# Investigation of Wide Band Modified Bowtie Antenna

**Sayed Mayed Hussain**

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Master of Science
in
Electrical and Electronic Engineering

Eastern Mediterranean University
April 2017
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Mustafa Tümer
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

Prof. Dr. Hasan Demirel
Chair, Department of Electrical
Electronic and Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Electrical and Electronic Engineering.

Prof. Dr. Şener Uysal
Supervisor

Examining Committee

1. Prof. Dr. Osman Kükrer
2. Prof. Dr. Şener Uysal
3. Asst. Prof. Dr. Rasime Uyguroğlu

# ABSTRACT

The wide band width is one of the most demanding characteristic of patch antennas in the current advanced technology and research studies. Several studies on improving the bandwidth of patch antennas have been reported in the literature. Spiral patch antenna, fractal patch antenna and bowtie patch antenna are among the major configurations that are investigated primarily for improving the bandwidth of patch antennas. Bowtie patch antenna has the simplest layout that is used for its wide bandwidth and significant antenna for improving bandwidth and gain. Perfect Electric Conductor (PEC) with a Taconic TLY-5 as a substrate with 0.79 mm thickness are used in the simulations in this thesis. Three different modifications are used in the simulations to improve the bandwidth and gain of a simple 2x2 bowtie array. 1st modification which involves a slot with different lengths increase the bandwidth from 5.09 % to 8.62 % and gain from 13.4 dB to 13.7 dB. 2nd modification is applied to the feed network to make the antenna radiation symmetrical which increased the bandwidth from 5.09 % to 5.91 % but decreased the gain to 12 dB. 3rd modification involves a combination of the first two modifications that would make the antenna radiation symmetrical, increase bandwidth from 5.09 % to 9.51 % and increase the gain from 13.4 to 13.7 dB. The simulations cover the X-band region.

**Keywords:** Modified bowtie patch antenna array, high bandwidth, improved gain, symmetric antenna, simple array, X-band.

# ÖZ

Mevcut yüksek teknoloji ve araştırma konusu, patch antenleri ve patch antenlerinin en önemli bir özelliklerinden olan geniş bantgenişliğinin araştırılmasıdır. Yapılan araştırılmalarda bantgenişliğinin geliştirilmesi üzerine çalışılmış ve rapor edilmiştir. Spiral patch antenler, fractal patch antenler ve bowtie patch antenler ana konfigurasyonlar olarak tanımlanır ve araştırmalar bu antenler üzerine yapılarak patch antenlerin bant genişlikleri geliştirilmiştir. Bowtie patch antenler en basit mizanpaj'a sahiptirler. Bu sebeple, patch antenlerin bantgenişliklerinin geliştirilmesinde ve kazancında önemli bir payı vardır. Bu tezde, kalınlığı 0.79 mm olan Taconic TLY-5 alt katmana sahip bir Perfect Electric Conductor (PEC) kullanılarak simulasyon araştırması yapılmıştır. Similasyonda üç farklı modifikasyon kullanılanılarak 2x2 bowtie dizisinin kazancı ve bant genişliği geliştirilmiştir. Ilk modifikasyonda farklı uzunlukların olduğu yarıklar kullanılarak bantgenişliği % 5.09'dan % 8.62'ye, kazanç ise 13.4 dB' den 13.7 dB'ye çıkarılmıştır. Ikinci modifikasyonda feed network uygulanarak anten radyasyonları simetrik yapılmıştır. Böylece bantgenişliği % 5.09'dan %5.91'e yükseltilmiş fakat kazanç 12 dB' e düşmüştür. Üçüncü modifikasyon ise bahsi geçen ilk iki modifikasyonun birleşimi ile yapılmıştır. Bu sayede anten radyasyonları simetrik yapılmış ve bantgenişliği % 5.09'dan % 9.51'e kazanç ise 13.4 dB' den 13.7 dB'e kadar yükseltilmiştir. Simülasyon X-band bölgesini kapsamaktadır.

**Anahtar Kelimeler:** Değiştirilmiş bowtie patch anten dizisi, yüksek bantgenişliği, yükseltilmiş kazanç, simetrik anten, basit dizi, X-bant.

To:

My Beloved Country, Pakistan.

# ACKNOWLEDGMENT

Specifically, I would like to thank my supervisor Prof. Dr. Şener Uysal for his support and guidance during the execution of this thesis.

I would also like to thank the Chairman of Electrical and Electronic Engineering Department Prof. Dr. Hasan Demirel for his good advice, support and friendship .

Last but not least, I would like to express my deepest love to my family for their endless support during my MS studies.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| UHF | Ultra High Frequency |
| EMI | Electromagnetic Interface |
| EMW | Electromagnetic Waves |
| VSWR | Voltage Standing Wave Ratio |
| LPDA | Log-Periodic Dipole Antenna |
| UWB | Ultra Wide Band |
| AF | Array Factor |
| MBA | Modified Bowtie Antenna |
| RL | Return Loss |
| CP | Coaxial Probe |
| MPA | Micro-strip Patch Antenna |
| WG | Wave Guide |
| WBA | Wide Band Antenna |
| IA | Isotropic Antenna |
| PEC | Perfect Electric Conductor |

# Chapter1

# INTRODUCTION

## 1.1 Microstrip Patch Antenna

In the recent decades microstrip patch antennas attracted a huge interest because of its low profile, compatibility with Monolithic Microwave Integrated Circuit (MMIC) technology and conformability with any geometrical surface. Microstrip patch antennas are also very easy to fabricate which makes them highly repeatable and ideal for mass manufacture. The recent advances in low or very low power electronics also make miniaturized patch antennas ideal choice for many applications such as implantable antennas, next generation mobile communications and sensors. The compatibility of the antenna with other planar circuits is very easy and requires only an impedance matching or transition network. The geometry of the microstrip patch antenna is shown in Figure. 1.1.

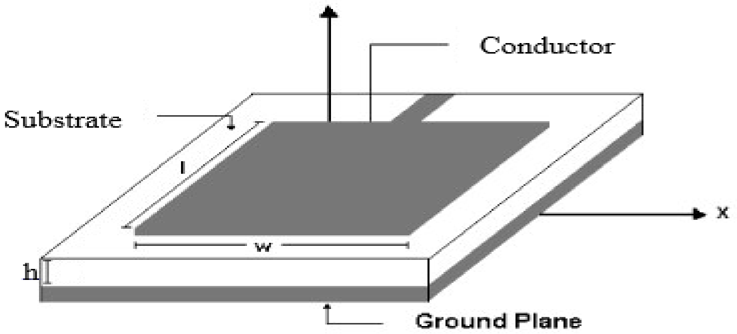


Figure 1.1: Microstrip Patch Antenna Cofiguration

Microstrip patch antenna has three parts.

1. Patch of the antenna
2. Substrate of the antenna
3. Ground of the antenna

The substrate means $\varepsilon_r$ (relative dielectric constant) and h (height) which decide the length and width of the rectangular patch at the desired resonant frequency. Formulas for calculating the width and length of the patch are given in the following equations.

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{1.1}$$

where $f_o$ is the resonant frequency and c is the speed of light.

To calculate the length of the patch, first we find the effective dielectric constant $\varepsilon_{eff}$ , effective length $L_{eff}$ and length extension $\Delta L$ due to the fringing fields.

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{1. 2}$$

where h is the height of the substrate.

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} \tag{1. 3}$$

$$\Delta L = 0.412h\,\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{1.4}$$

Hence the length of the patch is given by

$$L = L_{eff} - 2\Delta L \tag{1.5}$$

The choice of the substrate usually depends on the application. For example, flexible types can easily be bended and constructed on curved or round surfaces. However, there are some other electrical characteristics in which the microstrip antennas need to be improved. Such metrics are (higher) gain, (wider) bandwidth, power handling, and polarization and radiation pattern. There are many work reported in the literature to improve all these (quality) metrics of microstrip patch antennas.

## 1.2 Problem

The problem with a microstrip patch antenna is that when one parameter is improved other parameters lose their characteristics. Generally, a solution may be found by using array or similar antenna geometries to alleviate some of the problems faced when designing patch antennas. An increased size may add new problems like increased losses and unwanted couplings which may result in blind spots.

## 1.3 Thesis Framework

In Chapter 1 there is a short summary of thesis. Chapter 1 discussed how parameter of micro-strip patch antenna improves. Chapter 2 discussed fundamental of an antenna. This chapter shows us how antenna behaves in the surrounding. In Chapter 3 wide band antennas are introduced. It tells us which antenna is able to solve the problem easily of improving bandwidth, gain and radiation pattern. Chapter 4 shows us the behavior of bowtie antenna. This chapter also gives knowledge about antenna array. Chapter 5 shows investigation of bowtie antenna in detail and its modification with simulations and results. Chapter 6 composed over conclusion and future work.

## 1.4 Objective

There are many wide band antennas which improve above parameters of antennas. One of the wide band antennas is that is most commonly used is the bowtie patch antenna. To improve the gain of the system, antennas may be arranged in an array where the characteristics are repeated to achieve cancellation and addition of beams in specific directions.

The main objective of this thesis is to employ an array of $2 \times 2$ bowtie antennas as reported in [15] and apply some physical modifications. The antenna is investigated in the X-band frequencies ranging from 8 GHz to 12 GHz.

Electromagnetic simulation software is used to analyze all the properties such as gain, return loss and radiation pattern.

# Chapter 2

# ANTENNA FUNDAMENTALS

This chapter describes the fundamental parameters of the antenna. These parameters show how the antenna behaves and communicate with the surrounding. In other words, these parameters show us how the antenna transmits and receives the electromagnetic waves. Some of the parameters are discussed in this chapter.

## 2.1 Radiation Pattern

Radiation pattern is an antenna performance parameter which shows how energy is radiated from the patch or it is shows us how the energy is received by the antenna from the surrounding. There are some special coordinates which show how the antenna radiates in the far field region. These coordinates are azimuth angle phi and elevation angle theta. The antenna which radiates energy in all directions equally, is called isotropic antenna. The power intensity is measured at a distance S that shows if the antenna radiates power P equally in all directions. This is spread in the0020form of a sphere having a radius r which is represented by the following equation.

$$S = P / areaofsphere = \frac{P}{4\pi r^2} \tag{2. 1}$$

The intensity is defined by

$$U_1 = r^2 S = P/4\pi \tag{2. 2}$$

Isotropic antenna is used for gain comparison with other antennas. The real antenna radiates more power in a specific direction. Those antennas which radiate in one specific direction are directional antennas. These antennas radiate power in the form of lobes in different directions. These lobes are shown in Figure 2.1.

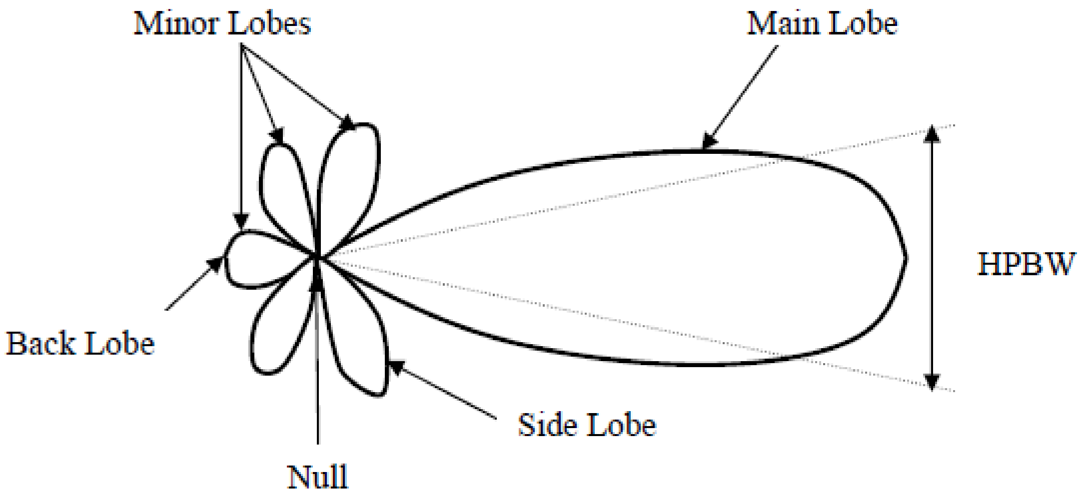


Figure 2.1: Lobes of The Antenna

There are many types of lobes. Some are presented here.

**Main lobe**: this is the lobe which shows the direction of the maximum radiation from the antenna

**Minor lobes:** these lobes show the power radiated in other directions from the antenna.

**Side lobes:** these are in that category of the minor lobes adjacent to the main lobe.

**Back lobe:** this is the lobe which is in 180° out-of-phase with the main lobe.

Good antennas have very low power radiated in the back lobes.

## 2.2 Directivity

It is the parameter which shows us the ratio between the radiation intensity in the given direction and radiation intensity averaged in overall directions [22]. So the radiation intensity averaged is equal to the transmitted power of the antenna divided by $4\pi$ . The directivity is given by the following equation.

$$D_{(\vartheta,\phi)} = \frac{P_{\vartheta,\phi}}{\frac{P_t}{4\pi}} \tag{2. 3}$$

It is also defined as

$$D_{\max} = {4\pi U_{\max}}/{P} \tag{2. 4}$$

There is no dimension of the directivity. Mostly, directivity is given in dB and is calculated by two different methods. It is calculated in terms of the measured power density or by H-plane and E-plane.

## 2.3 Antenna efficiency

This parameter of the antenna shows or tells us how well the antenna radiates power into the direction of observation. It is also defined as ratio between the radiated powers from antenna $P_{rad}$ to the input power supplied by the antenna $P_{in}$. Antenna efficiency tells us how well the antenna is radiates power. It also depends on the matching of impedance of transmission line (feed) and antenna. If the impedance is fully matched it shows high efficiency. If there is a mismatch between the transmission line and antenna then efficiency is low. In case of ideal antenna input power is completely transferred to radiated power. Then, there is no power loss and the input power is equal to the radiated power. Antenna efficiency is shown in eq. 2.5.

$$\varepsilon_r = {P_{rad}}/{P_{in}} \tag{2. 5}$$

$\varepsilon_r$ = Antenna efficiency

$P_{rad}$ = Radiated power

$P_{in}$ = Input power

## 2.4 Gain of Antenna

One of the most important performance parameter is gain. It is formed or we can say that it is drived from the combination of directivity and antenna efficiency. Antenna gain is the amount of power transmitted in the direction of maximum radiation to that of an isotropic source. Usually gain is calculated in dB.

$$Gain = radiationIntensity \Big/ \left( P_{in} \big/ 4\pi \right) \tag{2. 6}$$

$$Gain = 4\pi \, U_{(\vartheta,\phi)} \big/ P_{in}$$

$U_{(\vartheta,\phi)}$ = radiation intensity

$$\mathrm{P}_{rad} = \varepsilon_r P_{in} \tag{2.7 }$$

$$P_{in} = \mathrm{P}_{rad} \big/ \varepsilon_r$$

Put equation 2.7 in equation 2.6 the whole equation becomes

$$Gain = \varepsilon_r D \max \tag{2. 8}$$

## 2.5 Voltage Standing Wave Ratio (V.S.W.R)

VSWR is related to the transmission of the power. When the impedance of the transmission line and impedance of the antenna are matched, the transition of the power from source to antenna happens smoothly. Here we denote the impedance of the transmission line by $Z_{in}$ and impedance of the antenna by $Z_s$. The input impedance is the impedance at the output terminal of the source. If both of the impedance is not completely matched so there is a very low quantity of transmission happening and some high quantity of reflection which is measured with a ratio, i.e., VSWR. The maximum power transmission [22] theorem explains that the maximum power transfer from source to antenna occurs only in one condition, when both the impedance are complex conjugate of each other , i.e., $Z_{in}$ and $Z_s$ . These are shown in Figure. 2.2.

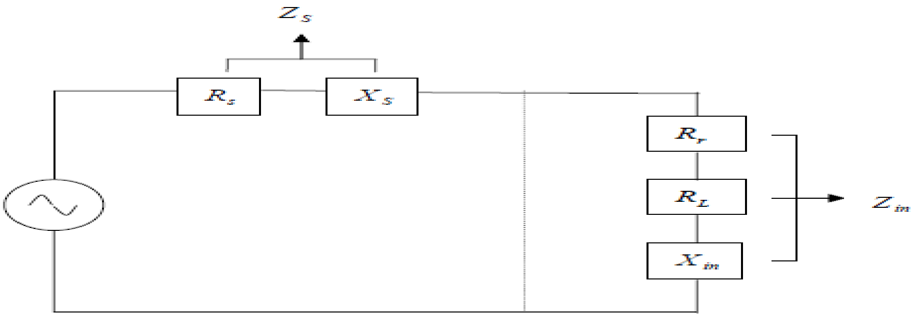


Figure 2.2: Power Transmission from Transmitter to Antenna

It is also shown in the following equation.

