

**REPUBLIC OF TURKEY
FIRAT UNIVERSITY
THE INSTITUTE OF NATURAL AND APPLIED
SCIENCES**



**DESIGN AND OPTIMIZATION OF NEXT
GENERATION MOBILE SMART ANTENNA**

**Master's Thesis
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July-2017

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July-2017

DECLARATION

I declare that this thesis entitled “Design and Optimization of Next Generation Mobile Smart Antenna” is prepared by myself as a partial fulfillment of the requirements for the degree of Master of Science in Software Engineering.

Shokhan Ali Omar

ELAZIĞ-2017



DEDICATION

This work is dedicated to my beloved parents who have supported me through the course my master degree. It is also dedicated to my sincere supervisor Dr. Mehmet Kaya for their endless and unconditional support.



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I would like to express my sincere gratitude to my advisor Dr. Mehmet Kaya. I would also like to thank Prof. Dr. Asaf Varol for his constant support and help. I am grateful to my family for their constant support and help. I am very thankful to my husband who has always supported and motivated me for this great achievement.



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ABSTRACT

DESIGN AND OPTIMIZATION OF NEXT GENERATION MOBILE SMART ANTENNA

A smart antenna is a co-planar broadband antenna which is made from an electrical platform-utilized on both sides. Double-sided printed circuit board used in the design of this type of smart antennas makes it cost effective at the microwave level of frequencies exceeding 1GHz. This type of antennas is used for broadband frequencies, especially ultra-wideband as their manufacturing is easy for which PCB production is used. In this research, a new Model Vivaldi UWB is designed, fabricated and measured. After the successful implementation of single unit Vivaldi antenna, an 8x8 array of the same shape UWB antenna is designed, fabricated and measured in the laboratory conditions. Return-loss, VSWR, radiation pattern, and gain of the single-unit-antenna, as well as the 8x8 array, are measured and compared with the simulated results obtained through HFSS software. The compared results of the single unit antenna and array antenna show reasonable agreement. The designed antenna has a large bandwidth and high gain and it is very useful for the next generation mobile communications and MIMO applications. This is due to its fast speed, increased capacity, and its ability to eliminate the harmful effects of fading and signal multipath while attempting to obtain high data throughput deploying limited bandwidth transmission channels.

Keywords: M-shape Vivaldi Smart Antenna, Array M-shape, MIMO, Next Generation, Parameters.

ÖZET

GELECEK KUŞAK AKILLI ANTENLERİN TASARIM VE OPTİMİZASYONU

Akıllı anten bir koplanar boadband anten olup her iki tarafındanda elektrik kullanan bir platform üzerinde yapılmıştır. Bu tür akıllı antenlerin tasarımında kullanılan iki taraflı bu devre kartları mikrodalga seviyesinde daha fazla etki etmesini ve frekansların 1 GHz'i aşmasını sağlamaktadır. Bu tip antenler broadband frekansları içindir ve özellikle ultra geniş bant üretimleri PCB üretimi için kolay olduğu için kullanılmaktadır. Bu tezde, yeni bir UWB tasarlanmış, üretilmiş ve ölçülmüştür. Tek birimli ve M biçimli Vivaldi anteninin başarılı uygulamasından sonra, aynı biçimdeki UWB anteni için 8x8 bir dizim tasarlanmış, üretilmiş ve laboratuvar koşullarında ölçümlenmiştir. Geri dönüş kaybı, VSWR, radyasyon modeli ve tek birimli antenin kazanımı, 8x8 dizim gibi unsurlar HFSS yazılımı yoluyla elde edilen sonuçlarla kıyaslanmış ve ölçülmüştür. Kıyaslanmış bu tek birimli anten ve dizgili antenin kayda değer bir uyum içerisinde olduğu gözlemlenmiştir. Tasarlanmış anten büyük bir bant genişliğine sahiptir ve oldukça kullanışlı olmakla birlikte gelecek kuşak mobil iletişim için ve MIMO uygulamaları içinde yeterlidir. Bu onun yüksek hızına, artan kapasitesine ve zarar veren unsurları eleyen yapısına vesınırlı bant genişliğindeki tranmisyon kanallar üzerinden yüksek veri tranmisyonu esnasındaki çok yollu sinyal özelliğine bağlıdır.

Anahtar Kelimeler: M biçimli Vivaldi akıllı anten, M biçimli dizim, MIMO, gelecek kuşak, parametreler.

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SYMBOLS AND ABBREVIATIONS

1D	: One Dimensional
3D	: Three Dimensional
AF	: Array Factor
AVA	: Antipodal Vivaldi Antenna
BAVA	: Balanced Antipodal Vivaldi Antenna
CDF	: Cumulative Density Function
CPW	: Co-Planer Waveguide
CWSA	: Constant Width Slot-Antenna
dB	: Decibel
EM	: Electromagnetic
GSM	: Global System Mobile
H	: Horizontal
HFSS	: High-Frequency Structure Simulator
HPBW	: Half Power Beam width
LTSA	: Linear Tapered Slot-Antenna
MIMO	: Multiple Input Multiple Output
MISO	: Multiple Input Signal Output
MTL	: Microstrip Transmission Line
PCB	: Printed Circuit Board
SIMO	: Signal Input Multiple Output
SISO	: Signal Input Signal Output
SNR	: Signal Noise Ration

STBC : Space-Time Diversity Block Code

TSA : Taper-Slot Antenna

TSVA : Taper-Slot Vivaldi Antenna

UMTS : Universal Mobile Telecommunications System

UWB : Ultra Wide Band

V : Vertical

VNA : Vector Network Analyzer

VSWR : Voltage Standing Wave Ration

1. INTRODUCTION

1.1. Introduction

The rapid innovation of satellite, remote correspondence, remote detection, etc. has prompted the development of Ultra-Wide-band (UWB) electronic frameworks. Any radio innovation utilizing signals with a range involving a data transfer capacity either more noteworthy than 20% of the inside recurrence or a transmission capacity more prominent than 500MHz is characterized as UWB innovation [1]. UWB innovation needs special antennas with expansive transmission capacity and least mutilation of received and transmitted signals. Besides, UWB airborne applications have stern prerequisites on the measure of antenna exhibits to be utilized because of the constrained space.

The Tapered Slot Antenna (TSA) is considered as an excellent contender for different UWB applications and innovations. TSA antennas types produce a high level of gain, an extensive transfer speed, and they symmetrically perform in co-polarization and cross-polarization maneuvers. Essentially, these antennas are productive and are generally light in weight. In addition, TSAs are apparently basic in design constraint which makes them more favorable. Vivaldi antenna is the most regularly utilized TSA type for UWB applications. TSA Vivaldi antenna was initially presented in the work of Gibson in 1979 [2]. As a special type of TSA, Vivaldi antenna offers an expansive transmission capacity, a little directive propagation and cross polarization at m-wave frequencies. In addition, these antennas require minimal effort to develop and create, and they are genuinely inhumane two-dimensional resilience in manufacture handle. These advantages are gained from the printed circuit innovation utilized for the development of this type of antennas. Furthermore, Vivaldi antennas have compactness that is why they are generally consuming little power. It should be additionally noted that the directivity and beam-width of a Vivaldi antenna may be extensively enhanced by shifting the parameters of the plan.

This work deals with small size Vivaldi M-Shape smart antennas and arrays. The parameters affecting the Vivaldi smart antennas and the Vivaldi arrays and some parameters of MIMO application are studied and analyzed in the proposed thesis. The outlines of Vivaldi

antennas and the exhibition of the necessities, given in the taking after parts, are acknowledged also in light of this parametric review.

A tapered slot antenna as a broadband strip line cluster component that fits for multi-octave transmission capacities was presented in 1974 [3]. Taking after TSA, Vivaldi antenna, which is an exponentially tapered slot antenna, was originally outlined by Gibson in 1979 [2]. Gibson expressed that Vivaldi antenna had a critical pickup and direct polarization in a recurrence range from below 2 GHz to over 40 GHz. Gibson's Vivaldi antenna with a lopsided uneven microstrip to slot line move was built on alumina utilizing microwave photolithographic thin film systems. It served genuinely well for 8-40 GHz video recipient module [4].



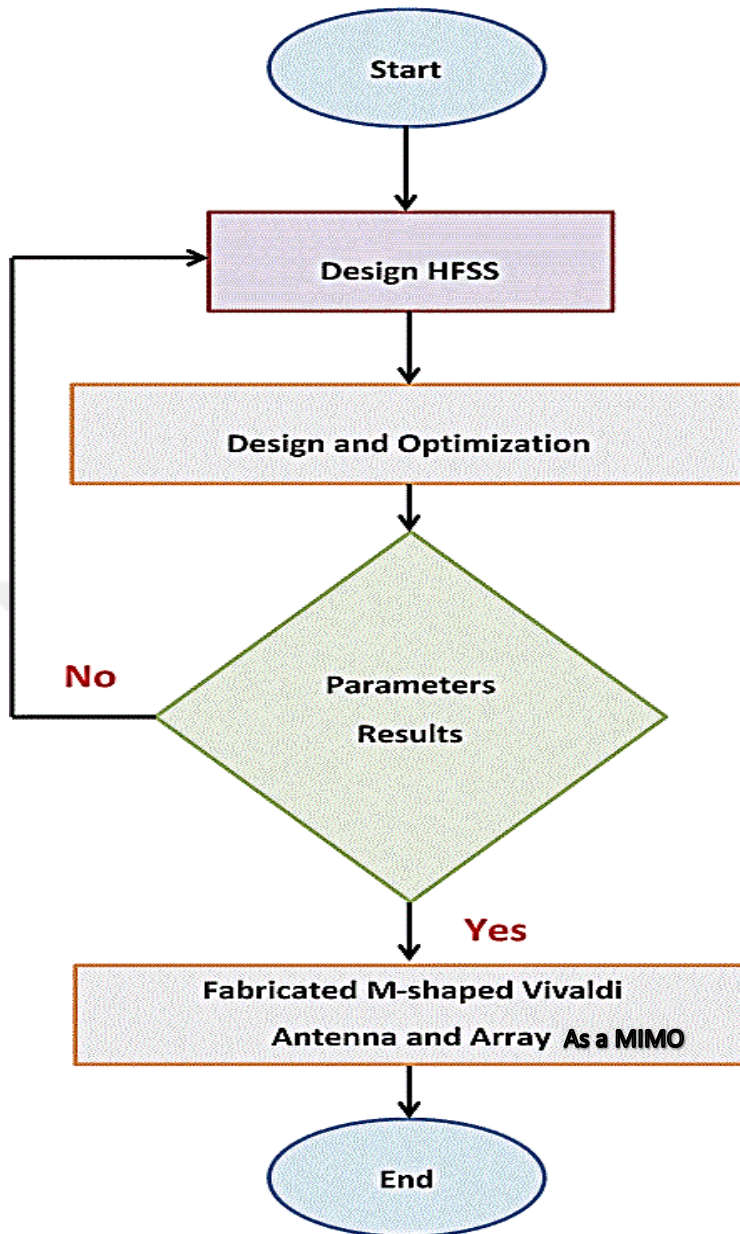


Figure 1.1: Flowchart of the Work

The basic workflow is provided in a flowchart format presented in Figure 1.1. The flowchart shows the research methodology of the work. In the first step, the antenna is analyzed and designed in HFSS. It is fabricated in the laboratory and tested for the antenna parameters.

1.2. A Brief Overview of Previous Work

Vivaldi antenna, here and there is additionally named Vivaldi core antenna, is a coplanar radiating-wave aerial with endfire radiation. In 1979, Vivaldi antenna was explored by Gibson and numerous developments to the underlying outline came afterward, specifically, in the progress of Gazit in 1988 as well as Langley and Halland-Newham in 1996.

Yngvesson *et. al.* in 1985 looked at three different types of TSAs, namely Constant-Width-Slot-Antenna (CWSA), Gibson's exponentially tapered-slot-antenna or Vivaldi-antenna and Linear-Tapered-Slot-Antenna (LTSA). Yngvesson noticed that Vivaldi antenna had the smallest side lobe levels followed by CWSA and LTSA. In the same time, Vivaldi antenna had the most extensive beam width while the narrowest beam width was achieved by CWSA. Likewise, they examined the impact Vivaldi antenna's length and the dielectric substrate's thickness on the obtained beam width [5].

In 2000, Gazit *et. al.* proposed two critical changes to the customization of Vivaldi outline. He utilized a low dielectric substrate ($\epsilon_r=2.45$) rather than alumina and an antipodal slot line move. The antipodal slot line move was developed by decreasing the microstrip line using a parallel strip fashion to an uneven two fold sided opening line. This sort of move offered moderately more extensive transmission capacity which was confined by the microstrip to slot line move of the customary outline. In any case, antipodal slot line move had the issue of high cross-polarization [6].

Langley *et al.* enhanced the antipodal move of Gazit with another adjusted structure keeping in mind the end goal to enhance the cross polarization attributes. This kind of structure, known as adjusted antipodal move, is comprised of a trouble layer tapered slots nourished, specifically, by a stripline. The E-field dissemination of transition antipodal was adjusted by the expansion of the said layer. Here, the tapered slots on both sides of the reception apparatus were filled-in as ground planes. The adjusted antipodal move offered an 18:1 data transmission with genuinely well cross-polarization qualities at that point [7].

Langley *et. al.*, likewise, built a wide transfer speed staged cluster utilizing this adjusted antipodal Vivaldi radio wire. He accomplished great cross-polarization levels and an additional wideband broad point checking [8].

In 2004, the cross-polarization of the antipodal Vivaldi reception apparatus was also enhanced utilizing distinctive systems as presented in the work of Kim *et. al.* [9]. They set the antipodal receiving antenna and its identical representation on the other hand in the cross-polarization. The cancellation of cross-polarization fields was pointed in this review and more than 20 dB decrease of the cross-polarization level at broadside was acquired.

In the same regard, Schuppert *et. al.* thought of an idea based on the roundabout stubs connected to a microstrip for slot line move, keeping in mind the end goal to offer a less demanding prototype [10]. In 2007, Sloan *et. al.* utilized outspread stubs rather than roundabout ones and enhanced the transfer speed of these sort of transition [11]. The progress of a similar work fashion was achieved in 2005 by Schaubert *et. al.* They utilized both round and spiral stubs, keeping in mind that the end goal is to outline strip line encouraged, metal balances placed on both sides of the component, for the Vivaldi receiving the wire. They expressed in their review that the transmission capacity of the radio wire was enhanced with the use of non-uniform stubs. Furthermore, they noticed that the outspread stub was more favorable in regards to the covering between round strip line and slot line stubs. It additionally appeared their review that the strip line encouraging expanded the reception apparatus data transmission and the microstrip sustainability [12].

1.3. Work Scope

The rapid innovation of mobile, satellite, remote correspondence, remote detection, and radar have prompted UWB electronic frameworks. Any radio innovation utilizing signals with a range involving a data transfer capacity: either more noteworthy than 20% of the inside recurrence or a transmission capacity more prominent than 500 MHz is characterized as UWB innovation.

The extent of this venture is to outline and create a novel M-Shaped Vivaldi UWB smart antenna. This antenna will have more than 500 MHz bandwidth as required for UWB applications. Moreover, the antenna will have a small contortion of UWB pulse to be used for the next generation mobile networks. The main objective of this work is to develop and design a smart Vivaldi antenna applicable for the next generation of wireless front ends, mobiles networks as well as Multiple Input Multiple Output (MIMO) applications.

