DESIGN OF A WIDEBAND ANTIPODAL VIVALDI ANTENNA OPERATING FROM 800 MHZ TO 6 GHZ

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DESIGN OF A WIDEBAND ANTIPODAL VIVALDI ANTENNA

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This thesis is dedicated to my friends, Landry, Nabrice, Desiré, Henri Joel, Yannick, Euphrem, Hamed, Stephane and Amanda who have always been a constant source of support and encouragement during the challenges of my whole university life. Also, to my sisters Angela and Titi, whom I am truly grateful for having in my life. This work is also dedicated to my parents, who have always loved me unconditionally and whose good examples have taught me to work hard for the things that I aspire to achieve.

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I would like to extend a word of thanks to all my friends all my friends, thank you for your understanding and encouragement in many, many moments of crisis. (our friendship makes my life a wonderful experience. I cannot list all the names here, but you are always on my mind.

I am grateful my parents and sisters, whose unlimited love and support has made this effort possible.

Finally, I thank Almighty God for always being there to guide me through thick and thin.

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LIST OF SYMBOLS AND ABBREVIATIONS

APVA	Antipodal Vivaldi Antenna
UWB	Ultrawide band
FCC	Federal Communications Commission
TSA	Tapered Slot Antenna
RF	Radio Frequency
FNBW	First-null Beamwidth
HPBW	Half-Power Beamwidth
BAVA	Balanced Antipodal Vivaldi Antenna

ABSTRACT

Development of UWB antennas has gained tremendous impetus since the Federal Communications Commission approved the unlicensed use of UWB technology (3.1 – 10.6 GHz) for commercial applications [2]. In the design of UWB antennas, the challenges that are mostly encountered include good impedance matching, miniaturized antenna size, omni-directional radiation pattern and low production cost. Ultra-Wideband (UWB) has many advantages that make it attractive for a variety of applications such as microwave imaging, wireless communications, ground penetrating radars, remote sensing and phased arrays.

This thesis is focused on the design of an Antipodal Vivaldi antenna (APVA) operating from 800 MHz to 6 GHz using standard low cost FR4 substrate and copper as the patch of the antenna. The key parameters to observe with this design included reflection coefficient (S11), gain, radiation pattern, realized gain and directivity of the antenna. The results of the performances of APVA are only covered by the simulation of the design using CST Studio Suite Software. The selection of the sizes and the materials will be discussed in this thesis. The target application for this antenna imposes the value of return loss to be less than -10 dB at starting frequencies (800MHz)

1.INTRODUCTION

In developing of communication system nowadays, ultra-wideband (UWB) antennas are widely designed and developed for medical and military purposed. The antennas usually being proposed in radar application for detect the images in greater accuracy and more efficient. Referring to the Federal Communications Commission (FCC) standards, an antenna is known as UWB antenna as it is reaching the range of spectrum from 3.1- 10.6 GHz. Therefore, such antenna must be compact in size as well as less weight for portability at both transmitter and receiver.

The Antipodal Vivaldi Antenna (APVA) is having the suitable features suit the characteristics of the UWB design characteristics as it is classified as Tapered Slot Antenna (TSA). It is explained as an end-fire travelling wave antenna which exhibits a wide beam width and moderately high directivity. Besides that, antipodal Vivaldi antenna has some other advantages such as low lobe level, high gain and adjustable beam width. The stripline tapered notch is the first TSA presented in the industry.

For the design of this APVA antenna, constraints have been set on the type of conductor and substrate material to be used in order to minimize the production cost. It was then imposed to use the FR4 as substrate and copper as metal for this design. With such characteristic, the objective was to obtain a good behavior of the antenna characteristics between 800 MHz to 6 GHz**.**

1.1 Objective

a) To design the Antipodal Vivaldi antenna (APVA) by taking in account the material constraints and the targeted performance between 800MHz to 6 GHz.
b) To simulate and analyze the reflection coefficient, gain, radiation pattern, realized gain and directivity over the designed APVA.
c) To optimize the antenna parameters in order to match the targeted performance.

1.2 Scope

The scope of this project is to cover the design of the antipodal Vivaldi antenna by varying the dimension parameters of the antenna. Since the antenna design is focused at a range of frequency from 800 MHz to 6 GHz the optimization of the performance in that range is going to through varying antenna length, thickness of patch, width of flares and stripline as parametric study. It is crucial so that different number of results can be obtained in order to get the most optimized version of the design. Therefore, before proceeding with the project a parametric study is made to get the optimized design of the antenna.

The design and simulation of this APVA is made in CST software suite.

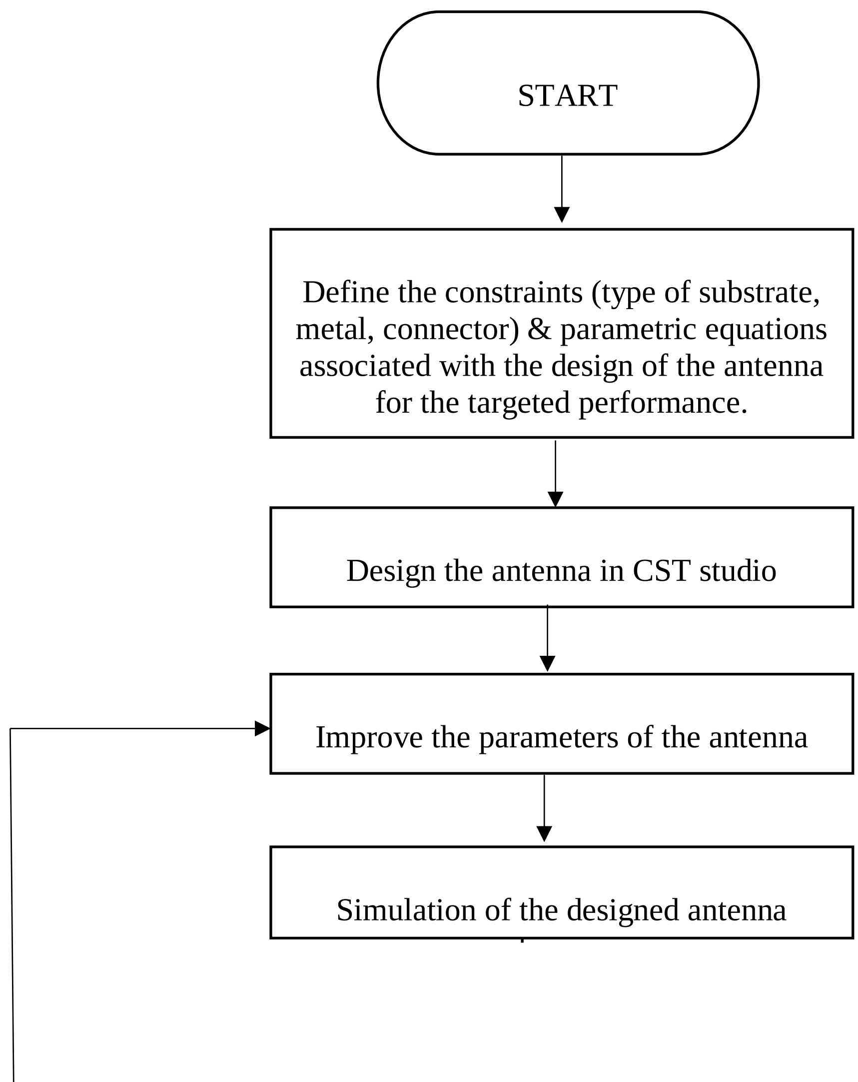
1.3 Methodology

The flow of this thesis starts with a literature review of the related topics. The literature is done by referring to various books, technical journals, articles, websites as well as technical reports related to the APVA. This preliminary stage of literature review is done in order to have a better understanding of the parameters and design of the antenna in order to ease the actual design process.

Then comes the design of the antenna followed by the simulations at the different frequencies of interest. The antenna parameters are then observed and measured.

The last stage involves tuning the antenna by varying the various parameters(dimensions) in order to meet the targeted specifications. The design and simulation of the antenna is entirely done using CST Microwave Studio as it provides a dynamic definition of parameters during the design.

1.4 Flowchart of the project



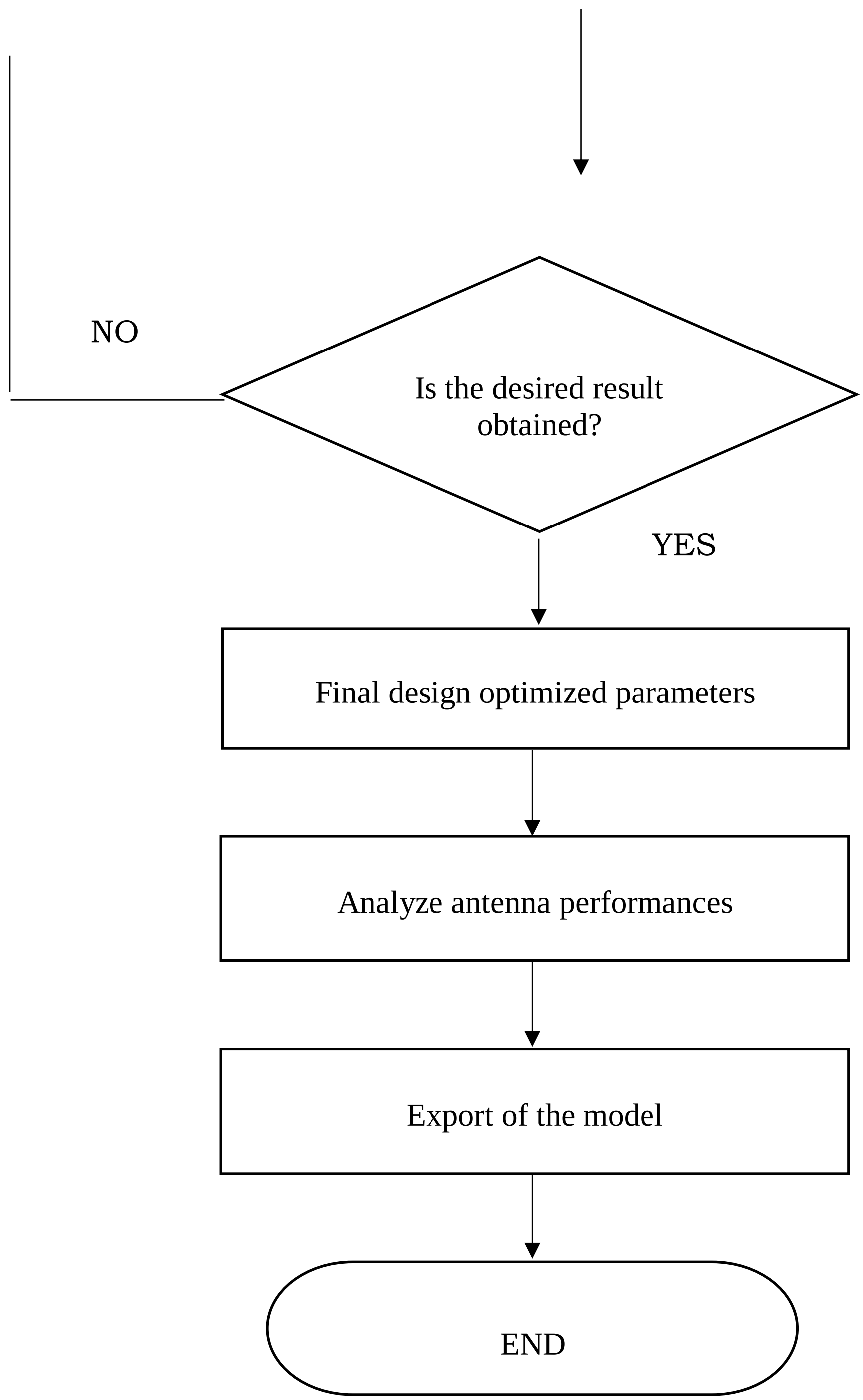


Figure 1.1: Flowchart of the project

1.5 Thesis outline

This thesis is consisting of five chapters that covered all the research works of the design of APVA.

a) Section 1 introduces the surface of the project. This includes a brief introduction of the APVA design. At this part of the thesis, the problems statements, objectives of the project, scope of works, methodology, and flow chart of the methodology used in the project are also stated.

b) Section 2 is the literature review for the design. This chapter is concerned about the study, research and the design technique which are related to this project.

c) Section 3 describes the complete methodology that be used in the project implementation. The methodology discusses about the design and simulation of the APVA by using CST Software. The related parameter such as gain, realized gain and directivity will be discussed thoroughly in this section.

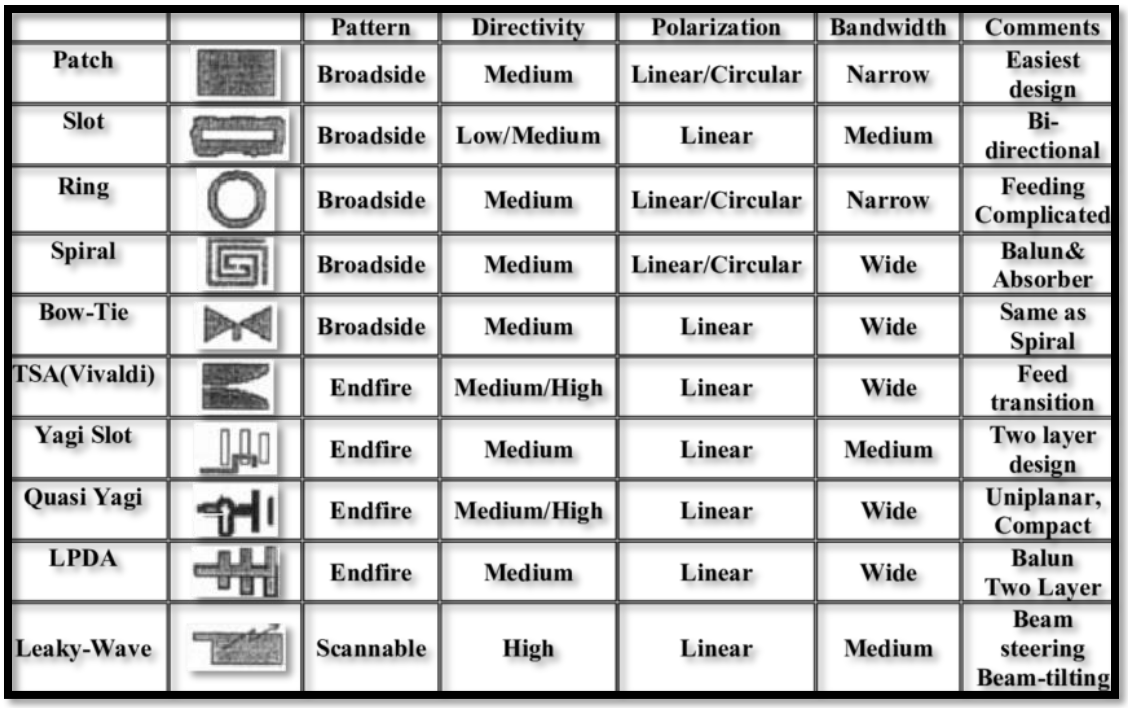
d) The findings of the final design of APVA are deliberated at section 4. All the results of the simulations will be observed and discuss in this chapter. The results will also be recorded and explained at the chapter.

e) Lastly, section 5 will sum up the conclusion of the processes which occurred along the thesis. Hence, this part will also conclude and provide the suggestion for future research and development on related project.

1.LITERATURE REVIEW

2.0 Introduction

Antennas are the main components of most of the wireless communication systems. An antenna is a transducer that converts radio frequency (RF) fields into alternating current or vice versa. Referring to the IEEE Standards, the term of the antenna is defined as a means of radiating or receiving of the radio waves at free space. There are lots of antenna parameters that can be measured. Those parameters involve the return loss, the gain, the radiation pattern, the Half-Power Beamwidth (HPBW), the First-null Beamwidth (FNBW), the directivity, and the efficiency. These parameters are very important as they are used to characterize the types and the performance of the antenna. There are various types of antenna commonly used in the industry. Each antenna is designed according to its application. The APVA belongs to the family of planar antennas. Figure 2.1 below shows a quick overview of planar antennas.



		Pattern	Directivity	Polarization	Bandwidth	Comments
Patch		Broadside	Medium	Linear/Circular	Narrow	Easiest design
Slot		Broadside	Low/Medium	Linear	Medium	Bi-directional
Ring		Broadside	Medium	Linear/Circular	Narrow	Feeding Complicated
Spiral		Broadside	Medium	Linear/Circular	Wide	Balun& Absorber
Bow-Tie		Broadside	Medium	Linear	Wide	Same as Spiral
TSA(Vivaldi)		Endfire	Medium/High	Linear	Wide	Feed transition
Yagi Slot		Endfire	Medium	Linear	Medium	Two layer design
Quasi Yagi		Endfire	Medium/High	Linear	Wide	Uniplanar, Compact
LPDA		Endfire	Medium	Linear	Wide	Balun Two Layer
Leaky-Wave		Scannable	High	Linear	Medium	Beam steering Beam-tilting

Figure 2.1 Types of planar antennas

2.1 Basic parameters of antenna

For describing the antenna's performance, various defining parameters need to be discussed first. These parameters are quoted from *the IEEE Standard Definitions of Terms for Antennas*.

2.1.1 Radiation Pattern

It basically defines the radiation behavior of antenna with respect to space coordinates. The radiation pattern is defined in its polar coordinates which are calculated at far field. Power flux density, radiation intensity, directivity, field strength and polarization are some of the properties that can be evaluated by studying radiation pattern. Field Pattern is generally described as a linear scale plot that evaluates the amplitude of either magnetic or electric field in angular space whereas Power Pattern (Linear Scale) evaluates the squared value of magnitude of either magnetic or electric field in angular space.