For maximum power transmission

$$Z_{in} = Z_s^* \tag{2. 9}$$

where the impedance of the transmitter is given by equation (2.5) and the impedance of the antenna is

$$Z_s = R_s + JX_s \tag{2. 10}$$

VSWR is given by [22]

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{2. 11}$$

where Γ is called the reflection coefficient given by

$$\Gamma = \frac{V_r}{V_i} = \left. Z_{in} - Z_s \middle/ Z_{in} + Z_s \right. \tag{2. 12}$$

## 2.6 Return Loss

Return loss explains the same as the VSWR but this parameter is different than VSWR. It is the antenna performance parameter which shows how much power is radiated from the load and does not reflected back to the transmitter. When the reflection coefficient $\Gamma$ is zero and the return loss $R_L$ is infinitely small which means that full power is dissipated in the load. If there is good matching between the impedance of the transmitter and the impedance of the antenna then it shows that full power is lost in the load. The return loss is given by

$$R_L = 20\log_{10}\left|\Gamma\right| dB \tag{2. 13}$$

Graph off the return loss shown in the following Fig. 2.3.

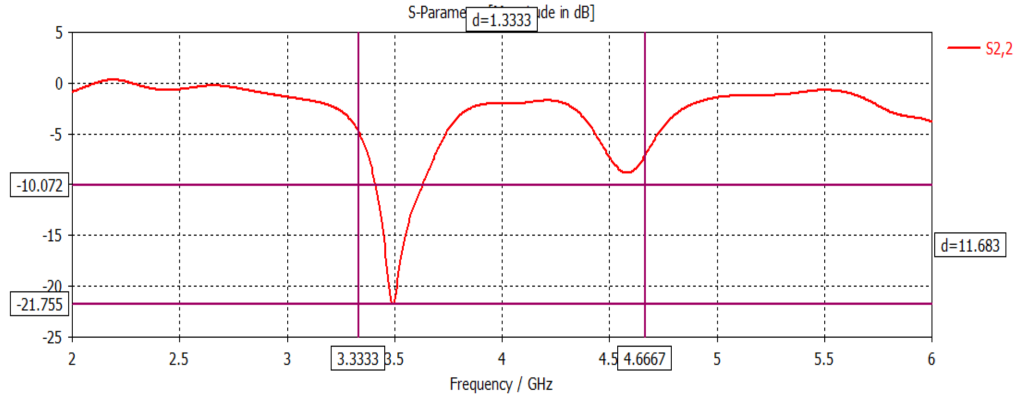


Figure 2.3: Return Loss of Patch Antenna

The bandwidth of the radiating antenna is defined when the value of VSWR is less than 2.

# Chapter 3

# WIDE BAND ANTENNAS

Patch antennas are very narrow band having low gain. This is the deficiency of the microstrip patch antennas. There are some communication areas where a number of frequencies transmitted and received. Microstrip patch antennas are very narrow banded antennas so there is a need for a number of antennas used in such cases. For avoiding this number of antennas one wide band antenna is used which transmits and receives almost all the frequencies. That antenna is called Wide Band antenna. These wide band antennas bring revolutionary change in the microstrip patch antennas. These wide band antennas provide us a high bandwidth, low power demand, multi accesses capability, very low cost transceiver, precise point posting and improved gain.

Wide band antennas have applications in navigation systems, satellites, radio frequency identification, wireless sensor networks and many more. There are a number of wide band patch antennas in the communication field given below and described in the proceeding subsections.

1. Bowtie patch antenna
2. Log periodic patch antenna
3. Fractal patch antenna
4. Spiral patch antenna

## 3.1 Bowtie Patch Antennas

The shape of the antenna is composed of two triangular patches. The length of the bowtie is small which is used for miniaturization purposes [23]. The design of the bowtie antenna is relatively simple compared to other wideband antennas; the bowtie antenna is shown in Figure 3.1

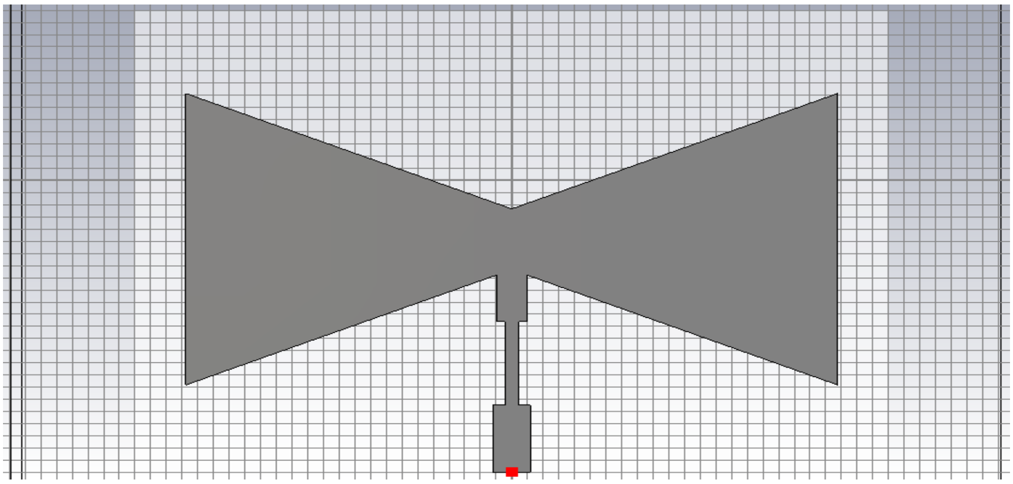


Figure 3.1: Bowtie Antenna

There are many advantages of bowtie antennas such as good radiation efficiency, low profile, and low cost of fabrication.

## 3.2 Log Periodic Antenna

Band of the antenna is also improved by using different types of feed techniques. These techniques include aperture coupled, perforated and log periodic feed techniques. So, log periodic patch antenna is one of the best feeding techniques by which bandwidth of the antenna is improved. Log periodic antenna was first introduced by Du Hamel and Isabell in 1957 [25]. Log periodic antenna operates over omnidirectional pattern. Multiple radiating patches are used in the log periodic antenna which improve the radiation pattern and bandwidth. Every element in the antenna radiates in a particular band which provides overlap with each individual radiation pattern which gives the overall desired bandwidth. Log periodic patch antenna is shown in Figure 3.2.

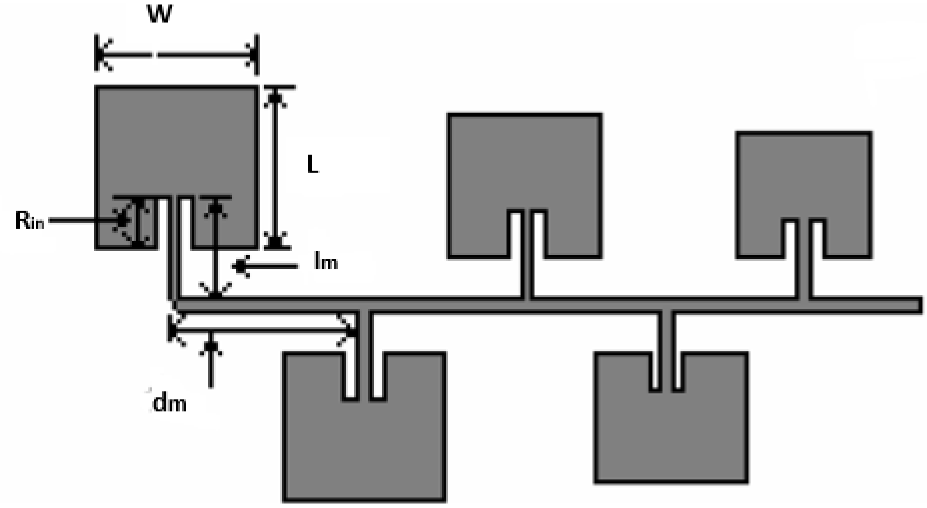


Figure 3.2: Log Periodic Array

Log periodic antenna is approved for use in Wi-Fi, WLAN and many other directional broadcasting applications. Due to its small size and low weight it is also used in detecting of ineffectual source such as army radar, high frequency bugs and satellites [26].

## 3.3 Spiral Antenna

The shape of spiral antenna consists of two spiral arms. The band of this antenna can extend from 2 to 18 GHz. The spiral antenna is that kind of antenna which polarized circularly. It is usually used in military applications as a detection device. The general geometry of spiral wide band antenna is shown in Figure.3.3.

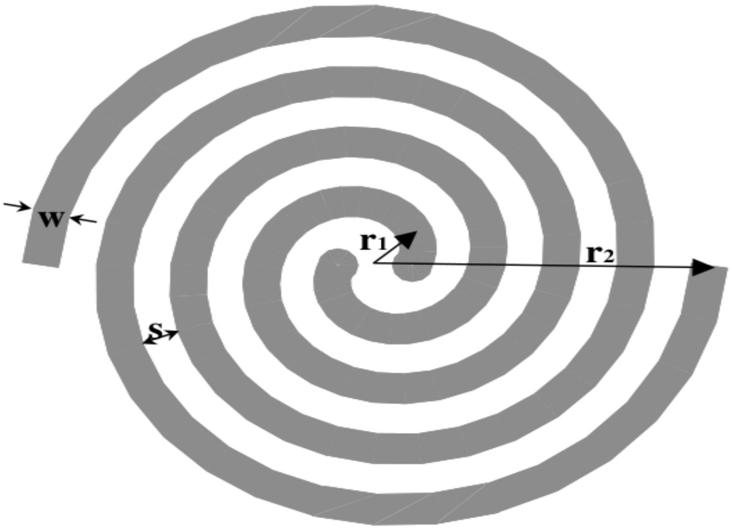


Figure 3.3: Spiral Antenna

According to the right-hand rule, thumb shows direction of radiation and fingers shows direction of polarization. Higest frequency and lowest frequency are found by the radius r1 and r2.

## 3.4 Fractal Patch Antenna

Nathan Cohen was the first to introduce fractal antenna in 1988 [24]. Fractal antenna become important because of its geometry. In other words, fractal antenna is a well “decorated” antenna. Fractal antenna also shows us nature such as leaves on a tree, snail shell, pine corn and many more natural shapes. The changes at the edges in the shape continually radiates high frequencies. Fractal antenna is also used for miniaturization. Miniaturization means to reduce the size of the antenna compared to other types with comparable functional properties. Fractal antenna is shown in Figure 3.4.

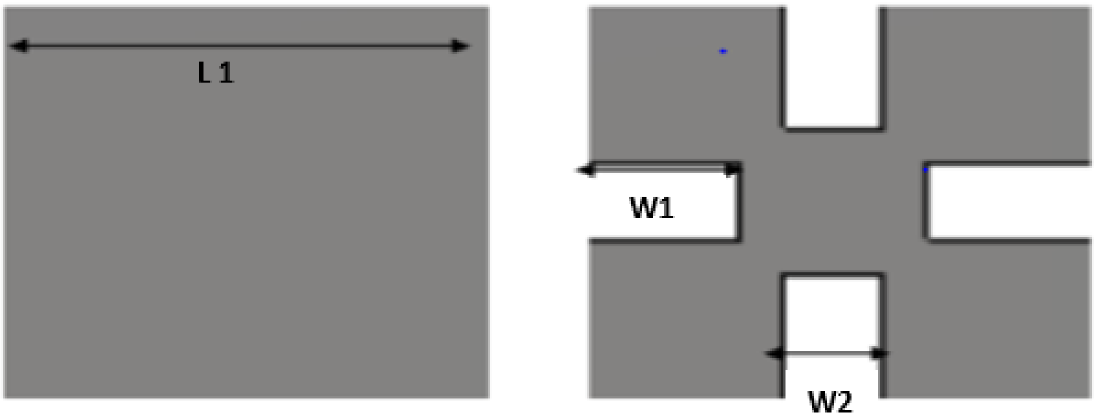


Figure 3.4: Fractal Patch Antenna With Different Iteration

Most of the wide band patch antennas have been briefly discussed here in this chapter. One of the simplest antenna with the most advantages is bowtie patch antenna. Fabrication of the antenna is simple, simulation of the antenna is easy, etching of the antenna in the software is very simple, it is not a complex antenna, it gives wide bandwidth, improved gain and improved radiation. That is why bowtie patch antenna is used for this thesis’s topic. Bowtie antenna is discussed in detail in Chapter 4.

# Chapter 4

# BOWTIE ANTENNA

## 4.1 Introduction

Basically, antenna is a type of transducer which converts input power or we can say electromagnetic energy from free space into a signal and vice versa. Bowtie antenna receives a great deal of attention because of its simple structure, ease in manufacture, low profile, low cost and wide bandwidth. Oliver Lodge introduced the bowtie antenna in 1889 and later it was investigated by Brown and Wood [27]. The design of the bowtie antenna is shown in Figure 4.1

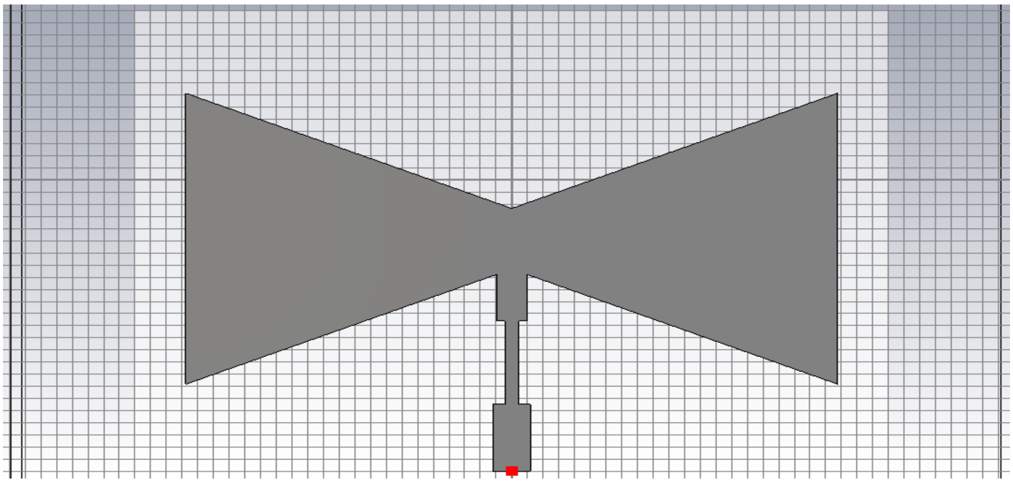


Figure 4.1: Bowtie Antenna

## 4.2 Different Types of Bowtie Antenna

There are different methods used on bowtie antenna for improving its bandwidth. Some of the modifications/methods used for improving the bandwidth are round bowtie, CPW (coplanar waveguide) fed bowtie antenna, sierpinski bowtie antenna and simple bowtie antenna. Simple bowtie antenna is chosen in this thesis. This antenna is known for its simplicity, improved gain, small profile, wide bandwidth and improved radiation pattern. Such antennas are shown in Figure 4.2, 4.3, 4.4 and 4.5.

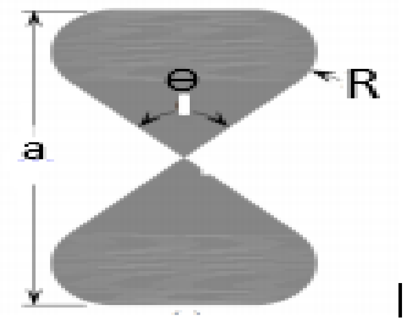


Figure 4.2: Round Side Bowtie Antenna

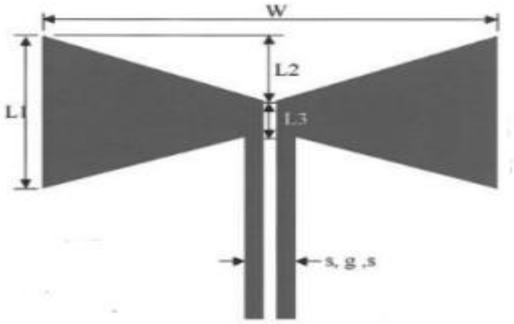


Figure 4.3: CPW Fed Bowtie Antenna

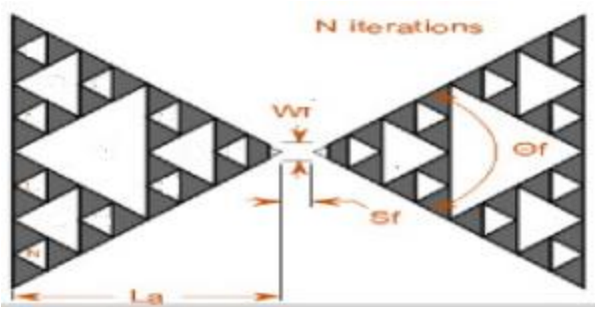


Figure 4.4: Sierpinski Bowtie Patch Antenna

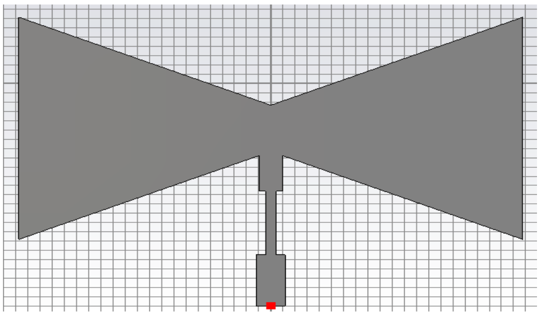


Figure 4.5: Simple Bowtie Antenna

## 4.3 Antenna Array

Array means arrangements of things in a specific way. So, here we did arrangements of antennas in a particular way. Antenna array is made of many antennas or more than one antenna having the same dimensions and properties. Each antenna of the array is called antenna array element.

