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DESIGN AND DEVELOPMENT OF SUB-6GHZ PLANAR ANTENNA FOR 5G APPLICATION

This report is submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Electronic Engineering Technology (BEET) with Honours.

by

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TECHNOLOGY

2021

DECLARATION

I hereby, declared this report entitled DESIGN AND DEVELOPMENT OF SUB-6GHZ PLANAR ANTENNA FOR 5G APPLICATION is the results of my own research except as cited in references.

Signature: ……………… ***SIMON*** ………………

Author : SIMON TEO YIP QUAN

Date: 14/02/2021

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APPROVAL

This report is submitted to the Faculty of Mechanical and Manufacturing Engineering Technology of Universiti Teknikal Malaysia Melaka (UTeM) as a partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Automotive) with Honours. The member of the supervisory is as follow:

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Supervisor : DR A.K.M ZAKIR HOSSAIN

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ABSTRAK

Antena patch mikrostrip (MPA) adalah kelas antena rata yang selama empat dekad terakhir telah banyak dinilai dan dikembangkan. Dalam sistem komunikasi tanpa wayar, antenna ini menjadi pilihan pertama bagi pereka antena untuk digunakan di kebanyakan aplikasi. Walau bagaimanapun, sebahagian besar reka bentuk antena planar mikrostrip hanya dapat memberikan lebar jalur yang sempit dalam julat 500MHz. Terdapat juga beberapa reka bentuk antena planar mikrostrip yang rumit untuk mencapai lebar jalur lebar. Projek ini bertujuan untuk merancang dan mensimulasikan antena planar dengan lebar jalur lebar yang dapat digunakan dalam aplikasi 5G sub-6GHz dengan reka bentuk tampalan sederhana. The Rogers 3003 digunakan sebagai substrat dengan tinggi 1.55mm. Antena patch berbentuk-Z dirancang dan mensimulasikan hasilnya pada perisian CST untuk memastikan ia dapat dicadangkan. Lebar jalur lebar diperoleh dalam julat 3GHz hingga 6GHz. Corak radiasi stabil dan dapat digunakan dalam aplikasi 5G.

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ABSTRACT

Microstrip patch antennas (MPA) are a class of flat antennas which in the past four decades have extensively been investigated and evolved. In the wireless communication system, they become the popular choice for those antenna designers to use in most applications. However, most of the design of the microstrip planar antenna can only provide a narrow bandwidth in the range of 500MHz. There also some design of microstrip planar antennas that are complicated to achieve wide bandwidth. This project aims to design and simulate a planar antenna with wide bandwidth that can be used in sub-6GHz 5G application with a simple patch design. The Rogers 3003 is used as the substrate with a high of 1.55mm. A Z-shape patch antenna is designed and simulates the result on the CST software to make sure it can be proposed. The wide bandwidth is obtained in the range of 3GHz to 6GHz. The radiation pattern is stable and can be used in 5G application.

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DEDICATION

This thesis is dedicated to my parents and family member who give me many kinds of support and encouragement during completing this project. I also would like to dedicate my friends and supervisor that always possibly help me when I have trouble with this project

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ACKNOWLEDGEMENTS

I would like to take this opportunity to express my deepest gratitude to all the outstanding people who have provided continuous support, guidance, experience, understanding and commitment to my successful project. In addition, I would like to express my heartfelt thanks to my supervisor, DR A.K.M ZAKIR HOSSAIN for his support, wiling to share his knowledge, suggestions and encouragement for helping me in completing the implementation and documentation of this project. I would like to thank every lecturer who has taught me, especially those who have given me all the knowledge, skills and tips for my research. These knowledge, skills and tips are very important for me to complete this project. In addition, I would like to thank all my friends for providing me with giving suggestions and improvements on my project. I really appreciate their guidance and cooperation. It is blessings and gracious encouragement of my parents, respected elders and my supporting colleagues that make me able to accomplish this project.

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LIST OF SYMBOLS

GHz	Giga Hertz
MHz	Mega Hertz
Mm	Milli-meter
A/m	Current per meter

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LIST OF ABBREVIATIONS

MPA	Microstrip Patch Antenna
GSM	Global System For Mobile Communication
PCB	Printed Circuit Board
5G	Fifth Generation
LTE	Long-Term Evolution
WLAN	Wireless Local Area Network
3D	Three Dimensional
EM	Electromagnetic
ADS	Advanced Design System
RF	Radio Frequency
MMIC	Monolithic microwave integrated circuit
RFID	Radio-frequency identification
EMC	Electromagnetic compatibility
EMI	Electromagnetic interface
MWS	Micro-wave software
PET	Polyethylene

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CHAPTER 1

INTRODUCTION

1.1 Background

Microstrip patch antennas (MPA) are a class of flat antennas which in the past four decades have extensively been investigated and evolved. In the wireless communication system, they become the popular choice for those antenna designers to use in most applications. Microstrip planar antenna was first developed in the early 1950s. However, in the 1970s, the idea was kept on almost 20 years only to be realized after the advancement of the Printed Circuit Board (PCB) technology. The microstrip patch antenna is a low-profile directional antenna. The microstrip patch antenna becomes familiar because it consists of some advantages for example low profile, inexpensive, simple, and can be fabricated easily in the circuit board.

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According to (Balanis, 2005), due to the special characteristic of the antenna, it is popular for specific applications in satellite communications, mobile communication for Global System For Mobile Communication (GSM). The comprehensive research and evolution of microstrip antennas and arrays, leveraging the benefits, has led to the diversification of applications and the establishment of the subject as a separate entity within the broad field of microwave antennas. After many years of study, scientists had found a few ways to increase the efficiency of the microstrip planar antenna.

In Fifth Generation (5G) applications, there are two types of frequency bands which are Sub-6GHz frequency band and millimetre-wave spectrum bands. Sub-6GHz also called mid-band 5G is one of the frequency bands and it is widely used in 5G technology. Sub -6 band can cover radio frequencies in the range of 2GHz to 6GHz. The most resonant frequency of the sub-6GHz is about 3.5GHz. Sub 6GHz can cover a greater area of 5G coverage but in another way, it cannot provide higher speed downlink compare to millimetre-wave.

1.2 Problem statement

The research and study on the microstrip planar antenna in the sub6GHz 5G application had been done by the antenna designers. There are many shapes of the patch antenna that had been developed or modified by the researcher to improve the uses of the microstrip planar antenna. However, most of the design of the microstrip planar antenna can only provide a narrow bandwidth in the range of 500MHz. Besides, some design of the microstrip planar antenna is complicated to achieve wide bandwidth. It may use a lot of time and cost to develop the design and expected result. Besides, some of the design of microstrip antennas are having low efficiency.

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In this project, the simple design of the patch antenna will be proposed, and the proposed antenna can provide a wide bandwidth to increase the efficiency and can be used in many wireless communication systems.

1.3 Objective

The objectives of this project are:

1. To design and simulate the planar antenna on PCB with wide bandwidth that can be used in sub-6GHz 5G application
2. To design and simulate the antenna on different flexible substrates
3. To develop a prototype of planar antenna

4. To bench-mark of the existing work

1.4 Project Scope

This project mainly focuses on the designation of the microstrip planar antenna to works in a sub6-GHz 5G application. The CST Studio Suite is used as the microwave software to design the microstrip planar antenna and simulate the result. In this project, the dielectric constant of the substrate is not the variable of choice and depends on which dielectric material the antenna is designed. The Rogers 3003 substrate with dielectric constant 3 and a thickness of 0.51 mm has been used in the microstrip planar antenna. Next, the Polyimide substrate and PET substrate are used as flexible substrates to determine the stability of the antenna. The dielectric constant of the polyimide substrate is 3.5 and the height is 0.125 mm while the PET substrate with dielectric constant 3.2 and the thickness of the substrate is 0.125 mm. Bending technique is then apply on the flexible substrate to observe the effect on the antenna performance.

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1.5 Expected results

In this project, there will be 2 sections of results to be observed, which is the simulation result and hardware result that fabricated on the PCB. The geometry of the microstrip planar antenna will be designed and the simulation result will be simulated by the microwave software. To make sure that the microstrip planar antenna able to works in the sub 6GHz 5G application, the result of the S-parameter should cover the wide bandwidth in the range of 3 to 4 GHz. The result of the directivity and gain must be good and stable. After that, the fabrication process is done according to the design of microstrip planar antenna in the software. The S-parameters, radiation patterns, and directivity will need to be close to the simulated result to make sure that it is suitable to use in the sub 6GHz 5G application. Next, for the antenna designed on the flexible substrates which is Polyimide substrate and PET substrate, it can show the wide bandwidth that can cover from 3 to 4 GHz and show the higher efficiency compare to Rogers 3003 substrate. The proposed antenna that design on the flexible substrate will apply the bending technique to observe the result.

1.6 Thesis Organization

In this project, there will be 5 chapters provided. Chapter 1 will briefly explain the background of the project. The problem statement, objectives, and scope will be stated in this chapter. Chapter 2 will describe the related work of the project. The comparison between the previous paper will also be discussed and discuss the software to be used in this project. Next, the Chapter is the methodology of the project. In this chapter, the procedure, the materials have chosen to use and the parameters for the design will be stated to achieve the objectives of the project. Besides, Chapter 4 will show and discuss the results obtained based on the methodology step. The comparison results with the previous paper will also be discussed. Chapter 5 will conclude the overall result of the project. The suggestion to improve future research will also be discussed.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss the basic design of the microstrip planar antenna. Next, the related work from the previous research paper. Besides, the comparison table about the previous paper is provided. In addition, the comparison of software applications used to design and simulate the microstrip planar antenna. Overall, this chapter summarizes current information about the microstrip planar antenna including the main theoretical and methodological findings.

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2.2 The geometry of microstrip antenna

The microstrip patch antenna used to provide high resonant frequency depends on the designation of the microstrip planar antenna. The single-layer design of the microstrip planar antenna can be divided into three parts which are patch, substrate, ground plane with feeding technique. A microstrip patch antenna contains either a planar or a non-planar geometry patch on the upper side of the substrate and a ground plane on the bottom side of the substrate (Singh, 2011). The rectangular patch is the normally used microstrip antenna and used for the simplest and most challenging applications. The basic structure of a rectangular patch antenna is shown in figure 1 below.

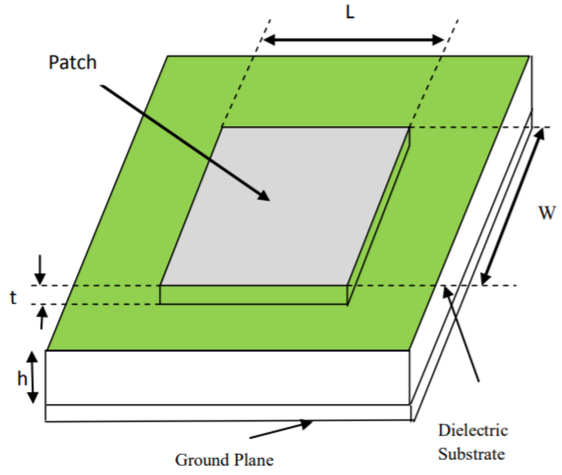

Figure 2.1: The structure of a rectangular microstrip patch antenna (Singh, 2011)

The other common shapes of the patch antenna are square, elliptical, and circular. The advantages of microstrip antenna are low profile, conformity, and lightweight. However, the standard rectangular microstrip patch antennas have a disadvantage which is small bandwidth. Many techniques have been used or applied by the researcher to solve the problem of narrow bandwidth. For example, increase the substrate thickness, introducing parasitic patch elements or stack configuration, or changes the shape of the patch itself. E-shaped patch antennas, U-slot patch antenna, Elliptical antenna, and Vivaldi antenna are the example of the modified design.

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2.3 Related Work

2.3.1 A microstrip quasi-yagi antenna in 5G application

Based on (Wang and Yang, 2017), the Yagi antenna was a popular directional antenna with a simple design, high gain, and high directivity and normally used in the wireless communication system. However, the size of the antenna is too big which limits

its application in certain application situations. Therefore, a microstrip Quasi-Yagi antenna was introduced which is the combining microstrip antenna with the Yagi antenna to use in 5G applications.

The substrate used was the FR4 substrate for this antenna design. There were three main components which were dipole driver, reflector element, and parasitic directors. The reflector of the antenna was the ground plane and its function was to obtain a directive radiation pattern. There were also four parasitic directors were designed and optimized at the frequency of 3.5 GHz to improve the directivity.

