T.C
ISTANBUL AYDIN UNIVERSITY
INSTITUTE OF SCIENCE AND TECHNOLOGY

VIVALDI ANTENNA DESIGN FOR GPR APPLICATION

THESIS

Bader AWAD

Department of Electrical and Electronics Engineering
Electrical and Electronics Engineering Program

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(Y1713.300013)

Department of Electrical and Electronics Engineering
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Advisor: Assoc. Prof. Dr. SAEID KARAMZADEH

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İSTANBUL AYDIN ÜNİVERSİTESİ
FEN BİLİMLER ENSTİTÜSÜ MÜDÜRLÜĞÜ

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FOREWORD

This thesis is about Designing antenna for GPR application. According to the thesis we introduced meaning of GPR, principle of GPR work, major area for using this technology, moreover our interest in the most important part of GPR application.
I started to study Electrical and Electronics Engineering in Bachelor degree, my passion to study this field comes from my love to analytical subjects like mathematics and physics and engagement in this two field.
During my study I attended a lot of courses in this field like Mobile Communications Radar Equations, wireless communication, Microwave theory and Antenna design. But, my interest was in studying Antenna and how this device work and the criteria that must be taken to design a good antenna according to work that interest in. The amount of researches fast paced development and the number of opportunity in this area grasped my interest and I decided to complete my Master Degree in this field.
When I joined to my Master Degree in Electrical and Electronics Engineering I started to take courses in Electrical Engineering but, I wanted to be my thesis in Antenna Design , after that I met Assoc. Prof. Dr. SAEID KARAMZADEH, in that time he advised me to study some subjects related to Antenna Design , one of those subjects was GPR . I began to collect information about the subject, what is the GPR?, how its work? what are the parts of the device? what type of antenna that will be used to design GPR? What is the simulation programs that I shall use that to design the antenna?
My experience in this work during one year started from knowing the principle of GPR and the fields which GPR work in. In additional to design the important factor to work this technology properly, that is the Antenna. After knowing the type of antenna I had to learn about some simulation programs related to antenna. So, I interested in two types of these simulations programs; Asis HFSS and CST.
Therefore, I started to design the required antenna (Vivaldi Antenna) after reading a lot of reference papers and literature reviews about the design and antennas characteristics. But during the work I faced some difficulties like to choose appropriate size, substrate material and frequency band, until to get the final designs.
Eventually, I would like to thank my advisor Assoc. Prof. Dr. SAEID KARAMZADEH and appreciate his efforts during our work for deeply advices and for his guidance, assistant and support.
And all thanks to my family.

January, 2019 **Bader AWAD**

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ABBREVIATIONS.

UWB : Ultra -wide Band
AVA : Antipodal Vivaldi Antenna
GPR : Ground Penetrating Radar
SAR : Synthetic- Aperture Radar
EMW : Electromagnetic Wave
SFCW : Stepped-Frequency Continuous-Wave
IF : Intermediate Frequency
RFI : Radio Frequency Interference
HPBW : Half-power beamwidth
FNBW : First-null beamwidth
dBi : Decibels relative to isotropic
VSWR : Voltage Standing Wave Ratio
DSAVA : Double Slot Antipodal Vivaldi Antenna
HFSS : High Frequency Structure Simulator
CST : Computer Simulation Technology
AR : Axial Ratio

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VIVALDI ANTENNA DESIGN FOR GPR APPLICATION

ABSTRACT

Ground Penetrating Radar (GPR) is a radar which detects objects and interfaces buried beneath the earth's surface. It is considered as a very effective tool for non-destructively sensing of the subsurface environment, since the radar can detect any object that has different electrical properties than the surrounding soil. Thus it senses both metallic and nonmetallic targets as opposed to metal detectors. The GPR system usually contains a receiver and transmitter antennas. Transmitter connected with a source, and receiver connected with signal processing. Civil and military sections are the most popular areas for the GPR applications. In military area, it is commonly used for finding unexploded bombs, underground warehouses, bomb shelters, discovering enemy communication channels, secret rooms. In civil life GPR is commonly applied for finding, buried pipes and undetected voids. Together with these, GPR is used to find people behind the rubble also.

The antennas type is very important, so the antenna plays an important role in GPR systems. The antenna efficiency is also an important part of the system. The high efficiency provides reliable and more information. Having better antenna efficiency depends on the optimization works in antenna's physical features.

Therefore, Vivaldi antenna is one of UWB Antenna that used to build GPR , because it has some properties like great bandwidth , end-fire radiation, moderate gain , small dimension and easy to fabricate. So, in this thesis we have a plan to build two types of Vivaldi antenna one is Antipodal Vivaldi Antenna (AVA) and another Double Slot Vivaldi Antenna (DSAVA), for AVA the substrate material that used is Taconic with dielectric constant 3.55 we aim in this design to get a good antenna pattern at low frequencies and a high radiation pattern at high frequency , whereas it has a small dimension (70×50×0.76)mm3 . In DSAVA we have to get radiation pattern greater than that in AVA , because DSAVA is improved to enhance the Directivity and radiation pattern , the substrate material that used is FR4 with dielectric constant 4.3 and dimension 50×70×1 mm3 , in two designs we used the dielectric lens to improve the radiation pattern at low and high frequency , and for AVA we used a technique elliptical curved edge to enhance the return loss or S11 at low frequencies.

Keywords: *Double slot Antipodal Vivaldi Antenna (DSAVA), Antipodal Vivaldi Antenna (AVA), dielectric lens, UWB Antenna, GPR.*

YERALTI GÖRÜNTELEME RADARI İÇİN VİVALDİ ANTEN TASARIMI

ÖZET

Yeraltı Görünteleme Radarları (YGR) günümüzde birçok askeri ve sivil uygulamalarda kullanlımlaktadır. Askeri alanda, gömülü nesne, mayın ve patlayıcı tesbiti için önemli rol almaktadır. Sivil uygulamalarda ise, arkeologi çalışmalarında tarihi eserlerin hasarsız tesbiti, plastik ve metal boruların su sızıntılarını bulmak ve inşa edilmiş bir binanın iskelet yapısını incelemek için kullanılmaktadır. Bu radar çeşiti, sadece tesbit etmek değil, harek izleme yeteniğine de sahiptir. Bu doğrultuda insan hareketleri tesbiti de yapılmaktadır. Duvar arkasında saklanan insanlar, deprem sonrası enkaz altında kalmış ve kurtarmayı bekleyenlerın hayatını kurtarmak için, önemli bir teknoloji olarak sunulmuştur.

YGR teknolojisinin en önemli parçası olarak YGR anteni de geliştirilmekte olup, araştırmacılar için odak noktası olmuştur. Bu teknolojide anten tasarımı yaparken, antenin daha iyi ve eş zamanlı data alışverişini sağlamak için geniş bant genişlğine sahip olması, gönderilen işaretin daha derin mesafelere ulaşmak için yüksek kazanca ve başlangıç frekansının düşük olmasına özen gösterilmesi önerilmiştir. Ayrıca, tasırımı yapılacak olan antenin, alıcı verici sitemi ile beraber kullanılması gerektiği ve dron gibi araçlara monte edilebilmesi için oldukça hafif olup, küçük boyutlara sahip olması büyük bir avantaj sağlayacaktır.

Bu doğrultuda, tez çalışması esnasında, YGR sistemleri kapsamlı birşekilde araştırılıp, kullanılan anten yapıları incelenecektir. Anten tasarımına başmadan önce, antenin tüm parameteleri ve çeşitleri gözden geçirelecektir. Tasarım aşamasında ise, literatür araştırmasının ardından oldukç hafıf, küçük boyutlu, yüksek kazanca sahip ve ultra geniş bantlı Vivaldi anten tasarımı gerçekleştirilecektir.

Anahtar Kelimeler: *Yer Altı Görüntüleme Radarı, Vivaldi anteni.*

1. INTRUDUCTION

1.1 What is Ground Penetrating Radar?

GPR (Ground Penetrating Radar) is the non-devasting device used to detect object or hidden materials underground by using a pulses of electromagnetics wave. The electromagnetic pulses will be reflected or diffracted when the dielectric constant of ground is variable [1], [2].

GPR is a non-devasting device, a GPR system transmits an electromagnetic pulses some these pulses reflected on the ground when the dielectric constant is varying the reflected pulses received by a receiver and then transmits to the control unit, in this unit the period of time between transmitting and receiving will calculated, in the display unit it appears the different material [3].

1.2 GPR's Structure

GPR, includes a data collection device, transmitter, and a receiver (digital recorder or analog printer). The transmitting antenna transmits wave of electromagnetic to the ground, after that a sensor detects the wave that reflected from the surface. the radar paly to transmits wave after that the receiver receive the reflected wave on the surface, the control unit play to calculate the period time of transmitting and receiving signal.

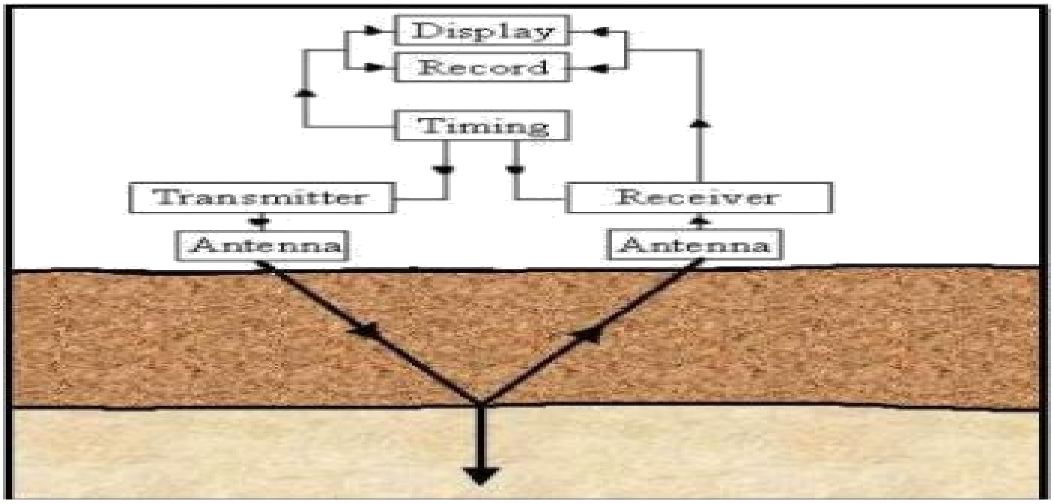


Figure 1.1: GPR working principle [1].

The electromagnetic wave travel in the ground as the elliptical cone as in the figure 1.2 , the radio wave penetrate the ground and then spread in elliptical shape as shown in the figure [4].

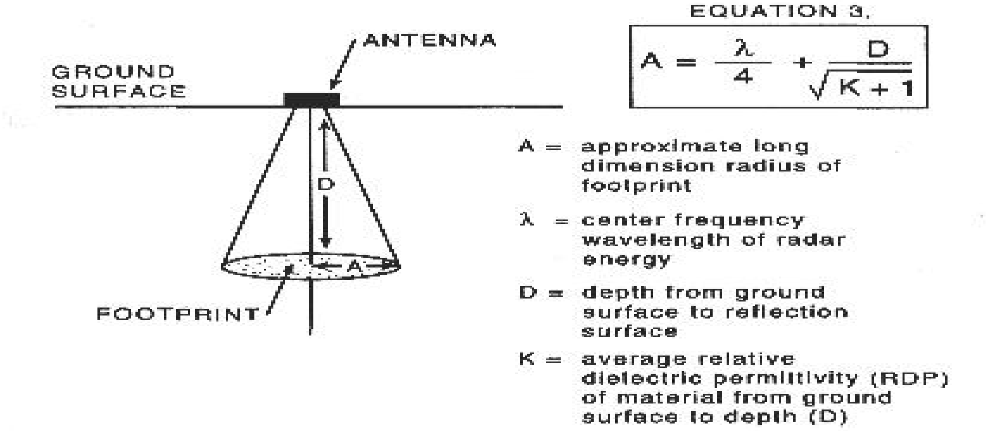


Figure 1.2: Radio wave penetrate the ground as elliptical cone [4].

1.2.1 Reflected signal

The quantity of reflected signal at an surface is collected by $\rho_{1,2} = \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon r2}}{\sqrt{\varepsilon r1} + \sqrt{\varepsilon r2}}$,

Where $\rho_{1,2}$is the reflection coefficient and ε_{r1} and ε_{r2} are the relative permittivity.

Table 1.1. shows Dielectric constants for some materials.

Table 1.1: Dielectric constant for some materials.

Material	Dielectric constant
Air	1
Asphalt: dry	2-4
Clay	2-40
Dry sand	3-5
Concrete: dry	4-10
Fresh water	80
Metals	∞

1.2.2 GPR Depth Determination

The reflected wave has data on: how much was attenuated and how quickly the signal traveled [5].

The depth of a surface is presented by:

$$D = \frac{(5.9t)}{\sqrt{Er}}$$

D = depth of object (inch).

t = time of travelling wave (nanosecond).

5.9 = Constant.

Er = Relative permittivity of surface material.

1.2.3 How deep can GPR go into ground?

It depends on two conditions:

1-The type of rock or soil in the GPR survey area.

2- The frequency that used of the antenna.

- Low frequency system are more penetrating but resolution of data is low.
- High frequency systems have finite penetration but supply a high resolution [6].

1.3 Types of Ground Penetrating Radar

Types of GPR: CW and impulse. Generally most of GPR system are regarded on the impulse penetrating radar and are widespread in the commercial market. stepped-frequency radars and Continues-wave have been improved over the past decade, though most have implicated research universities, institutions, and laboratories. Advanced ways and differences like synthetic aperture radar (SAR) and ultra wideband (UWB) [7].

1.3.1 Impulse GPR

When a data is calculated in time domain by a radar this is called impulse radar. The pulses is transmitted by the domain and the receiver receives the reflected wave in time domain . the major of GPR work as impulse radar. The antenna works a main job in the impulse GPR system as in figure1.3.

