AN ANALYSIS OF MIXED BOW-TIE AND ICE-CREAM CONE ANTENNA AT 120GHz FOR MILLIMETER WAVE APPLICATION

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This report is submitted to Faculty of Electronics and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM) In partial fulfillment of requirements for Bachelor of Electronics Engineering (Telecommunication) With Honours

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I would like to dedicate my thesis to my beloved parents,
lecturers and my fellow friends.

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ABSTRACT

Millimeter wave generally corresponds to the radio spectrum between 30 GHz to 300 GHz, with wavelength between one and ten millimeters. In this project, an analysis was done by combining two separate antenna design into one which is the Bow-Tie design and the Ice-Cream cone design. This antenna was design to operate at 120GHz for millimetre wave application by using CST Microwave Studio Simulation Software. An investigation was done on the antenna return loss and radiation efficiency and other antenna parameters to the new combined design. This antenna was design on an Alumina substrate with a dielectric constant 8.8. The dimension of the proposed antenna is 1.6mm x 1.2mm. The proposed antenna shows improvement in terms of gain, return loss, radiation efficiency and the ability to operate at high frequency which can support millimetre wave applications.

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ABSTRAK

Gelombang milimeter secara umumnya dikategorikan sebagai gelombang yang berfrekuensi sangat tinggi yang sepadan dengan spektrum radio antara 30 GHz sehingga 300 GHz, dengan panjang gelombang antara satu hingga sepuluh milimeter. Projek ini merupakan suatu analisis dimana dua reka bentuk antena yang berasingan iaitu reka bentuk Bow Tie-dan reka bentuk kon Ice-Cream yang telah digabungkan kepada satu rekabentuk yang tunggal. Antenna ini telah direka untuk beropreasi pada 120GHz yang dapat berfungsi untuk aplikasi gelombang millimeter. Proses reka bentuk antenna tersebut telah dilakukan dengan menggunakan perisian CST Microwave Studio. Analisis telah dilakukan ke atas kecekapan radiasi dan parameter antena lain untuk reka bentuk gabungan baru tersebut. Antena ini telah direka dengan menggunkan Alumina sebagai substrat dengan pemalar dielektrik 8.8.Dimensi antena yang telah direka adalah berukuran 1.6mm x 1.2mm. Antena yang telah dicadangkan dalam analisis ini menunjukkan peningkatan dari segi parameter antenna dan keupayaan untuk beroperasi pada frekuensi tinggi yang boleh beroperasi pada aplikasi gelombang milimeter.

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LIST OF ABREVIATIONS

MMW	–	Millimeter Wave
CST	–	Computer Simulation Technology
RF	–	Radio Frequency
AC	–	Alternating Current
VSWR	-	Voltage Standing Wave Ratio
HPBW	-	Half Power Beamwidth

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CHAPTER I

INTRODUCTION

1.1 Introduction

Nowadays as the rate of urbanisation increasing with end users ranging from corporate data centres teenagers with high tech devices, demanding higher bandwidth, the demand for newer technologies to deliver this bandwidth is higher than ever before. A plethora of technologies exist for the delivery of bandwidth, with fiber optic cable considered to be the ultimate bandwidth delivery medium. However, the fiber optics are not unmatched by any means, especially when all economic factors are considered. Millimeter wave wireless technology or also known as (MMW) presents the potential to offer bandwidth delivery comparable to that of fiber optics, but without the financial and logistic challenges of deploying fiber. Millimeter wave generally corresponds to the radio spectrum between 30 GHz to 300 GHz, with wavelength between one and ten millimeters.

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1.2 Project Background

Major advances in millimetre wave antennas have been made in recent years due to the high competition of users for the bandwidth and for the speed. Nowadays most of the devices are minimized so that it is portable and user friendly as well. Interesting developments have taken place also in a group of millimetre wave antennas, that of microstrip antennas and printed circuit antennas in general and furthermore. Therefore, attempts were taken to analysis and design an antenna for millimetre wave application. Bow-tie antennas and Ice-cream cone antennas have become popular in the present day communication scenario due to their compact in nature compared to a rectangular patch antenna. The efficiency of the antenna sometimes depends on the structure and the design of the antenna as well. This project is an analysis of mixed bow-tie and ice-cream cone antenna at 120GHz for millimeter wave application.

1.3 Problem Statement

As the number of users is increasing day by day, frequency bands are being congested, therefore resulting in poor quality and interrupted services. Certain telecommunication applications or systems does not require long time frame in order to receive or transmit a data and doesn"t occurs in a long distance. Systems that are operating in a short distance can be formed by using more effective devices and economical without making it complex. In order to deliver higher data speeds, more radio frequency bandwidth is needed.

Nowadays, in telecommunication field, size and performance are the most important aspect in current applications and devices. Things are getting smaller and productive as well as the efficiency of the devices. Users are looking forward for portable and productive devices. Antenna is one of a major factor in the telecommunication sector which determines the efficiency and the size of a device. Therefore, millimetre wave antenna can be implemented to curb this problem. In the millimetre wave application, frequency range at 120GHz shows a better data transmission rate in the previous discussion.

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1.4 Objectives of Project

- To calculate and design a mixed bow-tie and ice-cream cone antenna at 120GHz for millimetre wave application.

- To achieve high performance rate such as in gain and radiating efficiency by simulating and optimizing the millimetre wave antenna.

- To analyse and observe on the performance of the mixed bowtie and ice-cream cone antenna.

1.5 Project Scope

The design of this mixed bow-tie and ice-cream cone antenna is a combination of two different antennas. In this analysis, only the design of bow-tie and ice-cream cone was used. Therefore the design of this antenna is only based on these shapes. The antenna was design at the frequency range of 120GHz for millimetre wave application. All the antenna parameters were determined by theoretical calculation and by referring to the journals.

The antenna was design and simulated by using CST (Computer Simulation Technology) software to analyse the radiation efficiency, gain, bandwidth and the return loss as well. The antenna was design in the software by using Alumina as the substrate and gold for the conductor. The limitation of the design is the frequency value which is approximately at 120GHz and not more than that.

1.6 Expected Outcome

The expected outcome of this project is to design a mixed bow-tie and ice-cream cone antenna for a millimetre wave application at 120GHz by using CST design software in terms of good radiation efficiency, gain and return loss.

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1.7 Thesis Outline

The background and objective of the project was elaborated in the above together with the problem statement. Fundamental theory on antenna parameters, compact techniques and antenna types are presented in literature review which is in Chapter 2. In Chapter 3, the methodology of every design was presented. Parametric study of the antenna parameter and an overview of the antenna design simulation, fabrication and measurement procedures are included in this thesis. The return loss, radiation pattern and gain of every stage are closely analysed in result and discussion part. Finally in Chapter 5, conclusion of the overall project and verification of the objective are stated. Recommendation for future work was suggested as well in this chapter.

1.8 Conclusion

As a conclusion, this antenna design can be used in many applications in the telecommunication field in future for a system which needs high precision. The small wavelength allows this kind of modest size antenna to have a small beam width, further increasing frequency reuse potential. The next activity to be carried out is complete the chapter 2. Chapter 2 consists of facts and finding, literature review, project requirement, project scheduling and milestone. In order to complete this chapter a lot of effort needs to be done on research about proposal title, including study on related journals, research papers and articles.

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CHAPTER II

LITERATURE REVIEW

2.1 Introduction

Literature review was done based on some deep research that has been done regarding the millimetre wave antenna and its functionality. This literature review covers the theory and concepts of the bow-tie and ice-cream cone antenna system. In this part, the research related to the project was shown. It is important to review the literature related to the project because it shows the target of the project.

This chapter contain all the research that have been done on the previous system and existing system on the internet including reviews on the features, capabilities and so on. The current or existing system was identified in order for this project to overcome and the strength of the existing system are identified and studied so that it can be implemented in this system.

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2.2 Antenna Theory

Antenna is a device which acts as an interface between transmission lines and air space. As a basic concept of understanding the antenna is that, these devices are passive devices. Voltage supply is not required in order to make them to operate. Other than that, they do not alter or process RF signals especially to amplify the RF signals. In other context, an antenna is a device which converts an electromagnetic signal to an electrical signal at a receiver or vice versa at the transmitter. [12]

There are two basic types of antenna. Receiving antenna is an antenna which intercepts RF energy and delivers alternating current to electronic equipment, while the transmitting antenna, which is fed with AC from electronic equipment and generates an RF field. At low frequencies, many different types of antennas are used. The simplest is a length of wire, connected at one end to a transmitter or receiver. More often, the radiating or receiving element is placed at a distance from the transmitter or receiver, and AC is delivered to or from the antenna by means of an RF transmission line, also called a feed line or feeder. If the antennas are functioning 100% efficiently, it shows that they radiate no more power than is delivered to the input terminal. This is due to the absolute absorption of the energy signal. [10]

2.3 Fundamental Antenna Properties

The basic properties that are used to describe the performance of the antenna include impedance, bandwidth, Voltage Standing Wave Ratio (VSWR), radiation patterns, 3 dB beam width, gain and finally polarization.

2.3.1 Impedance

The characteristic impedance of the transmission line must identically match the input impedance of the antenna in order to achieve maximum energy transfer between the antenna and transmission line. If the input impedance of the antenna does not match with the characteristic impedance of the transmission line, a reflected

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wave will be generated at the antenna terminal and travel back towards the energy source. This reflection of energy results in a reduction in the overall system efficiency. This loss in efficiency will occur if the antenna is used to transmit or receive energy. [10]

2.3.2 Bandwidth

Frequency range of a certain antenna that it radiates in any respective value is known as bandwidth or in other words when the antenna meets a certain set of specification criteria. When antenna power drops to half of its power rate which is also referred as 3 dB, the upper and lower extremities of these frequencies have been reached and the antenna no longer performs efficiently. An antenna that operates over a wide frequency range and still maintain satisfactory performance must have compensating circuits switched into the system to maintain impedance matching. [10]

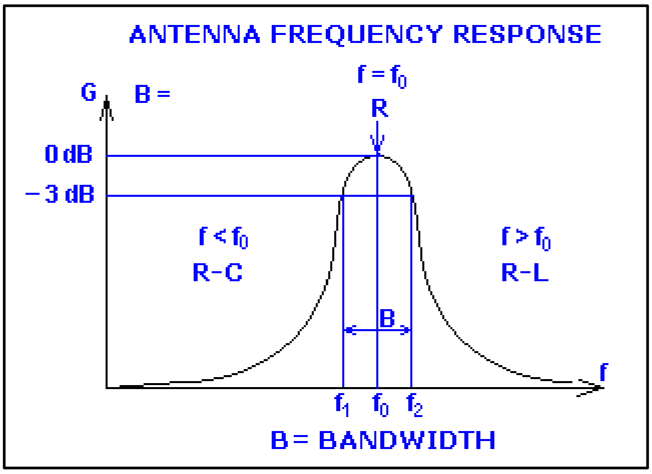

Figure 2.1 Frequency Response of Antenna

2.3.3 Voltage Standing Wave Ratio (VSWR)

The ratio between the maximum voltage and the minimum voltage along the transmission line is called as the Voltage Standing Wave Ratio (VSWR). The VSWR

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indicate that how closely or efficiently an antenna‟s terminal input impedance is matched to the characteristic impedance of the transmission line. As the value of VSWR increases, the mismatch between antenna and the transmission line also increase. In many systems, the antenna is required to operate with a VSWR better than 1.5:1 with 50Ω impedance value. Therefore an antenna VSWR should be closely to the 50 Ω of the antenna impedance. The system are perfectly match if the VSWR equals to 1:1 where there is no power reflected and all the energy are absorbed at their input terminal. The equations to determine the VSWR are as below. [10]

$$\text{VSWR}= \frac{1+\Gamma}{1-\Gamma} \qquad (2.1)$$

Whereby,

$$\Gamma = \frac{Z_{in}-Z_{out}}{Z_{in}-Z_{out}} \qquad (2.2)$$

2.3.4 Antenna Gain

The antenna‟s overall efficiency is measured and called as gain. The antenna would have an equal gain to its directivity if the antenna were 100% efficient. There are many factors that effect and reduce the overall efficiency of an antenna. Some of the factors that affect the antenna gain are VSWR/Impedance, Matching Network Losses, and Material Losses.

a) VSWR/Impedance

VSWR provides an indication of how closely the impedance of an antenna matches the impedance of the connecting transmission line. If an impedance mismatch exists, a reflected wave will be generated towards the energy source. These reflected waves will reduce the level of energy transferred between the transmission line and the antenna as well.

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b) Matching Network Losses

A matching circuit or a network is constructed at the antenna terminals in order to match the impedances. This is due to the terminal impedance of an antenna that usually will not exactly match the characteristic impedance of the connecting transmission line to the required VSWR level.

c) Material Losses

Antennas are constructed of discrete materials which include both metallic and non-metallic components. When these materials are used during the design process of an antenna, especially for the dielectric substrates or wire elements, they will dissipate some energy as heat rather than radiating the signals.

While considering these factors during the antenna design, it clearly shows that the antenna has to overcome a lot of adversity in order to achieve an acceptable gain value. These losses also can be eliminated or minimized by analysing the structure of the antenna. [10]

2.3.5 Radiation Pattern

An antenna‟s radiation pattern is one of its characteristics that give a big impact on its coverage and performances. The radiation pattern of an antenna describes the energy direction and pattern of the antenna or how it receives it. All the antennas do not radiate more total energy than is delivered to their feeder. Antenna radiation pattern are usually presented in the polar plot form for 360 ̊angular pattern in one of two sweep planes and it is presented on a relative dB scale.

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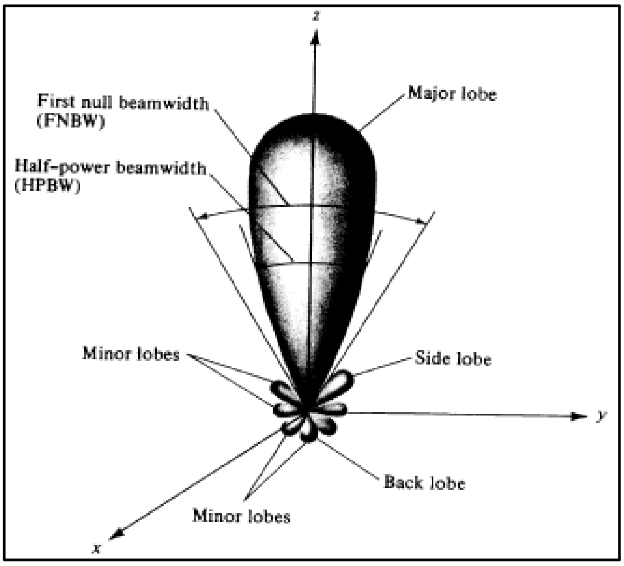

Figure 2.2: Radiation Lobes and Beamwidth of an Antenna

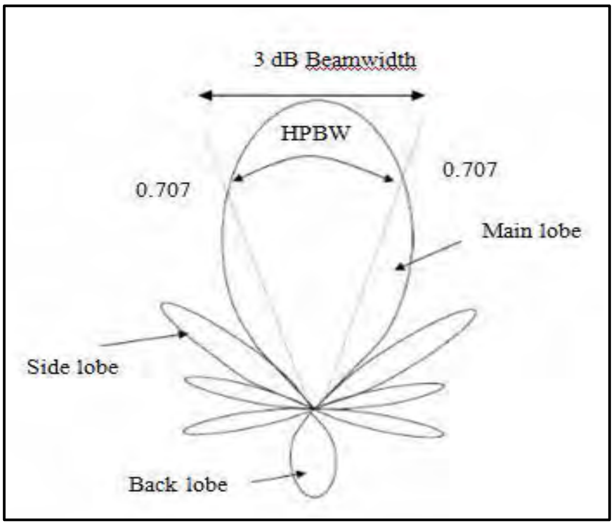

Figure 2.3 3dB Beamwidth Pattern of an Antenna

From Figure 2.3, we can see that the field strength drops to 0.707 of the maximum voltage at the center of the lobe. These points are known as the half power points or Half Power Beamwidth (HPBW). The other radiation pattern properties of significance are the antenna‟s side lobes, back lobes and front to back ratio (f/b). In practice, it is impossible to eliminate antenna side lobes and back lobes completely.