For achieving higher gain and higher directivity we usually increase the length of the antenna from $\lambda/4$, $\lambda/2$ and $\lambda$. But when the length of antenna increases above $\lambda$ then antenna loses its properties. That is, the number of lobes increases, directivity and gain decrease and so on. So, for very high gain and high directivity we do not use this process of changing the length. So antenna array made up of identical elements with the same properties is used for the purpose of high directivity and gain.

The overall radiation pattern of antenna array is the composition of all the radiation patterns of each single element in the antenna array. The composition results in a radiation pattern controlled by the array factor. The composition of the entire pattern is actually a multiplication which is the pattern multiplication.

Arrangements of the bowtie antenna array elements are discussed in the next section.

## 4.4 Geometrical Bowtie Array

Geometry of the elements in the bowtie array antenna play a vital role. Geometrical configuration shows us how the combinations of each radiation pattern for each element are formed [18]. Here, only two types of configurations are discussed

1. Linear bowtie array
2. Planar bowtie array

### 4.4.1 Linear Bowtie Array

It is that type of array in which all the antenna elements are in a straight line. The axis of array is obtained from the line or orientation in which elements are placed. The distance between the elements of the antenna is chosen randomly. The excitation of the element is depended on the requirements either it is in phase or out of phase.

Uniform linear bowtie arrays are those linear antenna arrays which are excited in phase. A linear array is shown in Figure. 4.6.

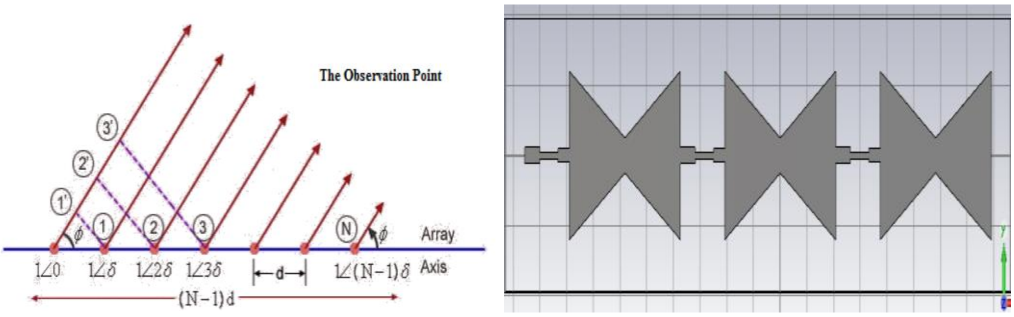


Figure 4.6: Linear Bowtie Array

In Figure 4.6 N shows the bowtie antenna array element. $\delta$ represents the phase shift which is equally given to each element and $\phi$ represents the direction towards the observation point. Before considering the overall phase lets study the phase. Here, we have two phases, one which is formed by the excitation and the second is due to the propagation. So, the total phase is calculated by the following equation.

$$\Psi = \beta d \cos\phi + \delta \tag{4.1}$$

For calculating the total field, we assume two steps.

- $1^{st}$ element of the linear array is the reference.
- At the point of observation the amplitude of the antenna element is unity.

The equation of the total field is given by

$$E = e^{j0} + e^{j\Psi} + \ldots\ldots. + e^{j\Psi(N-1)} \tag{4.2}$$

which leads to

$$E = \frac{\sin\left(N\frac{\Psi}{2}\right)}{\sin\left(\frac{\Psi}{2}\right)} \tag{4.3}$$

The maximum radiation is obtained when $\Psi = 0$:

$$\beta d \cos\phi + \delta = 0 \tag{4.4}$$

$$\phi_{\max} = \cos^{-1}\left(-\frac{\delta}{\beta d}\right) \tag{4.5}$$

There are three different types of antenna arrays with respect to directionality.

1. Directional array
2. End fire array
3. Broad side array

### 4.4.2 Planar Bowtie Array

In two dimensional array elements are in rows and columns. This type of array is ore important than the linear array. There are some qualities that the linear array does not have like the symmetrical nature and reduction in the side lobes. It is highly flexible in words of beam scanning. The planar array is either square or rectangular. Planar bowtie antenna array is shown in Figure 4.7.

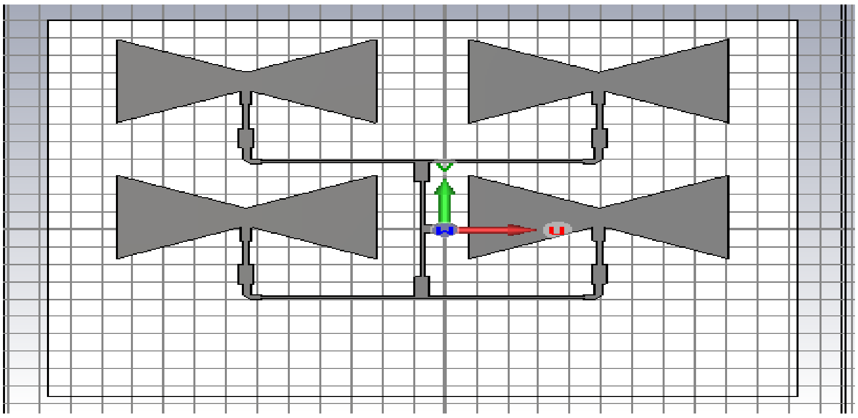


Figure 4.7: Planar Bowtie Array

We denote $U \times V$ as a rectangular array. Planar antenna Array Factor (AF) for the $U \times V$ array is

$$A.F(\phi,\theta) = \sum_{U=0}^{U=1} \sum_{V=0}^{V=1} I_{UV} Z_x^U Z_y^V \tag{4.2}$$

$I_{UV}$ is the excitation current. In both $U^{th}$ row and $V^{th}$ column we have uniform planar antenna array having uniformly excitation. As a result the AF is given by

$$A.F = \left| \frac{1}{U} \frac{\sin\left(\frac{U\Psi_x}{2}\right)}{\sin\left(\frac{\Psi_x}{2}\right)} \right| \left| \frac{1}{V} \frac{\sin\left(\frac{V\Psi_y}{2}\right)}{\sin\left(\frac{\Psi_y}{2}\right)} \right| \tag{4.2}$$

## 4.5 Excitation Network

We have two types of feed networks mostly used for the microstrip patch antenna array excitation, and they are.

1. Series bowtie feed network
2. Parallel bowtie feed network

### 4.5.1 Series Bowtie Feed Network

The elements are connected in series. Transmission lines to the elements are connected in series as a cascaded system [19]. This network is shown in Figure. 4.8.

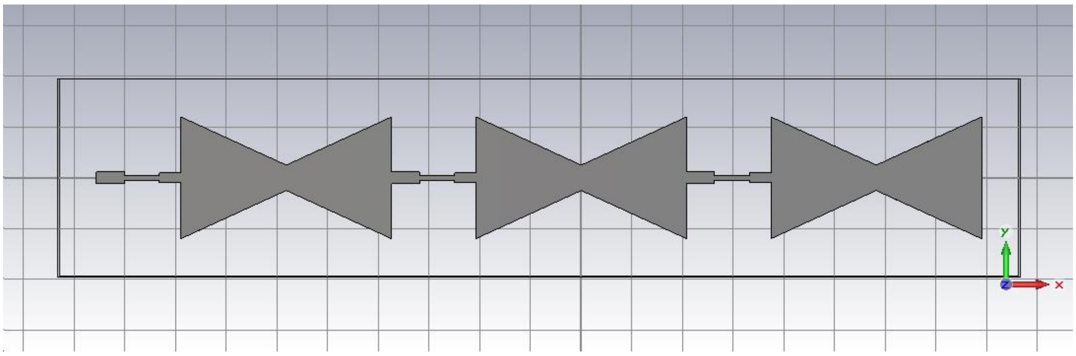


Figure 4.8: Series Bowtie Feed Network

In this feed network the main disadvantage is the narrow beam width. There are some advantages of the series feed network like small losses, packed form and low cost.

### 4.5.2 Parallel Bowtie Feed Network

The parallel bowtie feed network is more important for the antenna array. It’s not only used for feeding purposes but also acts as a power splitter [19]. The parallel feed network is shown in Figure. 4.9.

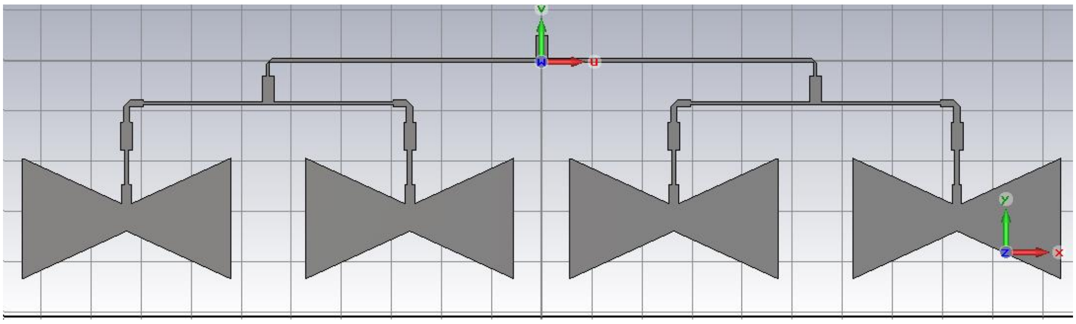


Figure 4.9: Parallel Bowtie Feed Network

This feed network is also known as corporate feed. The parallel feed network has three parts.

1. Strip-line
2. T junction or power Divider
3. Strip-line bend

The width of the strip-line depends on the permittivity and its height from the ground. Strip-line, T junction and strip-line bend are shown in Figure. 4.10, 4.11 and 4.12.

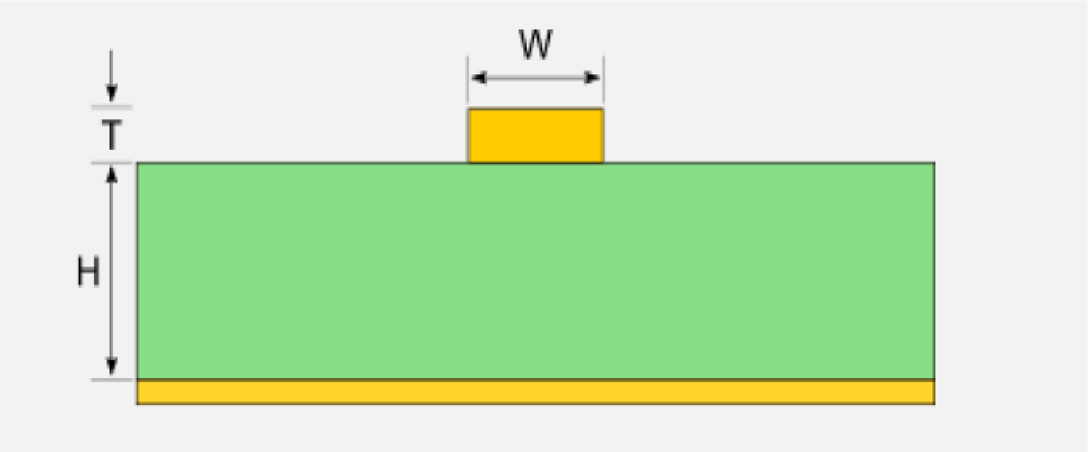


Figure 4.10: Strip Line

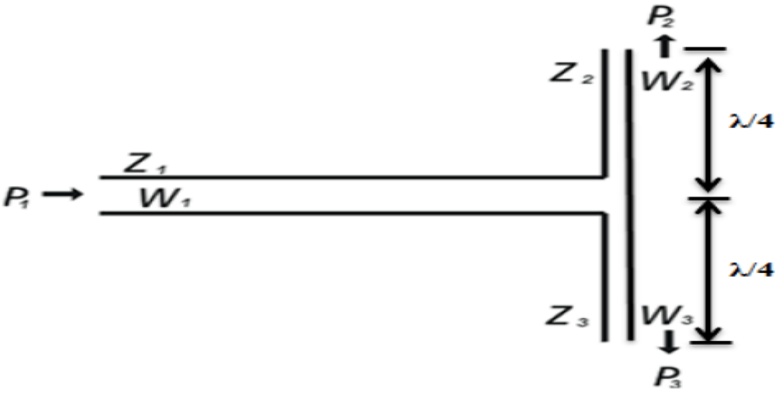


Figure 4.11: Power Splitter Or T Junction

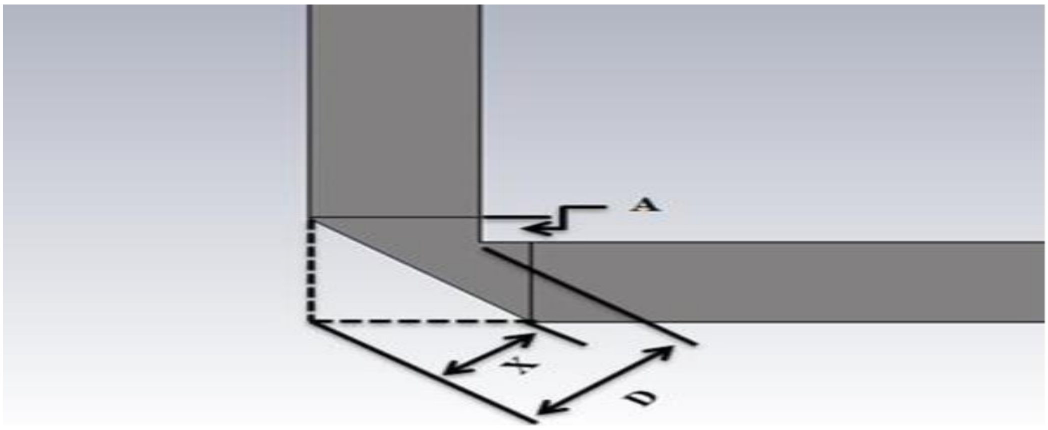


Figure 4.12: Strip Line Bend

# Chapter 5

# MODIFIED BOWTIE PATCH ANTENNA

Simulations of the microstrip bowtie patch antenna are processed in five different steps. First, there is design of single element bowtie antenna and its simulation. In the second design, there is a $2 \times 2$ array and simulation results of the reference bowtie patch antenna array. In the third design, different slots are made on the antenna array elements and simulation results are discussed. In the fourth design, there is a change in the feeding network of the second design and also slots are introduced in the same antenna array. In the fifth step there is a comparison between the simulations of the four designs. These designs help us to achieve a wideband bowtie patch antenna array. All the simulations are carried out using Electromagnetic simulation software.

## 5.1 Patch of Bowtie Antenna Array

Patch of the bowtie patch antenna array has been discussed in detail in different sections.

### 5.1.1 Single Bowtie Patch Element [30]

Single bowtie patch antenna is shown in Figure 5.1. The design parameters of the single element is the same as the parameters for the reference antenna. And these parameters are shown in Table 5.1.

