

Atmospheric Effects on EM Propagation and Weather Effects on the Performance of a Dual Band Antenna for WLAN Communications

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Abstract. Despite the fact that most of the research studies are based on “free space electromagnetic waves analysis”, this consideration is only an approximation. In order to accurately predict an antenna performance, we must include the effects of the earth and its atmosphere in EM (electromagnetic) waves’ propagation. This should account for ground reflections, diffraction, bending or refraction of EM waves and attenuation or absorption of EM energy by the small particles constituting the atmosphere. More specifically, in radar systems the unwanted returns are referred to as clutter. These returns may be from the surface, surrounding the target (ground), or from the volume of space around it (rainfall). In this paper, precipitation effects on the EM wave propagation are presented. Moreover, the rapid development in the field of Wireless Local Area Networks (WLANs) demands the existence of devices capable of operating in more than one frequency bands. For this reason the design of a printed antenna to conform to multiple communications protocols, in the band of 2.4GHz and 5.1GHz, is presented in this paper. A microstrip-fed printed bow-tie antenna is designed and simulated in order to achieve dual bandwidth, high gain, and size reduction. The patch antenna is designed with the help of the High Frequency Structure Simulator and the design optimization is based on the variation of its shape, the conductive material, the nature and the thickness of the substrate, in order to have a structure which resonates in the frequencies used for Wi-Fi applications. Simulation results confirm a strong dependence of propagation losses on the humidity of the atmosphere.

Keywords: Wireless Local Area Networks; Microstrip Antennas; Weather Phenomena; Precipitation; Relative permittivity; Refractivity.

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I. INTRODUCTION

One of the main goals of every individual or organized society is the provision of adequate telecommunications links, especially on wireless internet. Therefore, many hotel units, ports or

commercial enterprises advertise free Wi-Fi throughout their own area, while all organized companies provide Wi-Fi access, even with restrictions on access (passwords, limited data quantity or quality on accessible information). The USA President himself, has set a goal to reach 98% of all Americans to be able to access to wireless internet, with the hope of bringing every part of America into the digital age by 2016 [1].

The rapid advances in the wireless communication industry demand novel antenna designs that could be used in more than one frequency bands and that will allow size reduction [2]-[4]. Therefore, the design of small antennas suitable for portable devices covering multiple bands such as GSM900, DCS1800, PCS1900, UMTS2000, ISM2450, is of great interest. Many techniques have been proposed for the design of radiating elements of this type, the great majority of which are microstrip antennas. The common feature is that they usually come from an ordinary shape which is perturbed in appropriate schemes [5], [6].

Furthermore, one of the major criteria to the antenna design is the low profile. People do not want to see a large hideous metal mounted near a historical building which could ruin the scenery. It must be relatively small and fit in almost any space. The antenna has to be of low weight, so it can be easily mounted without the need of heavy mechanisms which could cause an ugly landscape and an increase in cost.

The design of a multi-frequency band printed antenna is a difficult task and in many cases is an art [7], [8]. It requires that the efficient operational characteristics must be ensured in all the frequency bands of operation, such as Gain greater than 0dB and small reflection coefficient at the feeding port. Furthermore, these properties must not be obtained at the cost of a complex feeding network, a non compact fabrication or an antenna arrangement of large size [9], [10]. Therefore the design of this type of antennas is a difficult task and any novel concept or modification of the existing methods is useful.

II. ANTENNAS FOR WLAN COMMUNICATIONS

2.1. Bands for IEEE802.11

The motivation for this work is the high cost of designing and maintaining acoustic and optical systems. WLAN has the potential to provide an ideal solution for certain applications, where high data rate transmission is required at short distances. Because WLAN devices are globally available, their cost is relatively low and there is adequate knowledge in handling them. Also, due to the fact that WLAN can operate in frequency spectrums that have been released for free public use like unlicensed ISM (Industrial, Scientific and Medicine) radio bands, there is no cost for using these frequencies. In spite of the real purpose of the ISM bands, there has been a rapid growth in their use in low-power, short-range communications platforms.

IEEE 802.11 is the current standard for WLAN. Most people refer to WLAN as Wi-Fi. It has four popular protocols: 802.11a, 802.11b, 802.11g, and 802.11n. While 802.11a operates at 5 GHz, 802.11b and 802.11g operate at the 2.4GHz. Furthermore, 802.11n operates at both 2.4 GHz and 5GHz band. Nowadays, 802.11ac is becoming more popular among vendors.

The 2.4 GHz band is divided up into fourteen channels which have a bandwidth of 22 MHz for 802.11b and 20MHz for 802.11g and is more popularly used than the 5 GHz band. This means that there are many users in these frequency ranges including wireless phones, microwave ovens or even baby monitors, which amend to the rising of the ambient noise and interference and thus making communication less effective. Due to the fact that from those fourteen channels, only three of them (1, 6 and 11 with center frequencies of 2412, 2437 and 2462 MHz respectively) do not overlap with each other and that all other channels overlap with each other and with the aforementioned three channels, a safe conclusion can be made that there is a strict

limitation in the quantity of the concurrently existing non interfering Access Points (AP). Channel 14 also does not overlap with channel 11, but the lack of separation between these channels might create many problems. According to 17.4.6.3 Channel Numbering of operating channels [11], "In a multiple cell network topology, overlapping and/or adjacent cells using different channels can operate simultaneously without interference if the distance between the center frequencies is at least 25 MHz". For this reason exactly, even though channels 1, 5, 9 and 13 seem to non overlap when used for 802.11g communications, the concurrent usage of them is avoided but under no circumstances prohibited. Finally, there are many countries that do not allow the full usage of the spectrum such as Central and North American countries which for instance allow the usage of channels 1 through 11 and thus limiting more their availability.

On the other hand, the 5 GHz band operates between the frequencies of 5.1 to 5.8 GHz with wider channel-widths up to 80 or even 160 MHz (802.11ac). The number of distinct none overlapping channels is up to twenty one, which provides the availability of using a greater amount of concurrent non interfering APs.