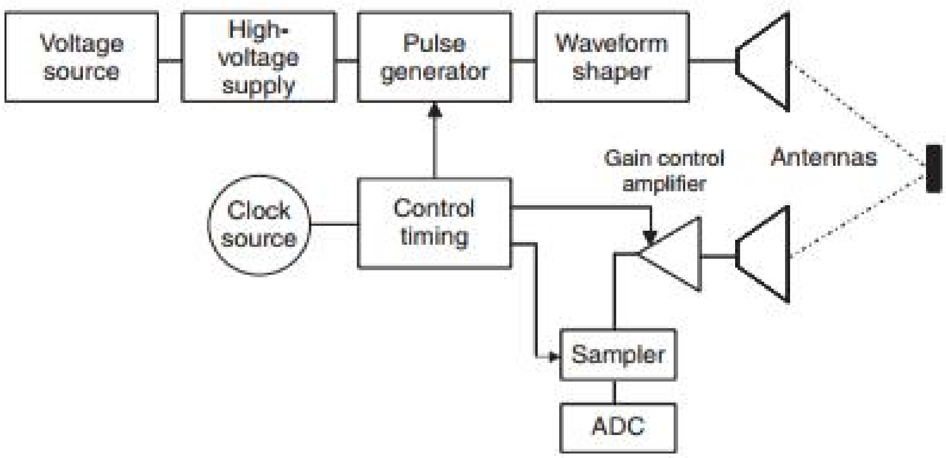


Figure 1.3: Impulse GPR system block diagram [7].

1.3.2 Continuous-Wave GPR

Stepped frequency continuous-wave radar

SFCW GPR system uses separate transmitter and receiver, the signal of the transmitter is received by a radar receiver after reflecting [8].

1.4 GPR Applications Area

GPR application area can be classified in two main application group.in military field, GPR is used for underground warehouses, un exploded bombs, sector room sand also bomb shelter. Besides, in civilian life, it is used for finding buried pipes, undetected blanks and the people who are left under collapsed buildings [9].

In the Science of Earth GPR is worked to detect, soils, bedrocks, water, and ice. [10].

1.5 Three _ Dimensional Imaging

Registration a full-resolution 3D dataset demands a very intensive, whereas in this technique the radar system work to plot the image in 3D and displaying all the information about image and the layer of ground [11]

The example shown below describe the 3D imaging GPR principle.

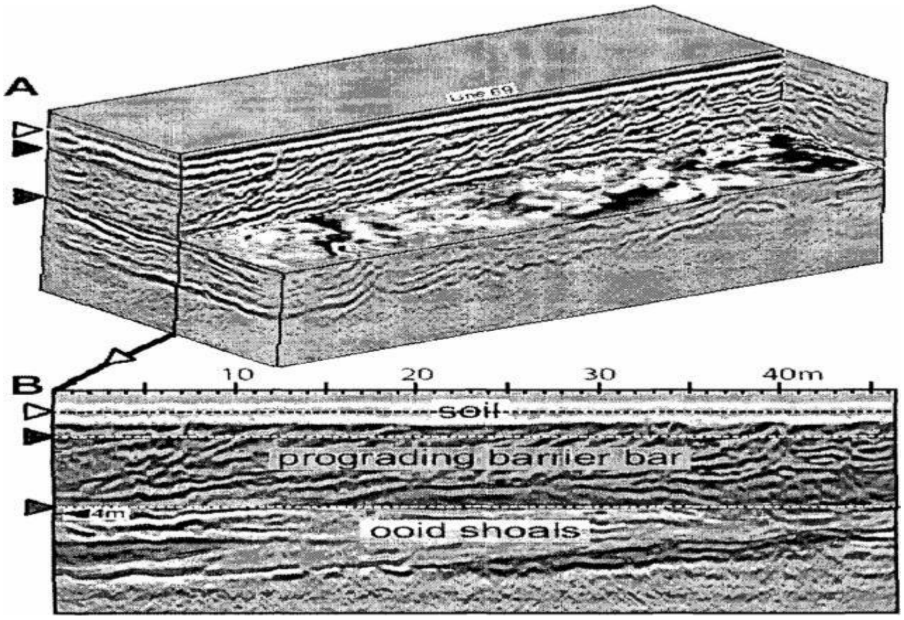


Figure 1.4: A: Chair display of the Miami Oolite 3D GPR survey [12].

The most important part of GPR system is antenna, improvements in antenna designing way will provide better results in GPR application. SO, in the next chapter fundamental parameters of antenna will be explained.

2. ANTENNA

2.1 Definition

The Antenna is a device used to convert radio frequency into current or vice versa . two types of antenna used in communication systems transmission and receiving antenna . Antenna works a major part in all radio systems and communications [13].

2.2 Radiation Pattern

An antenna pattern or antenna radiation pattern defined as the variation of the power transmitted by an antenna as a function of the direction far away from the antenna. This power deference as a function of the arrival angle is observed in the antenna's **far field** . Radiation properties include radiation intensity, power flux density, field strength , directivity , polarization or phase [14].

The far field is the area far from the antenna. In this area, the antenna pattern does not change form with distance.[14].

2.2.1 Antenna pattern in 3D

The antenna pattern is a 3D figure and showed in spherical coordinates (r, θ, Φ) regarding its origin at the middle of spherical coordinate system. figure2.1 [15].

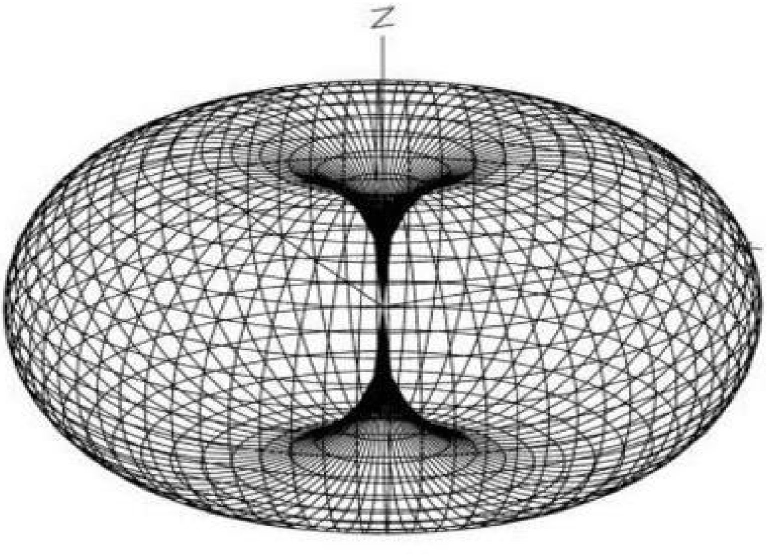


Figure 2.1: The 3D Antenna Radiation Pattern [15].

2.2.2 Antenna Pattern in 2D

The antenna radiation in 2D it represents the vertical and horizontal and it can be represented from 3D radiation pattern. as shown in figure 2.2.

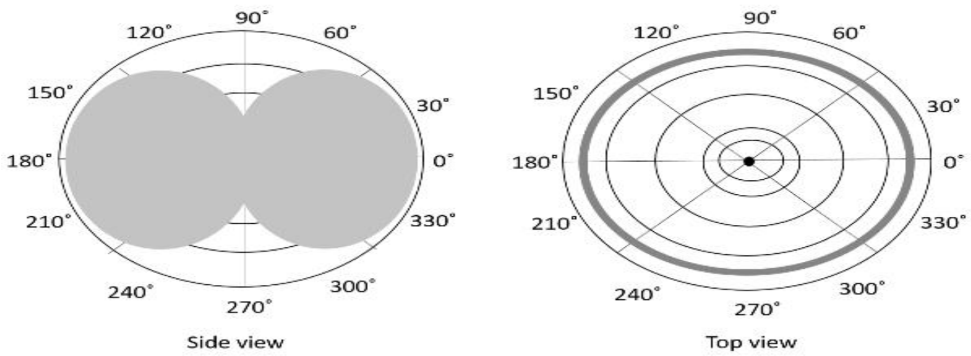
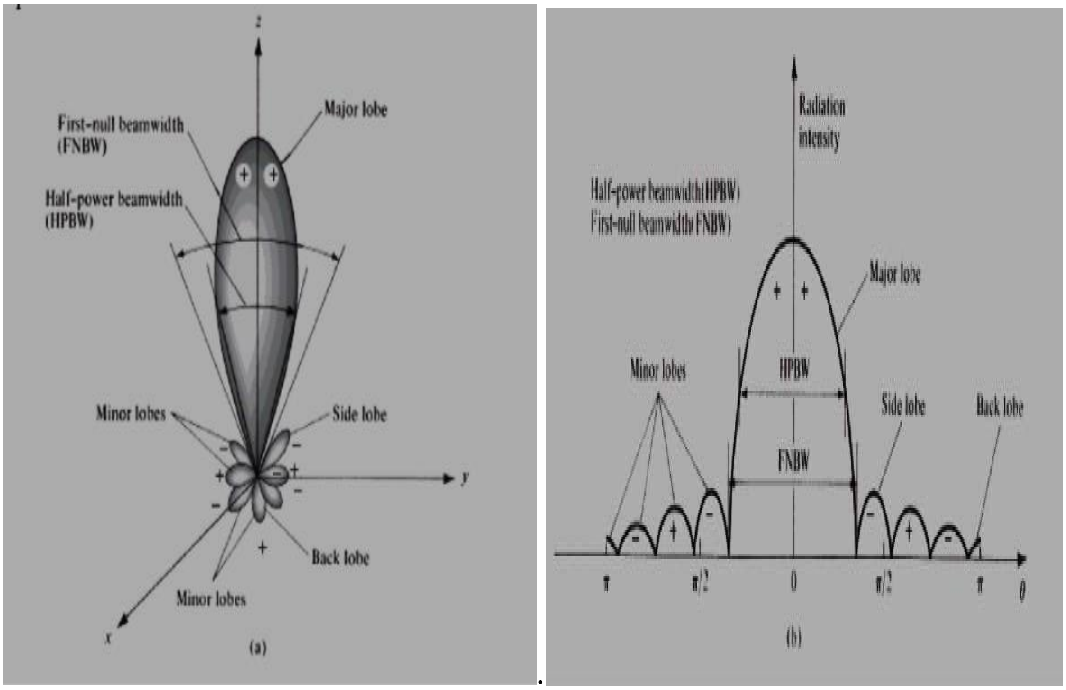


Figure 2.2: The one direction antenna pattern in V and H planes. V plane represents the Vertical pattern, where H plane represents the Horizontal pattern [14].

2.2.3 Antenna pattern lobes

Different areas of an antenna pattern are classified to as lobes, which may be classified into main or major , back , and side lobes [16].



(a) (b)

Figure 2.3: (a) antenna pattern of radiation main lobe .(b) power pattern and radiation[14].

2.3 Intensity of Radiation

Radiation Intensity in a provided guidance is characterized as "the power emanated from an antenna for every unit angle." The intensity of radiation is a far-field parameter, and it very well may be acquired by essentially duplicate the radiation density by the square of the separation . In numerical structure can be gotten as:

$$U = r^2 W_{rad} \tag{2.1}$$

Where

U= intensity of the radiation (W/unit solid angle)

W_{rad}= density of radiation (W/ m^2)

r = Radius of the sphere or circle

2.4 Beamwidth

The beamwidth of a radio wire design is characterized as the partition between two indistinguishable focuses on inverse sides of the example most extreme. In antenna pattern, there are difference beamwidths. A most exceptionally utilized beamwidths is the half power beamwidth (HPBW)[17].Another critical beamwidth is the angle division between the main nulls of the radiation design , and it is called to the first null beamwidth (FNBW).

Anyway , by and by , the term beamwidth , with no other recognizable proof , for the most part alludes to the HPBW [17].

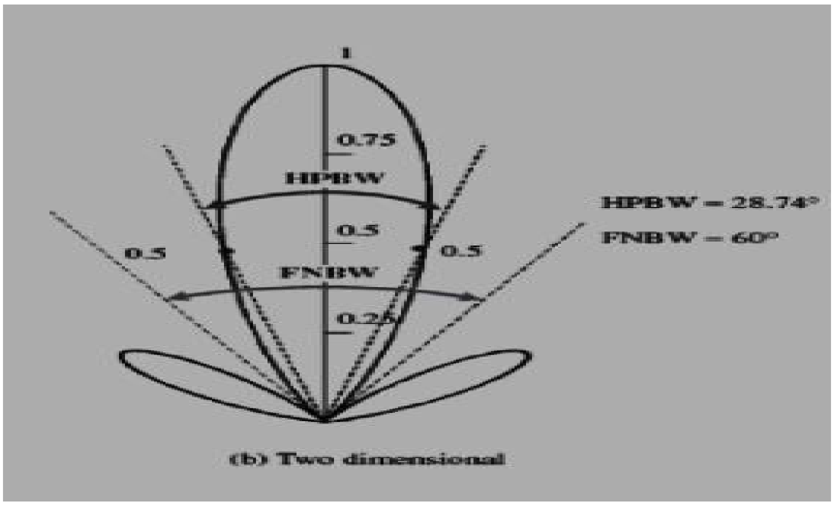


Figure 2.4: the two dimensional power pattern [17].

2.5 Directivity

Isotropic antennas are theoretical point sources that spread electromagnetic energy similarly every which way. The total power radiated is determined by integrating the power flux

density on the surface of a sphere of radius r that surrounds the antenna (surface area =$4\pi r^2$) [14].

Antenna directivity is described as "the rate of the radiation power in a provided direction from the antenna to the intensity of the radiation found the middle value of over all bearings. [18].

$$\frac{U}{U0} = \frac{4\pi U}{P_{rad}} \quad \textbf{(2.2)}$$

Maximum directivity can be expressed as

$$D_{max} = Do = \frac{U_{max}}{Uo} = \frac{4\pi\, U_{max}}{P_{rad}} \quad \textbf{(2.3)}$$

while

D = directivity (directionless)

Do= highest directivity (directionless)

U= intensity of the radiation (W/unit sold angle)

U_{max}= highest intensity of radiation (W/unit sold angle)

Uo = intensity of the radiation of isotropic source (W/unit solid angle)

P_{rad}= total power radiated (W)

And the maximum directivity written as

$$Do = \frac{4\pi}{\Omega_A} \quad \textbf{(2.4)}$$

is the beam solid angle

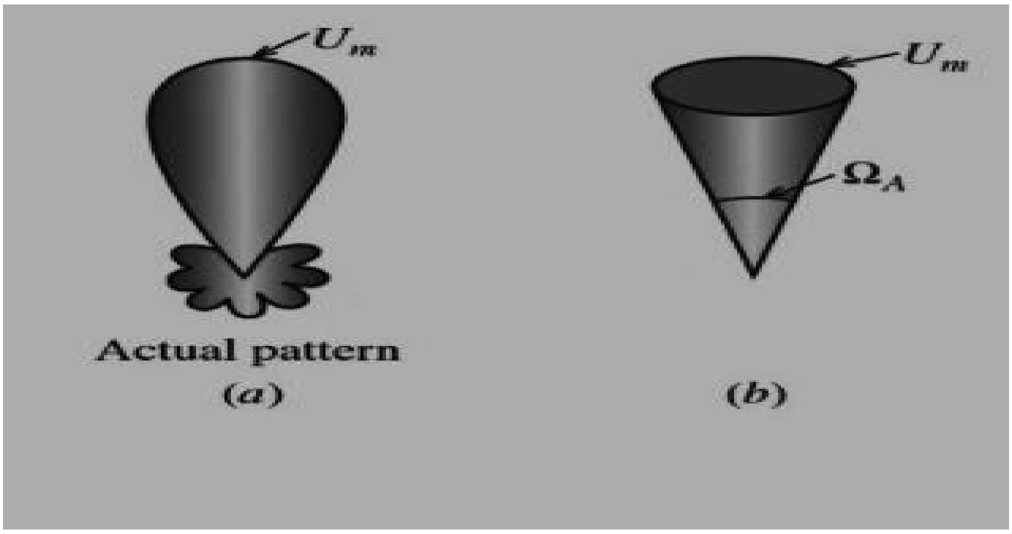


Figure 2.5: Antenna beam Ω . (a) radiation intensity U from a real antenna . (b) intensity of the radiation with all radiation from the real antenna focused into a cone of solid angle Ω with constant intensity of the radiation equal to the maximum of the real pattern [14].