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Figure 2.2: The 3D view of the microstrip Quasi-Yagi antenna (Wang and Yang, 2017)

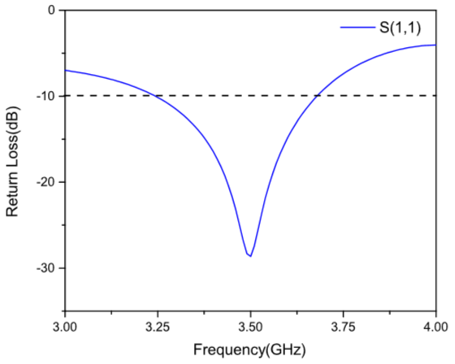

Figure 2.3: The S_{11} of the microstrip Quasi-Yagi antenna element (Wang and Yang, 2017)

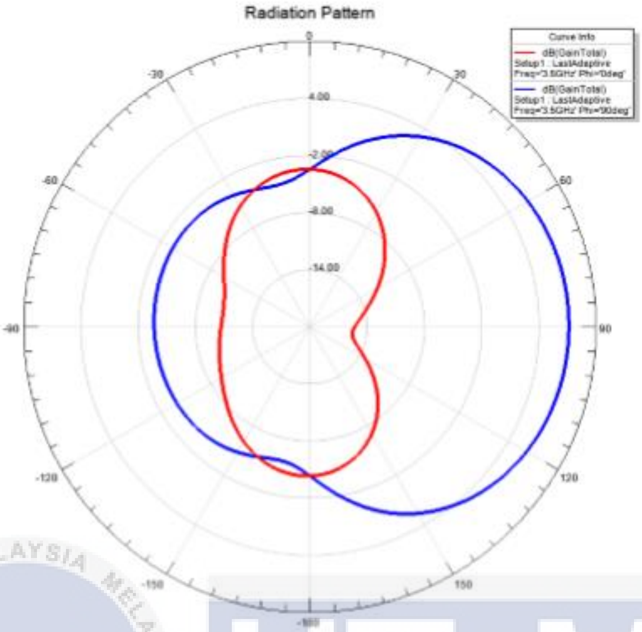

Figure 2.4: The radiation pattern of the single antenna element at the frequency of 3.5GHz (Wang and Yang, 2017)

After that, the authors had introduced the 4 X 4 microstrip Quasi- Yagi Antenna array with sixteen elements, and the result was simulated as shown in the figure below.

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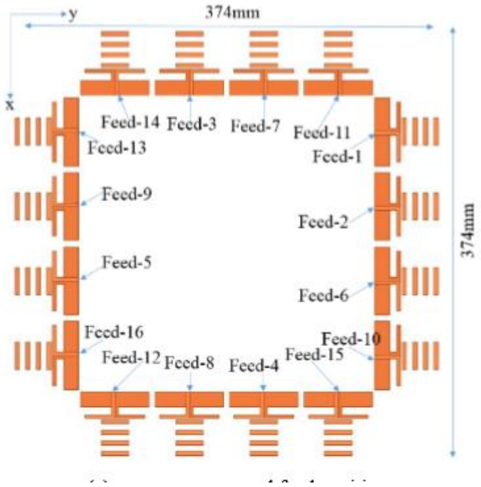

Figure 2.5: The array structure and feed position (Wang and Yang, 2017)

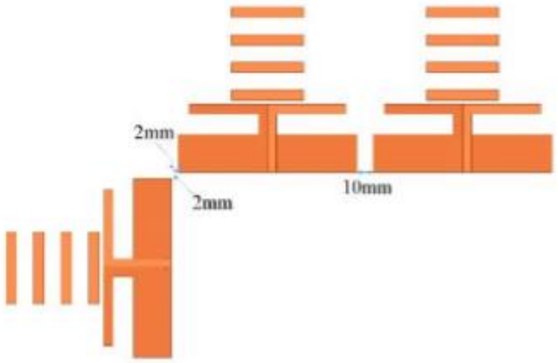

Figure 2.6: The element spacing of the array (Wang and Yang, 2017)

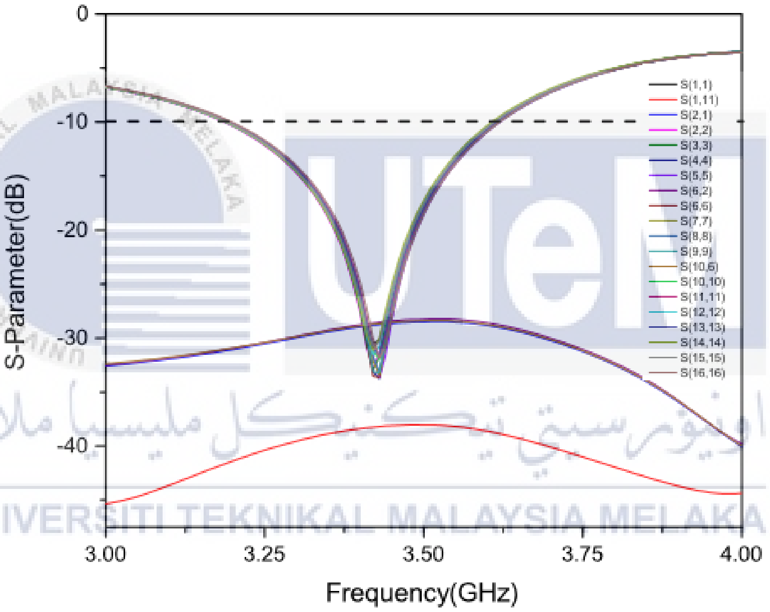

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Figure 2.7: The reflection coefficient of the microstrip Quasi-Yagi antenna array

(Wang and Yang, 2017)

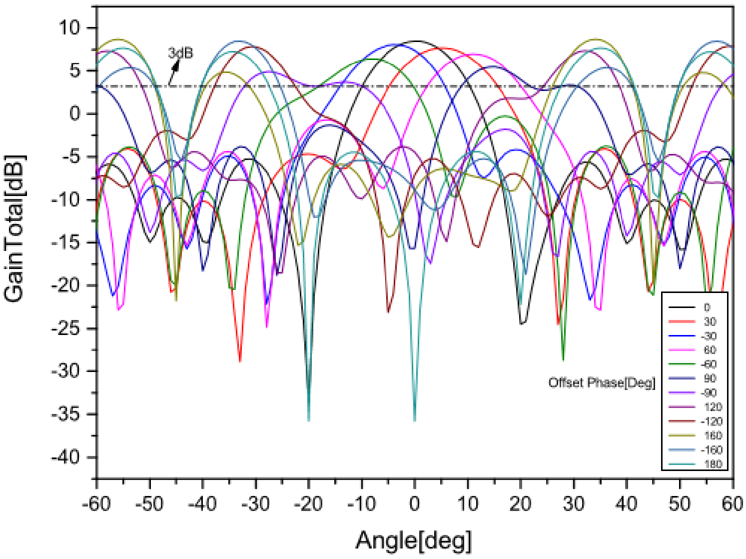

Figure 2.8: The scanning angle of a linear subarray with 3dB main lobe width

(Wang and Yang, 2017)

In conclusion, a wireless communication antenna was developed which 4x4 square structure design with resonant frequency operate in 5G low-band at 3.5 GHz.

2.3.2 A dipole-like antenna for sub-6GHz in 5G applications

According to (Liu, Li and Li, 2019), a small size dipole-like antenna for a sub-6GHz in 5G applications was developed. The microstrip line was used to fed the antenna and a semi-circular ring patch was used to connect with meander lines. The authors stated that the antenna had a simple structure and cover high bandwidth of about 4.8 to 5GHz. The HFSS software was used to design the 5G antenna and to verify the effectiveness. The resonance frequency of the antenna could be manipulated by control the dimensions of the semi-circular ring, the coupling between two meander dipole and the meander lines. The substrate used in this research is the FR4 substrate. The geometry of the proposed antenna is shown in the figure below.

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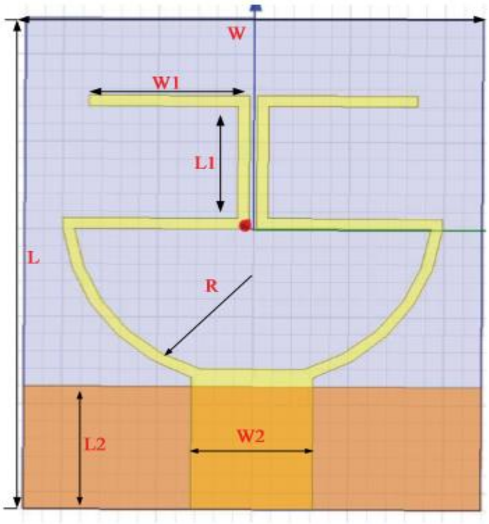

Figure 2.9: The element spacing of the array (Liu, Li and Li, 2019)

After complete the design of the proposed antenna, the simulation was carried up by the HFSS software. The results include S-parameter, voltage standing wave ratio (VSWR), effects of the key parameter, and the radiation patterns of the antenna.

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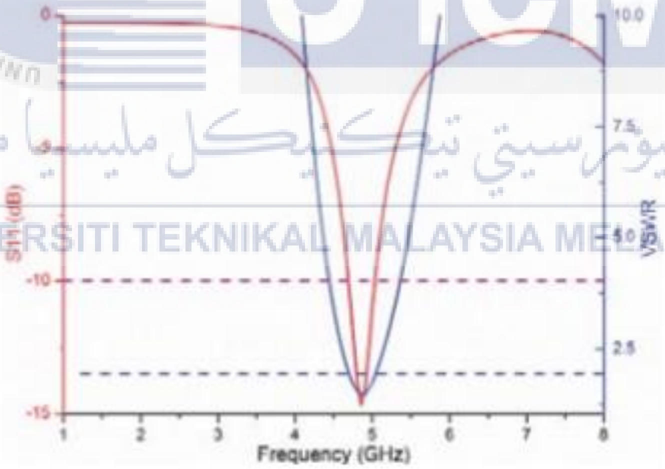

Figure 2.10: The result of S_{11} and VSWR of the proposed antenna (Liu, Li and Li, 2019)

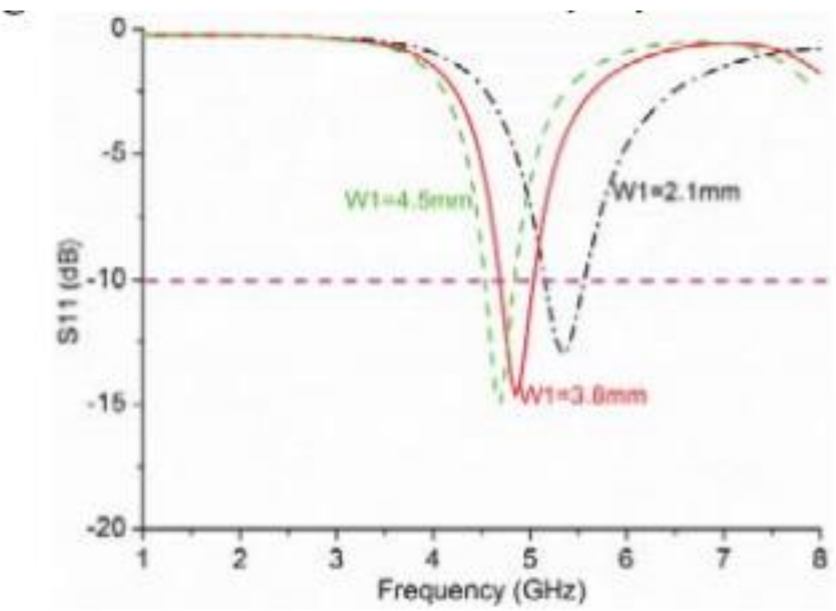

Figure 2.11: The effects of the key parameter on S_{11} a.) width, W1 (Liu, Li and Li, 2019)

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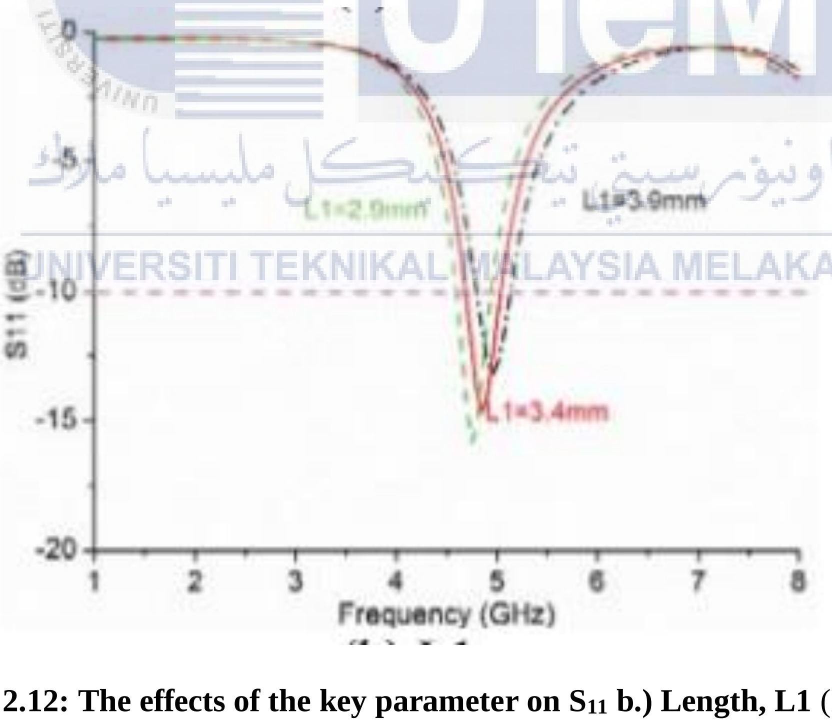

Figure 2.12: The effects of the key parameter on S_{11} b.) Length, L1 (Liu, Li and Li, 2019)

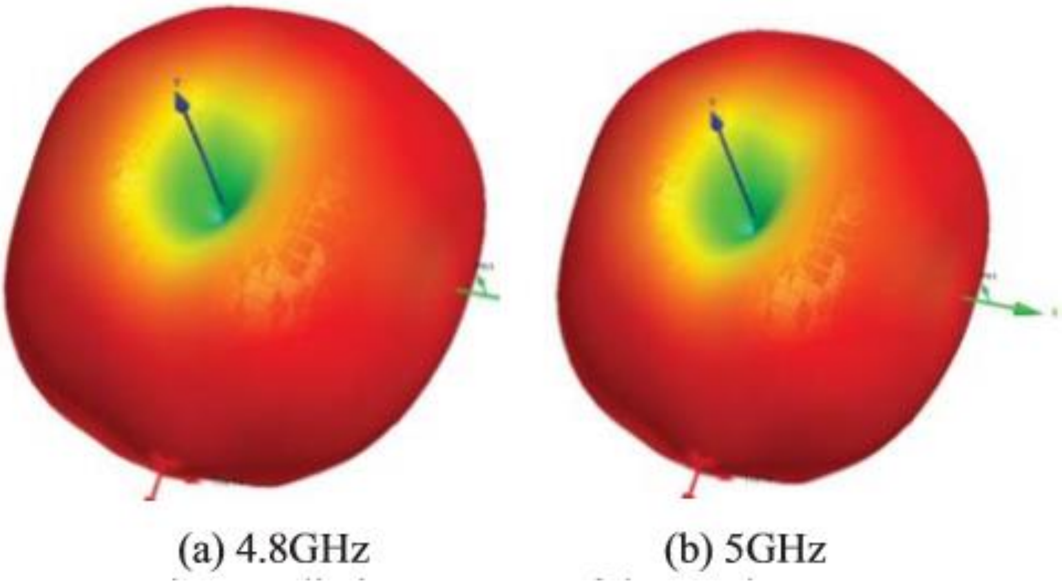

Figure 2.13: The radiation patterns of the patch antenna (Liu, Li and Li, 2019)

In the nutshell, the resonance frequency was shifted to a lower frequency when increasing the value of W1 in this paper. However, when increasing the value of L1, the resonance frequency changed from 4.8GHz to 5GHz. The resonance frequency can be modified by setting the correct dimensions of the semi-circular ring and the meandering lines to allow the antenna to reach the target. The design of the antenna was suitable for 5G communication applications.