The UWB antenna is ought to be small and simple-to-produce with accessible research center gear. The return loss is ought to be not more than (-10 dB) in the UWB defined range.

Some advantages, such as the bandwidth, directivity and side-flaps were not believed amid the design stages but, be that as it may, they were assessed for the last plan.

Extraordinary consideration has been paid to the impact feed parameters on pulse bending as well as the decrease. This is considered in the time-space and on the coordinating properties of the reception apparatus. A few procedures on the best way to expand the time-area beat constancy is then recommended and used in the last outline.

In the last stage, the proper simulation and design for an 8x8 array M-shaped UWB antenna are presented. This antenna will be suitable for future communication technologies where it will provide extensive bandwidth, high gain and smallest contortion of UWB pulse. The designed antenna shall be applicable for the next generation of mobile communications. The objective of this research is mainly to design a smart Vivaldi antenna applicable for the next generation wireless front ends, mobiles networks as well as MIMO applications.

1.4. Structure of the Thesis

This thesis consists of five chapters. The first chapter gives a brief introduction to Vivaldi antenna, its applications and its importance in the modern wireless communication systems. The same chapter also describes the previous work done in the area of Vivaldi antennas. In addition, the scope of the thesis work is also provided in the same chapter. The second chapter describes the antenna parameters. The third chapter is committed to the decision of transmitting framework from the assortment of known Vivaldi antenna designs. The best alternative is then chosen by the criteria stated already in the introductory part. Chapter four explains the steps of design, fabrication, and measurements of the simple Vivaldi-antenna and its array. Finally, the conclusions and directions for future work are presented in Chapter five.

2. FUNDAMENTAL OF ANTENNAS

2.1 Introduction

According to Webster's dictionary, the antenna is regarded as a metallic tool deployed for the purpose of emitting and acquiring radio waves from the environment. If we make an examination of radio or any correspondence circuit, we would see that the reception apparatus (antenna) has a transitional structure between the free-space and the controlling gadget. The managing or transmission line is frequently presented as a coaxial link or praise tube (wave direct). This transmission line is utilized to transmit electromagnetic energy generated from the radiating source to the reception apparatus, and the passed by the receiving wire to the conveying receiver circuitry. By nature, each metallic structure is an antenna, which will work for a particular scope of frequencies called the band of the reception apparatus (antenna) [13].

In a circuitry sense, the antenna can be expressed in its Thevenin and Norton equivalences.

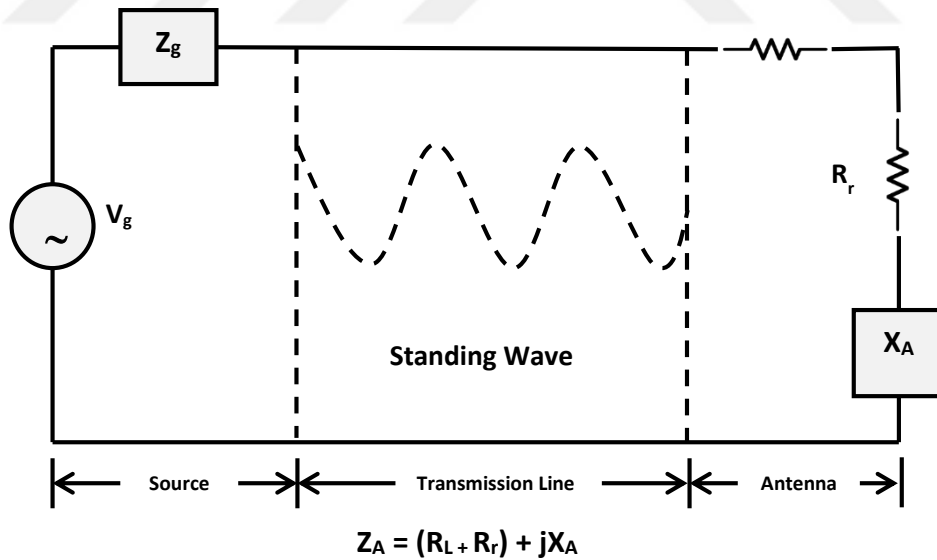


Figure 2.1: Antenna Equivalent Circuit Layout

In the above equation, Z_A is representing the antenna impedance in the antenna circuit, R_L is representing the conduction and dielectric losses, R_r represents the radiation resistance, and X_A is the reactance which is the imaginary portion of the complex antenna impedance as shown in Figure 2.1.

At whatever point there is a mismatch in the antenna and transmission line impedance, replication of electromagnetic energy through standing waves happens. Standing waves and capacity limit can be minimized by coordinating impedance of the reception apparatus to trademark the line impedance.

The purpose of the antenna, apart from transmitting and receiving, is also enhancing and accentuating energy in certain precise direction and suppress it in other directions. Such an antenna is called directive antenna [14].

2.1.1 Antenna Radiation Pattern

In antenna theory, the radiation pattern is called antenna pattern. Antenna pattern can be defined as a mathematical representation or graphical view created from the radiated energy's properties of an antenna. This representation is usually considered as a function of certain coordinates; for instance, the spatial coordinates.

The most frequently considered radiation property is the spatial dimension appropriation of the emanated energy [15]. This is considered as an element of onlooker's position in a direct way or consistent range surface. The radiation pattern is frequently marked in logarithmic scale (dB) as shown in Figure 2.2.

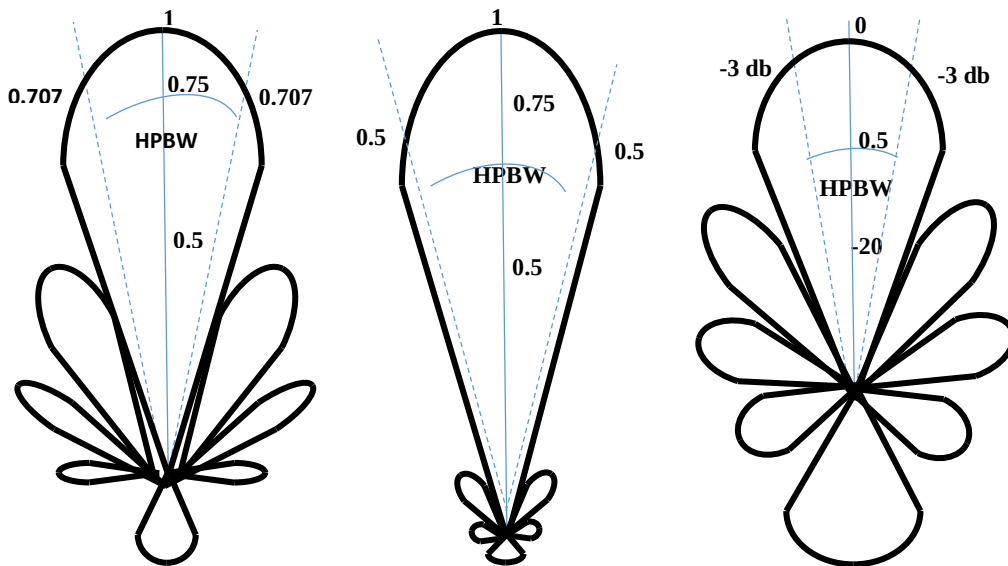


Figure 2.2: Radiation-Patterns (a) Field-Pattern, (b) Linear Power Pattern (c) Logarithmic Power Pattern

2.1.2 Radiation Intensity

The intensity of the radiation can be defined as the antenna's radiated power per unit of the rigid angle. The typically used unit for radiation intensity is W/m^2 . The unit of rigid is steroidal. One steradian is the rigid angle subtended to the surface of the sphere by an area equals to the square of the radius of the same sphere. Hence, the unit W/m^2 is used [16].

2.1.3 Beam Width

In accordance with the antenna's pattern, there is another parameter called beam width. The beam of the pattern can be stated as the angular separation between two identical points on the opposite of the pattern maximum. One of the most used beam width representations is the half power width. The half power beam width can be defined as the angular width separating two points where the intensity of the radiation is half of peak point of the beam, in the plane enclosing the peak of the beam as shown in Figure 2.3 [17].

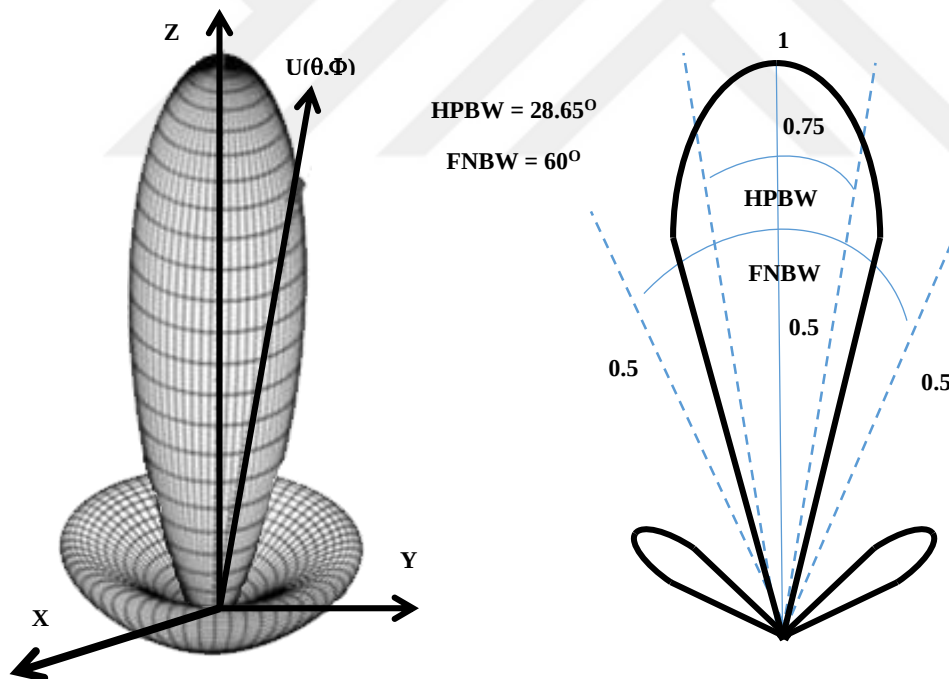


Figure 2.3: Beam Width and Half Power Beam width

2.1.4 Directivity

Antenna directivity is the antenna's ability to focus the radiated energy towards a specific desired direction. The directivity is also labeled as directive gain. There is an extensive range of definitions for directivity; however, the most effective one of them is the ratio the intensity of radiation in a specific direction originating from the antenna to the averaged intensity of radiation over all directions originating from the antenna. This can be mathematically presented in equation 2.1 [18].

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \quad (2.1)$$

Where

D is the antenna's directivity.

U is the radiation intensity of the antenna.

U_0 is the averaged over all directions radiated intensity.

P_{rad} is the antenna's radiated power.

2.1.5 Antenna Efficiency

There are some efficiency types associated with antennas. The total efficiency e_0 of an antenna is used to count for the loss generated by input terminals and within the antenna itself [17]. The loss types here are mainly categorized to reflection loss, conduction loss, and dielectric loss as shown in Figure 2.4.

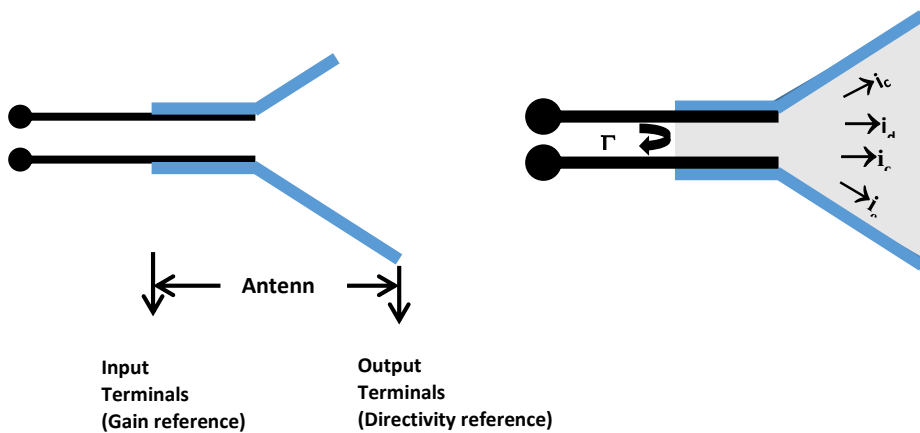


Figure 2.4: Diagram Showing Losses of Antenna

Generally, the total efficiency is presented in equation 2.2 [17].

$$e_0 = e_r e_c e_d \quad (2.2)$$

Where

e_r = reflect (mismatch) efficiency = $(1-|\Gamma|^2)$ (unit less)

e_0 = total efficiency (unit less)

e_d = dielectric efficient (unit less)

e_c = conduction efficiency (unit less)

Γ is representing reflection coefficient of voltage at the antenna's input terminals

$$(\Gamma = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}) \quad (2.3)$$

Where Z_{in} is the antenna's input impedance and Z_0 is the transmission line characteristic impedance.

$$VSWR = \text{Voltage Standing Wave Ratio} = \frac{(1+|\Gamma|)}{(1-|\Gamma|)} \quad (2.4)$$

2.1.6 Antenna Gain

Another measure which helps in describing the antenna is the gain. Gain and directivity are closely related. Gain is a measure which accounts for both antenna efficiency and directivity. The gain can be defined as “the ratio of intensity, in a given direction, to the radiation intensity that would be obtained if the power accepted by the antenna were isotropically” as presented in equation 2.5 [18].

$$Gain = \frac{4\pi * \text{radiation intensity}}{\text{Total input power}} = 4\pi \frac{U(\theta, \phi)}{P_{in}} \quad (2.5)$$

2.1.7 Bandwidth

Data transfer capacity or the antenna's bandwidth is characterizing the frequency scope. Here, the execution of reception apparatus (antenna) as for a few contracts ticks is adjusted to the indicated standard. The capacity of the bandwidth may be thought of as the scope of recurrence on any side of the focus frequency. Antenna qualities must be inside a satisfactory estimation of the ones at the focus frequency. For expansive band antennas, the transmission capacity is normally presented as the proportion of upper to lower of focus (central) frequencies. Since the attributes of an antenna don't, as a matter of course, a shift in the same

way, or are even basically influenced by the frequency, there is no one of a kind portrayal of the bandwidth [20]. This can be elaborated in equations 2.6 and 2.7.

$$\text{For narrowband} \quad BW = \frac{f_H - f_L}{f_c} \times 100 \quad (2.6)$$

$$\text{For wide band} \quad BW = \frac{f_H}{f_L} \times 100 \quad (2.7)$$

2.1.8 S-Parameters

The S-matrix (Scattering matrix) is the scientific development which evaluates how the microwave energy is propagated from multiple port system. The scattering matrix is the thing that permits us to precisely portray the properties of inconceivably confounded systems as basic black boxes. For a radio wave signal occurrence on a single port, some division of the signal reflects from that port, some of it disperses and leaves through different ports (sometimes amplified) and some of it is lost as even EM radiation or heat. The scattering matrix with N -port has N^2 coefficients for scattering matrix, every coefficient defines a probable input/output path [20]. Scattering parameters are complex in angle and magnitude because both the phase and magnitude represent the input signals which are varied by the system. The concern is always focused only on the magnitude since it has more interest.

S-parameters refer to the radio frequency “output voltage vs. input voltage”. Scattering parameters arrive in a lattice and tell about the quantity lines where the segments are equivalent to the number of ports. For the scattering parameter index “ ij ”, the j port is energized (the info. port), and the i port is kept for the yield. The parameters along the corner to corner of the scattering grid are alluded as reflection coefficients. This is considered in light of the fact that they just allude to what occurs at a solitary port, while off-inclining S-parameters are alluded as transmission coefficients [20]. This is basically on the grounds that they allude to what occurs starting with single port then onto the next. The S-lattices for one, two and three-port systems are shown in Figure 2.5.