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Antenna side and back lobes affect antenna and system performance in several ways. First, energy delivered to or received by side and back lobes is from a direction other than the intended region of coverage and is therefore wasted. At a transmitter, energy delivered to side and back lobes maybe directed towards other receive systems causing interference. Then at a receiver, energy from other transmit sites may be receive through the side and back lobes causing interference within the system. Main lobe is the radiation lobe containing the direction of the maximum radiation. For side lobe, it is a radiation lobe in any direction other than the intended lob direction. It is usually adjacent to the main lobe and occupies the hemisphere in the direction of the main beam and usually refers to a small lobe that occupies the hemisphere in a direction opposite to a main lobe are the definition for back lobe. [10]

2.3.6 Polarization

The direction in space of the electric vector or also known as E-field portion of the electromagnetic wave being radiated by the transmission system is known as polarization. Polarization in the direction of the maximum gain are refered when the direction is not stated. Low frequency antenna is usually vertically polarized because of the ground effect which is the reflected waves and physical construction methods while high frequency antennas are generally horizontally polarized.

All radiated waves are generally defined as elliptically polarized which have two components that lie in the same plane. The two most known and common cases of elliptical polarization are circular in which the two E-Field components are equal in magnitude and oriented at 90° to each other and linear in which the wave has a single E-Field component. These two E-Field components may be of different strength and are oriented at different angles. [10]

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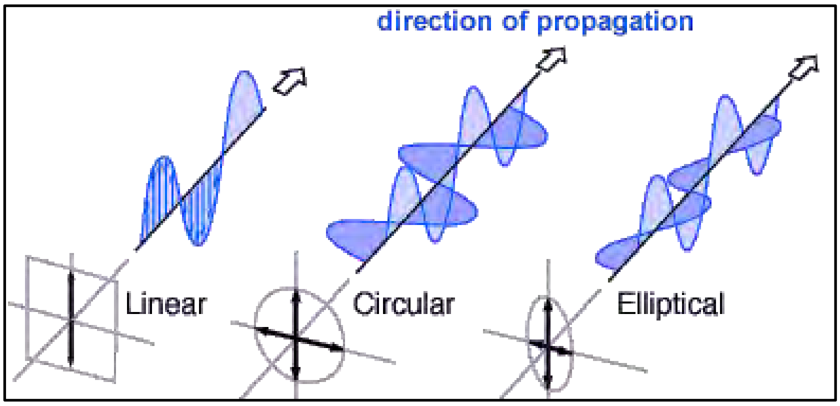

Figure 2.4 Graphical Depiction of Antenna Polarization

2.3.7 Antenna Directivity

Other than gain, radiation pattern and furthermore, directivity D is also an important parameter which shows the focused antenna radiating energy. It is the ratio of maximum radiated to radiated antenna. Reference antenna is also known as an isotropic radiator where the radiated energy is same in all direction with directivity of 1. Directivity of an antenna can be determined by using the following formula. [10]

$$D = \frac{F_{max}}{F_o} \tag{2.3}$$

Whereby,

$$F_{max} = maximum\ radiated\ energy$$

$$F_o = isotropic\ radiator\ radiated\ energy$$

2.3.8 Antenna Efficiency

Associate with an antenna are a number of efficiency and can be defined by using Figure 2.5 below. The total efficiency e_o is used to take account losses at the terminal and within the structure of the antenna. Such losses may be due to, referring to Figure 2.6. This reflection occurs because of the mismatch between the transmission line and the antenna. [10]

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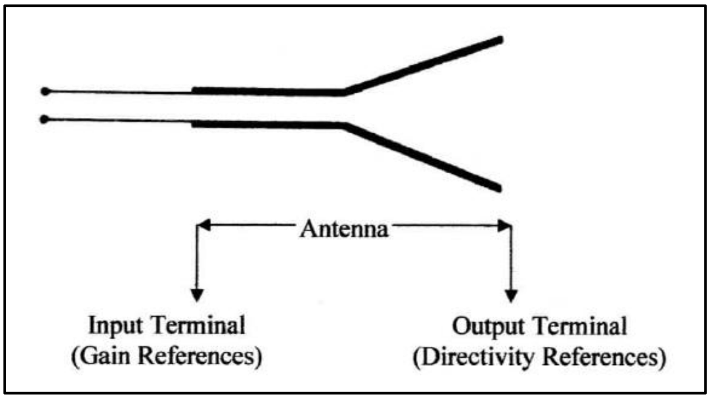

Figure 2.5 Antenna Reference Terminal

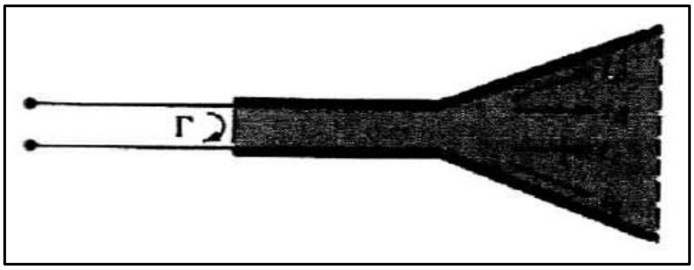

Figure 2.6 Reflection, Conduction and Losses of Antenna

2.4 Millimeter Wave Communication Technology

2.4.1 Technology Overview

Millimeter wave (MMW) generally corresponds to the radio spectrum between 30 GHz to 300 GHz, with wavelength between one and ten millimeters. However, in the context of wireless communication, the term generally corresponds to a few bands of spectrum near 38, 60 and 94 GHz, and more recently to a band between 70 GHz and 90 GHz (also referred to as E-Band), that have been allocated for the purpose of wireless communication in the public domain. This frequency level can exceed more until 300GHz for other application which needs more precision. [11]

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2.4.2 History of Millimeter Wave

Though relatively new in the world of wireless communication, the history of millimeter wave technology goes back to the 1890‟s when J.C. Bose was experimenting with millimeter wave signals at just about the time when his contemporaries like Marconi were inventing radio communications. Following Bose‟s research, millimeter wave technology remained within the confines of university and government laboratories for almost half a century. The technology started so see its early applications in Radio Astronomy in the 1960‟s, followed by applications in the military in the 70‟s. In the 80‟s, the development of millimetre wave integrated circuits created opportunities for mass manufacturing of millimeter wave products for commercial applications. [11]

2.4.3 Propagation Characteristic

The propagation characteristics of millimeter waves through the atmosphere depend primarily on atmospheric oxygen, humidity, fog and rain. The signal loss due to atmospheric oxygen, although a source of significant limitation in the 60 GHz band, is almost negligible – less than 0.2dB per km in the 70 and 80 GHz bands. The effect of water vapour, which varies depending on absolute humidity, is limited to between zero and about 50% loss per km (3dB/km) at very high humidity and temperature. The additional loss of signal as it propagates through fog or cloud is similar to the loss due to humidity, now depending on the quantity and size of liquid water droplets in the air. Though 50% loss of signal due to these atmospheric effects may seem significant, they are almost insignificant compared to losses due to rain, and are only important for long distance deployments which are not more than 5 km.

However, such conclusions are not well founded. Millimeter wave links can indeed perform flawlessly year after year without disruption, even in the presence of occasional downpours in excess of 100 mm/hour. The actual performance of a millimeter wave link depends on several factors, in particular the distance between radio nodes and the link margin of the radios, and sometimes includes additional factors such as diversity of redundant paths. [11]

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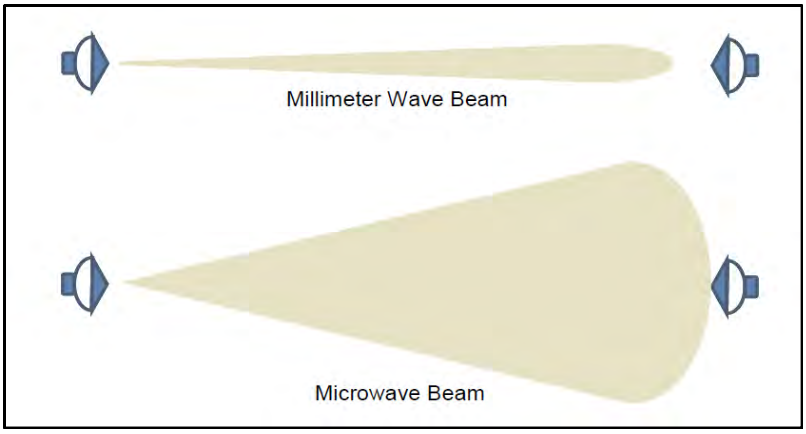

Figure 2.7: Millimeter wave links have narrow beams

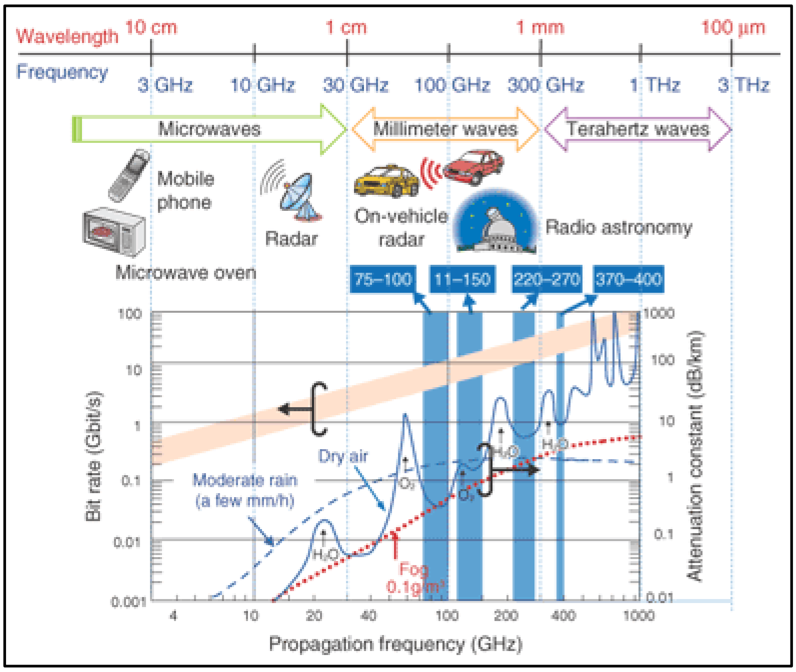

Figure 2.8: Features of Millimeter and Terahertz waves

2.4.4 Millimeter Wave Applications and Markets

- Semiconductors Market:- Electronic and Electrical Components
- Microwave Equipment Market: - Sub-segmentation into Ethernet-Only Microwave Technology Market, TDM-Only Microwave Technology Market, and Hybrid TDM/Ethernet Microwave Technology Market.

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- Global Millimeter wave technology components market:- Antennas and Transceiver components, Communication & Networking components, Interface components, Frequency Sources, Multipliers and related components, Imaging components, RF and Radio components, Sensing and Control components, Power and Battery components, and other components.
- MM Scanners and Imaging Systems: - Active and Passive MM RADAR and Satellite Communication Systems, Perimeter and Surveillance RADAR, Application Specific RADAR, Satellite Systems.
- MM Telecommunication Equipment: - Mobile Back-haul Equipment, (sub-segments - Small-Cell and Macro-Cell, Pico-Cell and Femtocell), Enterprise and other networking equipment.
- Mobile and Tele-communication sector, Consumer and Commercial sector, Healthcare sector, Industrial sector, Automotive and Transportation sector, Military, Defence and Aerospace sector, and Emerging and Next Generation applications.
- Wireless Home Networking (WSN), Airport Scanning and Security, Commercial Building and Event-security (concerts, sports-events), Residential and Institutional security applications.
- Medical Imaging and Scanning and Healthcare Facility applications.
- Industrial Automation applications, Industrial Wireless Sensor Networking (IWSN) applications.
- Automotive RADAR, Marine Transportation RADAR applications.
- RADAR applications and Satellite Communication applications.

2.4.5 Pros and Cons of Millimeter Wave Technology

Small size is another major advantage of millimetre wave equipment. While ICs keep the circuitry small, the high frequency makes very small antennas necessary and possible. A typical half-wave dipole at a cellular frequency like 900 MHz is six inches long, but at 60 GHz one half-wave is only about 2.5 mm in free space and even less when it‵‵s made on a dielectric substrate. This means the entire structure of a radio including the antenna can be very small. It‵‵s easy to make multiple-element

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phased arrays on a substrate chip that can steer and focus the energy for greater gain, power, and range.

Millimeter waves also permit high digital data rates. Wireless data rates in microwave frequencies and below are now limited to about 1 Gbit/s. In the millimeter-wave range, data rates can reach 10 Gbits/s and more.

Millimeter waves open up more spectrums. Today, the spectrum from dc through microwave (30 GHz) is just about used up. Government agencies worldwide have allocated the entire "good" spectrum. There are spectrum shortages and conflicts. The expansion of cellular services with 4G technologies like LTE depends on the availability of the right sort of spectrum. The problem is that there isn"t enough of it to go around.

One of the key limitations of millimeter waves is the limited range. The laws of physics say that the shorter the wavelength, the shorter the transmission range for a given power. At reasonable power levels, this limitation restrains the range to less than 10 meters in many cases. In fact, the short range can be a benefit. For example, it cuts down on interference from other nearby radios. The high-gain antennas, which are highly directional, also mitigate interference. Such narrow beam antennas increase power and range as well. And, they provide security that prevents signals from being intercepted.

Another challenge is making circuitry that works at millimeter-wave frequencies. With semiconductor materials like silicon germanium (SiGe), gallium arsenide (GaAs), indium phosphide (InP), and gallium nitride (GaN) and new processes, though, transistors built at submicron sizes like 40 nm or less that work at these frequencies are possible. [11]

2.5 Basic Microstrip Antenna

A microstrip antenna is a simple antenna that can be easily printed out in circuit boards and also can be said as an economic based on the design. These

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microstrip antennas consist of radiated patch component, dielectric substrate, and a group plane. The radiated part and the ground are thin layers of conductor which is used for the radiation purposes. For every type of dielectric substrate, it has their respective dielectric permittivity value. This permittivity will affect the size of the antenna. These microstrip antennas have several advantages like small dimension, light weight, low cost and easy to integrate with other circuit.

This concept was undeveloped until the revolution in electronic circuit miniaturization and large-scale integration in 1970. After that many authors have described the radiation from the ground plane by a dielectric substrate for different configurations. Various mathematical models were developed for this antenna and its applications were extended to many other fields. Low dielectric constant substrates are generally preferred for maximum radiation. The conducting patch can take any shape but rectangular and circular configurations are the most commonly used configuration. Other designs are complex to analyse and need heavy computations in order to obtain the design parameters. A microstrip antenna is characterized by its length, width, input impedance, and gain and radiation patterns.