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2.3.3 A simple tri-band proximity coupling fed compact antenna sub-6GHz communication applications

According to (Mao, Zhu and Li, 2018), a simple antenna for 2.7GHz, upper Wireless Local Area Network (WLAN), and sub-6GHz 5G wireless communication applications was proposed. A proximity coupling fed structure causes the two spiral of the proposed antenna was excited by using. The sizes of the spiral strips were different to obtain different frequencies. The HFSS software has been used to design the proposed antenna, and the obtained results concluded that the antenna can provide good triple-band characteristics and good radiation patterns for 5G wireless communication applications in 2.7GHz, upper WLAN, and sub-6GHz.

The substrate used in this proposed antenna was FR4 substrate with permittivity of 4.4, 0.02 dielectric loss tangent, and a thickness of 1.6mm. Besides, the center frequency could be changed while setting the dimensions of the spiral strips. The geometry of the proposed mm-wave antenna and the results of the designed antenna were shown in the figure below.

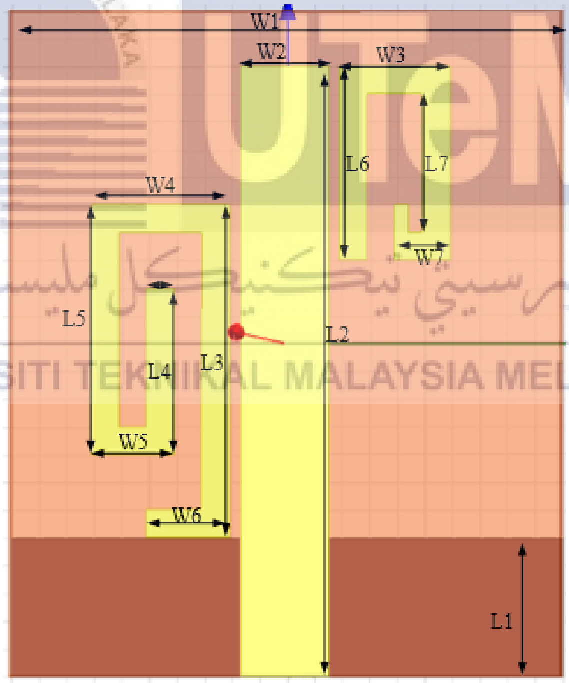

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Figure 2.14: The geometry of the proposed mm-wave antenna (Mao, Zhu and Li, 2018)

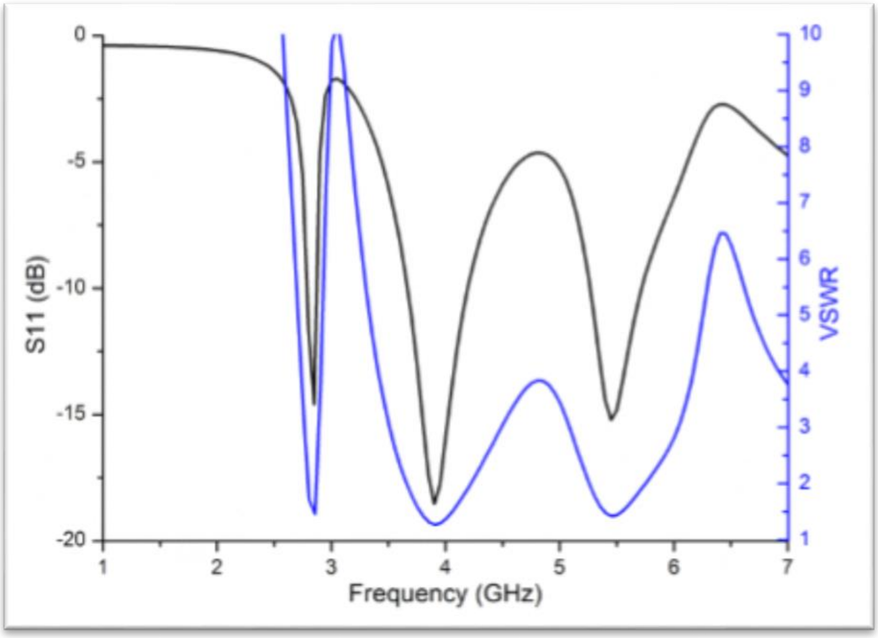

Figure 2.15: The S_{11} and VSWR of the proposed multi-band antenna

Source: (Mao, Zhu and Li, 2018)

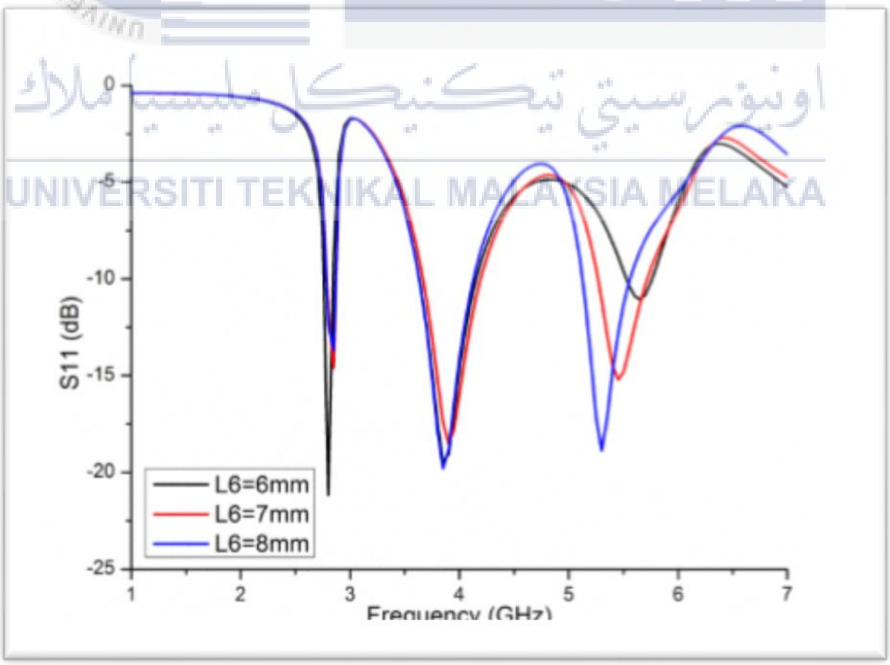

Figure 2.16: The effect of L6 on the bandwidth of the multi-band antenna (Mao, Zhu and Li, 2018)

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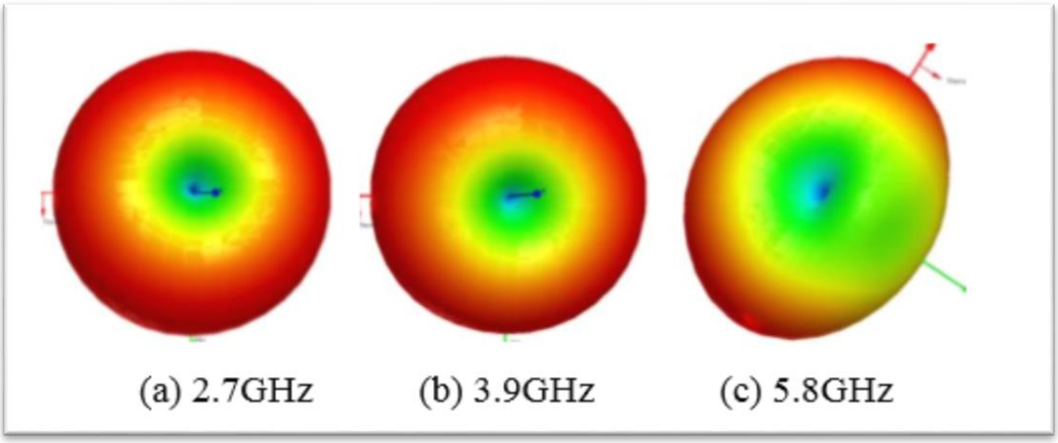

Figure 2.17: The radiation patterns of the proposed multi-band antenna (Mao, Zhu and Li, 2018)

Based on figure 2.2.21, the authors concluded that the antenna suitable to use in Long-Term Evolution (LTE), sub-6GHz, and WLAN communication applications because it can provide resonance frequencies at these 3 bands. Next, refer the figure 2.2.22, the L6 gaves the effects on the WLAN band's bandwidth because when increasing the value of L6, the low bandwidth obtains by the WLAN band. Last but not least, the omnidirectional radiation patterns were provided by the proposed antenna at desired operating bands as shown in figure 2.2.23.

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2.3.4 A dipole hybrid-mode antenna in sub-6GHz application

According to (Huang *et al.*, 2019), the authors focus on hybrid mode antenna for sub-6GHz communication. Hybrid mode was exciting for the adjacent modes in the interested band. The analyzing mode was more comprehensive to display the hybridization process. The broadband balun design helped to transfer single feed to different feeding lines. The proposed antenna was covered by the frequency band of 3300-4200MHz, 3300-3800 MHz, and 4400-5000 MHz for sub-6GHz communication.

The proposed antenna used an ellipse-shaped patch and place it on the substrate. The substrates used are FR4 material. The upper and bottom sides of the top substrate were filled with feeding dipole where it was split into two parts to ease the assembly and soldering. Transformation of impedance executed by a tapered line and placed on the upper side of the bottom substrate. The bottom side of the lower substrate is etched with the ground plane.

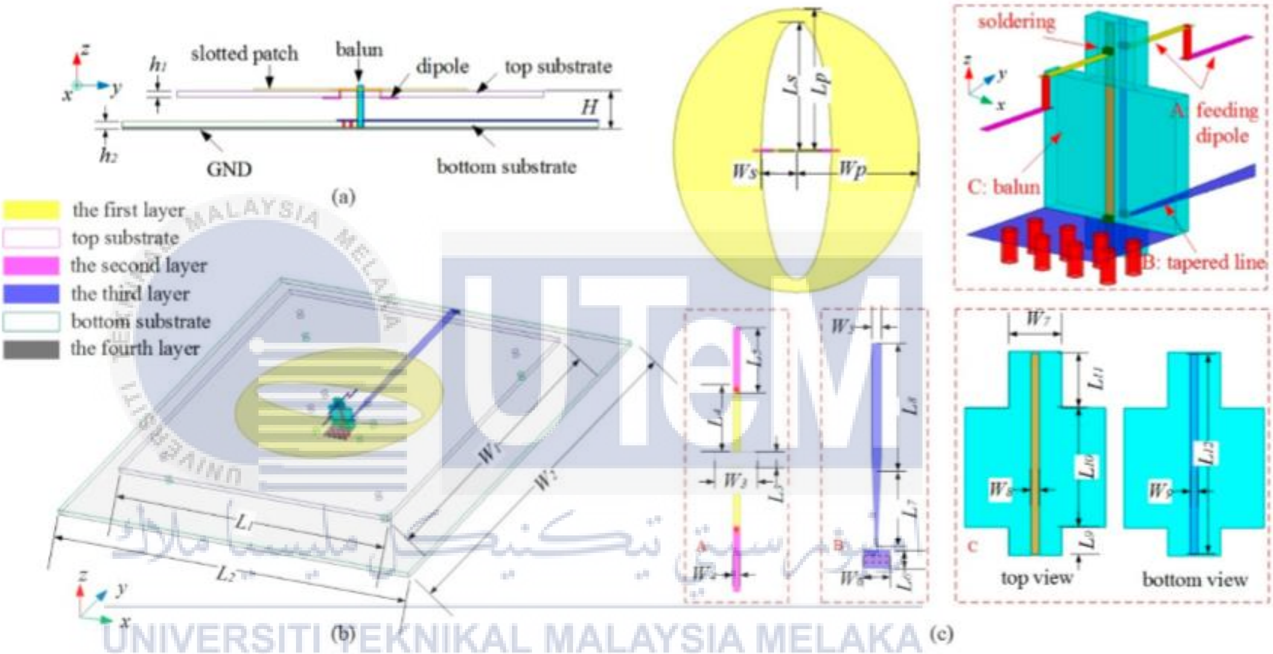

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Figure 2.18: The geometry of the antenna a.)side view, b.)perspective view, c.) zoom in feeding dipole, tapered line, and both sides of the balun. (Huang *et al.*, 2019)