The term for changing over the amounts of directivity and most astounding directivity to decibels (dB)are :

D(dB) = 10log$_{10}$ D **(2.5)**

Do(dB) = 10log$_{10}$ Do **(2.6)**

2.6 Gain

Gain is One of the useful way to calculate the execution of an antenna.

The intensity of the radiation relating to the isotopically transmitted power is equivalent to the power contribution by the radio wire partitioned by 4π."[13], [14].

Gain = 4π =

$$\frac{radiation\ intensity}{total\ input\ (accepted)\ power} = 4\pi\frac{U(\theta,\phi)}{P_{in}}\ (dimensionless) \quad \textbf{(2.7)}$$

$$Gain = 4\pi = \frac{U(\theta,\phi)}{P_{in}\ (lossless\ isotropic\ source)}\ (\ dimensionless) \quad \textbf{(2.8)}$$

The total power radiated (P_{rad}) is concerning to the total power input (P_{in}) by

(P_{in}) by

$$P_{rad} = e_{cd} P_{in} \quad \textbf{(2.9)}$$

Whereas is the radiation efficiency of antenna (dimensionless) Radiation efficiency can be bounded as

$$0 \leq e_{cd} \geq 1 \quad \textbf{(2.10)}$$

Then, the antenna gain is equal to its directional directivity multiplied by radiation efficiency [19] .

$$G = e_{cd}\ D \quad \textbf{(2.11)}$$

Units gain in decibels

(2.13)

G(dB) = 10log$_{10}$

2.7 Efficiency Of Antenna

The all efficiency of antenna e_0 is utilized to take losses at the input and inside the construction of the antenna. As in figure 2.6.

Anyway, the all efficiency can be expressed as

$$e_0 = e_r \; e_c \; e_d \tag{2.13}$$

$e_0 = total\ efficiency\ (dimensionless)$

e_r = efficiency of reflection (mismatch) $=(1 - |\Gamma|^2)$ (dimensionless)

e_c = efficiency of conduction (dimensionless)

e_d = efficiency of dielectric (dimensionless)

Γ = reflection coefficient voltage at the input terminals of the antenna

$$\Gamma = (Z_{in} - Z_o)/(Z_{in} + Z_0) \tag{2.14}$$

Where

VSWR = voltage standing wave ratio = $(1 + |\Gamma|) / (1 - |\Gamma|)$

$$e_o = e_r \; e_{cd} = e_{cd} \; (1 - |\Gamma|^2) \tag{2.15}$$

where $e_{cd} = e_c \, e_d$ = radiation efficiency of antenna.

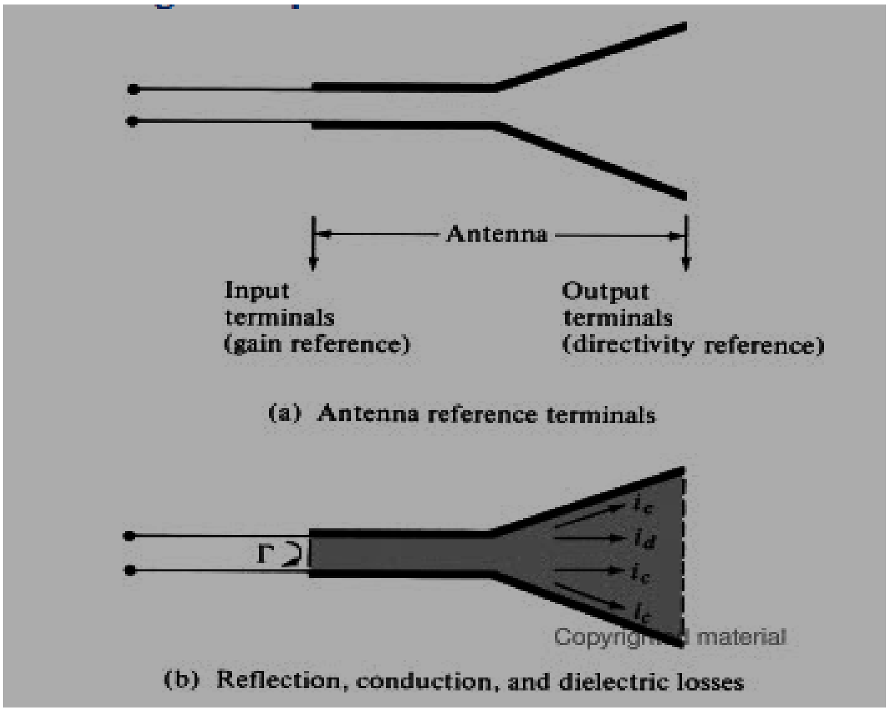


Figure2.6: Reference terminal and reference of antenna [14].

Polarization

Antenna Polarization in a genuine way is characterized as "the polarization of Antenna transmitted wave. Note: When the bearing isn't expressed, the polarization is toward greatest gain. "[20].

Polarization might be linear , circular , or elliptical as in Figure2.7.

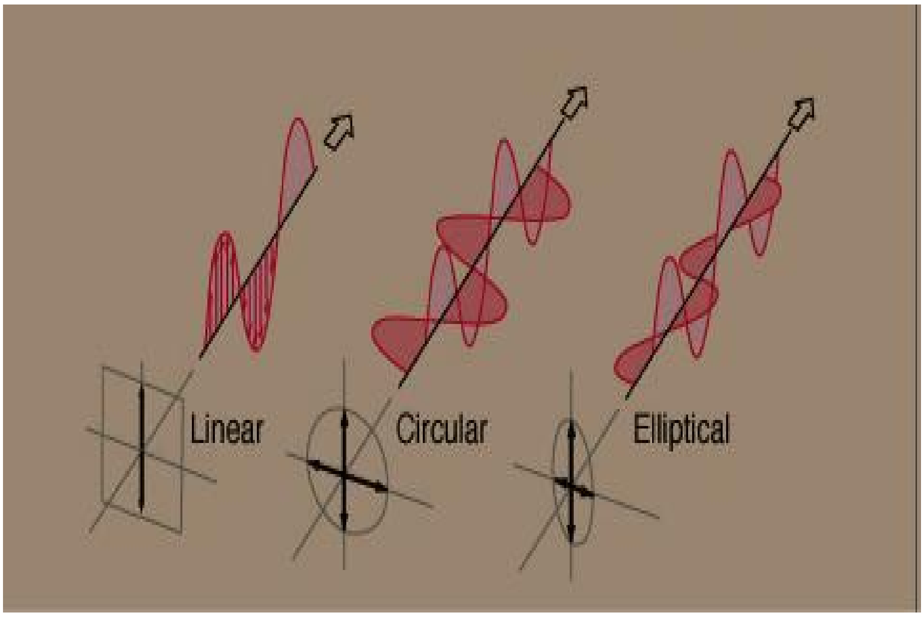


Figure 2.7: Linear , Circular and Elliptical Polarization[14]

Linear Polarization

Circular Polarization A period consonant wave is circularly polarized at a predetermined spot in space if the magnetic (or electric) field as a component of time .

In the event that the revolution is counterclockwise, the wave is left-hand (or counterclockwise) circularly polarized; if the wave is clockwise, the wave is Right-hand (or clockwise) circularly polarized.

Axial Ratio

It is clear that the pivotal proportion example can be depicted by external and internal envelopes. At any edge, the proportion of the inward and external envelope reactions speak to the pivotal proportion. In the event that the example is perused in decibels, the pivotal proportion is the contrast between the external and inward envelopes (dB); zero dB distinction speaks to roundabout polarization (hub proportion of solidarity).

So thep olarization design is appeared in Figure 2.8[21]

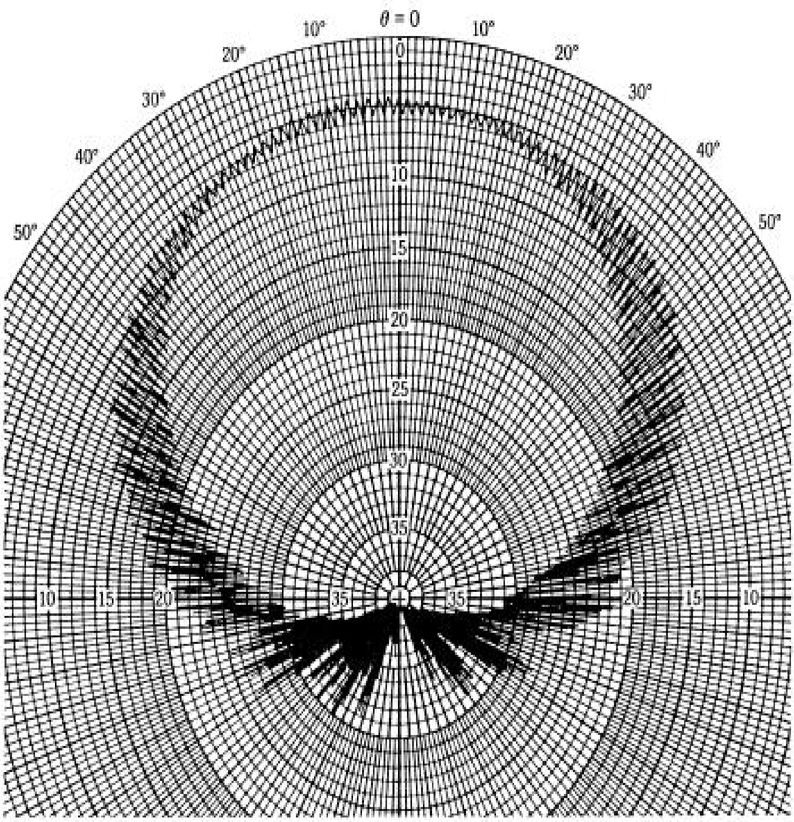


Figure2.8: Radiation Pattern of a polarized circular test antenna given with a rotating, polarized linearly, antenna source. [22].

Elliptical Polarization A period symphonious wave is circularly enraptured if the tip of the field vector (magnetic or electric) follows a elliptical locus in space. [23].

2.8 Input Impedance

Input impedance is characterized as "the impedance depicted by an antenna at its terminals or the proportion of the reasonable segments of the electric to magnetic fields at a point or the proportion of the voltage to current at a couple of terminals."

In Figure2.9 these end points are designated as a – b . The proportion of the voltage to current at these end points [24].

$$Z_A = R_A + jX_A \tag{2.16}$$

Where

Z_A= impedance

R_A= resistance

X_A= reactance

Generally, the resistance is,

$$R_A = R_r + R_L \tag{2.17}$$

Where

R_r= antenna radiation resistance

R_L=antenna loss resistance

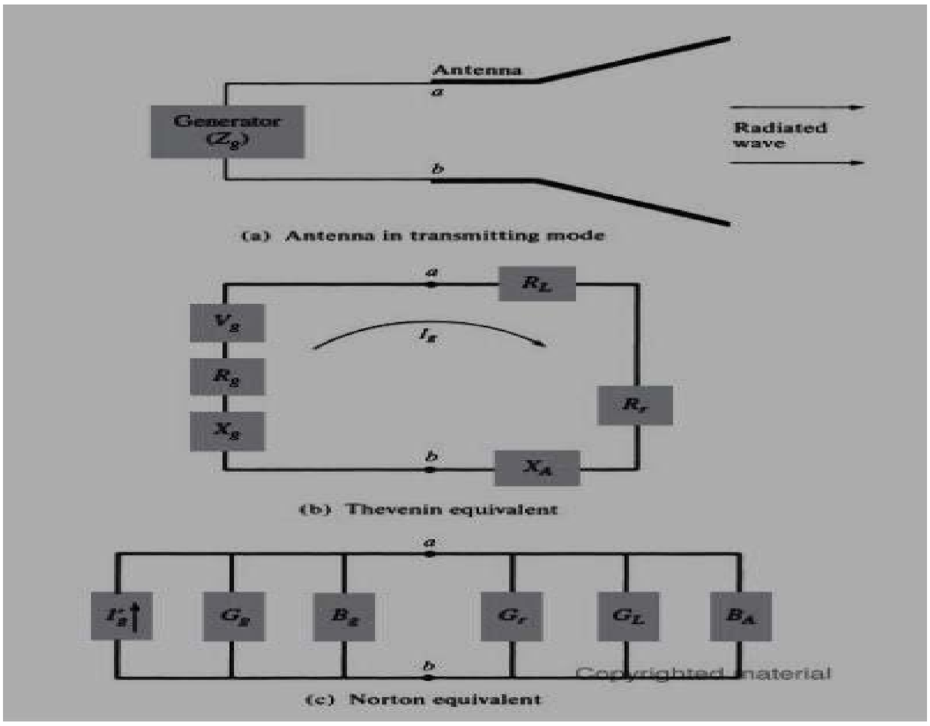


Figure 2.9: Equivalent circuits of transmitting antenna [24]

$R_r + R_L = R_g$ **(2.18)**

$X_A = -X_g$ **(2.19)**

2.9 Return Loss And S_{11}_Parameter

Return loss is a proportion of the proficiency of conveyed power from a transmission line to a load, an antenna return loss is characterized as [25].

$$RL = 10\log_{10}\left(\frac{P_{in}}{P_{ref}}\right)dB \tag{2.20}$$

in term of a transmission line or waveguide the relationship between return loss and reflection coefficient can be expressed as [26].

$$\begin{aligned} RL &= 10\log_{10}\left|\frac{1}{\Gamma^2}\right|dB \\ &= -20\log_{10}\Gamma dB \end{aligned} \tag{2.21}$$

In terms of (VSWR), this is

$$RL = 20\log_{10}\left|\frac{VSWR+1}{VSWR-1}\right| dB \qquad \textbf{(2.22)}$$

Low qualities for VSWR speak to a decent antenna coordinate. [26].