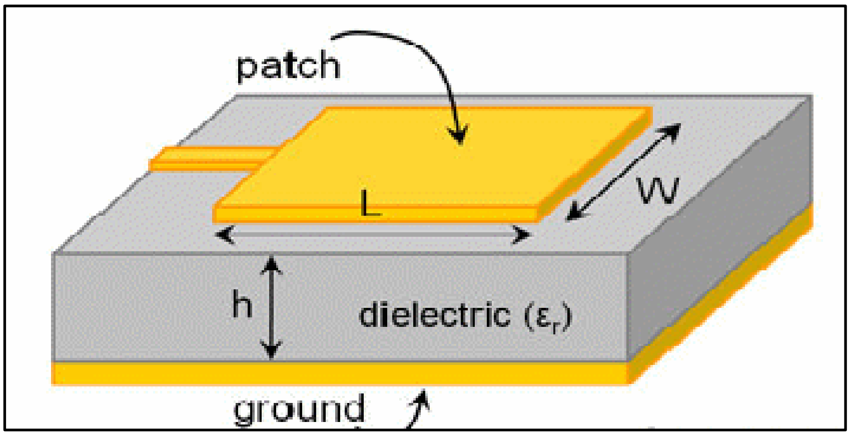

Figure 2.9: Structure of a basic Microstrip Patch Antenna

There is various kind of analysis and performance prediction based on the design of the antenna. There are square, rectangular, dipole, circular, elliptical, circular ring, triangular and other common shapes that can be used. These shapes are even sometimes combined together to form a new shape antenna.

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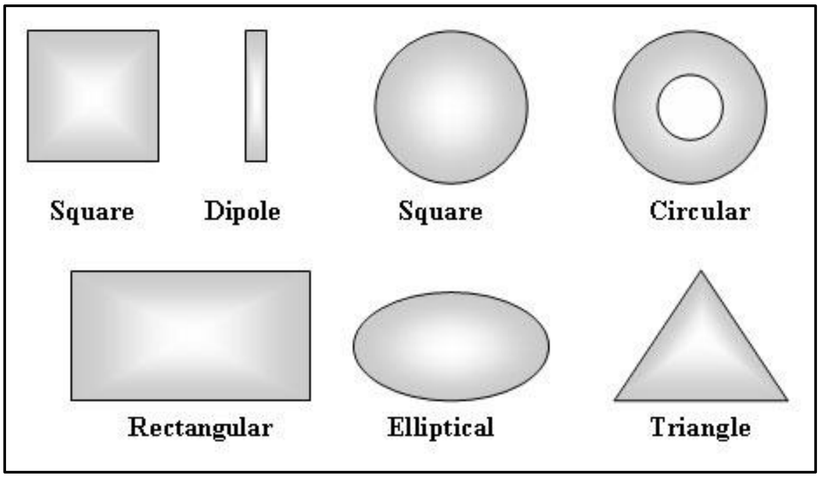

Figure 2.10: Common patch shapes

2.5.1 Feeding Techniques

Feeder design is an important procedure while designing the antenna. This is to ensure that the antenna structure can operate at full power of transmission. Feeder designing for high frequency needs a precise process. This is due to the input loss on feeder increases which depends on frequency. It can give a huge impact on the overall design. There are several methods in order to design the feeder. With different feeding methods, different antenna properties are constructed such as bandwidth, radiation pattern, gain, and furthermore.

2.5.2 Matching Techniques

As the feeder design technique, there are many ways used for matching. Normally quarter wave transformer are preferred and the most easy technique used for antenna. Quarter wavelength transformer is used as the side feed. If the impedance of the antenna is real, the transformer is attached directly to the load. If the antenna impedance Z_L is complex, the transformer is placed in a distance *d* away from the antenna. The distance *d* is chose to make sure input impedance toward the load is real. To provide a match for the transformer characteristic impedance Z_O should be determined by using the equation below. [11]

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$$Z_o = \sqrt{Z_L \times Z_{in}} \tag{2.4}$$

Whereby Z_{in} is the impedance of the input transmission line which is equal to 50Ω

2.6 Bow-Tie and Ice-Cream Cone Antenna Geometry

The bow-tie patch antenna is a combination of imaginary image of two triangular patches which are fabricated in a single substrate. The design of the bow-tie antenna is based on the design of triangular microstrip antenna which is mirrored. Those formula used in the design of triangular microstrip antenna to calculate the side length and effective value of dielectric constant, are also applicable in the design of bow-tie antenna.

The ice-cream cone antenna structure resembles a scoop of ice cream on a wafer cone. The antenna design can be a combination of a triangle and a semicircle on it or a combination of a rectangle and a semicircle on it. The formula used in the design to calculate the parameters of a rectangular shaped antenna and a circular antenna can also be implemented in this design.

In this project, a mixed bow-tie and ice-cream cone antenna was design. This design is a combination of the two different antennas. The design of the ice-cream cone antenna was placed above the bow-tie antenna whereby the center point of the bow-tie antenna meets the end part of the ice-cream cone structure. This structure was design at the frequency of 120GHz.The length of the triangle, feeder length, width, and other parameters were calculated by using the formula.

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CHAPTER III

METHODOLOGY

3.1 Introduction

This chapter covers the methodology process that is used in order to design the antenna as well as to simulate it in the software. This chapter also covers the entire design process and the procedures that had been carried out during this analysis. The entire procedure covers the parameter calculation, design simulation, and parametric study.

3.2 Design Specifications

In order to design the antenna, some preliminary researches are needed in order to determine what types of components that will be used and its suitability for

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the design. There are two main components in this design which is the type of conductor used and the type of material used for the substrate. [6], [7]

a) Substrate

It is important to choose the kind of material for the dielectric substrate. It is the center component between the top layer conductor and the ground. The thickness of the substrate and the relative permittivity are also determined. Appropriate thickness and material need to be chosen because it may affect the efficiency of the antenna. Therefore many journals were reviewed in order to select the type of material. [6], [7]

b) Conductor

The type of conductor used is also one of an important factor that needs to highlight. Types of conductor used is usually depends on the value of the frequency that the antenna is operating. Different frequency values perform in a different way based on the material that we use. Sometimes certain material does not support a high frequency level.

3.3 Design Procedure

In this project, the material that had been used for the substrate is Alumina. There are few reasons why this type of substrate is used. One of them is that Alumina can withstand very high temperature under reducing, inert or high vacuum condition. They remain good chemical resistance under high temperatures, and have excellent wear and abrasion resistance. The thickness of substrate that is used is 0.127mm and the loss tangent is 0.00033. While for the top layer conductor and the ground, the material that we used is gold. This is because, the antenna that is being design is operating at 120GHz. This is considered as EHF (Extremely High Frequency). Copper is not a suitable material for a high frequency antenna. The thickness of gold that we use in the design is 0.017mm. [1], [2], [3], [6], [7]

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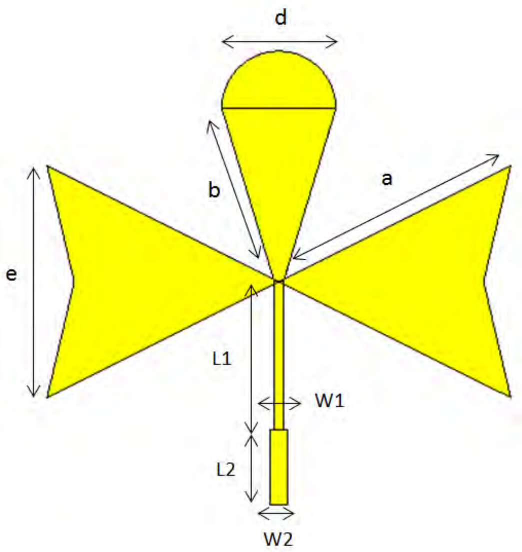

Figure 3.1: Dimension of Antenna Design

Characteristics of antenna:

Frequency,	f	= 120GHz
Characteristic Impedance,	Zo	= 50Ω
Dielectric constant,	ε_r	= 8.8
Thickness of substrate,	h	= 0.127mm
Loss Tangent,	δ	= 0.00033

Table 1 Antenna Geometry Parameters

Antenna Parameter	a	b	d	e	L1	L2	W1	W2
Measurement (mm)	0.78	0.62	0.39	0.69	0.51	0.25	0.031	0.061

The above parameters are the optimized value that has been obtained after some optimization process. Only certain parameters of the antenna were obtained through calculations and some are obtained through parametric studies especially the angles of the bow-tie design and the dimension of the ice-cream cone design which has been merged with the bow-tie design.

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The dimensions for the antenna design which is side length of the bow-tie strip a, length of the feeder 1 (L1), length of feeder 2 (L2), width of feeder 1 (W1), width of feeder 2 (W2), were calculated based on the formulas below. [1], [2], [3]
Resonant frequency for dominant mode is:

$$f_{10} = \frac{2c}{2f_r\sqrt{\varepsilon_r}} \tag{3.1}$$

Side length:

$$a = \frac{2c}{2f_r\sqrt{\varepsilon_r}} \tag{3.2}$$

Efficient value of side length:

$$a_{eff} = a + \frac{h}{\sqrt{\varepsilon_r}} \tag{3.3}$$

Efficient dielectric constant:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{4\sqrt{1+\frac{12h}{a}}} \tag{3.4}$$

Resonant Frequency for mn mode:

$$f_{mn} = f_{10}\sqrt{m^2+mn+n^2} \tag{3.5}$$

Wavelength in free space:

$$\lambda_0 = \frac{c}{f} \tag{3.6}$$

Wavelength of the antenna:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \tag{3.7}$$

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$$L_1 = d\lambda_g \tag{3.8}$$

Where d is the value of "wavelength toward load" in the smith chart.

$$L_2 = \frac{\lambda_g}{4} \tag{3.9}$$

$$\frac{W}{d} = \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right], \quad \text{For } \frac{W}{d} > 2 \tag{3.10}$$

$$\frac{W}{d} = \frac{8e^{A}}{e^{2A}-2}, \quad \text{For } \frac{W}{d} < 2 \tag{3.11}$$

Where

$$A=\frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}(0.23+\frac{0.11}{\varepsilon_r}) \quad , \qquad B=\frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \tag{3.12}$$

3.4 Design Process

In this project, after determining the antenna parameters, the antenna was design and simulated by using CST (Computer Simulation Technology) software. This software is a specialist tool for the simulation of high frequency components. CST Microwave Studio enables the fast and accurate analysis of high frequency devices such as antennas, filters, couplers, planar, multi-layer structures, SI and EMC effects. Exceptionally user friendly, CST MWS quickly gives an insight into the EM behaviour of the high frequency designs.

3.5 Design and Simulation Process in Software

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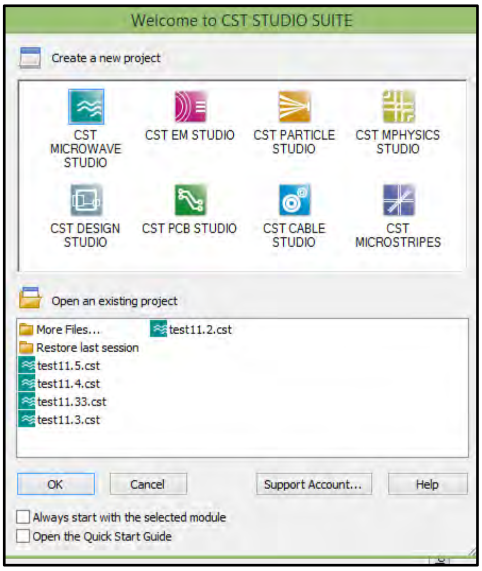

Figure 3.2: Choosing the project mode

At the beginning, before the antenna was started to design, the type of layout was chosen. For this design, CST MICROWAVE STUDIO project type was chosen. Then the dimension units of the antenna were set in millimetre as well as the frequency in gigahertz as shown in Figure 3.3.

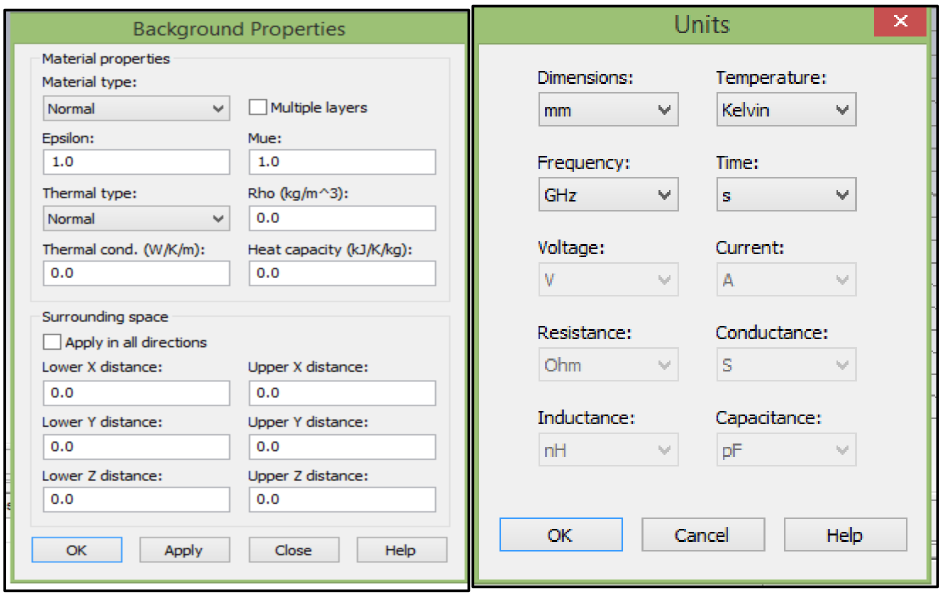

Figure 3.3: Setting the units

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The frequency range for the simulation process was set in the frequency range settings. This antenna was designed to operate at 120GHz, therefore the frequency range that was chosen is from 80GHz to 150GHz.

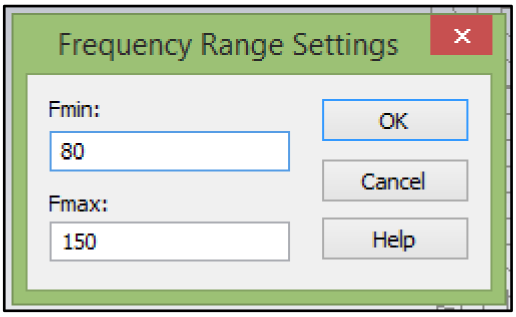

Figure 3.4: Frequency Range Setting

Antenna design was constructed by using „create brick‟ command that can be chosen at the icon panel at the top of the layout. The value of the antenna dimension was inserted in the brick panel. The design was begun by constructing the substrate. The thickness of the substrate was set at the Z-axis and the X-axis and Y-axis are set at the U/V axis. The types of material that going to be used can be choose in the material library. After some optimization process, the dimension of the antenna was set to 1.6mm x 1.2mm.