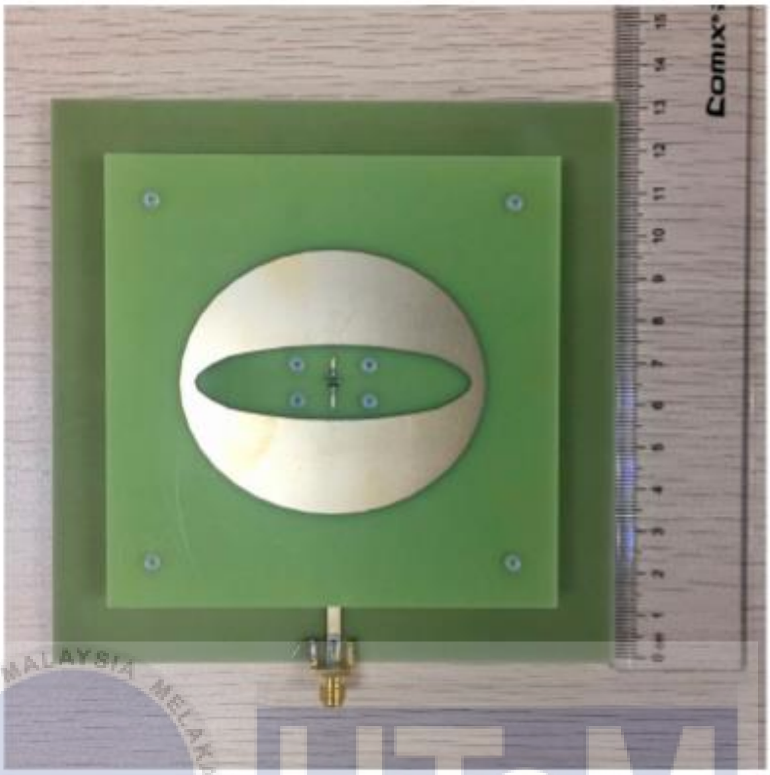

Figure 2.19: The photograph of the antenna prototype (Huang *et al.*, 2019)

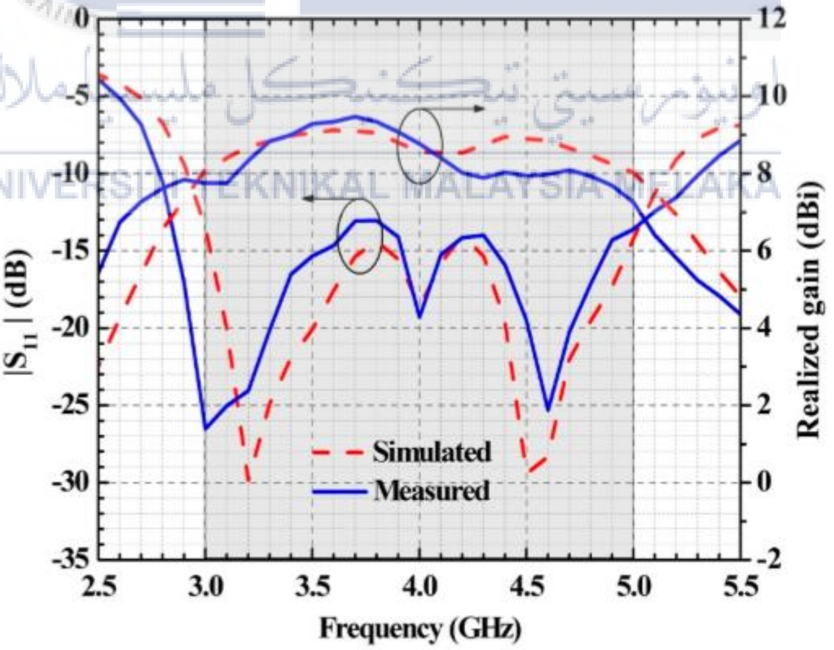

Figure 2.20: The S_{11} and realized gains of the antenna (Huang *et al.*, 2019)

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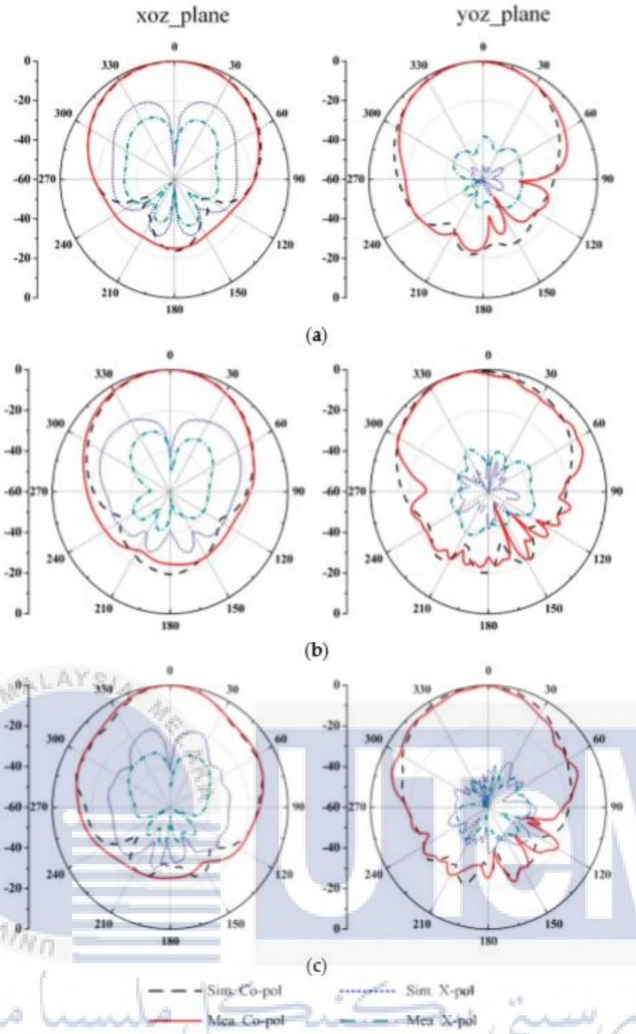

Figure 2.21: The radiation patterns of the antenna at a.) 3.0GHz b.) 4.0GHz and c.) 5.0GHz (Huang *et al.*, 2019)

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Based on figure 2.2.26, the 2.92GHz to 5.15GHz was covered with 55.75% of simulated 10-dB impedance bandwidth. Hence, the proposed antenna impedance bandwidth could accept the frequency bands of 3300-4200MHz, 3300-3800 MHz, and 4400-5000 MHz. In conclusion, the elliptical antenna of hybrid mode could be used in sub-6GHz communication with simple structure and low fabrication cost.

2.2.5 A cross dipole antenna for sub-6GHz 5G base station application

In-network coverage of wireless services, the base station antenna played an important role (Gopal and Thangakalai, 2020). A perform base station antenna needs to contribute wide bandwidth, stable radiation pattern, and high cross-polarization. A cross dipole antenna was proposed to achieve the requirements. There were three sections in the designing the cross dipole antenna.

The antenna starts with design a simple dipole structure on the substrate. The substrate used was FR4 and the substrate consists of a microstrip balun structure at the bottom of it. The function of balun is represented as a transformer from the fed line to the printed dipole strips. Therefore, the balun had to be modified into a curved shape to improve the impedance matching. The double-sided copper cladding was used to cover the substrate.

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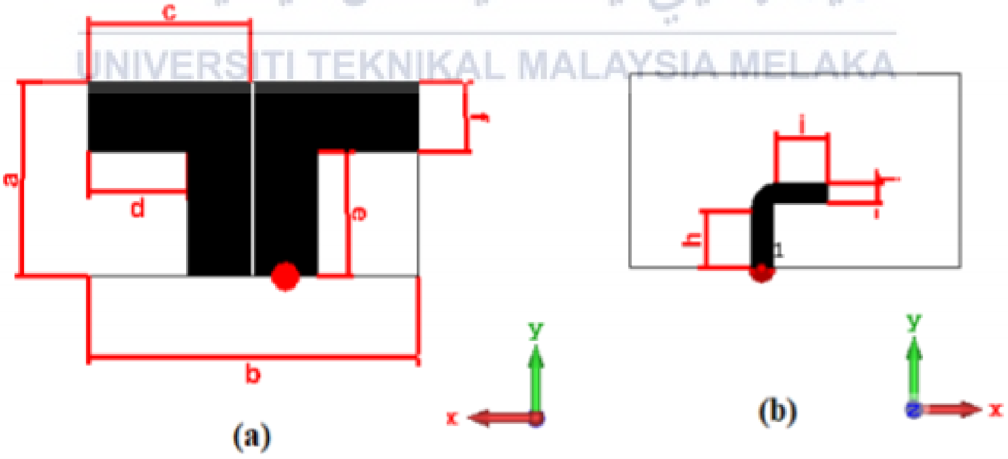

Figure 2.22: The geometry of the proposed antenna: a.) top view b.) bottom view

(Gopal and Thangakalai, 2020)

After designing the single dipole element, the two element dipole antenna was proposed to increase the gain compared to a single dipole element. The two dipole antenna were connected to each other with a distance of half the width of a single dipole antenna.

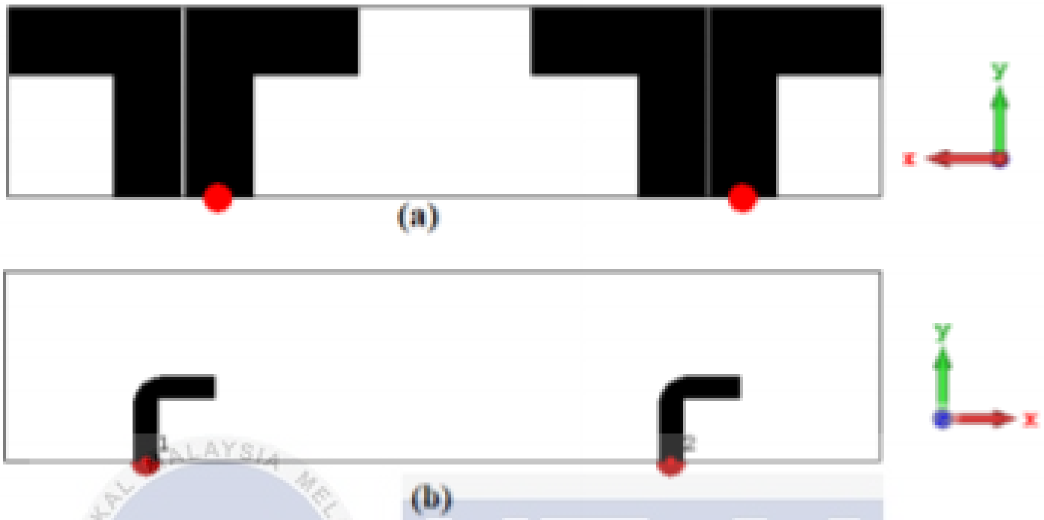

Figure 2.23: The two dipole element a.) top view b.) bottom view (Gopal and Thangakalai, 2020)

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The cross dipole antenna was introduced in the last part, whereby the two element dipole antenna joined with another two element dipole antenna at the center of both two elements.

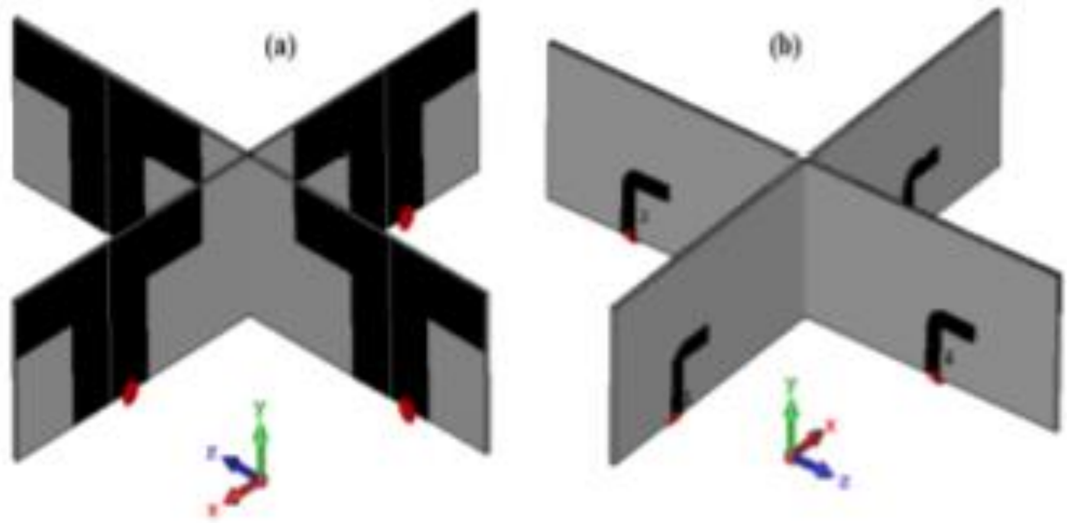

Figure 2.24: The cross dipole antenna a.) dipole elements b.) balun structure

(Gopal and Thangakalai, 2020)

After finish the design, the proposed cross dipole antenna was simulated in CST software and it showed a wide bandwidth of 2.492GHz from 1.341GHz to 3.834GHz. The radiation patterns of the cross element were stable and stable gain.