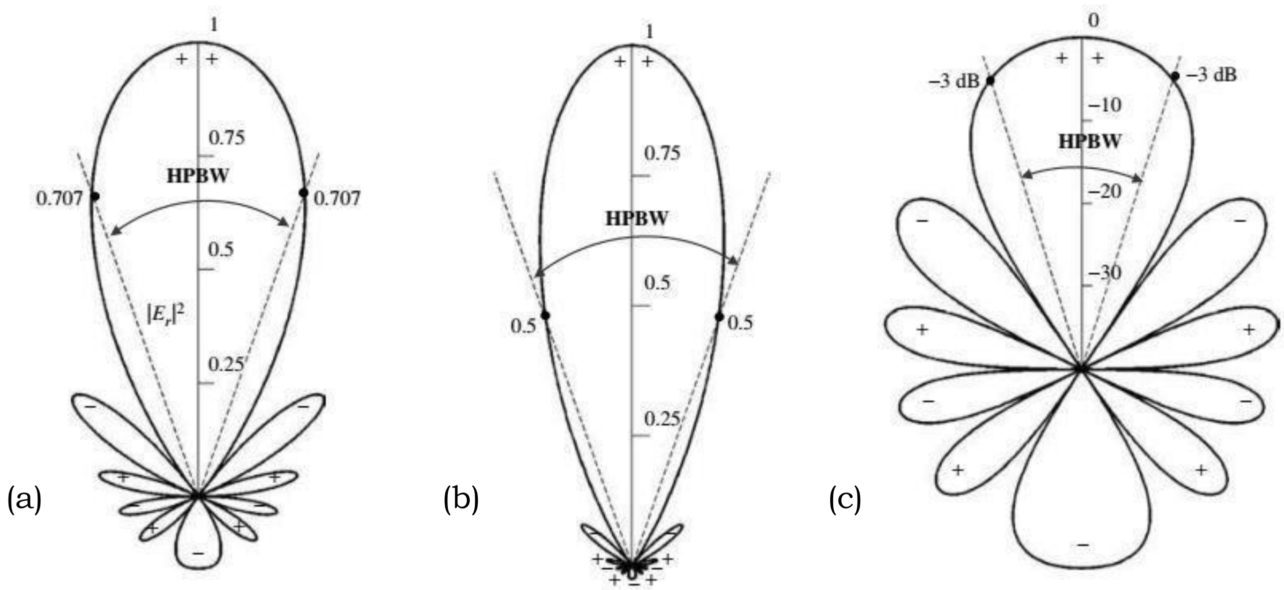


Figure 2.2 Radiation pattern

(a) Field pattern described in linear scale (b) Power pattern described in linear scale (c) Power pattern described in dB

Power Pattern (logarithmic scale dB) evaluates either the magnetic or electric field in

decibels, as a multinomial of angular space.

2.1.2 Field regions

The space encompassing an antenna is sub-categorized mainly into three

regions:

(a) Reactive Near-Field

(b) Radiating Near-Field (Fresnel)

(c) Far-Field (Fraunhofer)

The space just after the boundary of antenna is defined as Reactive near-field

region.

This region exists for a distance of $R < 0.62\sqrt{D^3/\lambda}$ where λ is the wavelength and

D is dimension of antenna.

Radiating near-field (Fresnel) region is defined as “The space wherein the

radiation

field is mostly dominated and where the angular field distribution is a function

of the distance from the antenna. This region exists at $0.62\sqrt{D^3/\lambda} \leq R < 2D^2/\lambda$.

The space where the angular field distribution is independent of the distance

from the antenna is termed to be Far-field (Fraunhofer) region. This region

extends for $R \geq 2D^2/\lambda$.

2.1.3 Radiation Pattern Lobes

Diverse forms of radiation pattern are mentioned as lobes, which can be further categorized as major, minor, side and back lobes. A radiation lobe is a chunk of radiation pattern allied with relatively weak radiation intensity. The radiation lobe encompassing the orientation in direction of maximum radiation is said to be Major Lobe. All other lobes except the major lobe is said to be Minor Lobe. The lobe whose axis is exactly opposite to the major lobe is termed as Back Lobe.

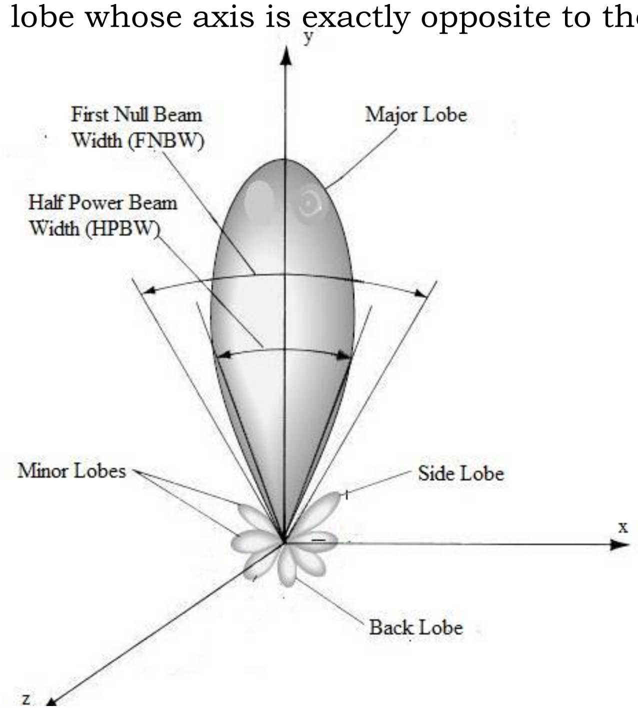


Figure 2.3: Radiation lobes and beamwidth of an antenna pattern.

2.1.4 Beamwidth

The beamwidth of radiation pattern can be determined by evaluating the angular separation between two homogeneous points in the major lobe. Basically, beamwidth is categorized as HPBW and FNBW. The angular separation at which the radiation intensity is one half of the major beam is stated as HPBW whereas the angular separation between the first nulls is stated as FNBW as shown in Figure 2.2

2.1.5 Radiation Intensity

Radiation intensity is termed as the power emitted by an antenna in a specified direction
per unit solid angle. It is a far-field parameter which can be evaluated by the product of
radiation density with the square of the distance. It can be expressed mathematically as

$$U = r^2 W_{rad}$$

2.1.6 Directivity

Directivity is a dimension less quantity and can be defined as the total radiation intensity in a specific direction divided by the radiation intensity averaged over all directions. The average radiation intensity can be evaluated by dividing total power radiated by 4π.

$$D = 4\pi U / P\_rad$$

2.1.7 Gain

Gain of an antenna is defined as the ratio of the radiation intensity, in a particular direction, to the radiation intensity which can be obtained if the power accepted is
radiated isotopically.

$$G = 4\pi U / P\_in$$

2.1.8 Antenna Efficiency

Antenna efficiency is the ratio of gain to directivity.

$$\eta = G / D$$

2.1.9 Polarization

Polarization is a parameter which is used to study the time varying directive nature of electric or magnetic field vector. It can be subcategorized as linear, circular and elliptical.

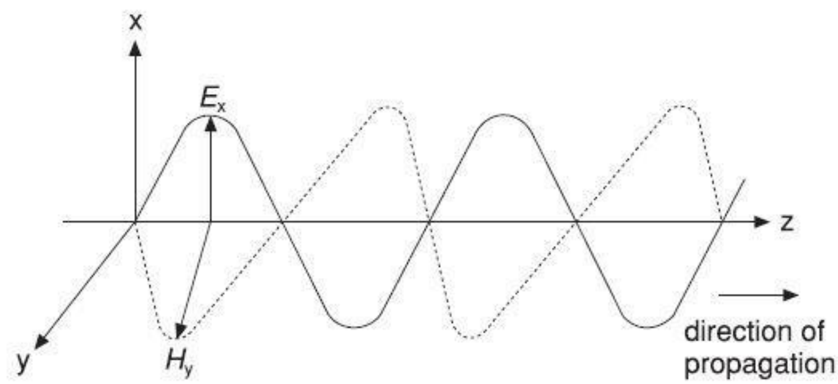


Figure 2.4: Orientation of E and H component for an em wave.

If the electric or magnetic field vector always point to a specific direction or line, then the behavior is termed as linear polarization. Similarly, if the electric or magnetic field vector traces the pattern of a circle then this behavior is said to be circularly polarized whereas if the pattern is elliptical in nature then it is said to be elliptically polarized.

2.1.10 Microstrip Transmission Line

Microstrip is an electrical transmission line. It is implemented on printed circuit

board and used to transmit em signals. Microstrip comprises of conducting strip on a ground plane.

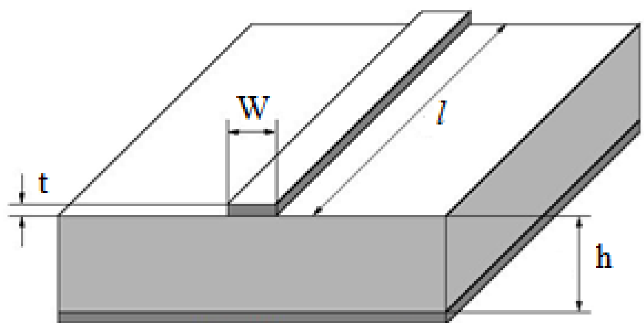


Figure 2.5: Block diagram shows a schematic prototype for designing a microstrip feedline.

The impedance of the transmission line depends on the dimension of the microstrip line

which is guided by the following equations [2]:

For $W/h \leq 1$, $$Z_0 = \frac{60}{\sqrt{\varepsilon_e}} \ln\left(\frac{8h}{W} + \frac{W}{4h}\right).$$

For $W/h \geq 1$, $$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_e}\left[\frac{W}{h}+1.393+0.667\ln\left(\frac{W}{h}+1.444\right)\right]}.$$

If it is required to evaluate the dimensions of transmission line for a particular impedance value than following equations can be taken into account:

$$ {}^{W}/_{h} < 2, \qquad W = h\frac{8e^{A}}{e^{2A-2}}. $$

$$ {}^{W}/_{h} > 2, \qquad W = \frac{2h}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right]. $$

Where $A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right).$ and $B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}.$

The effective dielectric value '*εe*' varies according to the design parameters of microstrip i.e. the height '*h*' of the substrate and the width '*W*' of the transmission line

which can be clearly explained by following equation:

$\varepsilon_e = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12h/W}}\right).$ where ε_r is the dielectric constant value of conduct strip.

2.2 The Vivaldi antenna family

What's in the Name?

Mr. Antonio Vivaldi introduced a musical instrument. On seeing the structure of that instrument Gibson got an idea for his antenna design. He was so much influenced by the structure of the musical instrument that he gave the name of the introducer to his antenna design.

The Vivaldi antenna was first introduced by Gibson in "The Vivaldi aerial" [ref]. Since then, it is widely used in different applications such as microwave imaging, wireless communications and ground penetrating radars. The Vivaldi antenna is a special kind of aperiodic travelling wave antenna. Here two words are mentioned to explain the behavior of Vivaldi antenna i.e. aperiodic and travelling. Aperiodic word emphasizes that the slot used in the design is aperiodic in nature whereas traveling emphasizes that the em wave will travel into the slot before leaving the antenna structure. Hence the design comprises of an exponential slot whose guiding equation for the curve can be expressed as

$$y = \pm\, c_1 e^{Rx} + c_2$$

Where, R is the exponential factor. The beamwidth of the Vivaldi antenna is affected by this power factor whereas c_1 and c_2 are constants. The design proposed by Vivaldi shows a significant improvement in antenna's performance parameters such as efficiency, gain, bandwidth and directivity.

In all of them, traveling wave propagate on the inner edges of the fares which is the main mechanism for radiation. So, exponentially tapered fare is the unique specific feature of this work which makes the antenna operates over a broad frequency band.

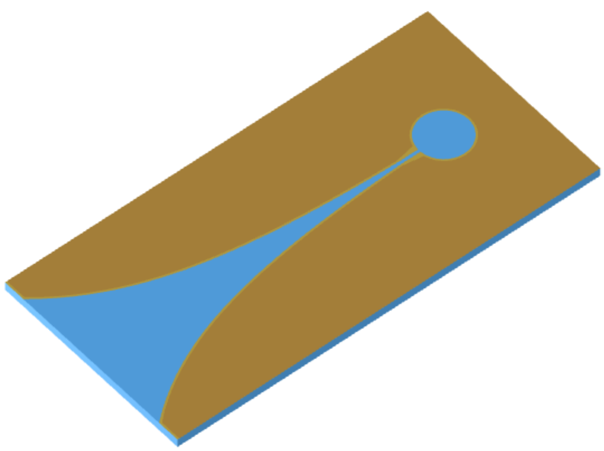
Vivaldi antenna can be manufactured reasonably cheap using PCB technology.

2.2.1 The coplanar or conventional Vivaldi antenna

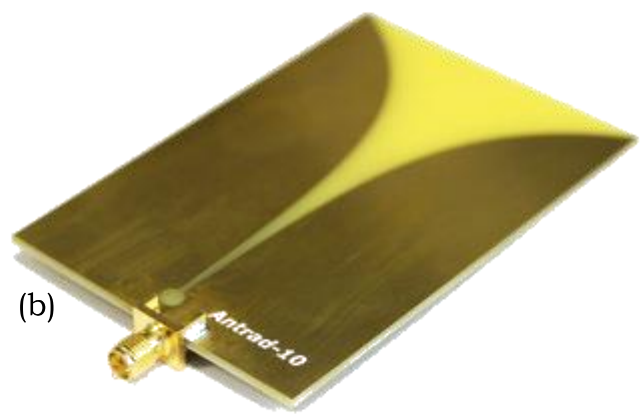
In coplanar Vivaldi antenna, the oldest form of Vivaldi ***Figure x (x)***, two radiator planes are on the same side of the dielectric sheet. The antenna can be fed by aperture coupling from the other side as depicted in this figure. There is another feeding circuit using broadband balloon which is not convenient in many designs due to the length of these balloons and the complexity they might add to the structure.

Vivaldi antennas have considerable attention due to their wideband characteristics, simple integration, tapered slot antennas are used in most of the modern designs. Vivaldi antennas can provide bandwidth up to several octaves. A printed Vivaldi antenna is end fire antennas with tapered step and provides large bandwidth and gain and as well as relatively easy to manufacture on standard printed circuit board substrates. The exponential function will decide the shape of the tapered slot. The traditional way of Vivaldi antenna is generally fed from a slot line. To provide feed to the slot line of the Vivaldi antenna from a stripe line, a micro-strip circuit with transition is very much required. Such kind of transitions can take a number of forms in general, but typically include a quarter wavelength section. This limits overall performance to a few octaves because of the frequency dependent nature of the transition.

(a)



(b)



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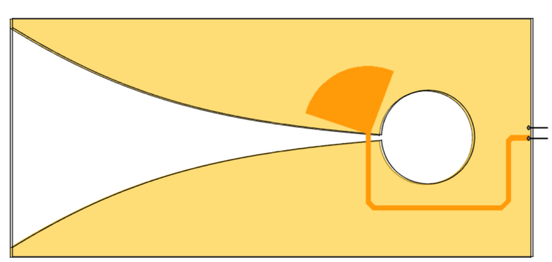
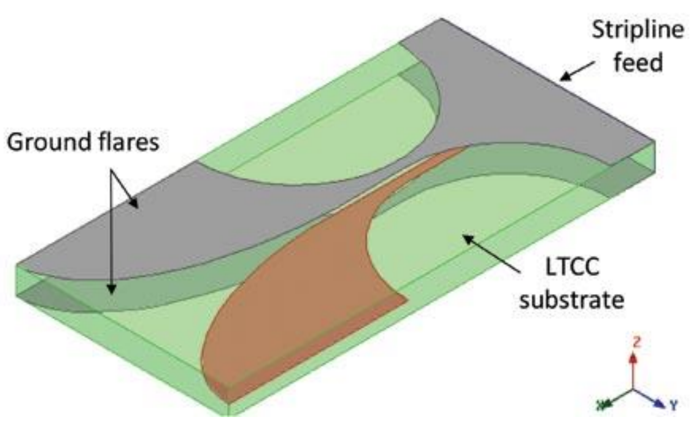


Figure 2.6: The conventional Vivaldi antenna

2.2.2 The Antipodal Vivaldi antenna

The antipodal version of the Vivaldi antenna overcomes the problem of bandwidth limiting transitions.

The APVA antenna uses a clever tapered feed to gradually transform an unbalanced coax microstrip transmission line into a balanced microstrip line. As show this is achieved by gradually reducing the width of the ground plane(a) until it matches the width of the microstrip(b). This then gradually merges into an overlapped slot-line(c) as the throat of the Vivaldi opens up. So long as all these tapers are done gradually with respect to the wavelength they do not generate significant reflections. This feed results in the highest bandwidth as compared to conventional Vivaldi antenna.