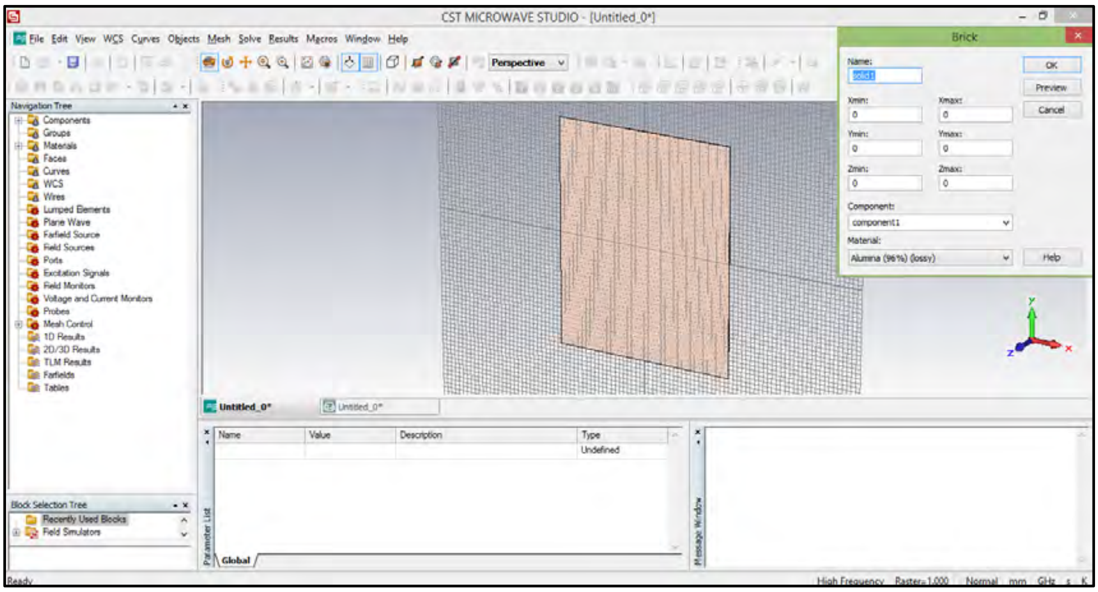

Figure 3.5: Designing the substrate

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The design of the antenna was begun by designing the structure of the basic bow-tie configuration. Then the design of the ice-cream cone was merged in the design by placing the structure in the middle between the two rectangular shapes.

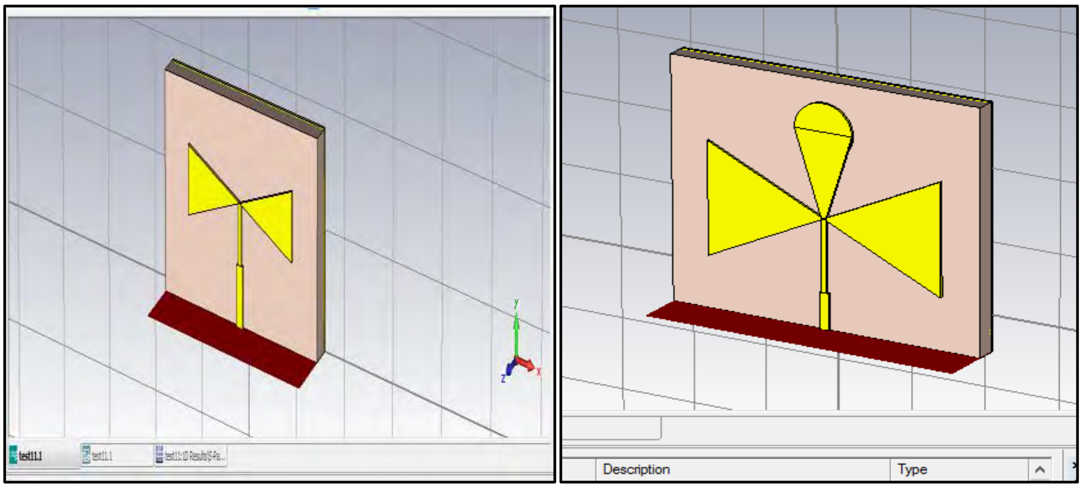

Figure 3.6: Designing the antenna structure

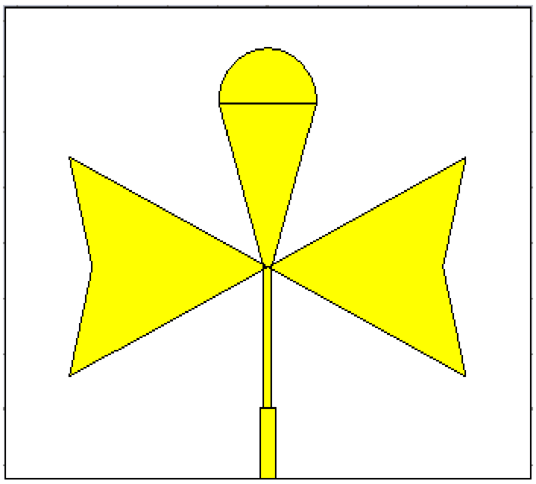

Figure 3.7: Antenna Front View

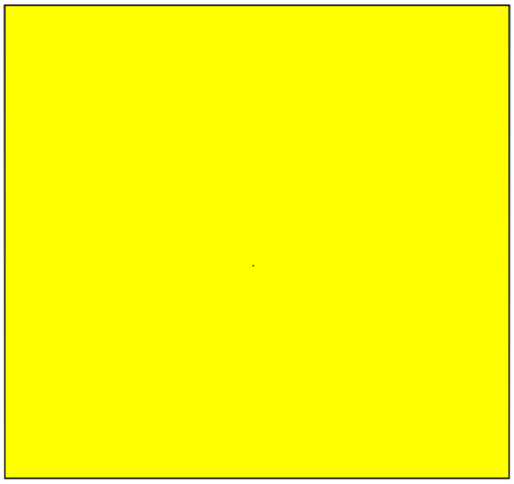

Figure 3.8: Antenna Back View

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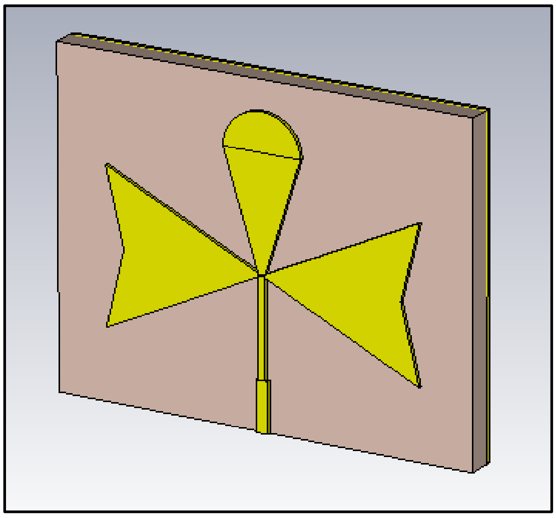

Figure 3.9: Antenna Perspective View

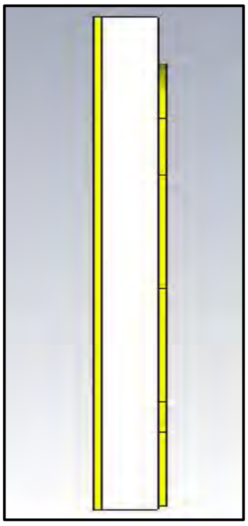

Figure 3.10: Antenna Side View

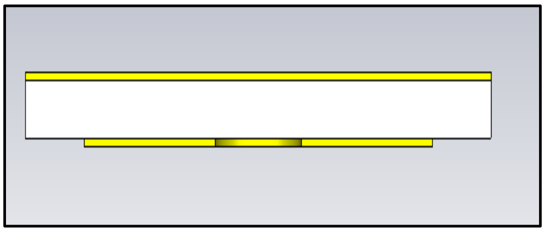

Figure 3.11: Antenna Top View

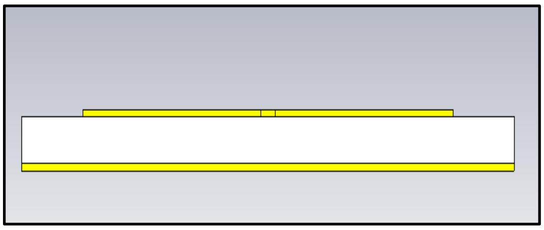

Figure 3.12: Antenna Bottom View

From the figures above, it is shown that the yellow layers are the conducting material which is the gold. While the layer between the two gold layer is the substrate Alumina. The entire figure above displays the six main views of the antenna from different angle.

After the antenna was designed, the structure was simulated by creating the waveguide port at the feeder. The dimension of the waveguide port was 5 multiply with the feeder width and 5 multiply with the thickness of the substrate. That is the standard dimension that will be used, but the dimension might be change while the tuning process is conducted to obtain a better result.

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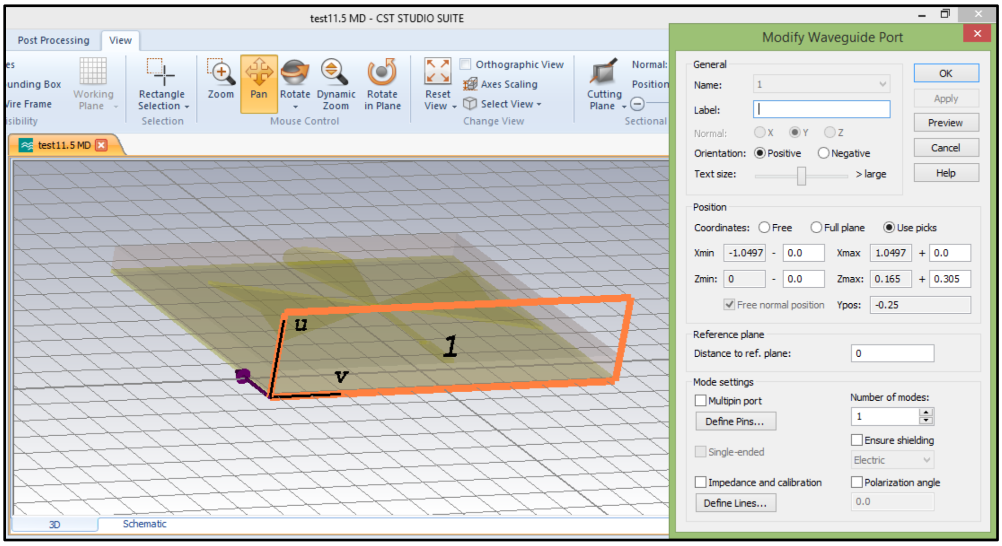

Figure 3.13: Waveguide Port Setting

Form the figure below, we can see that the port has a connection between the antenna structure which is at the top and the ground plane at the bottom. This is to ensure that the connection is established. For this microstrip design, waveguide port is suitable to be used in order to simulate it.

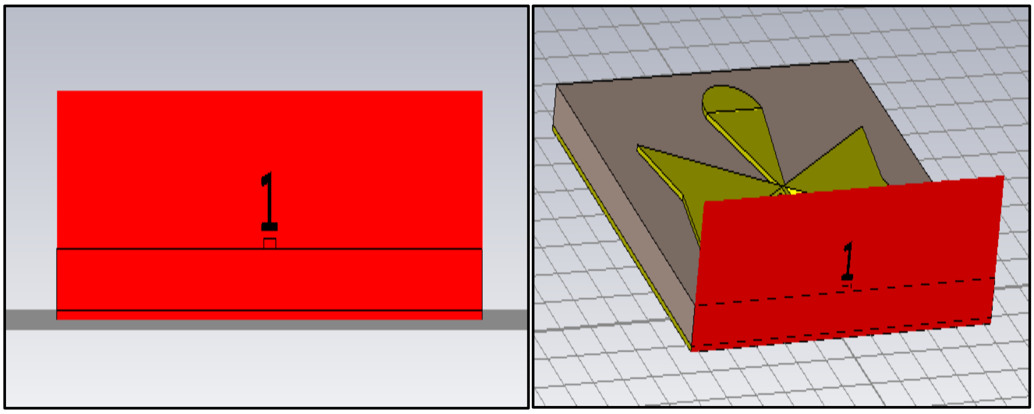

Figure 3.14: Waveguide Port after being created

The following step before the simulation is to set up the boundaries. The boundaries are set in the boundary condition panel. „Apply in all directions" mode was chosen and the type is „open (add space)". This setting is applied to for other boundary condition as well.

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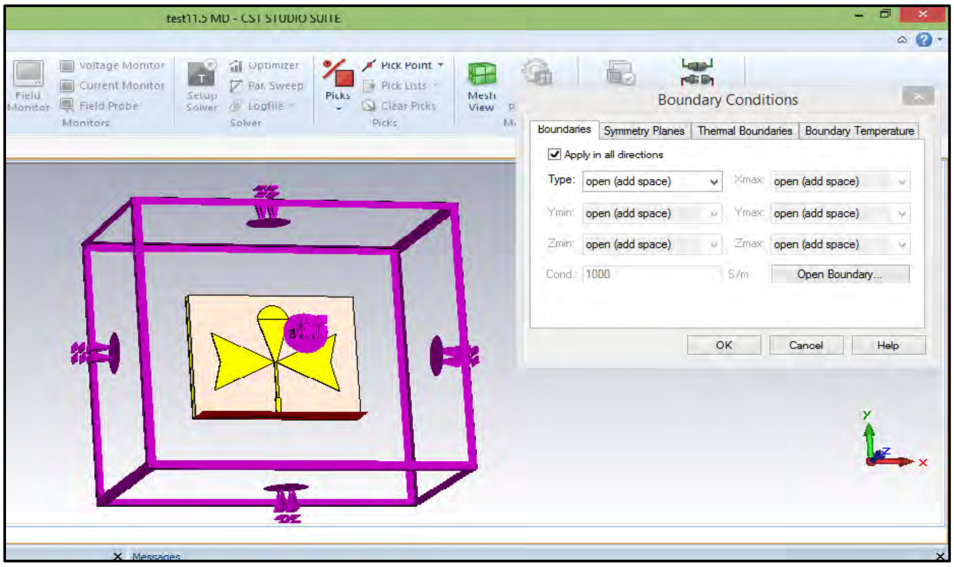

Figure 3.15: Boundary Condition settings

At the Field Monitor settings, the type E-Field, H-Field and FarField was chosen and at the specification column, the desired frequency was set to obtain the FarField at the specific frequency wanted. This setting enables the view of the radiation pattern and the intensity as well after the antenna being simulated. The directivity and other parameters can be observed and the gain as well.

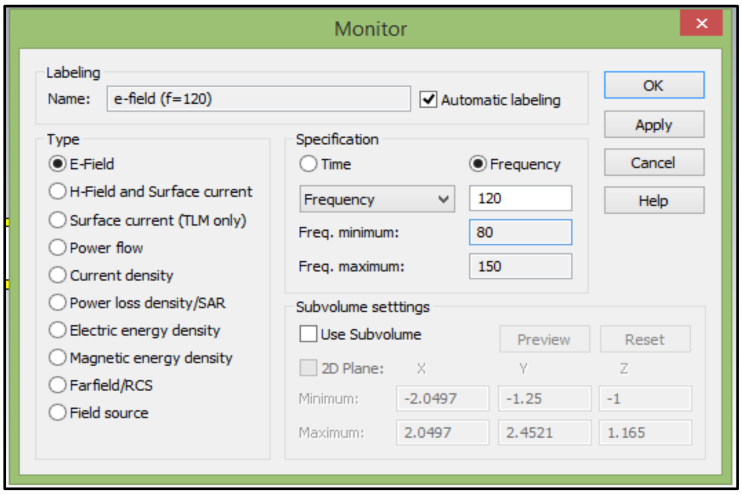

Figure 3.16: Field Monitor setting

The antenna was designed successfully and all the required settings have been done before the simulation process. The main settings have been shown in the above

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subtopics. The antenna was simulated, and all the parameters such as return loss, gain and furthermore are analysed and discussed. The results of the simulation will be explain more detail in the following chapter.

