WIDEBAND ANTENNA DESIGN FOR SUB 6 GHZ RANGE FOR 5G APPLICATION

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

Faculty of Electronic and Computer Engineering
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2021

DECLARATION

I declare that this report entitled "WIDEBAND ANTENNA DESIGN FOR SUB 6 GHZ RANGE FOR 5G APPLICATION" is the result of my own work except for quotes as cited in the references.

Signature : ....

Author : NUR FARZANA BINTI MOHD NAZLI

Date : 10 JULY 2021

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature : ………………………………….

Supervisor Name : DR IMRAN BIN MOHD IBRAHIM

Date : 10/7/21 ………………………………….

DEDICATION

Thank you for all the supports that have been given by my dad and mother and Dr Imran for all the support in order to accomplish this final year project.

ABSTRACT

A new patch antenna for wideband antenna design for sub 6 GHz range for 5G application is designed. This project research about wideband antenna was design and simulated using CST Software for the frequency range within 3.5 GHz- 5 GHz. The material of an antenna is using Rogers RT5880 as a substrate with a 0.254mm thickness, dielectric constant 2.20 and for a conducting part and patch of the antenna is made up of copper. The influence of design variation parameters such as size of substrate, size of patch and size of ground plane was observed and analyzed. Finally, the best parameter was selected based on performance return loss of the antenna. This project will be focusing on designing a wide band antenna for sub 6 GHz for 5G applications within frequency 3.5 GHz- 5 GHz. Computer Simulation Technology (CST) is used in this project to plan the structure of antenna.

ABSTRAK

Reka bentuk antenna jalur lebar untuk frekuensi sub 6 GHz di antara jarak dari 3.5 GHz – 5GHz untuk aplikasi 5G telah direka. Projek ini berkenaan antenna jalur lebar yang telah direka dan disimulasikan menggunakan aplikasi CST menggunakan frekuensi di antara 3.5 GHz- 5GHz. Bahan yang digunakan untuk membuat antenna tersebut adalah Rogers RT5880 sebagai substrat dan untuk bahan pengalir dan juga antenna patch adalah tembaga. Antara pembolehubah yang dapat mempengaruhi reka bentuk sesebuah antenna adalah, saiz patch, size bahan pengalir antara salah satu pemerhatian dan analisis yang telah dijalankan sepanjang perlaksanaan projek ini. Akhir sekali, pembolehubah yang terbaik telah ditentukan berdasarkan pemerhatian terhadap prestasi return loss sesebuah antenna. Tujuan projek ini adalah untuk mereka bentuk antenna jalur lebar untuk frekuensi 3.5 GHz- 5 GHz menggunakan aplikasi CST.

ACKNOWLEDGEMENTS

Bismillahirohmani rohim, Alhamdulillah all rahmat from Allah who give this chance for me completing the thesis. Most thanked to Dr. Imran Bin Mohd Ibrahim who guiding and support me physically and mentally and not forgotten to my beloved friends who never refuse to give a hand regarding some of the thesis's detail. Last but not least, special thanks to my dad and mother who had been giving moral support while completing this degree.

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LIST OF SYMBOLS AND ABBREVIATION

GSM	:	Global system for mobile communication
WCDMA	:	Wideband code division multiple access
CDMA	:	Code division multiple access
HSPA	:	High speed packet access
LTE	:	Long term evolution
IoT	:	Internet of Things
1G	:	First- generation
2G	:	Second- generation
3G	:	Third- generation
4G	:	Fourth- generation
5G	:	Fifth- generation
CST	:	Computer Simulation Technology
UWB	:	Ultra-wideband
C	:	Speed of light (3×10^8)
f_r	:	Resonance frequency
f_h	:	High frequency
f_L	:	Low frequency
εr	:	Relative permittivity
f_c	:	Center frequency
W	:	Total width of the antenna
L	:	Total length of the antenna
W_f	:	Width of microstrip line
L_f	:	Length of microstrip line
L_g	:	Length of ground plane
W_m	:	Width of matching stripline

L_m	:	Lentgh ofmatching stripline
W_p	:	Length of each log elements
w_1	:	Width of the microstrip feed line
ls	:	Length of substrate
ws	:	Width of substrate
lg	:	Length of ground
wg	:	Width of ground
wf	:	Width of feedline
lf	:	Length of feedline
R2	:	Radius of small circle
R	:	Radius of cirle

CHAPTER 1

INTRODUCTION

This chapter explained regarding the information that needed in this project. In addition, it also explained briefly about antenna design specification, scope of project, project planning and lastly the organization of the report.

1.1 Project Background

For more than two decades, the wireless communication industry has progressed tremendously, moving from analogue to digital systems known as 2G/GSM, multimedia transmission to high data rate cellular wireless communications 3G/WCDMA and eventually packet optimization with 3.5G/HSPA and 4G/LTE. The 5G refer as the fifth-generation mobile network used to enhanced mobile broadband. Other than that, in IoT it is grows rapidly in the worldwide. It allows for the establishment of a new type of network that connects virtually everyone and everything together including machines, objects and gadgets. A transmission channel with a wider bandwidth than a single voice channel is known as wideband. A wide band operating characteristics approximately same over a very wide passband. Nowadays, the antenna of wideband and small size in a high demands due to the progress in new world of technology.

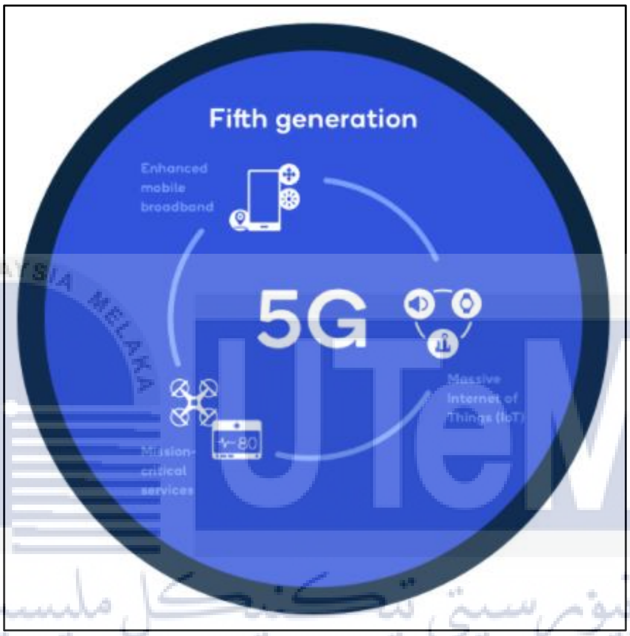


Figure 1.1: Fifth-Generation

In this research, the design of wideband antenna for sub 6 GHz range for 5G application was proposed to due to current antenna does not suitable with the new technology in wireless service. Due to demand in industry engineering of antenna, it is required in this new world due to increasing number of users. In addition, due to its unique structure the proposed antenna can be developed as a new design for wideband antenna in industry. For example, the structure of antenna can be as a logo for certain products. Lastly, a compact wideband antenna has been designed and presented with the main objective in this research is to get a return loss below -10 dB within frequency 3.5 GHz-5 GHz.

1.2 Problem Statement

Nowadays world had emerged to the new technology such as 5G networks. The rapid evolution of the mobile systems toward 5G systems requires the development of multiband, wideband and UWB antenna that suitable to covering mobile and wireless services while reducing system complexity, the overall device dimensions and costs.

The limitation for this project is when the bending of antenna increase, the effect on return loss decrease and the bandwidth will shift to higher band. The system requires material that suited and can adapt with flexibility of antenna. Furthermore, the engineering of antenna is required in this new world due to increasing number of users. Due to that problem, maybe the antenna can be upgrades to provide a better connection.

1.3 Objectives

The goal in this project:

- To design, simulate, fabricate and measure wideband antenna for sub 6 GHz range for 5G application within frequency 3.5 GHz- 5 GHz.
- To obtain S_{11} parameter below -10dB within frequency 3.5 GHz- 5GHz.

1.4 Antenna Design Specification

The specification of antenna is stated in the table below:

Table 1.1: Antenna Parameter

PARAMETER	VALUE
Bandwidth Operating Frequency	3.5 GHz- 5 GHz
Bandwidth Response	Below -10 dB

1.5 Scope of Project

This project started by doing some study on the background research regarding the design of a wideband antenna. In order to gain a better understanding about this project, a lot of article and journal were researched. Research is made to decide material that will be use in this project. The main parameter of the antenna need to be considered such as size of the substrate, size of the ground which means it include the width and length of the substrate and ground. Other than that, the size of patch and also the structure plan of an antenna.

To design an antenna within frequency 3.5 GHz-5 GHz, CST Studio Suite Software are used to design an antenna by a suitable parameter to obtain the desired result which is return loss below -10 dB. Design and simulation will be done repeatedly using the variety of parameter to ensure the purpose of the project is achieved. Finally, measure parameter of the antenna using network analyzer and compare the result experiment with simulation.

1.6 Project Planning

This project started with the study of literature review which are related to previous researchers once the title has been chosen. The research is about the designation of Wideband antenna. The designation of an antenna will be constructed in CST 2019 software. Then, when it meets, the requirements needed refers to the parameter of an antenna. Fabrication process will be conducted in lab. Last but not least, make the comparison of antenna parameter between measured and theory.

1.7 Organization Report

In this report consists of 5 chapters. Chapter 1 consists of project background, problem statement, goal, antenna design specification, scope of project and project planning. In chapter 2 discussed about background research of the project on the previous research which is related to this project to make as a reference. Chapter 3 consists of method on how to design and simulate an antenna of project on CST Microwave Studio also how the flow of fabrication an antenna. Chapter 4 discussed about the results and discussion. The results of gain or efficiency and directivity for proposed also discussed in this chapter. Chapter 5 will be discussing about conclusion and recommendation for future work.

CHAPTER 2

BACKGROUND STUDY

Chapter 2 concerning content of literature review of overall project in the previous research which is related to this title of project. The various method implemented in the project will be explained briefly in this chapter.

2.1 Previous Related Study

2.1.1 A Miniature Raspberry Shaped UWB Monopole Antenna Based on Microwave Imaging Scanning Technique for Kidney Stone Early Detection

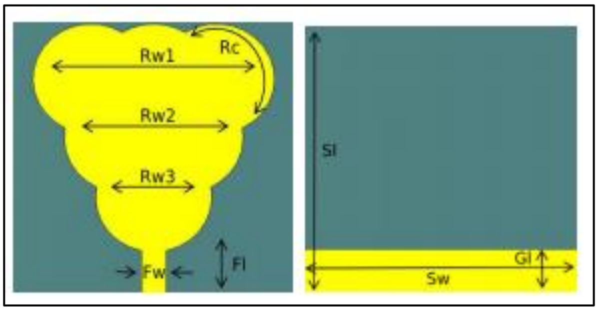


Figure 2.1: Geometry of the proposed antenna: (a) front view (b) back view [2]

According this article, author improved antenna bandwidth by replaced the conducting part with a quarter ground plane, then the UWB monopole antenna materials used is Rogers RT5880 (Lossy. The 50Ω microstrip line is fed in the structure circular monopole antenna. The impedance of the monopole is matched, employing a quarter wavelength (λ/4) transformer.

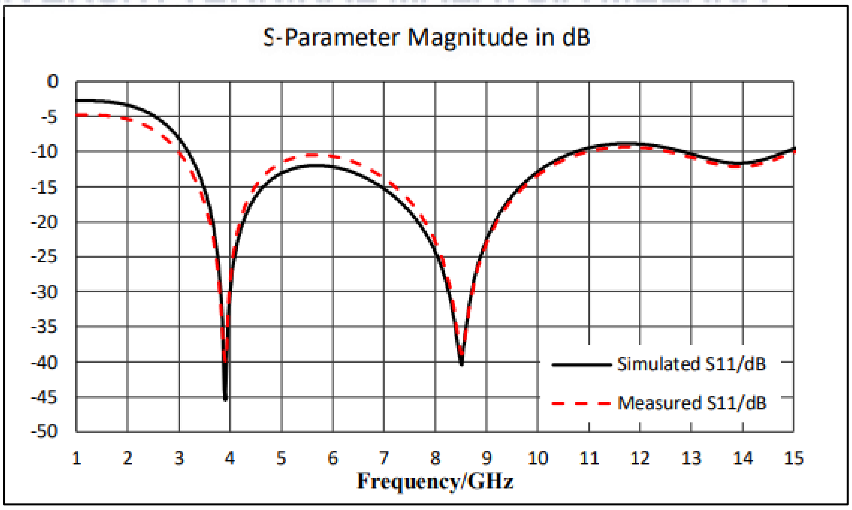


Figure 2.2: Simulated and Measured Reflection Coefficient Results of UWB Raspberry Monopole Antenna[2]

The illustrated simulation and measured comparison of s- parameters for the UWB monopole antenna are shown in Figure 2.2. The s- parameters performance of the UWB Raspberry shaped monopole antenna is radiating, as shown in the graph. Ultrawide band performance is possible within frequency 3 GHz- 11 GHz. The measurement results in free space are in match well with simulation results It demonstrates that the measurement result's resonant frequency has been altered when compared to the simulation result.

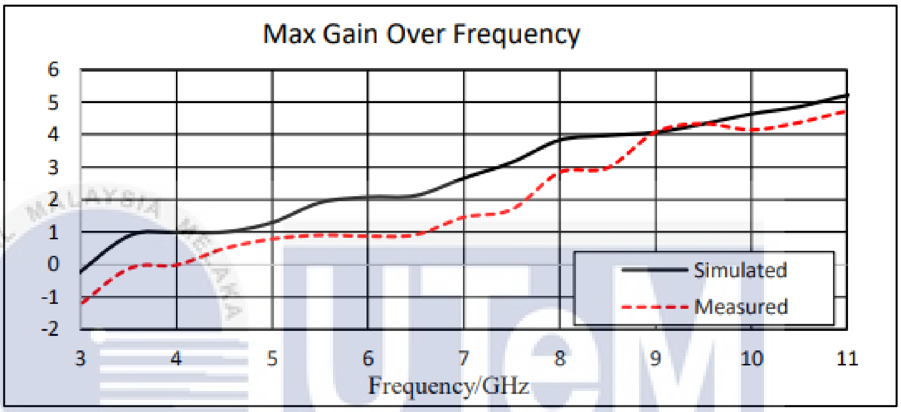


Figure 2.3: Simulated and Measured Gain Results of UWB Raspberry Monopole Antenna[2]

Figure 2.3 shows the curve graph of the UWB Raspberry shaped monopole antenna. When comparing the measured and simulated results for antenna gain, it shows that the measured result has a lower gain value.

2.1.2 Flexible Co-Planar Waveguide (CPW)-Fed Y-Shaped Patch UWB Antenna for Off-Body Communication

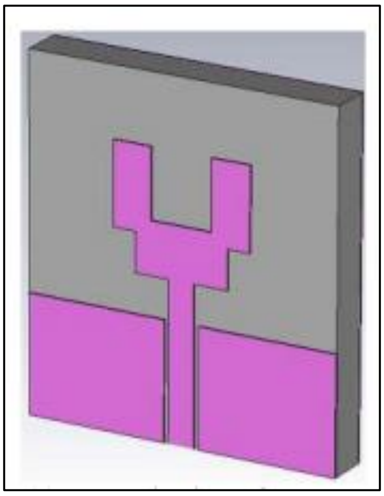


Figure 2.4: Isometric View of Antenna Structure[3]

This antenna was proposed to design an UWB slotted Y-shaped antenna integrated with CPW feedline. There are two materials use for substrate which are RO4350B and felt. RO4350B is using material for Y-shaped antenna and CPW feedline with a relative permittivity of 3.66 and for the radiator material used is ShieldIt conductive textile. The antenna made up of two layers of ShieldIt Super Textile and one layer of substrate.

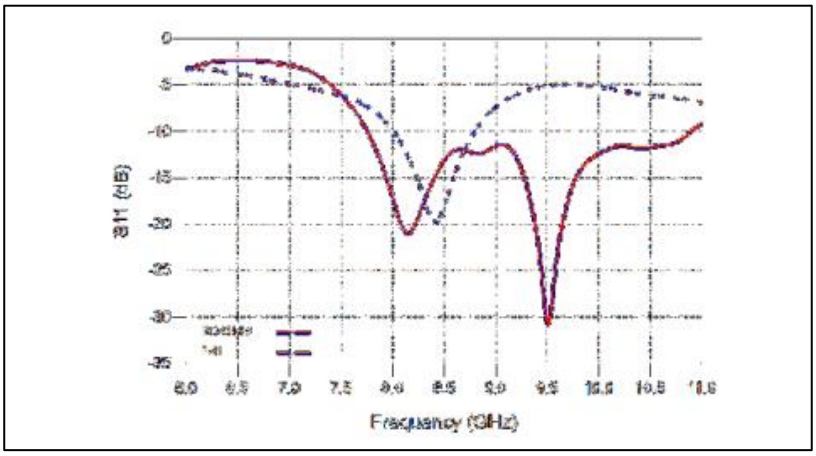


Figure 2.5: The S_{11} of Antenna with Rogers 4350B and Felt Substrate Material[3]

2.1.3 Design & Performance of Wearable Ultrawide Band Textile Antenna for Medical Applications

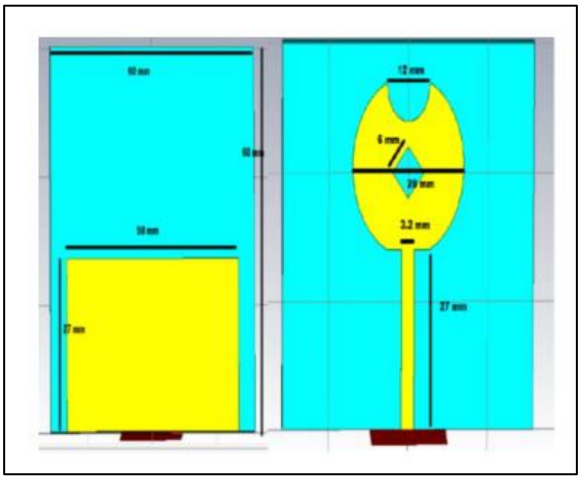


Figure 2.6: Particle Size Distribution[4]

In this proposed antenna the material that used as a substrate to design ultrawide band antenna is textile especially it is for medical applications. The results for simulated and measured of the antenna indicate an antenna has meet the requirements needed and provides bandwidth of 13.08 GHz with a compact size, washable and flexible materials. Furthermore, the antenna's small size verifies its applicability for portable UWB devices.

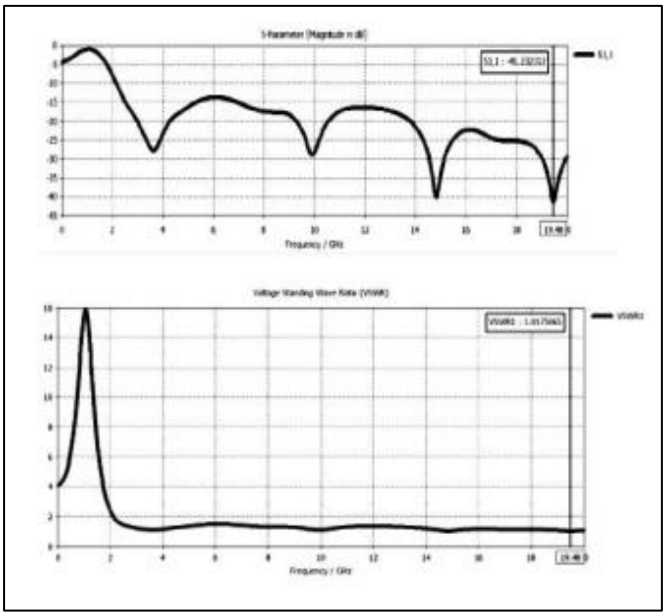


Figure 2.7: S_{11} parameter and VSWR Vs Frequency[4]

From the graph of the results, at 9.92 GHz with return loss -28.99 dB and gain is 3.8 dB. And the highest return loss in this antenna which is -27.86 dB, at frequency 19.48 GHz with return loss -41.232312 dB.