(S11) One port

$\begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}$ Two ports

$\begin{pmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{pmatrix}$ Three port S-matrix

There are two ways to represent S-parameters, either in linear magnitude or decibels (dB). For decibels (as scattering parameters are a voltage ratio), the formula is given in equation 2.8 [20]:

$$S_{ij} = 20\log[S_{ij}(\text{magnitude})] \quad (2.8)$$

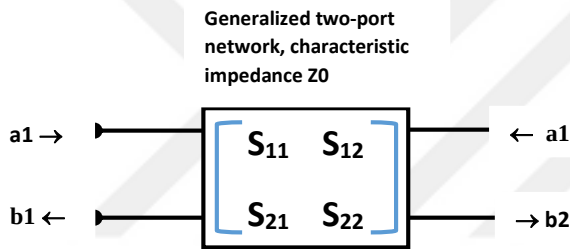


Figure 2.5: S-Parameters with Input and Output Ports

2.1.9 S-Parameter Definition

- For the two-port system, S_{11} , S_{22} , S_{21} , S_{12} are the scattering parameters.
- S_{11} is forward and S_{22} is reverse reflection coefficients terminated with opposite port with Z_0 (50 Ohm).
- S_{21} is forward and S_{12} is reverse gain coefficient terminated with source Z_0 and 50 Ohms load.

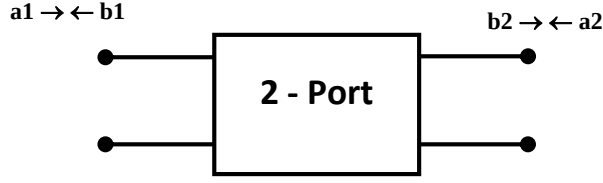


Figure 2.6: Two Port Network Diagram

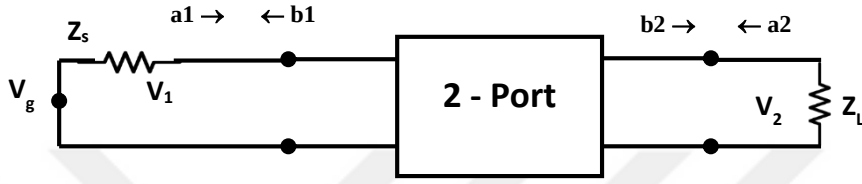


Figure 2.7: Two Port Network Circuit Model with Load and Source Impedances

Figures 2.6 and Figure 2.7 present a general model for two-port network circuit model [20]. The parameters here are elaborated as follows:

a_1 and a_2 represent the incident waves

b_1 and b_2 represent the reflected waves

Z_S and Z_L are source and load impedances respectively.

$$S_{11} = \frac{b_1}{a_1} \big|_{a_2=0} \quad = \text{input reflection coefficient } \Gamma_{in} \text{ when } Z_L = Z_0$$

$$S_{21} = \frac{b_2}{a_1} \big|_{a_2=0} \quad = \text{forward transmission gain (insertion) when } Z_L = Z_0$$

$$S_{12} = \frac{b_1}{a_2} \big|_{a_1=0} \quad = \text{reverse transmission gain (insertion) when } Z_S = Z_0$$

$$S_{22} = \frac{b_2}{a_2} \big|_{a_1=0} \quad = \text{output reflection coefficient } \Gamma_{out} \text{ when } Z_S = Z_0$$

2.1.10 Voltage Standing Wave Ratio

In antennas, the result of dividing the maximum voltage on the minimum voltage is called VSWR (Voltage-Standing-Wave-Ratio). VSWR is the measure of antenna matching with the feeding lines. VSWR tells if the impedance match occurs between antenna impedance and transmission line impedance. For the perfect matching value, VSWR should be kept equals to 1 based on the following equations [21]:

$$\text{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} \quad \text{Here } \Gamma \text{ is the reflection coefficient.} \quad (2.9)$$

$$\Gamma = \frac{Z_1 - Z_0}{Z_1 + Z_0} \quad (2.10)$$

2.1.11 Polarization

The electric field lines of the flux that are received by the antenna through their development are representing the polarization. Polarization is one of the important aspects of the antenna [16]. Polarization can be found by the direction of the antenna. There are three kinds of polarization: linear, circular and elliptical as shown in Figure 2.8.

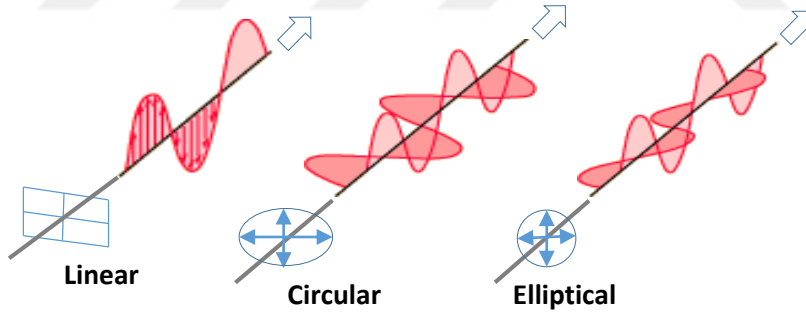


Figure 2.8: Types of Polarization

2.2 Evaluation of the Next Generation Wireless Mobile System

As the next generation mobile system will be using a higher frequency band than the current mobile systems like GSM and UMTS [37], the coverage of the base stations will be smaller.

In addition, the data rate shall be much higher than GSM and UMTS. One of the possible candidates applicable for the next generation mobile communication is the MIMO (Multiple Input/Multiple Output) system. In MIMO systems, there is more than one antenna used.

Hence, there is a demand for designing suitable types of antennas with lower size and wider bandwidth. In this research, a new model of the antenna is designed that satisfies the specified requirements. In addition, the designed antenna can be extended to an array fashion to form a MIMO system.

In this research, the deployment of Vivaldi antenna, TSA model, is used for evaluating the smart antenna characteristics based on its far-field pattern and impedance.

The evolution of wireless mobile technology from 1G to 5G are explained below as follow:

- First Generation (1G) refers to the cellular systems that developed during the 1970s as analog communications standards. The sound channel used for frequency modulation in 1G was through FDMA techniques [33].
- Second Generation (2G) is the cellular telecommunications systems which developed in the 1980s. The system had been arranged to sound with simplest low velocity for data manipulation [34].
- Third Generation (3G) offers high-speed data services and sound capability. This technology provides multimedia to 2G phones by enabling graphics, audio and video applications. With a 3G-enabled phone, it is possible to conduct a video telephony or watch a streaming video. The third generation increased the used bandwidth to up to 384 kbps [35, 36].
- Fourth Generation (4G) offers the global mobility support and multimedia anywhere and anytime. It has also been providing effective wireless solutions and personal services since 2009.
- Fifth Generation (5G) is a used terminology and has not officially or technically been used. Rather, 5G is considered as an ongoing research progress in the field of mobile telecommunication area. The research of 5G realization was initiated in 2012 and it is expected to be commercially released in 2020 [37].

The details of mobile wireless technology developments are provided Table 2.1.

Table 2.1: Mobile Wireless Technology Generations Development

Next Generation	Frequency Band	Data Rate	Band Width	Switching	Application
1G	800MHz	2.4Kbps	30KHz	Circuit	Voice
2G	850-900MHz	10Kbps	200KHz	Circuit	Voice + Data
3G	(900-2100)MHz	384Kbps	5MHz	Packet, Circuit	Voice + Data + Video Calling
4G	(1.8-2.6)GHz	3Gbps 1.5Gbps	1.4MHz to 20 MHz	Packet	Online gaming + High Definition Television
LTE Advanced	(2.3GHz-2.5GHz - 3.5GHz)	100-200Mbps	(3.5MHz, 7MHz, 5MHz, 10MHz, 8.75MHz)	Packet	Online gaming + High Definition Television
5G	3.5-50 Gaps (expects)	1.8, 2.6 GHz and expected 30-300 GHz	3.5GHz-60GHz	Packet	Ultra High definition video + Virtual Reality applications

3. RADIATING STRUCTURES

3.1. Introduction

The three basic sorts of Vivaldi antennas, which can be utilized to outline the transmitting process are discussed in the following sub-sections. The followings are the fundamental sorts of Vivaldi antennas:

- Tapered-slot Vivaldi Antenna (TSVA)
- Antipodal Vivaldi Antenna (AVA)
- Balanced Antipodal Vivaldi Antenna (BAVA)

The components and properties of every specific outline were examined at the very beginning of this chapter after the fundamentals of the antenna without further. Thus, these outline sorts are mimicked and their belongings are researched with respect to the specifications set of the coveted antenna. Towards the section end, the most rational plan is decided for the practical work to be achieved [22].

3.2. Vivaldi Antenna Design's Overview

3.2.1. Tapered-Slots Vivaldi Antennas

Planning Vivaldi antenna in tapered-slot fashion was firstly suggested by Gibson in 1979 [4]. It is fundamentally a wide slot line, created on a solitary metallization sheet and upheld by the dielectric substrates of some known permittivity.

The decrease outline is exponentially bent, making a smooth move from the still into the exposed area. This outline presents multi-cut of points for the working bandwidth of the proposed antenna, taking the lead for slot line radiation. Slot line begins to transmit essentially under the state presented in equation 3.1 [23].

$$ws = \frac{\lambda_0}{2} \quad (3.1)$$

Where ws is the width of the slot.

In this manner, the exponential decrease of the wide end roughly characterizes the most minimal conceivable or recurrence which is transmitted via the framework. However, the slot's width at the decrease is presenting the high recurrence cutoff [2].

Different impediments accompany the slot line itself. Above all else, the slot line is an adjusted transmission line. Along these lines, it is important to fuse a balun (move) if the bolstering line is ought to be coaxial or by and large uneven. Making a wideband balun is, as a rule, entangled assignment, rendering this arrangement to some degree inconvenient. The utilization of balloons was, in this way, regular during the early planning stages; however, it has been outperformed by the antipodal outlines in recent years [10].

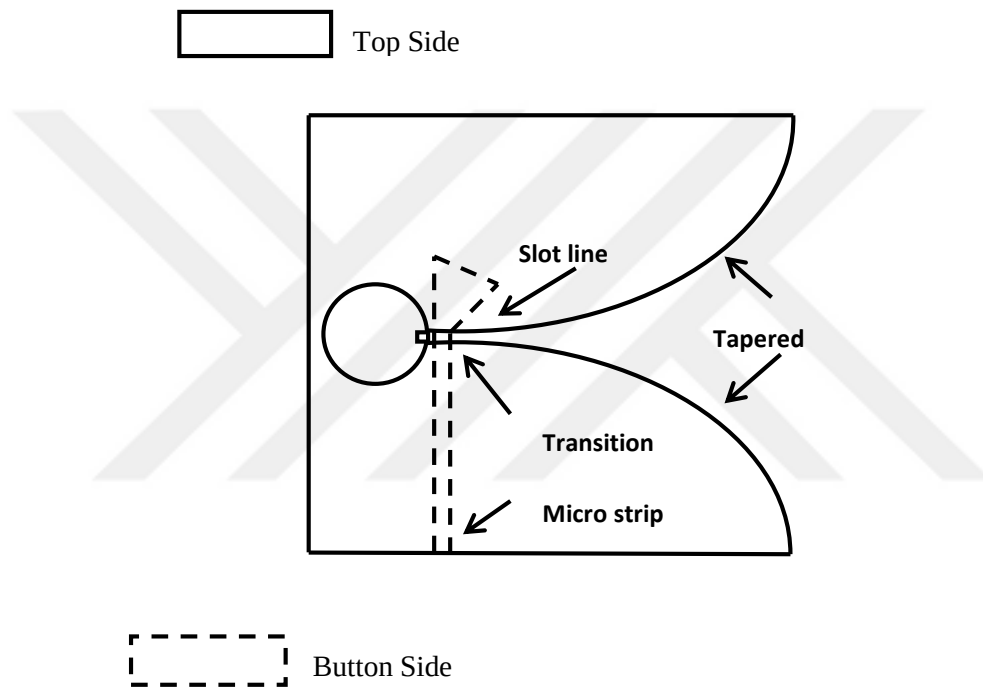


Figure 3.1: Tapered-slot Antenna

Microstrip to slot-line move is, as appeared in Figure 3.1, for the most part, utilized for decreased slot Vivaldi antenna. It is conceivable to the configuration moves which work over the timing of bandwidth or supplementary [6]. Issues might be brought on by the way that on a thin substrate with low dielectrics steady, it is hard to create nonradioactive limit 50 slot line. A slot line with higher line impedance is then utilized and considered as the best candidate for any desired structure. In such a case, an impedance adapter must be consolidated.

Previously, the microstrip to slot line move used to require extra space on board which basically makes the entire plan more intricate [5].

Vivaldi antenna, as a decreased slot framework, is using a voyaging wave. This voyaging wave engenders forever the decrease with stage speed v_{ph} , that needs to hold to the accompanying condition, as presented in equation 3.2 [6].

$$v_{ph} \leq c \quad (3.2)$$

Keeping in mind the end goal is to accomplish an endfire radiation. In the event that the stage speed surpasses C , the fundamental bar in the radiation example becomes a part and the radiation is no longer an endfire. An ideal speed proportion has been characterized in [5], bringing about the most extreme directivity as presented in equation 3.3 [23].

$$p = \frac{c}{v_{ph}} = 1 + \frac{\lambda_0}{2L} \quad (3.3)$$

It can be similarly said that the greatest directivity happens on the account of an aggregate stage increment of 180° , created by the dielectric backing off the voyaging wave. On the off chance that the stage move is any greater than 180° , the fundamental bar gets off the endfire bearing.

Based on the previously presented perceptions, the ideal scope of compelling dielectric thickness standardized to the free space wavelength λ_0 has been recognized. The ideal range is around (0.005) to (0.03), and the standardized successful dielectric thickness is characterized in the connection as given in equation 3.4 [10].

$$\frac{t_{eff}}{\lambda_0} = (\sqrt{\epsilon_r} - 1) \frac{t}{\lambda_0} \quad (3.4)$$

Where t is the genuine substrate's thickness.

This manager is ought to hold for any decreased from work inside the distance of $4\lambda_0$ to $10\lambda_0$. Industrial dielectric substrates slenderer than the ideal esteem brings about a more extensive shaft. However, thicker substrates than the ideal cause the example to part up with an invalid outcomes in the end-fire bearing.

If there should arise in the occurrence of the ideal range, the directivity of the radiation structure is, for the most part, characterized by the distance of decrease. An experimental govern inferred by Yngvessn *et al.* characterizes a common connection between the decrease distance and direction of a subjective decreased slot antennas takes after in equation 3.5 [10].

$$D = 10\log\left(\frac{10L}{\lambda_0}\right) \quad (3.5)$$

Where L is the distance or length of the decrease.