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CHAPTER IV

RESULT AND DISCUSSION

4.1 Introduction

In this chapter, more detailed result is presented and explained. The result that has been simulated are studied and analysed. In this chapter the simulated results of return loss, bandwidth, directivity, and gain are shown. Certain parametric study has been conducted in this design in order to obtain an optimum result. All the data obtain are tabulated in a proper manner and analysed. The findings are discussed below.

4.2 Antenna Design A

The initial design A of the antenna has been design as shown in the figure below. The back view does have any changes which are in a full ground rectangular

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shape. This design was begun by constructing the bow-tie structure at first. The parameters for this design were obtained through calculation which has been shown in the previous chapter. The result that has been obtained is the original result without any optimization process. All the parameters are the initial value from the calculation.

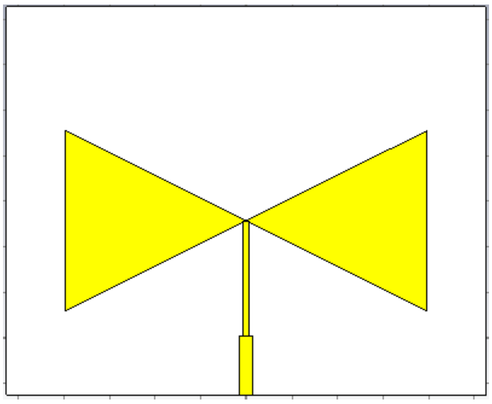

Figure 4.1: Antenna „A" Front View

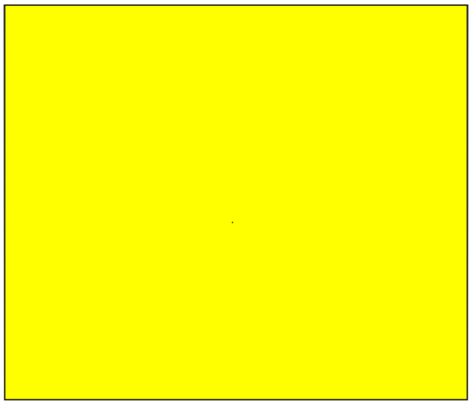

Figure 4.2: Antenna „A" Back View

Table 4.1 Antenna Parameter for Design A

Antenna Parameter	a	e	L1	L2	W1	W2
Measurement (mm)	0.67	0.56	0.51	0.25	0.031	0.061

Figure 4.3 shows the return loss graph of the antenna design A after being simulated. From the result it can be seen that the antenna is operating at122.83GHz with a return loss of -37.567dB. The antenna also has another frequency resonating approximately at127GHz which acts as a dual band.

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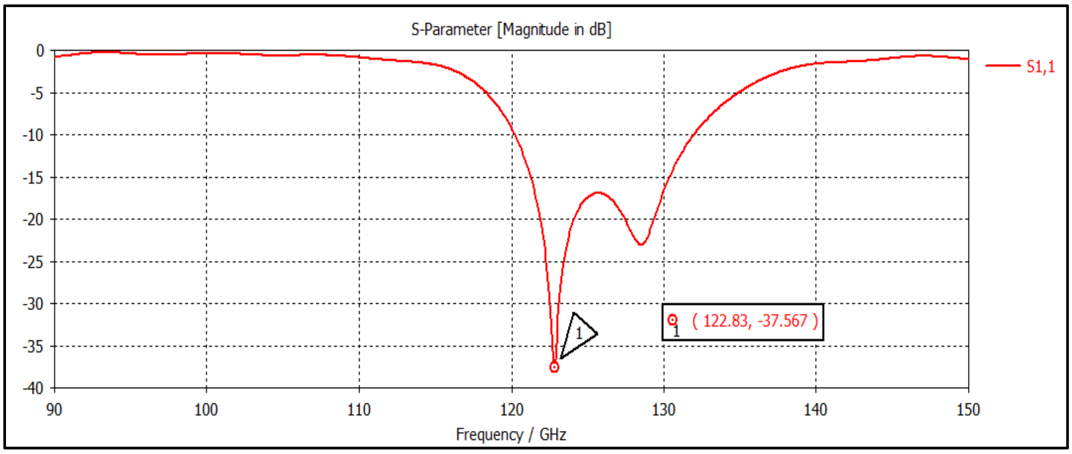

Figure 4.3: Antenna Design A Return Loss

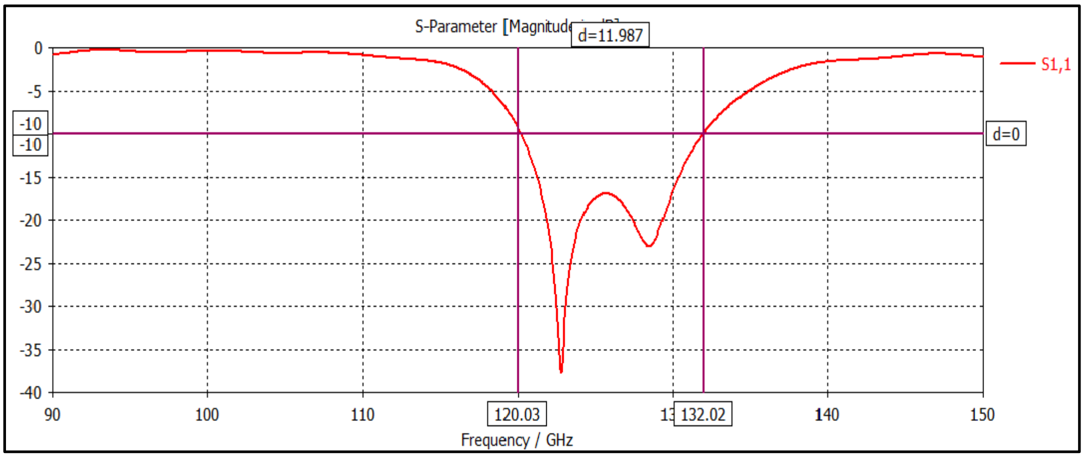

Figure 4.4: Bandwidth measurement of the resonating frequency

The farfield result shows the antenna has a gain of 3.727dB with a total efficiency of -2.592dB and radiation efficiency of -2.033dB. From the farfield result, it shows the antenna has a three high radiation spot as shown in figure 4.5 below. The high radiation intensity is at the centre. While the directivity achieved for this design is 5.759dBi.

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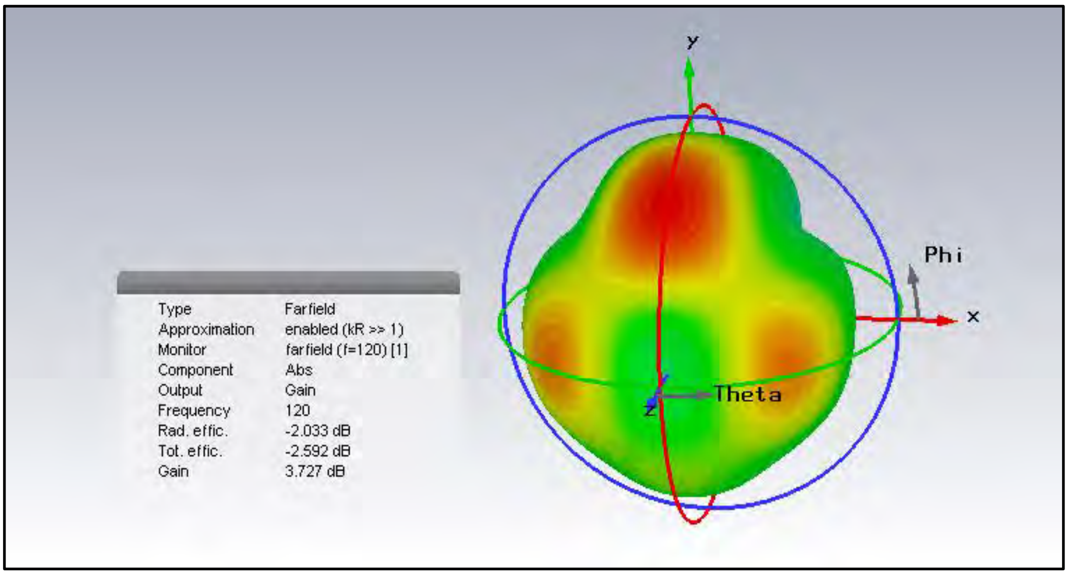

Figure 4.5: Farfield Result

Below are the result of the directivity and the farfield gain in a 2D polar view.

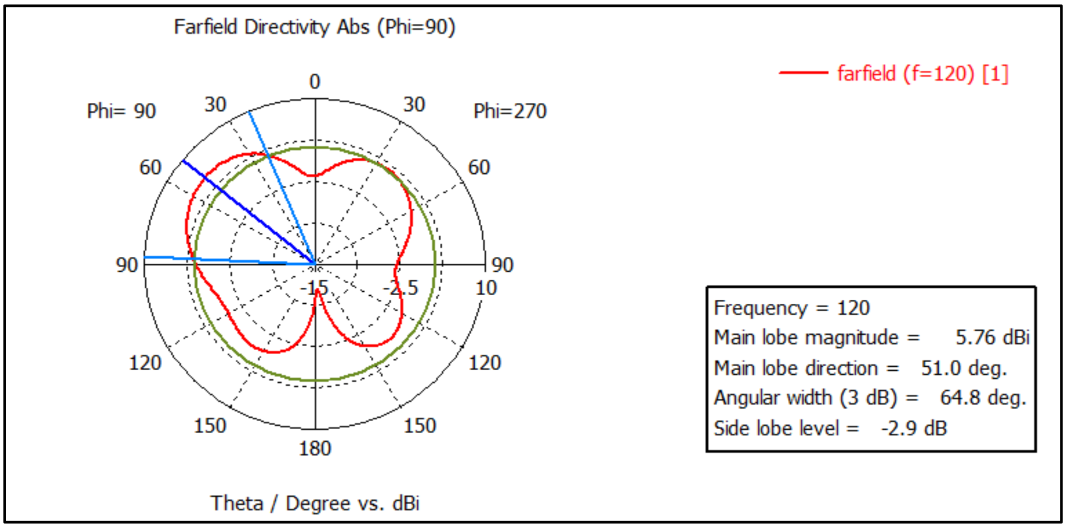

Figure 4.6: 2D Polar View (Directivity)

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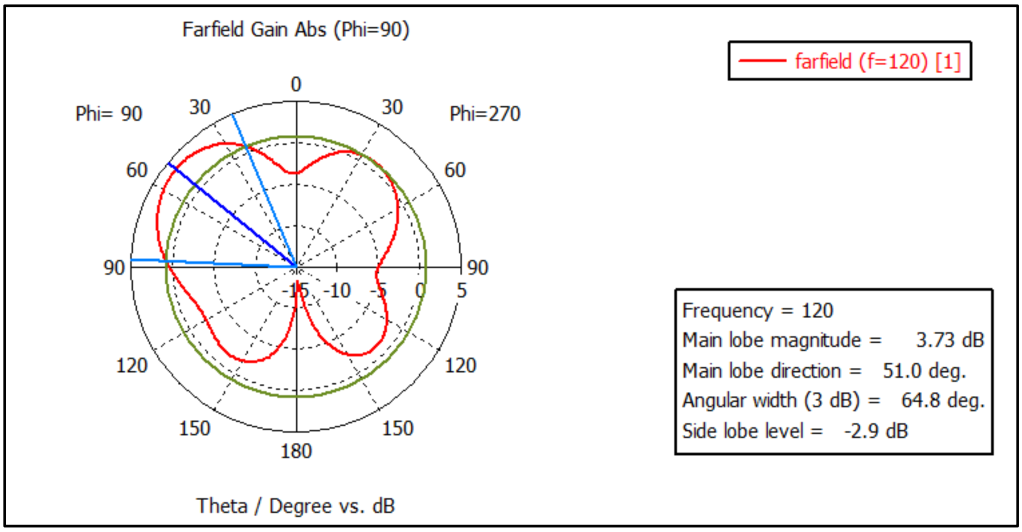

Figure 4.7: 2D Polar View (Gain)

4.3 Antenna Design B

In the design B, the structure of the ice-cream cone has been combined with the bow-tie structure. The cone is placed in the centre between two triangles that form the bow-tie design. A semi-circle was combined with the cone triangle at the top resembles a scoop of ice cream on a cone. This design was simulated without any optimization process and the result was analysed.

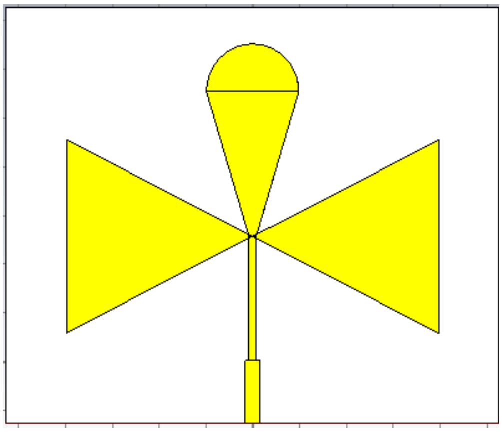

Figure 4.8: Antenna „B‟ Front View

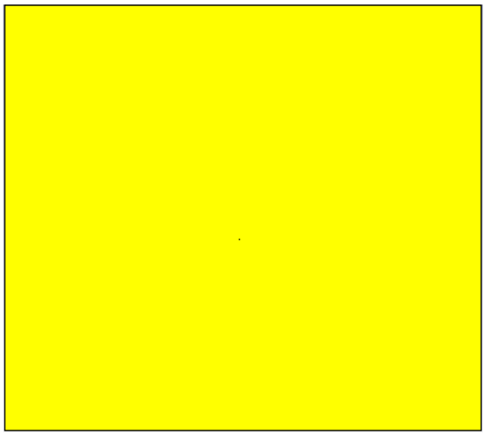

Figure 4.9: Antenna „B‟ Back View

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Table 4.2 Antenna Parameter for Design B

Antenna Parameter	a	b	d	L1	L2	W1	W2
Measurement (mm)	0.67	0.56	0.39	0.51	0.25	0.031	0.061

Figure 4.10 shows the return loss graph of the antenna design B after being simulated. From the result it can be seen that the antenna is operating at126.9GHz with a magnitude of -15.326dB. From figure 4.11, the simulation result shows that this design has a bandwidth 7.003GHz which was measured by using -10dB as the reference level.