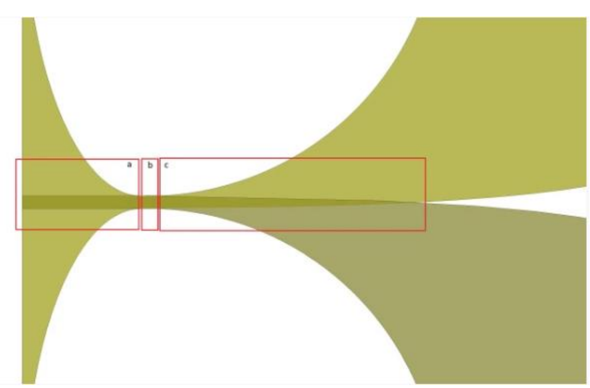
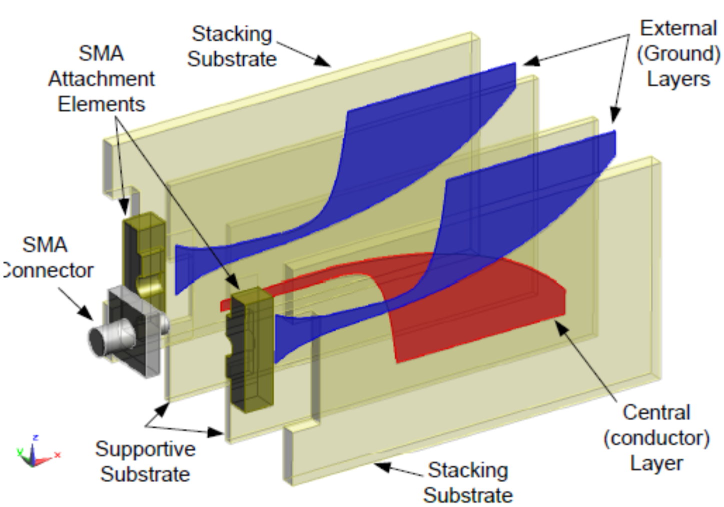


Figure 2.7: Antipodal Tapered Feed

2.2.3 The Balanced Antipodal Vivaldi antenna

A further improvement to the Antipodal antenna aims to improve the polarization purity. The BAVA[1] antenna uses a 3-layer PCB with one element sandwiched between two layers of board. The effect is to make the antenna symmetrical. The downside is that this design requires a very custom PCB stack-up. While 2 layer and 4-layer PCBs are fairly common. 3 layers is very rare. The larger cross-pol rejection is caused by the mirrored ground fins cancelling the cross-polarized electric field component through superposition of opposing vectors.



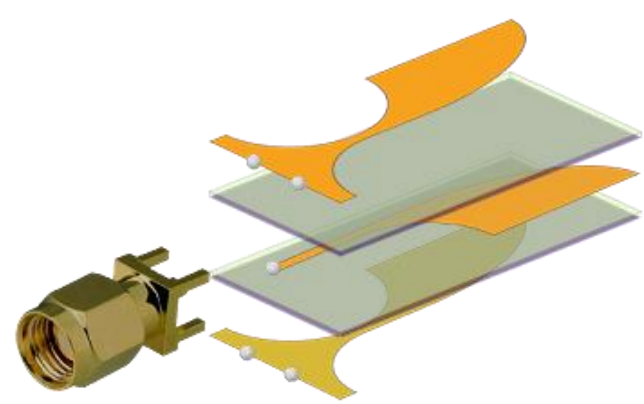


Figure 2.8: Balanced Antipodal Vivaldi antenna

2.3 The Choice of substrate

An important step in the process of designing an antenna is to choose an appropriate substrate. The substrate in micro strip antennas is principally needed for the mechanical support of the antenna. To provide this support, the substrate should consist of a dielectric material, which may affect the electrical performance of the antenna, circuits and transmission line. A substrate must, therefore, simultaneously satisfy the electrical and mechanical requirements, which is sometimes difficult to meet.

The selection of the substrate in the design of antennas should respond to certain criteria:

- **The Dielectric constant Ɛr**

Dielectric constant dictates the effective speed of light(RF) in the medium. Higher values make the antenna look smaller electrically.

In our design, a constraint has been set on the type of substrate hence imposing the low-cost FR4 as the type of substrate and hence the value $\varepsilon r = 4.4$.

- **The Loss Tangent**

The Loss Tangent is a measure of how much energy a material will absorb. A high loss material will reduce the antenna efficiency and power handling capability. The loss is directly proportional to frequency. For the FR4 substrate, the loss tangent is typically around $\tan \delta = 0.02$ and $\tan \delta = 0.025$.

- **The Thickness**

The thickness (along with the Dielectric Constant) will dictate the trace width of a 50Ω transmission line. What we really want here is a material and thickness that lets us choose a sensible width. Too thick and our tracks will be very wide and hard to connect to an RF connector. Too thin and the tracks will become very thin and be overly sensitive to manufacturing errors. Additionally, if our tracks are too thin then the electrical resistance be too great and limit the efficiency and power handling capability. Given the fact that skin effect is very significant in the GHz frequencies, so we really want a large surface area for our tracks if possible. Again, high performance RF substrates will have a carefully controlled thickness, and generally manufacturers that use this understand the importance of controlling this carefully.

- **The Cost**

Cost cannot be ignored. Choosing a purpose made high performance RF substrate will both increase the cost and reduce you supplier options. For this project, a constraint has been set on the FR4 as the substrate material. One of the motivation for this choice is the low cost of the FR4 as well as the wide range of suppliers available.

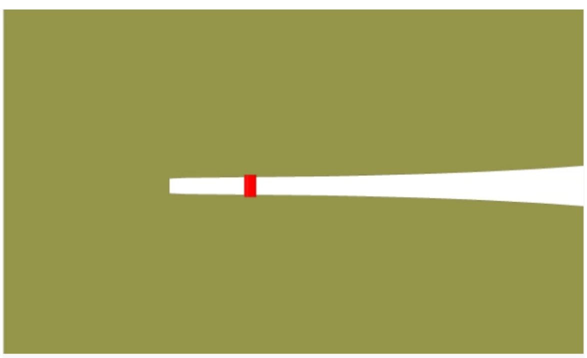
2.4 Feeding techniques

The feed is often the limiting factor of the Vivaldi antenna bandwidth as well as other factors such as polarization purity and efficiency. The aim of the feed design is to efficiently transfer the power from a (normally) coax transmission line into the antenna with as few reflections and little loss as possible. Below, I describe a number of potential feed mechanisms and explain the decisions I made as part of my design.

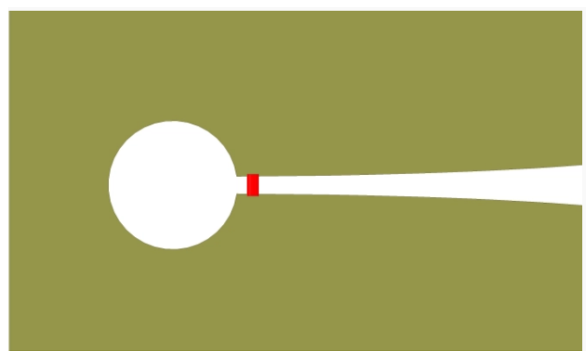
2.4.1 Direct coupled Vivaldi Antenna

In direct coupled Vivaldi, the antenna is fed with a simple coax feed across the slot ***Figure x (x)***. One of the problems with this is that the optimum distance of the feed to the short end of the slot changes with frequency. Hence there is no single correct distance and a compromise must be chosen. This in turn limits the bandwidth.

Often in order to improve the bandwidth [x], the impedance matching and the radiation pattern, a hole a placed at the end of the short ***Figure x (x)***.



(a)



(b)

Figure 2.9: Direct coupled Vivaldi antenna

2.4.2 Microstrip coupled Vivaldi Antenna

As a further improvement frequently used to improve the feed is to use a microstrip coupled fed. In this technique a microstrip transmission line on the other side of the substrate cuts across the slot. Using the microstrip feed allows the designer additional degrees of freedom to tweak the impedance match.

The microstrip lines widely used in microwave PCBs are unbalanced lines, although a Vivaldi antenna requires a feed with a slotline transmission line, which is balanced. The balun required for the unbalanced-to-balanced transformation must operate over a frequency range of at least two octaves, and up to several octaves. Preferably, the balun would be frequency independent.

In order to achieve a transition that has low return loss over a wide frequency band, the impedances of the microstrip line and the slot line must be matched to each other to reduce the reflections. The characteristic impedance of a slot line increases with increasing slot width, so the width of slot line must be selected to be as small as possible to achieve an impedance value close to 50Ω.

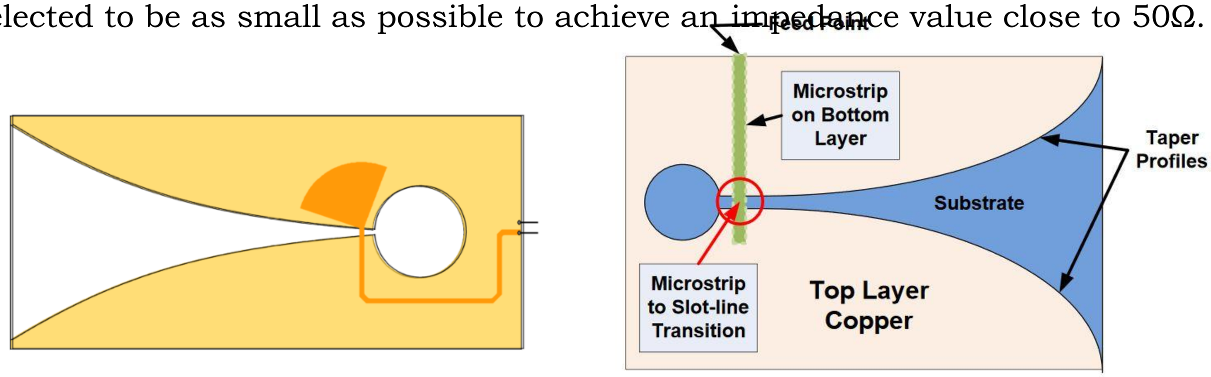


Figure 2.10: Microstrip coupled Vivaldi antenna

2.4.3 Antipodal coupled Vivaldi Antenna

The Antipodal Vivaldi Antenna uses a clever tapered feed to gradually transform an unbalanced coaxial microstrip transmission line into a balanced microstrip line. As show this is achieved by gradually reducing the width of the ground plane(a) until it matches the width of the microstrip(b). This then gradually merges into an overlapped slot-line(c) as the throat of the Vivaldi opens up. So long as all these tapers are done gradually with respect to the wavelength they do not generate significant reflections. This feed results in the highest bandwidth of all the mechanism.

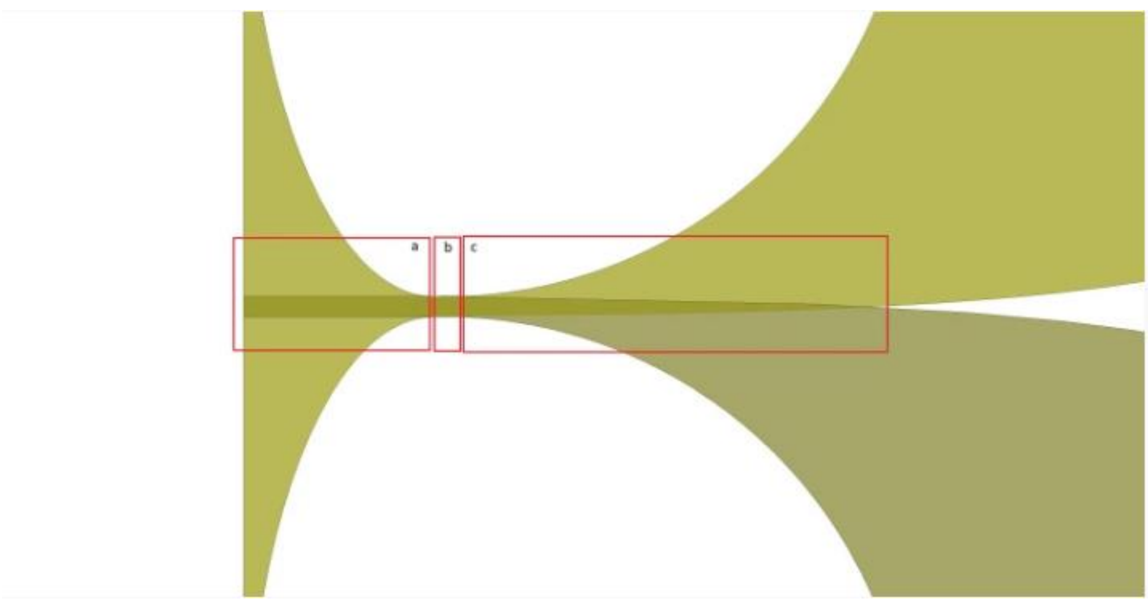


Figure 2.11: Antipodal coupled Vivaldi antenna

2.5 The Principle of Operation

For briefly understanding the operating principle of Vivaldi Antenna, it is required to sub-divide the antenna design into two sections:

i. Propagating section: This section deals with the propagation of em wave from the feed line to the slot of the antenna. The portion in red depicts the em wave travelling from the microstrip feedline to the exponential feedline.

ii. Radiating section: This is the outermost section of slotline after which the em wave leaves the structure of the antenna.

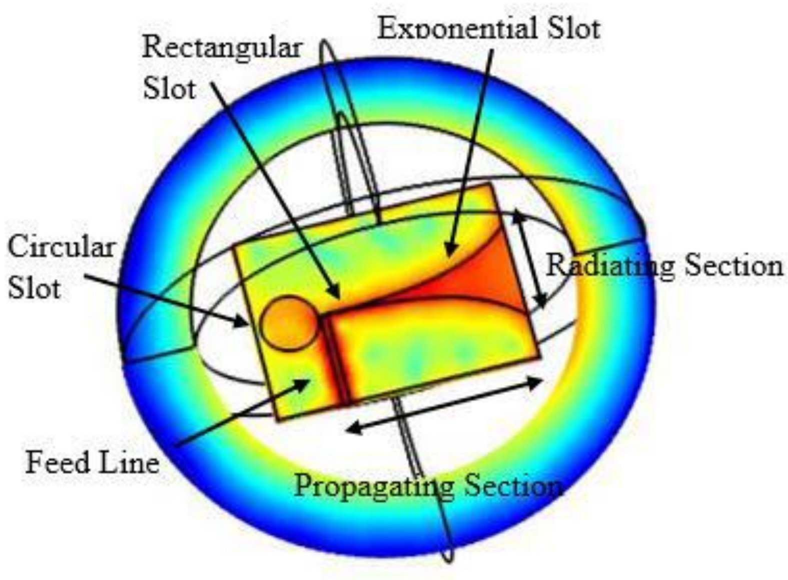


Figure 2.12: Layout of Vivaldi Antenna.

2.6 The Basic structure of Vivaldi

From the above figure the Vivaldi antenna structure comprises of mainly three different type of slots i.e.

i. **The circular slot:** This slot provides the ability to tune the impedance of the antenna in order to perfectly match it with the impedance of the microstrip transmission line.

ii. **The rectangular slot:** This slot fulfils the purpose of coupling of em wave from the microstrip feed line to slot line.

iii. **The exponential tapered slot:** This slot provides the guiding path for the radiating em wave. The exponential rate of the curve is the determining parameter for the bandwidth and directivity of the radiation pattern.

An endfire radiation pattern is visualized and the electronic field is in the same plane of the dielectric substrate. The radiation pattern is linearly polarized in two planes, yet an elliptical polarization exists between the E plane and the H plane. The E plane and the H plane shows almost the same beamwidth and the cross-polarization level is also low for it.

2.7 Advantages of Vivaldi Antenna

i. Configuration simplicity.

ii. Wide bandwidth.

iii. High gain at microwave frequencies.

iv. Broadband characteristics (suitable for ultra-wideband signals).

v. Easy manufacturing process using common methods for PCB production.

vi. Easy impedance matching.

vii. Low fabrication cost.

2.8 Design and simulation tools

For this project work we are going to use CST Microwave Studio as the tool for the design and the simulation of our Antipodal Vivaldi Antenna.

Some of the motivations behind this choice are:

- CST studio is available under Student version.
- CST studio has a simple self-intuitive interface.
- The parametrized variables can be created during the design before assigning them a value instead of creating them in advance.
- CST runs on relatively decent computer resources.

2.GEOMETRY & PARAMETRIC STUDY OF APVA

3.1 Geometry of APVA

The antenna is designed on a low-cost FR4 substrate with dielectric constant Ɛr = 4.4, thickness h = 1.6mm, and dielectric loss tangent δ = 0.02, respectively. The antenna geometry is shown in Figure 1. The proposed antenna includes two main parts: feed line and the radiation flares. The shape of the flares is designed in the form of elliptical curves. The elliptical configuration presents especially good broadband characteristics due to the smooth transition between the radiation flares and the feeding line. It is one of the optimum curvatures. Theoretically, the upper frequency limit of a Vivaldi antenna is infinity. The lower frequency limit depends mainly on the width of antenna and the effective dielectric constant (ε_{eff}) Lower frequency limit is calculated from

$$f_{min} = \frac{c}{2W\sqrt{\varepsilon_{eff}}} \quad ,$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + \frac{12h}{W}\right)^{-1/2}$$

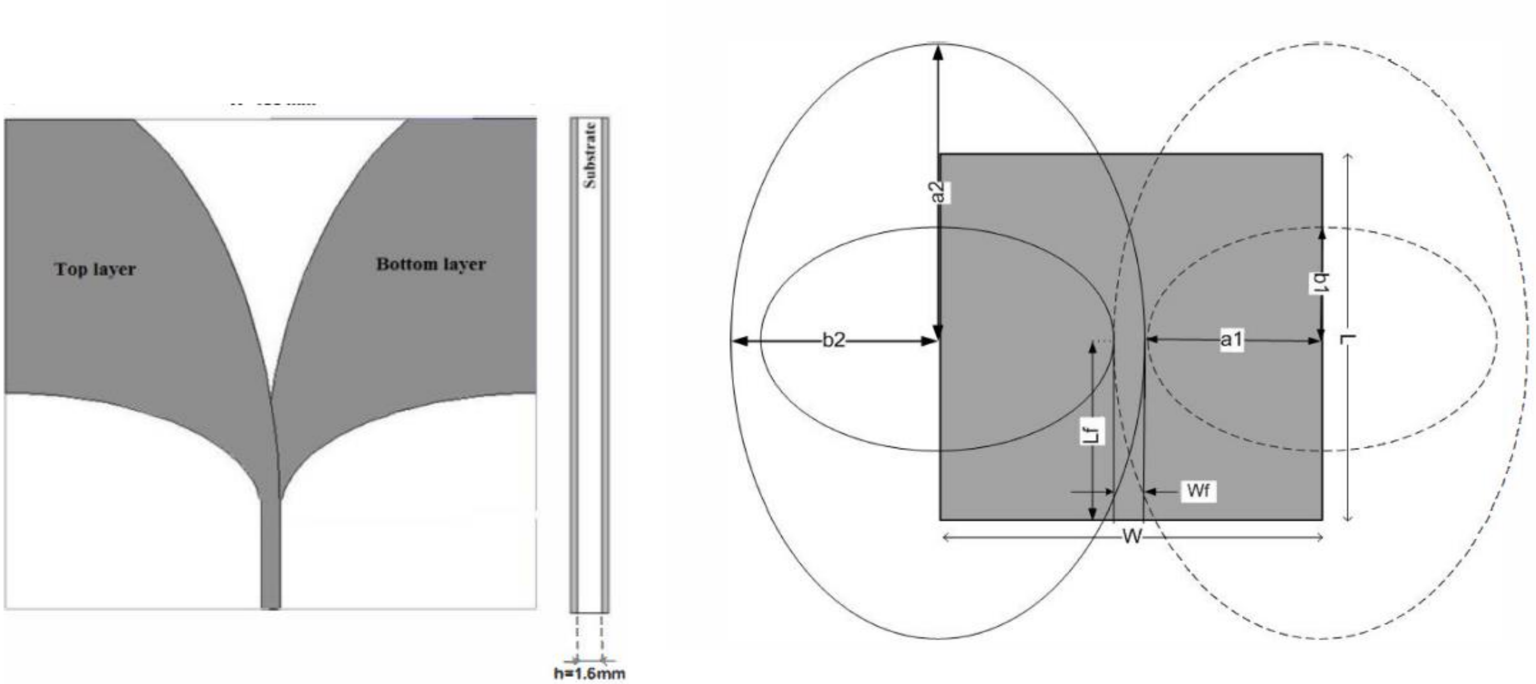


Figure 2.13: Geometry of Antipodal Vivaldi Antenna.