The 2.4 GHz has long been a standard around the world, while the usage of many channels within the 5 GHz band is prohibited in some countries, like China. One reason to use the lower frequency band is because the waves of the 2.4 GHz band have a better propagation behavior through obstacles than that of the 5 GHz band waves and thus provides better coverage. On the other hand, the main reason to use the 5 GHz band is that it is not used as widely as the 2.4 GHz band so there is less interference from neighboring Wi-Fi signals. Also, the higher the frequency is kept, the smaller the size of the antenna should be, meaning that 5 GHz waves need cheaper (in general terms) antennas which can be designed and built easier.

TABLE [1]. Various Wireless Standards

| Standard | Frequency | Data Rate |
|---------------|---------------------------------|--------------------|
| IEEE 802.11b | 2.4 GHz | 11 Mbps |
| IEEE 802.11g | 2.4 GHz | 54 Kbps |
| IEEE 802.15.4 | 2.45 GHz (Worldwide) | 250 Kbps |
| IEEE 802.15.4 | 868/915 MHz (N. America/Europe) | 20/40/100 Kbps |
| IEEE 802.11a | 5 GHz | 54 Kbps |
| IEEE 802.11n | 2.4/5 GHz | 54 Kbps – 600 Mbps |
| IEEE 802.11ac | 5 GHz | 1300 Mbps |

IEEE 802.15.4 standard supports communications up to 10 meters in free space propagation. Different atmospheric phenomena such as heavy rain or snowfall or even high humidity are expected to reduce more the effective range of the propagation and the quality of communication, more when operated in the 2.4 GHz frequency than operated the 868 or 915 MHz. Mainly this type of communication has been designed for very low-power consumption applications and enjoys strong interest, since consumption is a key factor in deployable sensor infrastructures.

2.2. Highly Directive Antennas

A highly directive antenna allows the signal from the WLAN Access Point (AP) to be aimed at a designed location. Signal can be directed towards high density location and provide WLAN to users. This provides a convenient way to provide an extended coverage area for a high density of people area, without the need of installing more APs. The same antenna would be beneficial in ships. A directional antenna can provide internet access to other ships in the same neighborhood.

Radiation efficiency E , is the “ratio of the total power radiated by an antenna to the net power accepted by the antenna from the connected transmitter” [12]. In the best case scenario, the maximum power accepted by the transmitting antenna is 50% of the total power supplied and this occurs when the generator impedance and the antenna are matched, usually to 50Ω . In practice, the radiation resistance has to be big and the loss resistance has to be as small as possible. The efficiency of an antenna is given by

$$E = \frac{P_{\text{rad}}}{P_{\text{in}}} = \frac{R_R \cdot I^2}{(R_R + R_L) \cdot I^2} = \frac{1}{1 + \frac{R_L}{R_R}} \quad (1)$$

where R_L is the loss resistance which corresponds to the loss of the antenna, R_R is the radiation resistance, P_{rad} is the power radiated by the antenna and P_{in} is the power input to the antenna.

Directivity D in a particular direction is “the ratio of the power density radiated in that direction to the power density that would be radiated in that direction if the antenna were an isotropic radiator (radiates equally in all directions).

This is similar to that of antenna gain with the following difference: the antenna gain takes into account the efficiency of the antenna whereas directivity takes into account the losses gain. Directivity can be calculated using the Poynting Vector P (energy flux in W/m^2), which gives the average real power per unit area radiated by an antenna in free space [13]. The equation for the directivity of an antenna is given by

$$D = \frac{P}{P_0} = \frac{P \cdot 4 \cdot \pi \cdot r^2}{P_{\text{rad}}} \quad (2)$$

where P_{rad} is the total power radiated by the antenna, P is the power density at distance r and $P_0 = \frac{P_{\text{rad}}}{4 \cdot \pi \cdot r^2}$ [14].

The antenna gain takes into account losses, so the gain of an antenna will always be less than the directivity. Knowing the directivity of the antenna, the total power radiated by the antenna, and the received power which takes into account loss, the antenna gain is

$$G = D \cdot E \leq D \quad (3)$$

2.3. Antenna Arrays

An antenna array is “an antenna comprised of a number of identical radiating elements in a regular arrangement and excited to obtain a prescribed radiation pattern” [15], [16]. Antenna arrays can be divided into two categories: Scanning and non-scanning antenna arrays. Scanning arrays are able to move their main beam electronically, usually by changing the phase of the elements. Non-scanning array can only change their main beam lobe by moving the antenna orientation and they are usually used for directional radiation applications. A common type of scanning array is the phased array. Non-scanning array examples are an array of dipoles, or a microstrip antenna. The multiple radiating elements of phased array antennas are connecting to a phase shifter. The phase shifting allows the radiation pattern to be “steered” towards a certain direction.

2.4. Antenna's Type Selection

Different antenna configurations were studied. Various types of high gain antennas were compiled to be considered for the WLAN possible antenna design. All types can provide sufficient gain with the use of a plain, parabolic, or corner reflector [14].

Aperture antennas use a waveguide and branch into an aperture which can be designed to achieve a desired high gain. They may be expensive depending on the type of the material used. Phased array radiation pattern can be changed by varying the phase of each/or certain radiating element. It can provide high gain but it can also be configured to direct high gain signals to multiple users in various directions.

Helix antenna in axial mode can produce directive radiation patterns. Axial mode helix antennas can be mounted easily, but the helix structure extends into the horizontal plane. The structure may not withstand high speed wind and may face problems in colder weather. Depending on how many turns(helices) are needed to achieve the desired gain, the antenna can be extremely long and may require a stronger middle support. Phased array antennas are expensive to manufacture with the cost increasing along with the number of the radiating elements. Phase shifters, numerous feeds, and multiple cables are needed. In addition, the building and assembling of a phased array require more time than any other antenna configuration.

Dimensions of a horn antenna are more complicated and one may be hard to manufacture. Last, but not least, reflector antennas cannot be considered as low profile antennas, especially parabolic reflectors. In addition, the reflectors are made of metal and are much heavier than a microstrip or a helix antenna.