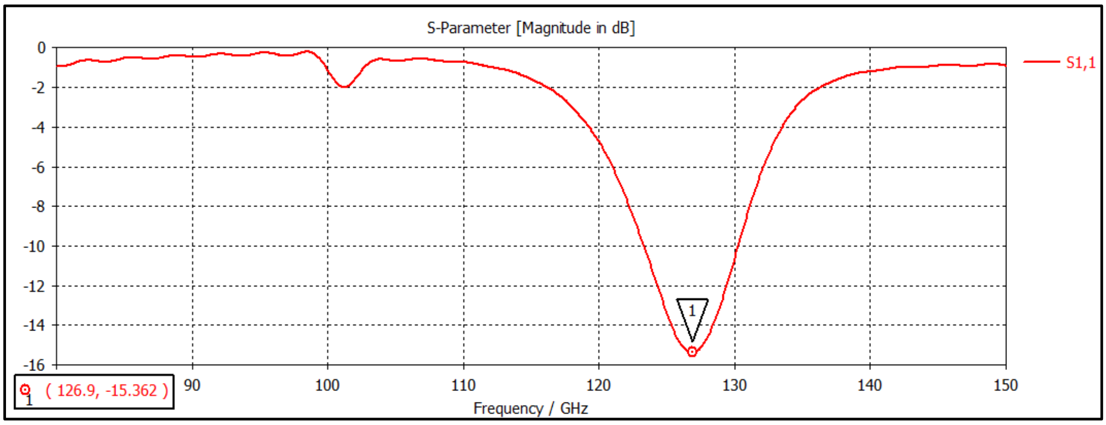

Figure 4.10: Antenna Design B Return Loss

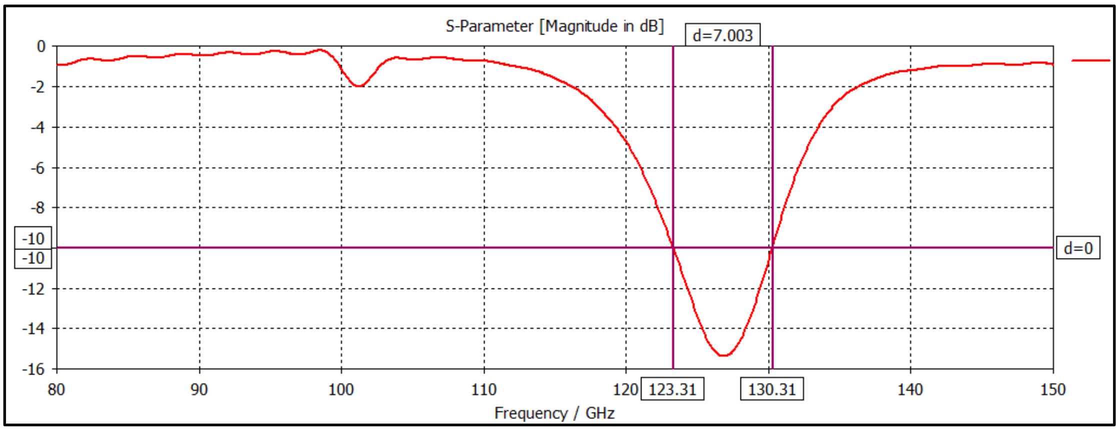

Figure 4.11: Bandwidth measurement of the resonating frequency

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The farfield result shows the antenna has a gain of 4.176dB with a total efficiency of -3.196dB and radiation efficiency of -1.415dB. After the combination of the ice-cream cone design and the bow-tie structure, there is an increase in the gain and some improvement in the radiation efficiency as well. The high radiation intensity is at the centre and area of effective radiation has increased compared to the previous design. While the directivity achieved for this design is 5.591dBi.

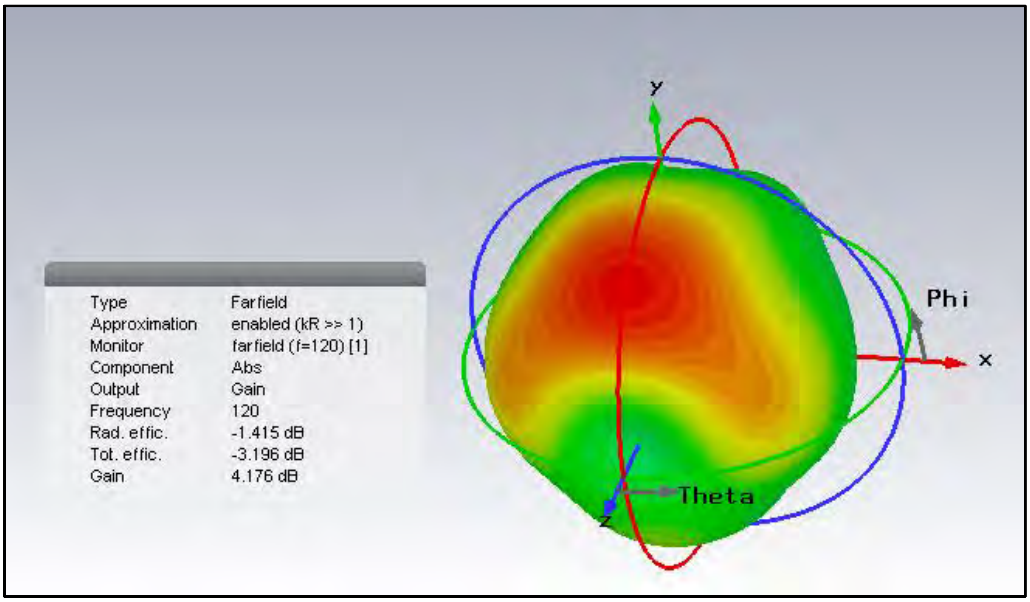

Figure 4.12: Farfield Result

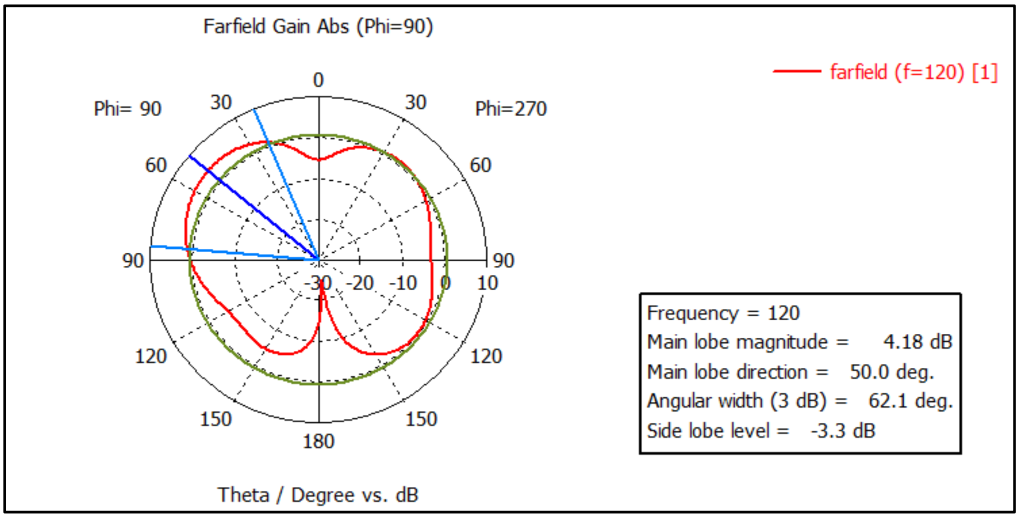

Figure 4.13: 2D Polar View (Gain)

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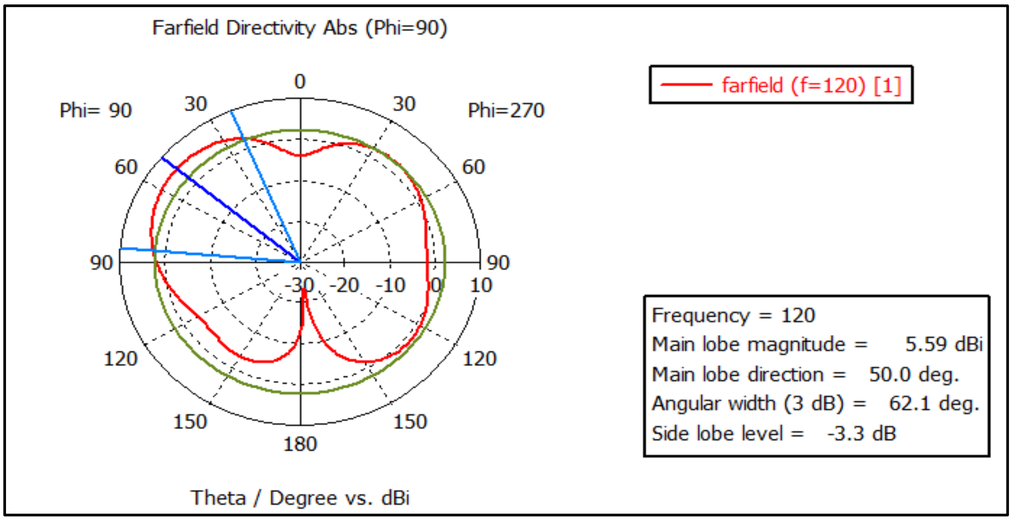

Figure 4.14: 2D Polar View (Directivity)

4.4 Antenna Design C

In the design C the previous antenna structure was modified. Parametric study was conducted on this design and certain optimization process was done in order to improve the antenna performances mainly in terms of return loss and gain. Parametric study was done on the antenna feeder, matching line, bow-tie structure and the cone structure as well. Parametric study was done on the side length of the bow-tie triangle. The side of the triangle was cut into certain angle to see the improvement in the antenna performance. The result shows certain improvement whereby the frequency is shifted near to the desired frequency which is at 120GHz. The suitable value was chosen based on the parametric study results. Figure 4.15 below shows the result of the parametric study.

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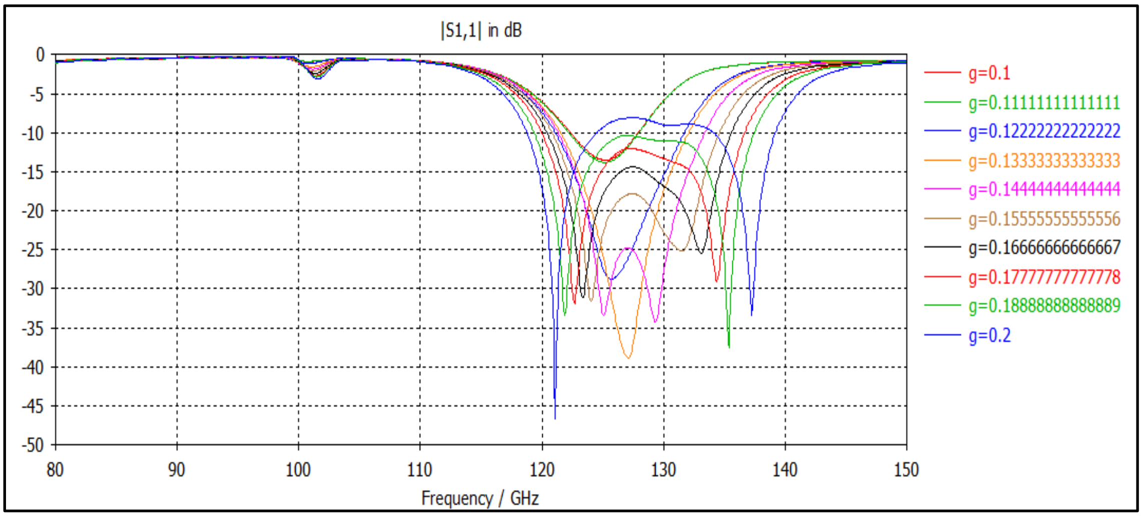

Figure 4.15: Parametric study result for the side length

Parametric study was also done to the inner angle of the bow-tie triangle in order to determine the suitable size of the bowtie structure. From the result below, we can see that the inner angle of the triangle structure plays an important role in order to determine the operating frequency of the antenna. Different angle value gives various resonating frequency in the s-parameter graph, but the bandwidth of the resonating frequency does not differ much. Therefore the suitable value that resonates near to the 120GHz was chosen.

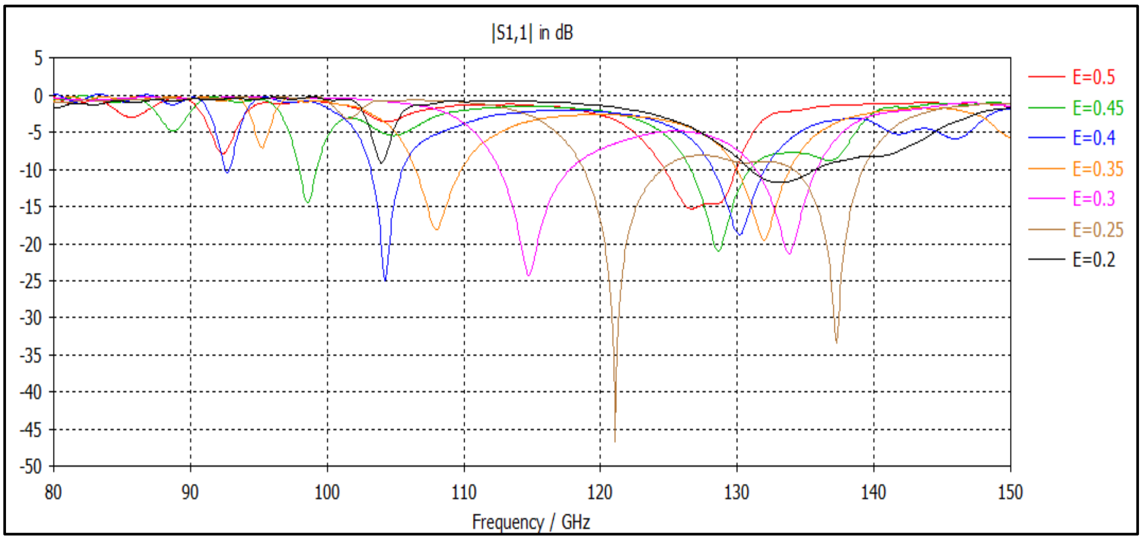

Figure 4.16: Parametric study result for the inner angle of the bowtie structure

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The length and the width of the feeder were also analysed. Certain range of width was done parametric study. Based on the calculation that has been done earlier in the design process, the width of the feeder obtained was 0.061mm. A range between 0.2 and 0.4 was used to increase and decrease the value of the width and the performance was observed. From the Figure4.17 below, we can see that the width of the feeder does not affect much on the s-parameter graph. The first resonating frequency does not shift much, but the second resonating frequency has some minor changes whereby the frequency shifted towards 135GHz and the magnitude increases as well.