S_{11} is a known starting at how much power is reflected back to the antenna port since mismatch from the transmission line. S_{11} values are calculated in dB and are negative, ex: - 8 dB. S_{11} is additionally once in a while alluded to as return loss, which is just S_{11} however made positive rather (Return Loss = - S_{11}). So if the reception apparatus Return Loss is 10 dB, S_{11} is - 10 dB.

In the next chapter, types of antenna will be discussed, which types of antenna is UWB antenna? and which one is appropriate to build GPR system?

These questions will be answered in the next part.

3. ANTENNA TYPES

3.1 Wire Antenna

Wire Antennas are the ancient and still the predominant of the antenna form. Wire antennas can be made from either tubular or solid conductors. They are relatively simple concept, easy to fabricate and cheap [13].

3.1.1 Dipole and Monopole Antenna

Dipole, loop, and monopole antennas are the most widely antennas utilized for communication systems, measurements, and broadcasting of magnetic and electric fields [14].

A dipole antenna is generally a metal wire. Generally, a dipole antenna contains two radiating arms symmetrically. A monopole antenna is a singular radiating arm whatever, monopoles are most usually utilized above a full or partial ground plane as in Figure3.1 [15].

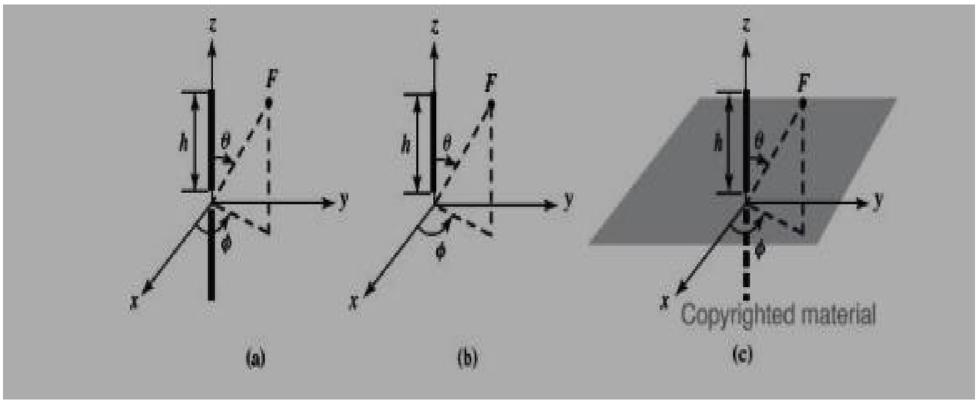


Figure 3.1: Dipole and monopole antenna (a) Dipole (b)monopole .[14].

$$I(z) = \begin{cases} Io\sin\left[k\left(\frac{L}{2} - z\right)\right], 0 \le Z \le \frac{L}{2} \\ Io\sin\left[k\left(\frac{L}{2} + z\right)\right], -\frac{L}{2} \le Z \le 0 \end{cases} \quad \textbf{(3.1)}$$

Where k= $\omega(\mu\ \varepsilon)^{1/2}$It is helpful to visualize the distribution current on the antenna . figure 3.2. Shows the current on the dipole for different lengths.

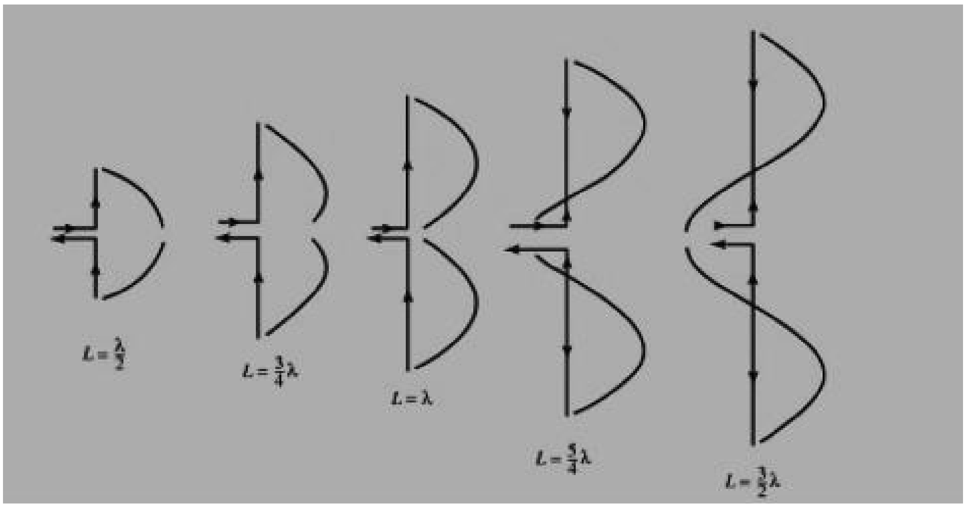


Figure 3.2. current distribution for various different-fed dipoles [13].

A chart of the variation of the feed-point reactance and resistance of a monopole antenna above ground is given in Figure3.3 as a function of length h/ λ, where λ is the free space wavelength at the radiation frequency [26].

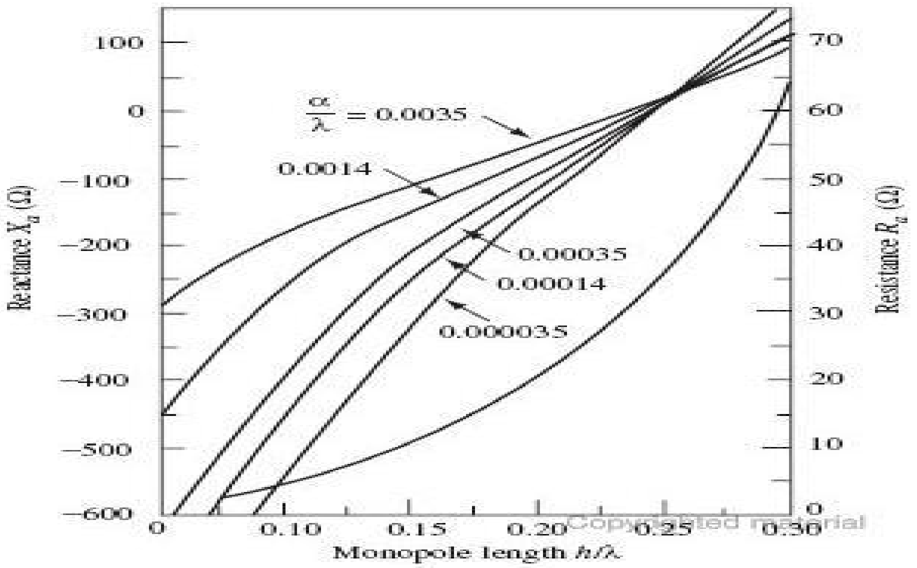


Figure 3.3: Feed point variations R a and reactance X [14].

3.1.2 Infinitesimal dipole

An infinitesimal Dipole or this is called a Hertzian dipole as in figure 3.4. The magnetic-and electric-field components of the Hertzian dipole are [27].

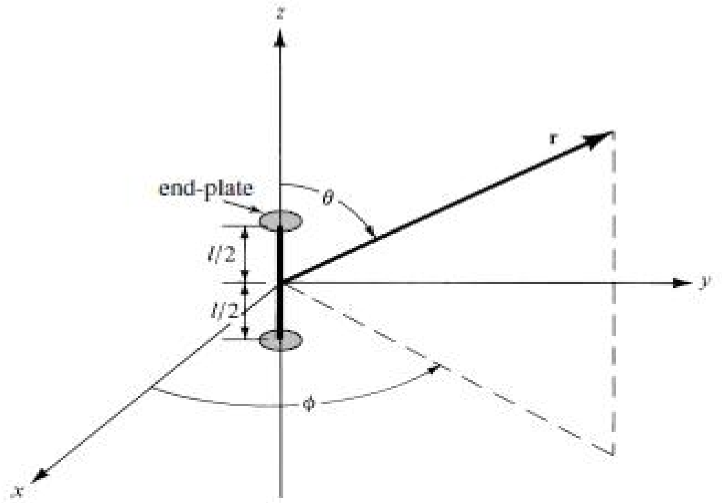


Figure 3.4: Infinitesimal dipole [13].

$$H = \frac{1}{4\pi} IL \sin\theta \left(\frac{jko}{r} + \frac{1}{r^2} \right) e^{-jk_0 r} \hat{\phi}$$

$$E = \frac{j\eta_o IL}{2\pi ko} \cos\theta \left(\frac{jko}{r^2} + \frac{1}{r^3} \right) e^{-jk_0 r} \hat{r} \qquad \textbf{(3.2)}$$

$$- \frac{j\eta_o IL}{2\pi ko} \sin\theta \left(-\frac{k_o^2}{r} + \frac{jk_o}{r^2} + \frac{1}{r^3} \right) e^{-jk_0 r} \hat{\theta}$$

The total power radiated is =40πİ ^{2} (L/ λ) ^{2}, current on the dipole is Io.

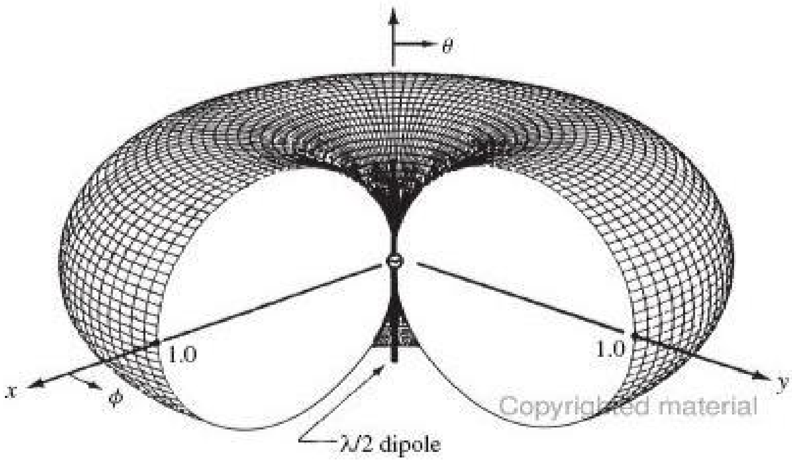


Figure 3.5: Antenna pattern for an infinitesimal dipole [14].

3.1.3 Folded dipole antennas

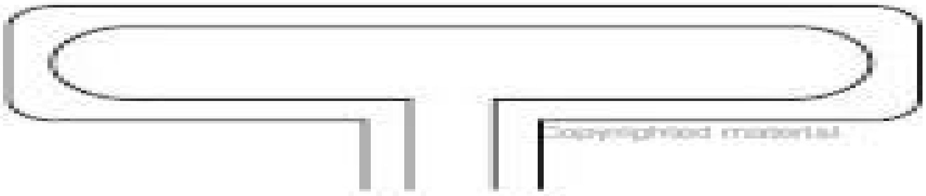


Figure 3.6: Folded dipole antenna [14].

Zt= jZo tanβ **(3.3)**

The input impedance Zt for this mode is given by the equation for a transmission line with a short circuit load .

3.1.4 Log-periodic antenna

log-periodic antennas are generally utilized as transmitter and receiver antennas. The shape of a log periodic array is in Figure 3.

$$\tau = \frac{R_{n+1}}{R_n} \frac{d_{n+1}}{d_n} \quad \textbf{(3.4)}$$

where $\tau = f\,n \,/\, f\,n + 1$ [15].

$$\sigma = \frac{d_n}{2L_n} \frac{(1-\tau)}{4} \cos\alpha \quad \textbf{(3.5)}$$

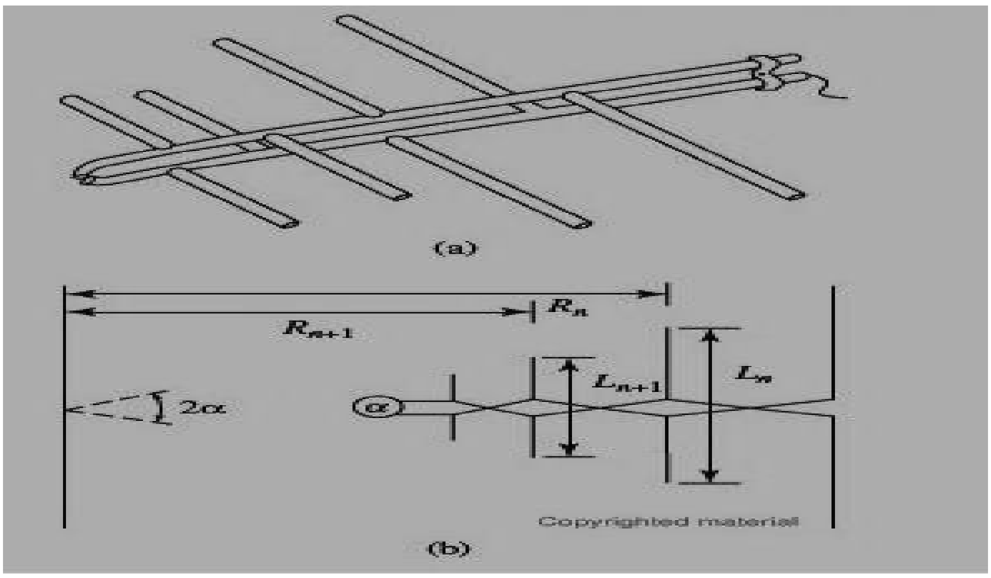


Figure 3.7: Log periodic dipole array(a)log periodic and (b) its equivalent [15].

3.1.5 Broad band dipole arrays

A broadband dipole curtain like in Figure3.8 is usually utilized for high power .

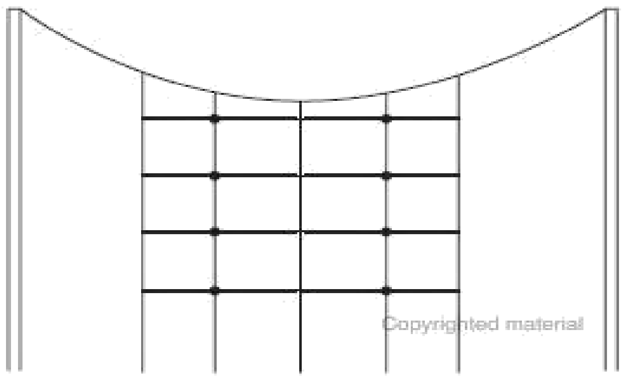


Figure 3.8: A broadband dipole curtain [14].