This connection contract for decrease distance of $3\lambda_0$ to $7\lambda_0$. Furthermore, $c/v_{ph} \approx 1.05$. The multiplicative co-insistent for longer antennas is fairly lower as presented in equation 3.6 [6].

$$D = 10\log\left(\frac{4L}{\lambda_0}\right) \quad (3.6)$$

The comparable empirical rules and beam width in degrees were previously discussed for their optimization purpose. This is thoroughly discussed in [6].

$$BW = \frac{55}{\sqrt{\frac{L}{\lambda_0}}}; BW = \frac{77}{\sqrt{\frac{L}{\lambda_0}}} \quad (3.7)$$

When all is said in done, it's protected to state that long structures can accomplish more than 10 dB directivity in the endfire course. The fundamental cutoff is the previously mentioned stage contrast separating the primary pillar. A diffract happening on the acute cornering of wide decrease end has an additional effect on the example discontinuity [3]. This could be dealt with by the suitable bending of the corners.

A few varieties of the first outline was acquainted with enhancing the properties of the proposed work. Documentary indicates endeavors to enhance both H and E-plane examples and before to back proportion. This is done by presenting the geometry on the external verge of the antenna [5] or joining a resistive stacking [8]. Anther upgrade manages the transmission capacity constraints by variable the geometric of the decrease to half-breed exponent flare [1].

3.2.2. Antipodal Vivaldi Antenna

Antipodal Vivaldi Antenna reception apparatus was examined by Nesteroin in 1985 and Gazitoin in 1988 [3]. The main aim was to solve the bolstering issues related to Gibson unique plan.

The antipodal design of the reception apparatus is made on a dielectric substrate with two-sided metallization. The bolstering part is considered as a microstrip line which is trailed by a microstrip to adjusted the movement of the strip line. This strip-line fills in as a bolster to the antipodal exponential decreased balances. Balances are orchestrated in such a path, from a perspective opposite to the substrates' plane, that makes a flared form. Not at all like the first Gibson's plan, antipodal balances additionally have extra nail edges which can impact return misfortune and radiation example of the reception apparatus [24]. More often than not, exponential ebbs and flows are utilized to characterize the external edge; therefore, the parameter of the shape can vary from the internal decrease. The antipodal outline can be seen in Figure 3.2.

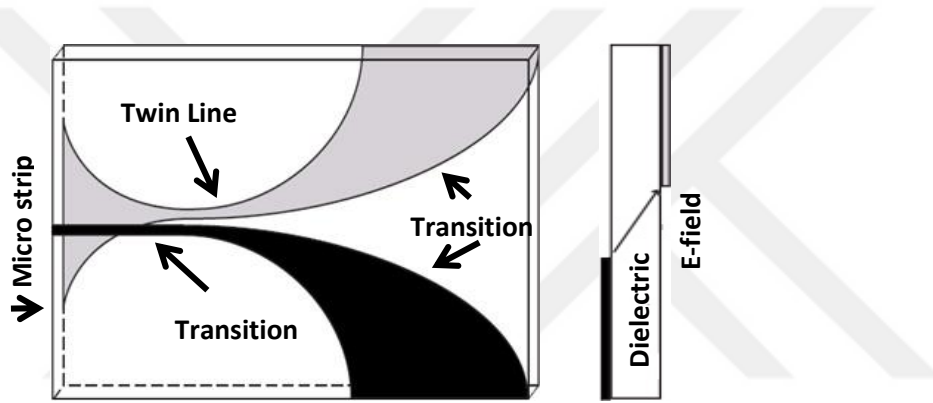


Figure 3.2: Antipodal Vivaldi Antenna

This plan holds a few points of interest contrasted with the single sided Vivaldi reception apparatus. Above all else, the microstrip to twin line move is genuinely simple to plan and fabricate. Additionally, the twin line bolster expands the high cutoff recurrence, due to the fact that there is no slot-line display confinement as inspected in the single side decrease [2]. The principle impediment of the antipodal design is the cross-polarizing, especially observed for high frequencies. The main reason for this observation is occurred due to the opening fields skewing. While considering the skew, it is important to mention that it is altered in conjunction with the decrease length. This situation is most noteworthy at the end part of the reception side. This is basically where the emanation of high frequencies take place. However, this situation is generally irrelevant at the open ends, depending on the substrate's thickness. The ultimate result here is a cross-polarization that is able to achieve a value more than -5dB [7] and, at the same time, it is altogether recurrence subordinate.

Separated from the polarization issues, the example parameters are like the first Vivaldi plan at last fire bearing. Be that as it may, there is typically a larger amount back projection brought about by the crawling wave taking after the edges of the antipodal balance and spilling to the external decreases. This imperfection is particularly critical when the corners of the transmitting flares are bent to limit the effects of both diffraction and reflection.

Different enhancements and varieties of the antipodal outline have been recorded. For instance, a marginally extraordinary geometry of the base side metallization without the twin line area is presented in [9]. Half and half - exponent flare from of the antipodal Vivaldi likewise exist, as recorded in [1].

3.2.3. Balanced Antipodal Vivaldi Antenna

This type of design is one of the most recent development to the first outline. It was discussed and presented by Langley and Halland-Newham in 1996 [7]. This plan is developed from the antipodal variant. The cross-polarizing is decreased by including another layer of metallized substance making an adjusted strip-line.

Such arrangements are portrayed in Figure 3.3. Generally, they portray the capacity of the third metallized layer and two vectors of the E-field. These are guided towards the path from the focal plate to ground planes aggregate up to offer a subsequent E-field vector that is parallel to the metallization. In this case, an adjusted antipodal Vivaldi receiving wire with a normal cross-polarizing of -20 dB is provided [20].

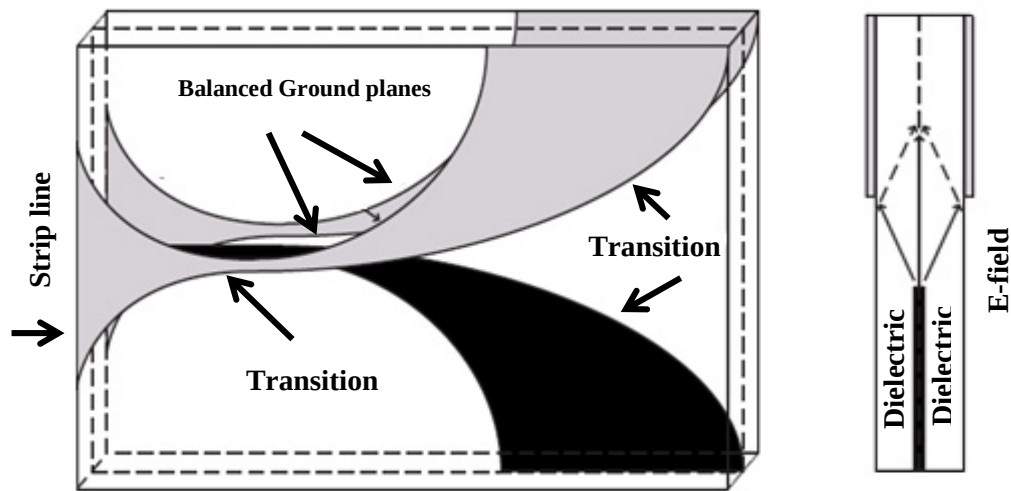


Figure 3.3: Balanced Antipodal Vivaldi Antenna

In addition, the way the bolstering line is made by a strapline is also favorable in this plan. The advantage here is lessening the radio wire radiation which may happen if there should be an occurrence of open bloster lines of the antipodal decreased space Vivaldi. This arrangement smothers the radiation design perturbances brought on by the lines' open encourage [20].

There are additionally few hindrances of the adjusted outline. Normally, the construction of such receiving wire is more entangled due to the triple from work, forestalling it from manufacture in some lab condition. Besides, the distinctive geometries of the ground planes and focal plan are bringing on an unequal engendering speed for the surgeon front streams, which brings about an E-plan radiation design squinting [7]. The squinting here is archived to be autonomous of recurrence and substrates dielectric permittance.

Except for cross-polarization, both examples, and coordinating possessions don't vary fundamentally from the antipodal plan. Consistent beam width for an extensive variety of frequencies has been accomplished, together with a directivity more than 10 dB.

4. ANTENNA DESIGN AND MEASUREMENT

A cutting edge M-shaped UWB Vivaldi smart antenna array is designed and presented in this chapter. Initially, the design of a simple M-shaped UWB Vivaldi antenna is produced. The design has considered the required properties such as radiation pattern, VSWR, return loss, gain etc. where these properties are analyzed to produce the optimal design. Basically, upon the successful simulation, design and implementation of a simple UWB Vivaldi antenna, a more complicated array of M-shaped UWB antenna is also simulated and designed. Once the simulation and design of the M-shaped UWB antenna are done, the design is fabricated in order to produce a real physical antenna for further testing. For antenna fabrication purposes, FR-4 substrates are used as they are commercially available and have a convenient price. The used FR-4 for this design's fabrication is having a relative permittivity of 4.4 and height of 1 mm. This design is enabling the antenna to produce a wideband and high gain. This makes the designed antenna very suitable for the next generation of wireless communication as it is efficient, has a wide bandwidth and high gain.

4.1. Introduction

Recently, UWB transmission applications have been widely considered. This is due to the fact that wireless communication applications are pervading the academic research as well as the industrial productions [25-26]. UWB technology has many advantages such as the reduced power consumption and interference, the availability of following a custodian receiver and the produced data rate level. One of the very classical UWB antennas is the Vivaldi antenna. Initially, this type of antenna was investigated in the work of Gibson in 1979, yet, the initial design has been reinvestigating and redeveloped in many research attempts [27-28]. The orientation of Vivaldi antenna is basically based on an endfire radiation planar traveling wave. Ever since its invention, the Vivaldi antenna has been widely preferred for UWB applications. The choice here is made as this antenna addresses critical required characteristics such as low cross-polarization, high bandwidth capacity and high directive patterns [28].

In general, if some antennas are transmitting at the same time within the same premise, the emitted electromagnetic (EM) waves may interact. The result of this interaction may lead

to a dissipation of the waves or, in some case, a reinforcement of the transmitted beams. The term “beam” here is scientifically referring to the pattern generated by the transmitted EM. This pattern may also be called lobe. In practical antenna design, there should always be a strict control on how antennas are transmitting and how the patterns are interacting. One of the ways to control this process is to shape or form the produced beams; this maneuver is specifically called beamforming. The most frequently used beamforming in practice is implemented by adjusting carrier phase based EM waves. However, in this experimental work and practical designed, the beam forming is produced by the impulse based process to eliminate the grating lobes.

Directional antennas have many advantages in certain communication applications. They are widely used in UWB applications and radar scanning. Essentially, directional antennas are energy efficient. This can be explained by the fact that directing the transmitted energy to one main lobe towards the direction of interest allows the receiving antenna to get the highest possible power. Compared to the standard omnidirectional antennas where the transmitted power is emitted in all directions, directional antennas are energy focused which reduces the overall power dissipation.

There are many applications developed based on high-resolution beamforming. For instance, lightweight EM cameras that are being developed as a replacement for the currently available bulky hospital imaging systems. In this context, EM beamforming is ideally used in Vivaldi antennas which allow them to be attractive antennas for many applications. Here, one of the aspects that should be carefully tackled to produce well-controlled transmitted lobes is the directivity. The directivity is specifically essential in controlling the radiated energy and produce the needed focus of the beams. In some applications, it is required to transmit some sort of short duration Gaussian pulses. In this case, the used transmitting antenna should maintain a wide bandwidth as it is vital for distortion reduction [29].

4.2. Design of a Simple UWB M-Shape Vivaldi Smart Antenna

This section explains the design procedure of the Vivaldi UWB antenna for emerging wireless technologies.

4.2.1. Antenna Design Parameters

To design Vivaldi antenna, there are some conditions and parameters must be satisfied. The peak operational frequency f_H and antenna's width $d+2w$ shall satisfy equation 4.1 to avoid the production of any grating lobes emitted by the designed M-Shaped Vivaldi [10]. For the proposed antenna in this work, as shown in Figure 4.1, the dimensions are set to $W=0.0455\text{mm}$ and $d=0.003\text{mm}$. Here, the equation will be multiplied by two as the proposed M-shaped is dual Vivaldi Antenna. This is elaborated as follows:

$$2*d+3*w = 2*0.0455+3*0.003=0.1\text{m} = \text{Width Taper-Slot M-shape Vivaldi Antenna}$$

$$d + 2w < \frac{c}{f_H \sqrt{\epsilon_e}} \quad (4.1)$$

$$2 * d * 3w < \frac{c}{f_H \sqrt{\epsilon_e}} \quad (4.2)$$

Where

d = width of taper slot

w =corner of tapered slot

ϵ_r Is a constant reflecting the effectiveness of the dielectric, c is light velocity = $3*10^8$ m/s.

$$0.11 < \frac{3*10^8}{f_H \sqrt{0.065}} \quad F_H < 8.85\text{GHz operational frequency}$$

Therefore, the maximum operational frequency for the proposed M-shaped Vivaldi antenna is less than 8.85GHz. The characteristic impedance is 50.57 Ohm.

The transition design of strip line to slot line starts with the choice of the substrate material and thickness. Strip line width is calculated using the strip line characteristic impedance formulas of equation 4.4 [11]:

$$Z_0 = \frac{n_o}{2\pi\sqrt{\epsilon_r}} \ln \left\{ 1 + 0.5 \frac{8b}{\pi w'} \left[\frac{8b}{\pi w'} + \sqrt{\left(\frac{8b}{\pi w'} \right)^2 + 6.27} \right] \right\} \quad (4.3)$$

$$w' = w + \frac{\Delta w}{t} \quad \frac{\Delta w}{t} = \frac{\ln(\frac{5b}{t})}{3.2} \quad (4.4)$$

$$Z_o = \frac{60}{\sqrt{\epsilon_r}} \ln \left(\frac{4H}{0.67\pi(T+0.8w)} \right) \Omega \quad (4.5)$$

Where

Z_o = Characteristic impedance of the strip line.

n_o = Free-space wave impedance

ϵ_r = Relative permittivity of dielectric

H= Height of the dielectric

T= Thickness of the strip-line

W= width of the strip line

The dimensions and geometry of the designed antenna are illustrated in Figure 4.1 and presented in details in Table 4.1. FR-4 is used in this research as a substrate for antenna fabrication purpose. The used FR-4 in this work has the following characteristics $h= 1$ mm and $\epsilon_r = 4.4$. This substrate has both top and bottom layers metalized and they are made of copper. In the fabrication process, top metal layer, bottom metal layer and the substrate are cut in an M-shape form to produce the Vivaldi antenna. In order to improve the bandwidth and create an efficient UWB antenna, the circular slot is deployed as a design maneuver. The designed antenna should be able to operate for UWB applications and in a frequency range of 3 GHz- 9.4GHz.

Table 4.1: Dimensions of Antenna Design

Dimension	Value (mm)
Total length	160
Taper width	50
Feedline length	7
Total width	100
Taper length	140

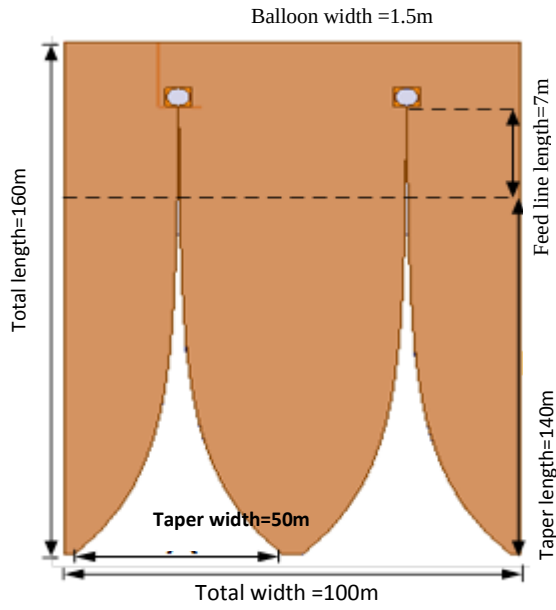


Figure 4.1: Top View of the Proposed M-shaped Vivaldi UWB Antenna

As a standard procedure for validating the simulation results, the antenna is fabricated, as shown in Figure 4.2, using the commercially available FR-4 substrate. This commercial substrate has 4.4 dielectric constant, 0.02 loss tangent and 1 mm thickness. The fabricated antenna is excited using a BNC coaxial port. The reflection coefficient, gain and VSWR of the designed antenna are measured and analyzed.