Microstrip antennas can provide directivity in the range of 7 to 9 dBi. An array of microstrip antennas can achieve a considerable higher gain. These antennas have a smaller cross-sectional area than the reflector antennas achieving the same gain, and are overall smaller than the parabolic antennas. Microstrip antennas are also low profile and can be mounted with simple screws. In addition, they can be designed to be completely weather proof. The cost of manufacturing a microstrip antenna can be inexpensive using cheap substrate material and thin conductive foil. For the same reason they are of light weight [17], [18]. A microstrip antenna is selected for this application.

III. ATMOSPHERIC EFFECTS ON EM WAVES

3.1. Troposphere Layer and EM waves

The troposphere layer extends from the Earth surface up to approximately 20 km above it and includes climatic phenomena such as rain, snow, cloud, fog, wind, and storms. Electromagnetic waves passing through the Earth atmosphere are subjected to the following major effects: Absorption and attenuation, reflection, refraction, changes of polarization, scattering and diffusion.

The velocity v of EM waves is related to the light velocity in free space c and to the relative permittivity ϵ_r and permeability μ_r of the medium [7].

In linear media, the frequency does not change when the EM wave goes from one medium to another. The velocity of an EM wave propagating at every frequency in distilled-water where $\mu_r=1$ and $\epsilon_r=81$ is $v \approx 0.3 \cdot 10^8 \frac{\text{m}}{\text{s}}$. Since we assume that the medium characteristics are constant with frequency, propagation velocity does not depend on the frequency, thus for every

frequency the velocity is the same, but the wavelength (λ) differs. However, one of main features of wet particles like rain, snow, etc, is their frequency-dependent attenuation. The index of relative permittivity can be introduced as follows

$$\epsilon_r = \epsilon'_r - j \cdot \epsilon''_r \quad (4)$$

where ϵ'_r is the real part of relative permittivity index and causes reflection and scattering of waves, while ϵ''_r is its imaginary part which introduces absorption of wave power and eventually imposes attenuation on it.

The relative permittivity of the air depends on the temperature T in $^{\circ}\text{K}$, the localized atmospheric pressure P in mbars and the water vapor pressure e in mbars too [19]-[21].

$$\epsilon_r = 1 + 155.1 \cdot 10^{-6} \cdot \frac{P}{T} + 746 \cdot 10^{-3} \cdot \frac{e}{T^2} \quad (5)$$

EM waves passing through a lossy medium will be attenuated. The depth of penetration (δ) is defined as a distance in the medium at which the wave amplitude of an EM wave incident at surface falls to $1/e$ of its initial value. In a conductor or medium with good conductivity, the depth of penetration denoted by δ is inversely proportional to the square root of the frequency, so it reduces while increasing frequency. By simple calculations it may be verified that for frequencies of more than 100 KHz, propagation of EM waves in Earth land and sea-water is lossy. Even for VLF bands the wave is descending remarkably in long distances.

3.2. Refraction and Spherical Scatterers

When an EM wave propagates through a medium which consists of atoms and molecules, it will interact with that medium through various processes, two of them being absorption and scattering. The efficiency of the interaction is related to the amount of signal absorption. Changes in propagation velocity due to this interaction result in a change in the wave's direction, called refraction and is described by the index of refraction n . Water, similarly to air has non magnetic properties, thus $\mu_r=1$ and the index of refraction, is

$$n = \sqrt{\epsilon_r} \quad (6)$$

Using equations (5) and (6) and selecting the first three terms of the binomial expansion, it yields that

$$n = 1 + 77.6 \cdot 10^{-6} \left(\frac{P}{T} \right) - 5.6 \cdot 10^{-6} \cdot \left(\frac{e}{T} \right) + 3.73 \cdot 10^{-1} \left(\frac{e}{T^2} \right) \quad (7)$$

where n is the index of refraction, T is the temperature in $^{\circ}\text{K}$, P is the localized atmospheric pressure in mbars and e is the water vapor pressure in mbars.

To alleviate the use of exceedingly small numbers, another parameter definition is introduced, called refractivity (N) and is related to n by

$$N = (n - 1) \cdot 10^6 = 77.6 \cdot \left(\frac{P}{T} \right) - 5.6 \cdot \left(\frac{e}{T} \right) + 3.73 \cdot 10^5 \left(\frac{e}{T^2} \right) \quad (8)$$

There is a strong variability due to humidity (vapor pressure). On average, refractivity decreases with altitude, but at a gradually decreasing rate [8]. Also, a new parameter called modified refractive index and denoted by n_M is defined by

$$n_M = n + \frac{h}{R_e} \quad (9)$$

where n is the refractive index of the air, h is the height of the location (altitude) and R_e is the Earth radius. The last two parameters have the same unit.

There is another parameter called refractive modulus or modified refractivity and is defined according to the following equation

$$M = (n_M - 1) \cdot 10^6 = N + 10^6 \cdot \frac{h}{R_e} \quad (10)$$

It is important to summarize that only minor changes in refractive index are necessary to cause a significant change in energy propagation. By using the relationship between refractivity N and refractive index, n can be derived in terms of total pressure, temperature, and water vapor concentration, as shown in Equation (7). Variations of temperature and moisture in the propagation path cause local refraction of the signal, resulting in signal loss and increase of noise [19].

It is often more convenient to represent EM radiation as rays of energy instead of waves. Rays are lines along which waves travel and are drawn perpendicular to each wave front. Snell law is a formula used to describe the relationship between the angles of incidence and refraction, of rays passing through a boundary between two different isotropic media:

$$n_1 \cdot \sin \theta_1 = n_2 \cdot \sin \theta_2 \quad (11)$$

where θ_1 , θ_2 are the incoming and outgoing incident angles respectively, and n_1 , n_2 are the materials.

These values are used to represent the factor by which a wave's speed decreases when traveling through a refractive medium. Snell law quantifies these speed changes in the form of angular change, rather than the degree of "bending" of the ray. This bending is one key factor which affects the propagated signal strength. Additionally, by knowing the refractive index in the atmosphere at each level, one can predict the path that the EM waves will follow.