2.1.4 Gain Enhancement for Whole Ultrawide Band Frequencies of a Microstrip Patch Antennas

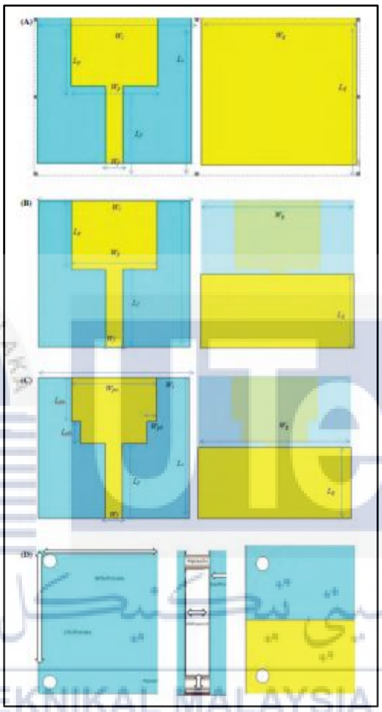


Figure 2.8: The Development Flow of UWB Micro-Strip Patch Antenna with Superstrate. (1) Iteration A and Iteration B Parameter Study of Micro-Strip Patch Antenna. (2) Iteration C is fully of UWB Micro-Strip Patch Antenna. (3) Iteration D is an UWB Micro-Strip Patch Antenna with Superstrate[5]

This article was proposed to design a rectangular microstrip patch antenna over ultrawide band with superstrate. The equations that used to calculate the parameter of the antenna in order to design a micro-strip patch antenna.

$$L = \frac{1}{2f_c\sqrt{\mu r \varepsilon_r}\sqrt{\varepsilon_e}} \quad \textbf{(2.1)}$$

$$W = \frac{c}{2f_c}\sqrt{\frac{2}{\varepsilon_r + 1}} \quad \textbf{(2.2)}$$

$$f_c = \frac{f_H + f_L}{2} \quad \textbf{(2.3)}$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} - \frac{1}{\sqrt{1 + (12d/w_1)}} \quad \textbf{(2.4)}$$

$$\frac{w_1}{h} = \frac{8e^A}{(e^{2A} - 2)} \quad \textbf{(2.5)}$$

Represented as:

C= speed of light (3×10^8)

$F_c = center\ frequency$

$\varepsilon_r = effective\ permittivity$

d= thickness of substrate material FR-4 (1.6)

$w_1 = width\ of\ the\ microstrip\ feed\ line$

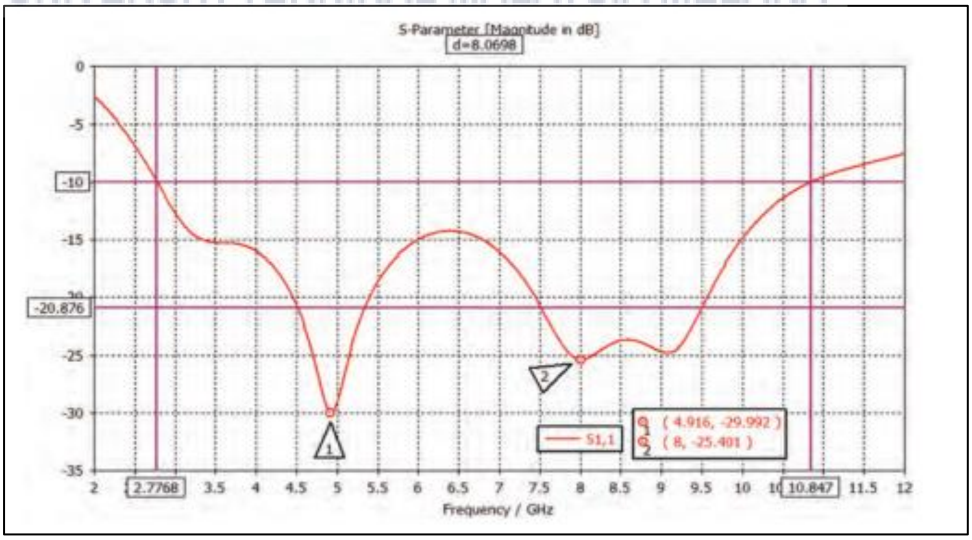


Figure 2.9: Simulation S-parameter Results of UWB Micro-Strip Patch Antenna with/without Superstrate[5]

Figure 2.9 shows a result for simulation S- parameter results of UWB micro-strip patch antenna with/ without superstrate. The result shows the iteration either with substrate or without substrate, does not have huge difference between two method. As of the outcome, it shows that the antenna is irradiate on ultrawide band frequency domain through up frequency of 4.92 GHz with approximately -29.992 dB, while at frequency 8 GHz achieves 25.4 dB of impedance bandwidth.

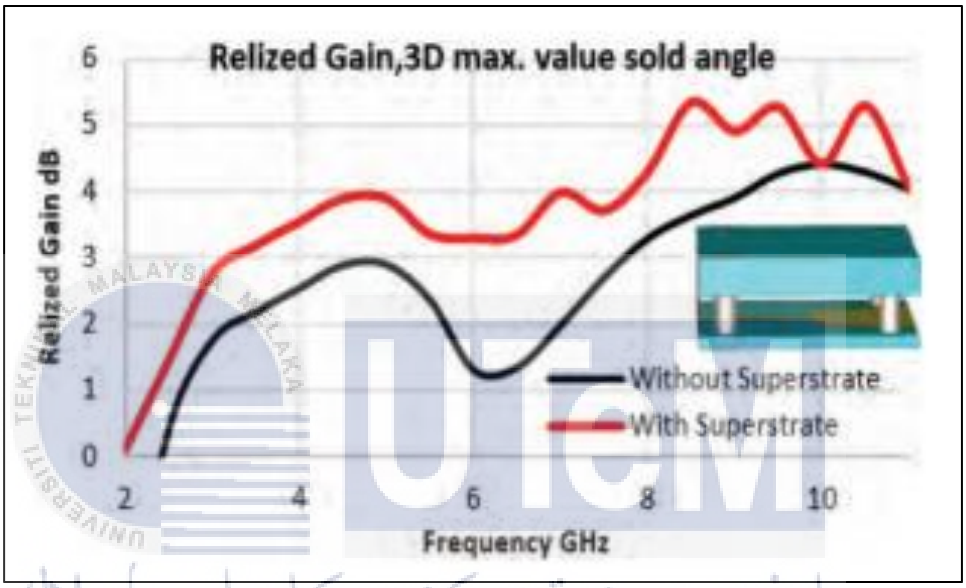


Figure 2.10: Antenna Gain Simulation of Basic UWB Micro-strip Patch Antenna with/ without Superstrate[5]

Figure 2.10 shows an antenna gain simulation of basic UWB microstrip patch antenna. Based on the figure, it shows that (black line) represents the gain of UWB patch antenna operates at 2 GHz and 11 GHz, which it presents that the gain achievement at 10.12 GHz and 3.44 GHz are 4.196 dB and 3.2, respectively. And the gain of superstrate (red line) between 2 GHz and 11 GHz, it shows the gain performance is enhanced from 2 GHz to 11 GHz with crest realized gain 5.3 dB at frequency response 10.55 GHz and 4.12 dB at frequency response 2.688 GHz.

2.1.5 Gain Improvement and Bandwidth Extension of Ultrawide Band Micro-Strip Patch Antenna Using Electromagnetic Band Gap Slots and Superstrate Technique

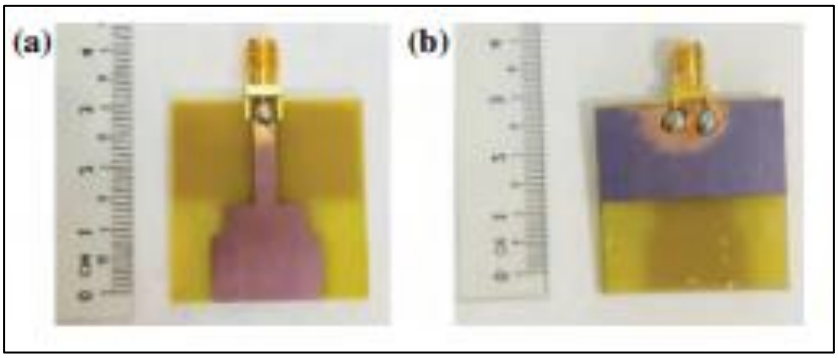


Figure 2.11: Measured of Micro-Strip UWB Patch Antenna, (a) side sight, (b) behind sight[6]

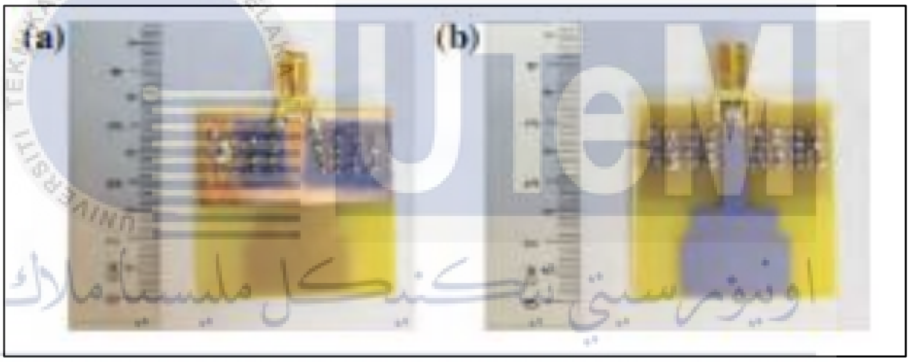


Figure 2.12: Measured of UWB Micro-Strip Patch Antenna Modified by EBG slots, (a) side sight, (b) behind sight[6]

In this article, the antenna was proposed to designed using techniques EBG slots and superstrate. The microstrip patch adapted with Electromagnetic band gap (EBG) slots as shown in the figure 2.12. It contains of second iteration of UWB micro-strip patch antenna altered by EBG slots. EBG slots was placed on the sides the patch of feed line whole EBGs by equal to scopes feed line.

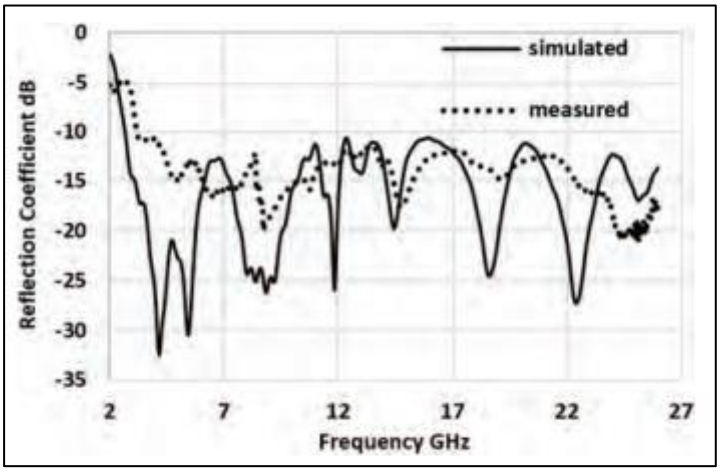


Figure 2.13: Simulated and Measured Results of Impedance Bandwidth for UWB Micro-strip Patch Antenna by adjusted EBG slots[6]

Figure 2.13 illustrates simulation and measurement results of impedance bandwidth for UWB micro-strip patch antenna with ebg slots. The antenna's resonance frequency ranges from 2.67 GHz to 26 GHz.

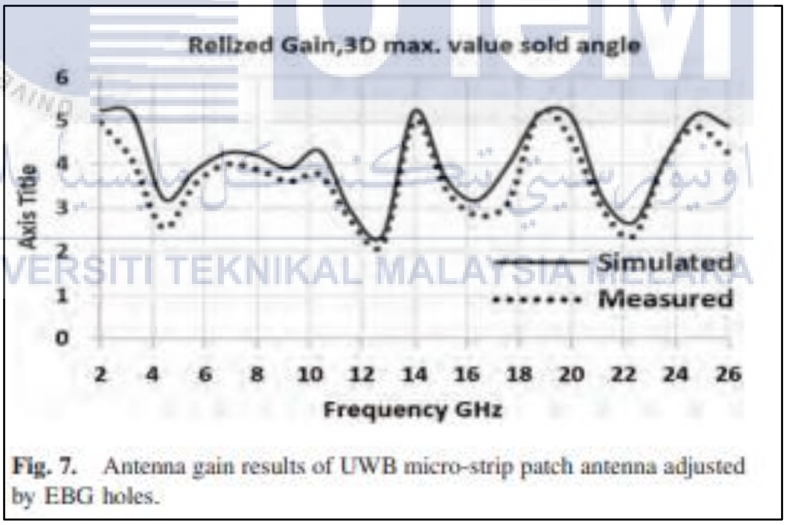


Figure 2.14: Antenna Gain Results of UWB Micro-strip Patch Antenna Adjusted by EBG Slots[6]

Figure 2.14 shows the gain increasing slightly by inserting EBG holes with a top relised gain 5.2 dB at 13.98 GHz. The finding for superstrate return loss are almost same as with EBG within frequency range of (2.5 GHz- 26 GHz) and a total return loss less than -30 dB absorbs 23.5 GHz of bandwidth.

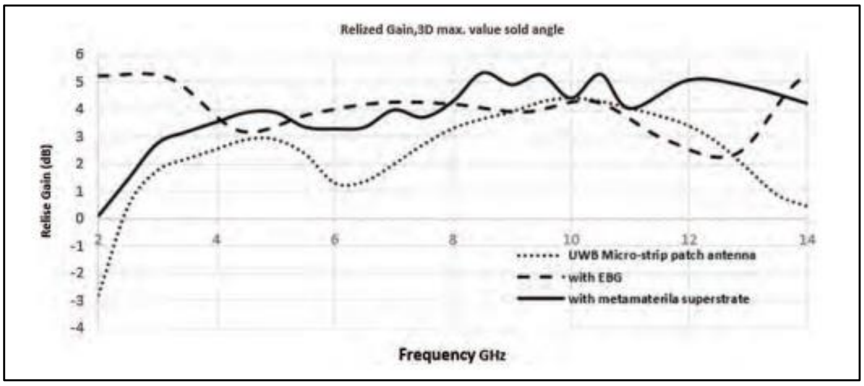


Figure 2.15: Gain Outcomes of UWB Micro-strip Patch adjusted with EBG Slots while Superstrate[6]

Figure 2.15 shows the antenna gain of initial design of UWB micro-strip patch antenna by EBG slots with superstrate which is it turn frequency to 2 GHz to 14 GHz presents the gain at 10 GHz is 4.5 dB. While for EGBs slot, the gain at frequency 13.32 GHz is 5.2 dB. The final patch antenna design adjusted with EBG slots and superstrate, the result of gain antenna is 5.3 dB at 10.55 GHz.

2.1.6 A 2.45 GHz Semi-Flexible Wearable Antenna for Industrial, Scientific and Medical Band Applications

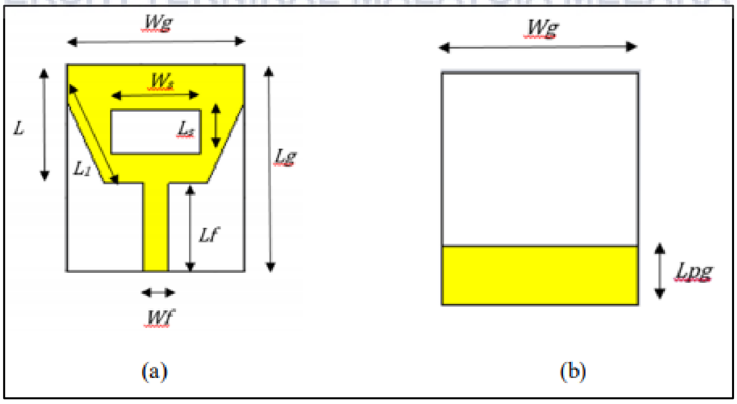


Figure 2.16: The Wearable Microstrip Patch Antenna with Rogers Duroid RO3003 Substrate; (a) Top View (b) Bottom View[7]

This article suggested to used CST software to construct a small, microstrip patch antenna with wearable ability with a 2.45 GHz operating frequency, as shown in the image above. The article was designed using material named as Rogers 29 Duroid RO3003. The substrate plays important part in designing antenna as it determines the important parameter of antenna.

Table 2.1: Dimension of the Wearable Microstrip Patch Antenna with a Rogers Duroid RO3003 Substrate[7]

Parameter	Value (mm)	Parameter	Value (mm)
L	16	L_s	6
W	24	W_s	12
L_g	28	L_1	11
W_g	24	L_{pg}	7.1
L_f	12	h_t(copper)	0.035
W_f	3.5	h_s (substrate)	1.52

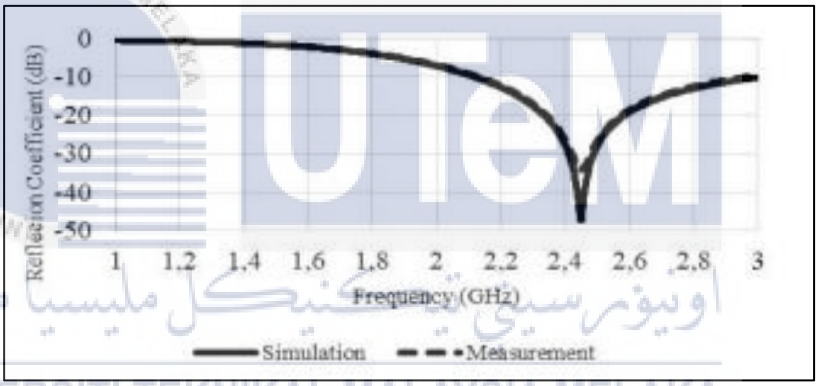


Figure 2.17: Simulated and Measured Reflection Coefficient of the Semi-Flexible Wearable Antenna[7]

Figure 2.17 shows a simulation result of reflection coefficient compared with the measurement result. In graph shows, with return loss -47.29 dB at frequency 2.45 GHz. While, measurement results shows at 2.45 GHz with return loss -34.13 dB which is has a slightly different which is the return loss.

2.1.7 A Novel Design of a Compact Wideband Patch Antenna for Sub-6 GHz Fifth-Generation Mobile Systems

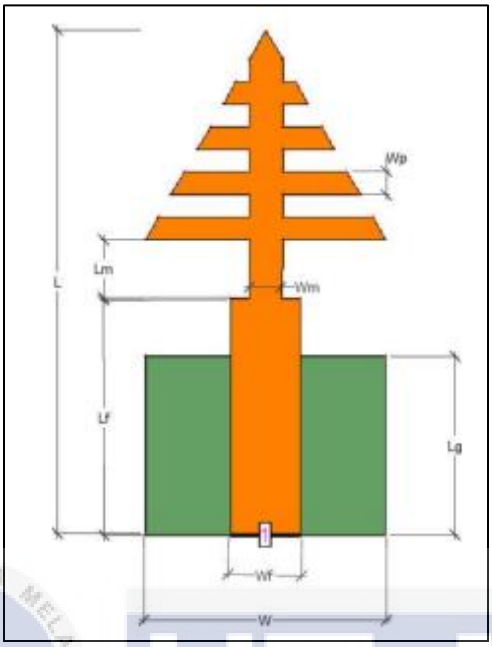


Figure 2.18: The detailed 2D Geometry of the Log- Periodic Patch 5G Antenna[8]

Table 2.2: Dimensions of the Log-Periodic Patch 5G Antenna[8]

Dimensions	Explanation	Size (mm)
W	Total width of the antenna	10.7
L	Total length of the antenna	22.5
W_f	Width of microstrip line	3.1
L_f	Length of microstrip line	10.5
L_g	Length of ground plane	8.0
W_m	Width of matching stripline	1.55
L_m	Length of matching stripline	2.7
W_p	Length of each log elements	1.0

In this article, the antenna was design based on an equilateral triangle- sized log- periodic array using log- periodic array design methods. By using formula below to calculate the length of the longest element (L_{max}) of the log-periodic array.

$$L_{max} = \frac{c}{4 f_{min} \sqrt{\varepsilon_r}} \tag{2.6}$$

Besides, in designing log- periodic array; the number of array elements also one of the parameters that need to determined using the following equation where B is the bandwidth ratio, Bar is the active region bandwidth and τ is scaling factor which is given as 0.87:

$$N = 1 + \frac{\log(B \times B_{ar})}{\log(1/\tau)} \tag{2.7}$$

Then, for bandwidth and active region bandwidth parameters determined by using equation α in the equation is half-angle of the antenna.:

$$B = \frac{f_{max}}{f_{min}} \tag{2.8}$$

$$B_{ar} = 1.1 + 7.7(1-\tau)^2 \cot\alpha$$

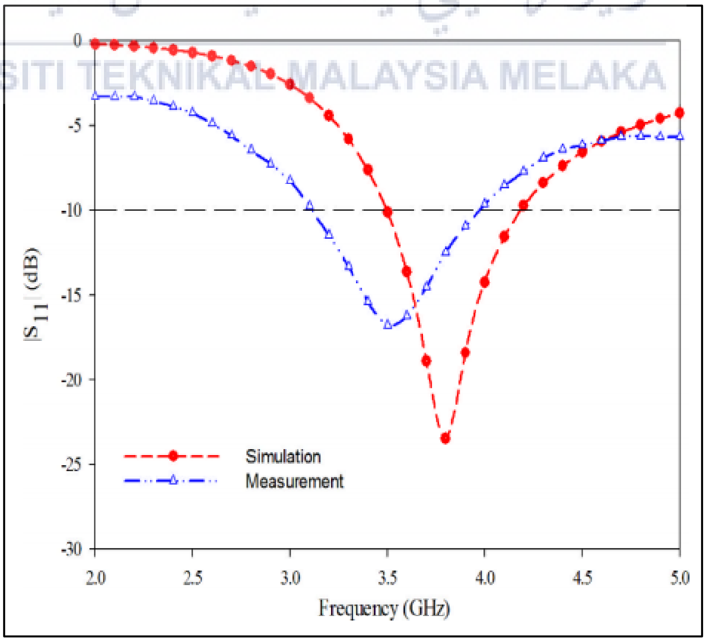


Figure 2.19: Measured and Simulated S_{11} Graph of the Log-Periodic Patch 5G Antenna[8]