The dimensions of the designed Vivaldi antenna are chosen based on the frequency and the parameters given in the abovementioned equations. Firstly, HFSS Ansoft is used to design both the M-Shape Vivaldi antenna and the array antenna. Then, the practical fabrication is made and tested using a spectrum analyzer, microwave signal transmitter and receiver and a motor shaft to calculate the radiation pattern with the use of the Signet software. Also, the same tests are conducted using Agilent Vector Network Analyzer (VNA) in open air conditions to produce the needed measurements. The snapshots of the VNA taken during the measurement are shown in Fig.4.2. For pattern measurements, the proposed antenna has been fixed on the positioner or turntable. The distance between the proposed antenna and probe antenna is adjusted to 8 meters for the purpose of far-field pattern measurements.



Figure 4.2: Setup for Radiation Pattern Measurements

4.3 Laboratory Optimization and Testing of Simple & Array M-Shaped Vivaldi antenna.

Some parametric studies and practical measurements of M-Shaped Vivaldi antennas start in their laboratory work by lowest to highest frequencies to give the best results.

4.3.1 E-Plane Pattern

The transmitter and receiver of M-Shaped Vivaldi smart antenna are initially designed and tested considering (Vertical to Vertical). The results for this case are provided in Table 4.2.

Table 4.2: The Frequency and Received Power (E-Plane Pattern)

Vertical To Vertical	
Frequency	Received Power
100 MHz	59.3dBuV
200 MHz	80.1dBuV
300 MHz	66.1dBuV
400 MHz	63.1dBuV
500 MHz	58.1dBuV
600 MHz	55.4dBuV
700 MHz	58.1dBuV
800 MHz	57.4dBuV
900 MHz	36.2dBuV
1000 MHz	46.3dBuV
1100 MHz	62.5dBuV
1200 MHz	63.4dBuV
1300 MHz	53.2dBuV

From Figure 4.3, it is shown that the Frequency of 200 MHz obtains the highest received power when the antenna is in (Vertical to Vertical Pattern).

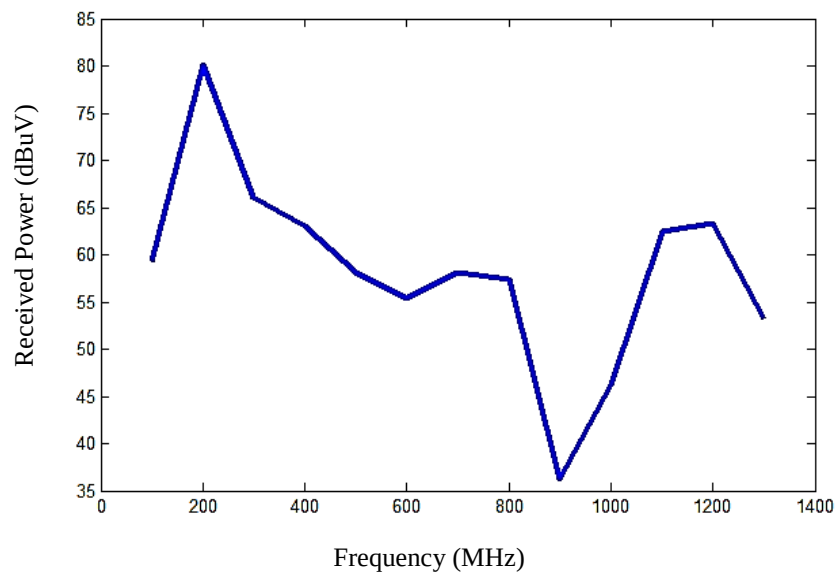


Figure 4.3: The Simulation of Frequency and Received Power (100MHz-1300MHz) in ((H-plane Pattern)).

4.3.2 H-Plane Pattern

The transmitter and receiver of M-Shaped Vivaldi antenna are designed and tested considering (Horizontal to Horizontal) the results are provided in Table 4.3.

Table 4.3: The Frequency and Received Power (H-plane pattern)

Horizontal to Horizontal	
Frequency	Received Power
100 MHz	56.9dBuV
200 MHz	80.1dBuV
300 MHz	61.9dBuV
400 MHz	60.1dBuV
500 MHz	63.1dBuV
600 MHz	54.1dBuV
700 MHz	57.9dBuV
800 MHz	51.4dBuV
900 MHz	49.5dBuV
1000 MHz	52.2dBuV
1100 MHz	59.1dBuV
1200 MHz	56.6dBuV
1300 MHz	37.1dBuV

From Figure 4.4, it is shown that the frequency of 200 MHz obtains the highest received power when the antenna is in (H-plane Pattern).

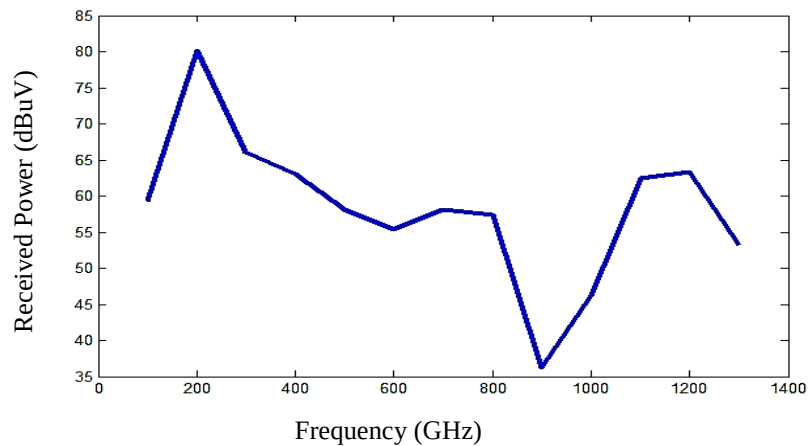


Figure 4.4: The Simulation of Frequency and Received Power (H-plane Pattern)

4.3.3 Vertical to Horizontal Polarization

The transmitter and receiver of M-Shaped Vivaldi antenna are designed and tested in (Vertical to Horizontal) and the results are given in Table 4.4.

Table 4.4: Frequency and Received Power (Vertical to Horizontal)

Vertical to Horizontal	
Frequency	Received Power
100 MHz	58.9dBuV
200 MHz	76.9dBuV
300 MHz	63.4dBuV
400 MHz	69.7dBuV
500 MHz	55.6dBuV
600 MHz	50.4dBuV
700 MHz	60.7dBuV
800 MHz	62.4dBuV
900 MHz	37.2dBuV
1000 MHz	50.5dBuV
1100 MHz	61.4dBuV
1200 MHz	61.6dBuV
1300 MHz	54.5dBuV

From Figure 4.5, it is shown that the frequency of 200 MHz obtains the highest received power when the antenna is in (Vertical to Horizontal Pattern).

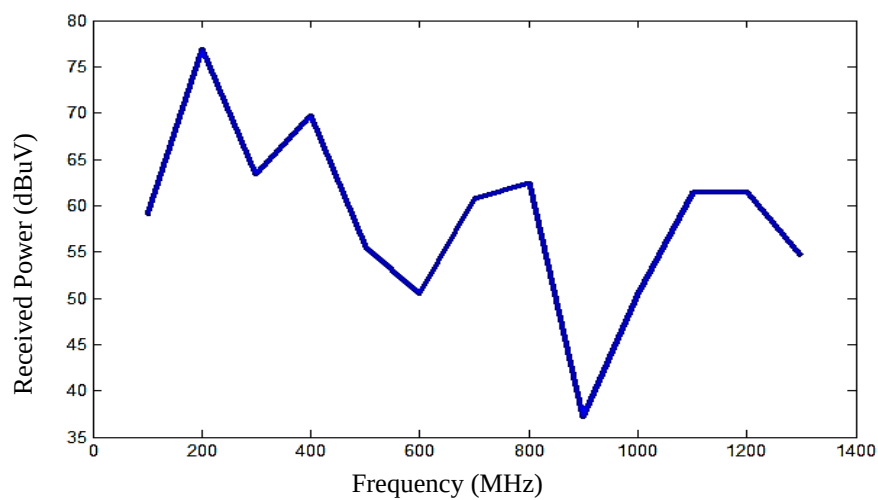


Figure 4.5: The Simulation of Frequency and Received Power (Vertical to Horizontal Pattern)

4.3.4 Horizontal to Vertical polarization

The transmitter and receiver of M-Shaped Vivaldi antenna are designed and tested considering (Horizontal to Vertical) and the results are given in Table 4.5.

Table 4.5: Frequency and Received Power (Horizontal to Vertical)

Horizontal to Vertical	
Frequency	Received Power
100 MHz	59.3dBuV
200 MHz	80.2dBuV
300 MHz	74.4dBuV
400 MHz	70.5dBuV
500 MHz	61.1dBuV
600 MHz	56.4dBuV
700 MHz	55.3dBuV
800 MHz	53.1dBuV
900 MHz	52.7dBuV
1000 MHz	52.4dBuV
1100 MHz	66.4dBuV
1200 MHz	63.2dBuV
1300 MHz	46.2dBuV

From Figure 4.6, it is shown that the frequency of 200 MHz obtains the highest received power.

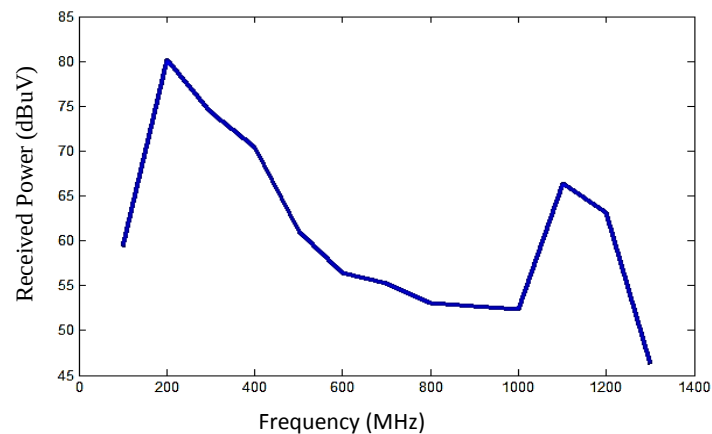


Figure 4.6: The Simulation of Frequency and Received Power at (Vertical to Horizontal Pattern)

All simulation results for all cases are presented in Figure 4.7.

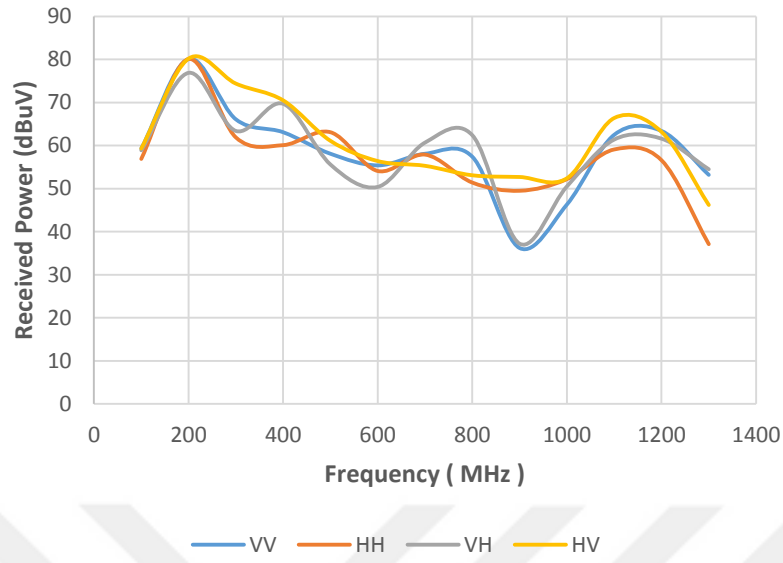


Figure 4.7: The Simulation of Frequency and Received Power at (VV-HH-VH-HV).

4.3.5 Radiation Pattern

The details of radiation patterns to the polarization (VV-HH-HV-VH) for the frequencies 200MHz, 500MHz, 1200MHz and 1300MHz are presented in Table 4.6.

Table 4.6: Radiation Patterns of (HH-VV-HH-HV-VH)

Polarization	Frequency (MHZ)	HPBW (degree)
HH	200	96
	500	25
	1200	95
	1300	23
HV	200	56
	500	110
	1200	31
	1300	127
VV	200	37
	500	26
	1200	30
	1300	80
VH	200	55
	500	58
	1200	70
	1300	55

Figure 4.8 shows the radiation patterns for the frequencies 200MHz, 500MHz, 1200MHz and 1300MHz. This is considered for the degree of Half Power Beam (HPBM) width.

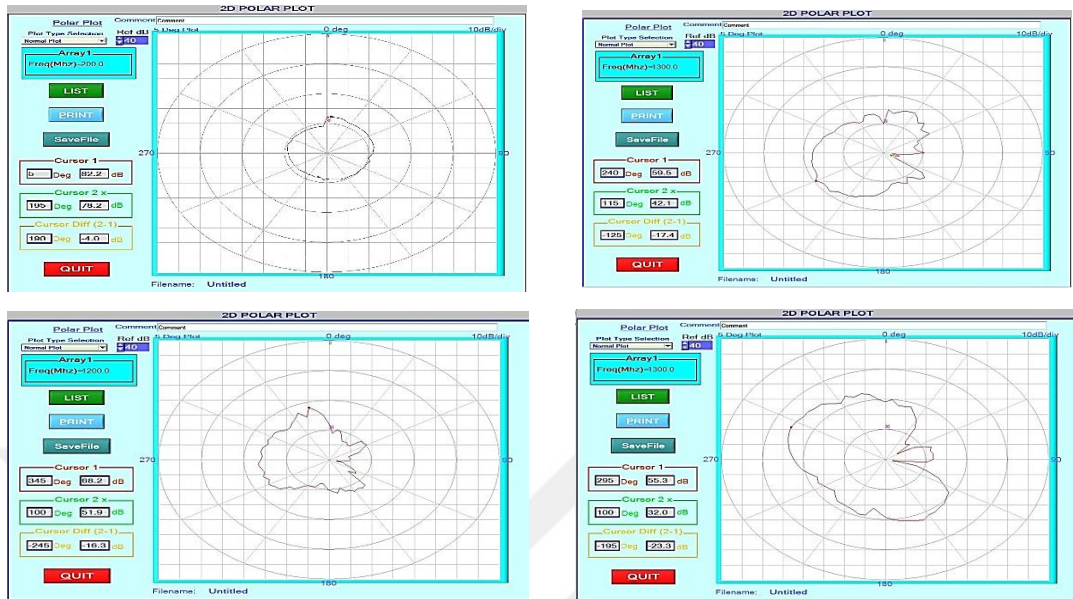


Figure 4.8: The Radiation Patterns of (200MHz -500MHz-1200MHz-1300MHz).

4.3.6 Voltage Standing Wave Ratio

For the range 100MHz -1300MHz, as shown in Figure 4.9, the best VSWR is about 1.2 in these frequencies for Horizontal-H polarization and Vertical-E polarization.