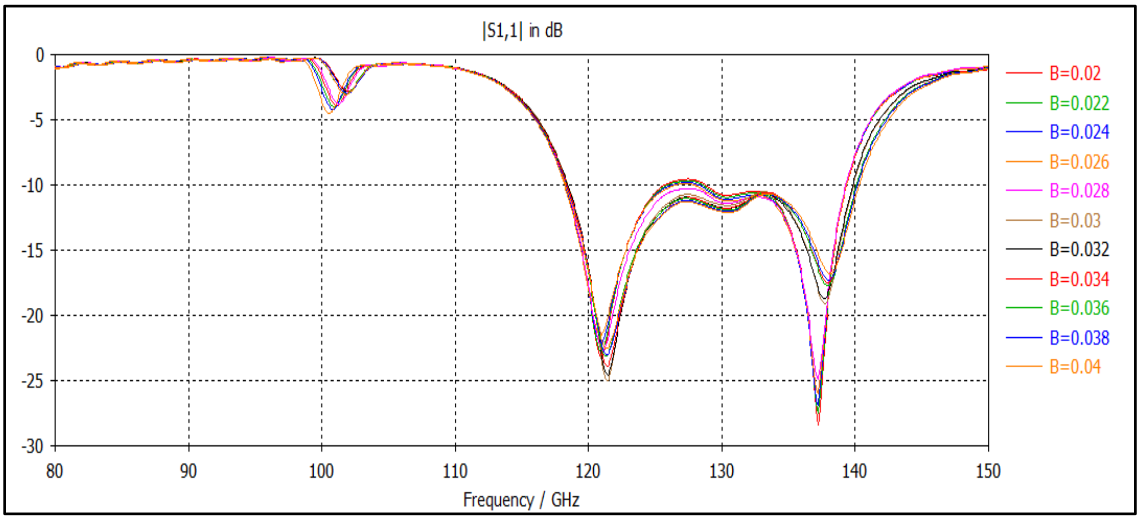

Figure 4.17: Parametric study result for the feeder width

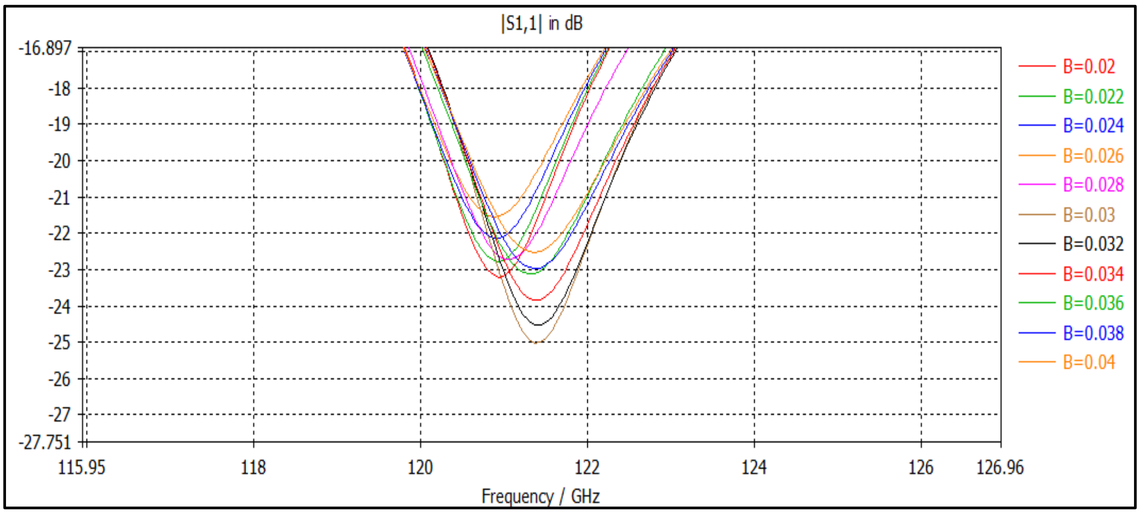

Figure 4.18: Differences in the parametric study result of the feeder width

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The parametric study on the matching line width does not give any severe impact on the return loss. The first resonating frequency remains the same while the second resonating frequency also does not change much but certain parametric value shifts the second resonating frequency from 137GHz to 136GHz.

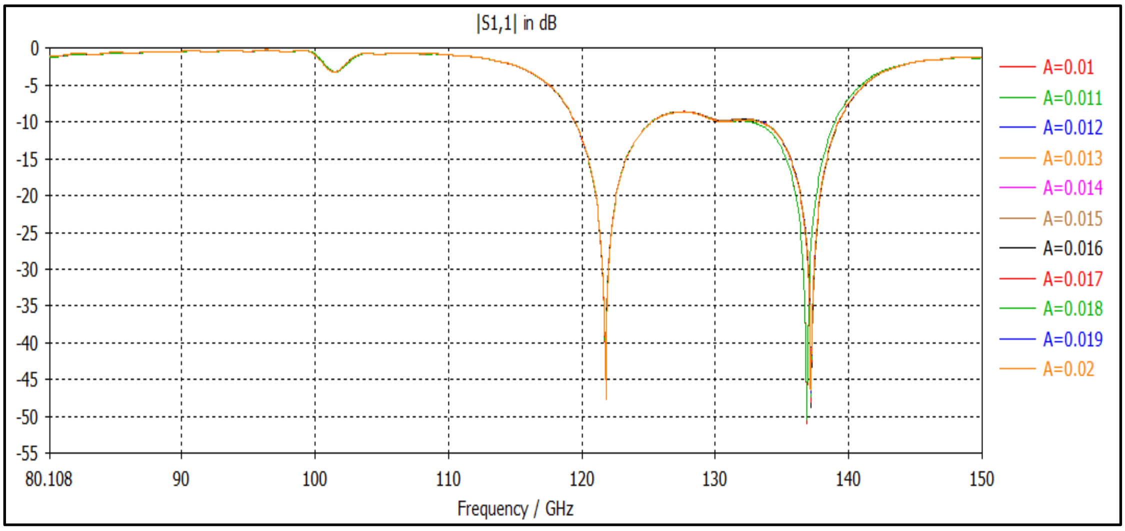

Figure 4.19: Parametric study result of the matching line width

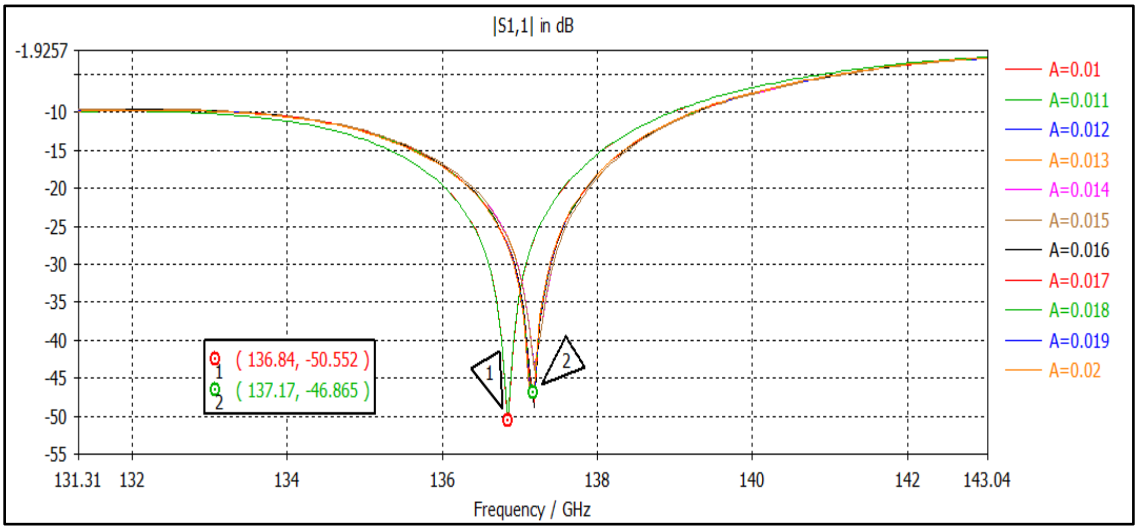

Figure 4.20: Differences in the frequency and magnitude

While for the size of the cone structure, it really affect on the return loss of the antenna. Different angle of the cone structure gives different resonating frequency. The structure influences the bandwidth and the magnitude as well. Certain value

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shifts the frequency forward between 90 to 100GHz and the bandwidth reduces. Certain value does not affect much on the return loss and the bandwidth as well. The frequency also does not shift much.

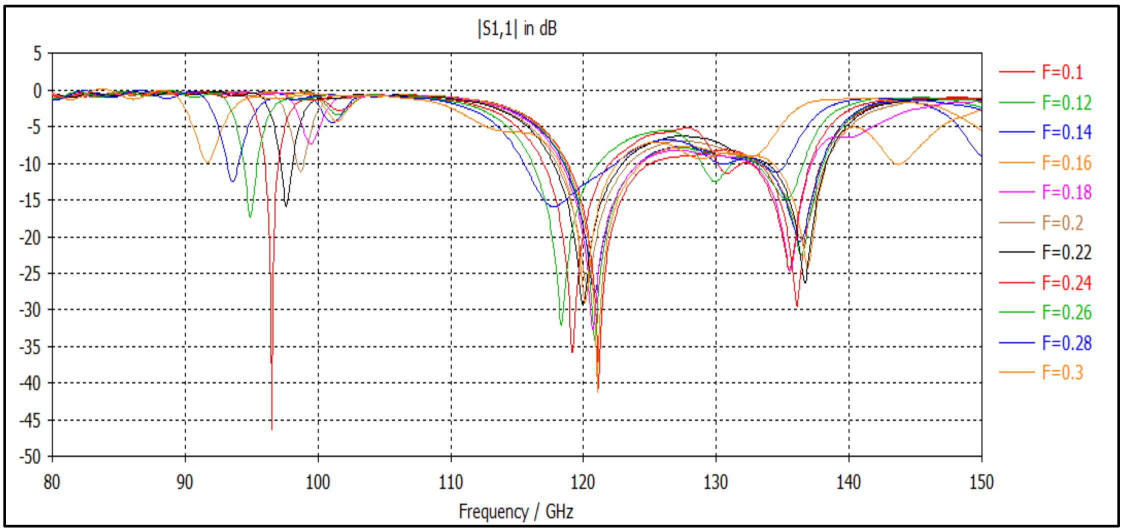

Figure 4.21: Parametric study result for the cone structure

After these parametric studies, the optimized antenna parameter was obtained and the design was finalised. The modification on the bow-tie structure gives an improvement in terms of return loss and gain. The final designs of the antenna are as below and other antenna parameters are discussed.

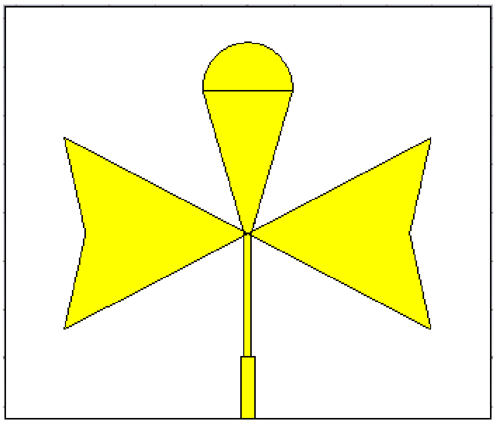

Figure 4.22: Antenna „C" Front View

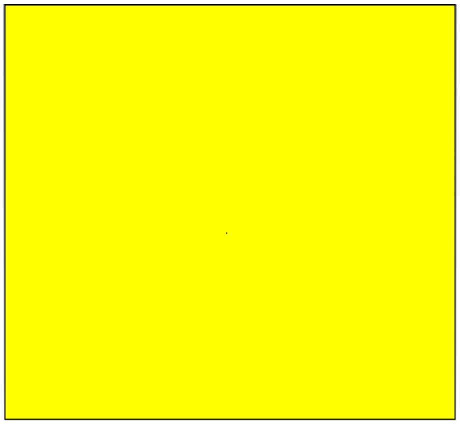

Figure 4.23: Antenna „C"Back View

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Table 4.3 Final Design Antenna Parameter

Antenna Parameter	a	b	d	e	L1	L2	W1	W2
Measurement (mm)	0.78	0.62	0.39	0.69	0.51	0.25	0.031	0.061

The proposed antenna shows a satisfying result. From the S-parameter graph, we can see that the antenna resonates at 121.1GHz and 137.27GHz. The return loss for the both resonant frequency are -46.158dB and -33.238dB respectively. The designed antenna resonates at two frequency points thus making it suitable for dual band applications.

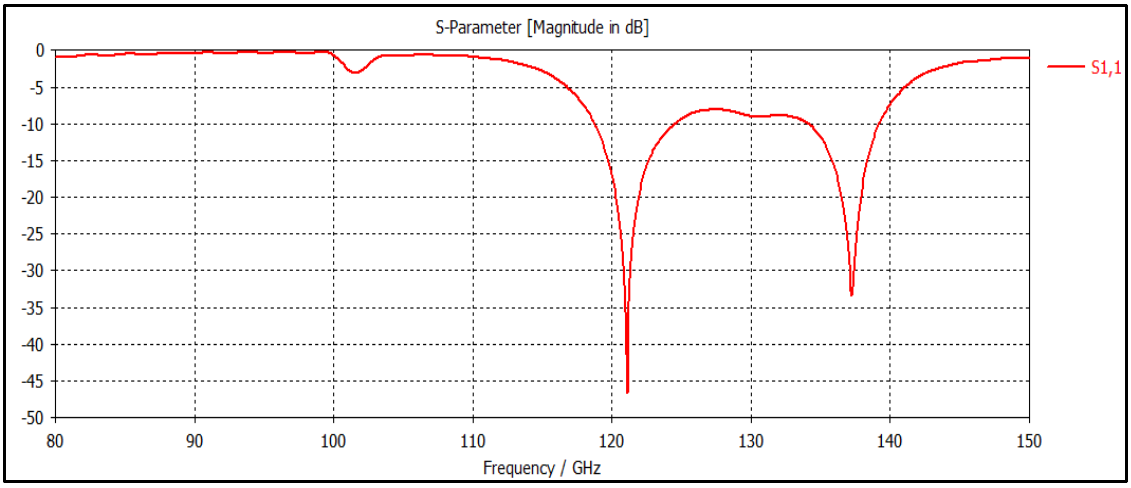

Figure 4.24: Return loss for the final design

From the S-parameter graph below, it can be seen that the bandwidth between the two resonating frequency is 20.597GHz whereby f_1 is 118.69GHz and f_2 is 139.28GHz. The bandwidth for each of the resonating frequency was measured as well and the results are in the figure 4.26 and figure 4.27 below. For the first resonant frequency the bandwidth measured was 6.0803GHz and the second resonant frequency is 5.1683GHz.

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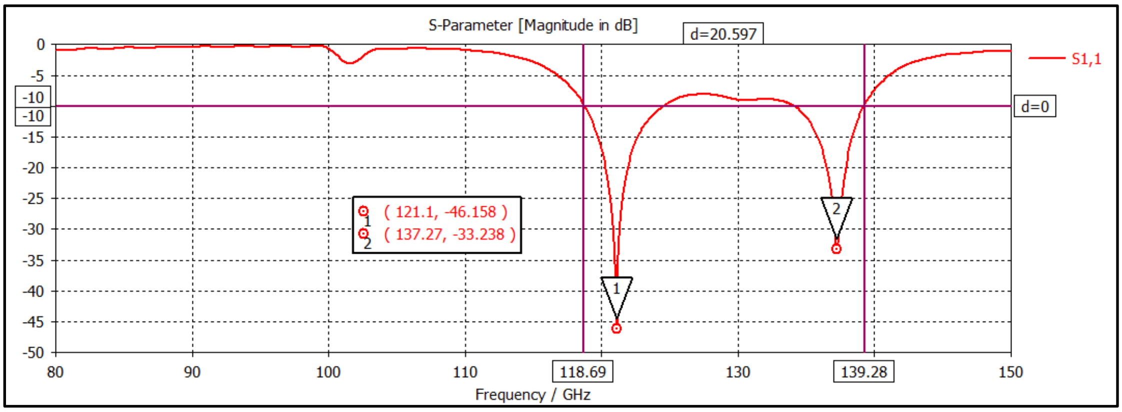

Figure 4.25: Distance between two resonating frequency

The magnitude for the first resonant frequency is -46.158dB while for the second resonant frequency is -33.238dB.