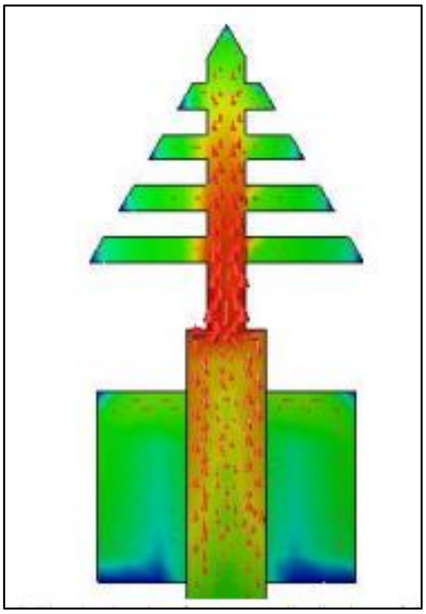


Figure 2.20: The Simulated Surface Current Distributions of the Log-Periodic Patch 5G Antenna at 3.5GHz[8]

2.1.8 A Wide and Tri-band Flexible Antennas with Independently Controllable Notch Bands for Sub 6GHz Communication System

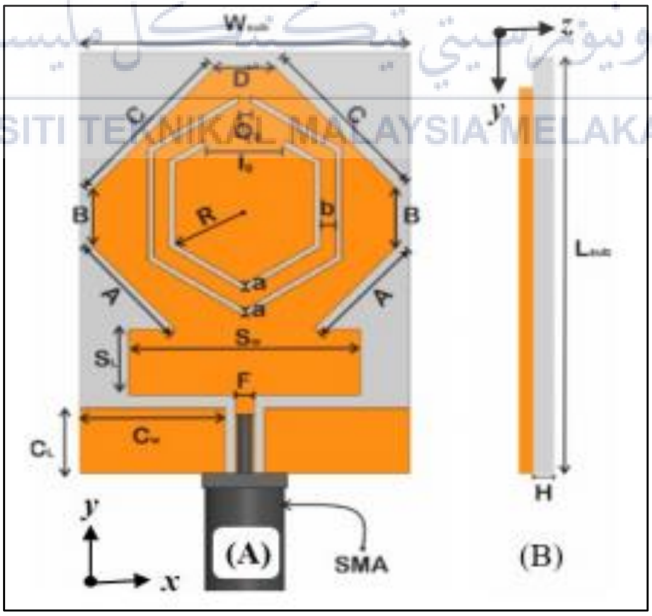


Figure 2.21: Geometry of the Proposed Printed Monopole Antenna: (A) Front View and (B) Side View[9]

In this article, the antenna's bandwidth is substantially improved by using an octagonal patch fed by a Co-Planar Waveguide (CPW) with a stub inserted along the feedline. Then, with the help of two hexagonal slots, two notch bands were created, which can be easily controlled by changing the slot length. The material used in this antenna is Rogers RO4835Twith thickness of 0.064 mm for substrate and for conducting material made up from copper with thickness 0.035 mm.

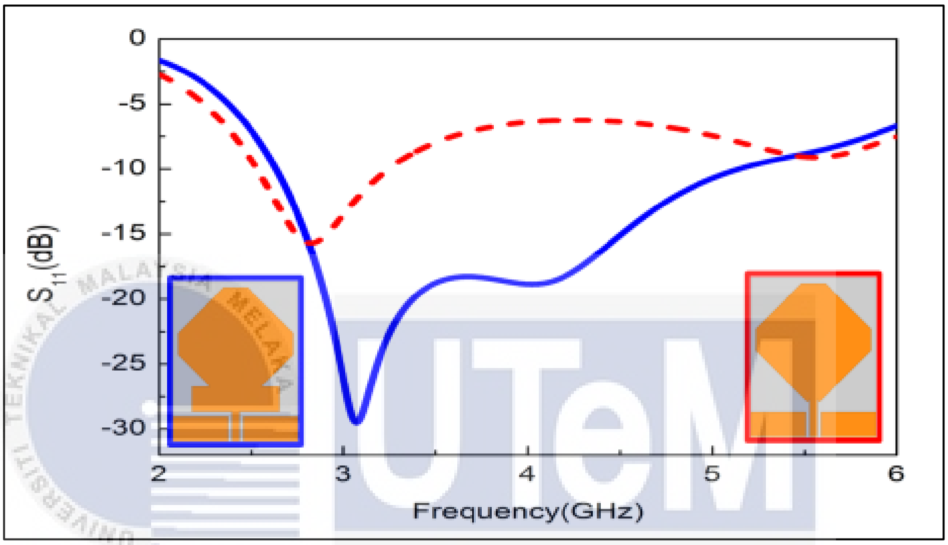


Figure 2.22: $|S_{11}|$ of the Conventional Antenna and Proposed Wideband Antenna[9]

In figure 2.23, it shows the result of the conventional patch and wideband stub loaded antenna. The octagonal patch has a narrow band in comparison to the stub loaded antenna.

2.1.9 Wideband Antenna Design and Fabrication for Modern Wireless Communications Systems

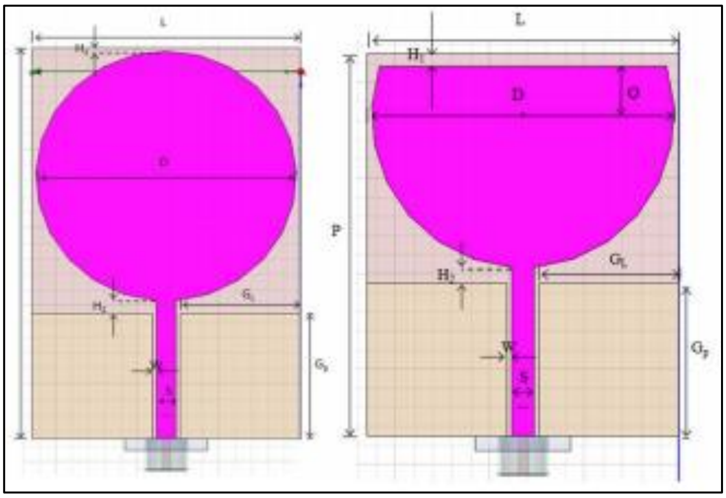


Figure 2.23: Wideband Antenna: (a) Circular Patch with 2-square Ground Plane, (B) Truncated Patch to Extend Antenna Bandwidth[10]

Proposed antenna is design based on circular patch and CPW- fed line. Material used for this antenna is FR4 epoxy for substrate. The frequency range covered by the wideband antenna characteristic is 2.3 GHz- 6 GHz. The result are shown below based on the comparison that has been done.

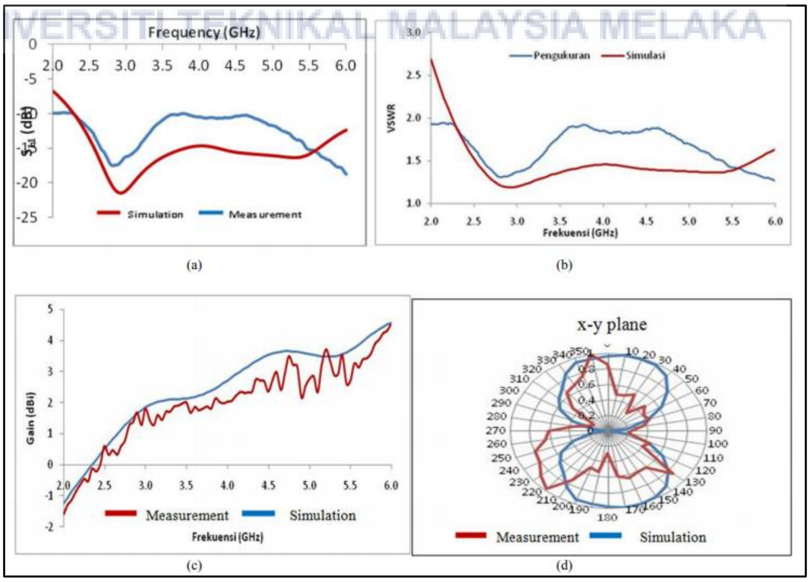


Figure 2.24: Antenna Measurement Results: (a) Return Loss; (b) VSWR; (c) Gain; (d) Radiation Pattern[10]

2.1.10 Design of Compact Dual-Wideband Antenna with Assembled Monopoles

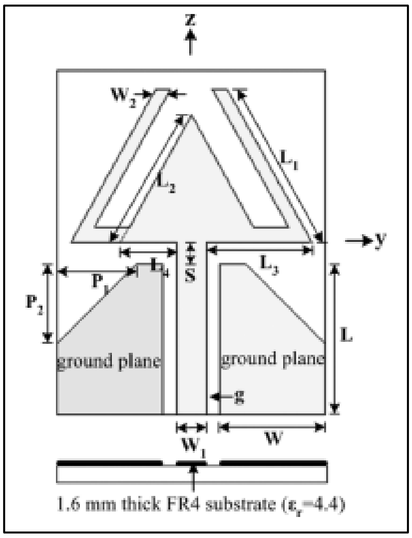


Figure 2.25: Geometry of the Proposed Antenna[11]

This article, an equilateral triangular monopole and circular monopole formed the antenna. A CPW microstrip feedline fed a modified U-shaped monopole. To design a compact antenna, the U- shaped monopole allocated outside the triangular monopole. The suggested antenna's multi-band performance is achieved by using dual resonant monopoles of various diameters. The results of the s- parameters has been provided in figure 2.30.

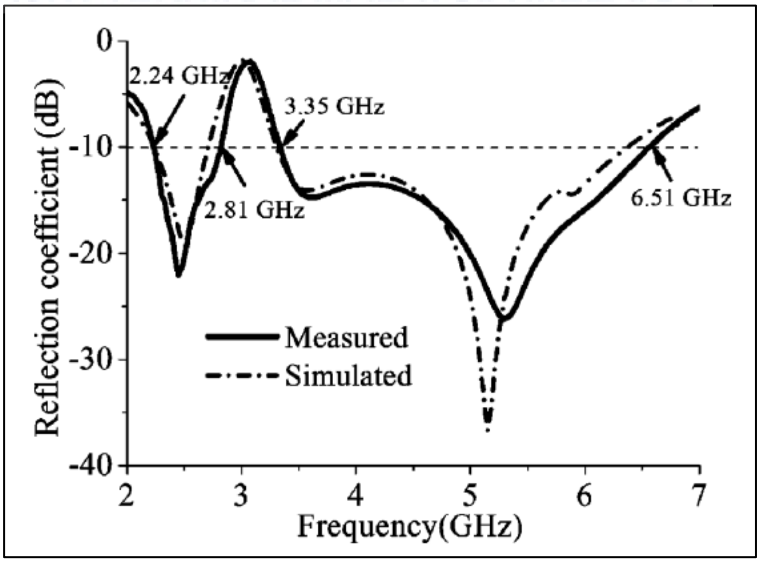


Figure 2.26: Measured and simulated reflection coefficient of the proposed antenna[11]

In figure 2.27, it shows the result of simulated and measured of the proposed antenna. Impedance bandwidth for the lower and upper bands is 2.24 GHz-2.81 GHz which is 0.57 GHz and 3.35 GHz- 6.51 GHz is 3.16 GHz.

2.1.11 Compact Wideband Transparent Antenna for 5G Communication Systems

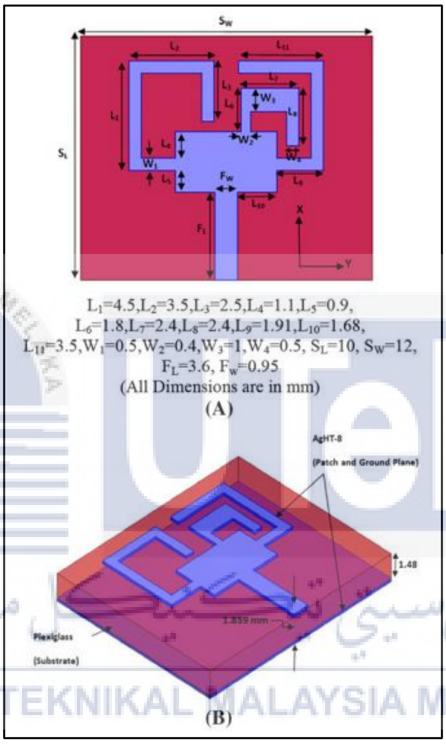


Figure 2.27: Antenna Geometry (A) top view (B) 3D view[1]

The proposed antenna has been designed with a transparent characteristics consists of rectangular shape branch linked to the center patch. The materials used for the patch and conducting part is AgHT-8 with thickness 0.177 mm. Materials of the substrate is made up from Plexiglas with dielectric constant 2.3 and loss tangent 0.00037. The results of simulated and measured of the antenna has been obtained and presented in the picture below.

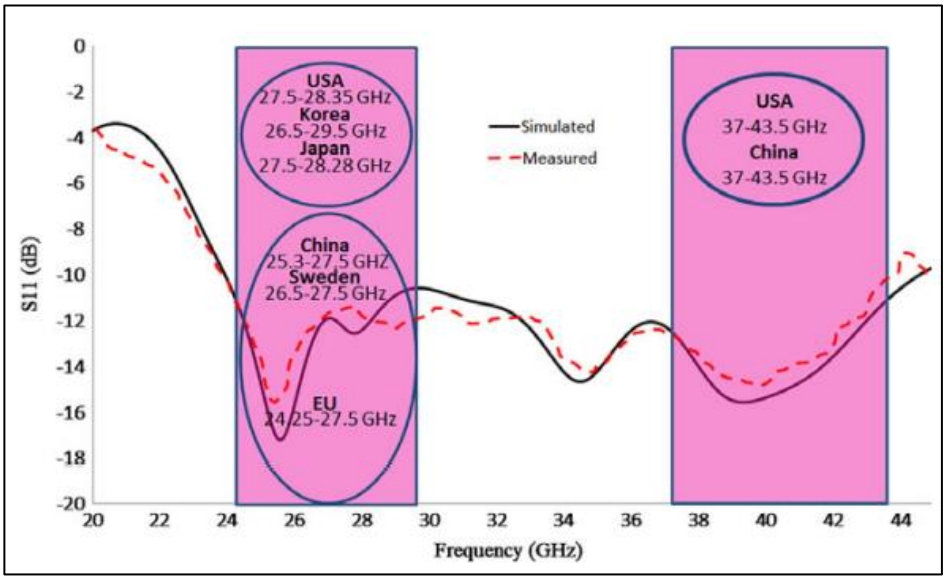


Figure 2.28: Simulated (solid) and measured (dashed) $|S_{11}|$ plot[1]

2.1.12 Design Techniques of Super- Wideband Antenna- Existing and Future Prospective

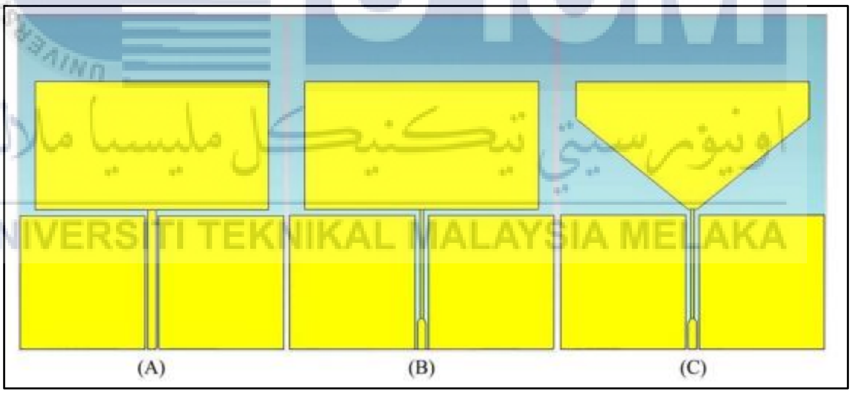


Figure 2.29: Evolution of the Proposed Antenna Structure[12]

Picture above shows that the antenna has been modified from a rectangular patch and standard CPW feedline to the new modified antenna as shown in the figure labelling with (c). In figure 2.33, the graphs of simulated and measured return loss has been presented. The measured result are obtained respected to -10 dB line to make sure at least 90% of non- reflected power.

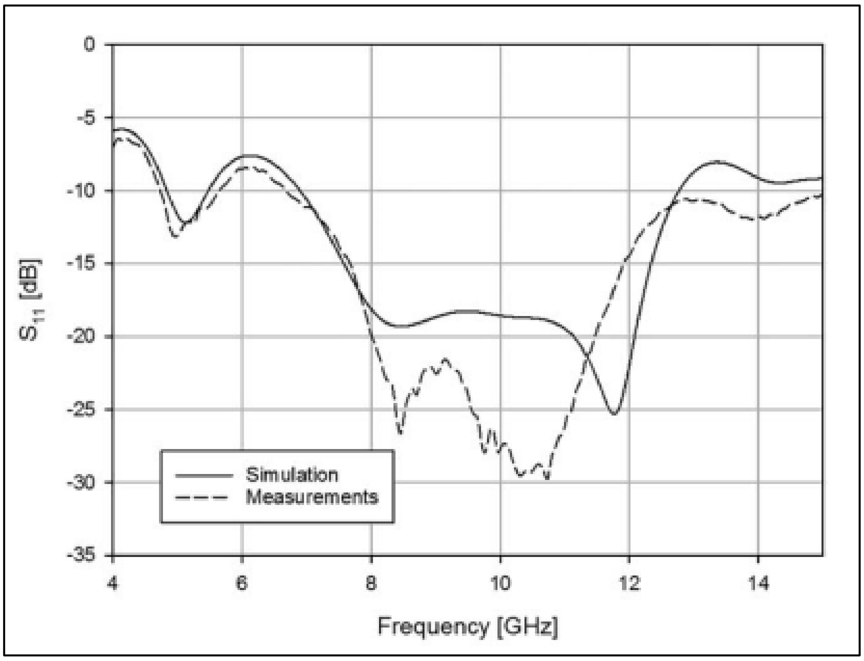


Figure 2.30: Simulated and Measured Return Loss[12]

2.1.13 A High Gain and Wideband Narrow-Beam Antenna for 5G Milimeter-Wave Applications

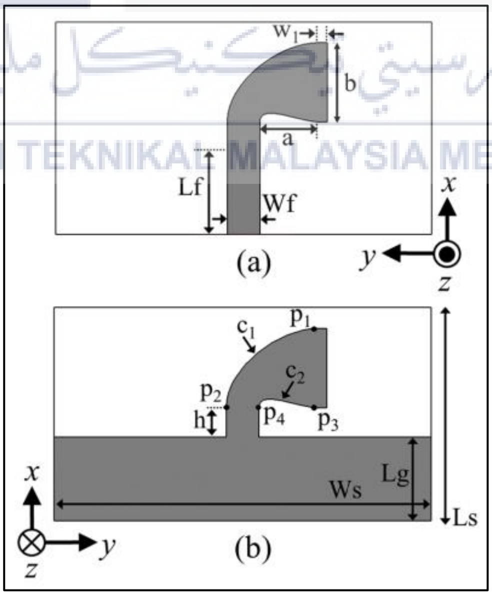


Figure 2.31: Geometry of Single Element Antenna (a) front side (b) back side[13]

From figure 2.35, it shows that the antenna that look like bowtie shape link with a microstrip line. The feedline is connected to the top layer, which is made up of a rectangle with a curved surface. The back side of the antenna, the ground plane was designed partial from the total length of the substrate. In figure 2.36, it shows when 'a' changed, it will effect th reflection coefficient of the antenna.