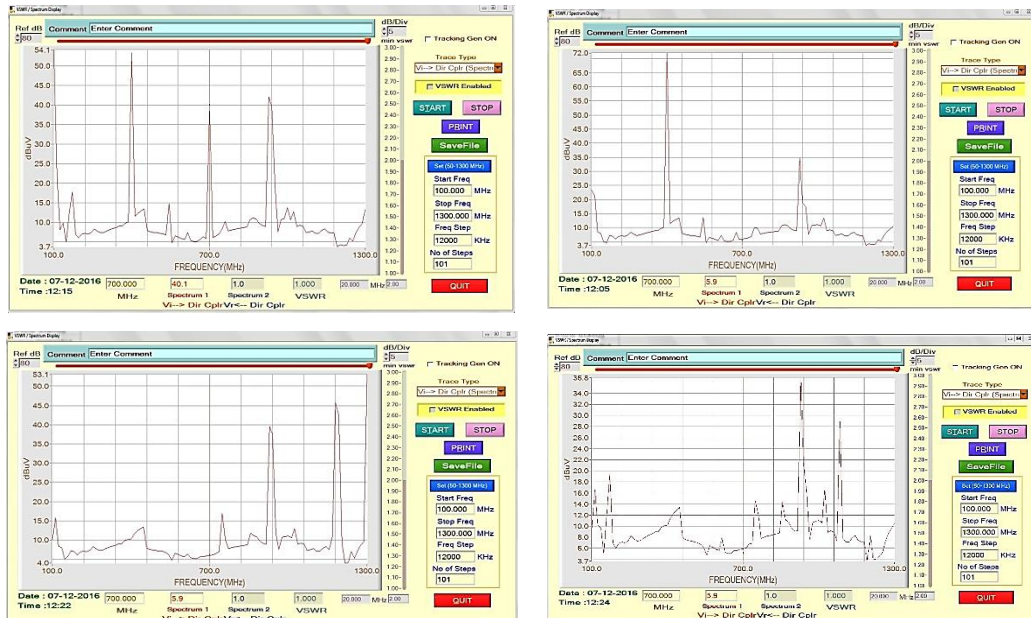


Figure 4.9: VSWR (about 1.2) for Horizontal-H and Vertical-E Polarization.

The Simulation and received power within the frequency range of 3GHz to 8GHz are presented in Table 4.7 and Figure 4.10. For a simple M-Shaped Vivaldi Antenna, it is shown that the highest power is obtained at a frequency of 6GHz.

Table 4.7: The Received Power and Frequency of M-shaped Vivaldi Antenna (3GHz-8GHz)

Vertical to Vertical	
Frequency	Received Power
2 GHz	6.1dB
3GHz	6.9dB
4GHz	7.5dB
5.GHz	8.4dB
6GHz	6.9dB
7GHz	6.3dB
8GHz	5.4dB

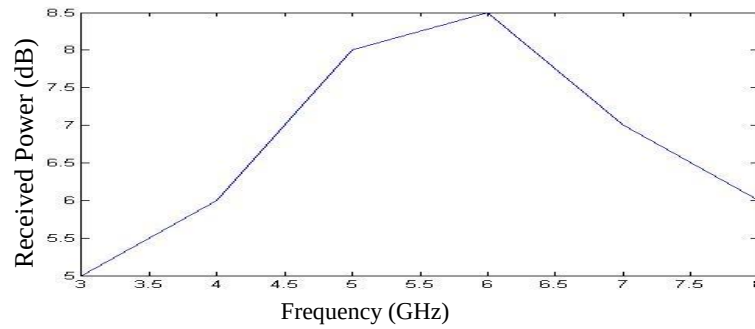


Figure 4.10: The Received Power at frequency of (3GHz-8GHz)

The Simulation and received power within the frequency range of 3GHz to 8GHz are presented in Table 4.8 and Figure 4.11. For a simple M-Shaped Vivaldi Antenna, it is shown that the highest power is obtained at a frequency of 6GHz.

Table 4.8: The Received Power and Frequency of the Array M-Shaped Vivaldi Antenna (3GHz-8GHz)

Vertical to Vertical	
Frequency	Received Power
2 GHz	6.2dB
3GHz	9.1dB
4GHz	14.5dB
5.GHz	16.4dB
6GHz	17.1dB
7GHz	17.3dB
8GHz	81.4dB

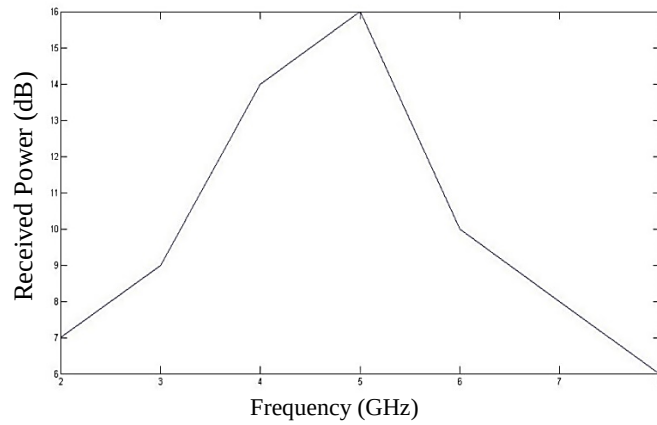


Figure 4.11: Received Power of the Array M-Shaped antenna at frequency of (3GHz-8GHz)

4.3.7 Voltage Standing Wave Ratio and Radiation Pattern

For the range 3GHz -8GHz, as shown in Figure 4.12, the best VSWR is about 1.2. Within these frequencies, the horizontal polarization has a wideband main lobe illustrated in Figure 4.12 and a beam width angle of about 150 degrees.

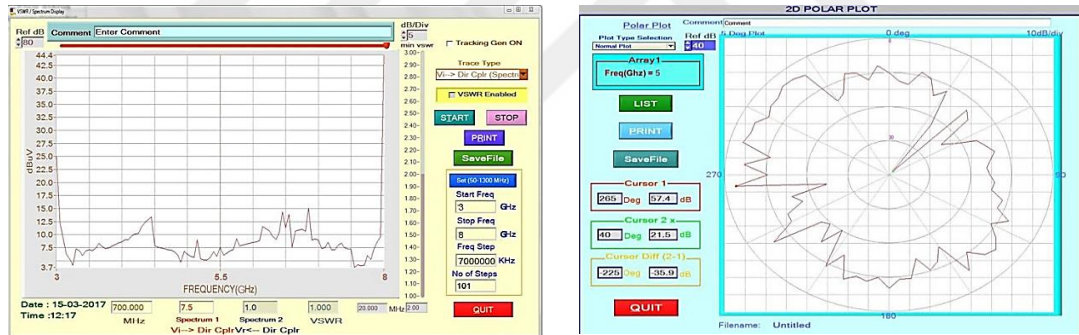


Figure 4.12: VSWR and Radiation pattern of Sample-Array M-Shape frequency (3GHz-8GHz)

4.4. Simulating the Designed Single Vivaldi Smart Antenna

According to the simulation of the proposed design of the UWB Vivaldi antenna, -10 dB bandwidth approximately equals to 6.4GHz. The portable frequency of the proposed M-shaped Vivaldi antenna is following the range between 3 GHz and 9.4 GHz. The proposed antenna has very effective applications in the modern wireless communication and frontends and also in MIMO. This is due to its wider band for high data rate transmission.

4.4.1. Results and Discussion

The reflection coefficient, shows the fraction of power being reflected backward from the antenna input to the excitation port. It is measured in decibels.

The resulting reflection coefficients of the simulated and measured M-shaped uniformed space linear Vivaldi UWB antenna array are illustrated in Figure 4.13.

In the proposed UWB Vivaldi array antenna, the simulated -10 dB bandwidth approximately equals to 6.4 GHz. The operatable frequency range of the proposed M-shaped Vivaldi antenna ranges from 3 GHz to 9.4 GHz. The proposed antenna has very effective applications in the modern wireless communication and frontends as well as in MIMO applications, due to its wider band for high data rate transmission.

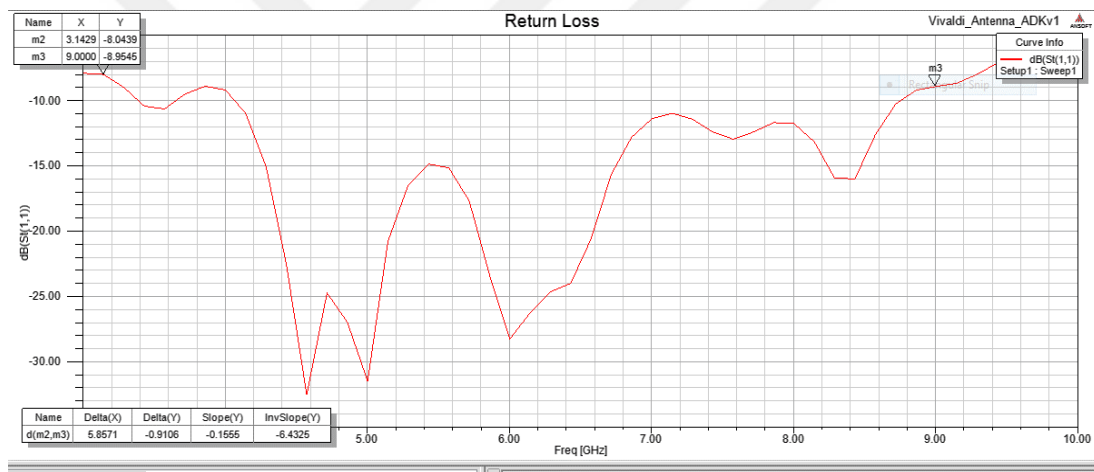


Figure 4.13: The Simulated Return Loss of the Proposed M-shaped Vivaldi UWB Antenna

The ratio of the minimum to the maximum produced voltages or electric fields along the transmission feed line of the proposed antenna is referred to by VSWR. Figure 4.14 presented VSWR. It is evident and very clear from the graph of Figure 4.14 that the VSWR is less than 2 for the all frequencies lay between 3.25 GHz and 8.85 GHz for both simulated. This shows that the antenna is reasonably matched in this entire band.

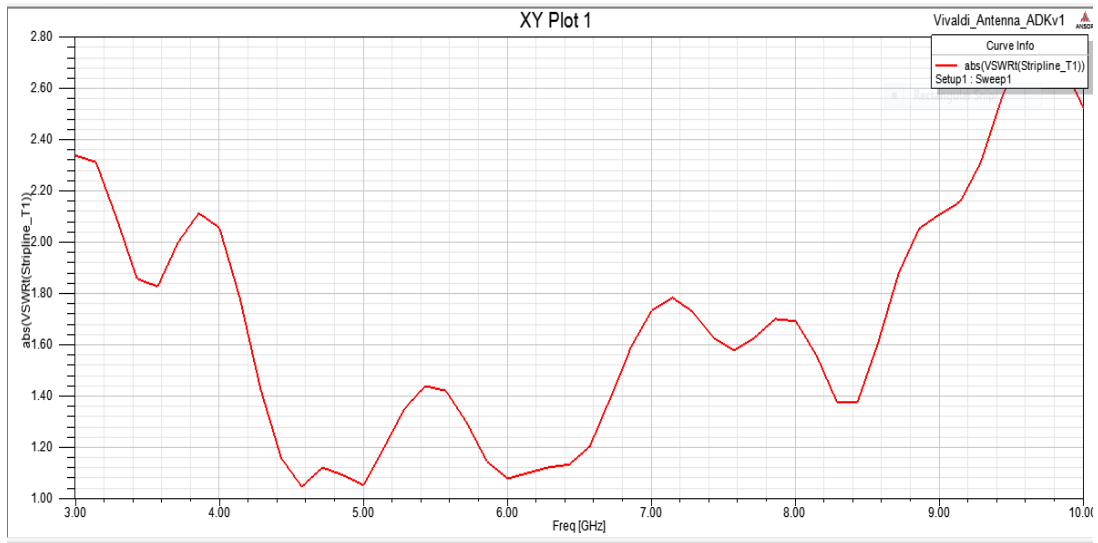


Figure 4.14: VSWR of the Proposed Vivaldi UWB Antenna

The radiation pattern of the designed UWB Vivaldi antenna is illustrated in Figure 4.15 and Figure 4.16. These figures show the radiation patterns simulated with the angle $\phi=0$ of the designed antenna at 5 GHz.

Figure 4.16 illustrates the radiation patterns simulated with the angle $\phi=90$ of the designed antenna at 5 GHz.

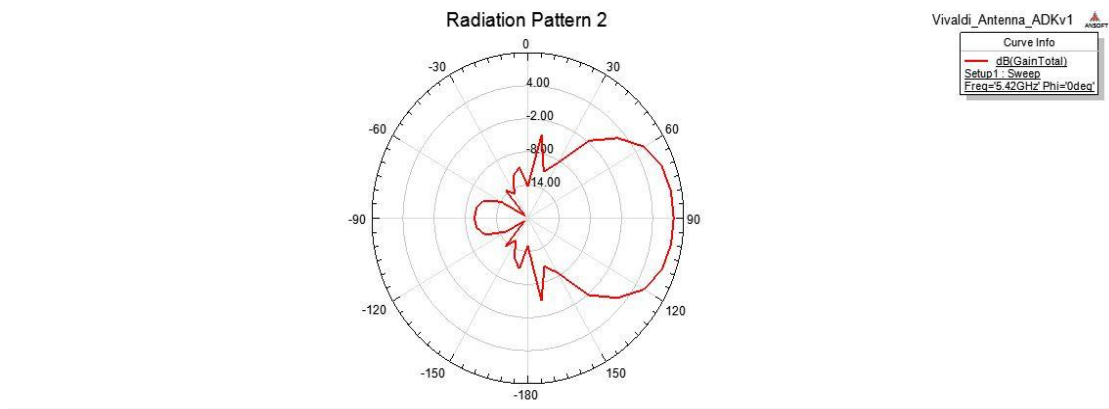


Figure 4.15: Simulated Radiation Pattern of the Antenna at 5GHz

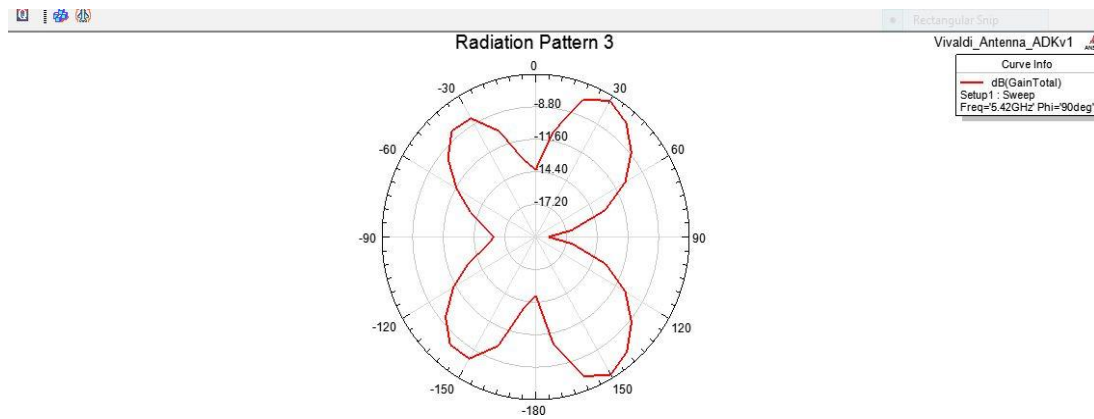


Figure 4.16: Simulated Radiation Pattern of the Antenna at 5GHz

The 3-D gain of the designed antenna is presented in Figure 4.17. It can be noticed from Figure 4.17 that the designed antenna has a gain of 9.5 dB. It is clear from Figure 4.17 that the antenna's maximum gain is found towards $\phi=0$ while the minimum gain is seen in the θ plane. Antenna designers do always wish for high gain antennas to be used in modern wireless communication.