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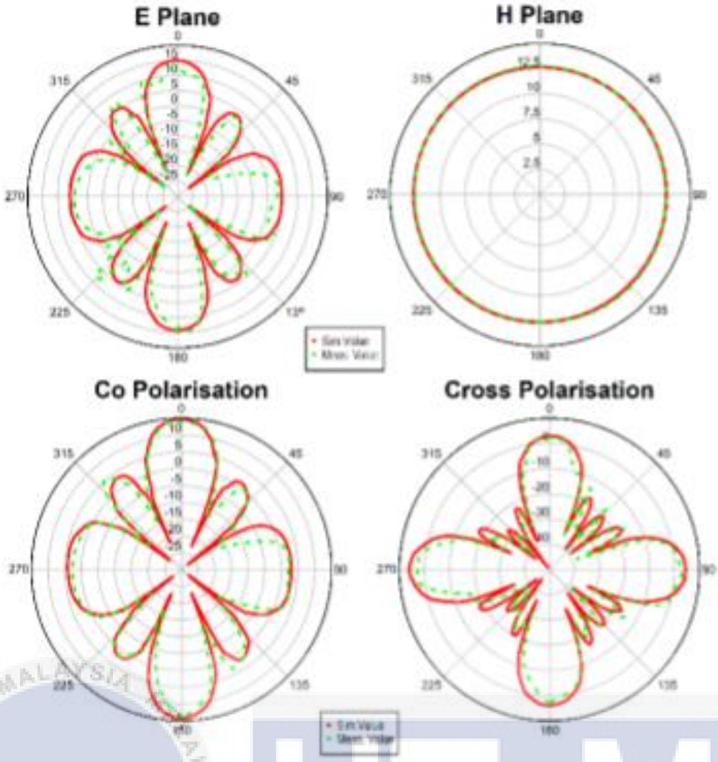

Figure 2.25: The radiation patterns of the cross element (Gopal and Thangakalai, 2020)

In the conclusion, the wide bandwidth, stable radiations pattern, and stable gain achieved in this proposed antenna. It was suitable for sub-6GHz 5G applications.

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2.4 Comparison of related paper

Based on the previous related papers, they have the same objective which designs the proposed antenna to use in sub 6 GHz 5G application. However, there is still a difference between them as their design, method, and dimension used to achieve the objective. The following table will show the comparison between the papers.

No	Title	Author	Method	Advantage	Disadvantage
1	A 4×4 microstrip quasi-yagi beam-steering antenna array in the frequency of 3.5GHz	Wang, H. and Yang, G. (2017)	- Microstrip Quansi-Yagi antenna - FR-4 used as the substrate - Dipole driver, parasitic directors, and reflector element	- High directivity - High gain	- Low resonance frequency - Complex design
2	A dipole-like antenna for sub6GHz applications	Liu, C., Li, B. and Li, Y. (2019)	- Dipole-like antenna - FR-4 used as the substrate - Semi-circular ring, meander lines and coupling between two meander dipole were designed	- High resonance frequency - Good radiation pattern	- Narrow bandwidth

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3	A simple tri-band proximity coupling fed compact antenna sub-6GHz communication applications	Mao, X., Zhu, Y. and Li, Y. (2018)	- Proximity coupling fed structure antenna - FR-4 used as the substrate - Two spiral strips were designed	- Multi-band - Good omnidirectional radiation pattern - Wide-band width	- Complex design
4	A dipole hybrid-mode antenna in sub-6GHz application	Huang, B. *et al.* (2019)	- Dipole hybrid-mode antenna - FR4 used as the substrate - Feeding dipole, tapered lime were designed	- Wide bandwidth - Good directivity	- Complex design - The distortion of the radiation pattern
5	A cross dipole antenna for sub-6GHz 5G base station application	(Gopal and Thangakalai, 2020)	- Cross dipole antenna - FR4 used as the substate - Introduce curved balun structure	- Wide bandwidth - stable gain - Stable radiation pattern	- Complex design

Table 1: Comparision between the related paper

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2.5 Simulation software

2.5.1 Scalable EM Simulation Solution, IE3D

Scalable EM Simulation Solution (IE3D), also known as formerly Zeland Software is the first SCALABLE EM design. This software also provides a platform that designs modeling with accuracy for model needs high-frequency circuit design and signal integrity. This software mainly uses in antenna design, Radio-frequency identification (RFID) design, Monolithic Microwave Integrated Circuit (MMIC) design, and Integrated Circuit (IC) package modeling. According to (Peixeiro, 2011), IE3D has a menu-driven graphic interface, mainly for automatic meshing of the model generation and solve current distribution on Three Dimensional (3D) by using a full-wave and method-of-moments field solver.

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Figure 2.26: The software of IE3D

2.5.2 High- Frequency Structure Simulation (HFSS) software

HFSS is a 3D electromagnetic (EM) simulation software for designing and simulating high- frequency electronic products. This software consists of E and H-fields, S-parameters, and radiation field results. This software is convenient because the user only needs to key in those important parameters, material properties, specify the geometry and desired output, the software has the automated solution process to complete the design. HFSS is used by engineers worldwide because of its precise and effective handling of 3D EM challenges through its adaptive automatically meshing technique and sophisticated solvers through high-performance computing technology.

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Figure 2.27: The software of HFSS

2.5.3 Advanced design system

Advanced Design System (ADS) is the world’s leading electronic design automation software created by Keysight EEsof EDA in the field of RF, microwave, high-speed digital applications. This software is easy to use and powerful in wireless communication when designing X-parameters and 3D EM simulation.

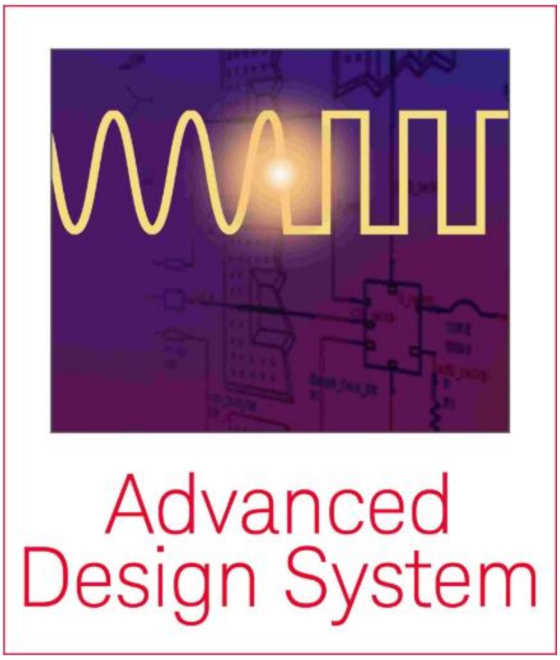

Figure 2.28: The software of ADS

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2.5.4 CST Studio Suite

CST is a professional tool for the 3D EM simulation, designation, optimizing of the high-frequency components. The software also one of the most famous software used by engineers because its flexibility to analyse all systems made up of different kinds of components inefficient and straight forward way. The common subjects of EM analysis for example antennas, filters, electromagnetic compatibility and interference (EMC/ EMI), and thermal effects in high-power devices.

Figure 2.29: The software of CST

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CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology of this paper. The content will start with the flow chart of the project. Next, the all materials used in this project. In addition, the designation of the microstrip planar antenna including the related formulas will be stated

3.2 Flow Chart

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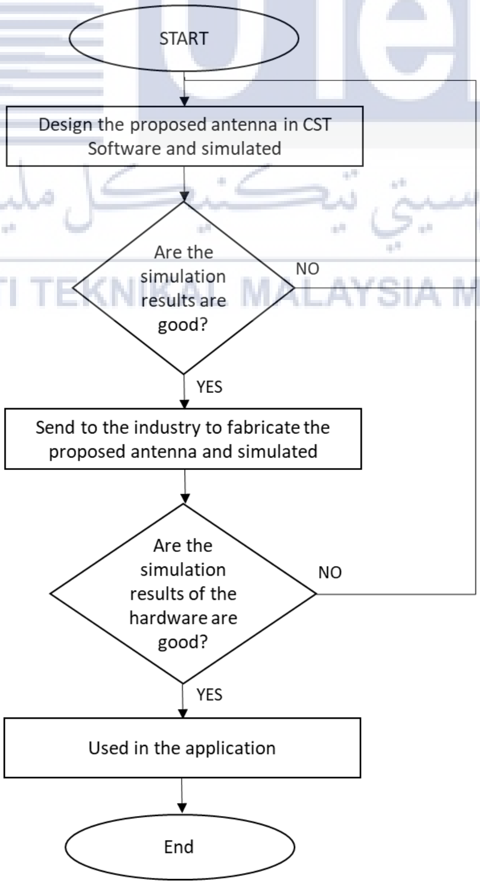

Figure 3.1: Flow chart of the project

The flow chart as shown in the figure above, the project will start with designing a proposed antenna in CST software and the simulation process is carried up. The proposed antenna will be fabricated if the simulation results are good and fulfilled the requirement. Next, the hardware of the antenna will be tested. If the result of the antenna is approximately the same with the result in simulation, hence the antenna can be used at the sub-6GHz in 5G application.

3.3 Materials

3.3.1 Rogers 3003

The substrate is an important material because it helps to minimize the size of the proposed antenna. In this project, the Rogers 3003 is used as the substrate of the proposed antenna. The substrate is stable in dielectric constant over the temperature when laminates. The substrate is also stable in the series product over the frequency, hence allowed the materials to use in a wide bandwidth application. Table 3.1 below shows the general parameters of the Rogers 3003 substrate.

General Parameters	Values
Dielectric constant, ε_r	3
Dissipation Factor, D_f	0.0013
Thickness Inches	0.005” (0.13mm), 0.010" (0.25 mm), 0.020" (0.50 mm), 0.030" (0.75 mm), 0.060" (1.52 mm)
Flammability	94V-0
Peel Strength	12.7 lb/in

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Water Absorption	<0.1 %
Dimensional Stability	0.01 mm/m
Weight	12"x18" (305x457 mm), 24" x 18" (610x457 mm)
Thermal Co-efficient	16 ppm/°C
Thermal Conductivity	0.95 W/m/K

Table 3.1: The general parameters of the Rogers 3003

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Figure 3.2: Rogers 3003

3.3.2 Copper

In this project, the copper is chosen as the materials in designing the patch and the ground plane for the proposed antenna. Copper is a common material used in the telecommunication system, especially for the antennas. The reasons are copper is an efficient conductor in conducting electrical energy and it is low cost compare to silver, which has high conductivity but costly. The conductivity of the copper is 100 while the conductivity of silver is 106, there is only a slight difference between them, but the cost difference is quite big. Due to the high conductivity of copper, the efficiency of the electrical energy is increasing, which makes the Radio Frequency (RF) energy to be conduct smoothly without trapping the heat in the antenna and a more efficient radiation pattern will be produced. Besides, the copper also suited in the fabrication techniques which including machining, forming, stamping, joining, polishing, and plating. The electrical properties and physical properties of the copper is shown in table 3.2 and table 3.3.

Electrical Property	Values
Electrical Resistivity	1.7 μ Ω-cm
Magnetic Susceptibility	-8.00e-8

Table 3.2: The electrical properties of the copper

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Figure 3.3: The example of copper used in the microstrip antenna.

3.4 Designation of microstrip planar antenna

The designation of the microstrip planar antenna need to achieve the requirement which is the microstrip planar antenna with a wide bandwidth of 3GHz to 4 GHz. The antenna is designed as Z-shaped planar antenna. The calculation formulas of the parameters are calculated, and the antenna will be designed in the CST Micro-wave software (MWS). Before starting the design of the antenna, 3 parameters need to be specified which are the resonant frequency of the antenna, the substrate, and the thickness of the substrate. In this project, the resonant frequency of the microstrip planar antenna is 3.5 GHz, Rogers 3003 with a dielectric constant of 3.0 had been used as the substrate and the thickness of the substrate is 0.51 mm.

At the beginning of the design, due to the specified value of dielectric constant (ε_r) and thickness of the substrate(h), the width and the length of the patch antenna are calculated by using formulas given.

Calculation of patch width (W_p)

$$W_p = \frac{c}{2f_r\sqrt{\frac{\varepsilon r+1}{2}}}$$

Calculation of patch length (W_L)

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{w}\right]^{\frac{1}{2}}$$

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$$

$$L_p = L_{eff} - 2\Delta L$$

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Where,

F_r= resonant frequency h = thickness of the substrate

W_p= width of patch ε_r = dielectric constant of the substrate

L_p= length of patch c= speed of light, 3×10^8

The calculations above are important because the width and length of the antenna determine the dimension of the antenna to achieve the resonant frequency. Next, the microstrip feed width (W_f) was calculated by the formulas and inset fed length (L_f) was adjusted to optimize value. The parameters of D, D1 are adjusted to obtain optimized and suitable values.

$$W_f = \frac{7.48 \times h}{e^{\left(z_0 \frac{\sqrt{\varepsilon r+1.41}}{87}\right)}} - 1.25 \times t$$

W_f = microstrip feed width (W_f)

t= trace thickness, t= 0.035mm

The figure below shows the design of the Z-shaped patch antenna in CST Software.