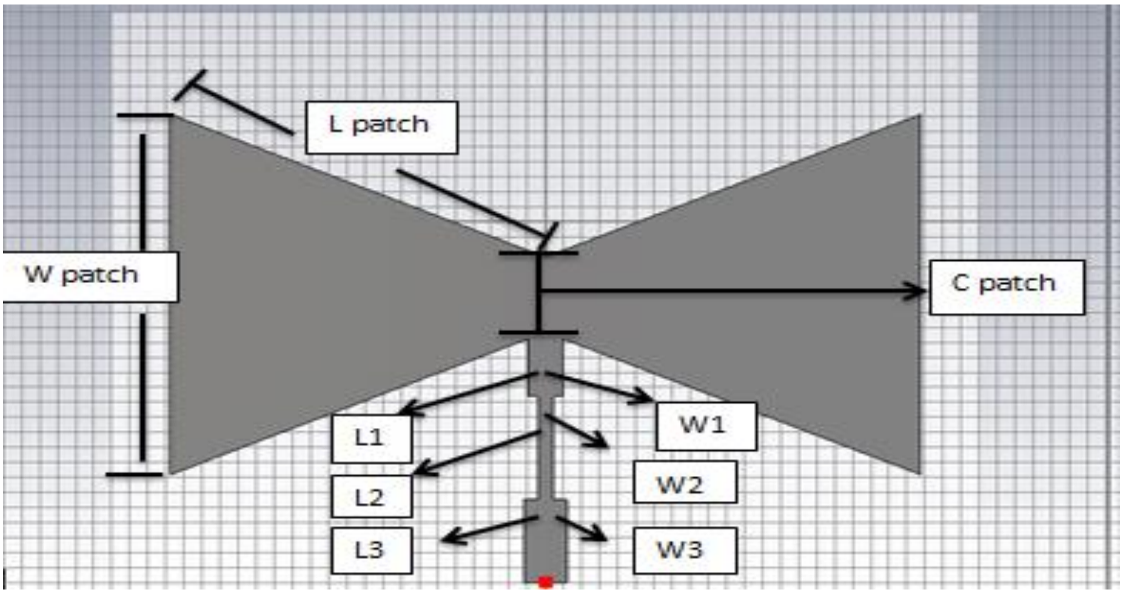


Figure 5.1: Single Bowtie Patch Antenna

Table 5.1: Parameters of single bowtie

| Parameter | Parameter length in mm |
|---|---|
| L patch | 20.76 |
| W patch | 23.97 |
| C patch | 5 |
| L1 | 4.26 |
| L2 | 6.87 |
| L3 | 5.54 |
| W1 | 1.88 |
| W2 | 0.9 |
| W3 | 2.37 |

Return loss:

Single element bowtie antenna is simulated to have a bandwidth from 9.874 GHz to 10.126 GHz. The calculated bandwidth is equal to 2.52%. The graph of the return loss has only one resonance which is at 10 GHz. Return loss is shown in Figure 5.2.

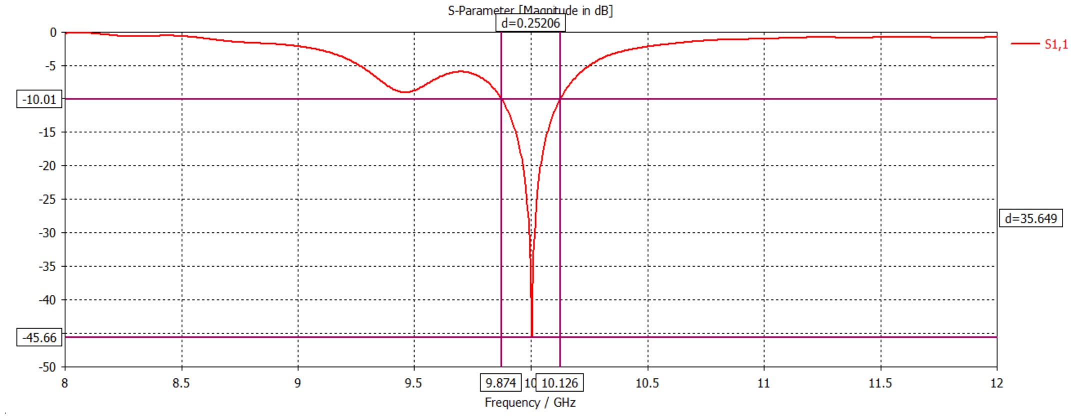


Figure 5.2: Return Loss of Single Bowtie Patch Antenna

## Gain and Radiation Pattern

Gain of the antenna is 9.27 dB at 10 GHz. Radiation pattern is having two lobes. Radiation pattern of antenna is not symmetrical. Gain and Radiation pattern are shown in Figure 5.3 and 5.4.

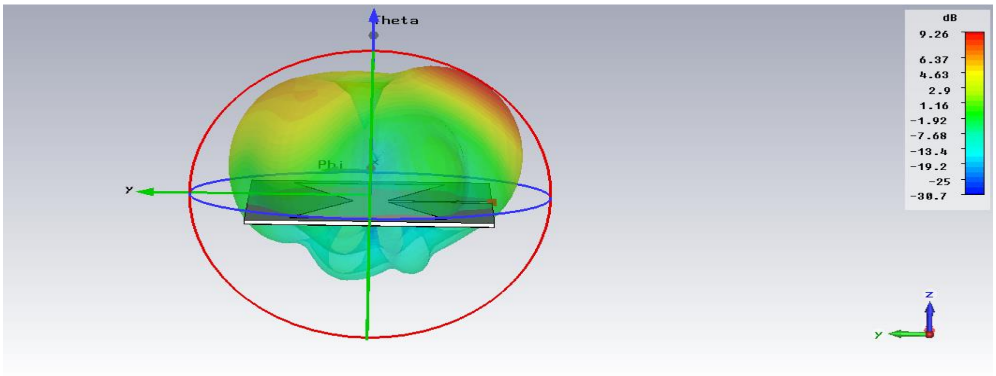


Figure 5.3: Gain of Single Bowtie

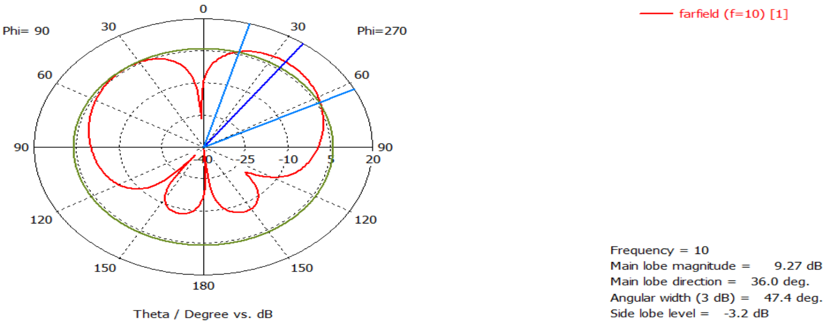


Figure 5.4: Radiation Pattern at 10 GHz

### 5.1.2 $2\times2$ Reference Array [15]

Design of the $2\times2$ antenna is shown in Figure 5.5 and its dimensions are given in Table 5.2.

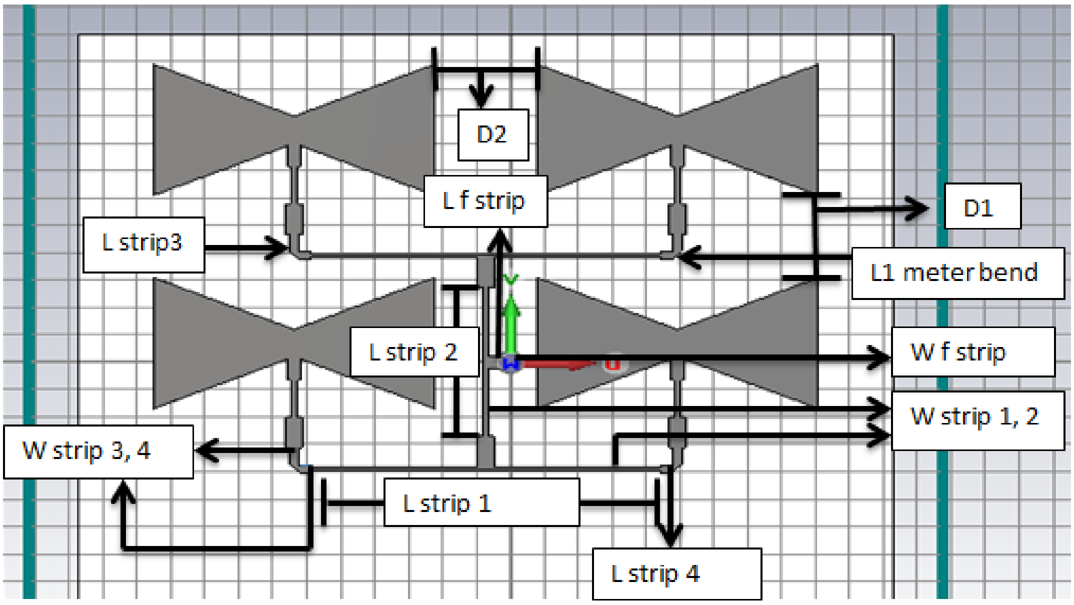


Figure 5.5: $2\times2$ Bowtie Patch Antenna Array

Table 5.2: Parameters of 2×2 bowtie patch antenna array

| Parameter | Length in mm |
|---|---|
| L strip 1 | 49.8 |
| L strip 2 | 27.14 |
| L strip 3 | 3 |
| L strip 4 | 2.56 |
| L 1 meter bend | 0.148 |
| L f strip | 5 |
| W strip 1 | 0.62 |
| W strip 2 | 0.62 |
| W strip 3 | 1.33 |
| W strip 4 | 1.33 |
| W f strip | 1.88 |
| D1, D2 | 15 |

The simulation results are in the form of return loss, gain and radiation pattern. The results are discussed as follows.

Return loss:

Return loss of the reference antenna is shown in Figure 5.6. The figure shows that the antenna starts the radiation from 9.74 GHz to 10.29 GHz. The calculated bandwidth is 5.09%. The graph of the return loss has two resonances at 9.852 GHz and 10.1956 GHz.

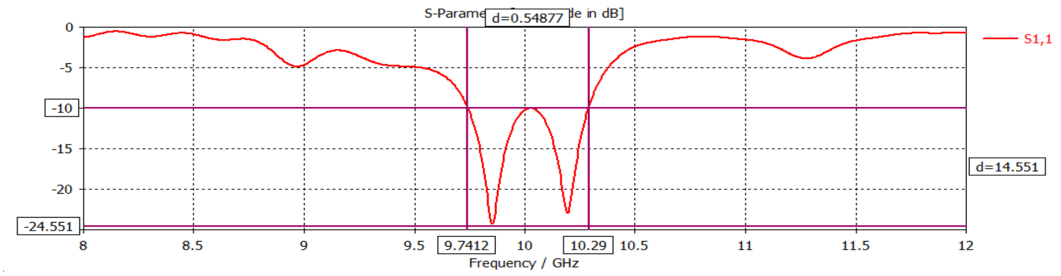
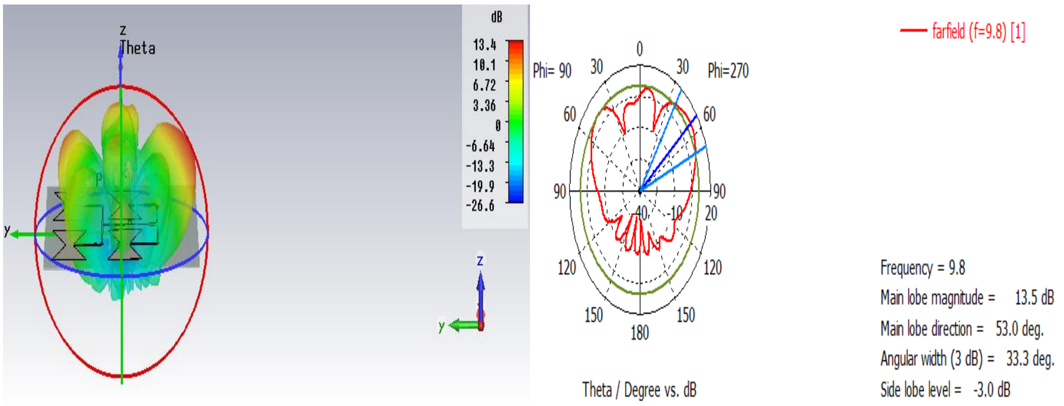


Figure 5.6: Return Loss of Reference $2 \times 2$ Bowtie Array

Gain:

Gain of the antenna is 13.4 dB at 9.8 GHz. The 3D radiation pattern shows the gain and directivity of the antenna. Radiation pattern is composed of two main lobes which are not symmetrical. Gain and radiation pattern are shown in Figure 5.7.



Frequency = 9.8
Main lobe magnitude = 13.5 dB
Main lobe direction = 53.0 deg.
Angular width (3 dB) = 33.3 deg.
Side lobe level = -3.0 dB

Figure 5.7: Gain of The $2 \times 2$ Bowtie Antenna Array at 9.8 GHz.

### 5.1.3 1st Modification

Here we use slot for improving the bandwidth of the basic bowtie patch [28-29]. The rectangular slot at the center of the patch has a length of 7.5 mm and the width of the slot is 0.9375 mm. The bandwidth obtained is 2.68 %. The configuration of the antenna and simulated bandwidth are shown in Figure 5.8 and 5.9

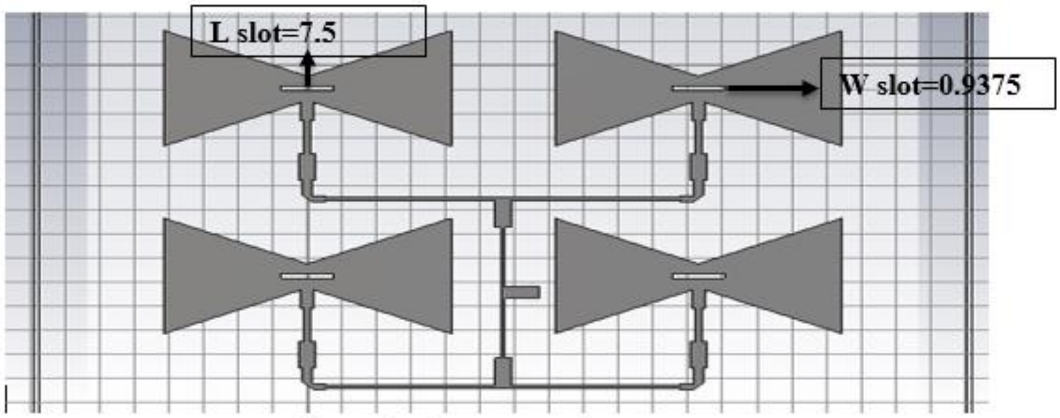


Figure 5.8: Slots Over Patch Antenna

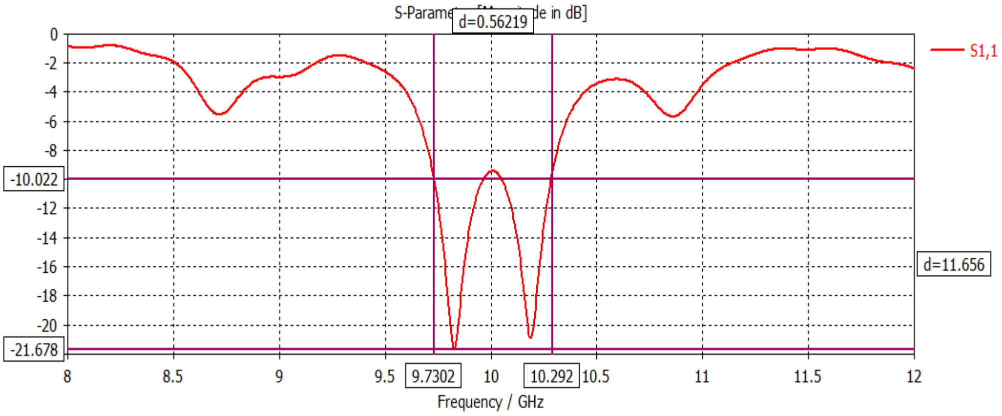


Figure 5.9: Return Loss

**Varying length of slot:**

When the length moves from 12.88 to 12 mm there is a considerable change in the bandwidth which is 5.29 %. As we move further in decreasing the length to 11 mm bandwidth is 5.47 %. At 10 mm bandwidth reaches its peak having a value of 5.51

%. After that decreasing the length of the slot the bandwidth starts to decrease. At 9 mm the bandwidth is 54.3 %. The graph of the bandwidth changes are given in Figure 5.10.