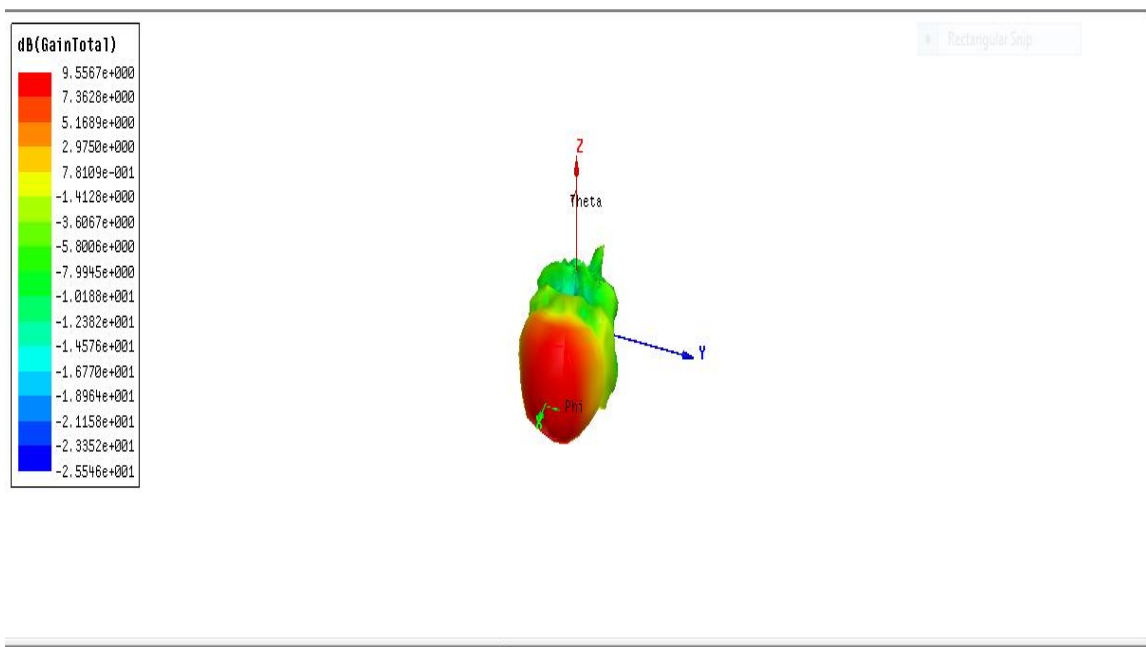


Figure 4.17: 3-D Polar Plot of UWB Vivaldi Antenna

4.5. Simulating the Designed Array Vivaldi Smart Antenna

The fabricated antenna's parameters are measured for further analysis and improvement. After the simulation and fabrication of the proposed single element antenna, its linear array is also simulated in HFSS software. The single element antenna made in the above section is assembled in the positive z-axis to make a linear array of the designed simple UWB Vivaldi antenna. The linear array elements are fed with a uniform linear array configuration keeping signal magnitude and phase angle exactly the same [31]. Simple configuration of the uniformly placed linear array is shown in Figure 4.18.

The Array Factor (AF) of a uniformly linear array of N elements is given by the formula provided in equation 4.6 [31].

$$AF = 1 + e^{j(kd\cos\theta+B)} + e^{j2(kd\cos\theta+B)} + \dots \dots \dots + e^{j(N-1)(kd\cos\theta+B)} \quad (4.6)$$

Alternatively, the above equation can be restated in the formula provided in equation 4.7 [31].

$$AF = \sum_{n=1}^N e^{j(n-1)\varphi} \quad (4.7)$$

$$\varphi = kd\cos\theta + B \quad (4.8)$$

Where:

φ = Gaps between two elements

$K*d = \pi$ for half-wave spacing

$B = \text{Constant}$

$\cos\theta$ = pointing angle direction

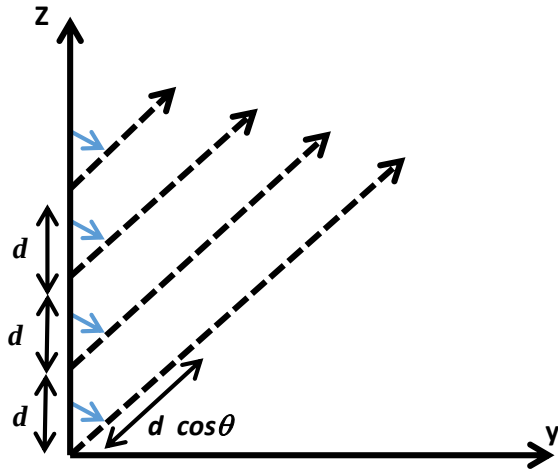


Figure 4.18: Configuration of Linear Placed Array

The designed Vivaldi antenna is shown in Figure 4.19. The gap between each element of the array is set to 10 mm. The designed array antenna is investigated in terms of the antenna parameters. FR-4 substrate is used for antenna fabrication. The deployed commercial substrate has 4.4 dielectric constant, 0.02 loss tangent and 1 mm thickness. The fabricated array antenna is then tested in the laboratory, where the measurements of the required parameters such as VSWR, radiation pattern and return loss are conducted. During the laboratory testing process, BNC power divider, characterized by 50-Ohm nominal input impedance, is used to ensure that each element of the antenna got the same signal power and the same signal parameters. The fabricated antenna array in the laboratory is shown in Figure 4.20.

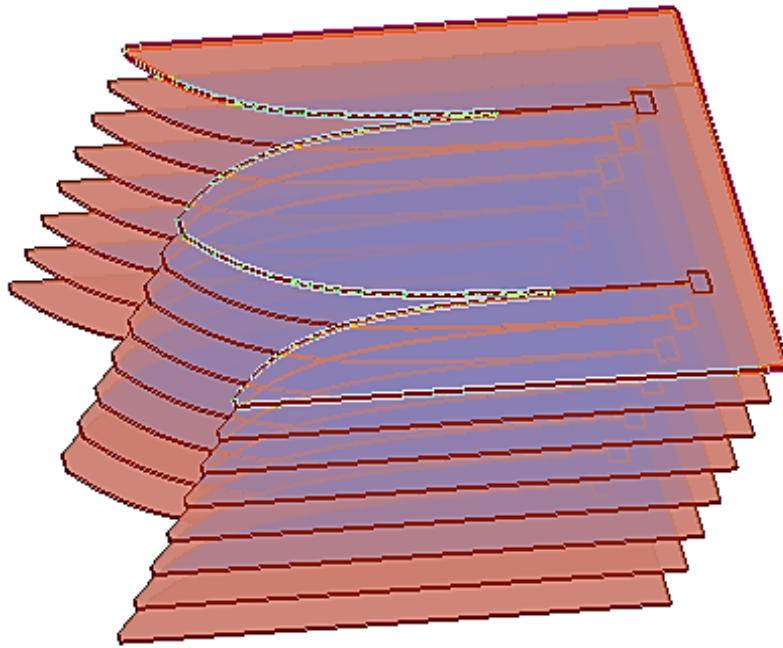


Figure 4.19: Designed Linear Vivaldi Array



Figure 4.20: Fabricated Antenna Array during the Testing Process

4.5.1. Results and Discussions

As a standard procedure for validating the obtained results obtained from the simulation process, the antenna is fabricated, as presented in Figure 4.20, on the commercially available FR-4 substrate. The used fabrication substrate has 4.4 dielectric constant, 1mm thickness and 0.02 loss tangent. The antenna is excited using a BNC coaxial port. The reflection coefficient, gain and VSWR of the proposed antenna are practically measured for analysis purposes.

The measurements are conducted using VNA in the open air conditions. The snapshots of the VNA taken during the measurement are shown in Figure 4.19. For pattern measurement, the proposed antenna is fixed on the positioner or turntable. The distance between the proposed antenna and probe antenna is adjusted to 8 meters for the purpose of far-field pattern measurements.

The reflection coefficient, shows the fraction of power being reflected back from the antenna in put to the excitation port. It is measured in decibels and it is given by the formula:

$$RL=-20\log (\Gamma) \quad (4.9)$$

The resulting reflection coefficient of the simulated uniform spaced linear Vivaldi UWB antenna array are illustrated in Figure 4.21.

In the proposed UWB Vivaldi array antenna, the simulated -10dB bandwidth approximately equals to 6.4 GHz. The operatable frequency range of the proposed M-shaped Vivaldi antenna is between 3 GHz and 9.4 GHz. The designed antenna is suitable for very effective applications in the modern wireless communication and frontends as well as in MIMO, due to its wider band for high data rate transmission and high gain.

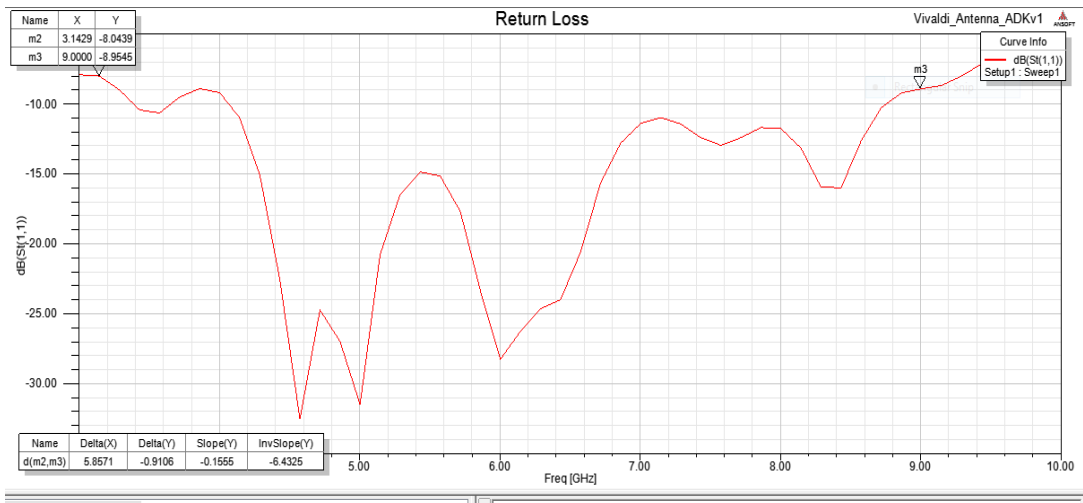


Figure 4.21: Return Loss of the Designed Linear Array

The ratio of the minimum to the maximum produced voltages or electric fields along the transmission feed line of the proposed antenna is referred to by VSWR shown in Figure 4.21. It is evident and very clear from the graph of Figure 4.22 that the VSWR is less than 2 for the all frequencies lies between 3.25 GHz and 8.85 GHz for simulated results.

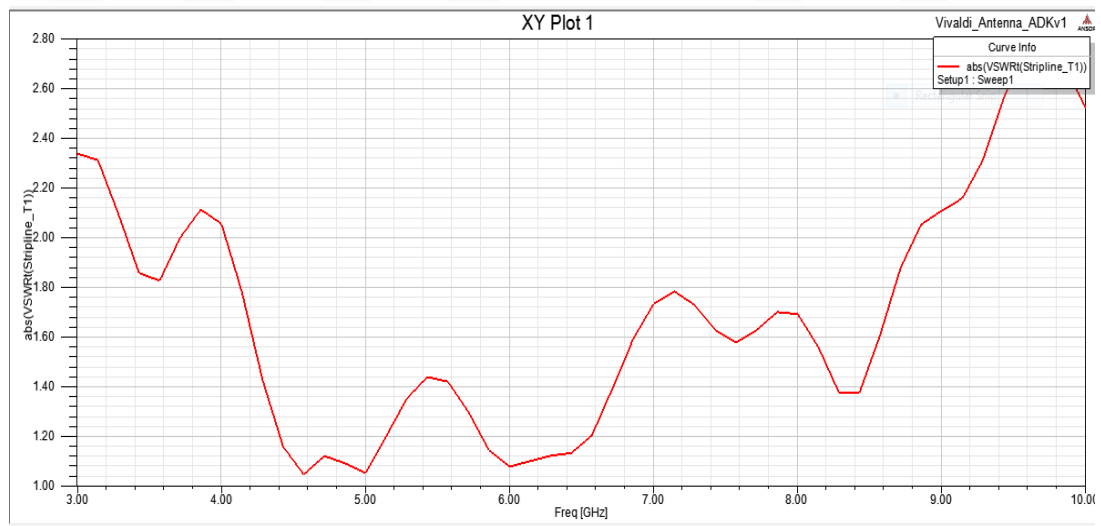


Figure 4.22: VSWR of the Proposed Linear Array

The radiation pattern of the designed UWB Vivaldi antenna is illustrated in Figure 4.23. These figures show the radiation patterns simulated with the angle $\phi=0$ of the designed antenna at 5 GHz.

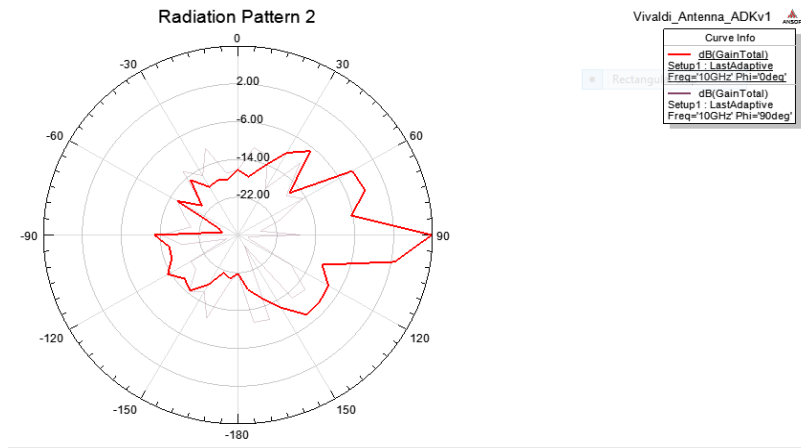


Figure 4.23: Radiation Pattern at $\phi = 0$

Figure 4.24 illustrates the radiation patterns simulated with the angle $\phi=90$ of the designed antenna at 3-10 GHz.

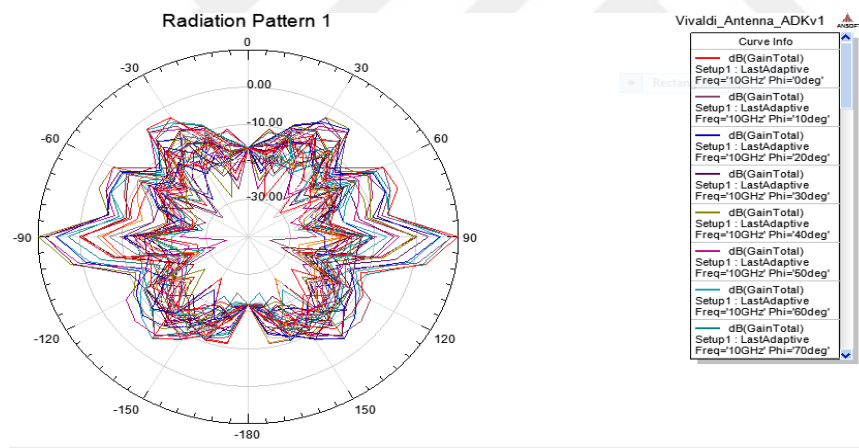


Figure 4.24: Radiation Pattern at $\phi = 90$

The 3-D gain of the designed antenna is presented in Figure 4.25. It can be shown from Figure 4.25 that the designed antenna has a gain of 16.5 dB. It is evident that the antenna's maximum gain is found towards $\phi=0$ while the minimum gain is seen in the θ plane. The antenna designers do always wish for high gain antennas to be used in modern wireless communication.