The width of the feeding line W_f has the characteristic impedance Zo = 50 Ω and can be calculated using the following equations

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}} \ln\left(\frac{8h}{W} + \frac{W}{4h}\right), \qquad \text{for } \left(\frac{W}{h}\right) < 1$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{h} + 1.393 + \frac{2}{3}\ln\left(\frac{W}{h} + 1.444\right)\right]} . \qquad \text{for } \left(\frac{W}{h}\right) \geq 1$$

The shape of the exponential flare is defined by the equation

$$\mathbf{y = A + e^{nt}}$$

With **n** growing rate of the fare.

3.2 Restrictions on the design

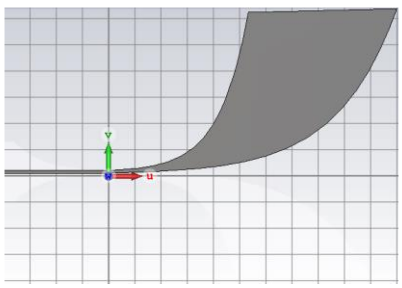
In the search of the proper response for the antenna, the physical size of the antenna may have to be varied. However, it has been imposed that the physical size of the antenna should not be greater than one wavelength of the lower band.

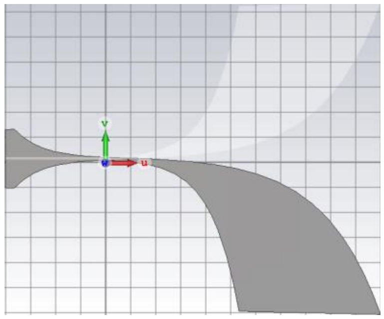
L or **l** should be less or equal to **37.5 cm.**

Our design is also restricted to a low cost FR4 substrate and copper of thickness **0.035 mm.**

3.Design of APVA in CST Studio

4.1 Definition of parametric equations & constants

SECTION	VIEW	COMPONENTS	EQUATIONS
TOP FARE		**ANALYTICAL CURVE 1**	**u(t) = t** **v(t) = A+exp(n*t)** **w(t) = 0** **max(t) = 220mm**
		ANALYTICAL CURVE 2	**u(t) = t** **v(t) = B+exp(m*t)** **w(t) = 0** **max(t) = 106.7mm**
		POLYGON	
BOTTOM FARE		**ANALYTICAL CURVE 1**	**u(t) = t** **v(t) = -(A1+exp(n*t))** **w(t) = 0** **max(t) = 220mm**

		**ANALYTICAL CURVE 2**	**u(t) = t** **v(t) = -(B1+exp(m*t))** **w(t) = 0** **max(t) = 106.7mm**
		ANALYTICAL CURVE 3	**u(t) = -(t+3)** **v(t) = -(B1+exp(m*t))** **w(t) = 0** **max(t) = 70mm**
		ANALYTICAL CURVE 4	**u(t) = -(t+3)** **v(t) = B+exp(m*t)** **w(t) = 0** **max(t) = 8.2mm**
		POLYGON	
CONSTANTS			
A	**1**		
n	**0.022**		

B	**3**
m	**0.045**
A1	**-5**
B1	**-2.8**

4.2 Design procedures

4.2.1 Design of the top fare

The top fare is used to guide the electromagnetic wave to radiate. The first step on our design is to draw a set of analytical curves in order to extrude the required shape.

We start by defining the analytical curve 1 represented by the equation

v(t) = A+exp(n*t)

- **t** varies to a maximum of **max(t) = 220mm.**
- The constant **A** is the spacing kept with the origin for the good symmetry of the two fares.
- The constant **n** defines the growing rate of the exponential fare.

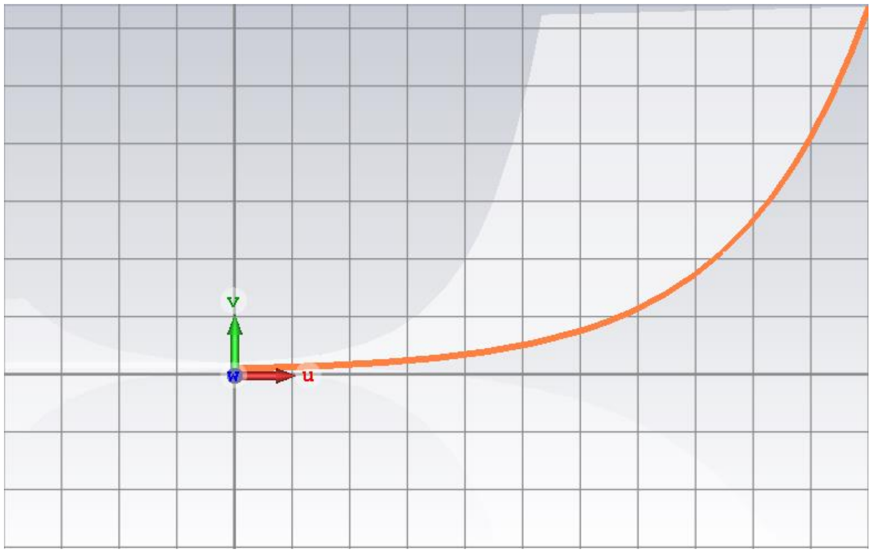


Figure 4.1: Analytical curve1 for top fare

In second, we are defining the analytical curve 2 represented by the equation

v(t) = B+exp(m*t)

- **t** varies to a maximum of **max(t) = 106.7mm.**
- The constant **B** is the spacing kept with the origin which defines the width of the transmission line at the origin.
- The constant **m** defines the growing rate of the second analytical curve.

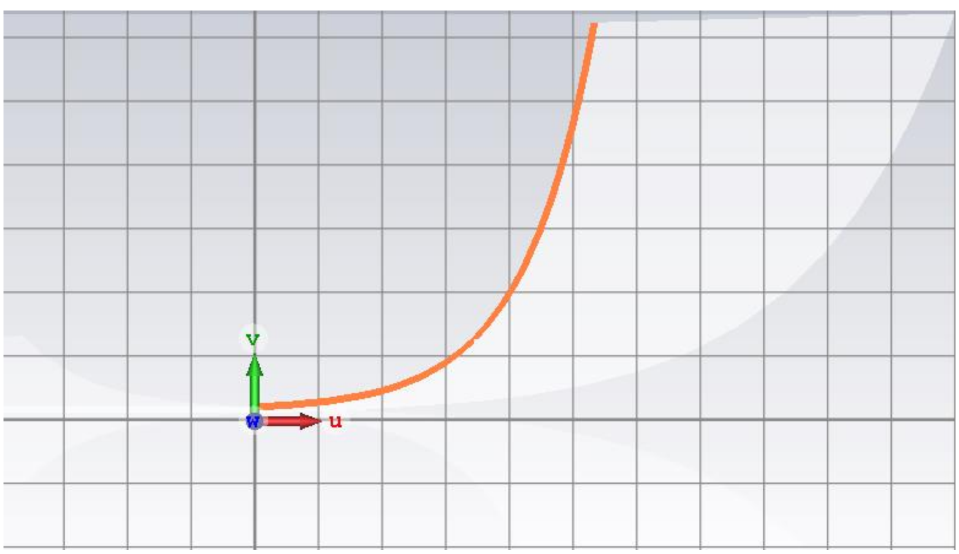


Figure 4.2: Analytical curve2 for top fare

With the use of the line tool, we join the two ends of the analytical curves 1 and 2.

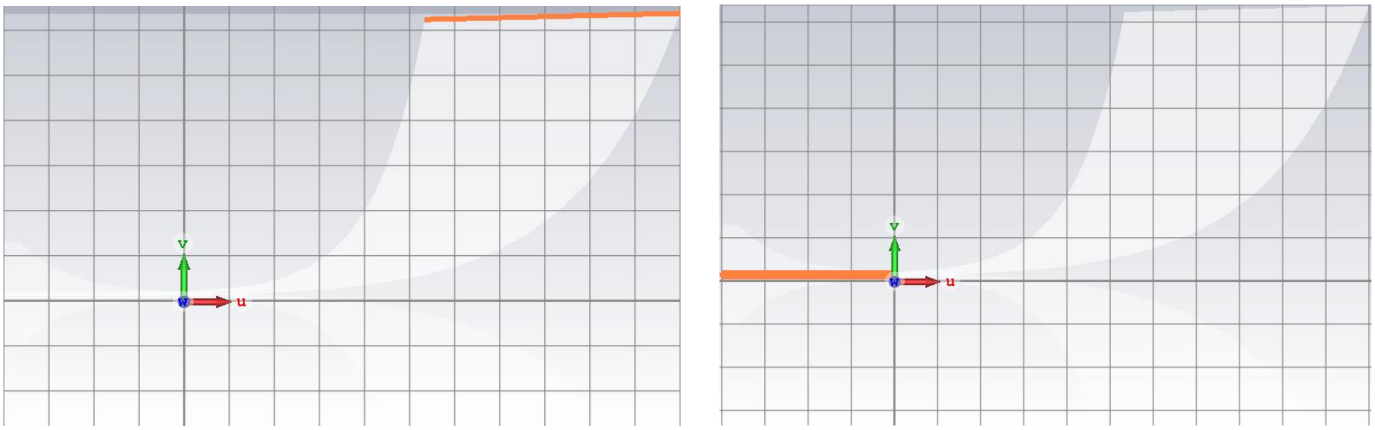


Figure 4.3: Line tools for top fare

For the transition to fares, we define the tail of the antenna with the polygon tool. The role of this part of the antenna is to assure the transition of impedances on the two superposed fares.

After defining all the curves required for the fares, we extrude the curve by injecting the thickness of the metallic conductor that will be used for the antenna. Here we are using the PEC (copper) with the thickness of 0.035 mm

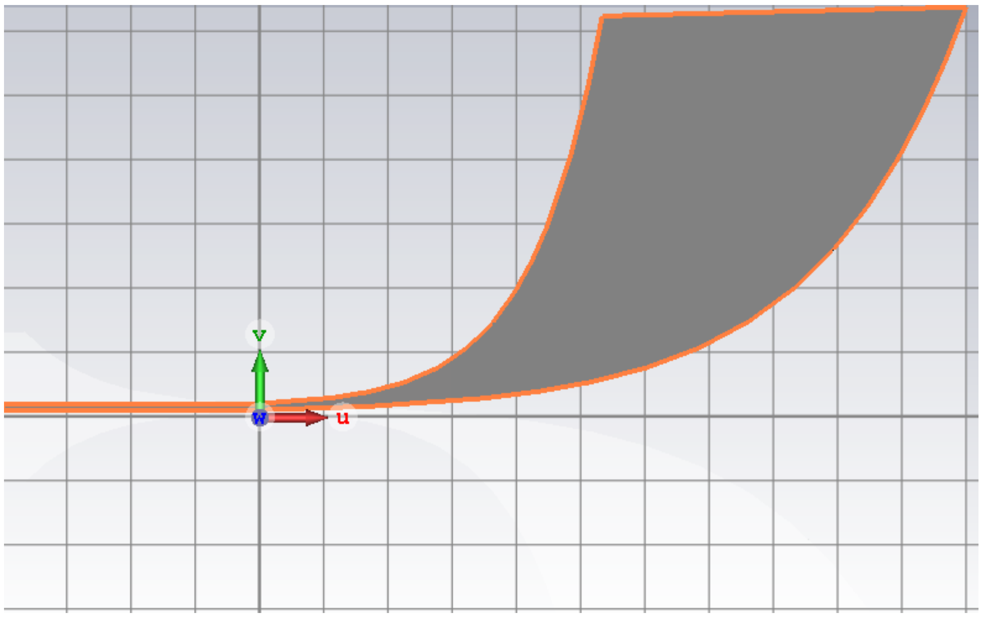


Figure 4.4: Top fare extruded

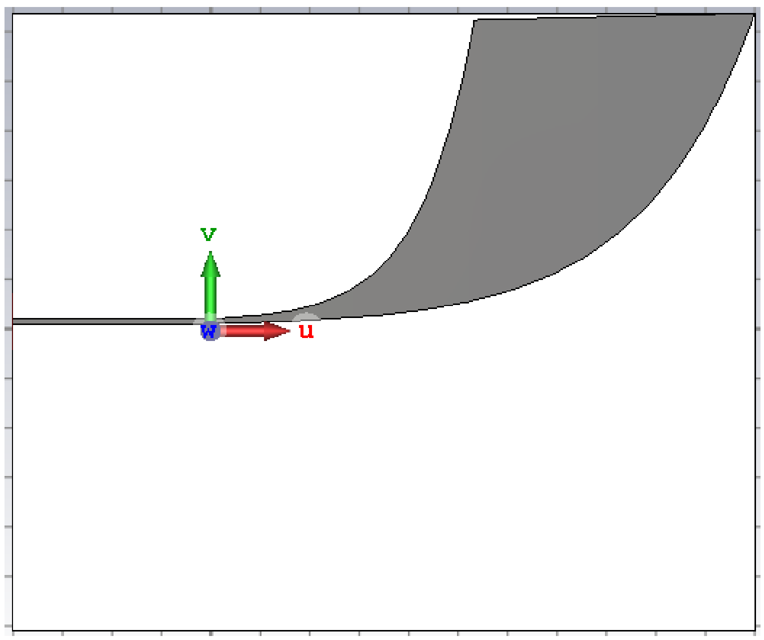
4.2.2 Definition of the substrate

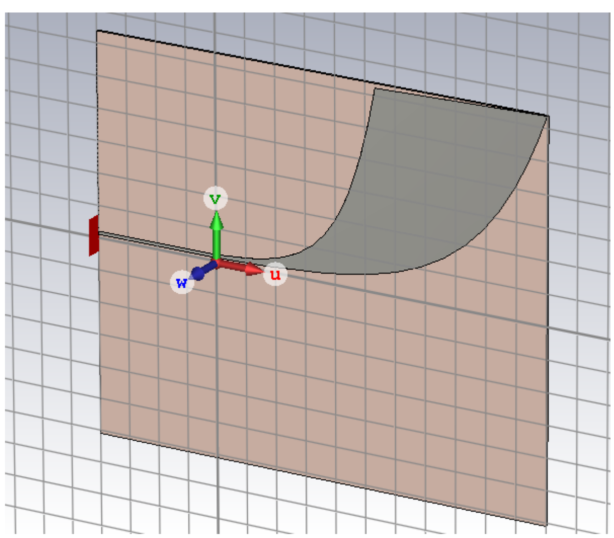
It was imposed for the design of this antenna to use a low cost fr4 substrate.

At this step we are building a brick of substrate around the extruded fare1.In the parameters of the substrate we are choosing the lossy FR4 which corresponds to the low cost FR4 highly available on the market.

In order to meet the targeted performance for the antenna, and specially the go behavior at low frequencies, we are using 1.6 mm as the thickness of the FR4.On the design plane we are applying a negative thickness -1.6mm as we want to apply the thickness on the lower part of the metallic fare.

We will late adjust the size of the substrate brick in order to fit the bottom fare.





4.2.3 Design of the bottom fare

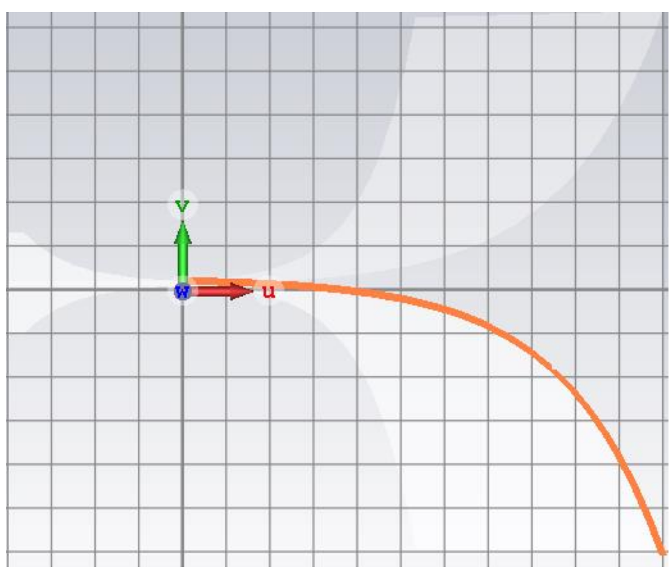
Before designing the bottom fare, we have to change the coordinate system.