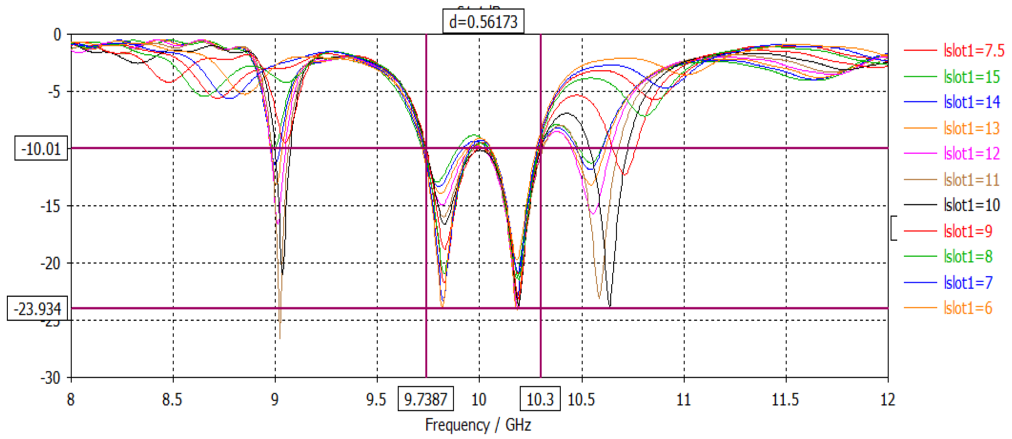


Figure 5.10: Variation Length of Slot

Return loss, gain and radiation pattern with slot having a length of 10 mm are shown in Figure 5.11 and 5.12.

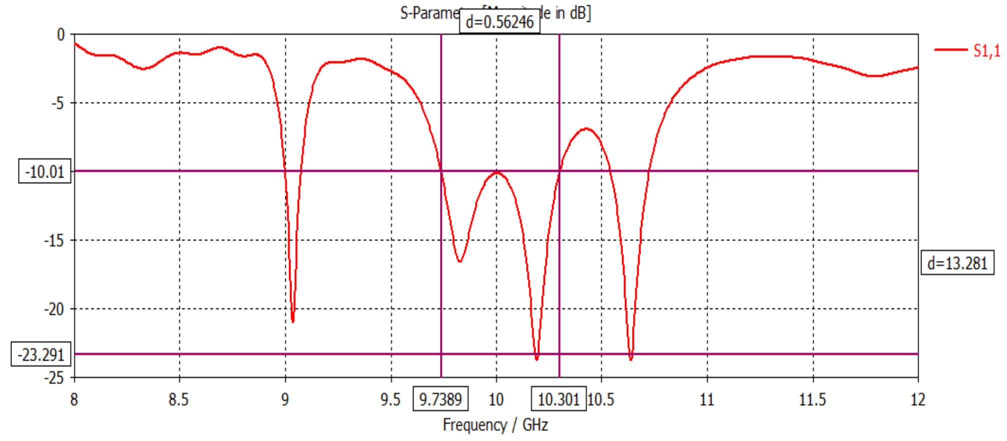


Figure 5.11: Slot Length 10 mm Return Loss

Radiation pattern and gain: Gain is 13.3 dB at 9.8 GHz; this shows that the gain of the antenna decreases from 13.4 dB to 13.3 dB.

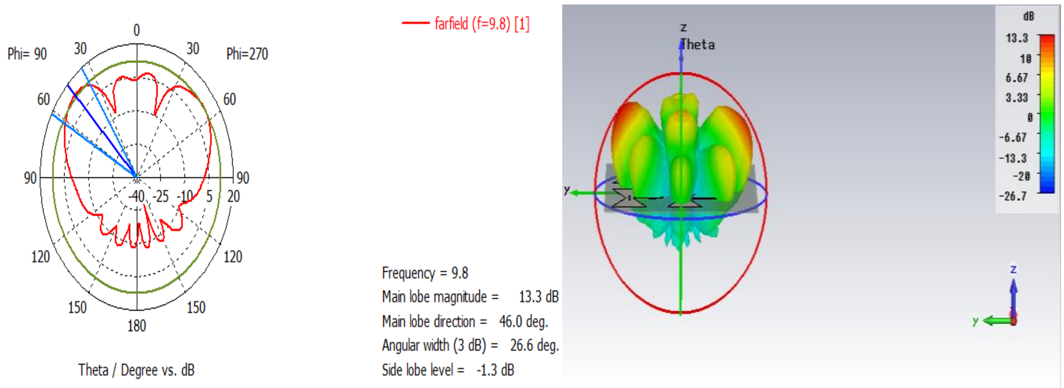


Figure 5. 12: Radiation Pattern at 9.8 GHz

**Varying width of slot:**

With the slot length fixed we now vary the width of the slot. At 0.4 mm slot width it gives highest bandwidth as 5.67 %. After that the bandwidth of the antenna starts to decrease; the simulations with varying slot width are shown in Figure 5.13.

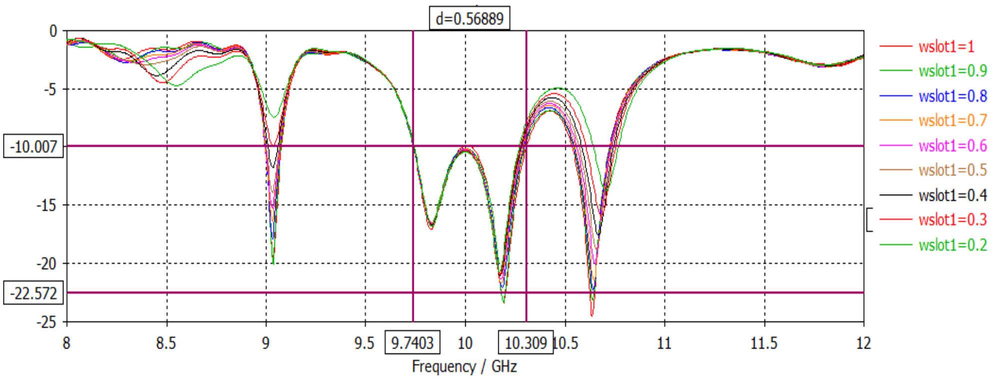


Figure 5.13: Variation Width of Slot

Return loss:

Return loss shows us the bandwidth of the antenna is 5.56 % at 0.4 mm width of the slot which is shown in Figure 5.14.

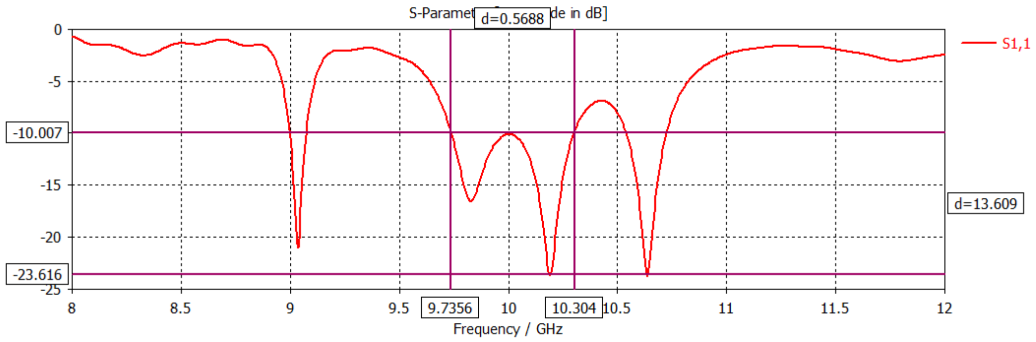


Figure 5.14: Return Loss

Radiation pattern and gain:

The gain of the antenna is decreased from 13.3 dB to 13.2 dB an the radiation pattern remains the same and are shown in Figure 5.15.

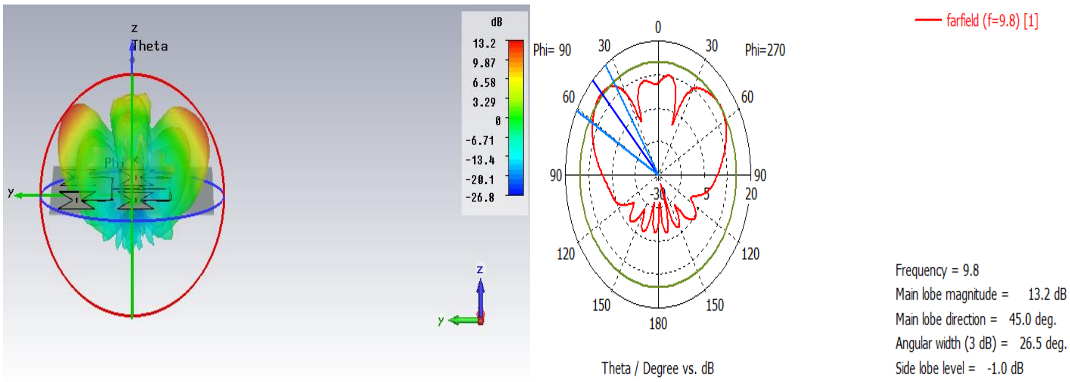


Figure 5.15: Gain and Radiation Pattern at 9.8 GHz

**Varying position of slot:**

After changing the width of the slot now it is time for changing the position of the slot. By changing the position of the slot we got some good results for the bandwidth of the antenna. By changing the position of the slot on y axis, we observe ups and downs in the value of the bandwidth. Position of the slot varies from 1 mm to -1 mm along y axis. Width and length of the slot remain constant. At position 1 mm value of the bandwidth is 2.6 %. At -0.33 mm the value of the bandwidth abruptly jumps to 8.6 %. After that as we change the position of from -0.33 to -0.55 mm the value of the bandwidth starts decreasing from 8.6 % to 5.5 % and so on. effects of varying the position are shown in Figure 5.16.

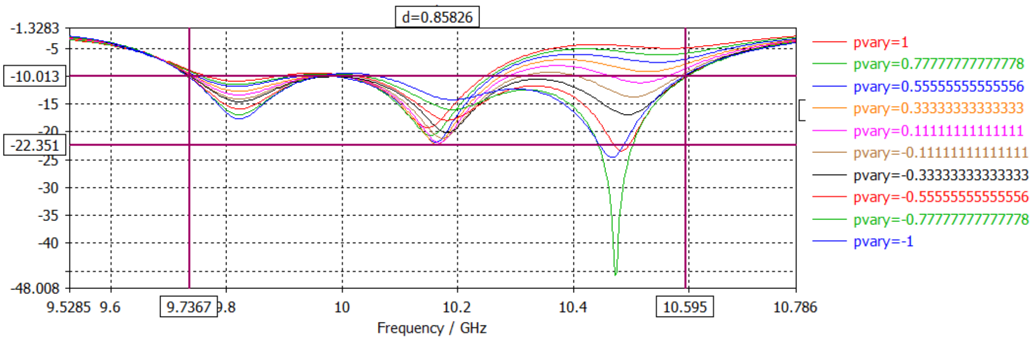


Figure 5.16: Variation of Slot Position Along Y Axis

Diagram of antenna, return loss, gain and radiation pattern are shown in Figure 5.17, 5.18 and 5.19 and 5.20.

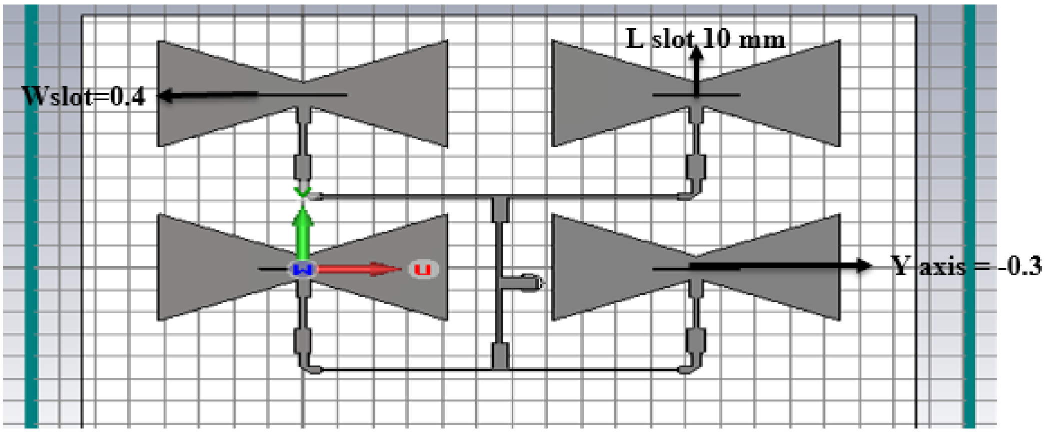


Figure 5.17: Final Dimension of Slot

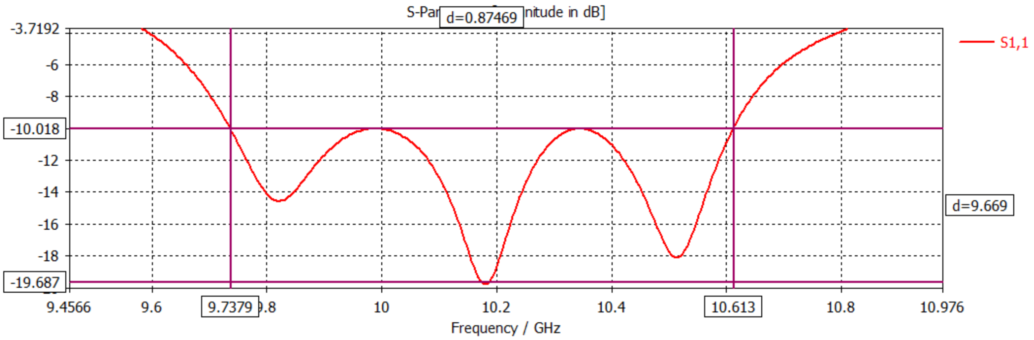


Figure 5.18: Return Loss Final of 1st Modification

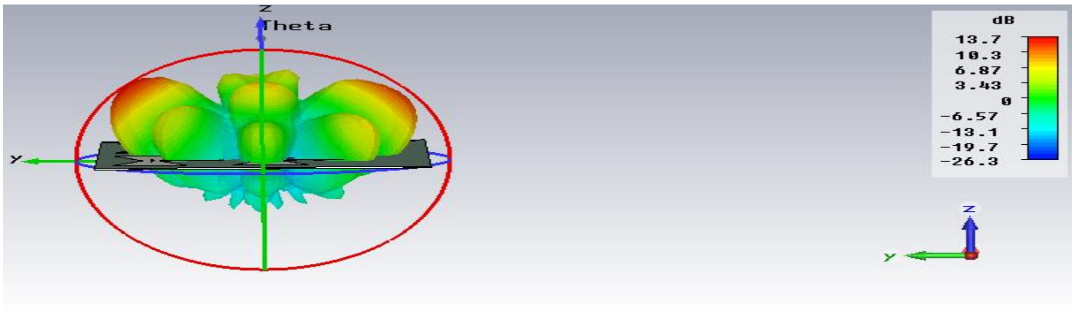


Figure 5.19: 3D Radiation Pattern at 9.8 GHz

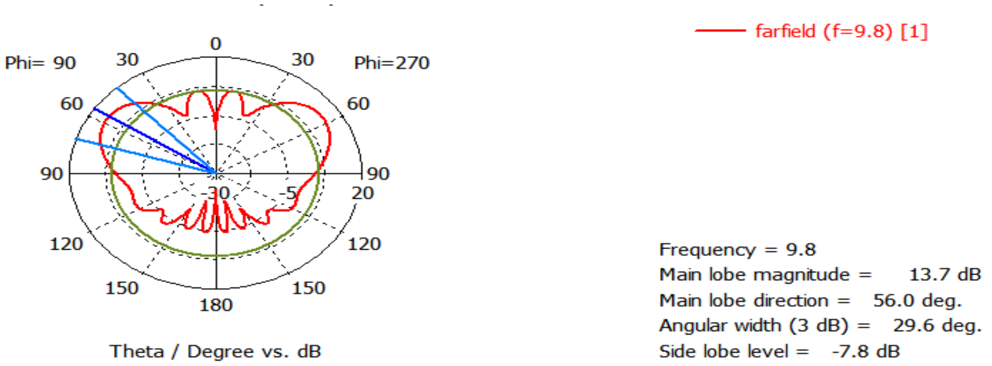


Figure 5.20: 2D Radiation Pattern at 9.8 GHz

**Variation of v slot:**

A triangular slot is added to the side of the rectangular slot and pointed toward the feed line. There are some variations in the bandwidth as the length changes from 1 mm to 0.1 mm. At 1mm it gives a bandwidth of 2.3 %. At 0.7 mm it gives the highest value of the bandwidth as 8.62 %. After that there is decline in the value of the bandwidth. The effects of variation of slot lengths are shown in Figure 5.21.