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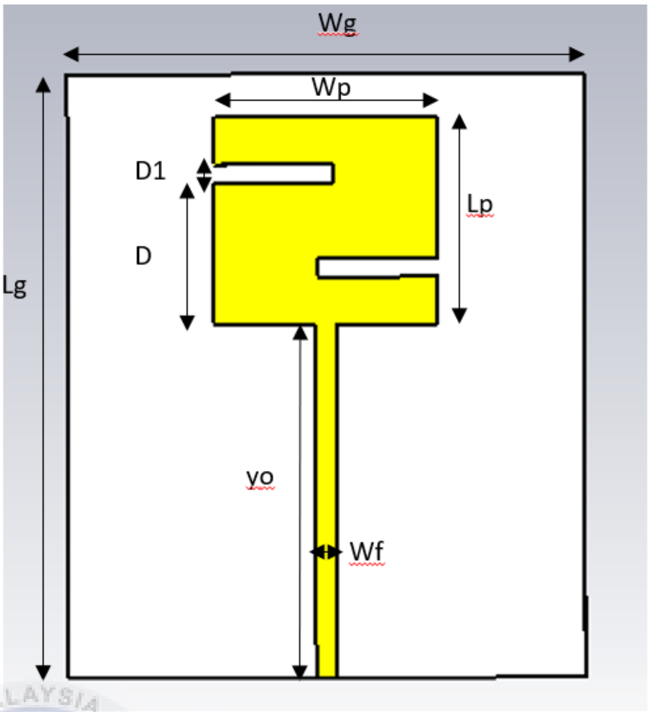

Figure 3.4: the top view of the Z-shaped patch antenna

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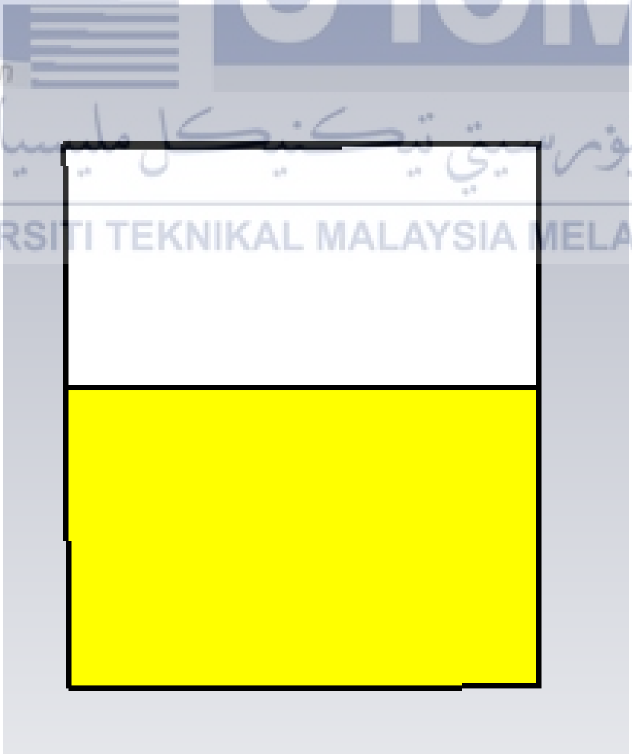

Figure 3.5: the back view of the antenna

The partial ground plane is used in this project because this method can help to increase the bandwidth of the proposed antenna to the fulfilled requirement of sub 6GHz. All parameters include in this design were stated in the table below.

Parameter	Value in mm
W	30.00
L	35.00
W_p	13.00
L_p	12.00
D	8.16
D_1	1.104
W_f	1.20
L_f	20.50
h	0.51
t	0.035

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Table 3.4: Parameters of the Z- shaped antenna

Chapter 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter is discussed about the results of the proposed antenna. First and forest, the parameters of the proposed antenna with Rogers 3003 substrate will be analysed in this chapter. Next, the comparison of three different substrate of the proposed antenna will also be analysed. The characterization of the planar antenna and bent antenna will also be shown in this chapter.

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4.2 The parameters of the proposed antenna with Rogers 3003 substrate

The proposed antenna is simulated in CST MWS and the result of S-parameters (S_{11}) have been shown in Figure 4.1. From the result, it clearly shows that the S_{11} value of the proposed antenna is -34 dB at 3.496 GHz and the bandwidth (BW) is between 3.02 GHz to 4.59 GHz which is 1.57 GHz at -10 dB. The VSWR response of the proposed antenna have been shown in Figure 4.2 whereby it can be used to prove the resonance further. As the result, it shows that the BW of the proposed antenna is under value 2.

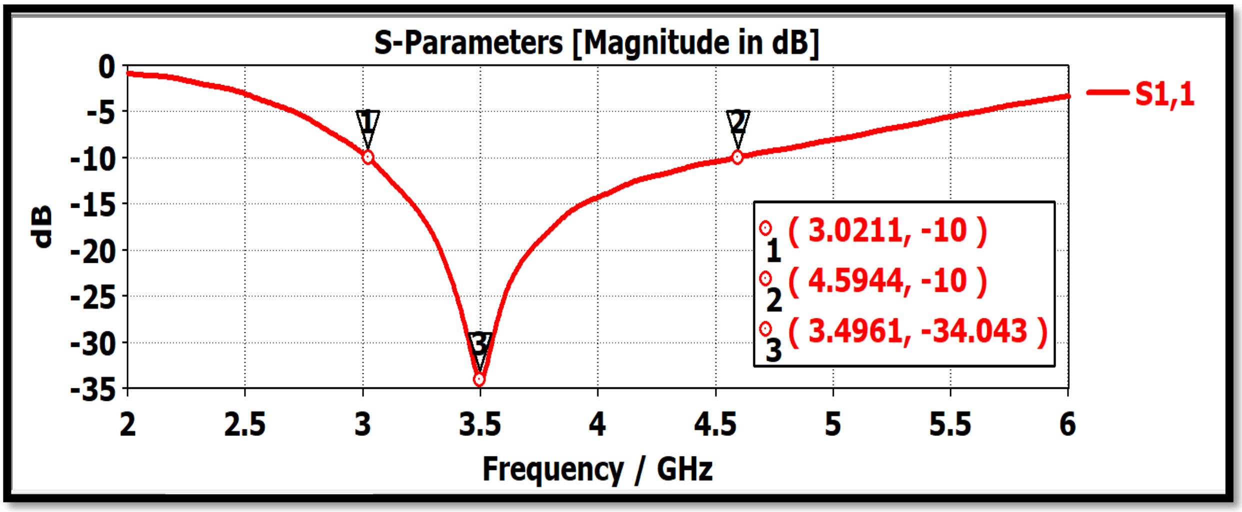

Figure 4.1: The S-parameters of the proposed antenna at resonance frequency 3.496GHz

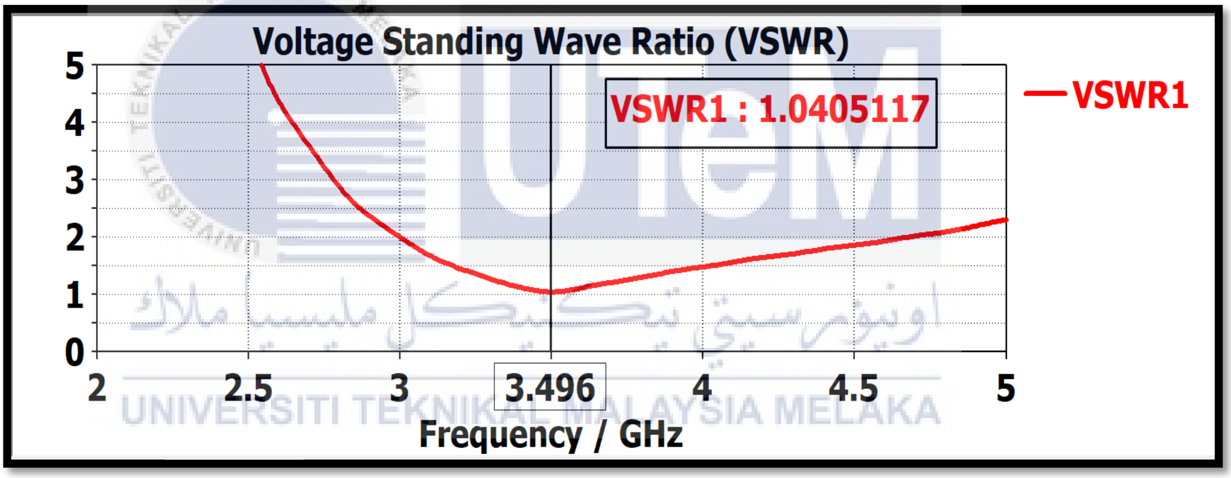

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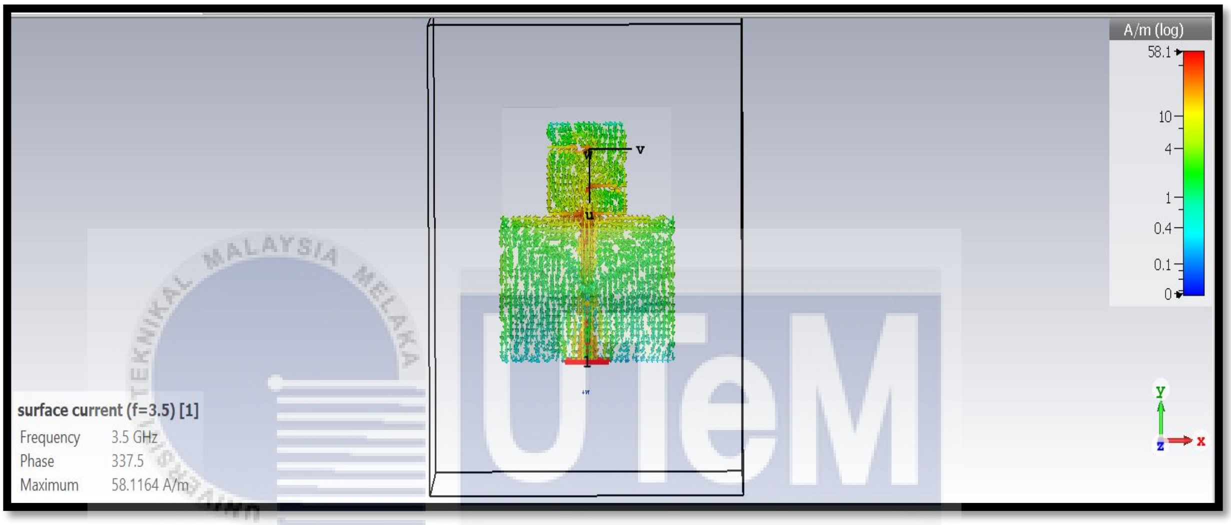
Figure 4.2: The VSWR of the proposed antenna at resonant frequency 3.496 GHz

The impedance matching quality of the proposed antenna is completely observed, the following step is to check the surface current density at resonance frequency and non-resonance frequency. Figure 4.3 show the surface current density at resonance frequency and figure 4.4 show the surface current density at non-resonance frequency. As the result, the surface current density at resonance frequency 3.5 GHz is 58.1 A/m while surface current density at non-resonance frequency 2 GHz is 107.9 A/m. As the result show that at resonance frequency, the current flow through all the patch by referring figure 4.3 while at the non-resonance frequency, although the surface current density is high, but the current does not flow through all the patch. The current only focus at the strip line of the antenna in figure 4.4.



surface current (f=3.5) [1]
Frequency 3.5 GHz
Phase 337.5
Maximum 58.1164 A/m

Figure 4.3: The surface current density at resonance frequency 3.5GHz

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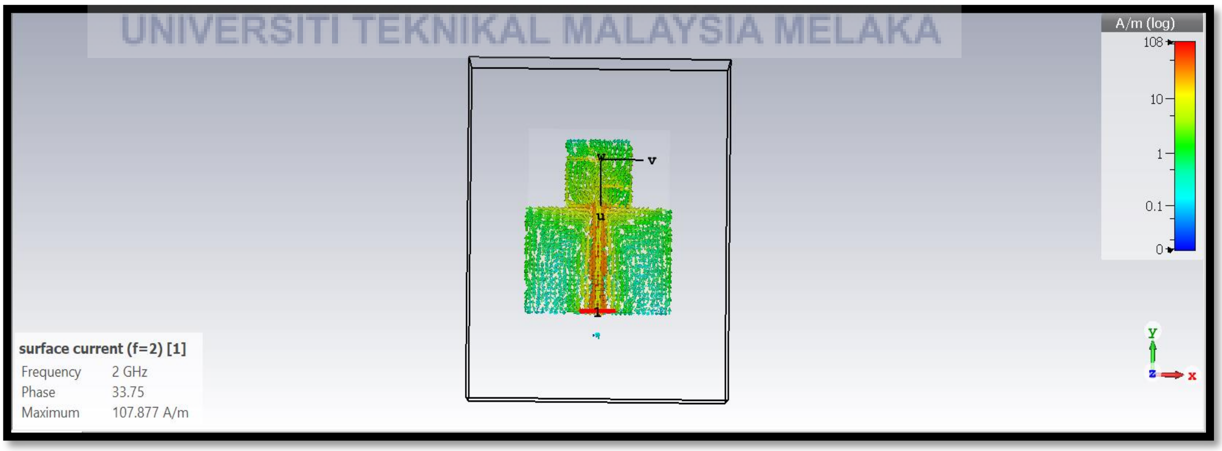

surface current (f=2) [1]
Frequency 2 GHz
Phase 33.75
Maximum 107.877 A/m

Figure 4.4: The surface current density at non-resonance frequency 2 GHz

The next parameters to be observed are the radiation properties. Figure 4.5 represent the 3D radiation pattern of the proposed antenna. It can be said that it is an omni-directional radiation pattern with the maximum realized gain of 2.50 dB at the resonance frequency of 3.496 GHz. To justify the omni-directional radiation pattern of the proposed antenna, figure 4.6 shown the 2 D polar pattern. From figure 4.6, the circular represents the E-plane where it cut 0 degree of the radiation pattern and the H-plane is the bidirectional 2D patterns whereby it cut 90 degree of the radiation pattern. The omni-directional radiation pattern can be used in many applications because it can collect the RF energy from every direction.