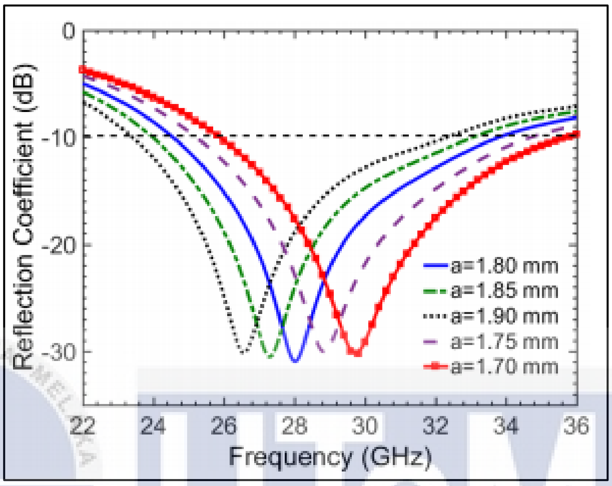


Figure 2.32: Effect of distance 'a' on reflection coefficient of the antenna[13]

2.1.14 A Compact Microstrip-Line-Fed Slot Antenna for Wideband Operation

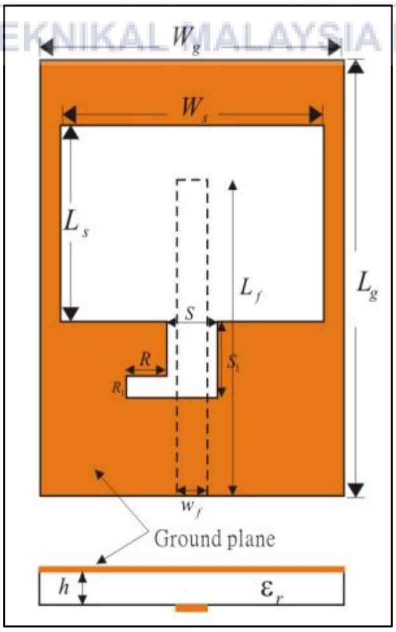


Figure 2.33: The Geometry of the Proposed Antenna[14]

The proposed antenna consist a reverse L- shape combined with a rectangular shape patch. The substrate of the antenna materials used FR4 with thickness 1.6 mm. Low frequency mode can effected by wide rectangular slot while high frequency can be effected by reversed L- shape slot.

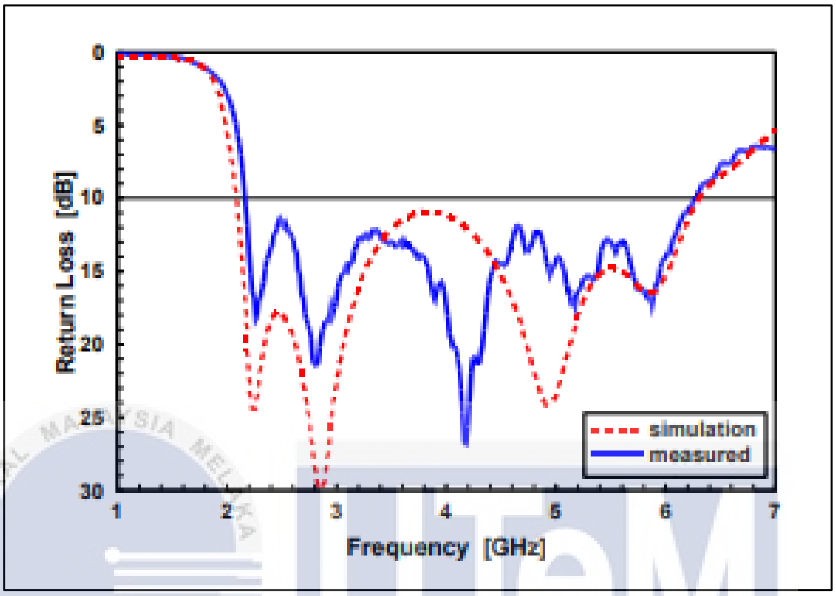


Figure 2.34: Measured and Simulated Return Loss of the Proposed Antenna[14]

By 10 dB return loss, the impedance bandwidth from frequency response within 2.17 GHz to 6.25 GHz is shown in the graph above. In this work, the length of the microstrip line is an important antenna parameter. So, if the line of microstrip changed it can produced lower resonant frequency and greater frequency impedancematching. As result, the suitable parameter of the proposed antenna has been chose due to the ability to achieve good impedance bandwidth and impedance matching.

2.1.15 Design of Wideband Fractal Antenna with Combination of Fractal Geometries

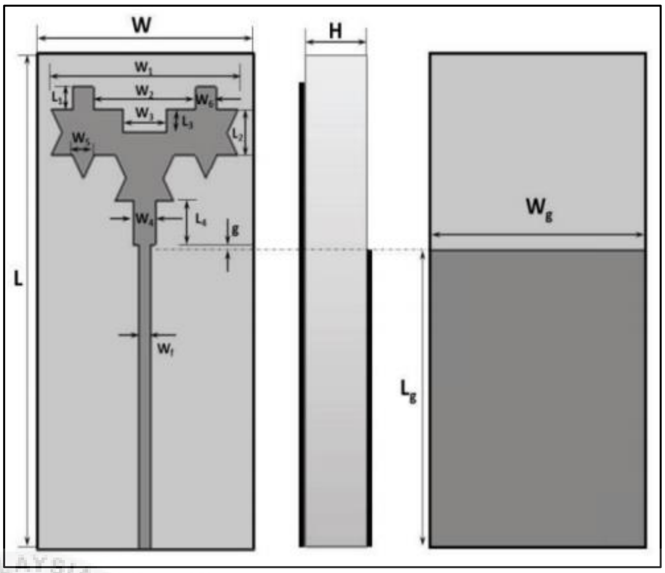


Figure 2.35: The Structure of Proposed Fractal Antenna[15]

The structure of the antenna known as a fractal antenna. It is made up of FR4 for substrate material with thickness 1.6 mm and losstangent 0.02. For the ground plane, it has been designed to cover the feedline with gap 0.5 mm from the patch. Then, the antenna was observed through a smilutaion using CST.

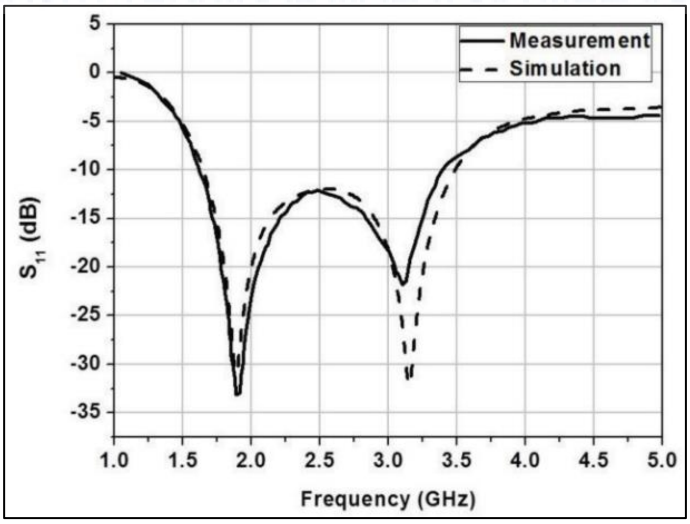


Figure 2.36: Simulated and Measured Return Loss of Proposed Antenna[15]

The curve of return loss was simulated for frequencies 1.6 GHz to 3.5 GHz in figure 2.42, which is beneficial for wideband range and wireless applications. The suggested antenna has a gain of 2.5 dBi to 6 dBi.

2.1.16 A Wideband Cross Monopole Antenna

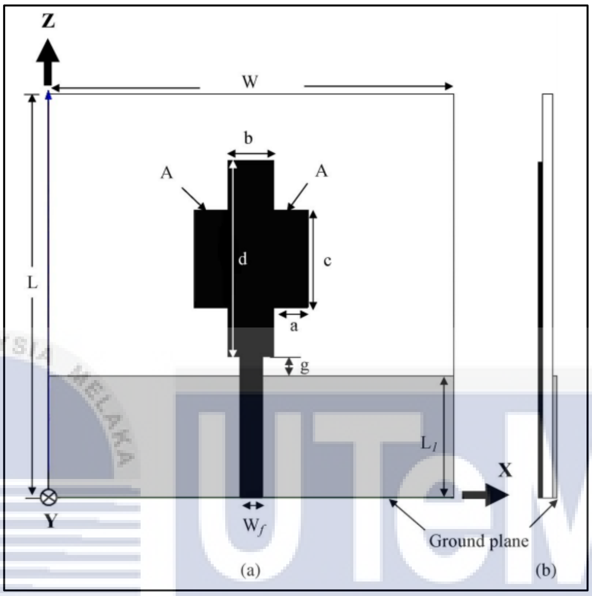


Figure 2.37: Geometry of the Planar Cross Monopole Antenna: (a) top view, (b) side view[16]

The designed has a cross-shaped planar monopole linked with 50Ω microstrip feedline and conducting part. The cross-shaped patch involving the vertical microstrip and two rectangular patch. In figure 2.43, it shows the results when using variety parameter of b.

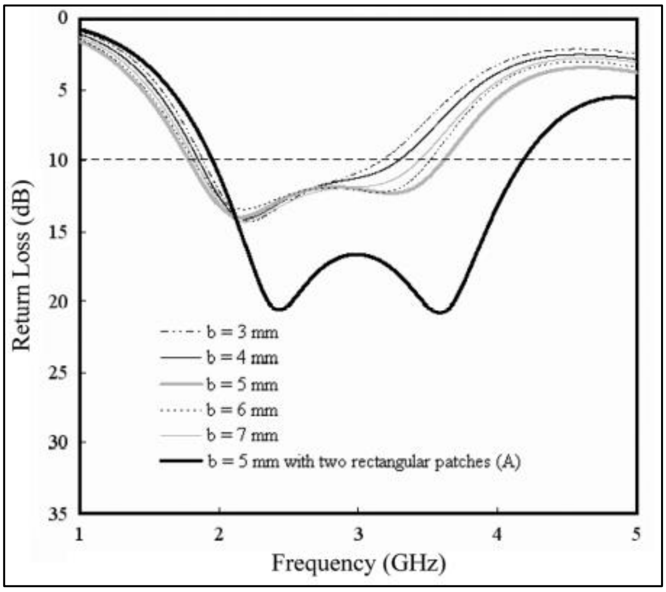


Figure 2.38: Simulated return loss against frequency for the proposed planar cross monopole antenna with various b; W= L= 50 mm, $L_1 = 15\ mm$, a= 9 mm, c= 12 mm, d= 24 mm, g= 1 mm, $W_f = 3\ mm$ [16]

2.1.17 A Small Wideband Microstrip-fed Monopole Antenna

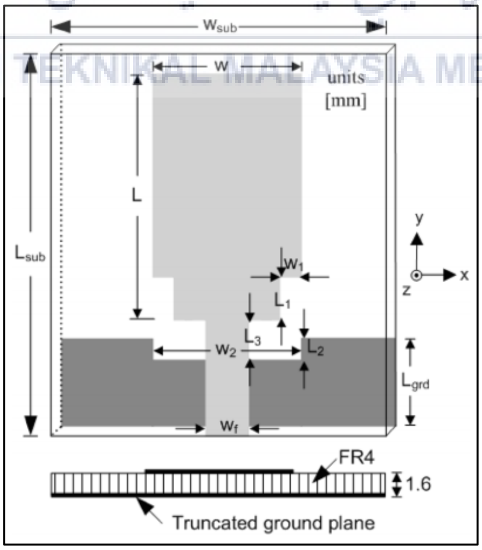


Figure 2.39: **Configuration of the Proposed Microstrip-fed Monopole Antenna[17]**

(Jihak Jung, Wooyoung Choi, Jaehoon Choi) were proposed to design antenna with a simple configuration and implemented in the proposed antenna. By using parametric analysis, the sizes of the notches at the two bottom corners of the patch and the notch on the truncated ground plane were developed based on the result. The return loss results for the comparison based on changes on L_1 has presented below.

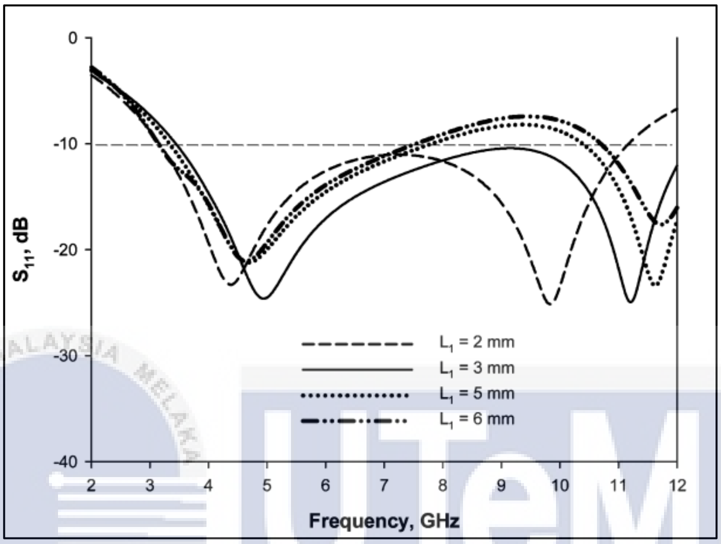


Figure 2.40: **Simulated Return Loss for Various L_1 at the Two Lower Corners of the Proposed Antenna. (W_1 is fixed at 1 mm)[17]**

From the figure 2.47, it shows when notch length L_1 is modified it would affects the impedance bandwith. With a reduction in the upper frequency, the impedance bandwidth increases to higher than 4 GHz when the notch widths are adjusted from 1 mm x 6 mm to 1mm x 2mm.

2.1.18 Design of a Printed Quarter-Elleptical Wide-band Antenna for Portable Devices

The proposed antenna has been designed and simulated at frequency from 1.9 GHz- 3.0 GHz. The antenna was designed as the following parameters; W = 60mm and L = 50mm, a= 17mm, b= 12mm with thickness of substrate 0.8mm and extending to 2mm above the elliptical element. Then, the results of simulation and measured return loss has been recorded and provided as in the figure 2.50.

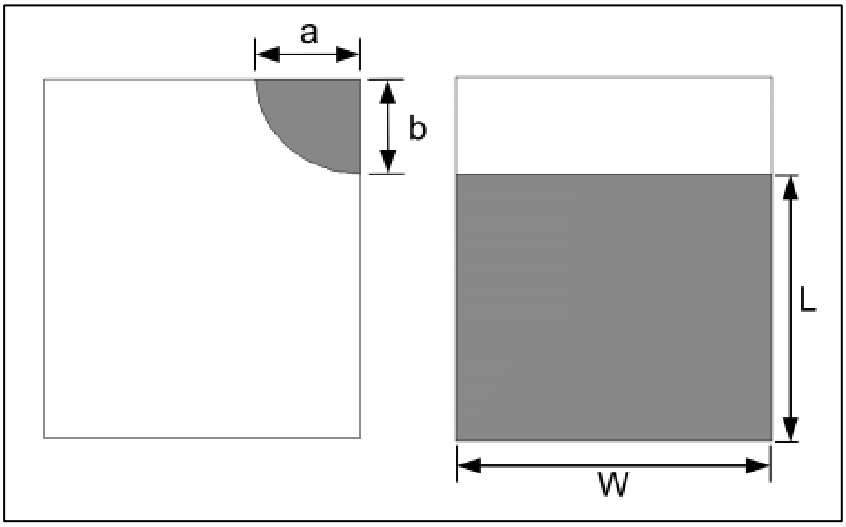


Figure 2.41: Quarter- Ellipse Design (Front, Back)[18]

Based on the observation in the figure below, it shows the return loss of compact quarter- ellipse antenna design. The results of measured and simulation of the antenna shows that the graph are matched with each other and does not has big different.

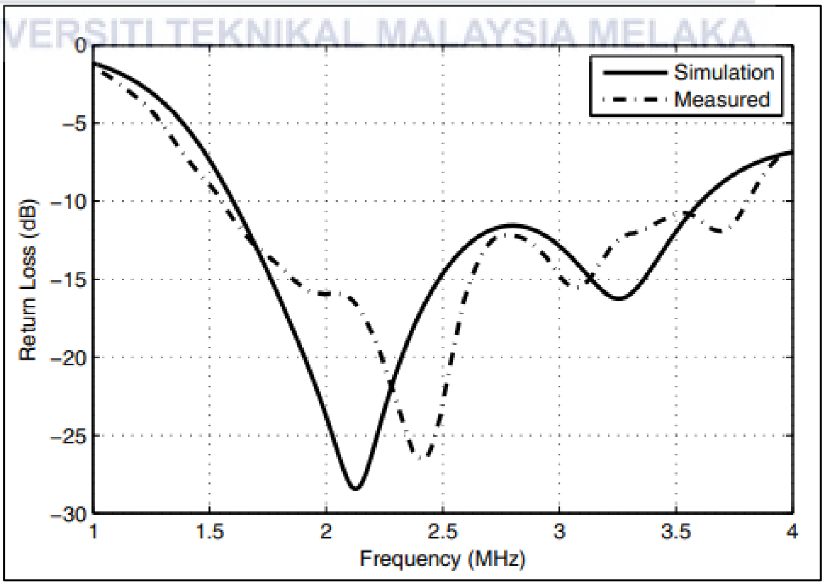


Figure 2.42: Return Loss of Compact Quarter- Ellipse Design[18]

2.1.19 Dual- band Circular Patch Antenna for Wideband Application

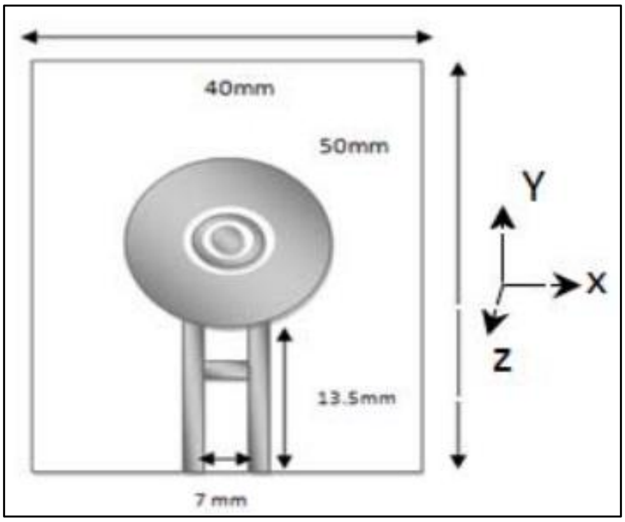


Figure 2.43: Geometry of the Proposed Antenna (Front View)[19]

This article proposed of a dual band circular patch antenna. In the picture above, it shows the structure of antenna consists of ring slot at the middle of circular patch linked with double feedline. Figure 2.54 shows a comparison of the proposed antenna's simulated and measured return loss. The graph shows the antenna has a gain of 5.6 dB at 5 GHz and it's 7.7 dB at 9 GHz.

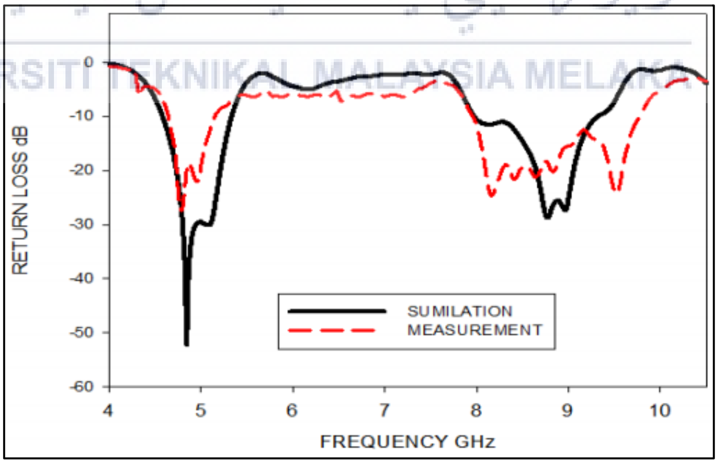


Figure 2.44: Measured and Simulated Return Loss of the Proposed Antenna[19]

2.1.20 A Compact Wideband Monopole Antenna using Single Open Loop Resonator for Wireless Communication Application

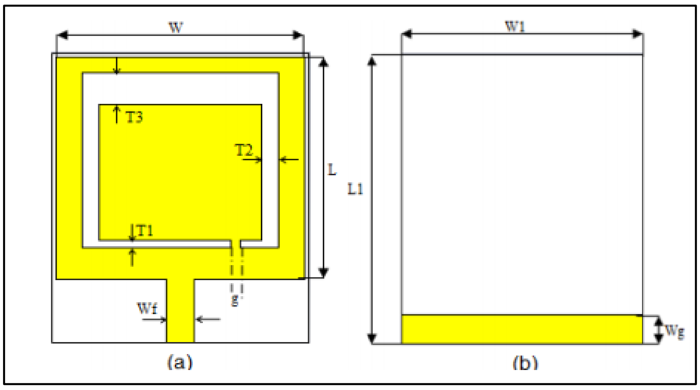


Figure 2.45: **Geometry of the Proposed Antenna (a) Top View and, (b) Bottom View[20]**

A rectangular patch antenna was designed with an open loop resonator as shown in figure 2.56. The ground plane was designed a partial from a total length of the substrate. The materials used in this design is FR4. In figure 2.57, the graph shows a wide impedance bandwidth under -10 dB level at frequency 2.0174 GHz- 3.7903 GHz.