We are applying an increment of -1.6 mm on the z (W) axis which corresponds to start the design of the bottom fare from the lower end of the substrate used.

We start the bottom fare with the bottom analytical curve 1 responding to

v(t) = -(A1+exp(n*t))

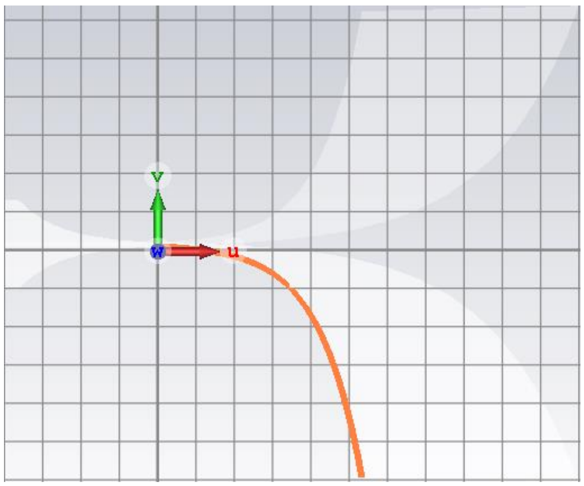
- **t** varies to a maximum of **max(t) = 220mm.**
- The constant **A1** is the spacing kept with the origin for the good symmetry of the two fares and to maintain the transmission line width.
- The constant **n** defines the growing rate of the exponential fare.



We proceed with the bottom analytical curve 2 responding to

v(t) = -(B1+exp(m*t))

- **t** varies to a maximum of **max(t) = 106.7mm.**
- The constant **B1** is the spacing kept with the origin for the good symmetry of the two fares and to maintain the transmission line width.
- The constant **m** defines the growing rate of the exponential curve.



We proceed with the bottom lower left and right curves wthi respond to the equations:

u(t) = -(t+3)

v(t) = -(B1+exp(m*t))

w(t) = 0

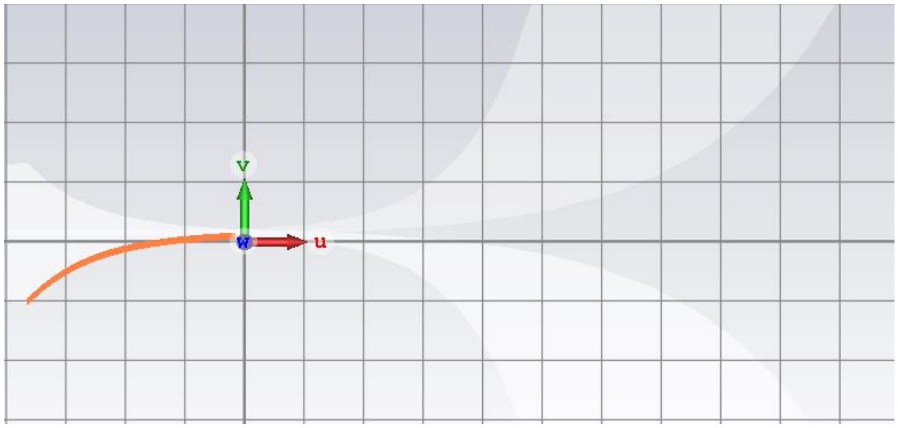
for the lower left curve and

u(t) = -(t+3)

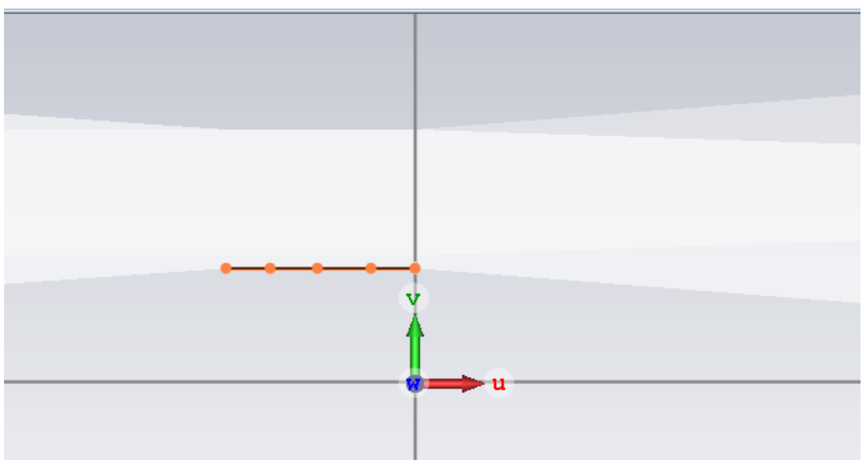
v(t) = B+exp(m*t)

w(t) = 0

for the lower right curve with **t** varying to a maximum of **max(t) = 70mm.**



The next step consists of closing the loop, by connecting all the main curves drawn with the use of line, polygon and spine tools.



As in the case of the top fare, we extrude the curve by injecting the PEC thickness 0.035 mm and we obtain the bottom fare of the antipodal Vivaldi antenna.

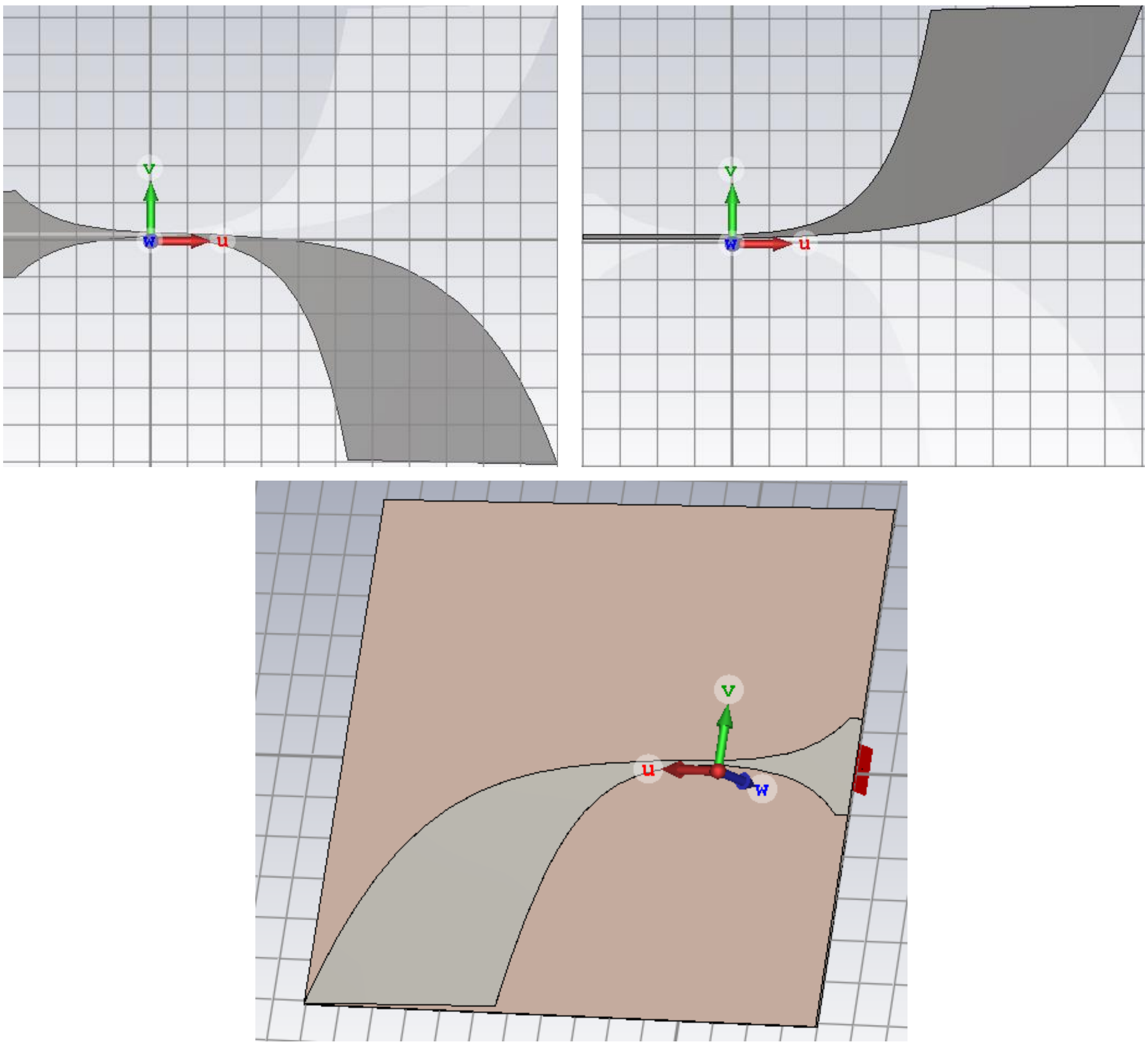


Figure 4.5: Top fare and bottom fares

4.Simulation of APVA in CST Studio

5.1 Port creation

Before simulating the designed antenna, we need to create a port.

As part of the parameter imposed for the project, it was given to consider a 50Ohm Balun when considering the port connector. The Balun steps down the high antenna impedance to match that of the 50 Ohm cable.

We will start by generating the port extension coefficient and define a variable k.

The port extension coefficient is a constant generated by the design tool which allows us to parametrically adapt the size of the port with the size of the antenna.

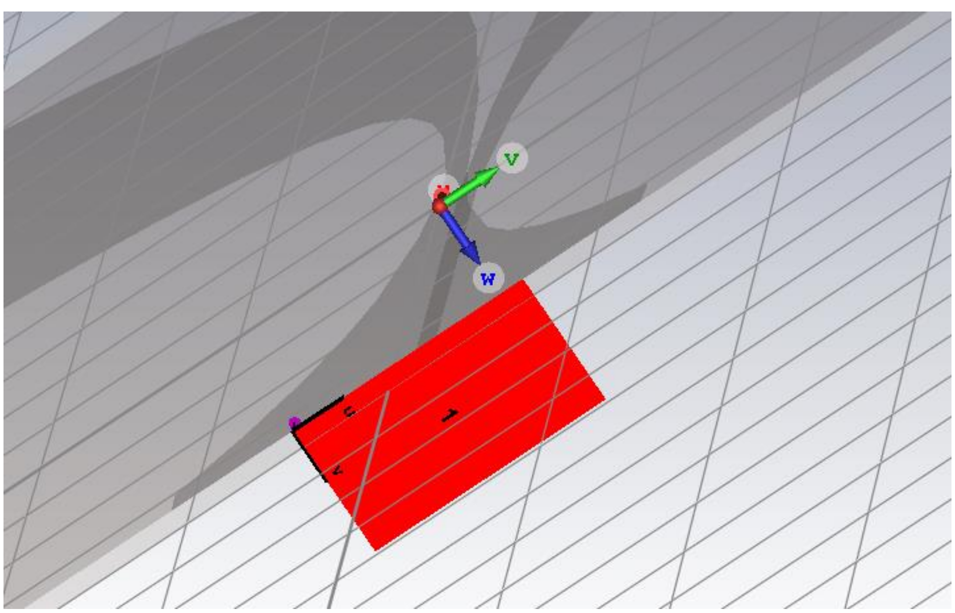


Figure 5.1: Waveguide port.

The value of the port extension coefficient automatically generated is used to calculate the port extension on each of the axis. We get

Ymin varies from 2 to k*h

Ymax varies from 4 to k*h

Zmin varies from 2.22044 to h

Zmax varies from 0.03499 to k*h

Where k is the port extension coefficient 6.5 in our case and h the thickness 1.6mm.

5.2 Simulation environment

Before starting the simulation, we also have to set the environmental parameters.

- The frequency

  We are simulating our design in a frequency range from 800 MHz to 6 GHz as prescribed by the design parameters.

- The background properties

They define the properties of the materials surrounding the antenna during the simulation, in our case we are keeping to normal.

- The Boundaries

The boundaries for our simulation are taken as open add space in all directions.

- Field monitors

To later analyze and interpret the results of our simulation, we create field monitors at specific frequencies of interest. In our case we set field monitors at 1.5 GHZ, 2.5 GHz, 3.5 GHz and 6.5 GHz to record the far field behavior at those frequencies.

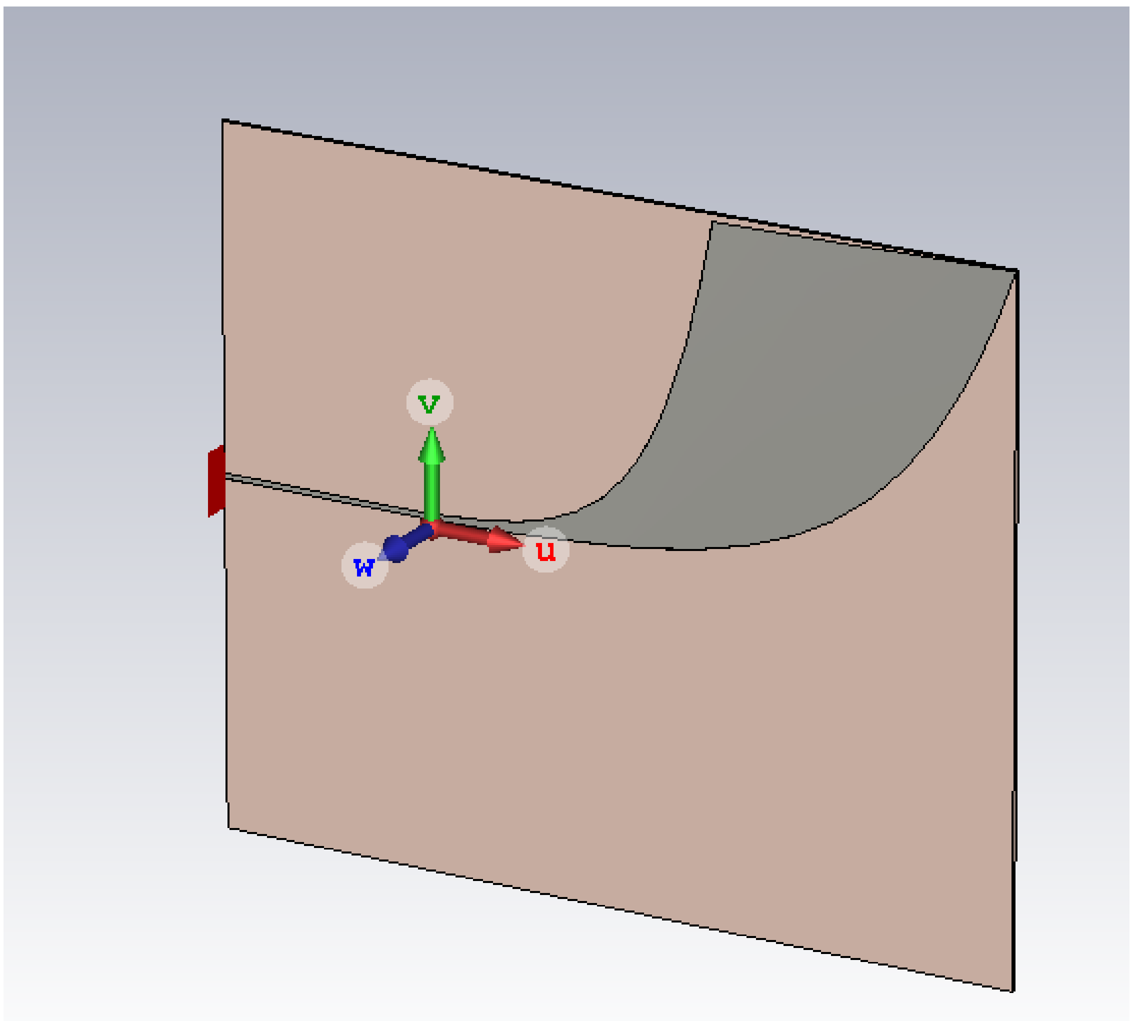
5.3 Simulation

We are performing the simulation in time domain with 815 166 high frequency mesh cells

5.Simulation results

In order to better interpret the results of the simulation and better evaluate the response of the antenna at different frequencies of interest, we are going to categorize the results in 1D results and 2/3D results groups.