3.1.6 Yagi uda dipole array

Yagi Uda arrays are usually utilized as general aim antennas, in special, as TV antennas. They are cheap, have credible bandwidth. They have single direction beamwidth [14]. As in Figure 3.9.

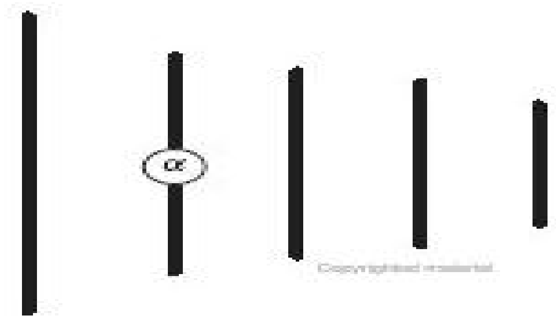


Figure 3.9: Yagi Uda array [15].

3.2 Microstrip Antenna

Printed antennas are constructed using printed circuit fabrication techniques like a portion of the metal layer is responsible for radiate power . [13, 14] [15].

In high execution spacecraft ,aircraft, missile, and satellite applications, where weight, size, performance, cost, ease of installation, and aerodynamic profile are constraints, low-profile antennas may be required. Recently there are many other commercial and government applications, like wireless and mobile radio communications, that have same specifications. To achieve these demands, microstrip antennas can be utilized. These antennas are simple and cheap .[15].

3.2.1 Microstrip patch antenna

Microstrip device in its simplest form is a layered structure with two conductors parallel inserted by a small dielectric substrate and the lower conductor playing as a ground plane. If the upper metallization is a long narrow strip, a microstrip transmission line is formed as shown in Figure3.11. Conventional patch designs yield bandwidths as low as a few percent. The resonant nature of microstrip antennas also means that at frequencies below UHF they become excessively large [13].

An approximate value for the length of a resonant half-wavelength patch is [13].

$$L = 0.49\lambda_d = 0.49\frac{\lambda}{\sqrt{\varepsilon_r}}$$ Half wave patch **(3.8)**

is the dielectric wavelength, and the dielectric constant of the substrate. We focus on our attention here on the half-wave patch antenna.

Input impedances at the edge of a rectangular resonant patch.[13].

$$Z_A = 90\,\frac{\varepsilon_r^2}{\varepsilon_r - 1}\,\left(\frac{L}{W}\right)^2\ \Omega$$ **(3.9)**

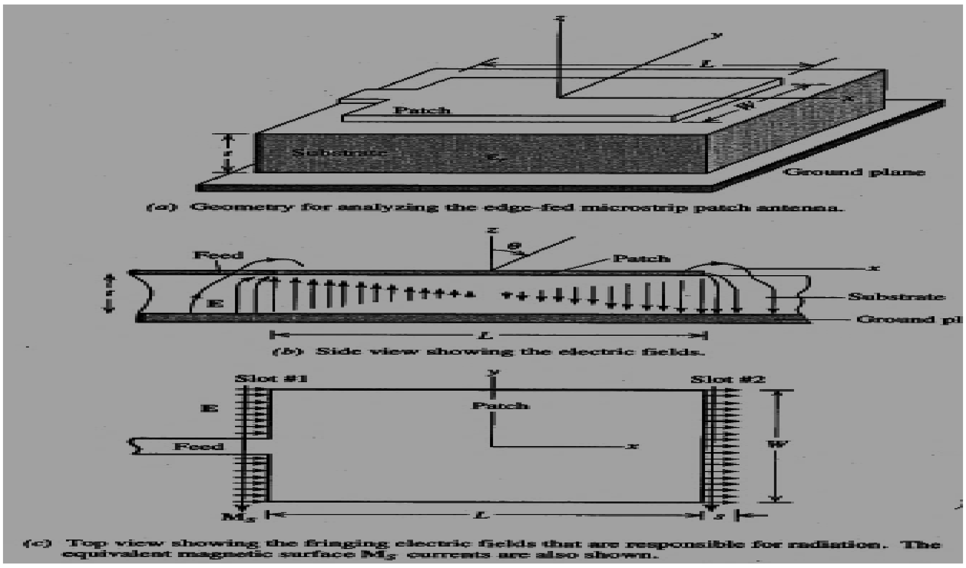


Figure 3.10: The rectangular patch microstrip antenna [13].

The microstrip antenna width w controls the input impedance

Microstrip field are plotted in figure3.12 for L=W=0.5 λ

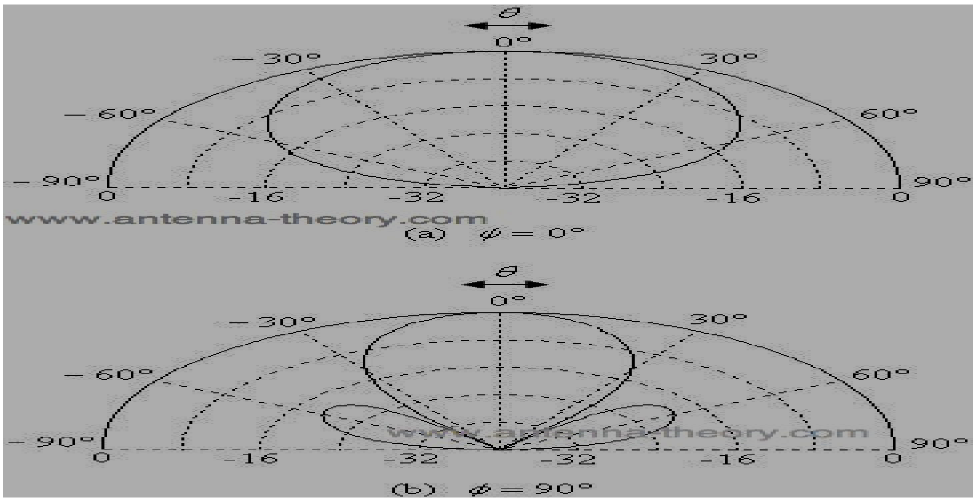


Figure 3.11: the fields of the microstrip antenna at W=L=0.5 λ[13].

Travelling Wave Antenna

3.2.2 Helical antenna

Simple, practical, and basic representation of an electromagnetic radiator is a helix, as shown in Figure 3. 13. In most condition the helix is utilized with a ground plane.as shown in figure 3.12 [20].

The geometric representation of a helix depends generally of N turns, spacing S and diameter D between each turn. The total length of the antenna is $L = NS$ whereas the total length of the wire is $L_n = NLo = N\sqrt{S^2 + C^2}$ where $Lo = \sqrt{S^2 + C^2}$ is the wire length between each turn and the circumference is $C = \pi D$ of the helix. [1].

$$\alpha = \tan{-1}\left(\frac{S}{\pi D}\right) = \tan{-1}\left(\frac{S}{C}\right) \quad \textbf{(3.10)}$$

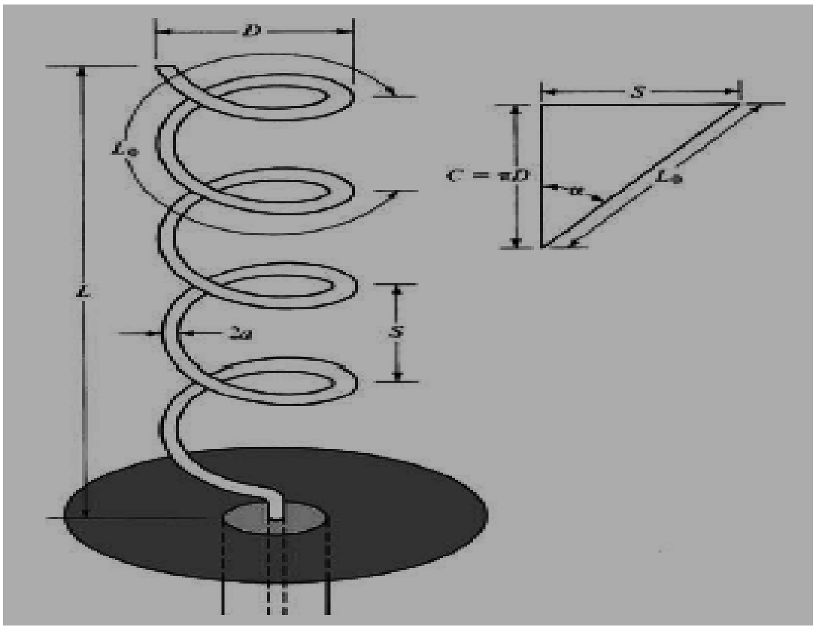


Figure 3.12: Helical antenna with ground plane [20].

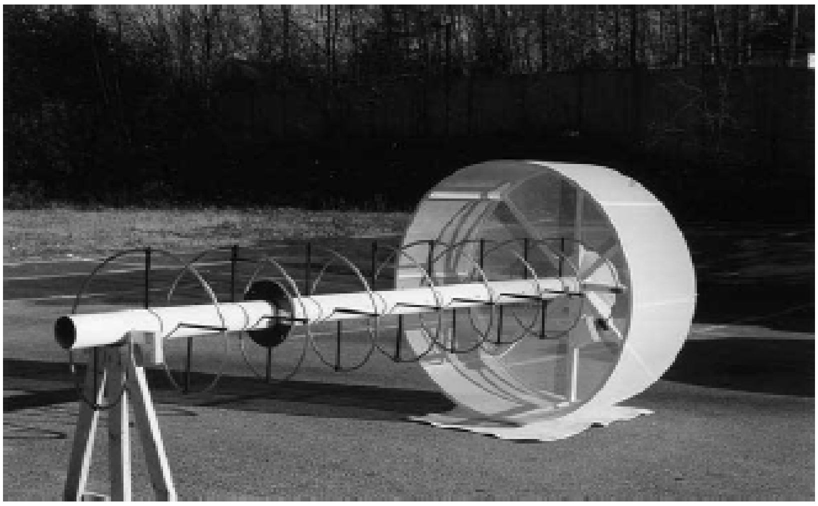


Figure 3.13: Commercial helix [13].

Figure 3.14 Design of helix [13].

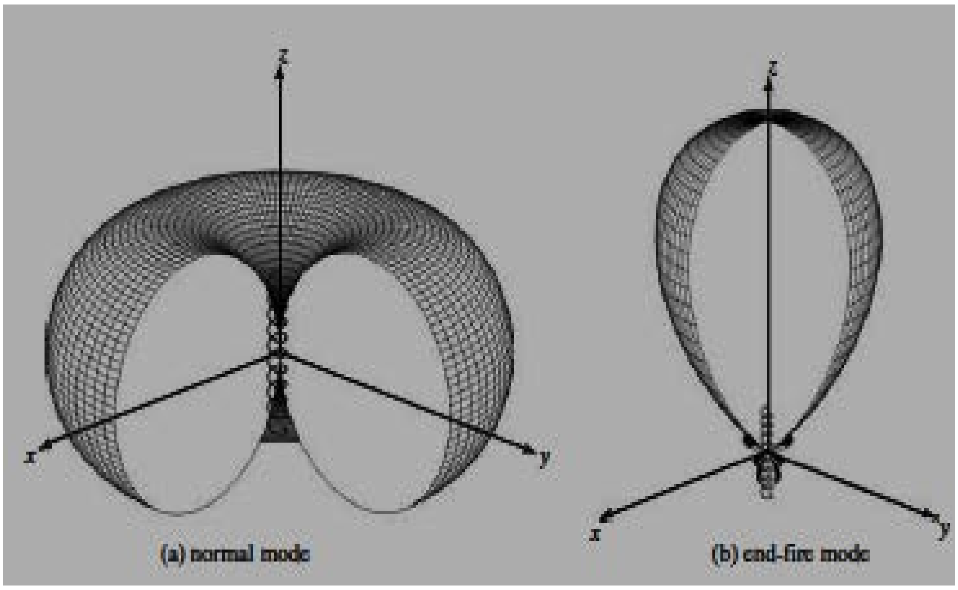


Figure 3.14: Design of helix[13].

3.2.3 SpiralAntennas

Spiral antennas and their differences are generally constructed to be either nearly or exactly self complementary. This achieve wide bandwidth.

- **Equiangular Spiral Antenna**

The equiangular spiral curve shown in Figure. 24 is given by the generating equation.

$$r = r_o e^{a\emptyset} \quad \textbf{(3.11)}$$

where *ro* is the radius for $\emptyset = 0$ and *a* is a controlling constant the spiral flare rate . The spiral of Figure 3.16 is right handed. If the values of a is negative the left hand spirals can be generated, or by simply turning over the spiral of Fig3.17. The curve of the equiangular spiral is used to create the antenna of Figure3. 25 [28]. Which indicate Planar equiangular spiral antenna.

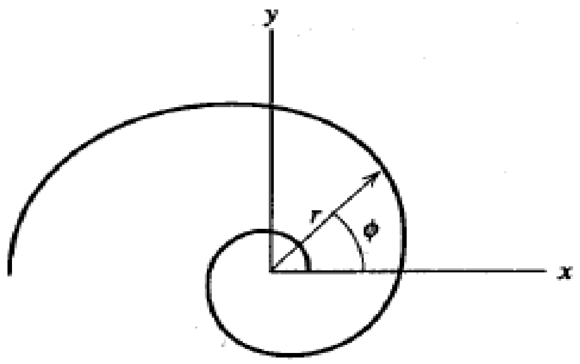


Figure3.15: curve of the Equiangular spiral with r= $r_o e^{a\emptyset}$ and
$r_o = 0.311\ cm\ and\ a = 0.221$

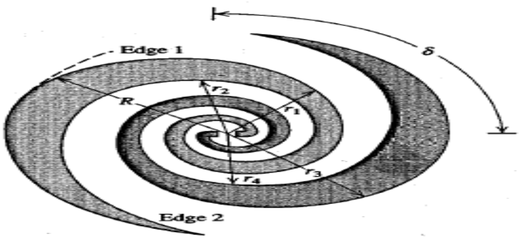


Figure 3.16: Planar equiangular spiral antenna [28].

