Height of Tower(m)	(E)longitude	(N) Latitude	Distance between station (km)
Hun	65	16:30:13	29:47:33	-
Woadan	90	16:28:27	29:29:58	33
WZ1	85	16:18:45	29:19:34	58
WZ2	90	16:34:27	28:52:30	55
WZ3	120	16:55:47	28:42:11	40
Zillah	65	17:40:04	28:24:36	45

II-Libyan center of metrologyin Libya:

Month	R.Humidity %	Wind speed(knots)
JAN.	58.5	10.3
FEB.	53.2	11.4
MAR.	21.3	8.9
APR.	38.1	8.9
MAY.	37.5	11.8
JUN.	38.8	12.7
JUL.	44.5	10.0
AUG.	42.1	12.9
SEP.	42.5	10.6
OCT.	48.3	8.5
NOV.	51.8	7.4
DEC.	71.8	10.5.
Yearly Average	45.70	10.24