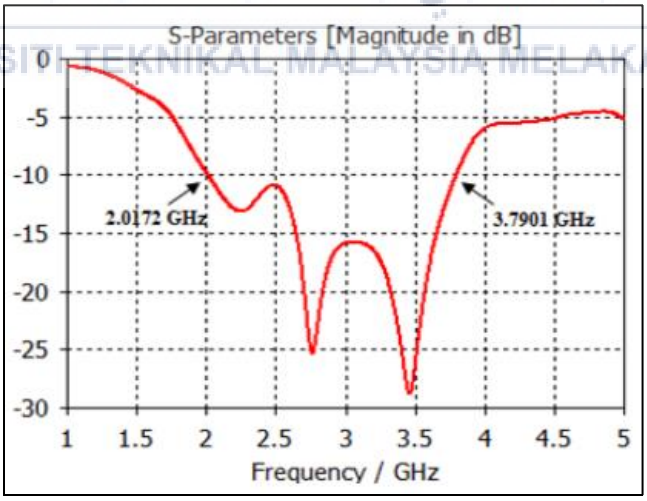


Figure 2.46: **Simulated S_{11} Parameter of the Proposed Antenna[20]**

CHAPTER 3

METHODOLOGY

Chapter 3 concerning content regarding the methods and approaches of project to be completed. Methodology is steps to developed by researchers to complete their work of defining, detailing, explaining, predicting phenomena and the management of the project. The idea gained for the project were based on the previous research. In addition, this project required the theoretical concept and experimental approach during the antenna development process.

3.1 Introduction

Flowchart is the most important thing to do because it can give overall overview of the project; how to start, what material is needed and what solution need to be taken to achieve the objective of this project. By referring flowchart as in figure

3.1, to complete this proposed project. First step needs to do is doing some analysis on literature review from an websites, journals, internets and books to collect some information regarding this project. All the required information is collected and observed from previous research to developed flow of project smoothly.

CST Studio Suite Software 2019 is used to design and gained simulation results of the antenna performance. This software will run a simulation of all the requiring parameters that are important characteristics of antenna such as return loss, gain and radiation pattern. After that, if antenna meets with all specifications, the designed antenna will fabricate on Rogers RT5880 with its specific permittivity. The design is measured to get the result and compare it with simulation result on CST.

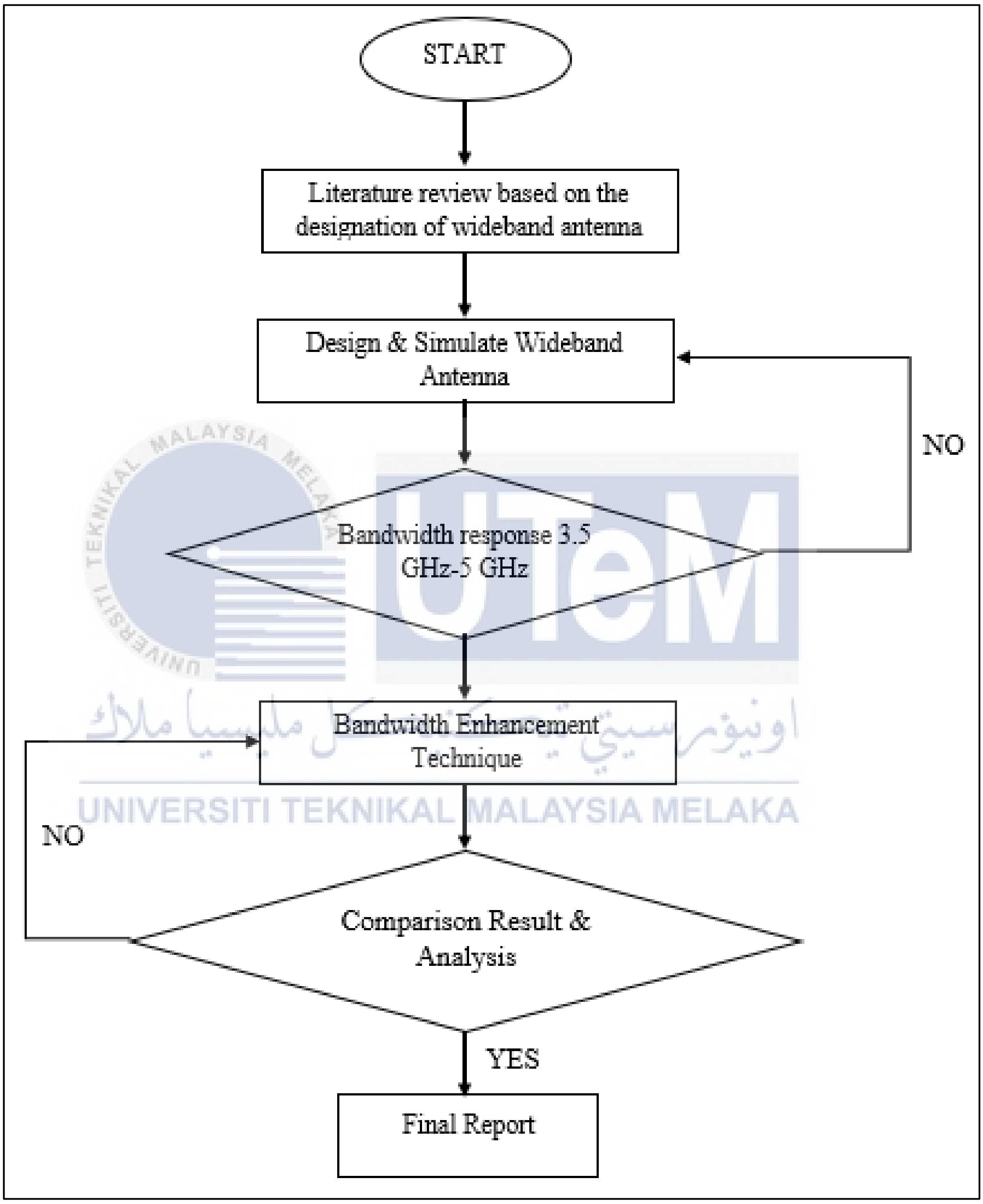


Figure 3.1: Flowchart of the Project

3.2 Research Progress

There are 3 stages in research progress which is for stage 1 is doing a background research on related project of previous project. Follow with stage 2 is to design an antenna using CST for designing review. Last stage is analyzing and optimize the results at operating frequency within 3.5 GHz- 5GHz.

3.2.1 Stage 1: Literature Review

For this stage, start with background research to get more understanding on this project. Collect some information such as the methods to design the antenna, value of parameter such as gain, directivity, s-parameters, impedance, bandwidth, radiation pattern and VSWR. Aim for this literature review to find a suitable parameter to design a wideband antenna with the return loss below -10dB. The title that involved in this literature review mostly related to wideband antenna design as stated in the proposal of an antenna.

3.2.2 Stage 2: Design Review

After discovering all the specifications that suitable with antenna, it will be simulated in CST Software and modify it to a suitable parameter. In order, to get a precises results, the simulation results must undergoing try and error process. Then, make a comparison between the results to get the best antenna.

3.2.3 Stage 3: Analysis of Simulation Result

Final step of designing the antenna is to compare the various of results of designed antenna. The results will be observed and choose a better parameter within a few designing that has been try and error. Analysis has been made to find a better antenna that suits with the objective that have been set up.

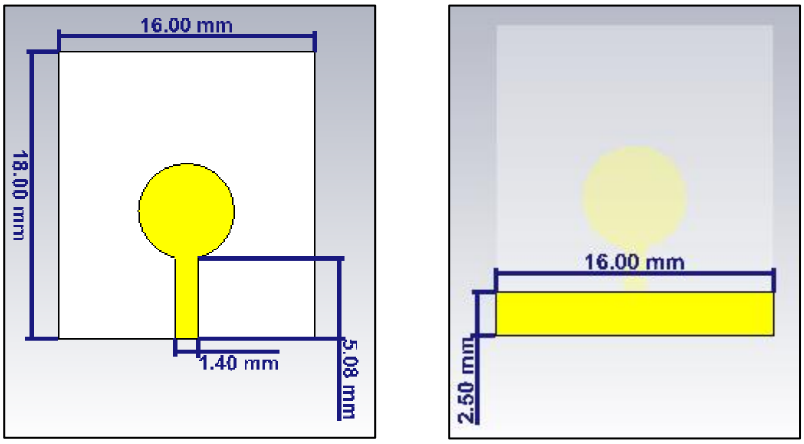
3.3 Antenna Parameter

The proposed antenna should follow antenna parameter which is impedance, bandwidth, directivity and gain, radiation pattern, s-parameters and VSWR. Important to plan the structure of an antenna using variety parameter in order to compare the result of simulation. The variety of antenna has been considered during the design process such as substrate width, substrate length, ground plane width, ground plane length and also the size of the patch itself.

3.4 Designation of Wideband Antenna for Sub 6 GHz Range for 5G Application

Proposed antenna designed based on the study through a few research articles regarding wideband antenna for sub 6 GHz. The substrate of the antenna was made up of Rogers RT5880, while the conducting part of the antenna materials used copper along with the patch. The thickness for substrate as refers in the datasheet was 0.254 mm with dielectric constant 2.20, while for circular patch and conducting part for antenna used the standard of the thickness which is 0.035 mm.

3.4.1 Design of Circular Patch Antenna



(A) (B)

Figure 3.2: Structure of Circular Antenna:

(A) Front View; (B) Back View

Table 3.1: Dimensions Parameter of Circular Patch Antenna

Dimensions	Explanation	Size(mm)
wf	Width of Feedline	1.4
R	Radius of Circle	3
ws	Width of Substrate	16
wg	Width of Ground Plane	16
ls	Length of Substrate	18
lg	Length of Ground	2.5
lf	Length of Feedline	3.07

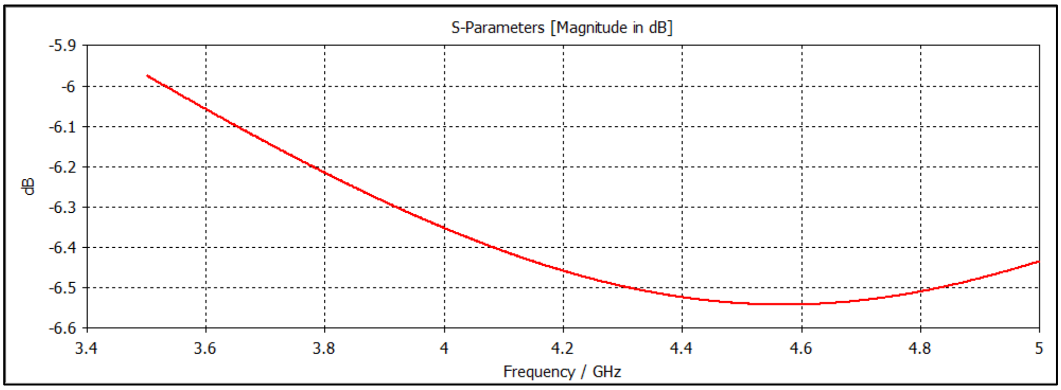


Figure 3.3: S_{11} Parameters of Circular Patch Antenna

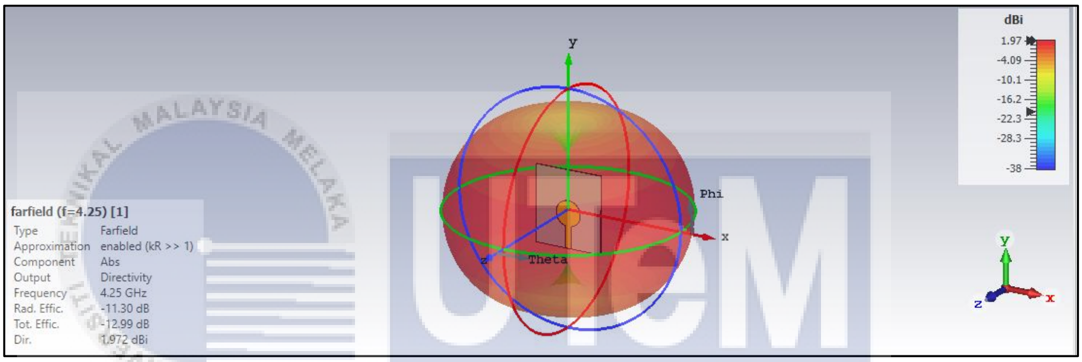


Figure 3.4: Radiation Pattern at Frequency 4.25 GHz, phi=90°

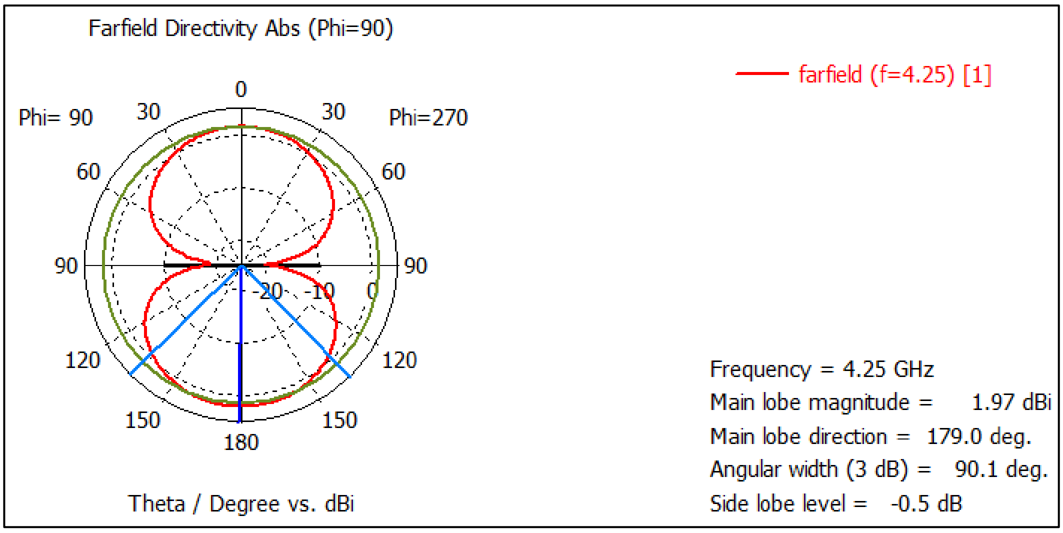


Figure 3.5: Polar View of antenna at phi=90°

3.4.2 Design of Wideband Antenna (DESIGN 1)

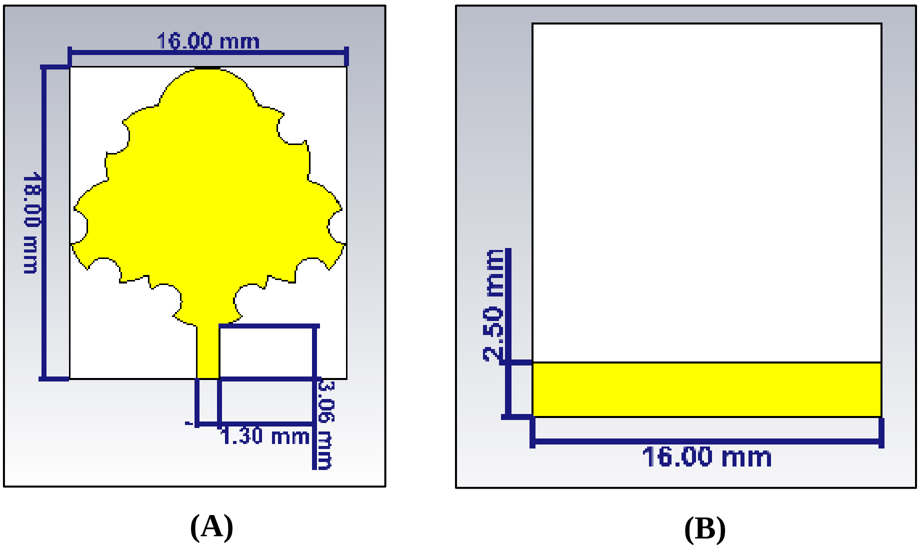


Figure 3.6: Structure of Antenna: (A) Front View; (B) Back View

Table 3.2: Dimensions Parameter of Antenna (Design 1)

Dimensions	Explanation	Size(mm)
R2	Radius of small Circle	1
wf	Width of Feedline	1.3
R	Radius of Circle	3
ws	Width of Substrate	16
wg	Width of Ground Plane	16
ls	Length of Substrate	18
lg	Length of Ground	2.5
lf	Length of Feedline	3.07

3.4.3 Design of Wideband Antenna (DESIGN 2)

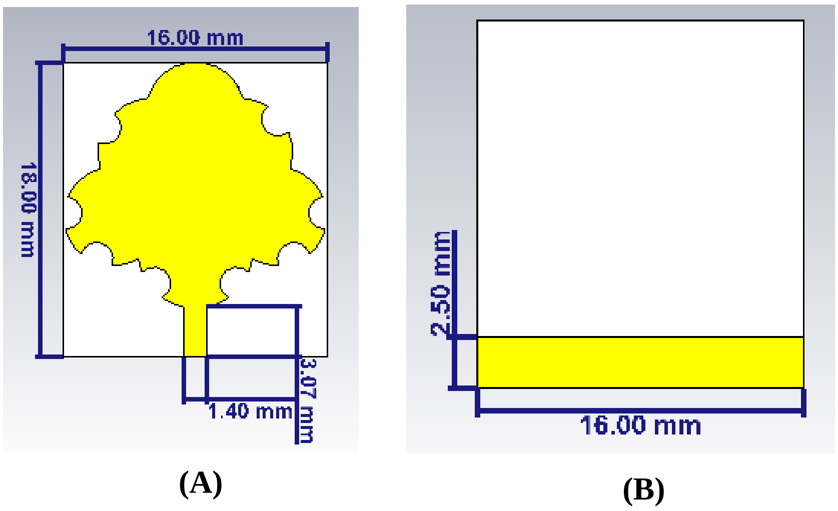
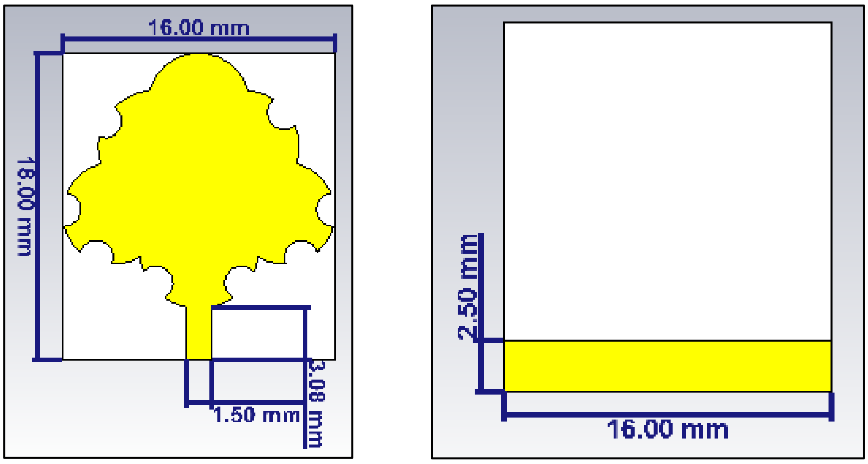


Figure 3.7: Structure of Antenna: (A) Front View; (B) Back View

Table 3.3: Dimensions Parameter of Antenna (Design 2)

Dimensions	**Explanation**	**Size(mm)**
R2	Radius of small Circle	1
wf	Width of Feedline	1.4
R	Radius of Circle	3
ws	Width of Substrate	16
wg	Width of Ground Plane	16
ls	Length of Substrate	18
lg	Length of Ground	2.5
lf	Length of Feedline	3.07

3.4.4 Design of Wideband Antenna (DESIGN 3)



(A) (B)

Figure 3.8: Structure of Antenna: (A) Front View; (B) Back View

Table 3.4: Dimensions Parameter of Antenna (Design 3)

Dimensions	**Explanation**	**Size(mm)**
R2	Radius of small Circle	1
wf	Width of Feedline	1.5
R	Radius of Circle	3
ws	Width of Substrate	16
wg	Width of Ground Plane	16
ls	Length of Substrate	18
lg	Length of Ground	2.5
lf	Length of Feedline	3.07

CHAPTER 4

RESULTS AND DISCUSSION

Chapter 4 concerning the results based on observation through designation of the wideband antenna. The results of the simulation of the project are recorded and presented in this chapter 4.