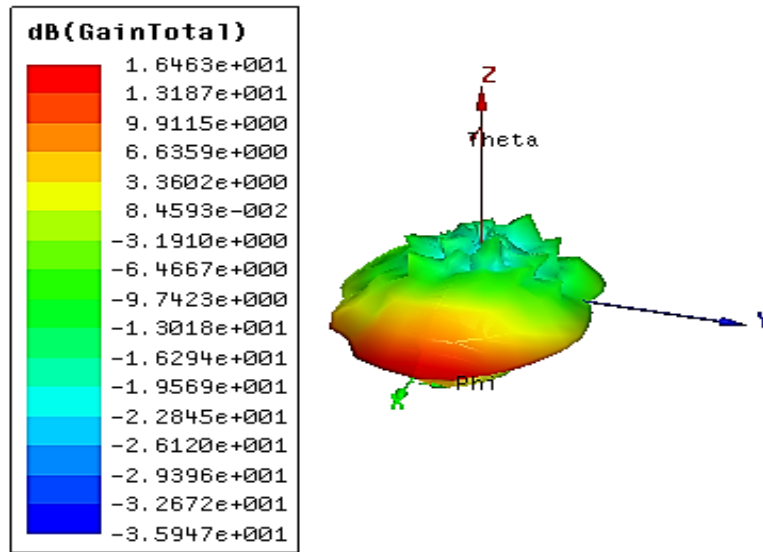


Figure 4.25: 3-D Polar Plot of Linear Antenna Array.

4.6. Multiple Input Multiple Output Application (MIMO)

MIMO is a wireless technology developed in order to use multiple transmitters and receivers for transferring extra information at the same time. In general, higher frequencies are expected to be used in the Next Generation of wireless communication; one of the features of these high frequencies is their short wavelengths. Thus, they are expected to scatter and be restricted due to obstacles. One of the possible solutions for this problem is to reduce the size of communication cells into smaller cells in the range of 300-meters propagation coverage or even smaller. As it is known, non-next generation cells might extend to up to 500 meters, 1 km, 5 km ...etc., according to different antennas and feeding powers. However, that doesn't work for the next generation. In this case, network providers have to lessen their cell sizes into smaller cells, like 300 meters, if they consider changing their network system to the next generation. Another solution is using MIMO technique. MIMO reduces the chance of missing different versions of a signal that arrives at different times due to obstacles. In MIMO, an array of antennas is used and they are placed with respect to the wavelengths of their operating frequencies [32].

4.6.1 MIMO Results of future to improve the design MIMO by using 8 elements of Vivaldi antenna

In this work by using the 8 elements of Vivaldi antenna as an 8x8 MIMO transmission system. This is done in order facilitate the development of researchers interested in applications such as the next generation mobile system. The most important parameter here is the signal-to-noise ratio (SNR). For a MIMO system, the relationship between SNR and some other parameters is a base for studying the MIMO system.

Figure 4.26 shows the outage probability versus SNR for Alamouti Space-Time diversity Block Code (STBC) for 8x1 (MISO) and 8x8 MIMO systems. It can be seen that there is a rapid decrease in the outage probability with the increment of the SNR. This will lead to an improvement in the system's performance during the data transmission, thus, higher data rates can be obtained.

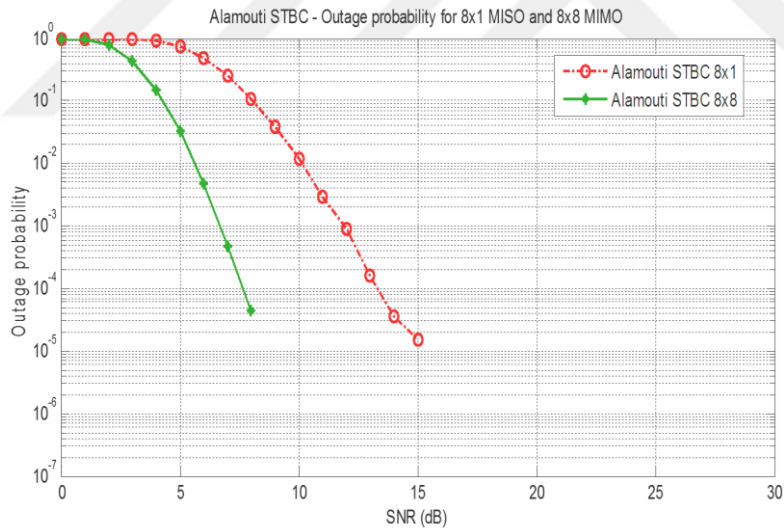


Figure 4.26: Outage Probability versus SNR for Alamouti STBC 8x1 and 8x8 System

In Figure 4.27, the Cumulative Density Function (CDF) probability is shown as a function of a selected data rate transmission for both 4x4 and 8x8 MIMO systems. The greatest data rates for 8x8 MIMO system is surpassing its 4x4 MIMO system's counterpart.

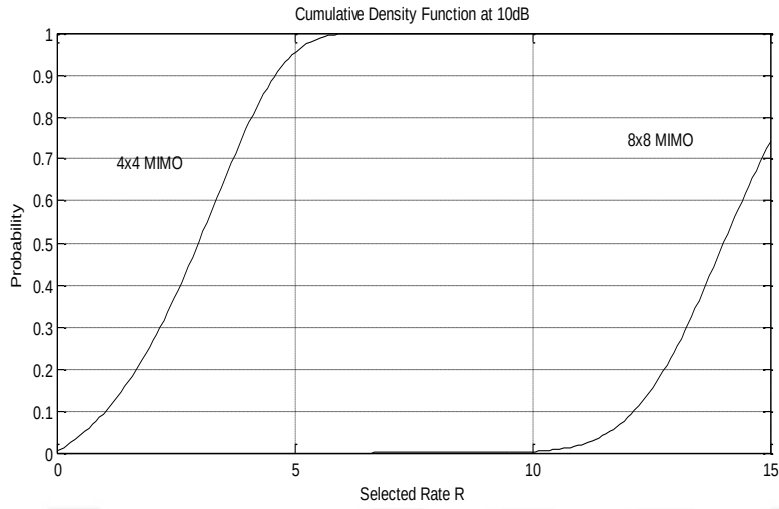


Figure 4.27: Cumulative Density Function Probability versus a Selected Data Rate Limit.

Another important parameter is the Ergodic capacity in bit per transmission versus the average SNR in fast fading Rayleigh channel. This is presented in Figure 4.28 for different systems, namely SISO, SIMO, MISO and MIMO. It can be observed from Figure 4.28 that the capacity of 8x8 MIMO system is much higher than all others by about 5 times. Basically, this what makes MIMO systems attractive when considering contemporary wireless systems especially 4G and 5G mobile.

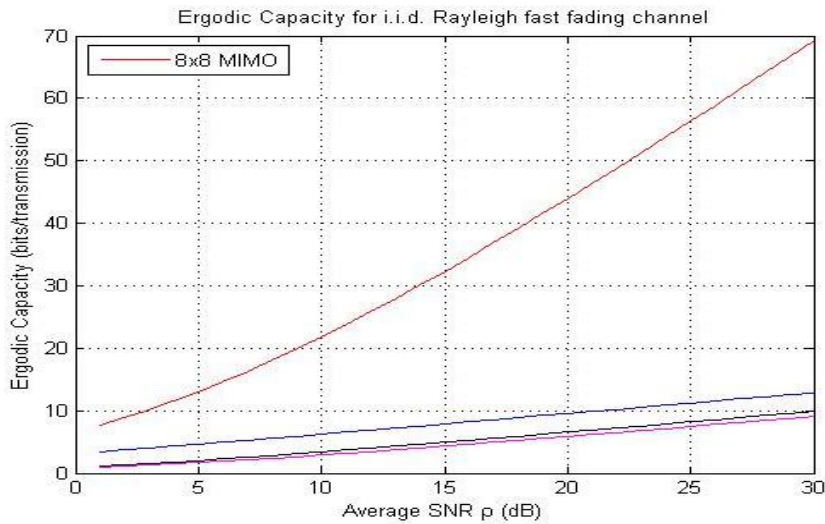


Figure 4.28: Ergodic Capacity Rate (SNR) to (SISO-SIMO-MISO- MIMO) System Fast Fading Ray Leigh Channel

Furthermore, Figure 4.29 shows the capacity with the outage probability versus the average SNR to SISO-SIMO-MISO and MIMO systems to a slow fading Rayleigh channel. Figure 4.29 presents the capacity with 10% outage probability versus average SNR in a slow fading Rayleigh channel for 1x1 SISO, 1x8 SIMO, 8x1 MISO and 8x8 MIMO systems. It can be seen that the increase in SNR gives higher capacity and decrease in the outage probability for 8x8 MIMO compared to other systems.

For example, the capacity with the outage of 8x8 MIMO needs less SNR than the other three systems by about 0.01bits/transmission. To get the same value for other systems, about 12 dB for 1x8 SIMO, 25 dB for 8x1 MISO and 35 dB for 1x1 SISO are needed.

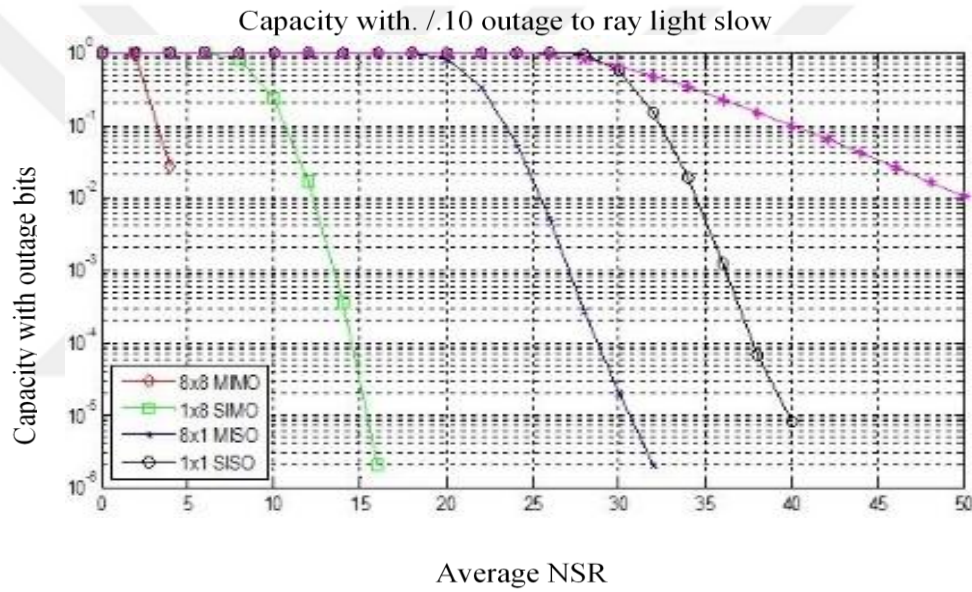


Figure 4.29: Capacity with Probability Outage via Rate SNR for SISO, SIMO, MISO and MIMO Systems for slow Fading Rayleigh Channel.

Finally, Figure 4.30 presents the Ergodic capacity versus a number of antennas for a fast fading Rayleigh channel of 1x1 SISO, 8x1 MISO, 1x8 SIMO and 8x8 MIMO systems. It is shown from Figure 4.30 that the higher size of MIMO system especially (8x8 MIMO) gives a higher Ergodic capacity, thus, a higher data transmission rate.

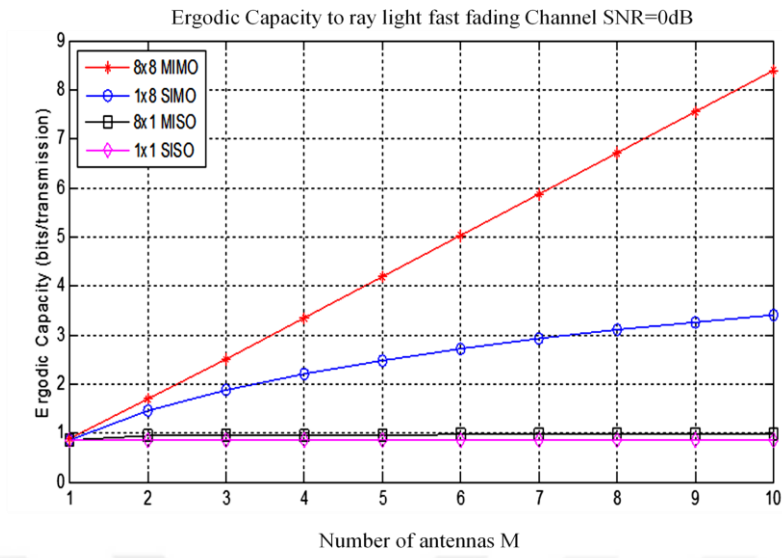


Figure 4.30: Ergodic Capacity against Antennas Number a Fast Fading Rayleigh Channel for 1x1 SISO, 8x1 MISO, 1x8 SIMO and 8x8 MIMO Systems.

5. CONCLUSIONS AND FUTURE WORK

5.1. Conclusions

This research work presented a new model to design for Vivaldi UWB smart antenna. The designed antenna was fabricated using the commercially available FR-4 substrate. The considered key design factors were radiation pattern, return loss and VSWR. These parameters were calculated from both HFSS software simulated antenna and its fabricated counterpart. After the design of a simple antenna, the same antenna is extended for an 8*8 elements Vivaldi antenna. A comparison was conducted between the actual and simulated results obtained from the designed antenna and a very close match was found. The results of simulation compared for both a single element and array element antennas, array elements have much higher results. To design first, using HFSS AnSoft used to design the Vivaldi antenna, then receiver practically, it is designed and tested using spectrum analyzer, microwave signal transmitter, and a motor shaft to calculate the radiation pattern with the use of the Signet software, from the results the radiation pattern for the Smart antenna shown with different frequencies. Also, the VSWR has been determined practically, it was about 1.2 which is good value because near the ideal value 1, from the results shown that this type of Smart antenna better for horizontal polarization than vertical. The designed smart antenna can be used for a frequency range of 100 MHz to about 8.85 GHz as given in the obtained results. The designed smart antenna is considered a good candidate for the next generation portable devices and future generation of wireless technologies. The designed smart antenna can be used for MIMO applications as it has a fast speed, increased capacity and high gain. Another advantage of the designed antenna is its ability to eliminate the effects signal fading and multipath, especially in when a high data throughput is needed with very limited bandwidth channels window.

5.2. Future Work

In future, a very precise method and insulation of dielectric material between the elements of the linear array can be done to reduce the mutual coupling reduction.

In addition, a dual M-shaped Vivaldi antenna for Ku-Band system can be designed based on 16x16 MIMO array. This design will be suitable for the next generation mobile system. Further, the future design of next generation mobile antenna may consider triple Vivaldi antenna to cope with required specifications.

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