- **Archimedean Spiral Antenna**

Different shape of the planar spiral is the Archimedean spiral antenna in Figure3.18. This antenna, as are many spiral antennas, is readily fabricated . The equation of the two spirals in Figure 3.26 are

r = $r_o\emptyset$ and $r_o(\emptyset - \pi)$ **(3.12)**

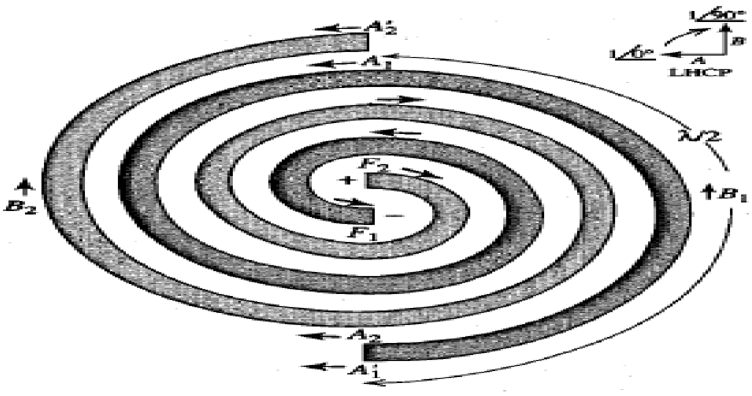


Figure 3.17: Archimedean spiral antenna [28].

3.3 Aperture Antenna

3.3.1 Vivaldi antenna

Vivaldi Antenna is a broadband antenna, which can be fabricate from a solid piece of metal sheet, board of a printed circuit , or from a dielectric substrate on one or both sides as in figure 3.19 [27].

The feeding line excites an open space via a coaxial cable or microstrip line, and may be terminated with a shaped sector area or a coaxial connection direct.

Vivaldi antennas can be fabricate for linear wave polarized or using two devices

putted in orthogonal direction for transmitter , receiver both polarization orientations[27].

Vivaldi antennas are work for any frequency.

Advantages of Vivaldi antennas are their wide broadband Antenna , their easy fabricating process , low cost , end-fire radiation.[28].

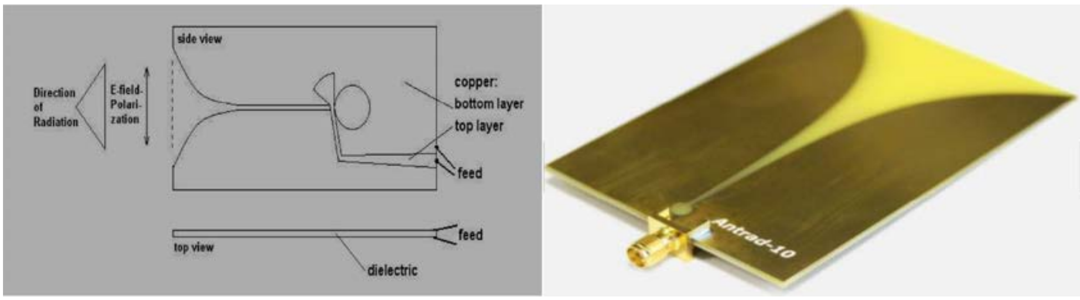


Figure 3.18: Vivaldi Antenna [28].

3.3.2 Horn antenna

Types Of Antenna Horn

1. Pyramidal horn

An antenna Horn with the horn in the form of a four sided pyramid, with a rectangle cross section [29].

2. E-plane horn

A radiation in the direction of the E-field in the waveguide.

3. H-plane horn

A radiation in the direction of the H-field in the waveguide.

4. Conical horn

A horn in the shape of a cone , with a circle cross section. As in figure 3.20.

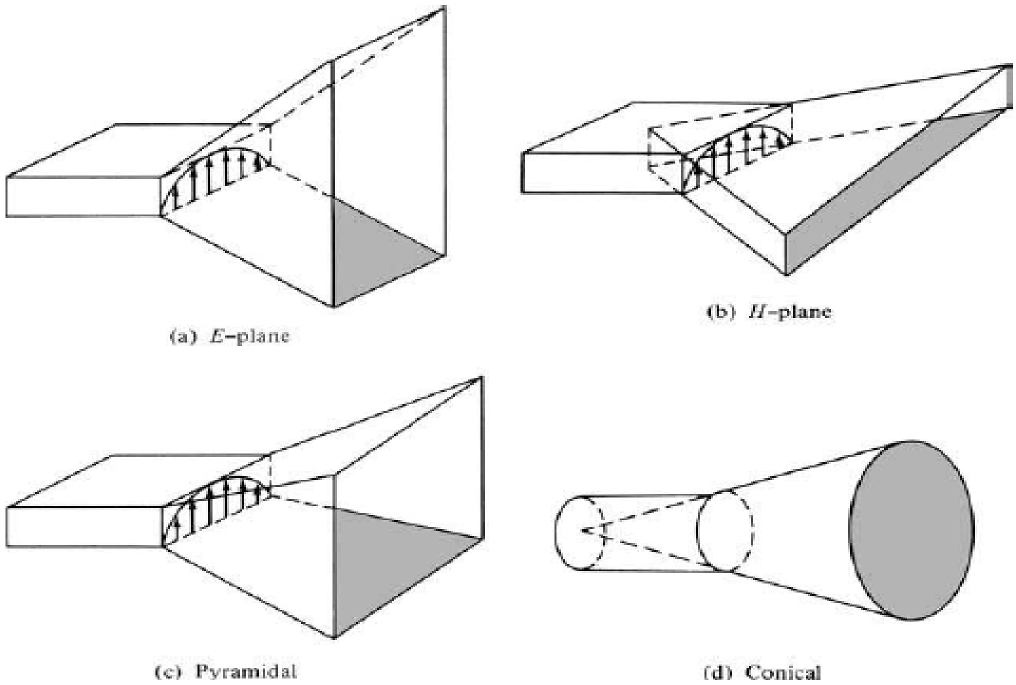


Figure 3.19: Typical electromagnetic horn antenna configurations [13].

In the next chapter, candidate Antenna and methodology of designing with results will be introduced.

4. METHODOLOGY AND RESULTS DISCUSSION

4.1 Antipodal Vivaldi Antenna (AVA).

Designing (AVA) starts from choosing the dimensions and substrate material that will assist to give a good reading in radiation pattern and return loss , after that we will move to any other additional techniques like dielectric lens , elliptical curve edges , that make any enhancement for required readings .

In this design we will discuss all factors that used for design, and how each factor made an improvement in the results. The antenna fed by 50 ohm coplanar waveguide and simulated by CST studio suit program 2018.

Figure 4.1(a) represents the structure of the proposed AVA with dimensions of 50 × 70mm^2 on a substrate of Taconic with dielectric constant of 3.55, tangent loss of 0. 0025 and 0.76 mm height. The antenna consists from one plate and two slots at front and back sides the thickness of slots are 0.035 mm.

But this design suffers from low and inconsistent gain and directivity.

For this, a dielectric lens is added as shown in figure 4.1. (b). The lens tends to limit their wide spread utilization. They are costlier due to complex fabrication process

For getting a good radiation pattern at low frequencies too and to make improvement in S_{11} parameter readings an elliptical curvature edge is inserted to the slots as shown in figure4.1.(c) .

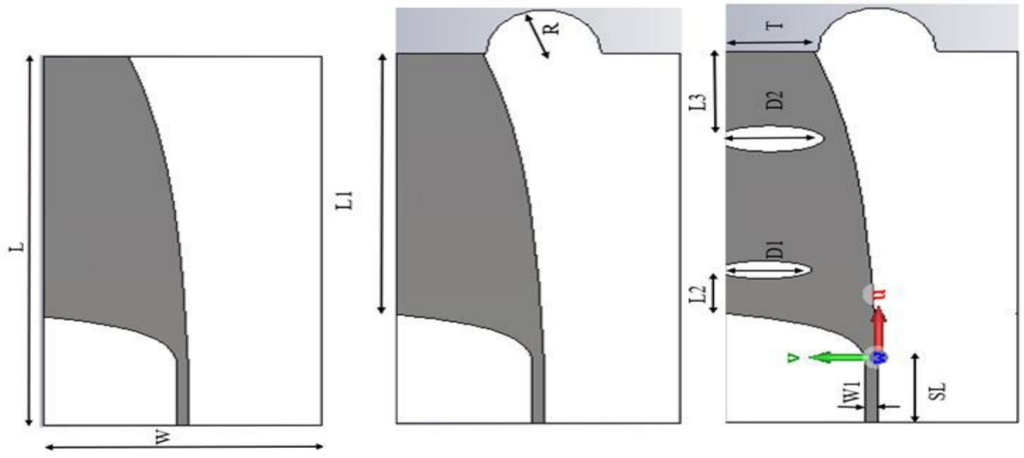
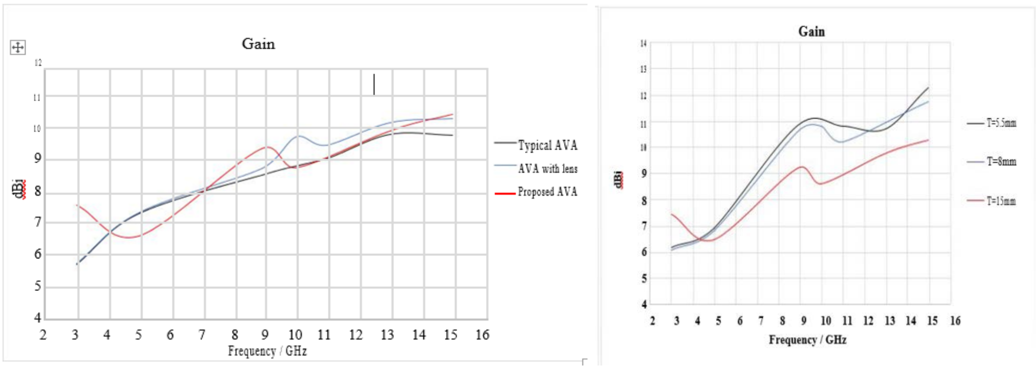


Figure 4.1: AVAs. (a) Typical AVA . (b) AVA with lens .(c) Proposed AVA.

According to figure 4.2.(a) the highest reading of proposed antenna was at 15 GHz (10.2dBi), whereas at Typical AVA and AVA with lens the highest gain was less than this result .Moreover at low frequencies at 3 GHz the reading when antenna designed with elliptical curvature edge the reading raised to 7.4 dBi , although the first result was at 5.7 dBi.



(a) (b)

Figure 4.2: Simulated gain. (a) Typical AVA ,AVA with lens and Proposed Antenna.(b) Proposed AVA with different T Distance.

On another hand , the gain is varied depending on shape of the curvature and length of the taper [30],according to the form of curvature the distance between two curves at slot T have revers relation with gain at high frequencies as shown in figure 4.2.(b).

When T=5.5 mm at 15 GHz the gain is 12.2 dBi , and T= 8 mm at same frequency the gain is 11.8 dBi, but the proposed antenna with T=15 mm has the advantage with highest gain at low frequency 3 GHz with gain is 7.4 dBi

.whereas at the same frequency the readings were 6.1 and 6 dBi at T=5.5 and T=8mm respectively.

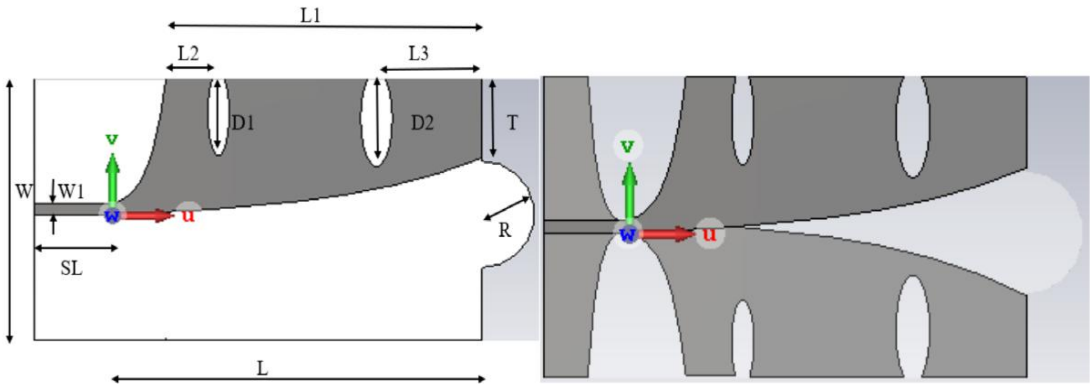


Figure 4.3: (a) Proposed AVA ,(b) Proposed AVA two slots

Figure 4.3. represent the proposed antenna table 4.1 shows the dimensions of the Antenna , with AVA the dielectric lens is utilized to enhance various specifications of the Vivaldi antennas, is utilized to increase gain of the antenna as represented in figure4.3.(a) , in order to the lens shape and its dielectric constant are most important parameter in its design [13-14]. Besides shape, dielectric constant of the lens works an important job in the antenna's specifications. High dielectric constant supplies higher gain and more beam directed.

To improve the S_{11} reading the elliptical curved edge is inserted to design with this dimensions , these edges play to make $S_{11} < -10$ dB at low frequencies in this design by this dimensions.

Figure 4.4(a). represent the S_{11} readings of the antennas and figure 4.4(b). Represent S_{11} readings of Proposed antenna at different T distances .

Table 4.1: Proposed AVA Dimensions.

Parameter	*Value(mm)*	*parameter*	*Value(mm)*
L	70	D1	14
L1	60	D2	17
L2	8.85	W1	2
L3	18.35	T	15
SL	15	R	10
W	50		

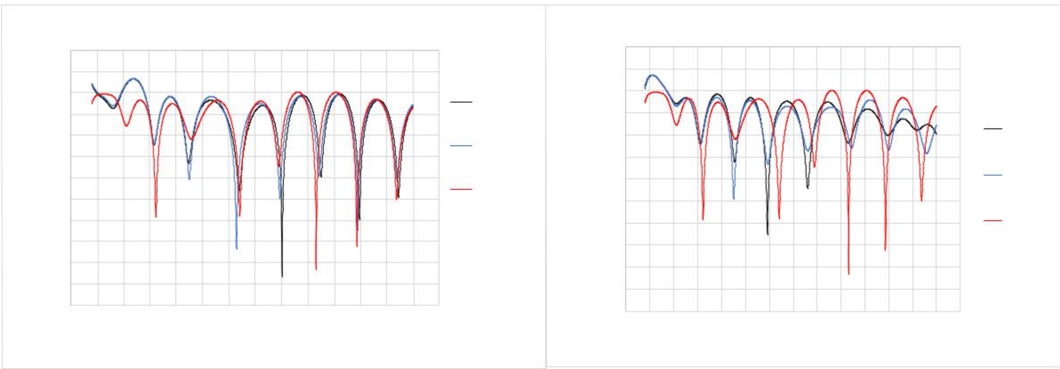


Figure 4.4: S11 simulations ,(a) Typical AVA, AVA with lens , Proposed AVA , (b) Proposed AVA at different T Distance.