Figure 4.7 represents realized gain of the proposed antenna in the range of 3 GHz to 4 GHz. It can be seen that the maximum realized gain is 2.50 dB at the resonance frequency. The efficiency of the proposed antenna is shows in figure 4.8. In the range of the BW, the efficiency of the antenna is high by reaching 95%. Hence, the proposed antenna has a good quality by observing the radiation parameters.

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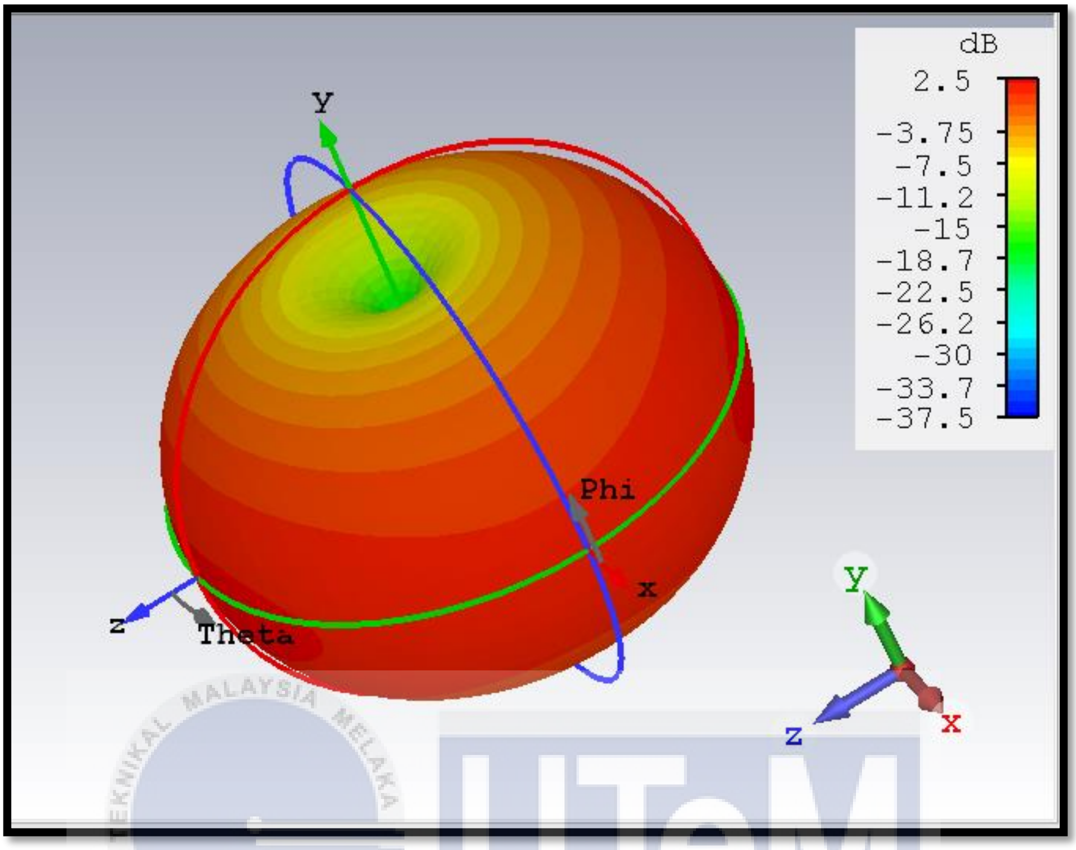

Figure 4.5: The 3D radiation pattern of the proposed antenna

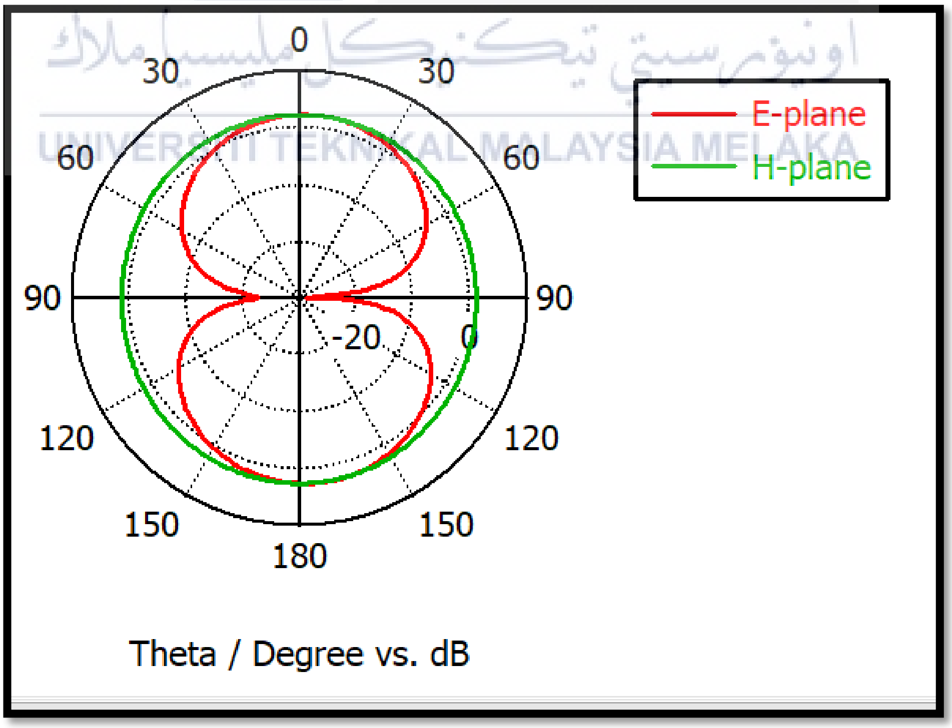

Figure 4.6: The 2D radiation pattern of the proposed antenna

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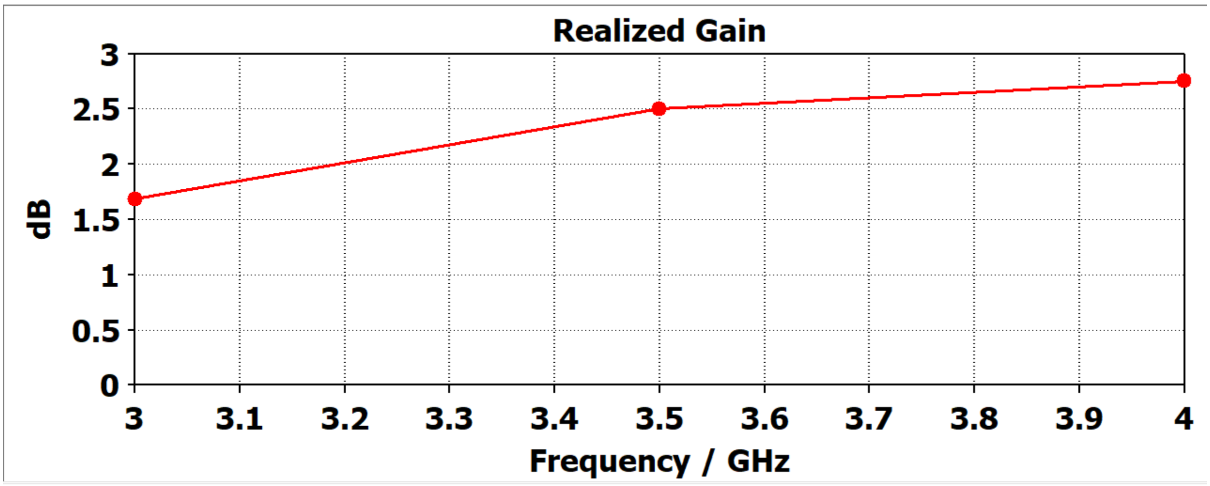

Figure 4.7: The realized gain of the proposed antenna

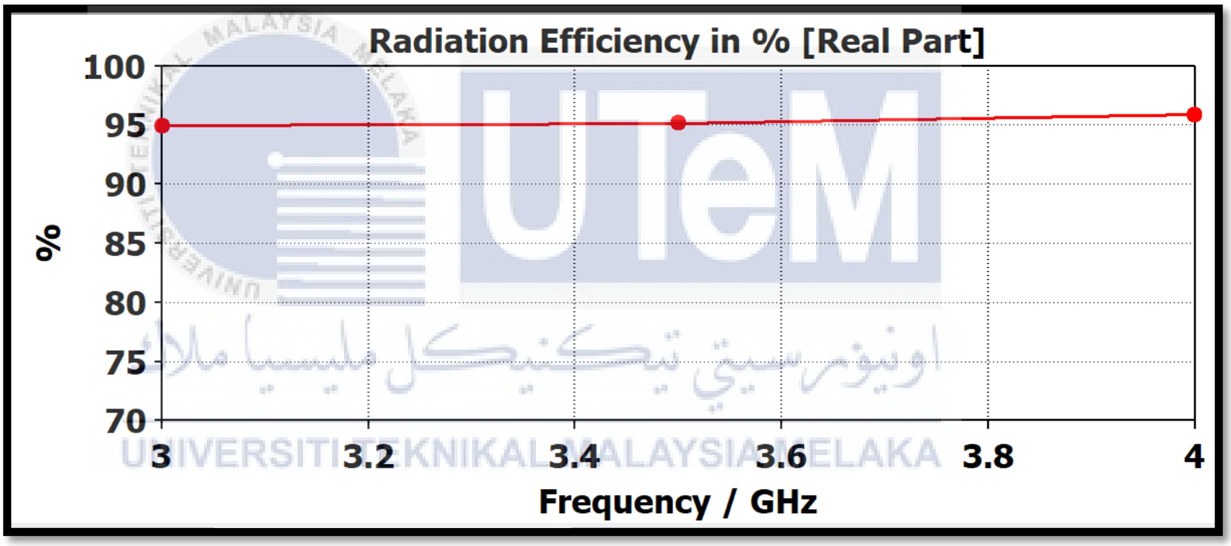

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Figure 4.8: The radiation efficiency of the proposed antenna

4.3 The comparison of parameters of three different substrate

The design of the antenna is further design in another two flexible substrates to observe the change in parameters and the further application will be discuss. The polyimide substrate and Polyethylene (PET) substrate are chosen as the flexible substrates and the proposed antenna is design on these two substrates. The proposed antenna is simulated, and the results of S-parameters in figures. Figure 4.9 show the S-parameters of the proposed antenna with Polyimide substrate, figure 4.10 show the S-parameters of the proposed antenna with PET substrate and figure 4.11 show the comparison of S-parameters of the three different substrates. Table 4.1 show the comparison of the return loss and the bandwidth of the three different substrates.