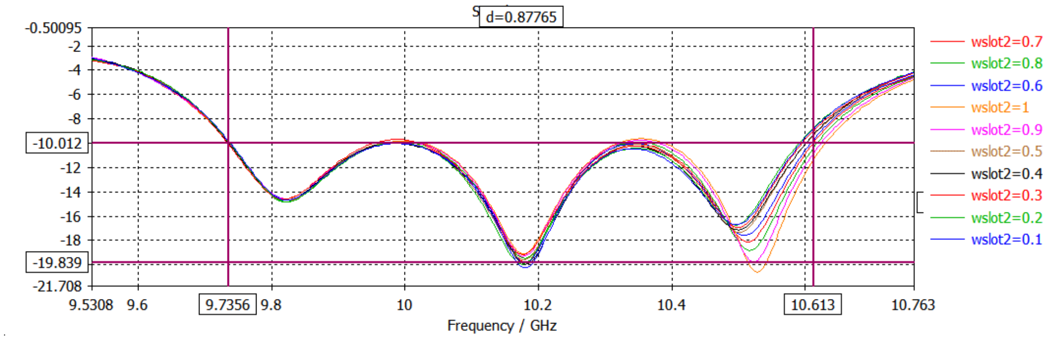


Figure 5.21: Variation of V Slot

Design of antenna and figure of return loss, gain and radiation pattern are shown in Figure 5.22, 5.23, 5.24 and 5.25.

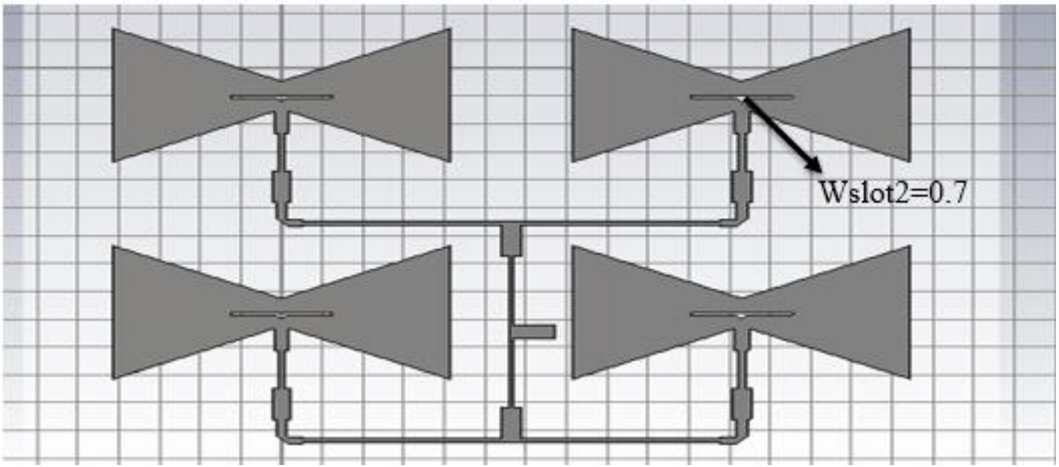


Figure 5.22: Design of Final 1st Modified Antenna

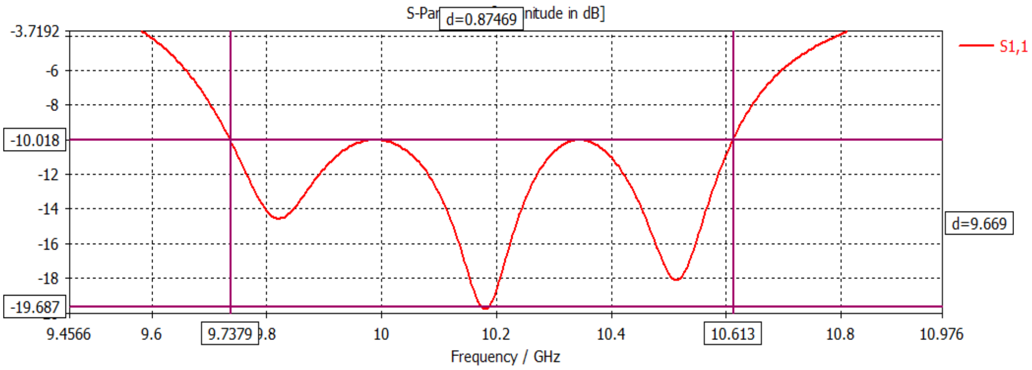


Figure 5.23: Return Loss of 1st Modified Antenna

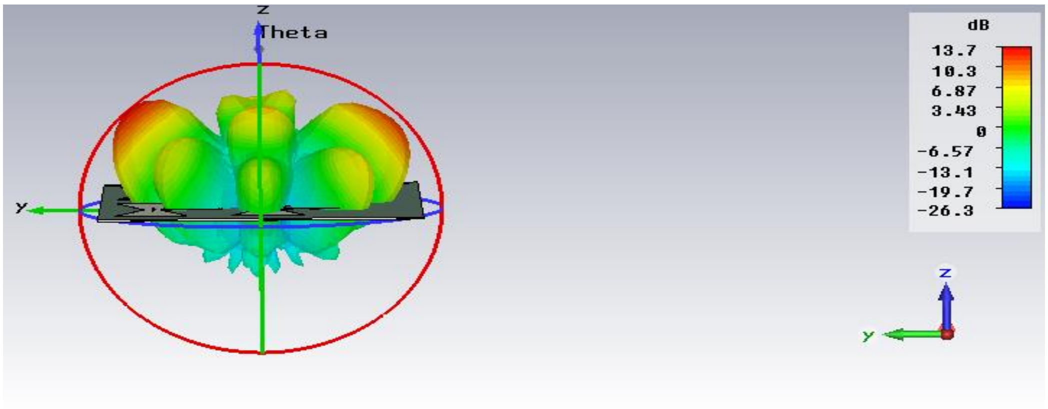


Figure 5.24: 3D Radiation Pattern

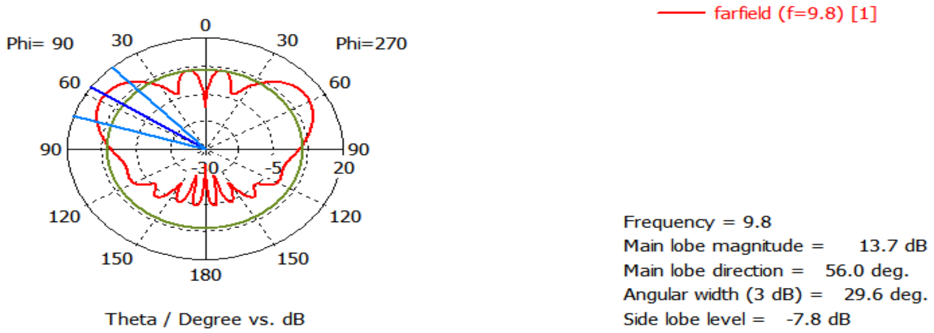


Figure 5.25: 2D Radiation Pattern

The bandwidth of the antenna increases from 5.09 % to 8.62 % with the help of the slot. But the radiation of the antenna is non-symmetrical. To make the radiation of the antenna symmetrical the modifications are discussed in the next section.

### 5.1.4 2nd Modification

Modified feed line network of $2 \times 2$ bowtie patch antenna array is shown in Figure 5.26. All dimensions of the antenna array elements are the same. Only the length of the feed lines and the lengths of the slots are changed.

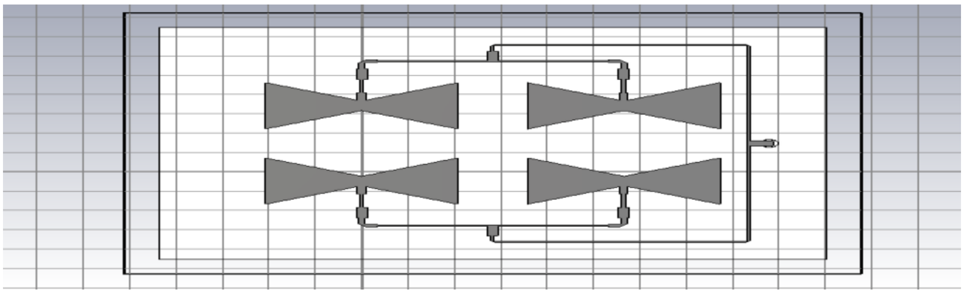


Figure 5.26: Modified Feed Line of Bowtie Antenna

The results of the simulation of modified feed network bowtie patch antenna array are discussed as follow.

Return loss:

Transmission of the antenna starts from 9.7365 GHz to 10.329 GHz. The calculated bandwidth of the modified antenna is 5.91 %. The graph of the return loss shows us that there are two resonances in the range of transmission. These are at 9.94 GHz and 10.25 GHz. Graph of the return loss is shown in Figure 5.27.

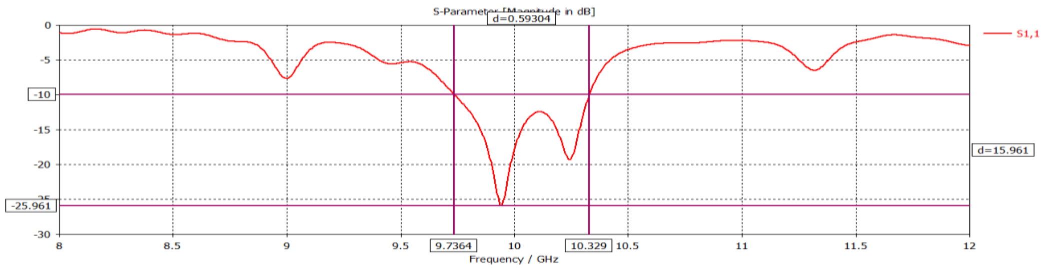


Figure 5.27: Return Loss of Modified Feed Network

Gain and Radiation Pattern:

Gain of the antenna is 12 dB at 9.8 GHz. The radiation shows that radiation pattern consists of two lobes and is symmetrical. This is shown in figure 5.28 and 29.

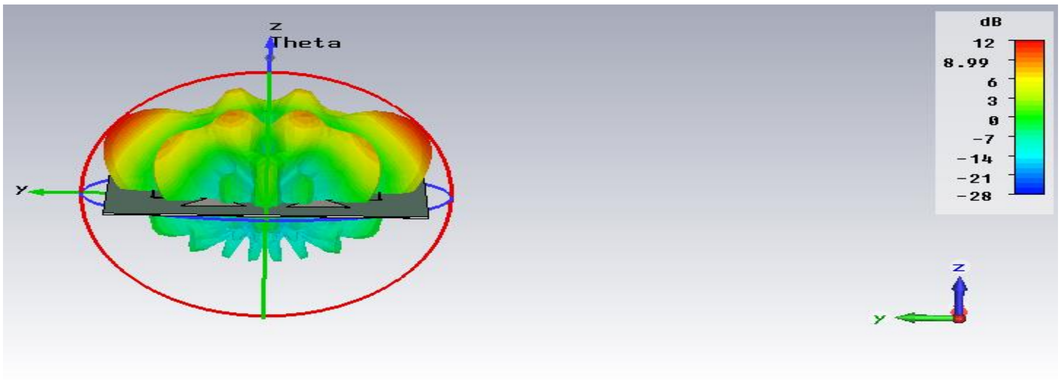


Figure 5.28: Radiation Pattern of Modified Feed Network at 9.8 GHz

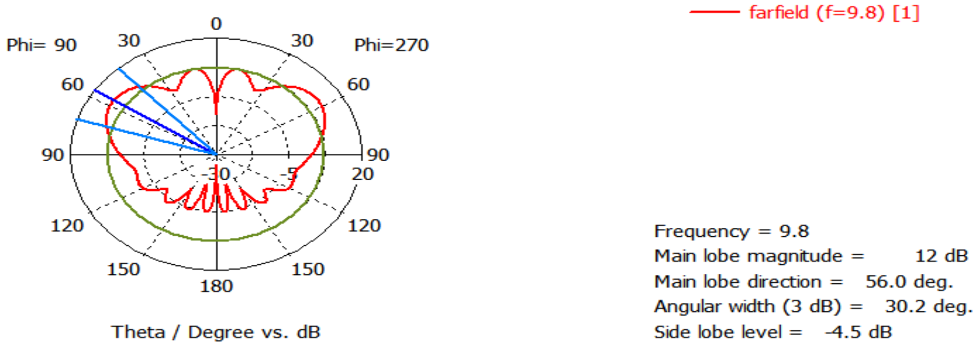


Figure 5.29: Radiation Pattern at 9.8 GHz

With the help of the 2nd modification the antenna is symmetrical. The bandwidth of the antenna is also improved. But in the 1st modification, the bandwidth of the antenna is increased more than the 2nd modification. For improving the bandwidth in the 2nd modification we did a 3rd modification in the 2nd modification.

### 5.1.5 3rd Modification

In the third modification we etch the slot in the center of the patch, the same as we did in section 5.1.2. Here, we etch the slot patch having a length of 7.5 mm and width of 1 mm. First, we vary the length of the slot and observe the changes in the bandwidth and after that we change the width of the slot and observe the bandwidth.

**Varying length of slot**

Changing the length of the slot starts from 24 to 12 mm and width of the slot remains constant. At 24 mm the bandwidth of the antenna is 1.8 %. At 22.66 mm the bandwidth of the antenna is increased to 3.1 %. When the length of slot decreased to 21.33 mm the bandwidth of the antenna dramatically increased to 9.1 %. At length of 20 mm bandwidth reached to its maximum point which is 9.17 %. After that there is a steady drop in the bandwidth, at 18.66 mm the bandwidth is 9.02 % and at 17.33 mm the bandwidth of the antenna is 8.89%. These variations are shown in Figure 5.30.

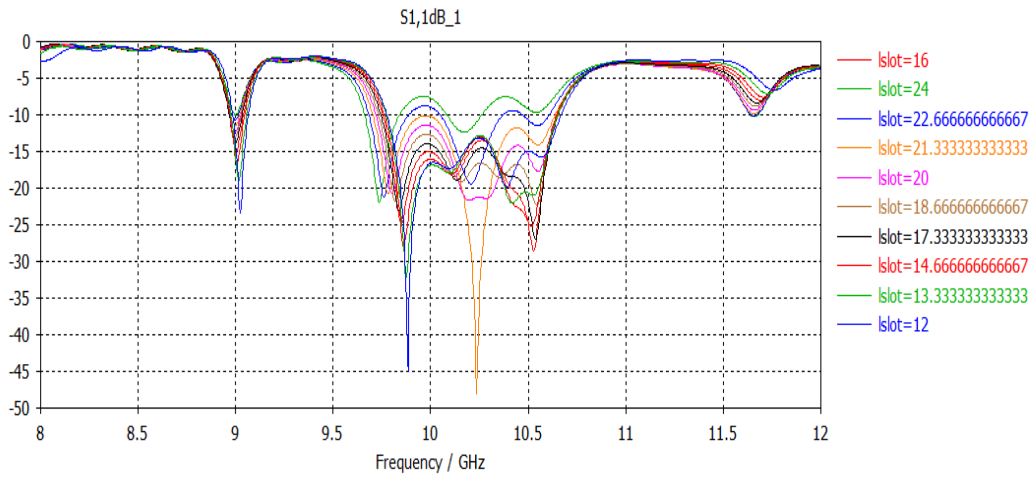


Figure 5.30: Variation Length of Slot

Bowtie antenna array with 3rd modification and the bandwidth, gain and radiation pattern are shown in Figure 5.31, 5.32, 5.33 and 5.34.