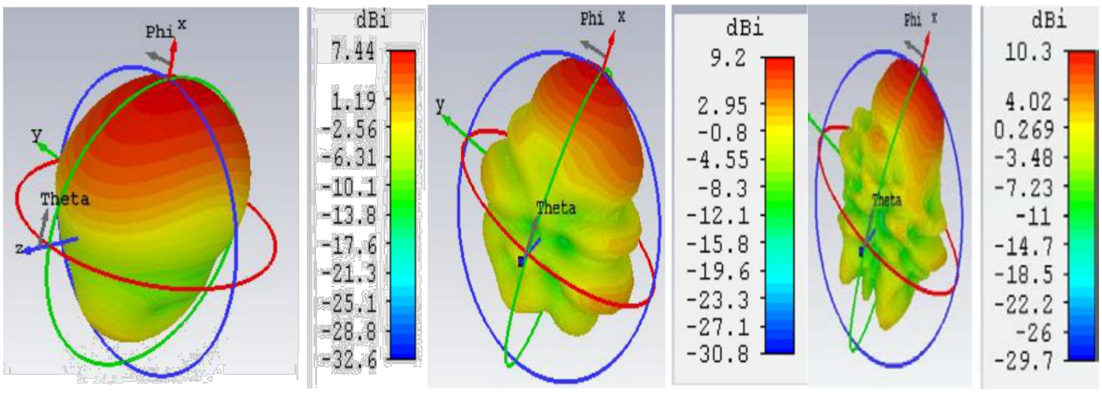
According to figure 4.4(a) typical AVA and AVA with lens have the S_{11} reading to whole frequency range and the S_{11} < -10 dB start from 4.9 GHz , it means at low frequency these designs don't work in good way, by this information the dielectric lens doesn't has a role to make improvement in S_{11} reading at low frequency , whereas when Proposed AVA designed with elliptical curvature edges , these edges work to improve S_{11} reading at low frequency and enhances the reading in high frequency , as shown in figure 4.4 (a) proposed AVA has S_{11} reading < -10 dB at whole frequency band .

According to this readings the elliptical curvature edges are most important parameter for design this AVA with good S_{11} readings at low frequencies.

In figure 4.4.(b) S_{11} reading for proposed Antenna at T=15 mm is better than at T=5.5 and T=8 mm , as showed in the figure at T=5.5 and 8 mm the S_{11} reading is same at whole frequency band , but when T= 15 mm the reading is improved at low frequency at 3 GHz to be less than -10 dB.

Proposed AVA with this design with dimensions has the best radiation pattern and S_{11} parameter reading.

All factors work together to apply this requirements, it depends on each others The radiation pattern in 3D at low and high frequency are presented in figure 4.5 . The antenna produce symmetrical antenna pattern in H-plane and E-plane[11] .



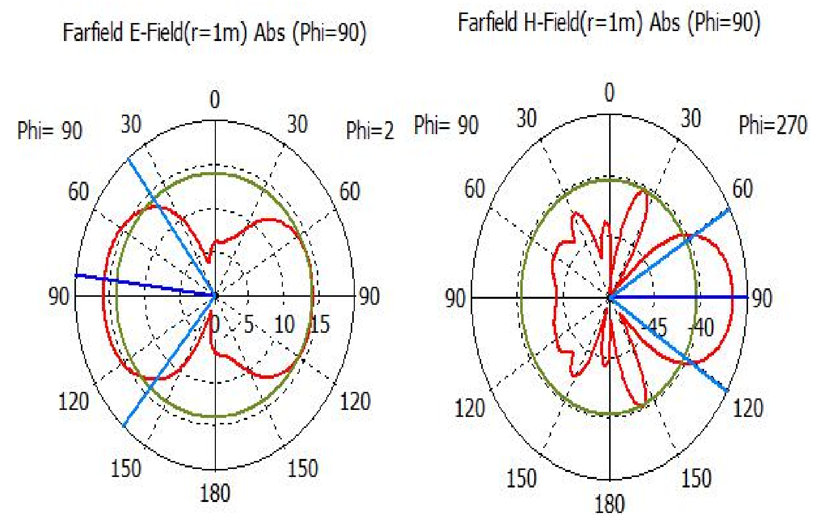
(a) (b) (c)

Figure 4.5: simulation radiation pattern of the antenna . (a) 3GHz. (b) 8.9 GHz. (c)15 GHz.

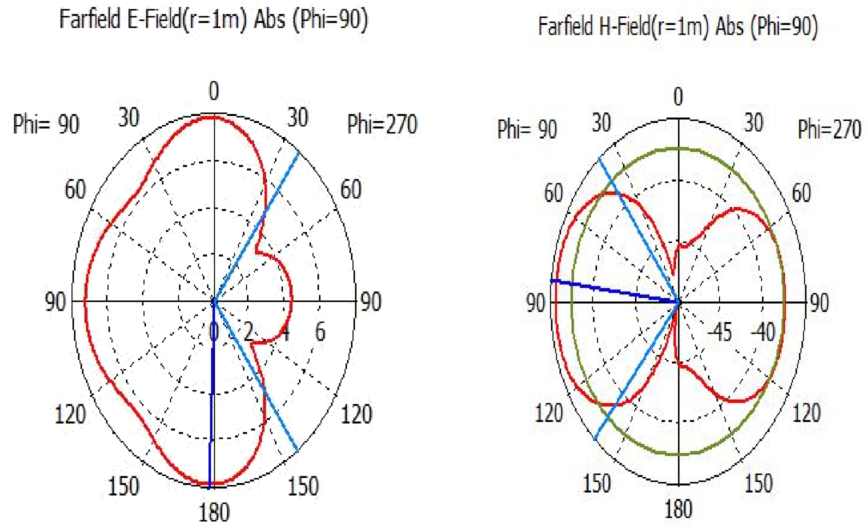
Table 4.2. recognize the antenna compression with other antennas literature according to The design and lens and the gain improvement with operational frequency.

Table 4.2: Comparison of Antenna Characteristic and literature.

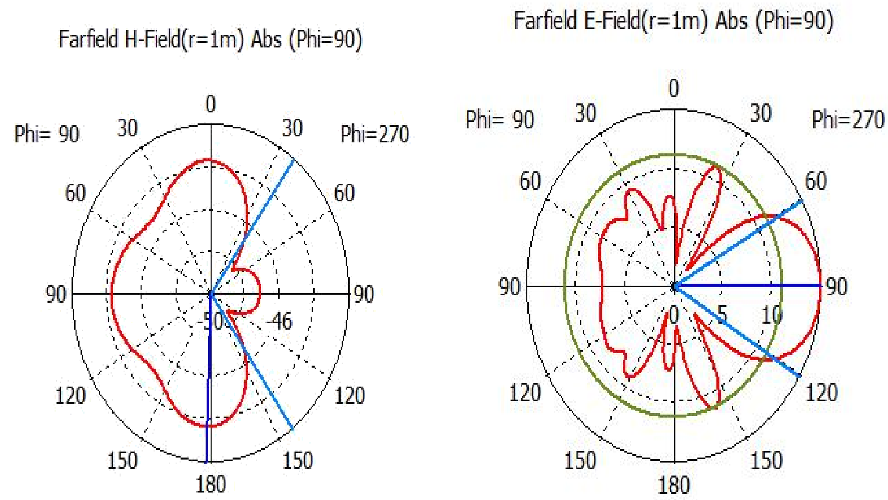
REF.	**Dimensions (mm^3)**	**Frequency (GHz)**	**Relative Permittivity and material**	**Freq(GHz) →Gain(dB)**
[30]	178×140×251	0.83-12.8	2.2 AN-79	0.83→ 0 12 → 10
[31]	96×50×3.15	3-18	2.55 ArlonAD255	3 → 5 18 → 14
[32]	130×76×1	3.1-14	4.2 FR4	3.1→ 5.8 10→ 7.26
[33]	40×90×0.508	3.8-40	3.3 RO4003C	3.4→ 8 19.5→ 12.8
This work	70×50×0.76	2.8-15	3.55 Taconic	3 → 5.2 15 → 9.9



(a)



(b)



(c)

Figure 4.6: Antenna pattern of the antenna. (a)3 GHz . (b) 8.9 GHz . (c) 15 GHz.

Figure 4.6. represent the radiation pattern of the antenna H-Field and E-field , it appears that at high frequency the radiation pattern is better than at low

frequency, for instance at 15 GHz E-Field is 15 dBV/m in direction of 90^o and with angular width 60^o ,whereas the angular width is the distance between the two half power beam width (HPBM) , for H-Field is -36.6 dBA/m at the same frequency in the direction in the same of E-Field.

4.2 Double Slot Antipodal Vivaldi Antenna (DSAVA).

DSAVA is a technique used to enhance directivity or radiation pattern, in this design the antenna is fed by 50 ohm coplanar wave guide and designed by FR4 substrate material of dielectric constant 4.3 . The first step is to choose the dimension of the antenna and the thickness of the substrate material after that we added some additional technique that assist to enhance the radiation characteristics like dielectric lens, the antenna is simulated by CST Suit Studio program 2018 , and fed by 50 ohm coplanar wave guide.

Figure 4.7 (a) represents the geometry of the proposed AVA with dimensions of 50×70 mm^2 on a substrate of FR4 of dielectric constant of 4.3, tangent loss of 0. 025 and 1 mm height. The antenna consists from one plate and two slots at front and back sides the thickness of slots are 0.035 mm.

Actually , the elliptical shape is added to enhance some parameters , but in this design unfortunately, this technique did not add any improvement to results as in figure 4.7 .(b). To enhance the directivity and radiation pattern a dielectric lens is added to design as shown in figure 4.7 .(c), whereas a dielectric lens play good role to limit their wide spread utilization. They are costlier due to complex fabrication process .

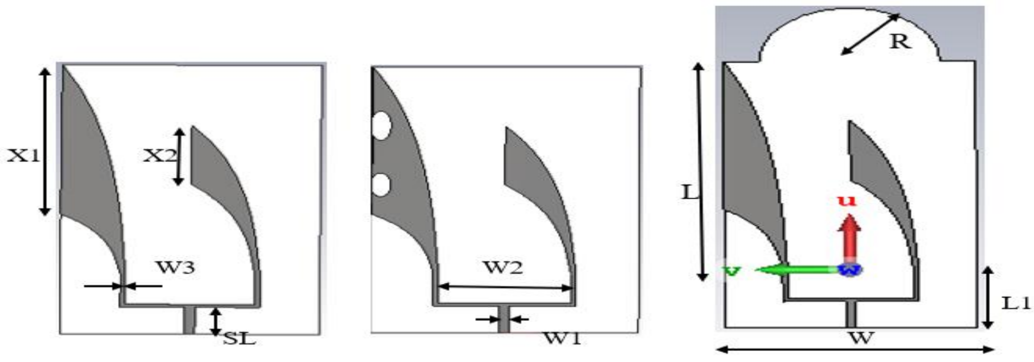


Figure 4.7: configuration of DSAVA . (a) Typical DSAVA. (b) DSAVA with elliptical shape . (c) Proposed DSAVA.

Figure 4.8 represents the S_{11} parameter reading of these designs , according to the figure 8 the DSAVA without lens has a good reading at low frequencies whereas the reading < -10 dB starts at 3.5 GHz and still until whole frequency band , but when dielectric lens is added figure 1 (c) the reading has a little enhancement at low frequency where the reading still starts at 3.5 GHz and stay until whole frequency band.

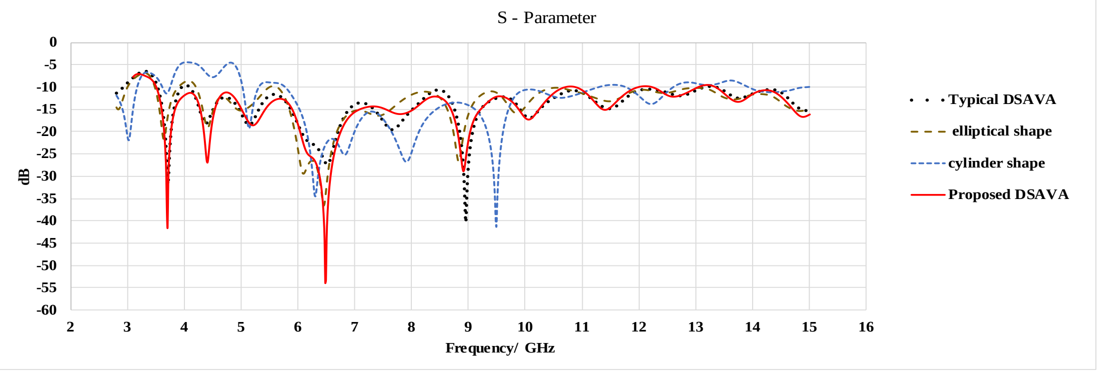


Figure 4.8: S_{11} simulations . Typical DSAVA , elliptical shape, cylinder shape and Proposed DSAVA.

When elliptical shape is added to design figure 4.7 (b), the S_{11} reading was not affected at low frequency it means this technic dose not has enhancement at S_{11} reading in DSAVA design.

In the same way the cylinder shape is added as another technic , but this method gave a negative results at low frequencies where the reading goes above -10 dB from 3.5 to 6 GHz as in figure 4.7.

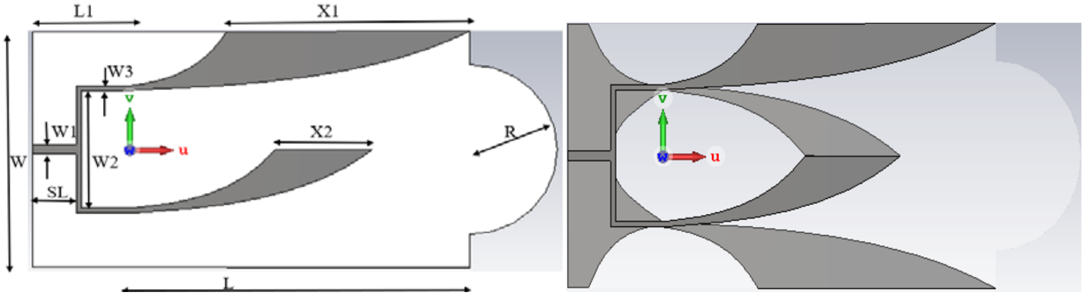


Figure 4.9: (a) Proposed DSAVA , (b) Proposed DSAVA two slots.

Figure 4.9. represents the Proposed DSAVA the dimensions of the antenna represented in Table 4.3, the dielectric lens is used to enhance various characteristics of the Vivaldi antennas, is used to enhance gain of the antenna as represented in figure 4.11, in order to the lens shape and its dielectric constant are most important parameter in its design [31-33].

With shape, dielectric constant of the lens works an important job in the antenna's specifications. High dielectric constant supplies high gain and more beam directed.