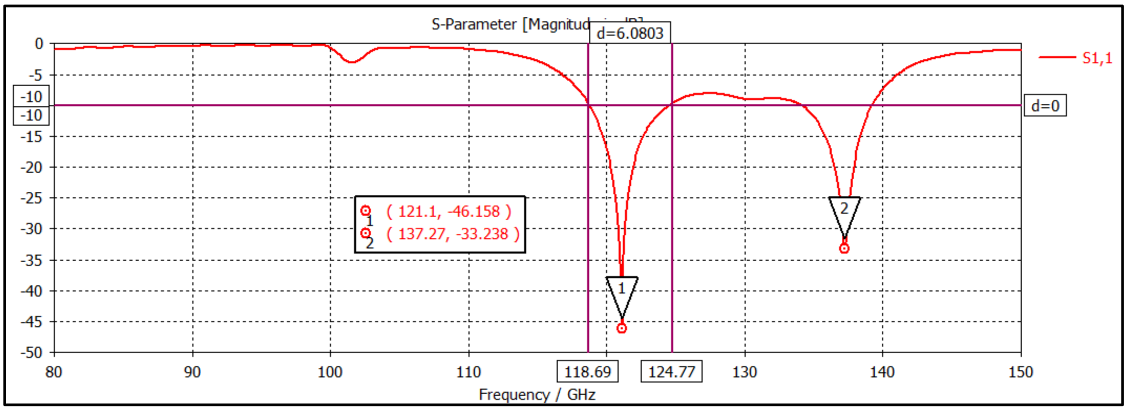

Figure 4.26: Bandwidth of the first resonant frequency

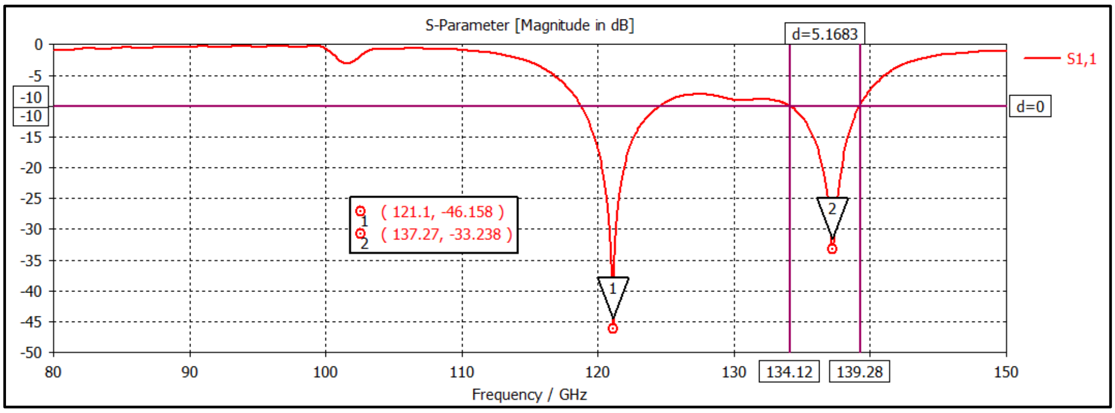

Figure 4.27: Bandwidth of the second resonant frequency

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Figure 4.28 below shows the farfield result of the proposed antenna. From the simulated result, we can clearly see the high radiation intensity part of the antenna. The red colour in the simulation shows that is the part more power is radiated. The gain that has been obtained for this proposed design is 6.118dB. While the radiation efficiency and the total efficiency is -1.600dB and -1.687dB respectively. This design shows a stable result in terms of gain and radiation efficiency.

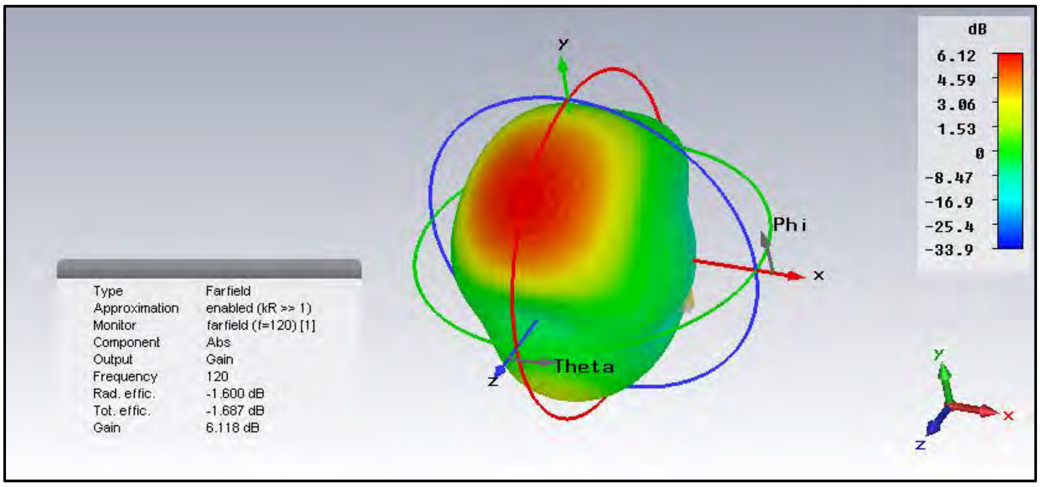

Figure 4.28: Farfield Result

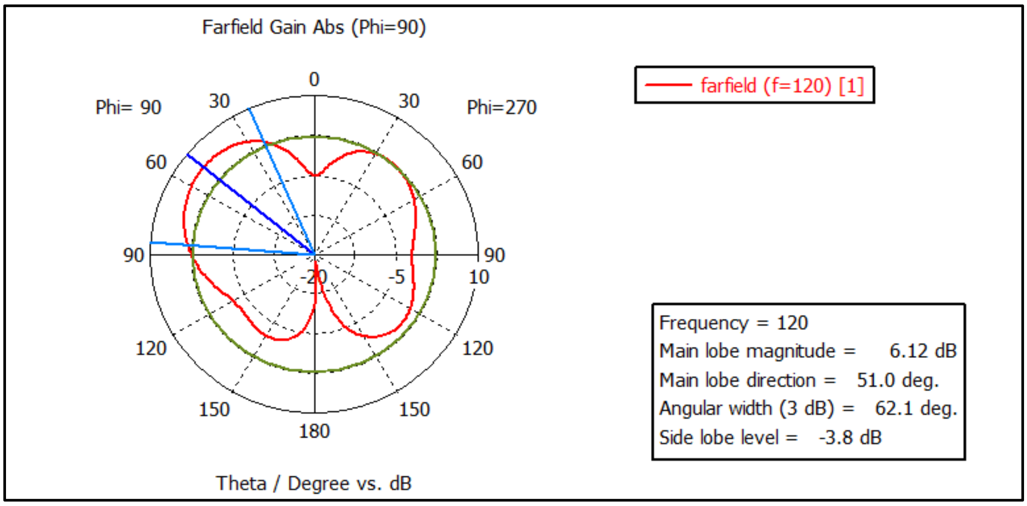

Figure 4.29: Farfield Gain in Polar

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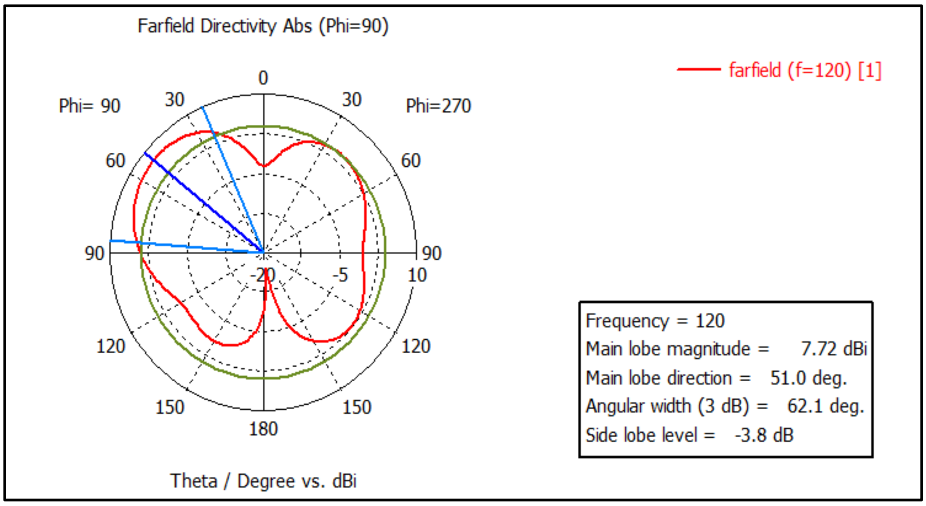

Figure 4.30: Farfield Directivity in Polar

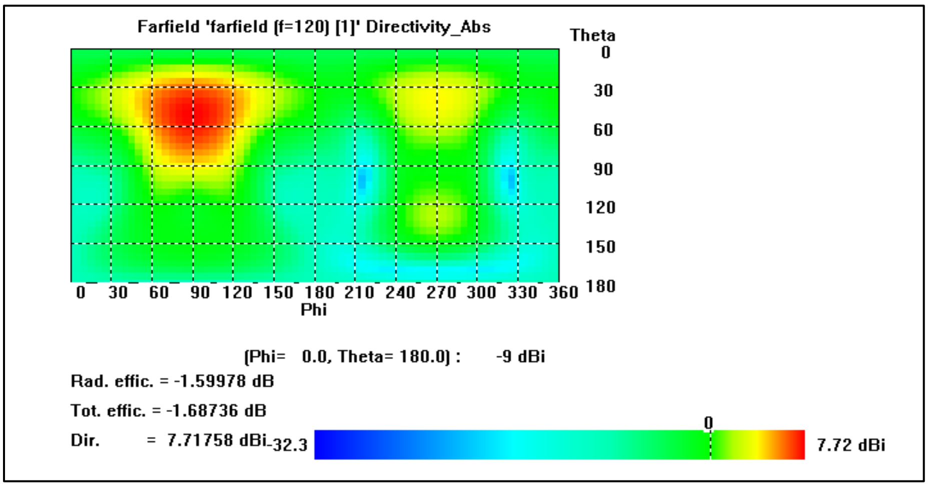

Figure 4.31: Farfield Result in 2D

After obtaining the result for the above designs, based on certain comparison and analysis that has been done earlier, the best performance that we obtained is from the design C. The antenna design C is just an improvement design from the design B. After the parametric study the result that has been obtained is satisfying. From the result, we can see the improvement especially in terms of return loss and the gain. Table 4.3 below shows the comparison of result among three antenna designs.

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Table 4.4: Result Comparison

Antenna Design	Resonant Frequency (GHz)	Return Loss (dB)	Gain (dB)	Bandwidth (GHz)	Total Efficiency (dB)
Design A (Bow-Tie Structure)	122.83	-37.567	3.727	11.98	-2.592
Design B (Bow-Tie and Ice-cream cone Structure)	126.9	-15.362	4.176	7.003	-3.196
Design C (Design B improvement)	121.1 & 132.27	-46.158 & -33.238	6.118	6.0803 & 5.1683	-1.6

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CHAPTER V

CONCLUSION AND RECOMMENDATION

In this chapter, the whole project is concluded and the objectives are verified to ensure that all the objectives of this project have been achieved as expected. Future improvement on this proposed antenna design was recommended and discussed in this chapter. Technical suggestion was also discussed in order to improve the antenna performance for future use which might be useful in the upcoming technology.

5.1 Conclusion

The main objective of this project is to calculate and design a combination of mixed bow-tie and ice-cream cone antenna at 120GHz for millimetre wave application. This bow-tie and ice-cream cone antenna is two different structures

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antenna. Therefore an analysis was done by combining both antenna designs into a single antenna. Then this proposed antenna design was analysed by rating the performance in terms of gain, radiation efficiency, return loss, and other parameters. Certain parametric study was done in this design in order to improve the antenna performance. At the beginning of the design, the antenna gives a moderate gain and different value of resonant frequency. The design was begun by constructing the bow-tie structure first. Then it was simulated to analyse the performance. After that, the antenna design was modified by adding the ice-cream cone structure with the bow-tie structure. Based on the simulation result, there is some improvement in the design, whereby the gain has increased and the radiation efficiency has improved. While the return loss in the s-parameter graph does not show a satisfying result. Therefore parametric study was done in this design to improve the result. A minor modification was done at the edge of triangle in the bow-tie design. The final design showed a satisfying result with a gain of 6.118dB and a total efficiency of -1.6dB. This design gives a dual band as a result whereby the antenna has a two resonant frequency. The first resonant frequency resonates at 121.1GHz with a magnitude of -46.185dB and the second resonant frequency resonates at 132.27GHz with magnitude of -33.238dB. The final dimension of the antenna is 1.6mm x 1.2mm by using Alumina as a substrate and gold as the conductor. This antenna is suitable for millimetre wave application due to its nature which enables it to operate at high frequency. From the result that has been obtained, finally it can be concluded that the objective of this project is achieved.

5.2 Future Recommendations

Further improvements can be done to this antenna design in order to improve the antenna performances. There are many techniques that can be done or modified to improve the parameters. The techniques are such as constructing array for this design to increase the antenna gain. Adding slot in the ground plane can also be done to study the antenna for other parameters. The effect of the slot can be tested on the top layer or in the ground plane as well. Same goes by adding slit to the antenna structure. Nowadays the most common technique used in antenna improvement analysis is by introducing EBG (Electromagnetic Band Gap) technique or the DGS

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(Defect Ground Structure) technique. Another technique to improve the antenna performance is by constructing the antenna by using different materials or higher dielectric constant material for the substrate. This is because different material gives different types of performances. By studying these techniques, improvement can be done by combining several existing techniques to produce a better antenna which can meet the user"s specifications.

5.3 Project Design for Sustainable Development

Project sustainability can be highlighted in many aspects especially in terms of social sustainability, economic sustainability and the ecology sustainability. In this analysis, this antenna design which has been designed for millimetre wave application does not give a heavy impact on the social sustainability, in fact this miniaturization of the devices is more preferred by the users nowadays as the rate development in the technology is keep on increasing. This antenna which supports millimetre wave application is naturally small in size due to the high frequency characteristics. When the frequency increases, the wavelength decreases and makes the structure small.

While when we look at the economic area for example in terms of production and resourcing, this design requires a precise process in order to complete the product. This might require some revise in the terms of technology and infrastructure. In the ecology sustainability, the material that will be used for this design will be slightly costly. The material that has been tested for this proposed design is gold and alumina. In order to obtain these materials, it might require a heavy process. Anyhow this design does not require a large amount of natural resources due to its compact size. This configuration will be mainly implemented in the semiconductor field.

5.4 Impact for Commercialization

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In the commercialization aspect, this project has a huge impact on the commercialization due to the rapid urbanization and upcoming new technologies especially in the telecommunication field. Nowadays everything is getting smaller; devices which were in huge size initially are now getting into a pocket size which can be easily brought to any place. This antenna is designed especially for millimetre wave application because of its high operating frequency. Devices that can operate for millimetre wave application nowadays are widely used especially in the semiconductor market for electronic and electrical components. Other field that using this application is in the communication field for the antennas and transceiver components. Medical imaging field and scanning facility also has an impact on this project and same goes to the industrial automation applications.

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