- **Antenna final design**



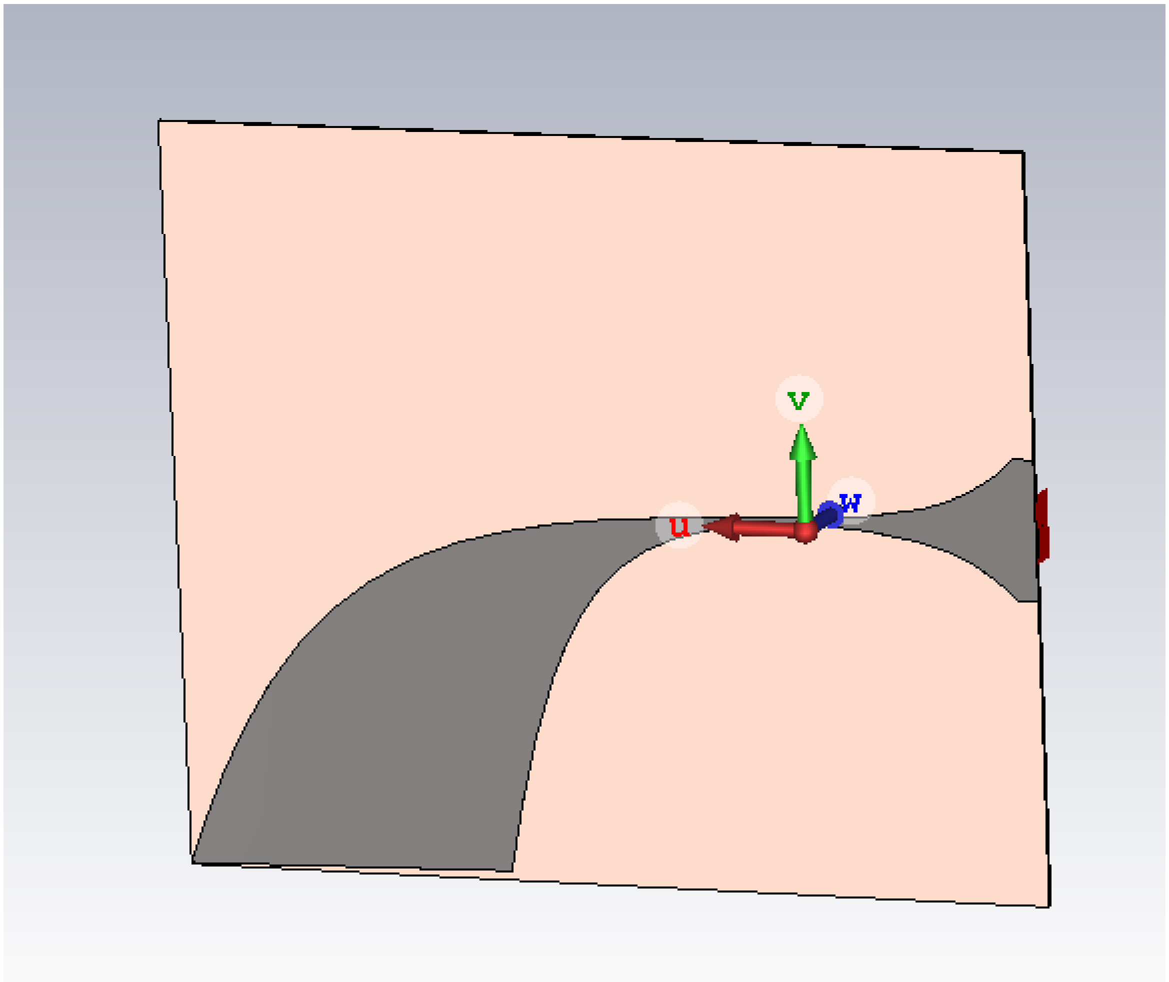
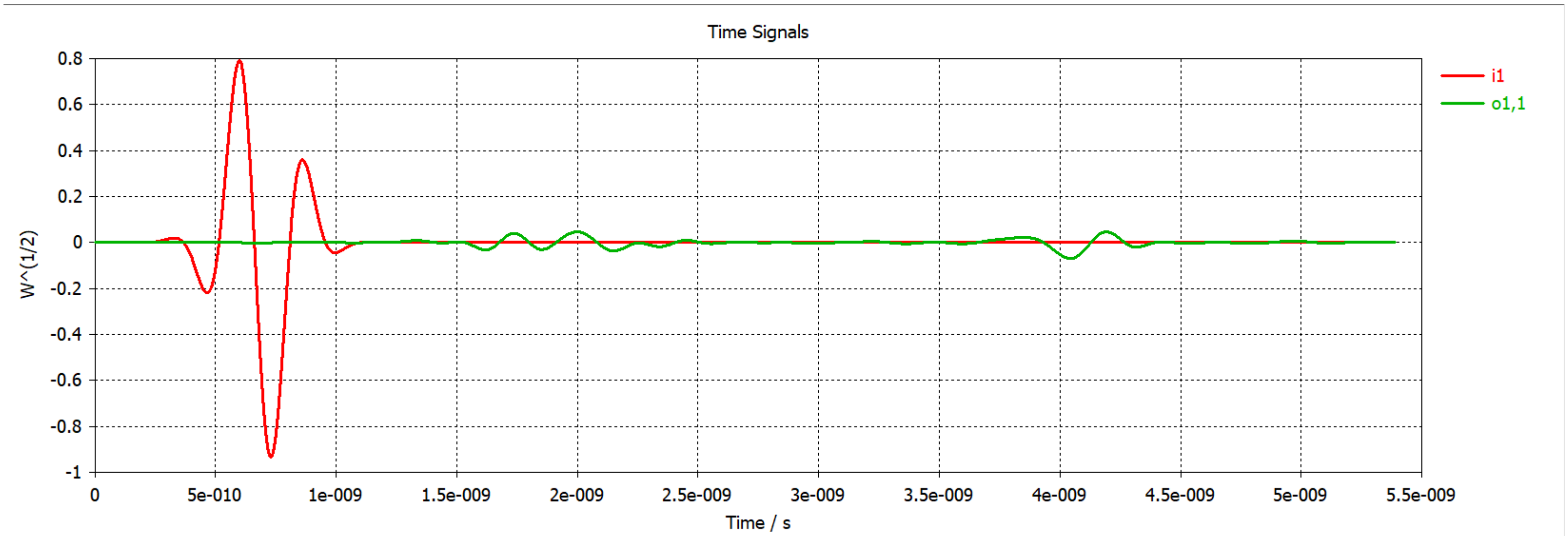


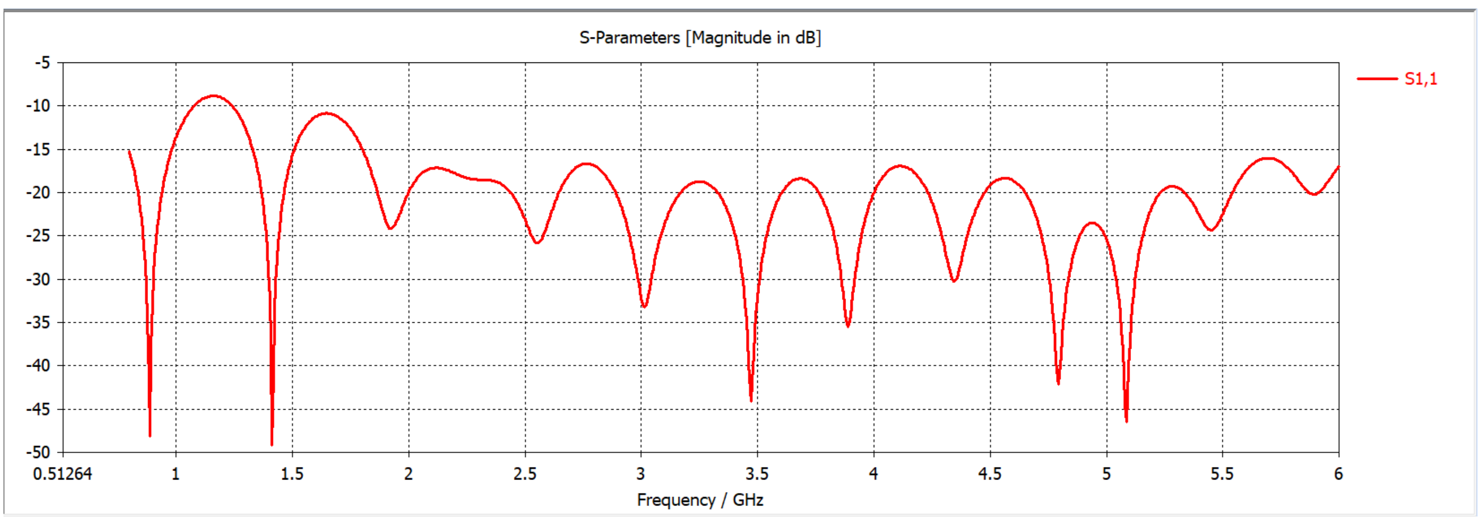
Figure 6.1: Antenna final design.

5.1 1D results

- **Port signals**



- **S-Parameters**



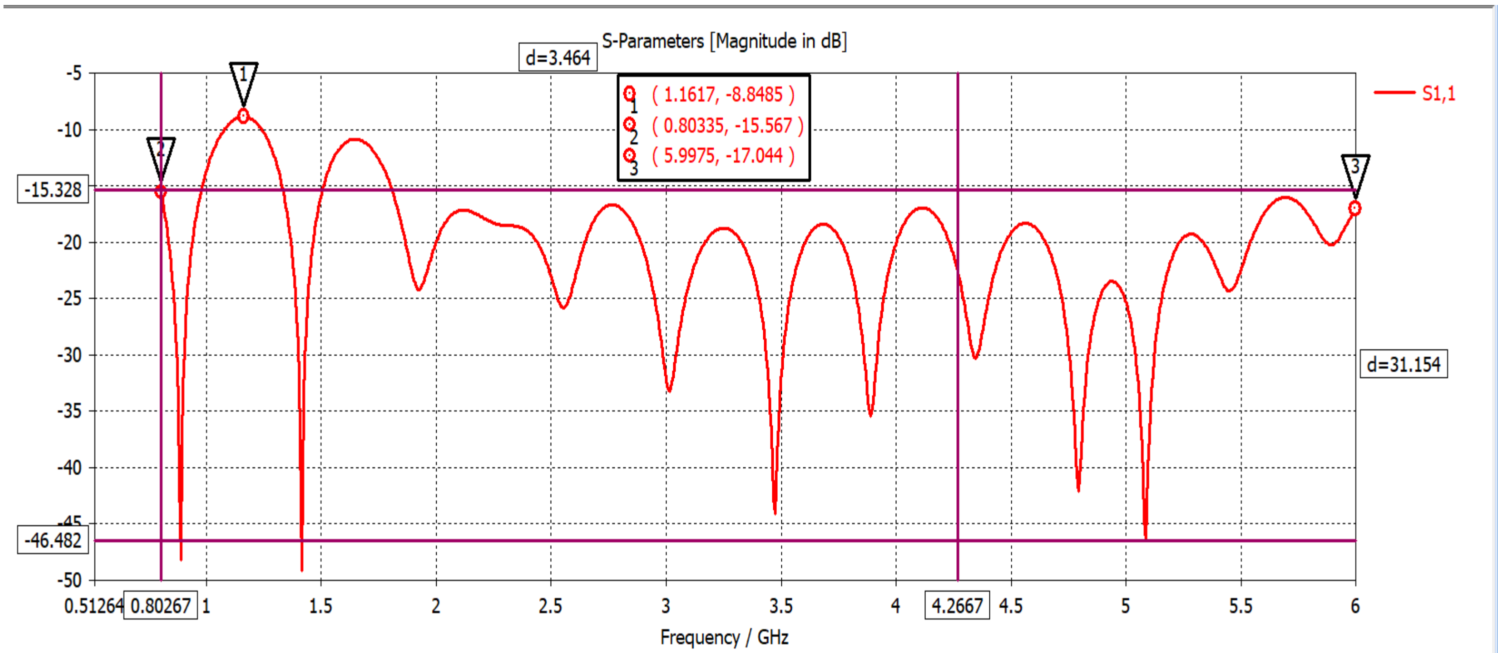
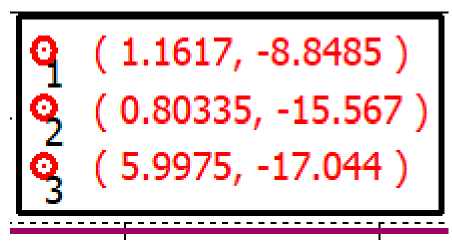


Figure 6.2: S-parameters.



- **Excitations**

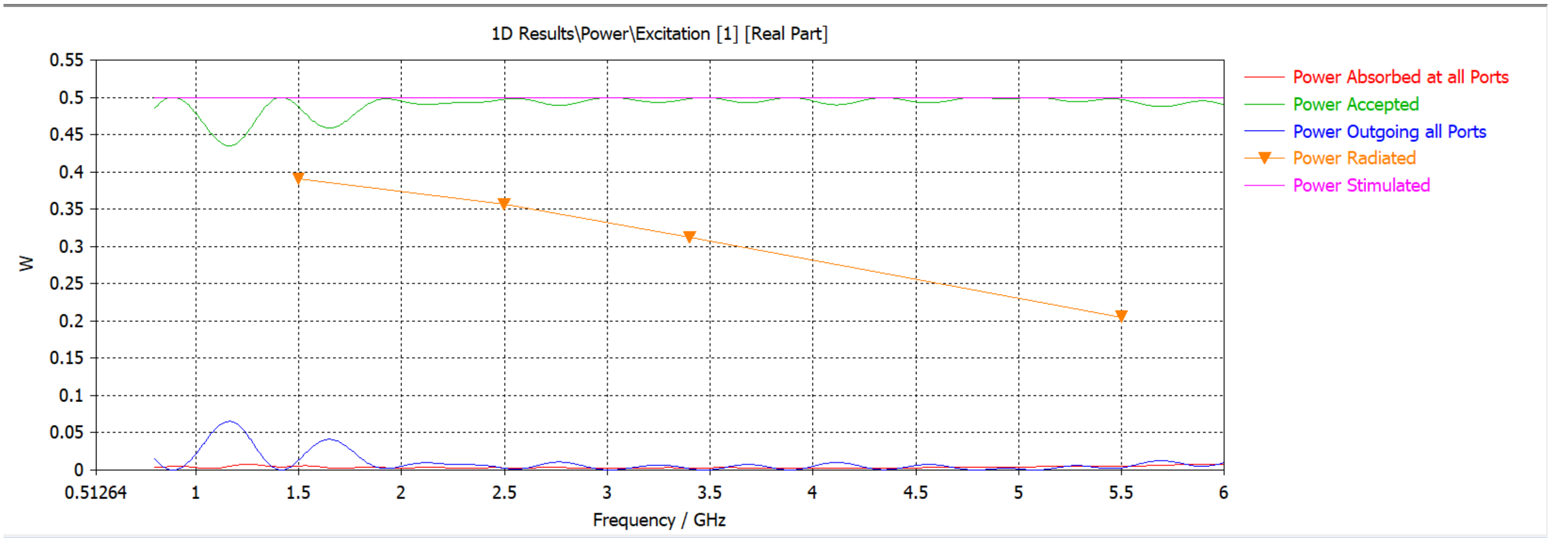


Figure 6.3: Excitation signals.

- **Field Energy**

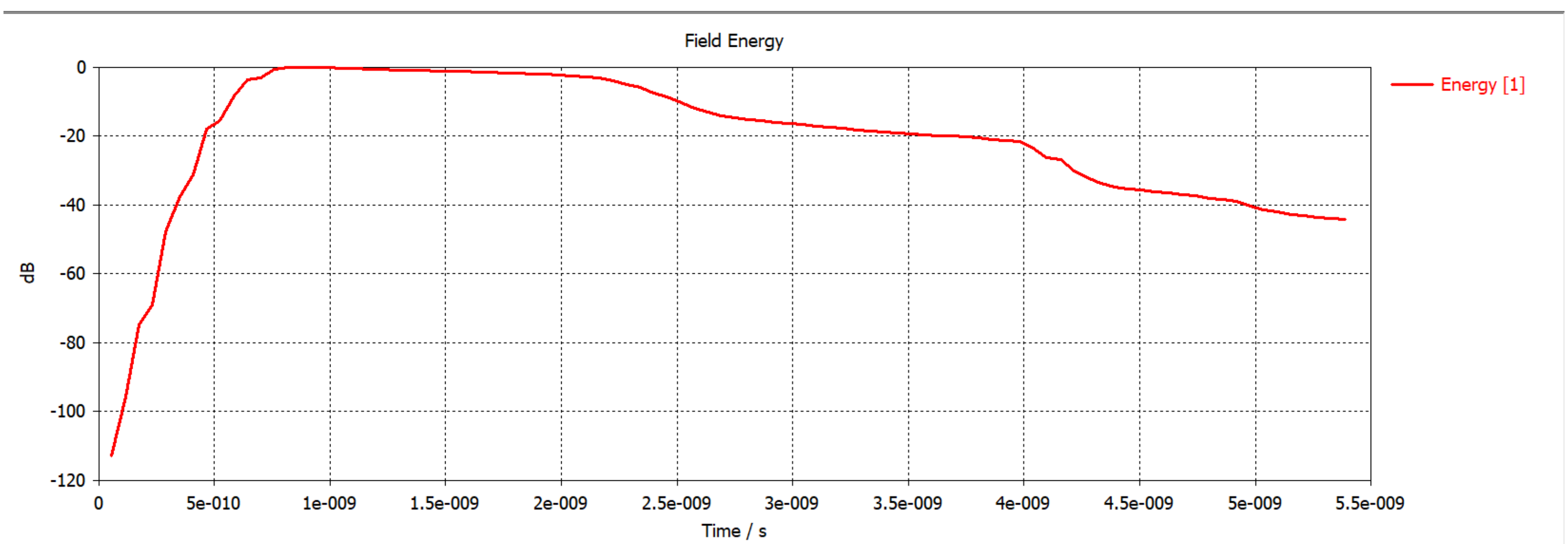


Figure 6.4: Field energy.