4.1 Introduction

This chapter point out regarding analysis that has been done on the structure of an antenna by using CST application. Parameter of the antenna focusing on a return loss. The antenna is designed using a basic circle with radius 3 and 1. The outcome of the combination of circle become a structure antenna. The study of antenna results based on the variety size of the antenna such as substrate, patch or conducting part.

The designation aim is to get a return loss which name as a S_{11} parameter range within 3.5 GHz- 5 GHz below -10dB.

4.2 Design for Wideband Antenna for Sub 6 GHz Range for 5G Application

The idea of the structure antenna come out after some research has been done regarding the antenna with wideband characteristic with a various type of antenna parameter has been designed to obtain a desired result. There are 3 designs of the antenna with comparison regarding size of width of feedline. It shows a slightly different of results due to its various size.

4.2.1 Design 1 of Proposed Antenna

For design 1, width of the feedline set to 1.3 mm and the result for the simulation has been obtained. The specifics parameter of the antenna can be refer in table 3.2.

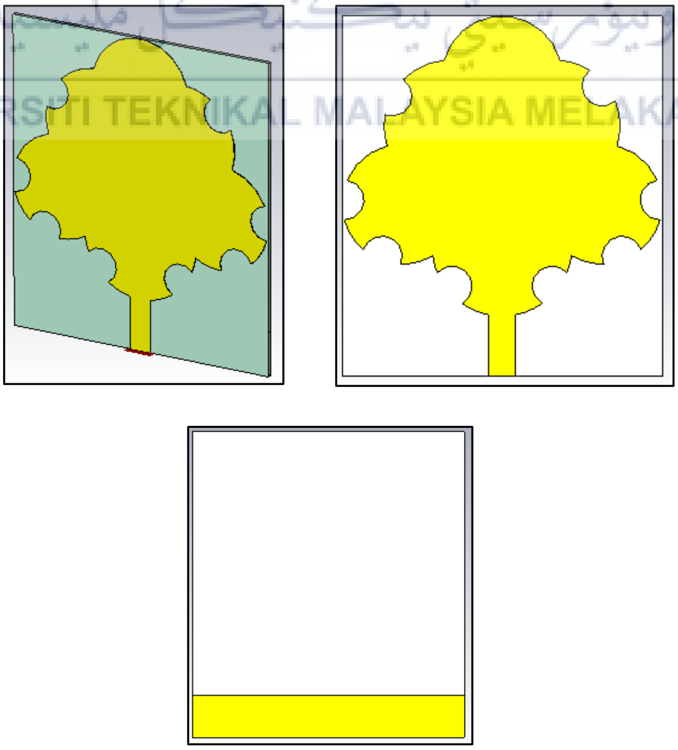


Figure 4.1: Structure of Antenna Design 1

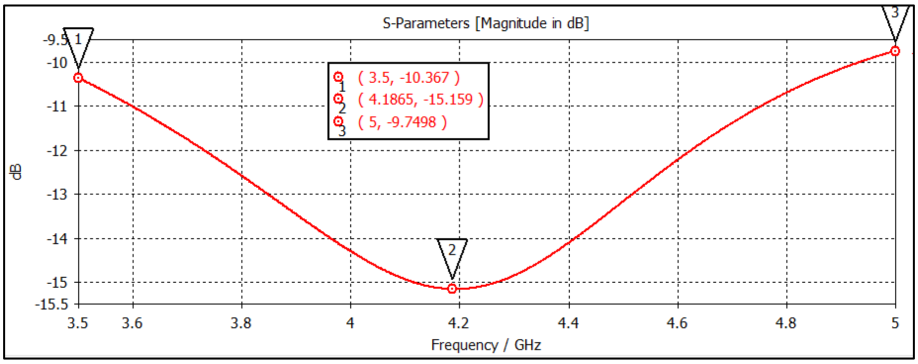


Figure 4.2: S- Parameters of Antenna Design 1

From figure 4.2, it is the result of simulation structure of antenna design within frequency range 3.5 GHz- 5GHz. At resonant frequency 3.5 GHz with return loss -10.367 dB, 3.8 GHz with return loss -12.589 dB, 4 GHz with return loss -14.335 dB, 4.2 GHz with return loss -15.158 dB, 4.4 GHz with return loss -14.065 dB, 4.6 GHz with return loss -12.179 dB, 4.8 GHz with return loss -10.693 dB and at 5 GHz with return loss -9.750 dB.

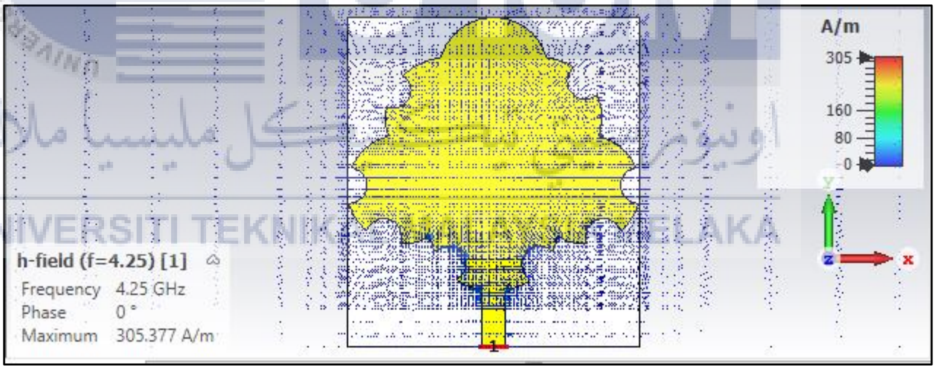


Figure 4.3: H- field of the Antenna Design 1

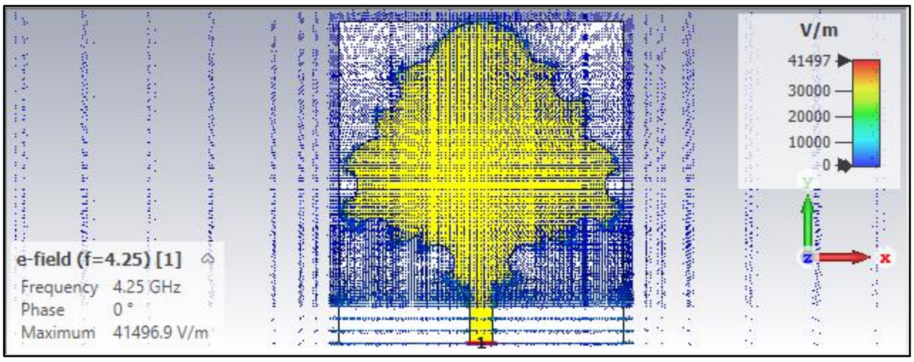


Figure 4.4: E- field of the Antenna Design 1

4.2.2 Design 2 of the Proposed Antenna

For design 2, width of the feedline set to 1.4 mm and the result for the simulation has been obtained. The specifics parameter of the antenna can be refer in table 3.3.

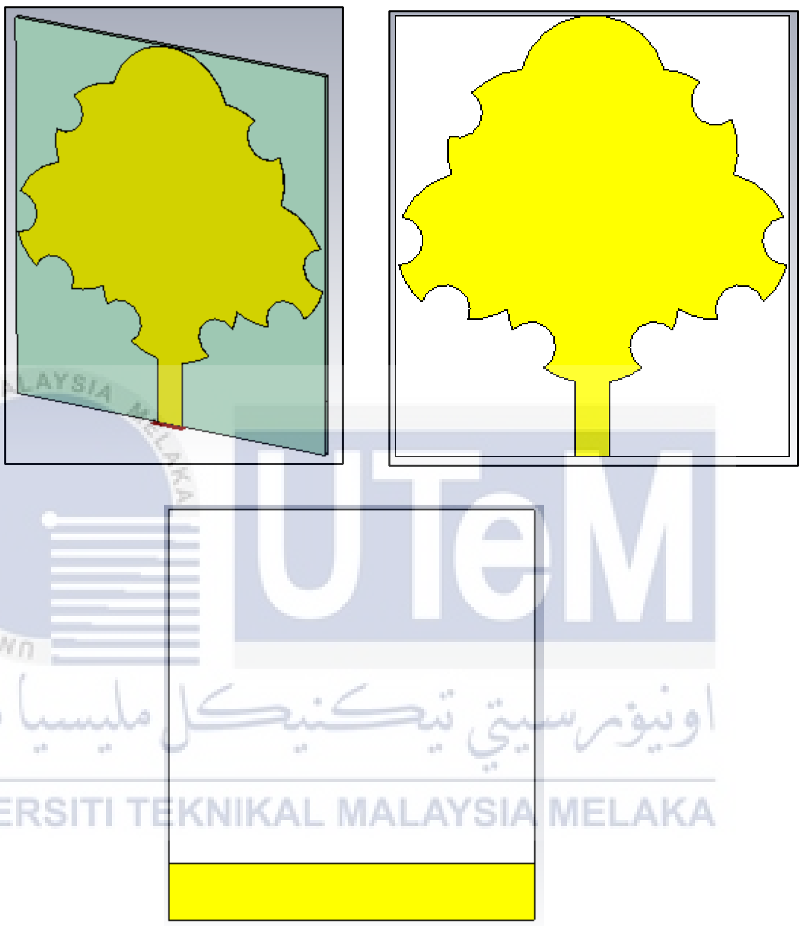


Figure 4.5: Structure of Antenna Design 2

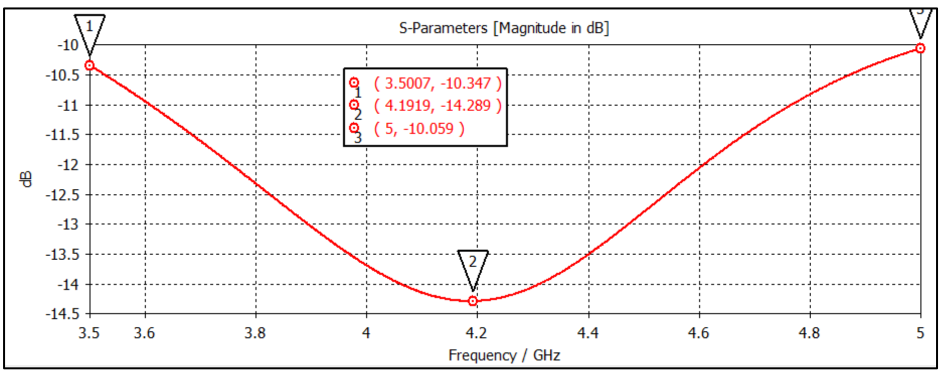


Figure 4.6: S-Parameters of the Antenna Design 2

The S- parameters graph has been plotted and recorded as shown in the figure 4.6. From the observation, its indicate that all the return loss plotted below -10 dB which is at frequency response 3.5 GHz with return loss -10.343 dB, 3.8 GHz with return loss -12.323 dB, 4 GHz with return loss -13.691, 4.2 GHz with return loss -14.284 dB, 4.4 GHz with return loss -13.475 dB, 4.6 GHz with return loss -12.026 dB, 4.8 GHz with return loss -10.805 dB and lastly at frequency response 5 GHz with return loss -10.059 dB.

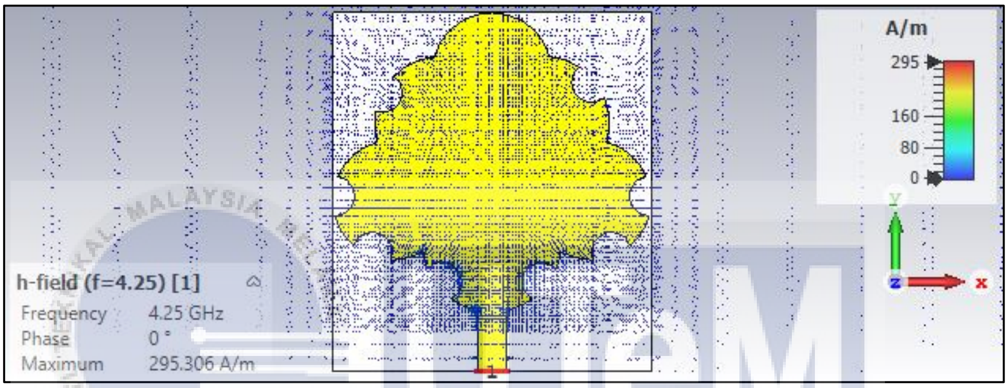


Figure 4.7: H- field of Antenna Design 2

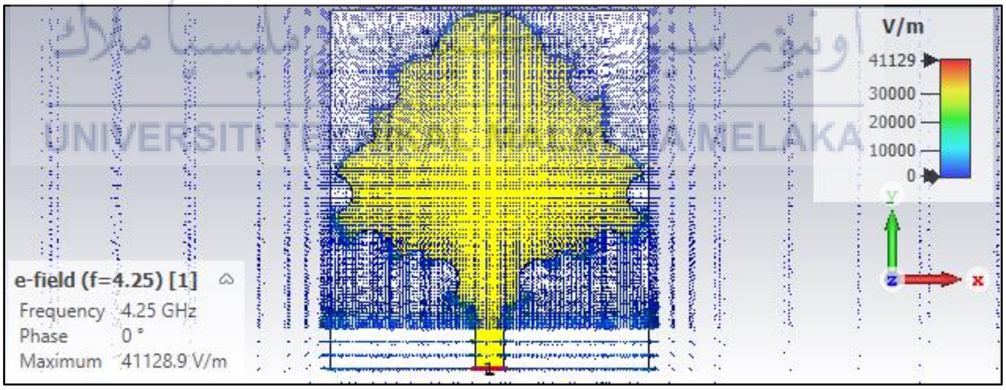


Figure 4.8: E- field of Antenna Design 2

4.2.3 Design 3

For design 3, width of the feedline set to 1.5 mm and the result for the simulation has been obtained. The specifics parameter of the antenna can be refer in table 3.4.

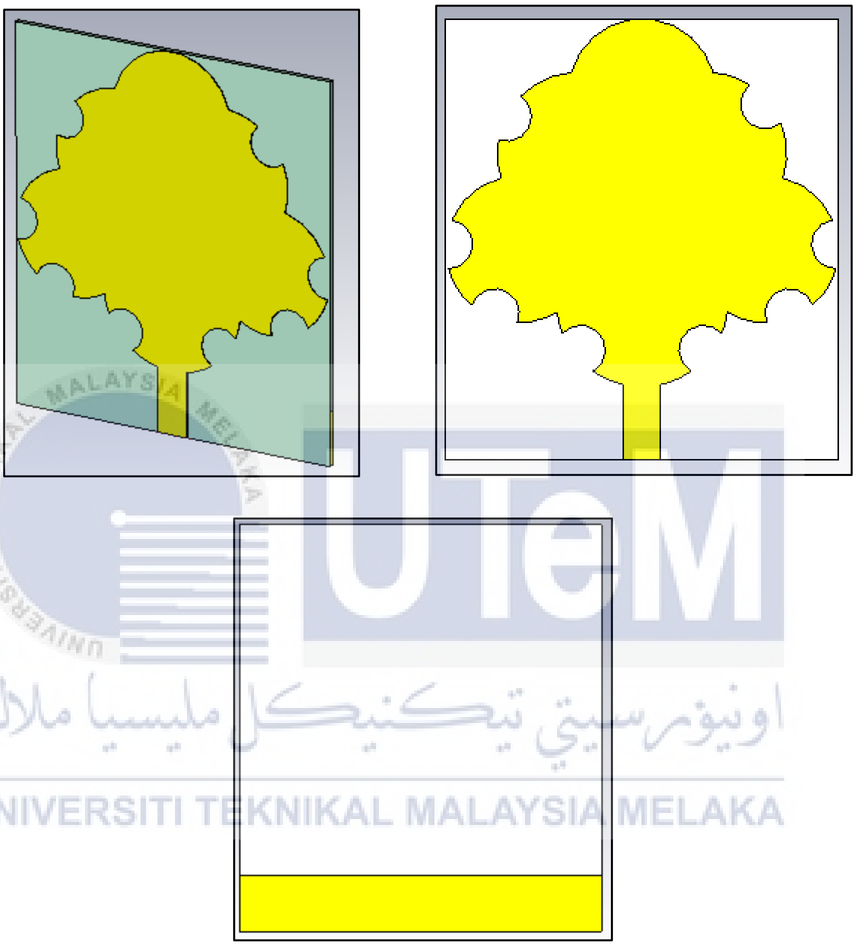


Figure 4.9: Structure of Antenna Design 3

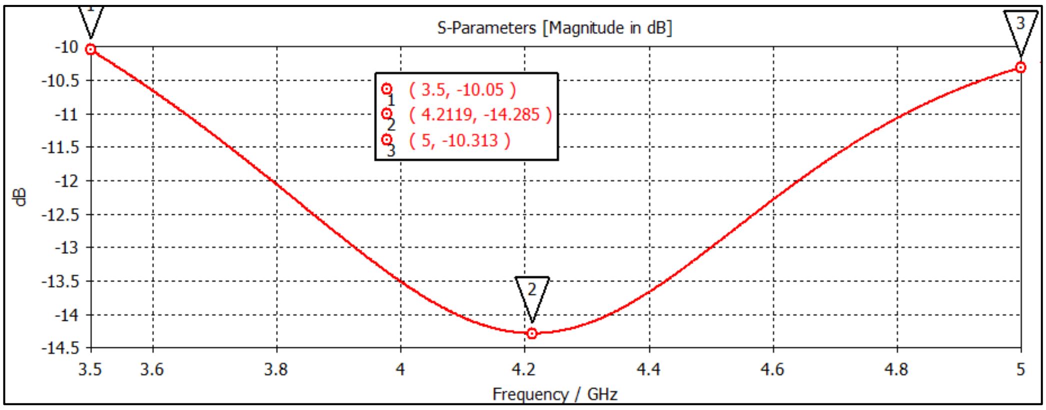


Figure 4.10: S- Parameters of Antenna Design 3

Based on the simulation on design 3 of antenna, the minimum point of the s-parameters is -14.285 dB at frequency response 4.2 GHz and the maximum point for the return loss is -10.050 dB at 3.5 GHz. Then, at resonant frequency 3.8 GHz with return loss -12.063 dB, 4 GHz with return loss -13.565 dB, 4.4 GHz with return loss -13.639 dB, 4.6 GHz with return loss -12.252 dB, 4.8 GHz with return loss -11.024 dB and lastly, 5 GHz with return loss -10.313 dB.