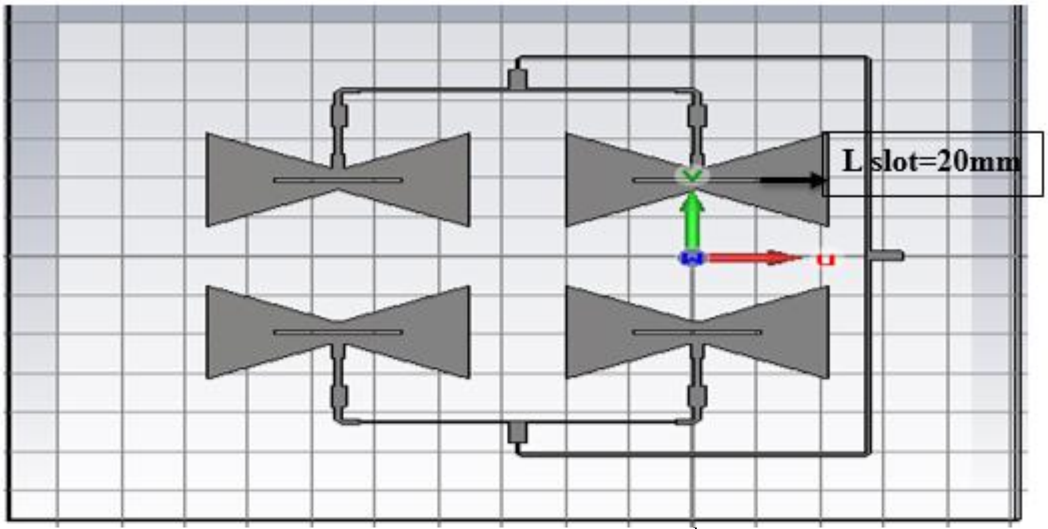


Figure 5.31: 2×2 Antenna Array with 3rd Modification

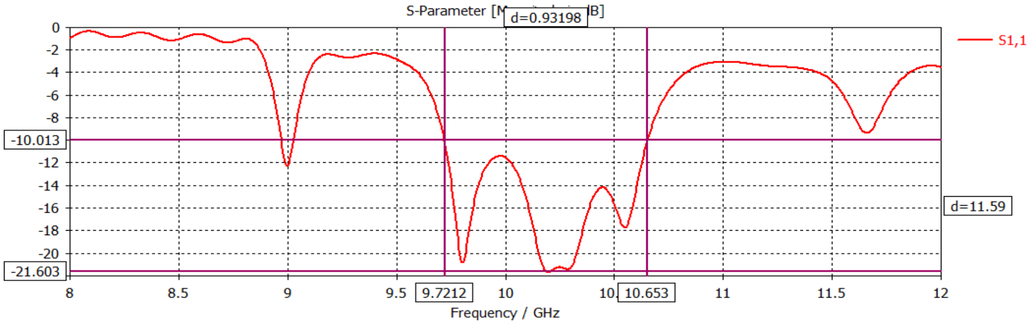


Figure 5.32: Return Loss of 3rd Modification at Length 20 mm

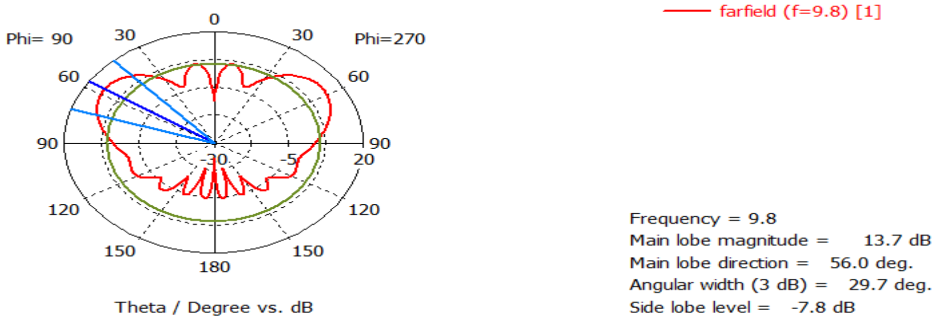
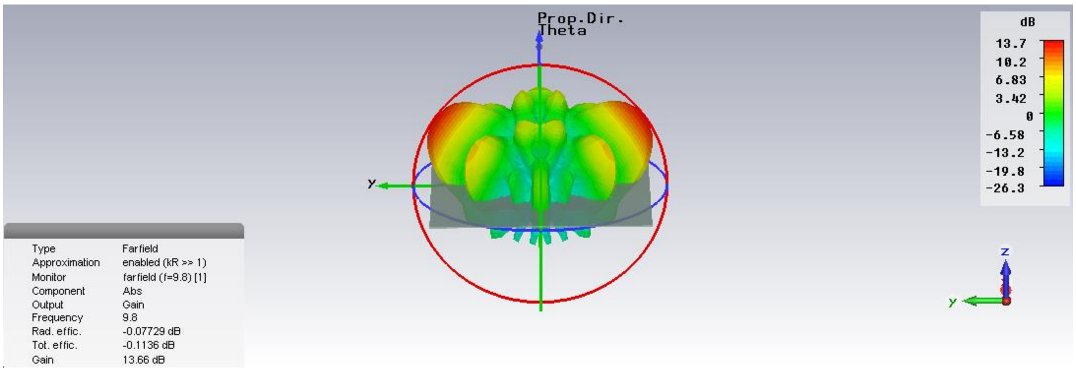


Figure 5.33: 2D Radiation Pattern at 9.8 GHz



| | |
|---|---|
| Type | Farfield |
| Approximation | enabled (kR >> 1) |
| Monitor | farfield (f=9.8) [1] |
| Component | Abs |
| Output | Gain |
| Frequency | 9.8 |
| Rad. effic. | -0.07729 dB |
| Tot. effic. | -0.1136 dB |
| Gain | 13.66 dB |

Figure 5.34: 3D radiation Pattern at 9.8 GHz

**Varying width of slot:**

After changing the length of the slot now we move towards changing the width of the slot. The variation of the slot width starts from 1.8 mm to 1.1 mm. At 1.8 mm the bandwidth of the antenna is 6.3 %. At 1.7 mm the bandwidth of the antenna is 6.5 %. At 1.6 mm the bandwidth of the antenna reached to maximum point which is 9.5 %. After that the bandwidth of the antenna decreases steadily. All variations are shown in Figure 5.35.

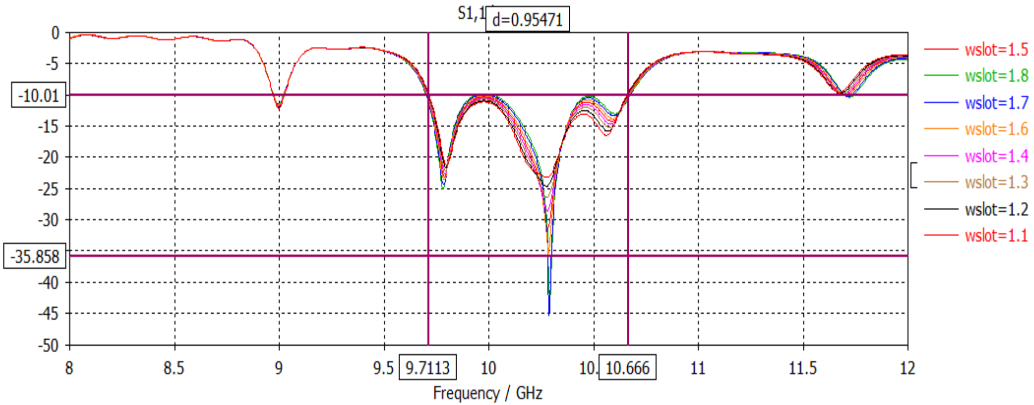


Figure 5.35: Variation Width of Antenna for 3rd Modification

Final dimension of the antenna, return loss, gain and radiation pattern are shown in Figure 5.36, 5.37, 5.38 and 5.39.

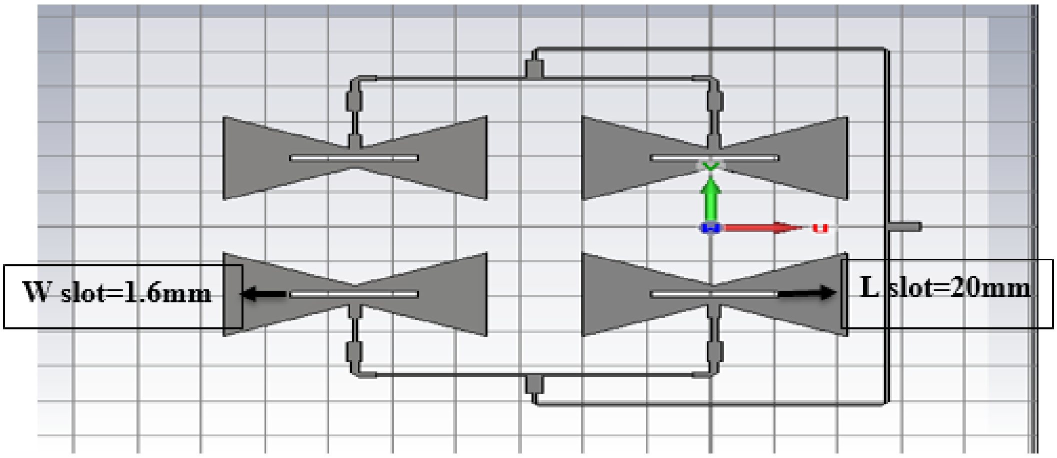


Figure 5.36: Dimension of Antenna at 3rd Modification

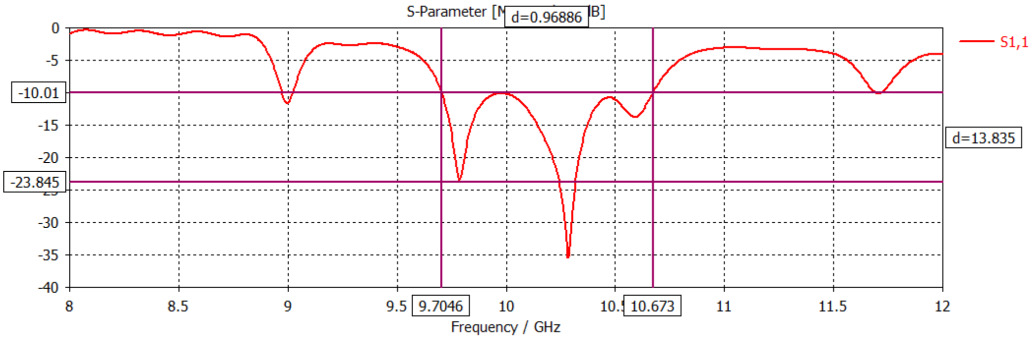


Figure 5.37: Return Loss

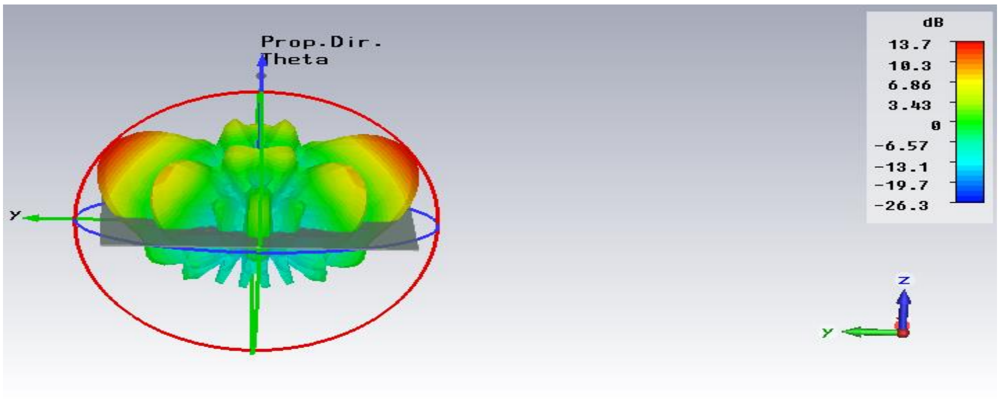


Figure 5.38: 3D Radiation Pattern

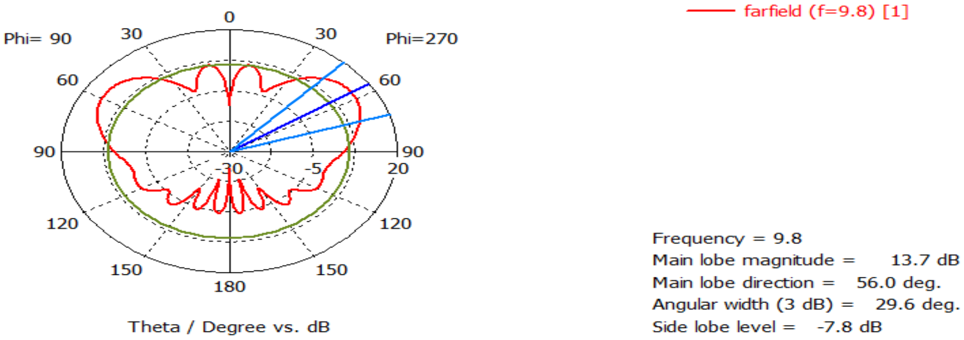


Figure 5.39: 2D Radiation Pattern

**Varying position of slot:**

By changing the position of the slot along y axis the bandwidth of the antenna is decreased. Only at zero position it gives its highest value of the bandwidth. The variations are shown in Figure 5.40.

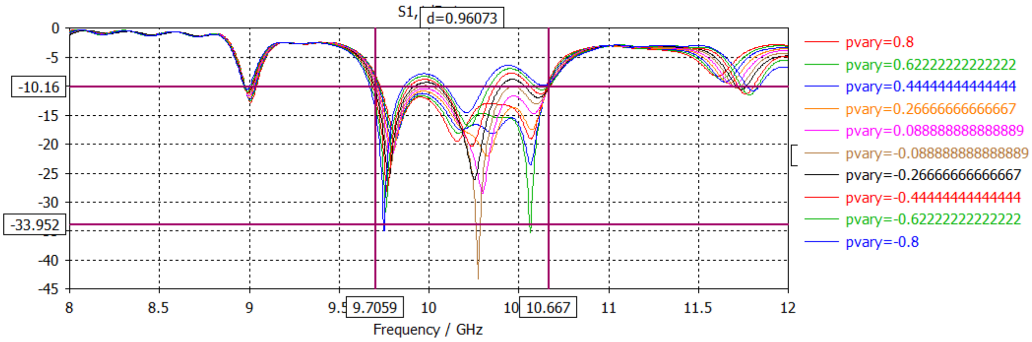


Figure 5.40: Varying Position of Slot

**Variation of v slot:**

A triangular slot is added to the side of the rectangular slot and pointed toward the feed line. Variations of all these lengths are shown in Figure 5.41.

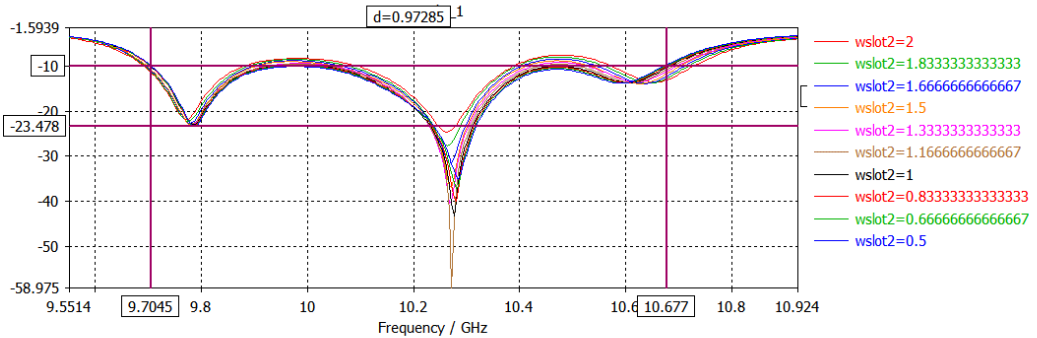


Figure 5.41: Variation of V Slot in 3rd Modification

Antenna configuration, return loss, gain and radiation pattern are shown in Figure 5.42, 5.43, 5.44 and 5.45.