- **Electric dispersion**

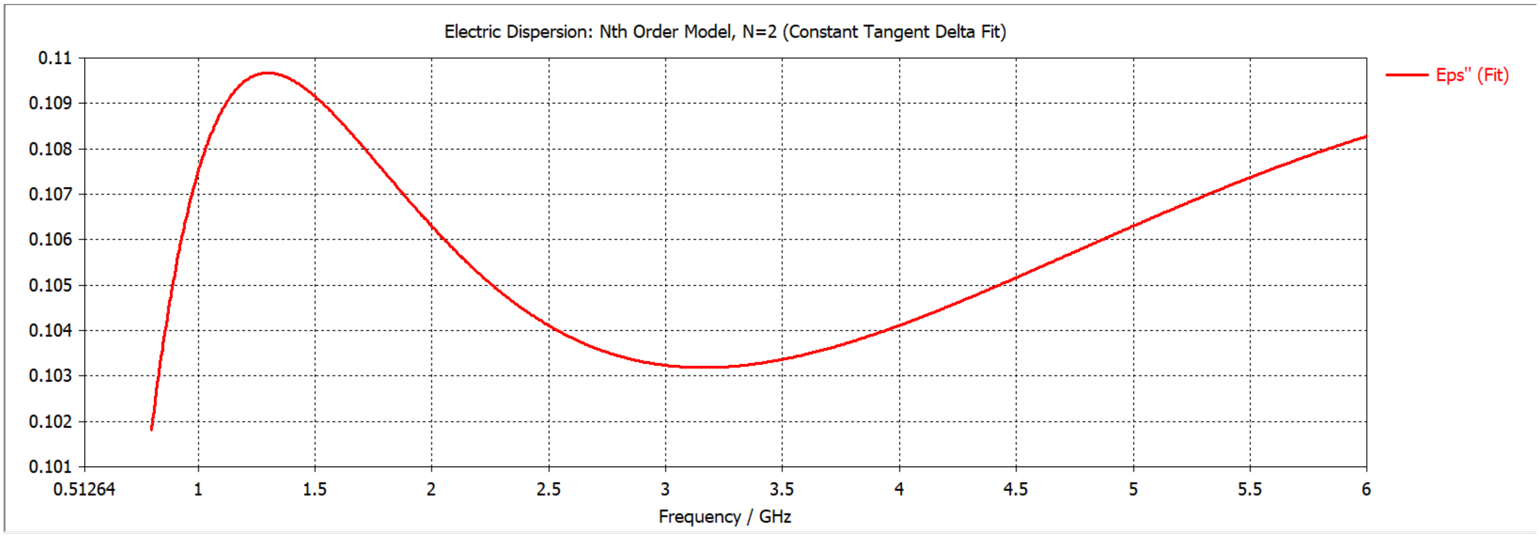


Figure 6.5: Electric dispersion.

- **Efficiencies**

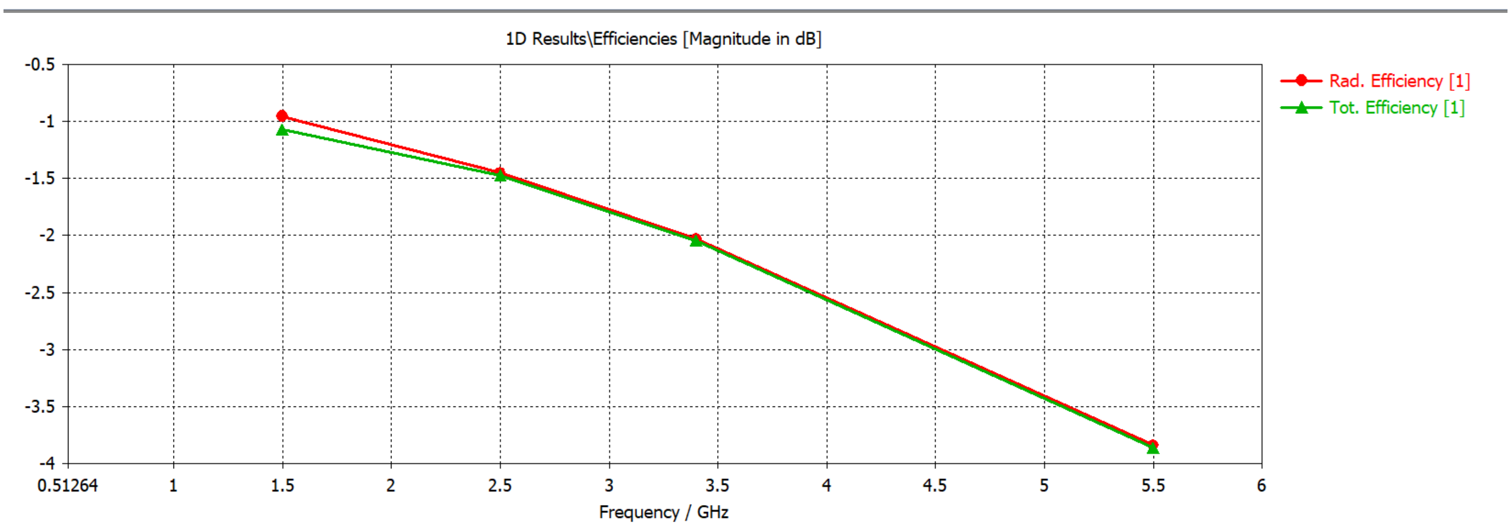
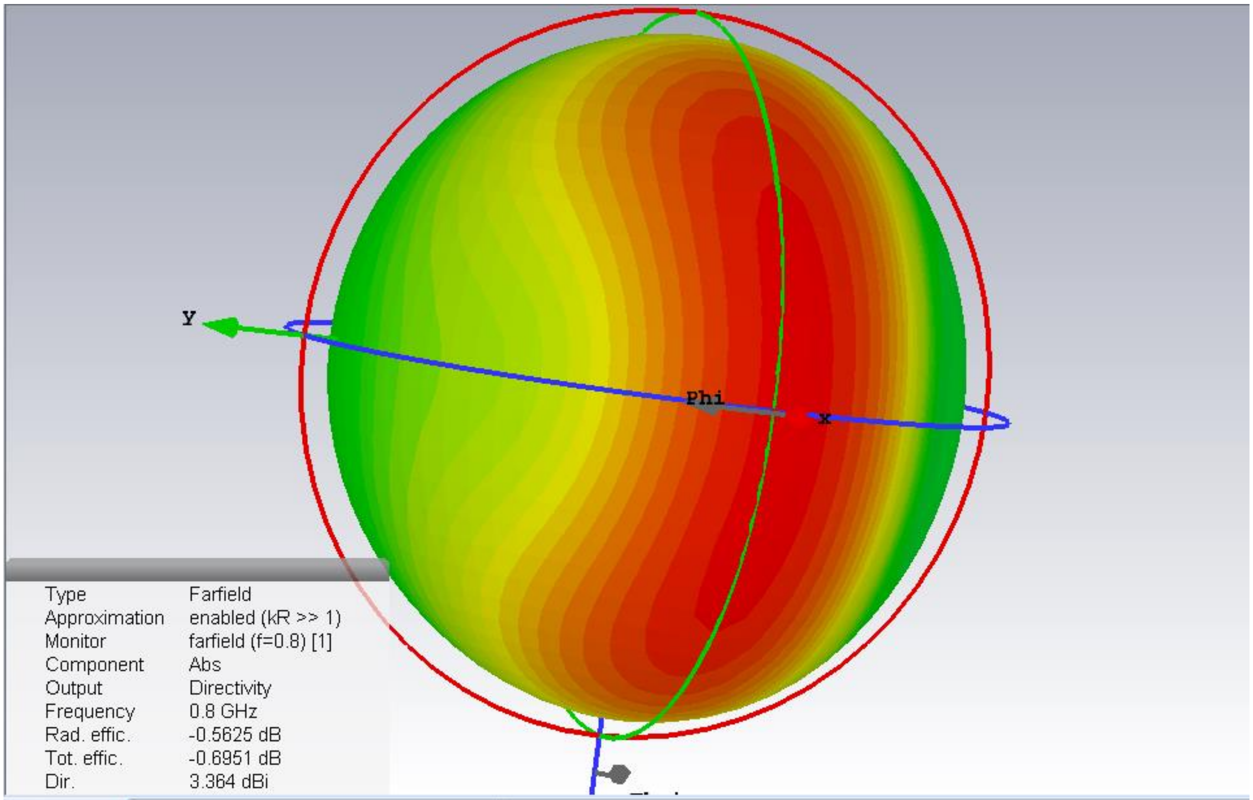
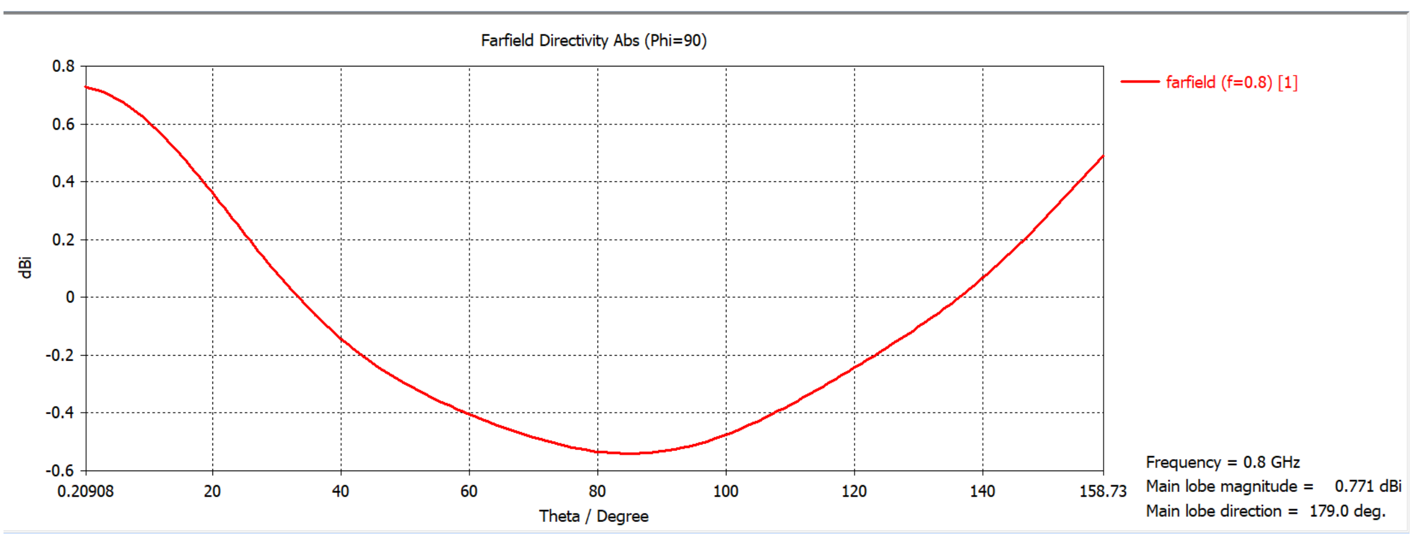


Figure 6.6: Efficiencies.

5.2 2D/3D results

- **Farfield at 800 MHz**





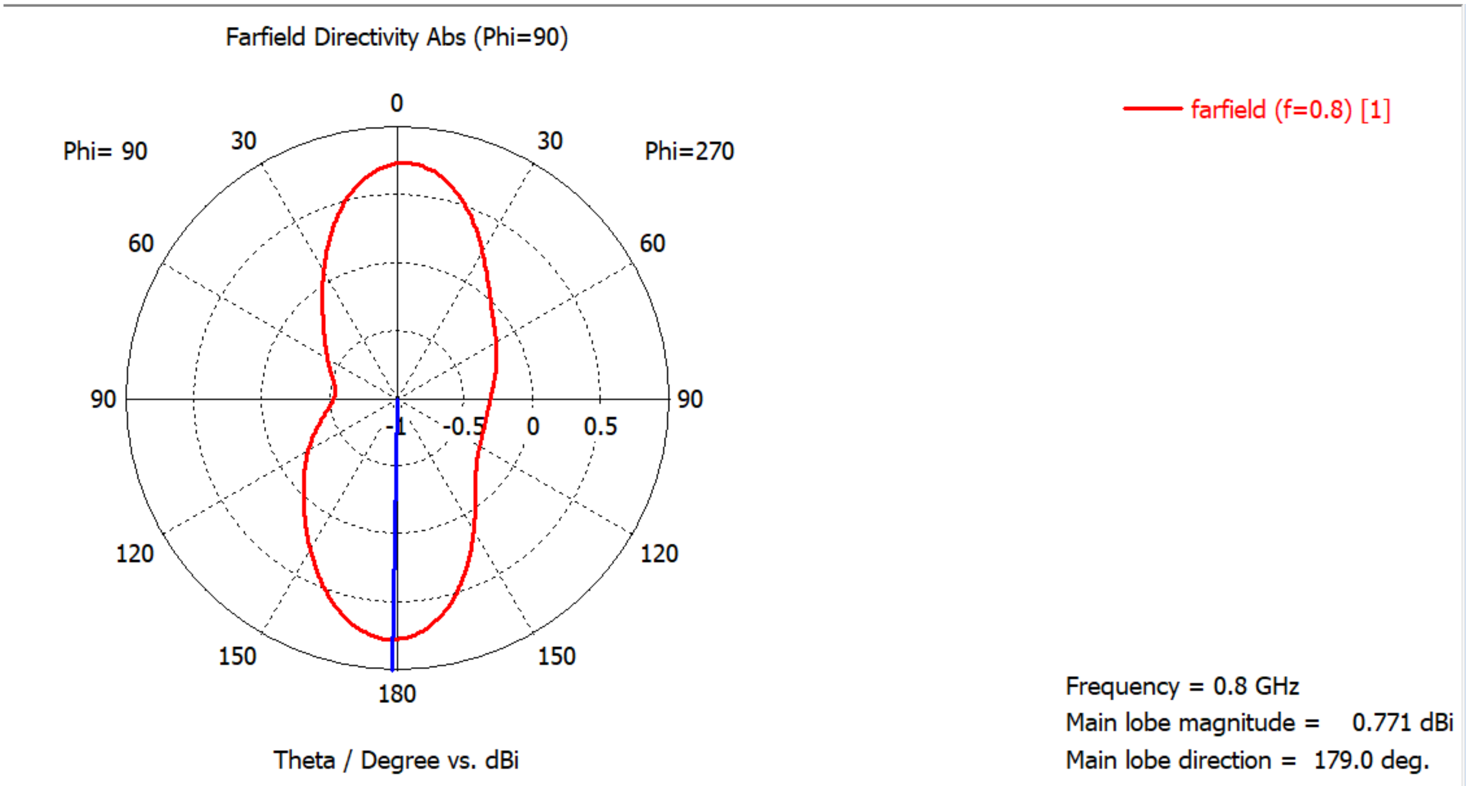
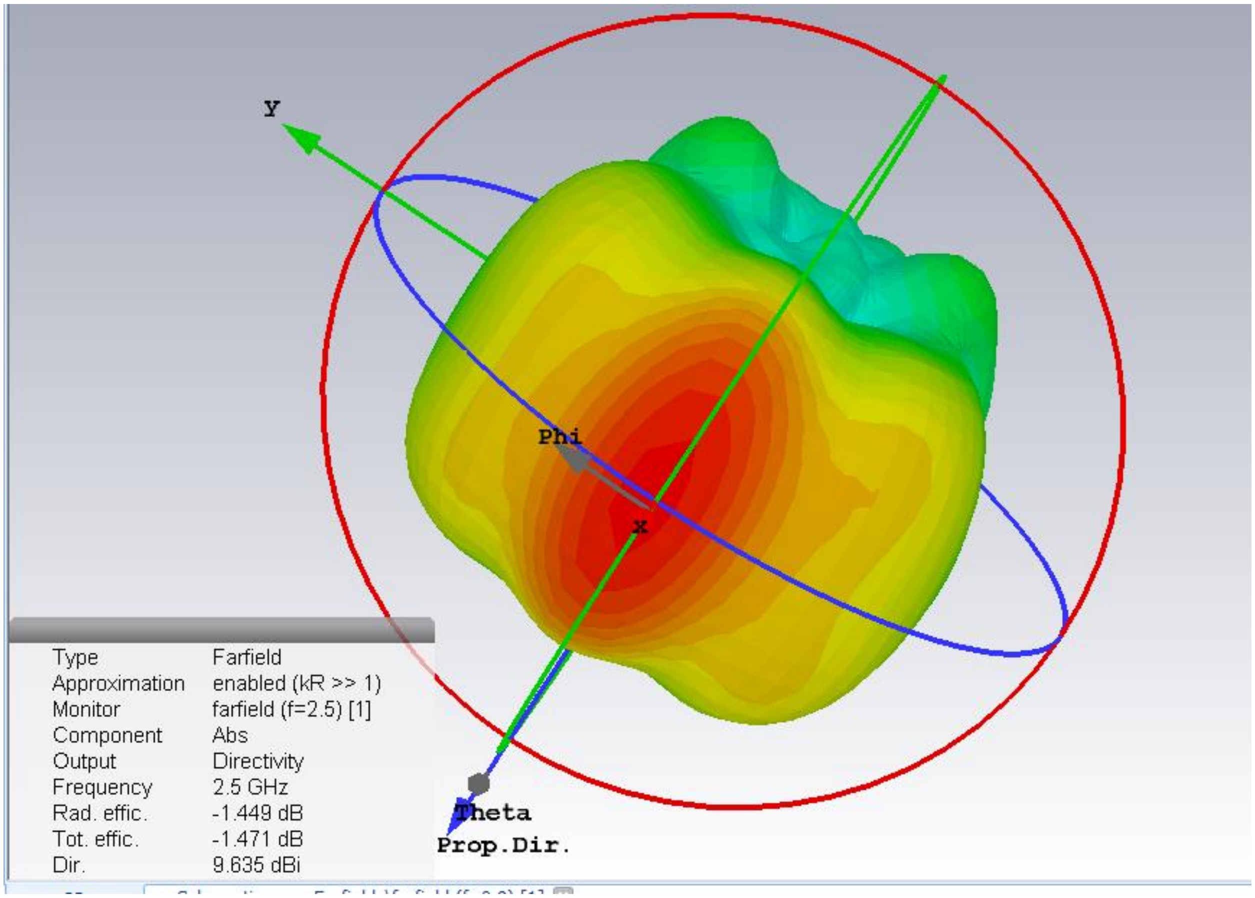
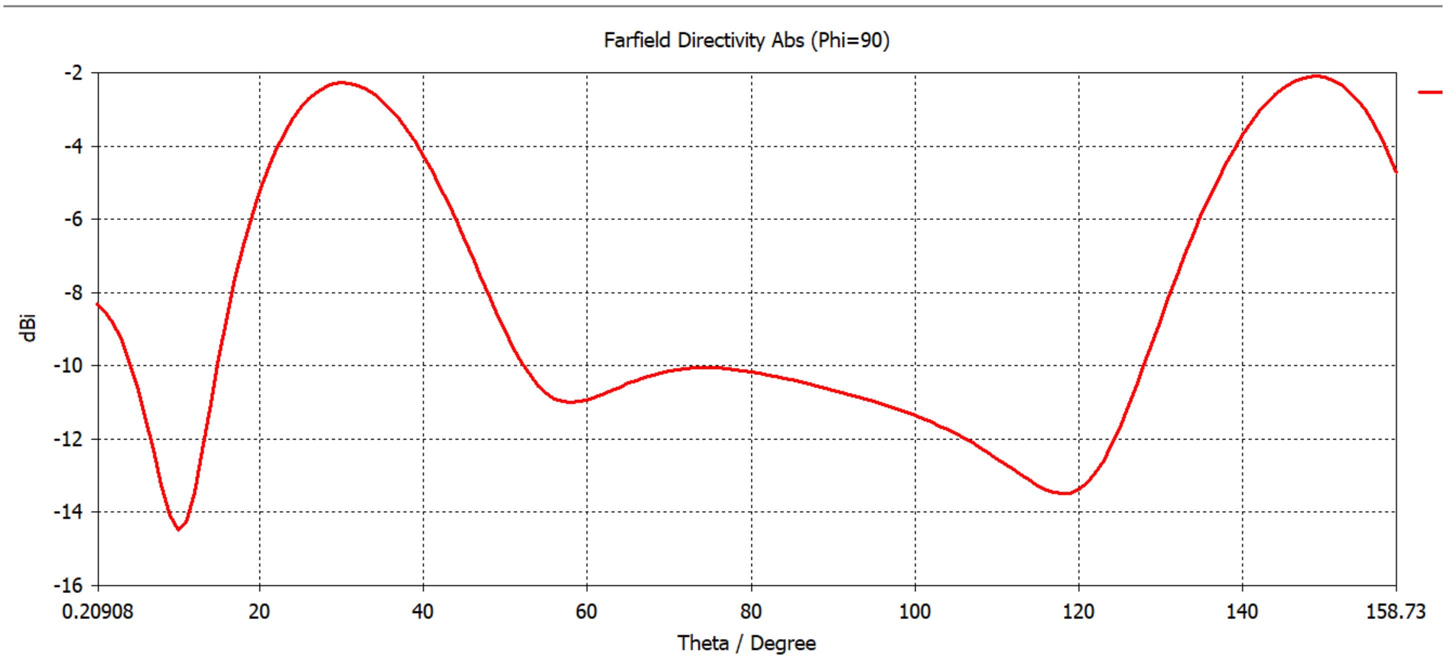