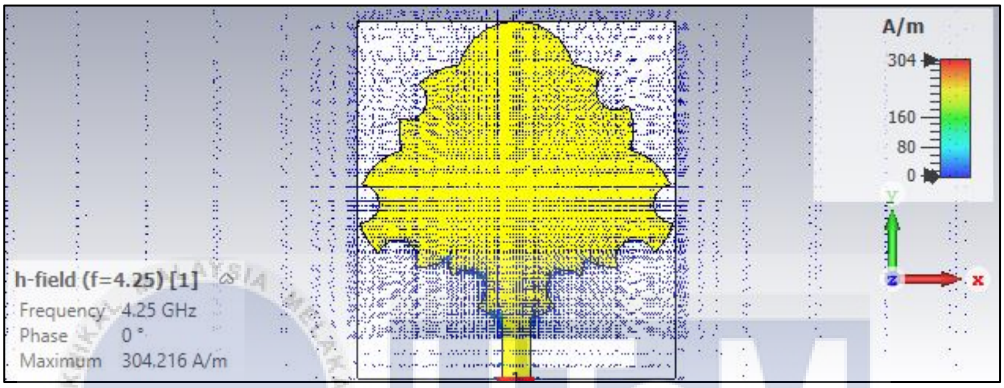


Figure 4.11: H- field of Antenna Design 3

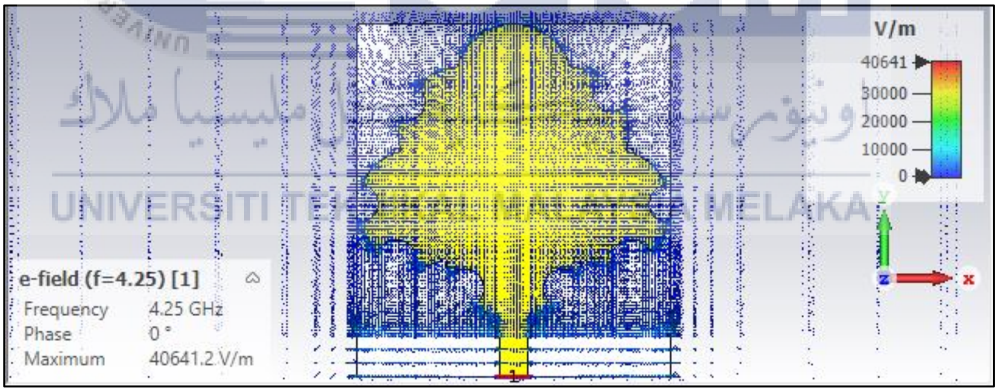


Figure 4.12: E- field of Antenna Design 3

4.2.4 Comparison of S_{11} Parameters Simulation

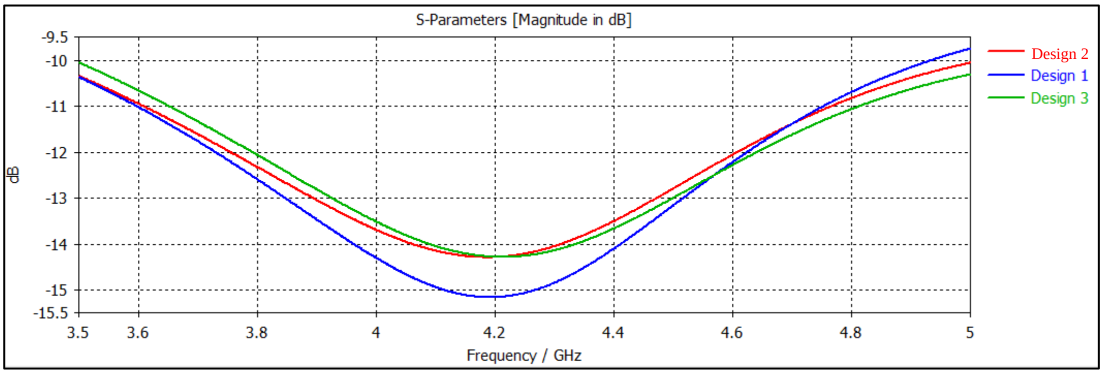


Figure 4.13: Comparison of S_{11} Parameters based on the Size Width of Feedline

Based on the figure above, the graph of simulated return loss curves shows the result after simulation had been done with the size width of feedline has been changed to 1.3 mm, 1.4 mm and 1.5 mm. In addition, when size width of feedline changed, the length of the feedline also changed. From the graph, it shows that the red line indicates for size width of feedline= 1.4 which is design 2. At frequency response 3.5 GHz with return loss -10.347 dB, at frequency response 4.1865 GHz with return loss -14.289 dB which is the minimum point and the highest point for this return loss with value -10.059 dB at resonant frequency 5 GHz. While the green line shows the graph when the size width of the feedline is equal to 1.3 mm which is design 1; with return loss -10.367 dB at frequency response 3.5 GHz, 4.1919 GHz with return loss -15.159 dB at lowest point and the maximum point reached -9.7498 dB at frequency response 5 GHz. Last but not least, the blue line shows the result of simulation for the feedline width size is 1.5 mm which is design 3. At highest point it shows the value of return loss indicate -10.05 dB at resonant frequency 3.5 GHz, follow by at resonant frequency 4.2119 GHz with return loss -14.285 dB and lastly, at 5 GHz with return loss -10.313 dB.

4.2.5 Simulation of Gain

The difference between the power transmitted by an antenna in one direction and the power sent by an isotropic antenna in the same direction is referred to as antenna gain. This specification specifies the maximum signal strength that an antenna may emit or receive in a given direction. Antenna Gain is a more essential criteria than directivity since it considers all losses. As seen in the table above, the gain that obtained in the simulation result is -0.9288 dBi for the size width of the feedline 1.3 mm, -0.9762 dBi the value of gain when the size of feedline width is 1.4 mm and -1.059 dBi for 1.5 mm width of the feedline.

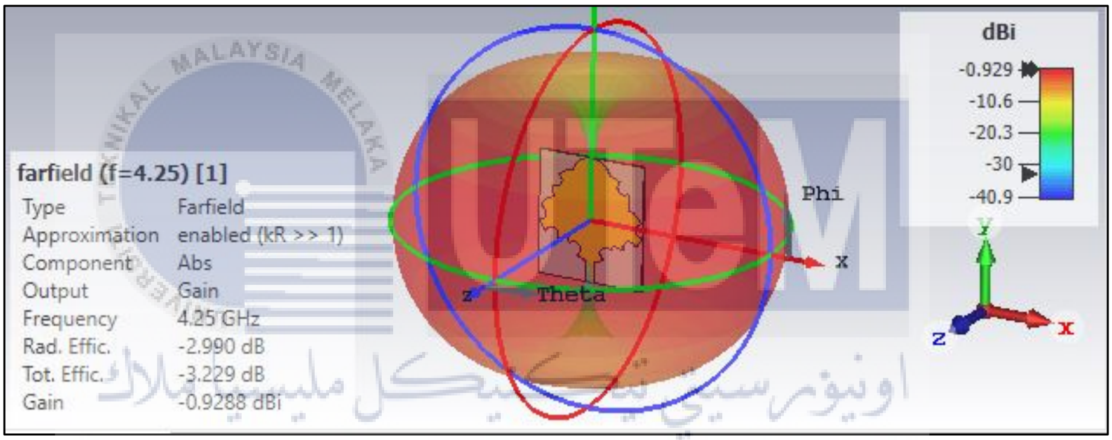


Figure 4.14: Farfield of Gain at 4.25 GHz for Design 1

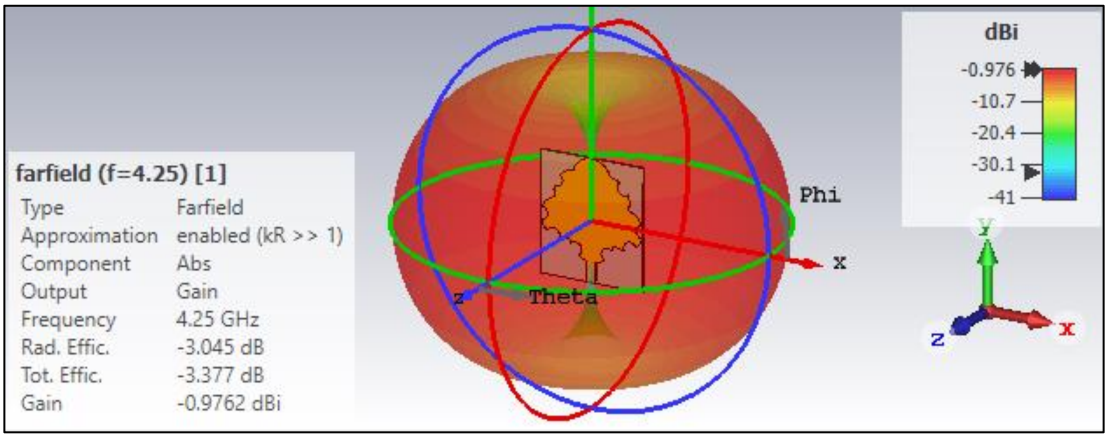


Figure 4.15: Farfield of Gain at 4.25 GHz for Design 2

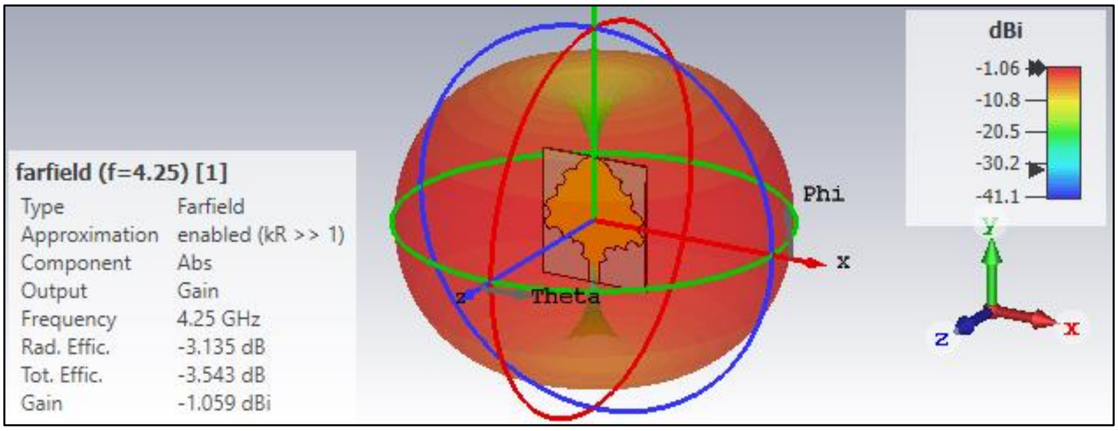


Figure 4.16: Farfield of Gain at 4.25 GHz for Design 3

4.2.6 Simulation of Directivity

Directivity is a metric that measures in the certain direction of the concentration of an antenna's radiation pattern. The term "directivity" is used in (dB). The more directed the beam emitted by an antenna is, the higher the directivity. The beam will travel further if the directivity is higher. Higher directivity is not necessarily desirable for a certain application such as mobile devices. It is required an omni-directional antennas which is need a low or no directivity. As for design 1, the result of the simulation for the directivity is 2.061 dBi. Then, for design 2 it shows the directivity result equal to 2.069 dBi. Lastly, the directivity for design 3 which is size of width=1.5 mm with the directivity 2.075 dBi.

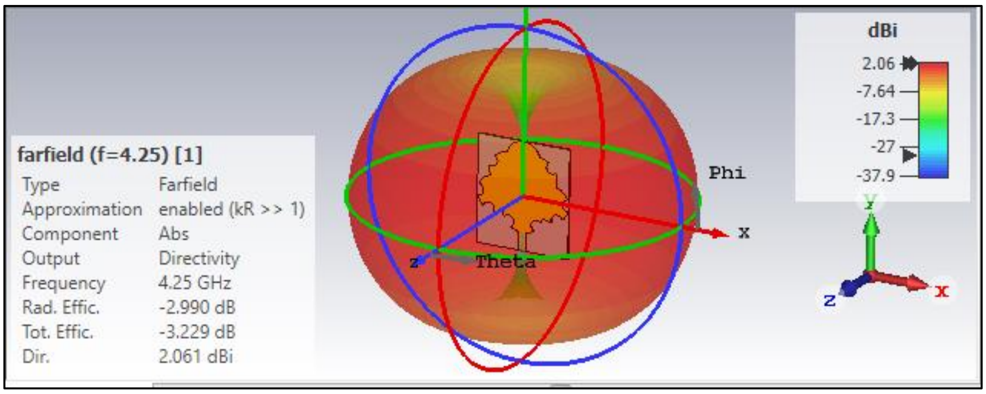


Figure 4.17: Farfield of Directivity at 4.25 GHz for Design 1

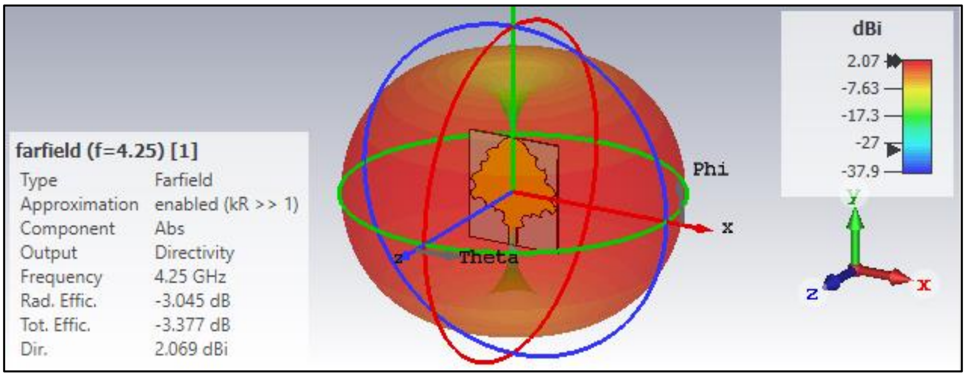


Figure 4.18: Farfield of Directivity at 4.25 GHz for Design 2

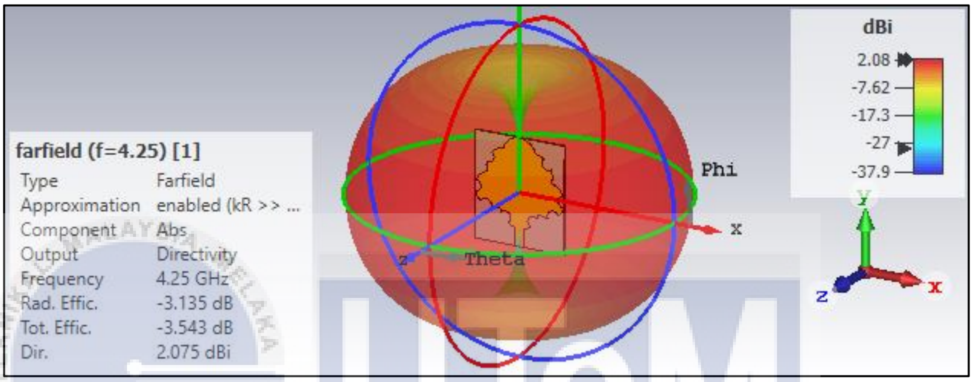


Figure 4.19: Farfield of Directivity at 4.25 GHz for Design 3

4.2.7 Simulation of Antenna Surface Current

For surface current of the antenna, if the structure of antenna was zoom out in CST software, it clearly showed that the flow of current through the patch of the antenna. Especially at the curve area of the antenna, a lot of the radiation come out of the structure. As refer in the figure below, when the different size of the curve is designed, the frequency that produced would be different depends on the curve. Due to that reason, the antenna known as wideband antenna. Based on the study from the simulation results, it can be seen the surface current decrease when the width size of the feedline is increase. As shows in the figure below named as figure 4.2, figure 4.3 and figure 4.4 which is 205.644 A/m for the width of feedline 1.3 mm, 195.829 A/m for the feedline size 1.4 mm and 185.281 A/m for the size width of feedline 1.5mm.

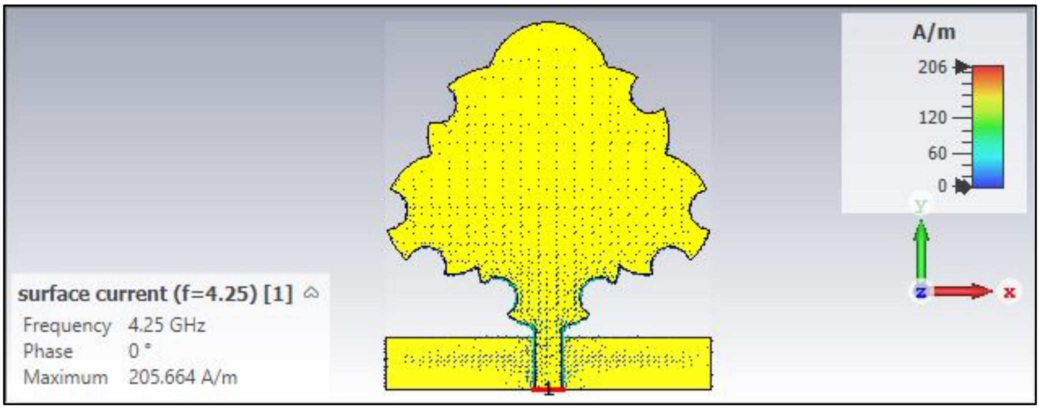


Figure 4.20: Surface Current of Design 1

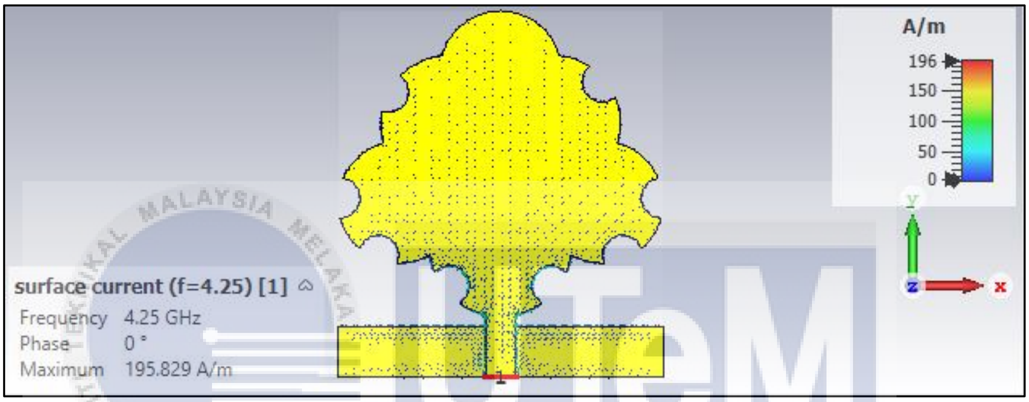


Figure 4.21: Surface Current of Design 2

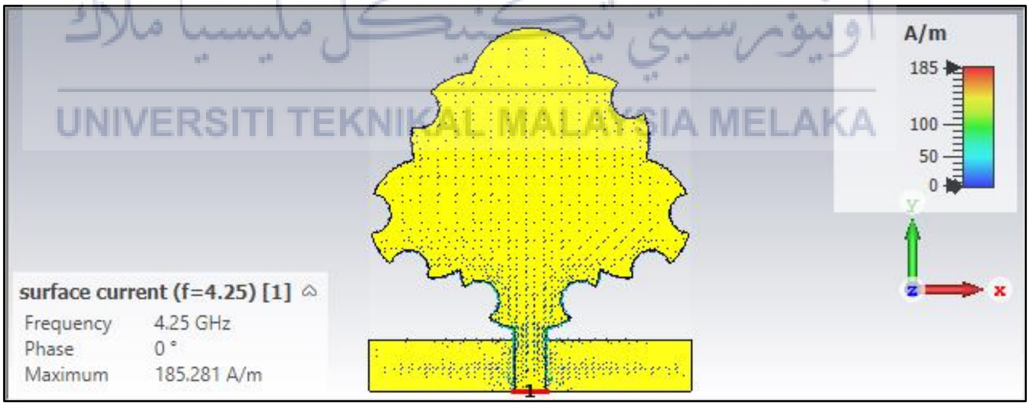


Figure 4.22: Surface Current of Design 3

4.2.8 Radiation Pattern of Antenna

The variety of power radiated by an antenna defined as a radiation pattern. The antenna 's far field is observed by power variation as a function of the arrival angle. From the figure of radiation pattern below, it shows that the directivity of the antenna is same either from front or back of the antenna which it means the signal transmit through front or back antenna is same. The results regarding radiation pattern of the antenna has been obtained during the simulation process and provided below.

4.2.8.1 Design 1:

In the figure 4.11, at frequency response 4.25 GHz the main lobe magnitude is 2.06 dBi at the direction 178.0°. Refer in the figure 4.12, it shows the main lobe magnitude for gain farfield is -0.926 dBi 178.0°. For e- field radiation pattern farfield, it shows the main lobe magnitude at 4.25 GHz is 13.6 dB (V/m) at 178.0°. For farfield H-field, at phi=90 for frequency 4.25 GHz the main lobe magnitude is -37.9 dB(A/m) at direction 178.0°.