Scattering of EM radiation plays a significant part in the total of atmospheric effects. Scattering is a function of several factors: particle shape, size, index of refraction, wavelength (λ) and geometry. In 1908 Mie applied Maxwell's equations (which describe EM radiation) to the case of a plane electromagnetic wave incident on a sphere. Mie showed that for a spherical scatterer, the scattered radiation is a function of only viewing angle, θ , and the size parameter χ , defined as:

$$\chi = \frac{2 \cdot \pi \cdot r}{\lambda} \quad (12)$$

This size parameter can be used to divide scattering into three regimes. Mie scattering occurs for size parameters in the range of values between 0.1 and 50, in which the wavelength of the radiation and the periphery of the particle are comparable. Rays undergoing Mie scattering are strongly scattered forward and backward. The second regime is for size

parameter values greater than approximately 50. The scatterer is large in comparison to the wavelength of the radiation and results in Geometric optics, widely observed in the occurrence of rainbows following a storm. Finally, Rayleigh scattering results when the size parameter is much smaller than the given wavelength and thus is largely insensitive to particle shape [22].

3.3. Discussion on Propagation Phenomena

EM wave refraction in the Earth atmosphere has several effects on the wave propagation and can result in transition of the wave over the horizon. It can be assigned to a straight line for propagation path of waves, provided that a new equivalent radius R_e' is assumed for the Earth instead of the real Earth radius R_e . For standard atmosphere, calculations resulted in $R_e' = 8500$ km while actual radius of the Earth is $R_e = 6371$ km.

The Earth atmosphere is more diluted as the height increases, thus the index of refraction is reduced. Variation of the refraction index is usually continuous and it causes to smooth the wave curvature. In case of assuming a direct path for EM wave propagation, denoted by R , the K-factor is defined as the ratio of equivalent radius of the Earth R_e' to its actual value R_e as in the following equation

$$K = \frac{R_e'}{R_e} = \frac{R}{R - R_e} \quad (13)$$

K-factor is about 1.33 for the standard conditions (EM waves path $R=25000$ km), based on equation (17). Due to some natural phenomena, the equivalent Earth radius is reduced and sometimes is less than real Earth radius. This situation, which is equivalent to K-factor value being less than 1, causes high bulge on Earth surface and produces an obstacle to the EM waves' propagation near the Earth surface [19].

Refractive losses, specifically those due to changes in wave propagation speed through a medium, can result in changes of the signal amplitude. Constructive interference results in an increase of the amplitude, while destructive interference can reduce the amplitude of the received signal. These effects are due to multipath, which is the propagation phenomenon resulting when an EM wave reaches the receiving antenna from two or more paths. Causes of multipath include atmospheric ducting, ionospheric reflection and refraction, and reflection from terrestrial objects, such as mountains, buildings or ocean waves. Additionally, the influence of multipath depends on frequency, path length and the reflection coefficient of the surface [22]-[33].

Modified refractivity is used to determine how rays are bent relative to the Earth's curvature and assist in determining regions of ducting. Thus, ducts, which can be surface based or elevated, are simply atmospheric layers that have formed when M decreases with height. Radar or other EM waves can be "trapped" within and may result in greater energy propagation than normally expected [26]-[35].

In addition to ducting, EM waves can also be refracted in different ways and their behavior forms the basis of the classes of refractivity. When rays are sub-refracted, their propagation distance to the horizon decreases. This occurs when dM/dh is greater than 157. Conversely, super-refracted rays occur when dM/dh varies between 0 and 78. As an effect the distance of the propagation will increase. Finally, normal refracted rays occur for dM/dh between 78 and 157. In such case the distance of propagation seems to be unaffected.

Equation (15) takes into account only air gases and does not consider liquid water content or free electron density. The presence of liquid water usually has negligible effect on N for the

band of frequencies of interest. The presence of free electron density is important only for high atmospheric attitudes, typically above 60 km.

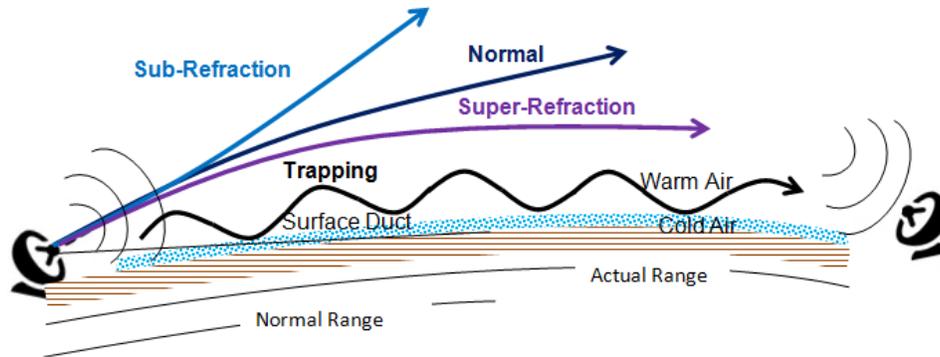


FIGURE 1. Propagation paths for various atmospheric refractive index conditions.

3.4. Earth Effects above the Seawater

The Earth effects consist of the following main factors [19], [26], [35]: Mountains and hills, forests, woodlands, vegetation covers, oceans, seawater, rivers, flat and coastal areas. VHF and UHF EM propagation above the seawater has the following main points:

- The sea surface is a good reflector for EM waves. In some conditions, detected signals in the receiver are the summation of propagated and reflected waves.
- The sea water attenuation index is very big and the penetration depth is very small.
- Cold and warm water have different effects on EM waves propagation. One of the most important effects of seawater in EM propagation is the creation of an air duct which is more significant in warm zones due to the settlement of water vapors (figure 1).
- The obstacle in EM wave's propagation is only high sea-waves which can be created from strong storms.

3.5. Weather Effects in the upper UHF band propagation

When EM waves propagate in atmosphere, are affected by magnetic storms, sky noise, sun spots, and also atmospheric events like rain, cloud, snow, hail, fog, humidity, wind or terrestrial parameters like mountains, forests, and seas.