Figure 6.7: Far fields at 800 MHz.

- **Farfield at 2.5 GHz**





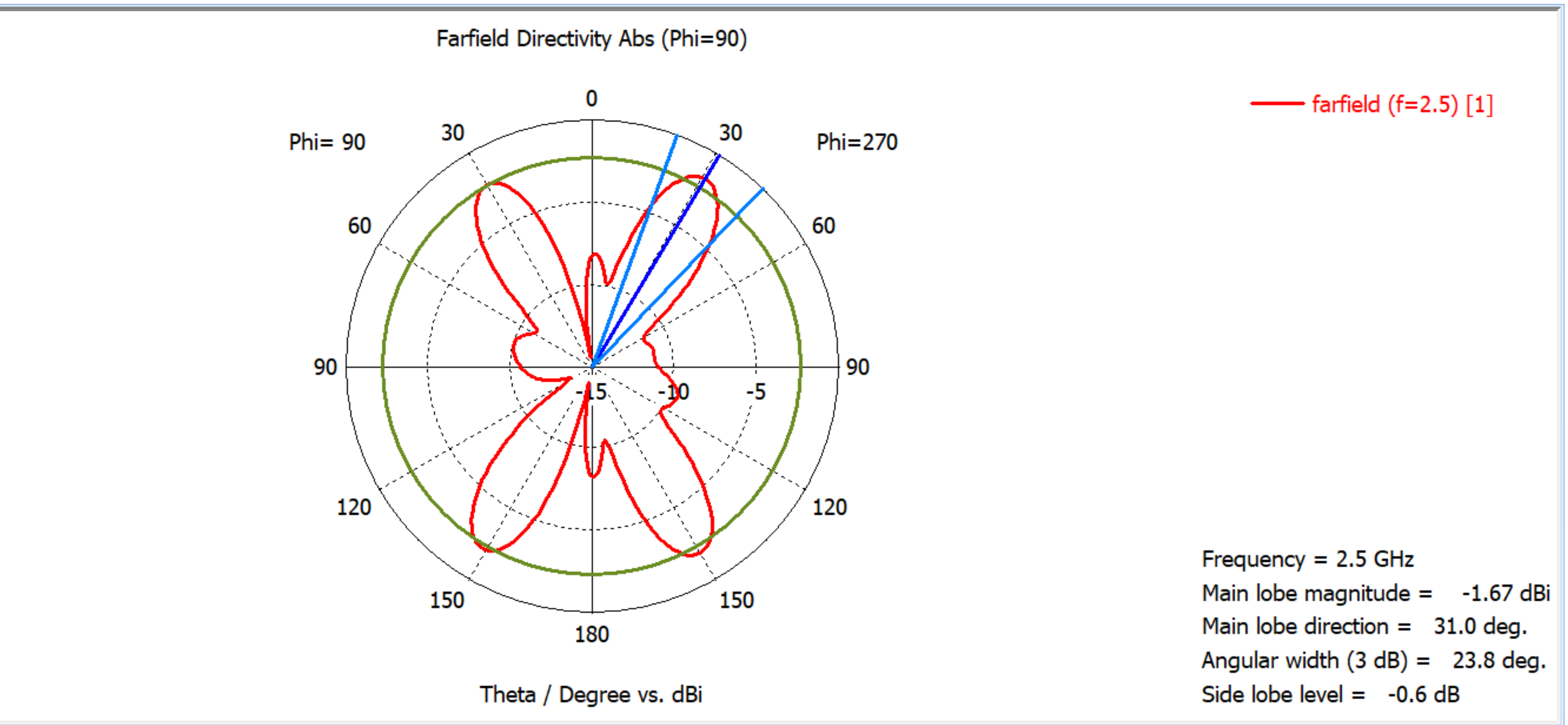
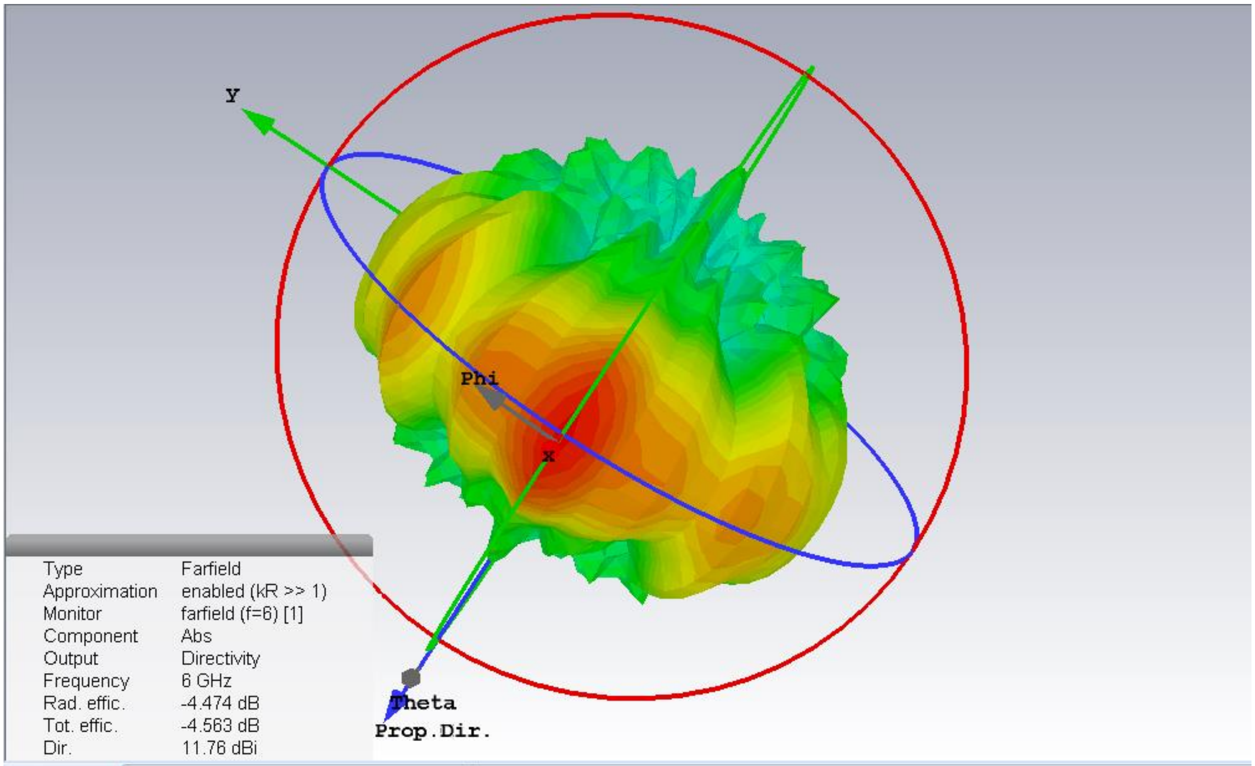
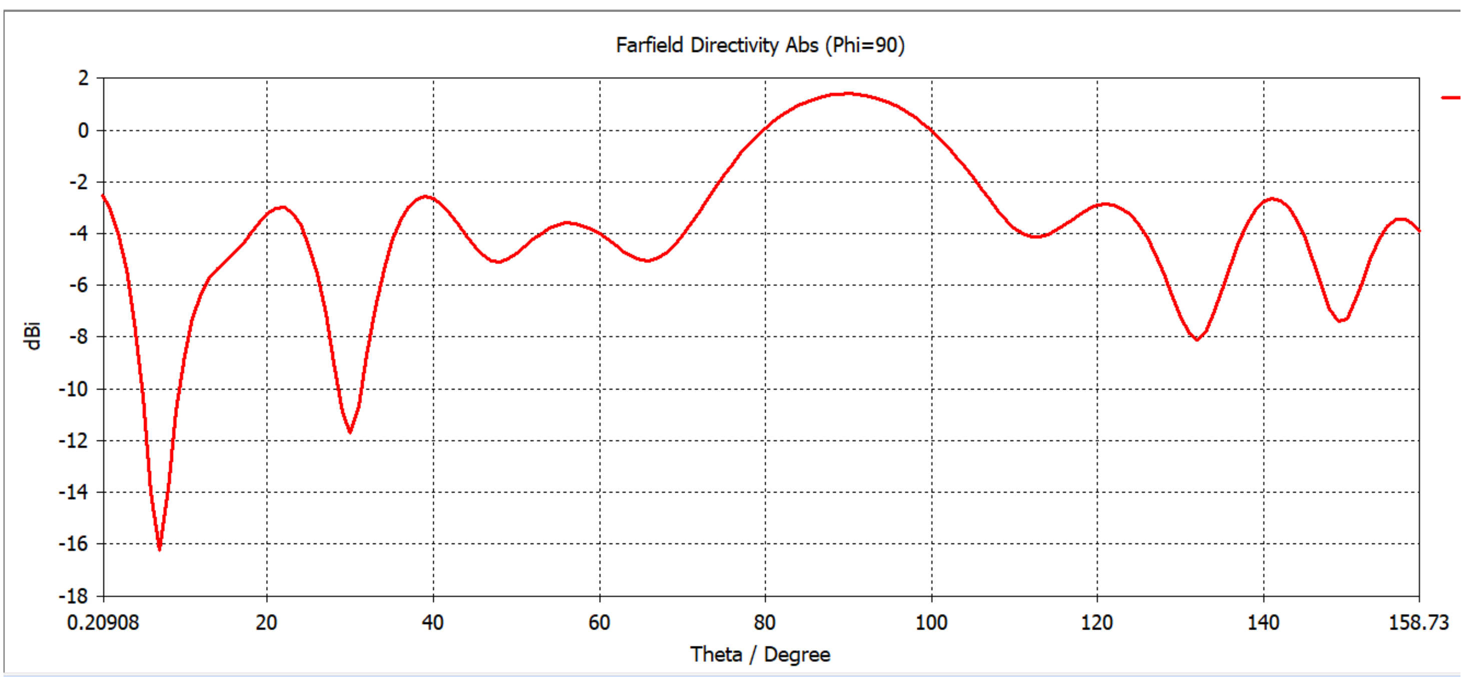


Figure 6.8: Far fields at 2.5 GHz.

- **Farfield at 6 GHz**





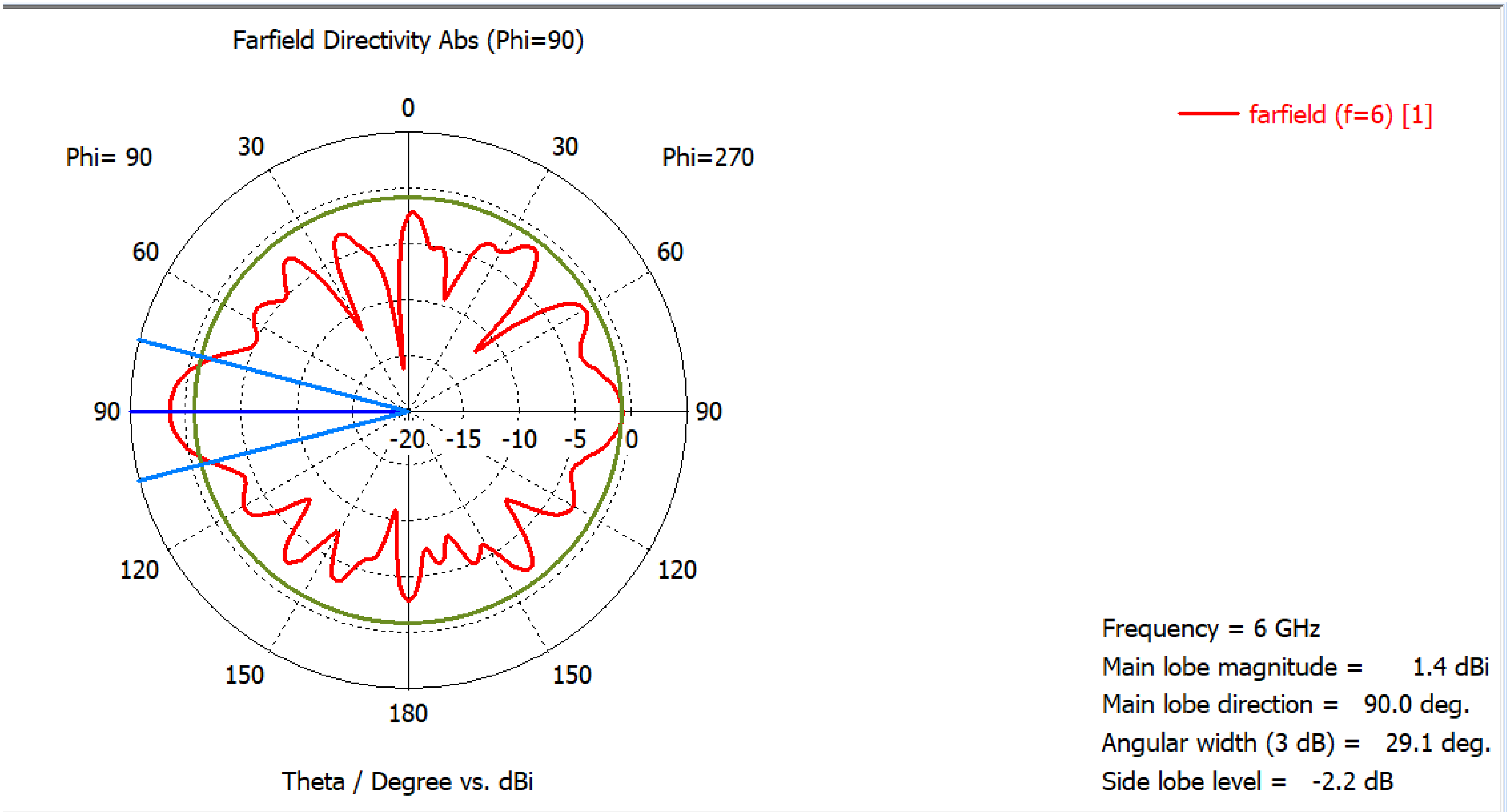


Figure 6.9: Far fields at 6 GHz.

7.Conclusion & recommendations

It was given at the beginning of this project the task to design an UWB antenna capable of good response in the range of frequencies starting from 800 MHz do 6 GHz. Looking at the simulation results we observe that the antenna in average behaves well in the bandwidth imposed. The S-parameter confirms this good behavior with most of the imposed frequency range below the -10db point. Beside the good return loss observed, we also notice that the antenna is highly directive at lower frequencies which can be an advantage as most of the power is concentrated in the wanted direction with the antenna tending to be less directive with the increase of frequency.

If we can be satisfied with the performance of this antenna we can still apply couple of improvements.

The first is the use of corrugations in the sides of the antenna arms. These work to suppress currents from flowing in these outer parts of the antenna arms. Any current flowing here will lead to radiation in directions other than the bore-sight, so suppressing this current will improve the directivity of the antenna specifically at high frequencies where the antenna seems to be les directive.

The second improvement consist in using performant dielectric for the antenna instead of FR4 which a good dielectric constant does not have, hence does not behave very well at high frequency. Materials such as Arlon 600 should be used instead as they high thermal conductivity, head dissipation and circuit miniaturization.

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