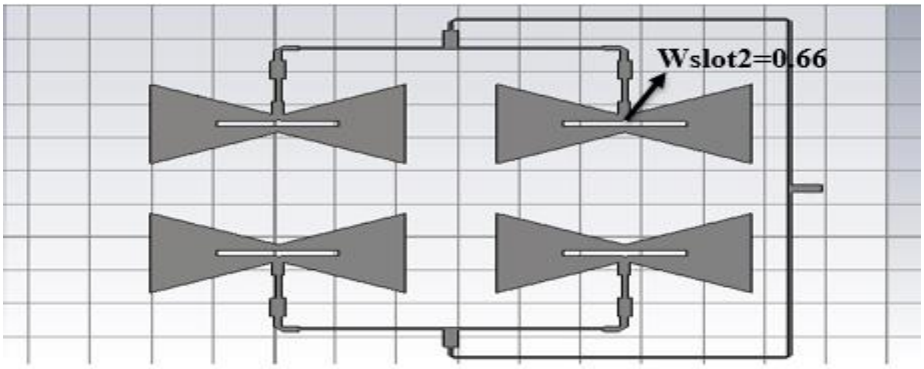


Figure 5.42: Design of V Slot 3rd Modification

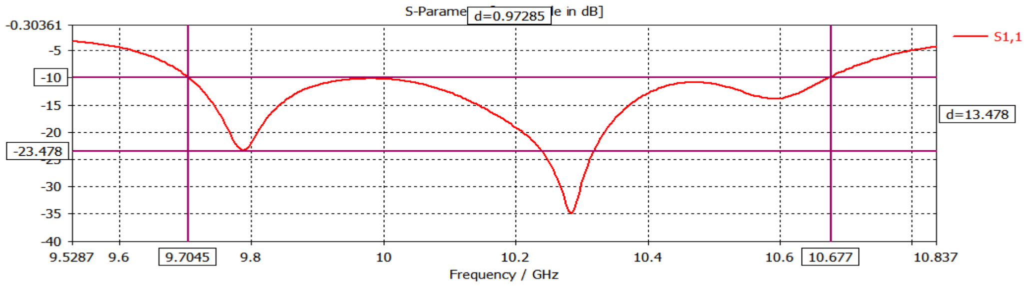


Figure 5.43: Return Loss of V Slot 3rd Modification

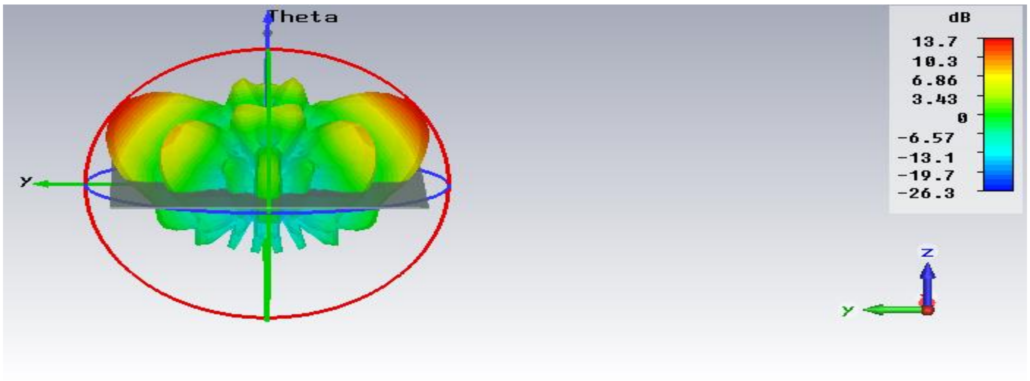


Figure 5.44: 3D Radiation Pattern of 3$^{rd}$ Modification

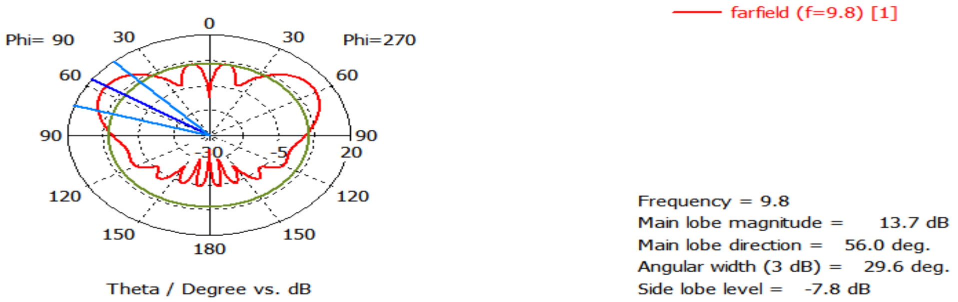


Figure 5.45: 2D Radiation Pattern of 3$^{rd}$ Modification

### 5.1.5 Results

Results of the modified bowtie antenna are compared with [3]. All the dimension of the antenna are fixed except the modification with respect to slot and feed lines. As in [3] all the results simulated for 9.8 GHz. The comparisons of the parameter are shown in Figure 46 and values are shown in Table 5.3.

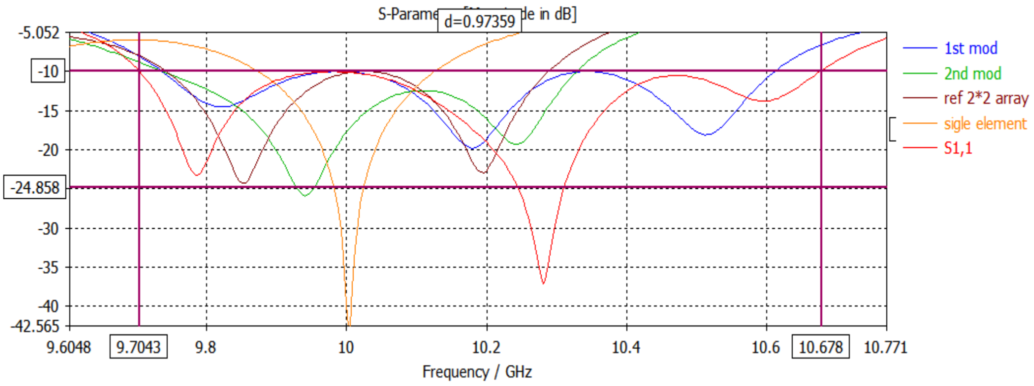


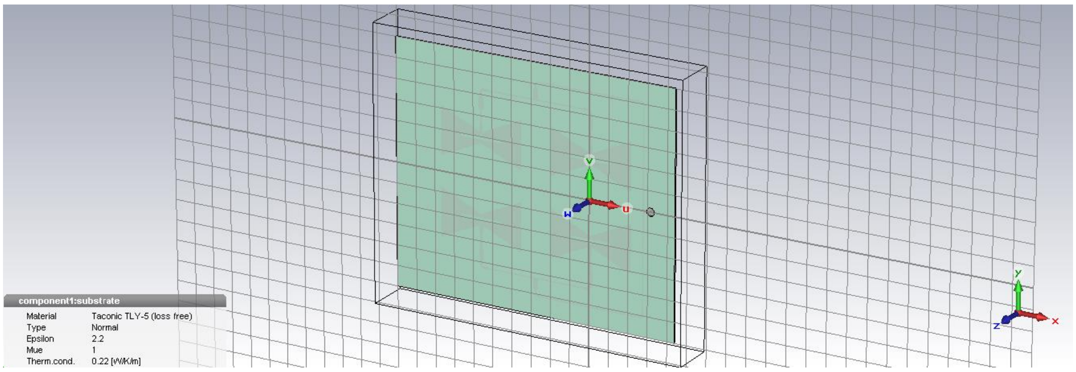
Figure 5.46: Final Bandwidth of All Modification

Table 5.3: Compared results

| Antenna type | Gain in dB | Bandwidth in % | Resonant Frequency in GHz | Symmetric status |
|---|---|---|---|---|
| Single bowtie antenna element array | 9.26 | 2.52 | 10 | Asymmetric |
| $2\times 2$ Reference array | 13.4 | 5.09 | 9.8 | Asymmetric |
| $2\times 2$ Modified slots array | 13.7 | 8.6 | 9.8 | Asymmetric |
| $2\times 2$ Modified feed network array | 12 | 5.91 | 9.8 | Symmetric |
| $2\times 2$ Modified feed network with modified slots array | 13.7 | 9.55 | 9.8 | Symmetric |

## 5.2 Substrate of Bowtie Patch Antenna Array

The material which is used here is Taconic TLY-5. The permittivity of this material is $\varepsilon_r$ = 2.2. Length and width of the antenna varies for different patch antenna but the height of substrate remains the same. The height of the substrate is considered as 0.79 mm. Length of the substrate is 164 mm. Substrate is shown in Figure 5.48.



component1:substrate

Material Taconic TLY-5 (loss free)
Type Normal
Epsilon 2.2
Mue 1
Therm.cond. 0.22 [W/K/m]

Figure 5.47: Substrate of Bowtie Antenna Array

## 5.3 Ground of Bowtie Patch Antenna Array

The ground plane is the same in the size of the substrate. The thickness of the metal is 0.05 mm. Length of the ground is varied for different antennas. The ground is shown in Figure 5.49.

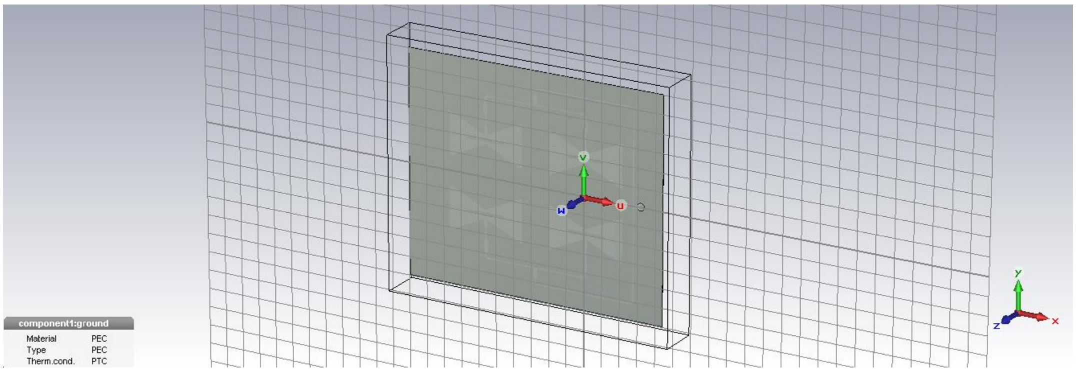


Figure 5.48: Ground of The Bowtie Patch Antenna Array

## 5.4 Feeding Technique of Bowtie Patch Antenna

In this case modified bowtie patch antenna array coaxial probe feeding techniques is used. The inner feed diameter is 0.6 mm. The dielectric diameter is 2 mm Teflon. The coaxial probe is shown in Figure 5.50.

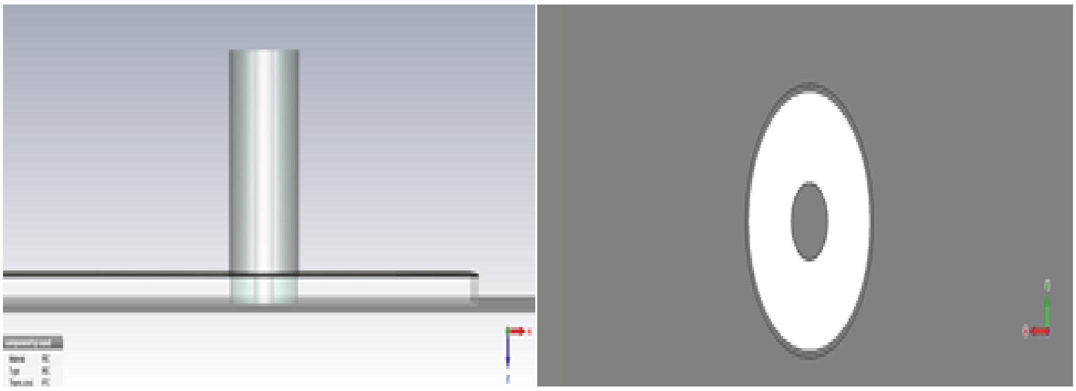


Figure 5.49: Coaxial Probe Feeding Techniques

# Chapter 6

# CONCLUSIONS AND FUTURE WORK

## 6.1 Conclusion

This thesis concludes that by using (etching) slots over the patch of 2×2 bowtie antenna array bandwidth as well as the gain of the antenna is improved. By a proper design of the feed structure, radiation pattern is also improved. The new array is designed by modifying feed network and etching slots. From these modifications, we conclude that impedance matching is improved which results in increased bandwidth and gain; additionally a more symmetrical radiation pattern is achieved. The 2×2 bowtie antenna array presented in [15] is used for the modifications.

## 6.2 Future Work

Future work may include the use of other modifications to improve antenna bandwidth and gain. Alignment of bowtie elements may also be considered to achieve different beam formations with enhanced gain and bandwidth.

# REFERENCES

[1] Hall, P. S. Multioctave bandwidth log-periodic microstrip antenna array. *IEE Proceedings H-Microwaves, Antennas and Propagation*. Vol. 133. No. 2. IET, 1986.

[2] Rahim, M. K. A., and P. Gardner. The design of nine element quasi microstrip log periodic antenna. *RF and Microwave Conference, 2004. RFM 2004. Proceedings*. IEEE, 2004.

[3] Rahim, Mohamad Kamal A., et al. Comparison between straight and U shape of ultra wide band micro strip antenna using log periodic technique. *2007 IEEE International Conference on Ultra-Wideband*. IEEE, 2007.

[4] Casula, Giovanni Andrea, Paolo Maxia, and Giorgio Montisci. Design of a printed wide band Log-periodic antenna dipole array with a new feeding tecnique. *2012 6th European Conference on Antennas and Propagation (EUCAP)*. IEEE, 2012.

[5] Das, Arindam. Analysis of Log Periodic Antenna with Printed Dipoles. *Diss. Jadavpur University, 2008.*

[6] Nguyen, Cam. A wide-band microstrip-fed log-periodic antenna. *Antennas and Propagation Society International Symposium, 1996. AP-S. Digest*. Vol. 1. IEEE, 1996.

[7] Dadel, Megha, and Shweta Srivastava. Arrays of patch antenna using log periodic property. *2011 IEEE International RF & Microwave Conference*. 2011.

[8] Azari, Abolfazl, and Javad Rowhani. Ultra wideband fractal antenna design. Proceedings of the Fifth IASTED International Conference on Antennas, Radar and Wave Propagation. ACTA Press, 2008.

[9] Cohen, Nathan. Fractal antenna applications in wireless telecommunications. *Electronics Industries Forum of New England, 1997. Professional Program Proceedings*. IEEE, 1997.

[10] Jamshidifar, M., et al. Miniaturized, wideband fractal patch antenna. As IEEE/ACES International Conference on Wireless Communications and Applied Computational Electromagnetics, 2005. IEEE, 2005.

[11] Yamini, Amir Hossein, and Mohammad Soleimani. Multiband behavior of wideband sierpinski fractal bow-tie antenna. *The European Conference on Wireless Technology, 2005*. IEEE, 2005.

[12] Pozar, David M., and Daniel H. Schaubert. Microstrip patch the analysis and design of microstrip antennas and arrays. *John Wiley & Sons, 1995.*

[13] Kimiagarov, N., and H. Matzner. A wide band flat spiral antenna with planar unbalanced feed. Microwaves, Communications, AntennaElectronics Systems, 2009. COMCAS 2009. IEEE International Conferenceon.IEEE2009

[14] Paulino, Nuno, et al. Design of a spiral-mode microstrip antenna matching circuitry for ultra-wide-band receivers. *Circuits and Systems,2002. ISCAS 2002. IEEE International Symposium on*. Vol. 3. IEEE,2002.

[15] Sener, Mook-Seng Leong, and Chee Hong Ng. Bowtie patch antennas and simple arrays for wireless indoor communications. *IEEE transactions on microwave theory and techniques* 47.6 (1999): 738-745.

[16] Wong, Hang, Ka-Ming Mak, Kwai-Man Luk. Wideband shorted bowtie patch antenna with electric dipole. *IEEE Transactions on Antennas and Propagation* 56.7 (2008): 2098-2101.

[17] Zhang, Fan, et al. Wide band antenna using bowtie-shaped microstrip patch. *Microwave and Millimeter Wave Technology (ICMMT), 2010 International Conference on*. IEEE, 2010.

[18] Waterhouse, R. B. Small Microstrip Patch Antennas. *Microstrip Patch Antennas: A Designer's Guide*. Springer US, 2003. 197-276.

[19] James, James R., and Peter S. Hall, eds. *Handbook of microstrip antennas*. Vol. 1. IET, 1989.

[20] Gajera, Sandip, Hasani Mahesh, and Naresh Patel. Comparative Analysis of Microstrip Line and Coaxial Feeding Technique for Rectangular Micro-strip Patch Antenna. *International Journal of Electronics and Computer Science Engineering*: 719-725.

[21] Balanis, Constantine A. Antenna theory analysis and design. *John Wiley & Sons, 2016.*

[22] Kaur, Rupleen, Satbir Singh, and Naveen Kumar. Review of Various Fractal Geometries for Wireless Applications. *International Journal of Electrical and Electronics Engineering 2.1 (2015): 34-36.*

[23] Waterhouse, Rod. Microstrip patch antennas. Handbook of Antennas in Wireless Communications. CRC Press, 2001. 177-203.

[24] Almutawa, Ahmad Tariq. Log-Periodic Microstrip Antenna Miniaturization Using Artificial Magnetic Conductor Surfaces. (2011).

[25] Ali, Mr Syed Rizwan, and Mr Suresh S. Gawande. *A Review on UWB Log-Periodic Antenna*. (2016).

[26] Kaur, Baljinder, Lakhvinder Singh Solanki. A Brief Review on Bowtie Antenna. Proceedings of 5th National Conference on Communication & Networking (NCCN-12).

[27] Mahmoud, M. Improving the bandwidth of U-slot microstrip antenna using a new technique (trough-slot patch). *Region 5 Conference*, *2008 IEEE. IEEE, 2008*.

[28] Rani, Aruna, and A. K. Gautam. Improvement in Gain and Bandwidth of Rectangular and U Slot Loaded Patch. *IJCSI (2011).*

[29] Loi, K. W., S. Uysal, and M. S. Leong. Design of a wideband microstrip bowtie patch antenna. *IEE Proceedings-Microwaves, and patch Antenna Propagation* 145.2 (1998): 137-140.