Some important climate factors and their possible effects to the upper UHF band wireless communications are:

- Atmospheric particles like Oxygen, Nitrogen, and other natural gases may not affect the EM wave propagation due to their low χ factor.
- Water vapor, fog, and air dust of comparable dimensions compared to the wavelength of UHF band, affect wave propagation.
- Wind produced by the motion of atmospheric molecules, has positive effects on wave propagation.
- Atmospheric precipitations such as rainfall, snow, and hail do not have tangible effects on amplitude attenuation and reflection in VHF band wave propagation but their effect is becoming important in 2.4 GHz and 5.1GHz.

- Air index of refraction variations will cause K-factor variations. In general, the normal values of K in VHF and UHF communications are: In VHF band it is similar to standard condition (equal to 1.33). In lower UHF band (less than 1GHz), K-factor is normally about 1–1.33. In upper UHF band, consisting of frequencies between 1 and 3GHz, K-factor is normally about 1 with 25% tolerance.
- Earth magnetic field effects which may cause the rotation of EM waves in elevated layers are negligible on the upper UHF band.
- Galaxy, sky, and sun noises are small as the frequency increases.

3.6. Attenuation due to Rain Rate

The specific attenuation γ_R (dB/km) is obtained from the rain rate R (mm/h) using the power-law relationship [39]:

$$\gamma_R = kR^\alpha \quad (14)$$

Values for the coefficients k and α are determined as functions of frequency, f (GHz), in the range from 1GHz to 1 THz, from the following equations, which have been developed from curve-fitting to power-law coefficients derived from scattering calculations:

$$\log_{10} k = \sum_{j=1}^4 a_j \exp \left[- \left(\frac{\log_{10} f - b_j}{c_j} \right)^2 \right] + m_k \log_{10} f + c_k \quad (15)$$

and

$$\alpha = \sum_{j=1}^5 a_j \exp \left[- \left(\frac{\log_{10} f - b_j}{c_j} \right)^2 \right] + m_\alpha \log_{10} f + c_\alpha \quad (16)$$

where f is the frequency in GHz, $m_k = -0.18961$, $c_k = 0.71147$, $m_\alpha = -0.05374$, $c_\alpha = 0.83433$ and the values for the constants a_j , b_j and c_j are given in table [2]

TABLE [2].

| J | a_j | b_j | c_j |
|---|---------|---------|--------|
| 1 | -5.3398 | -0.1001 | 1.1310 |
| 2 | -0.3535 | 1.2697 | 0.4540 |
| 3 | -0.2379 | 0.8604 | 0.1535 |
| 4 | -0.9416 | 0.6455 | 0.1682 |

For linear and circular polarization, and for all path geometries, the coefficients in equation (19) can be calculated using the following equations:

$$k = \frac{k_H + k_V + (k_H - k_V) \cos^2 \theta \cdot \cos(2\tau)}{2} \quad (17)$$

$$\alpha = \frac{k_H \alpha_H + k_V \alpha_V + (k_H \alpha_H - k_V \alpha_V) \cos^2 \theta \cos(2\tau)}{2k} \quad (18)$$

where θ is the path elevation angle and τ is the polarization tilt angle relative to the horizontal (45° for circular polarization).

IV. BOW-TIE ANTENNA DESIGN

The purpose of this paper is to design a highly directive, low cost, low profile and easily reproducible antenna. This antenna was designed for the use of WLAN 802.11. To achieve this goal we identified four main objectives. The antenna must have high gain, low build cost, small and light weight design, and finally, has to be easy to manufacture.

4.1. Materials and Dimensions

The patch configuration that drives the antenna system to multi-frequency operation is the bowtie shape. Bowtie microstrip antennas are very attractive in present-day communication systems due to their size, which is smaller than the size of a conventional rectangular patch, although they have similar characteristics and they operate at the same frequency. The shape of a bowtie microstrip antenna is shown in Figure 2.

As a substrate material, among plexiglass, FR4, Teflon and Arlon CuClad, the last one has been chosen, because of its properties and cost. The dimensions as shown in Figure 2 are 40x90 mm² and the thickness is 2mm. The thicker the substrate material, the higher it costs. The conductive material will be used to produce the microstrip arrays elements, the feed network, and the ground plane. Aluminum and copper were considered and copper has been chosen because of its lower energy loss.

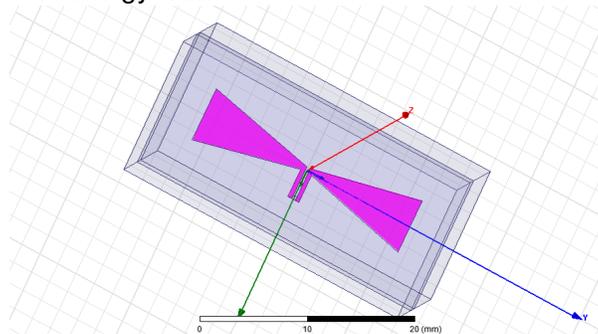


FIGURE 2. The fundamental shape of a bowtie microstrip antenna

The resistance of the transmission line is found by using Equation [7]

$$Z_0 = \frac{87}{\sqrt{\epsilon_r + 1.41}} \cdot \ln\left(\frac{5.98 \cdot h}{0.8 \cdot W + t}\right) \quad (19)$$

The location of the feed is at the center of the symmetrical microstrip patch design. The antenna is on the above described substrate which has a dielectric constant of 2.17 and the material of the conductor is copper. A radiation box was made to enclose the antenna and a perfectly matched layer (PML) material – an artificial absorbing layer is placed around the box. A parameter sweep was used to determine which height should be used to generate a resonant of approximately 2.4GHz.