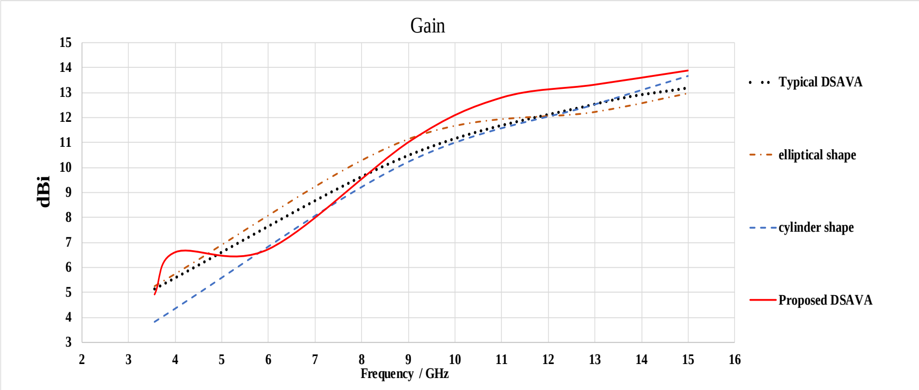


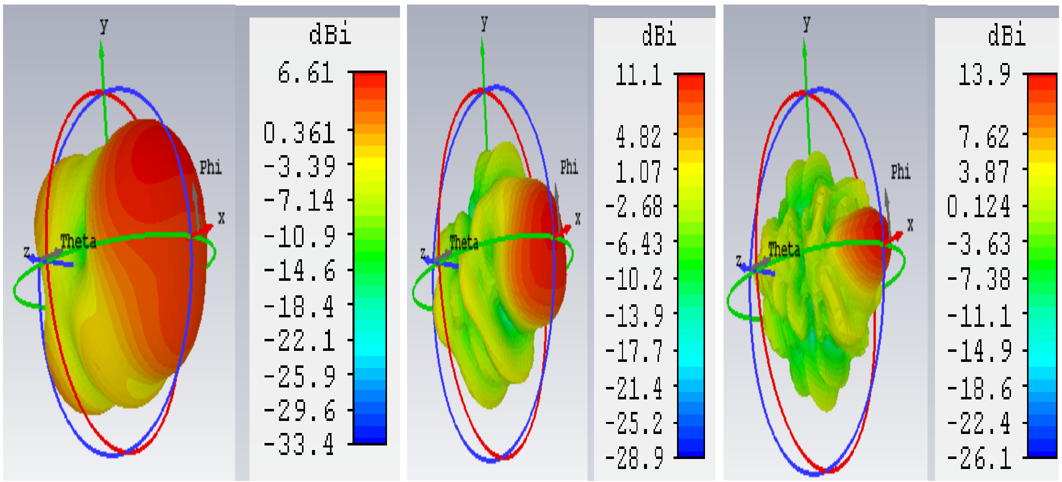
Figure 4.10: Kimulated gain. Typical DSAVA , elliptical shape , cylinder shape , Proposed DSAVA .

Table 4.3: Proposed DSAVA Dimensions.

Parameters	*Value (mm)*	*Parameters*	*Value(mm)*
L	70	W	50
L1	20	W1	2
X1	50	W2	25
X2	20	W3	1
SL	9	R	18

Proposed DSAVA with this dimensions and this design has the best radiation pattern and S_{11} parameter reading at low and high frequency , all parameter work together to achieve this results.

The radiation pattern in 3D at low and high frequency are presented in figure 4.11 . The antenna produce symmetrical antenna pattern in H-plane and E-plane[31] .



(a) (b) (c)

Figure 4.11: Simulation radiation pattern of the Proposed DSAVA (a) 4 GHz , (b) 9.05 GHz , (c) 15 GHz.

Table 4.4 recognize the antenna compression with other antennas literature according to the design and lens and the gain improvement with operational frequency.

Table 4.4: Comparison of Antenna Characteristic and literature

REF.	Dimensions (mm^3)	Frequency (GHz)	Relative Permittivity and material	Freq(GHz) →Gain(dB)
[30]	178×140×251	0.83-12.8	2.2 AN-79	0.83→ 0 12→ 10
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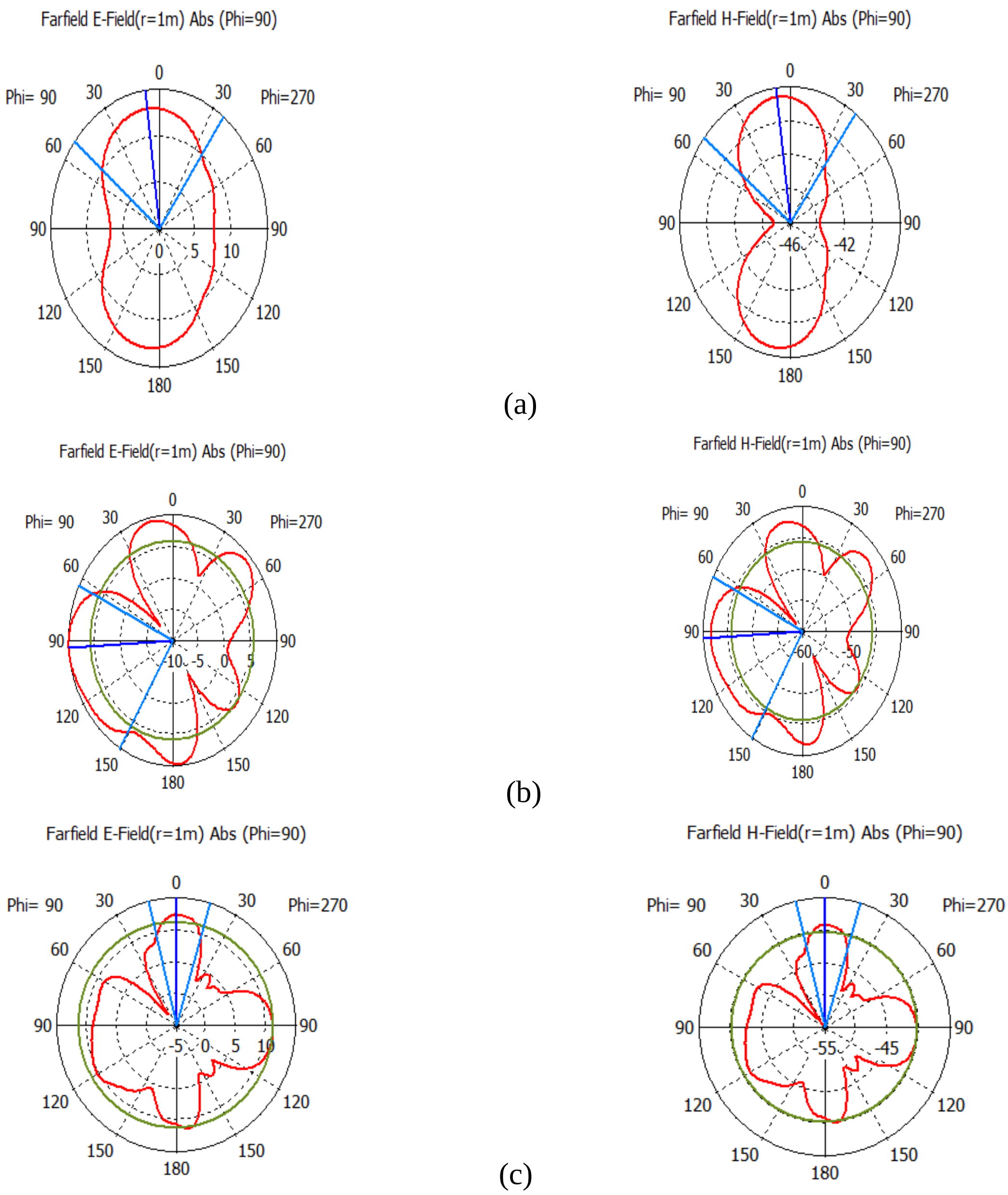
[31]	96×50×3.15	3-18	2.55 ArlonAD255	3→ 5 18→ 14
[32]	130×76×1	3.1-14	4.2 FR4	3.1→ 5.8 10→ 7.26
[33]	40×90×0.508	3.8-40	3.3 RO4003C	3.4→ 8 19.5→ 12.8
This work	70×50×1	3-15	4.3 FR4	4→ 5.57 15→ 10.3



E-Field pattern H-Field pattern

Figure 4.12: antenna pattern. (a) 3.55 GHz . (b) 9.05 GHz . (c) 15 GHz.

Figure 4.12. represents the radiation pattern H-field and E-Field of the antenna at different frequencies , we notice that at high frequencies the radiation pattern is better than at low frequencies , in comparison of the radiation pattern in DSAVA is better than in AVA.

4.3 CST Studio Suite

The CST Studio Suite design environment is common across all the modules. Comprising a 3D interactive model tool and a layout tool, the electromagnetic

(EM) design environment combines a pre processor for the solvers, post-processing tools tailored to industry needs, and an intuitive user interface for model construction and solver set-up.

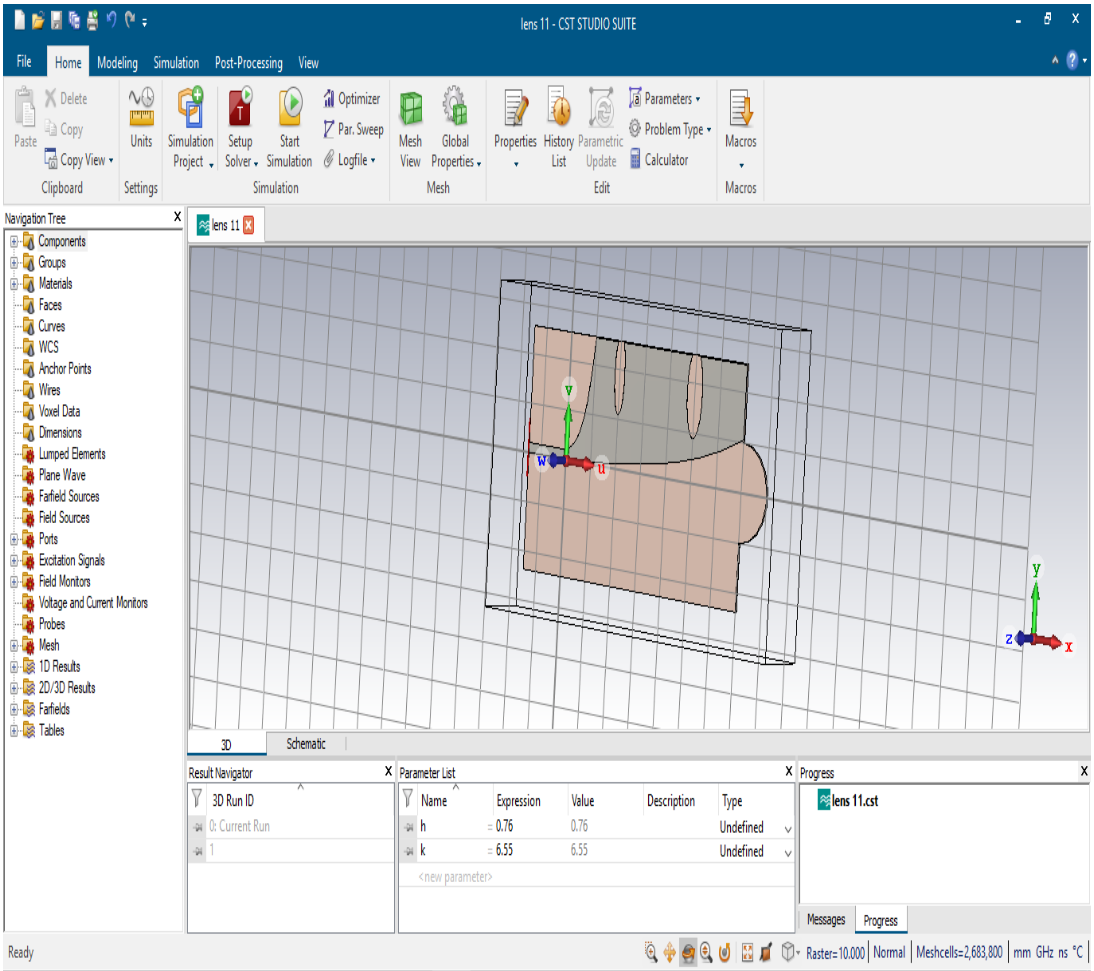


Figure 4.13: CST Studio 3D interactive modeling.

The two antennas are simulated , each one in different dimensions , different substrate material and different shape , the methodology and results are discussed .

5. CONCLUSION

This thesis was about Ground Penetrating Radar (GPR) is a radar which detects objects under the ground . The GPR system usually consists of receiving and transmitting device , transmitter connected with a source, and receiver connected with signal processing. The antennas type and antenna's efficiency is also an important part of the system. So, the antenna plays an important role in GPR .

GPR used in UWB application, therefor GPR required an UWB Antenna to design its system so, after a comparative study between all types of antenna as in chapter 3 and the specification of each type, one of the best UWB antennas has been used to build GPR system is Vivaldi Antenna , it refer for its end-fire radiation , moderate gain, small dimensions, and easy fabrication.

Two types of Vivaldi Antenna are designed in this thesis, one is Antipodal Vivaldi Antenna (AVA) and other one is Double Slot Antipodal Vivaldi Antenna (DSAVA) , each one of these antennas has some properties different than other one , starting from antenna shape until to the results as in chapter 4.

In this work , AVA with exponentially dielectric lens and elliptical curvature edge for GPR application has been introduce. The proposed geometry presents an introduce in radiation pattern of an antenna . working a dielectric lens enhance the radiation characteristic than when it hasn't introduced . Moreover, elliptical curvature edges improved the return loss (S_{11}) characteristics at low frequency , the substrate material that used is Taconic and the highest radiation pattern is 10.3 dBi at 15 GHz , although it has a good reading of radiation pattern at low frequency 7.4 dBi at 3 GHz. So, this proposed is a good candidate for UWB application and GPR.

In another hand , DSAVA is proposed with dielectric lens , DSAVA has an advantage because it produced to enhance directivity and radiation pattern , it is appear in the radiation characteristic is better than in AVA , in additional of dielectric lens tend to enhance radiation characteristic especially at high frequency.

The substrate material is FR4 with dielectric constant 4.3 , and the highest radiation pattern is 13.9 dBi at 15 GHz , in another side at 4 GHz is 6.7 dBi .

The presented structure proves stable radiation characteristics with the all range of frequencies, which makes it a good candidate for GPR and UWB application.

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RESUME

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