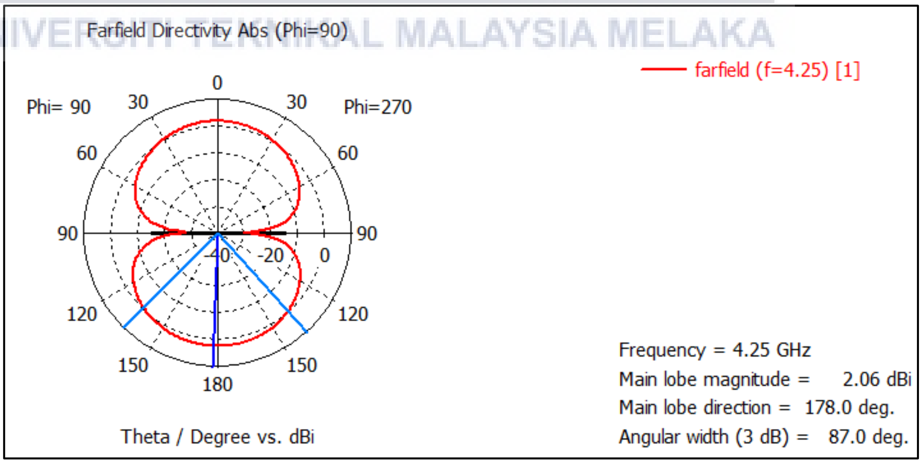


Figure 4.23: Radiation Pattern of Antenna (Directivity)

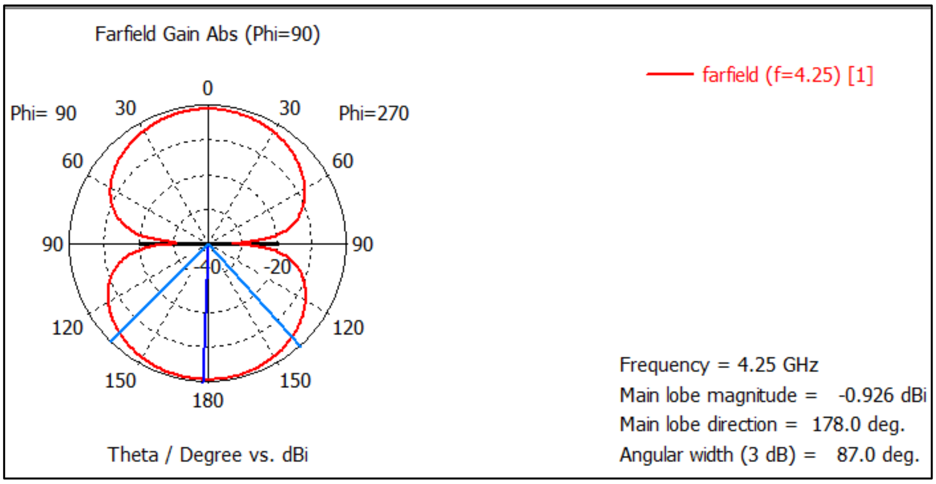


Figure 4.24: Radiation Pattern of Antenna (Gain)

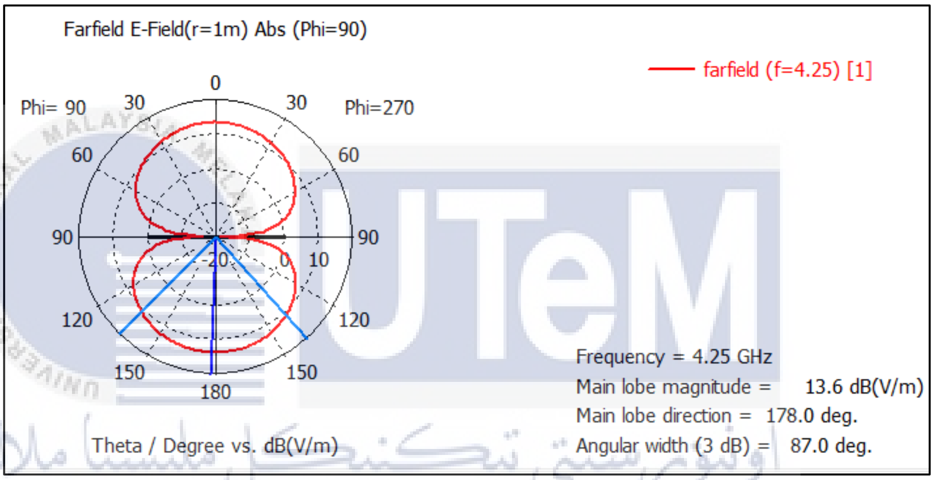


Figure 4.25: Radiation Pattern of Antenna (E-Field)

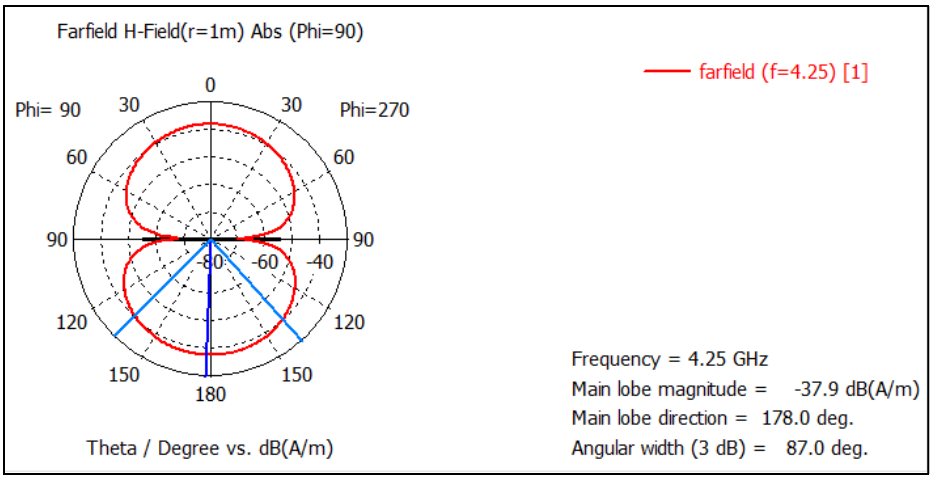


Figure 4.26: Radiation Pattern of Antenna (H-Field)

4.2.8.2 Design 2

For design 2, at resonant frequency 4.25 GHz in the farfield directivity at phi=90° the main lobe magnitude equal to 2.07 dBi in direction 178.0° at angular width (3 dB) is 87°. As shown in the figure 4.16, the main lobe magnitude of gain is -0.974 dBi at direction 178°. For figure 4.17, the radiation pattern indicate that the main lobe magnitude for e- field is 13.5 dB (V/m) at direction 178°. Lastly for h-field, at direction 178° the main lobe magnitude equal to -38.1 dB (A/m).

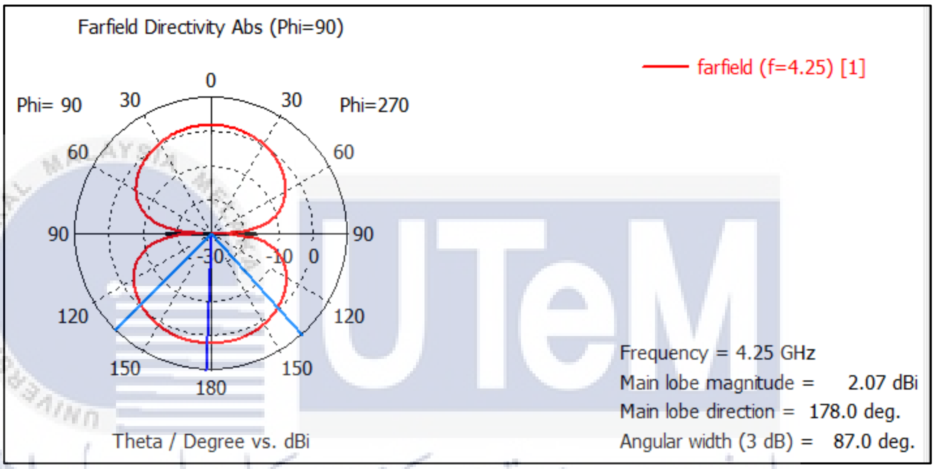


Figure 4.27: Radiation Pattern of Antenna (Directivity)

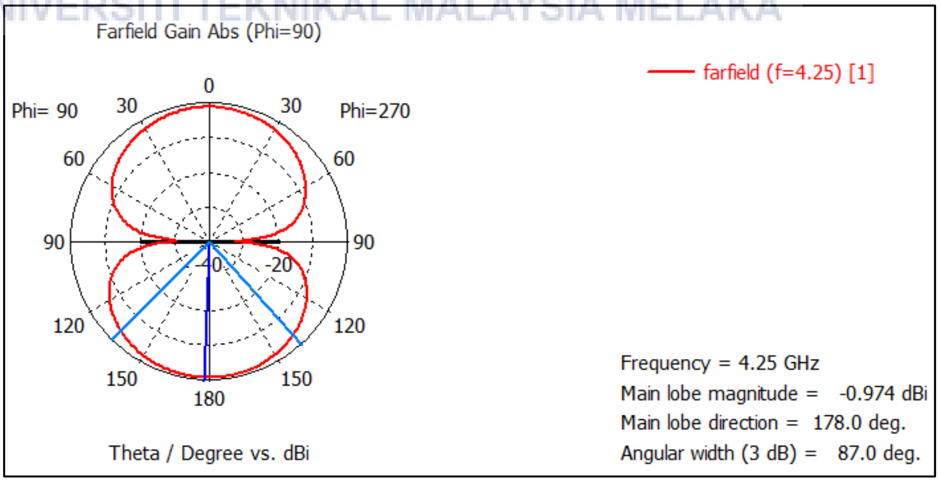


Figure 4.28: Radiation Pattern of Antenna (Gain)

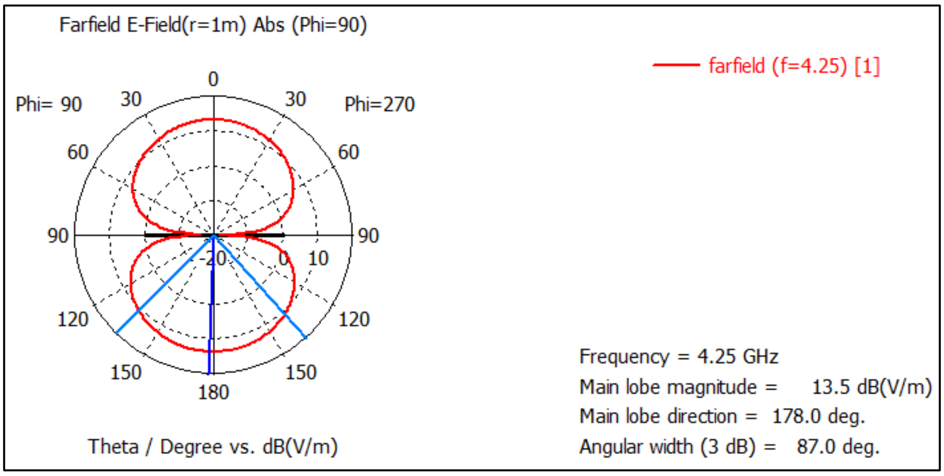


Figure 4.29: Radiation Pattern of Antenna (E-Field)

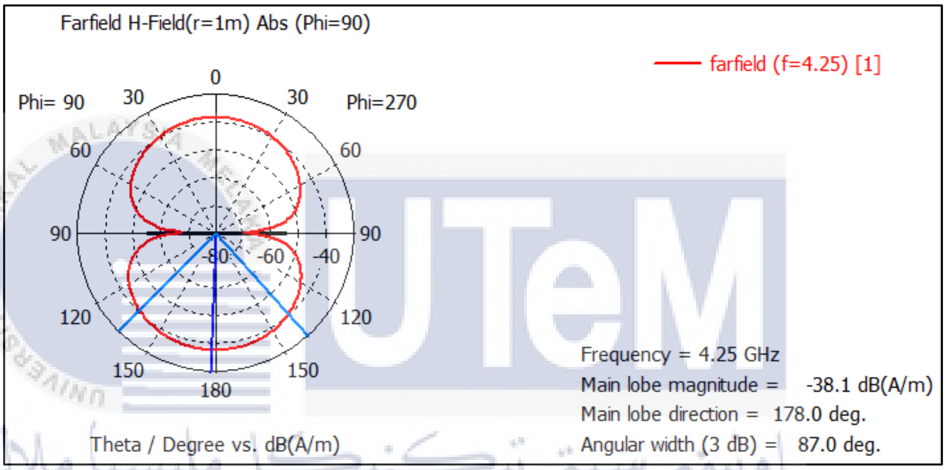


Figure 4.30: Radiation Pattern of Antenna (H-Field)

4.2.8.3 Design 3

Lastly, for design 3, at frequency 4.25 GHz; the main lobe magnitude for directivity equal to 2.08 dBi in direction 178.0° at angular width (3 dB) 87.1°. For gain radiation pattern at 4.25 GHz, at direction 178° and -1.06 dBi at the main lobe magnitude. Then, for the e-field radiation pattern the value of the main lobe magnitude is 13.3 dB (V/m). Last but not least, at phi=90° for h-field the main lobe magnitude is -38.2 dB (A/m) at direction 178°.

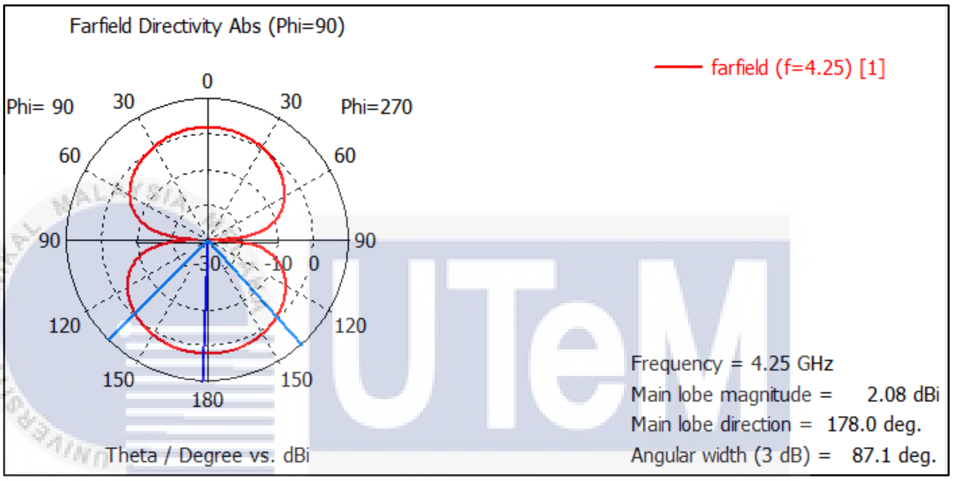


Figure 4.31: Radiation Pattern of Antenna (Directivity)

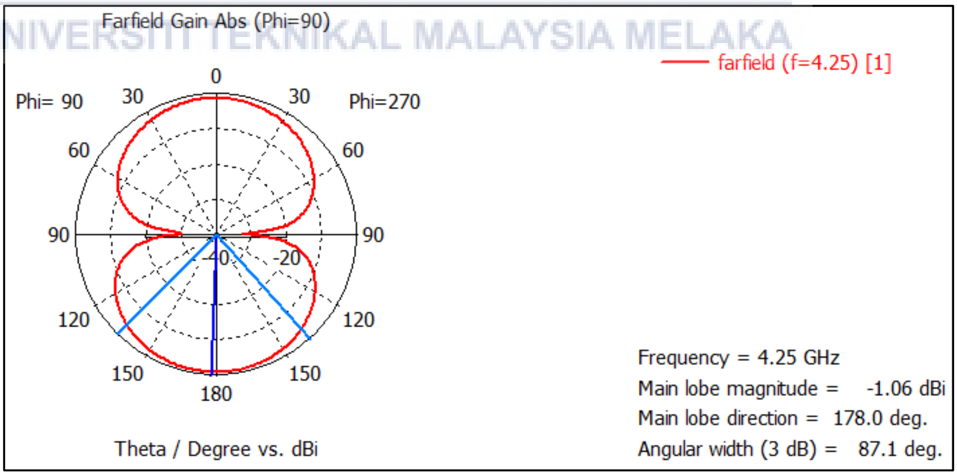


Figure 4.32: Radiation Pattern of Antenna (Gain)

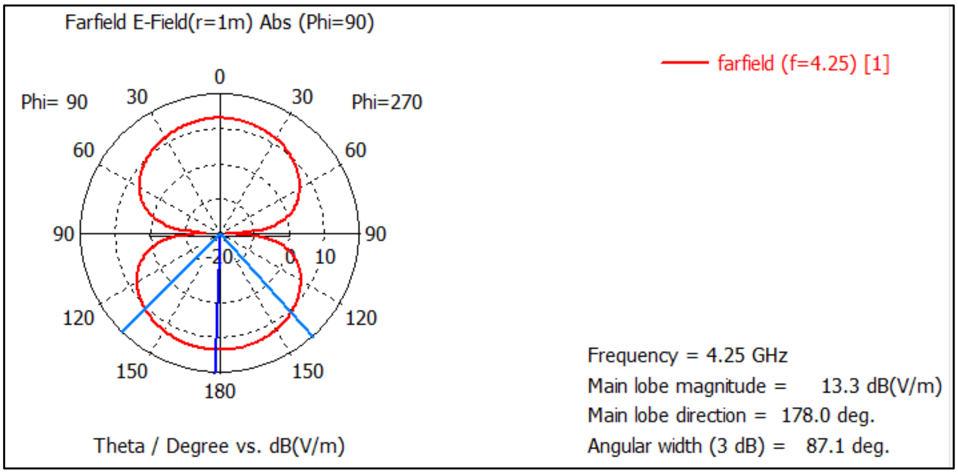


Figure 4.33: Radiation Pattern of Antenna (E-Field)

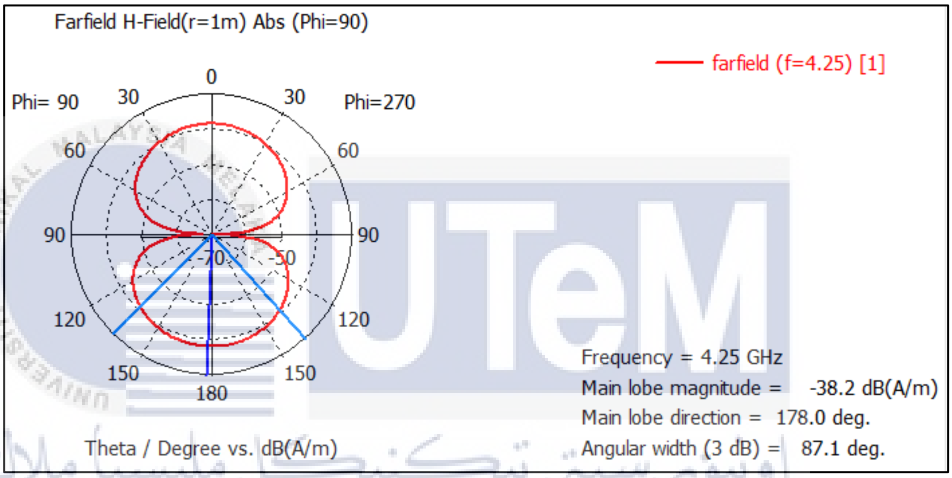


Figure 4.34: Radiation Pattern of Antenna (H-Field)

CHAPTER 5

CONCLUSION AND FUTURE WORKS

In this chapter, it consists of summary and the future work to improvise the project proposed and designed. It is the summarization all of the work that carried out in the previous chapter.

5.1 Conclusion

In this project, the wideband antenna was designed within range frequency of 3.5 GHz- 5GHz. The antenna was designed and simulated in CST Studio Suite 2019 software. The structure of this project was designed based on the previous research on the article as stated in the background research regarding the parameter and the look of the antenna.

5.2 Completed Work

In this project, the monopole antenna is designed with different size of feedline as shown in the previous figure oin chapter 3. As for ground plane part, it was designed with a certain size from a total length of antenna. Based on the observation, the performance for all the design antenna was differentiated. The parameters of the antenna decided based on the research of previous project. By changing parameters of the antenna, it can improve the results of the simulation.

According to the simulated results, the antenna in design 2 is more stable compare with design 1 and design 3. As the design has achieved the objective, it can be proved because all the S_{11} parameters simulation results indicate below -10 dB within frequency 3.5 GHz- 5 GHz which is at frequency 3.5007 GHz with return loss -10.347 dB, 4.1919 GHz with return loss -14.289 dB and 5 GHz with return loss -10.059 dB. Last but not least, due to pandemic covid-19 problem occur in Malaysia during this year, the antenna fabrication cannot be done because most of the University are not allowed to be open for students.

5.3 Recommendation on Future Work

The objective of this project successfully achieved during the process of the designing the antenna which is to obtain a return loss below -10. During the process of the simulation, a variety parameter has been tested by applying try and error concept before obtains a suitable one.

Lastly, this proposed antenna can be modified by using a different material with a different value of thickness and dielectric constant. Because dielectric materials have different effect on the results for return loss of the antenna. Then, run the simulation of wideband antenna using CST Suite. Besides, the designing structure of antenna also can be improved by using different method to ensure the return loss can be improved.

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APPENDICES

PROPERTY	TYPICAL VALUES	
	RT/duroid 5870	RT/duroid 5880
[1]Dielectric Constant, ε_r Process	2.33 2.33 ± 0.02 spec.	2.20 2.20 ± 0.02 spec.
[4]Dielectric Constant, ε_r Design	2.33	2.20

Standard Thickness	Standard Panel Size	Standard Copper Cladding	Non-Standard Copper Cladding
0.005" (0.127mm) 0.031" (0.787mm) 0.010" (0.254mm) 0.062" (1.575mm) 0.015" (0.381mm) 0.125" (3.175mm) 0.020" (0.508mm) Non-standard thicknesses are available	18" X 12" (457 X 305mm) 18" X 24" (457 X 610mm) Non-standard sizes are available up to 18" X 48" (457 X 1219 mm)	½ oz. (18µm) and 1 oz. (35µm) electrodeposited and rolled copper foil	¼ oz. (9 µm) electrodeposited copper foil ½ oz. (18µm), 1 oz. (35µm) and 2 oz. (70µm) reverse treat copper foil 2 oz. (70µm) electrodeposited and rolled copper foil
		Thick metal claddings may be available based on dielectric and plate thickness. Contact customer service for more information on available non-standard and custom thicknesses, claddings and panel sizes	