The bowtie printed object comes, substantially, from a rectangular patch via modification and the equations for the approximate calculation of the resonance frequency f in terms of the geometrical and material parameter values [17] are:

$$f = \frac{c}{4 \cdot \sqrt{\epsilon_{\text{eff}}}} \cdot \frac{W + W_c + 4 \cdot \Delta L}{3.472 \cdot (W + 2 \cdot \Delta L) \cdot (S + 2 \cdot \Delta L)} \quad (20)$$

$$\Delta L = \frac{0.412 \cdot h \cdot (\epsilon_{\text{eff}} + 0.3) \cdot \left(\frac{W + W_c}{2 \cdot h} + 0.262 \right)}{(\epsilon_{\text{eff}} - 0.258) \cdot \left(\frac{W + W_c}{2 \cdot h} + 0.813 \right)} \quad (21)$$

$$\epsilon_{\text{eff}} = \left(\frac{\epsilon_r + 1}{2} \right) + \left(\frac{\epsilon_r - 1}{2} \right) \cdot \sqrt{\frac{W + W_c}{24 \cdot h + W + W_c}} \quad (22)$$

By altering the dimensions W_c and L and keeping W constant it is possible to change the resonance frequency. The equations given above are a good starting point for the antenna design. However for the best impedance matching, the coordinates of the feed point must be found through iterative simulations. The resonant frequency corresponding to the mode TM_{10} of the equilateral triangular microstrip antenna is [7]

$$f = \frac{4 \cdot c}{3 \cdot L \cdot \sqrt{\epsilon_r}} \quad (23)$$

where c is the velocity of light in free space, L is the side length of the bow-tie patch and ϵ_r is the dielectric constant of the substrate.

The above equation is valid when the triangular resonator is enclosed by a perfect magnetic wall. In case it is not valid, the replacement of side length L by an effective value L_{eff} has been suggested [3], [7], [17]. An approximate expression for L_{eff} produced by curve fitting experimental and theoretical results for the resonant frequency for TM_{10} mode is given by

$$L_{\text{eff}} = h \cdot \left(\frac{L}{h} + 4.4 - \frac{25.71}{\sqrt{\epsilon_r}} + \frac{32.87}{\epsilon_r} + \frac{24.73 \cdot h}{L} - \frac{39.21 \cdot h}{L \cdot \sqrt{\epsilon_r}} \right) \quad (24)$$

where h is the thickness of the substrate.

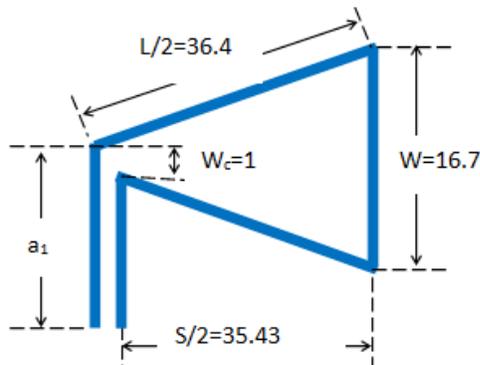


FIGURE 3. Dimensions of the Antenna

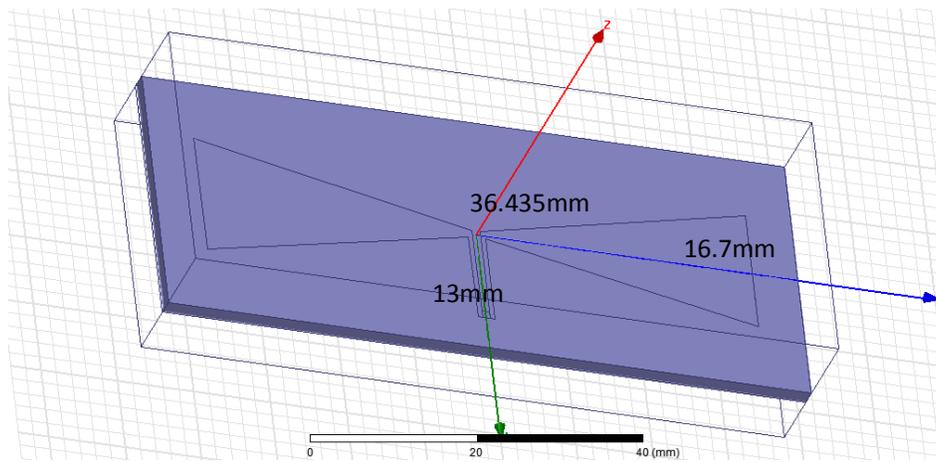
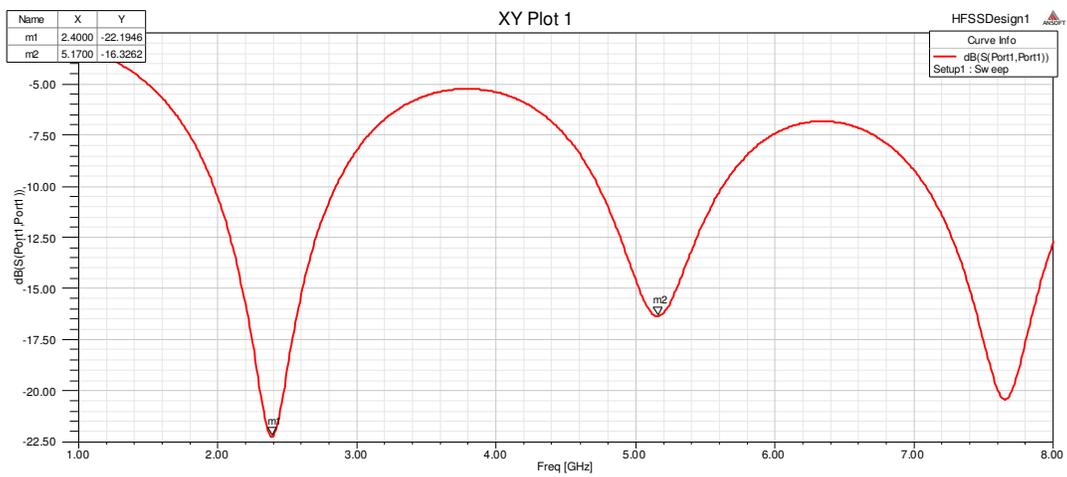
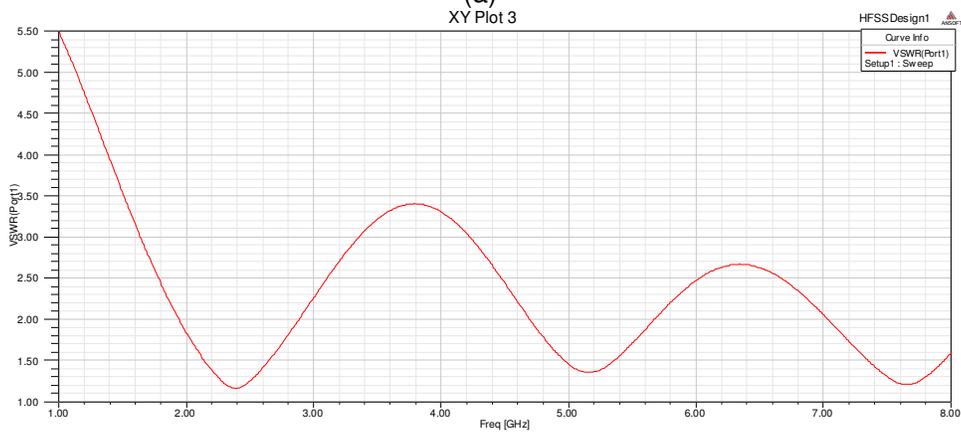


FIGURE 4. The Antenna that is simulated

4.2. Simulations



(a)



(b)

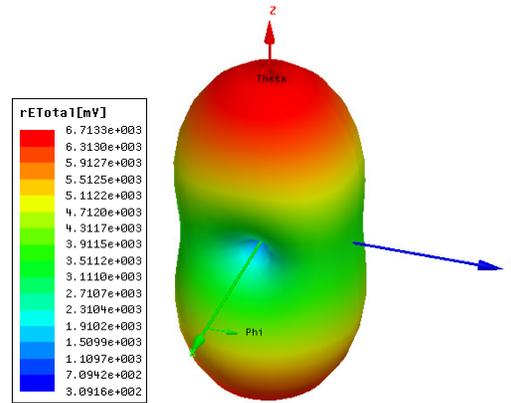
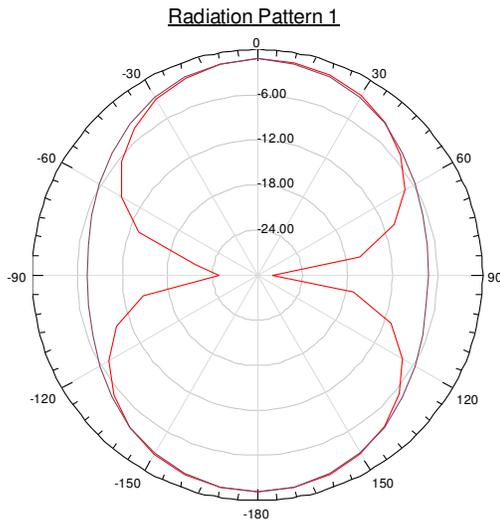
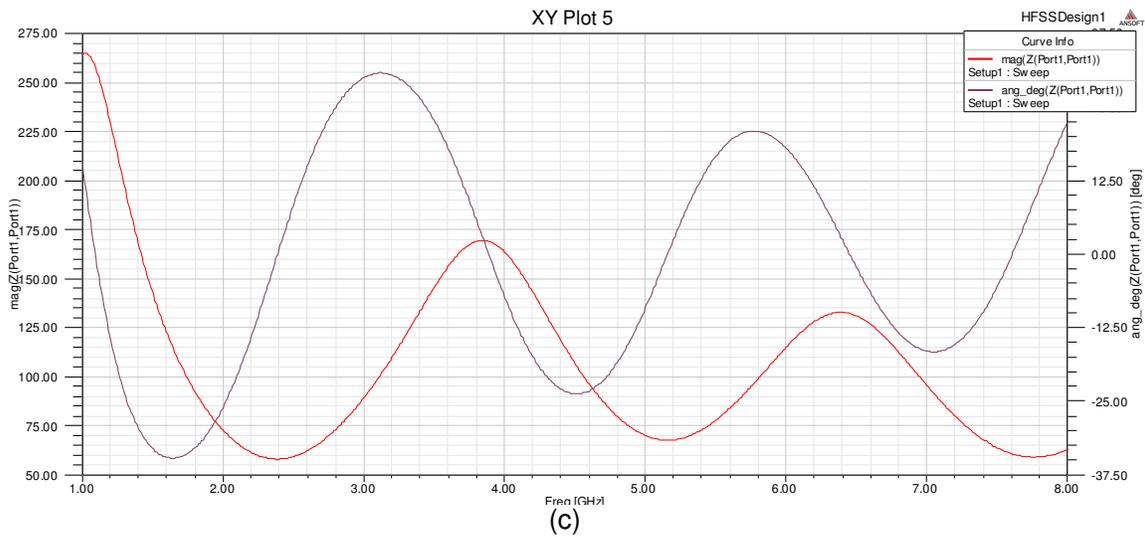


FIGURE 5. Simulation results for the antenna when works in air (a) Input reflection coefficient, showing that $S_{11}=-22\text{dB}$ for $f=2.4\text{ GHz}$ and $S_{11}=-16\text{ dB}$ for $f=5.1\text{ GHz}$ (b) $VSWR=1.1$ for $f=2.4\text{ GHz}$ and $VSWR=1.3$ for $f=5.1\text{ GHz}$, (c) Magnitude and Angle of the Input Impedance showing that at 2.4 GHz , $Z_{IN}=65\Omega$ and at 5.1 GHz is 70Ω approximately, (d) Radiation Pattern and (e) Directivity

The feeding method depends on the selected bow-tie configuration and the parameter values of the feeding network are calculated by the high frequency transmission microstrip line theory.

V. CONCLUSIONS

In this paper EM waves propagated in troposphere have been discussed. The effect of humidity, has been taken into account in order to characterize the EM wave attenuation. A simple design of a dual band printed antenna functioning in WLAN telecommunication systems, based on the Bow-Tie antenna concept is presented and analyzed by HFSS.

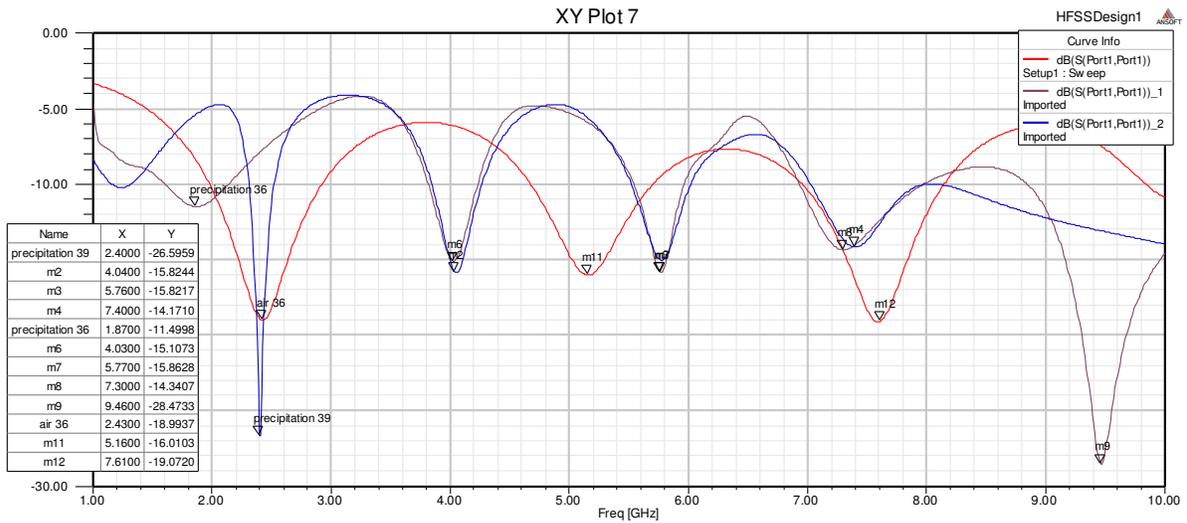


FIGURE 6. Simulation results for the input reflection coefficient of the antenna when works (a) in strong precipitation phenomena with $L/2=39\text{mm}$, (b) in strong precipitation phenomena with $L/2=36\text{mm}$ and (c) in air when $L/2=36\text{mm}$

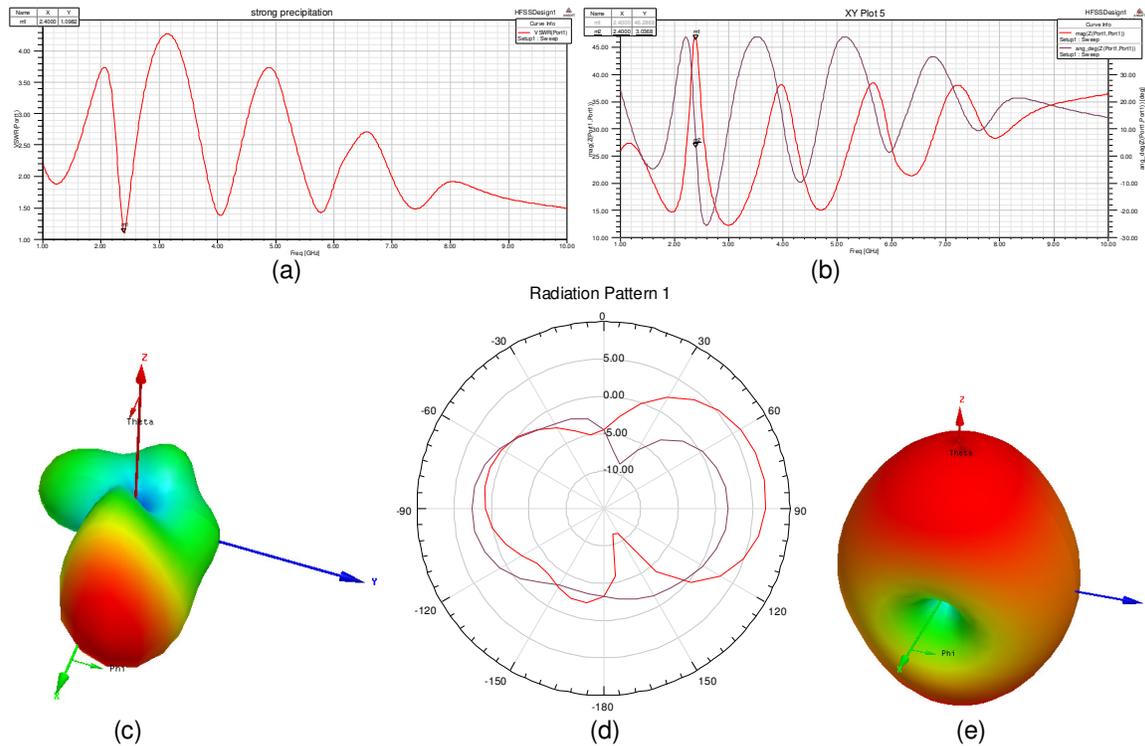


FIGURE 7. The antenna with $L/2=39\text{mm}$ under strong participation (a) $VSWR=1.1$ for $f=2.4\text{ GHz}$, (b) Magnitude and Angle of the Input Impedance showing that at 2.4 GHz , $Z_{IN}=47\ \Omega$ and $\phi=3^0$, (c) Directivity, (d) Radiation Pattern and (e) Gain

The antenna design based mainly on the change in the shape of the antenna and its conducting material, the nature and thickness of the substrate that resonates in the frequency desired for specified applications. The optimal variation of each of these parameters affects the resonance frequency, the return loss and the bandwidth of the antenna patch.

The proposed antenna has a wide bandwidth ranging from 2 GHz to 2.7 GHz and 4.7 GHz to 4.6 GHz in air, but in strong precipitation phenomena the bandwidth gets 28% narrower and its dimensions have to be 8% greater in order to work properly at 2.4 GHz. The proposed antennas are of simple structure, easy design, are suitable for the simple 50Ω port feeder, and comply with UWB requirements.

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