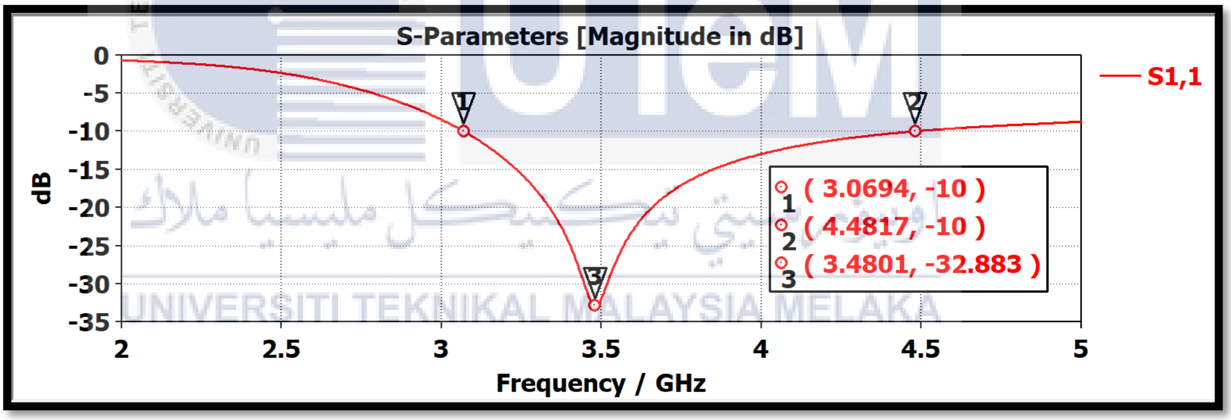

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Figure 4.9: The S-parameters of the proposed antenna with Polyimide substrate

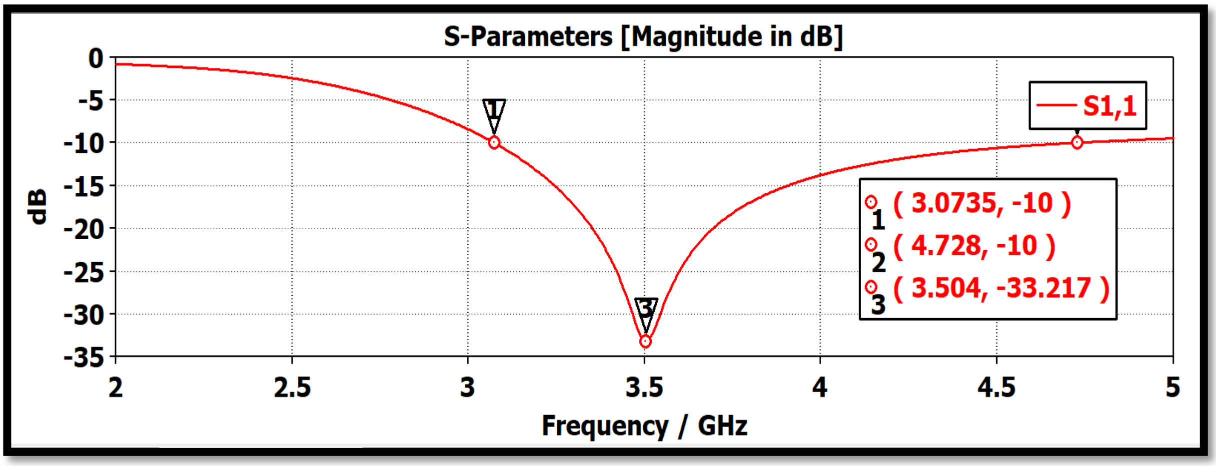

Figure 4.10: The S-parameters of the proposed antenna with PET substrate

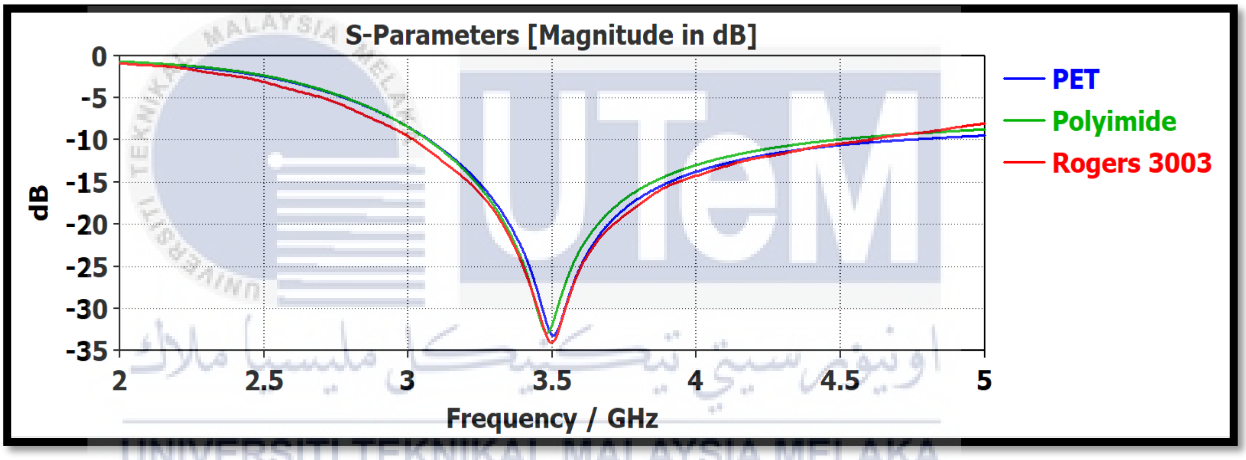

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Figure 4.11: The S-parameters of the proposed antenna with three different substrates.

Substrate	**Resonance frequency, f (GHz)**	**Return Loss (dB)**	**Bandwidth (GHz)**
Rogers 3003	**3.496**	**-34.043**	**1.573**
Polyimide	**3.480**	**-32.883**	**1.412**
PET	**3.504**	**-33.217**	**1.654**

Table 4.1: The comparison of the S-parameters of three different substrate

By referring table 4.1, the resonance frequency of Rogers 3003 substrate is 3.49 6GHz, Polyimide is 3.48 GHz and PET is 3.504 GHz. Three of them have the resonance frequency that fulfilled the 5G band 3.5GHz in Malaysia, hence it can be acceptable. Rogers 3003 substrate have the lowest return loss value -34.043 dB, follow by PET substrate with return loss value -33.217 and -32,883 for Polyimide substrate. The PET substrate has the highest bandwidth 1.654 GHz, follow by Rogers 3003 with bandwidth 1.573 GHz and lastly Polyimide with the bandwidth 1.412 GHz. The VSWR of Polyimide substrate and PET substrate are shown in figure 4.12 and figure 4.13. The comparison of VSWR of the three substrates also show in figure 4.14 and table 4.2 show the comparison of VSWR value of three different substrates. The VSWR response of the proposed antenna used to prove the resonance further. It shows that the BW of the proposed antenna is under value 2. The VSWR value of three different substrates are mostly same as show in figure 4.14.

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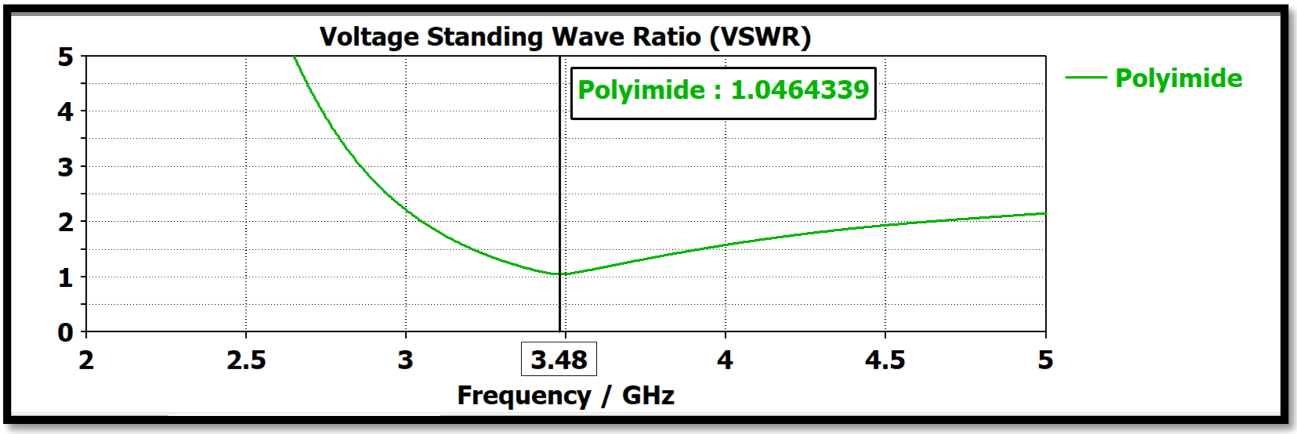

Figure 4.12: The VSWR of proposed antenna with Polyimide substrate

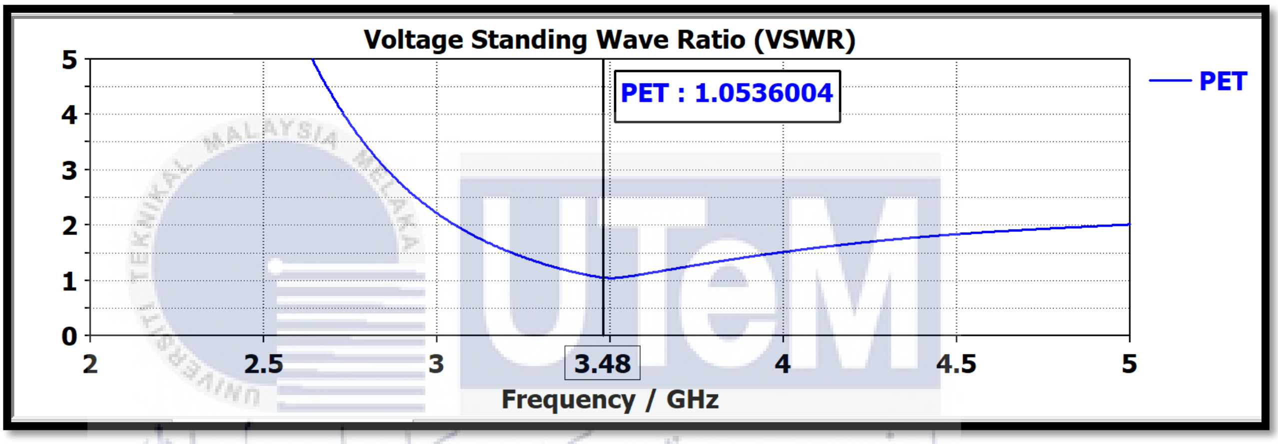

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Figure 4.13: The VSWR of proposed antenna with PET substrate

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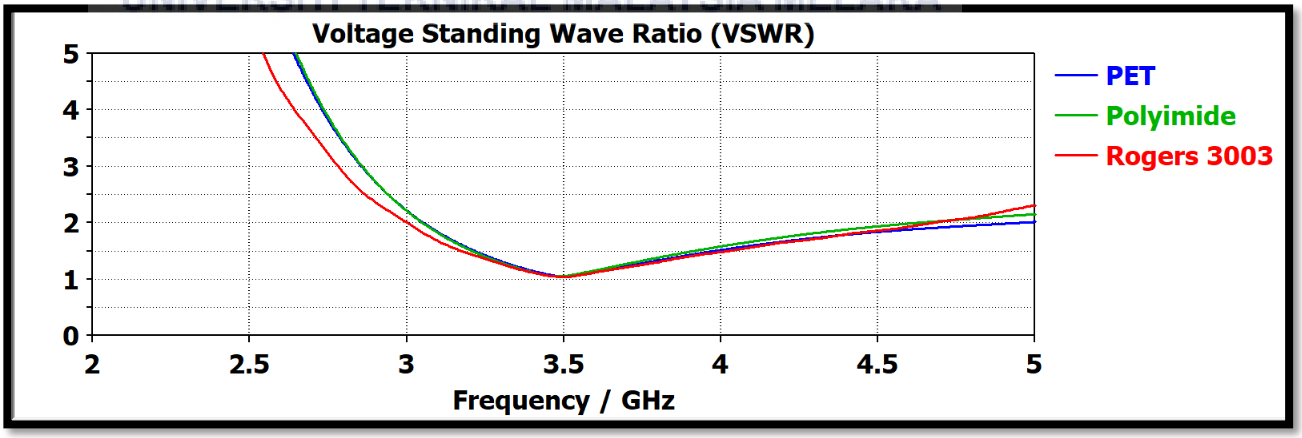

Figure 4.14: The VSWR of proposed antenna with three different substrates

Substrate	VSWR
Rogers 3003	**1.045**
Polyimide	**1.046**
PET	**1.054**

Table 4.2: The comparison of VSWR response of three substrates

Next, the surface current density of the proposed antenna with Polyimide and PET substrates are shown in the following figures. Figure 4.15 show the surface current density of non-resonance frequency with Polyimide substrate, figure 4.16 show the surface current density of resonance frequency with Polyimide substrate. Figure 4.17 show the surface current density of non-resonance frequency with PET substrate and figure 4.18 show the surface current density of resonance frequency with PET substrate. Table 4.3 analyze the value of surface current density of three substrates.

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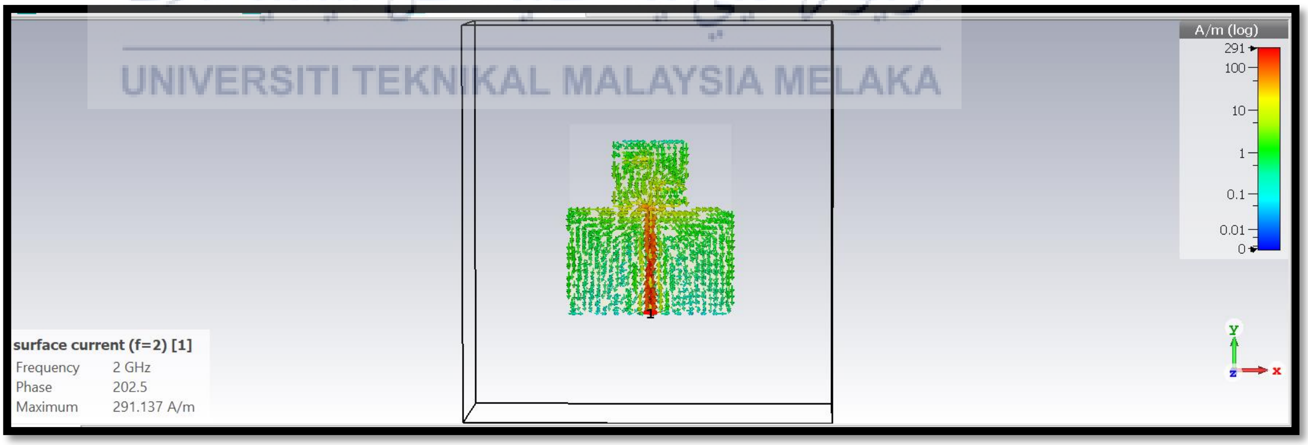
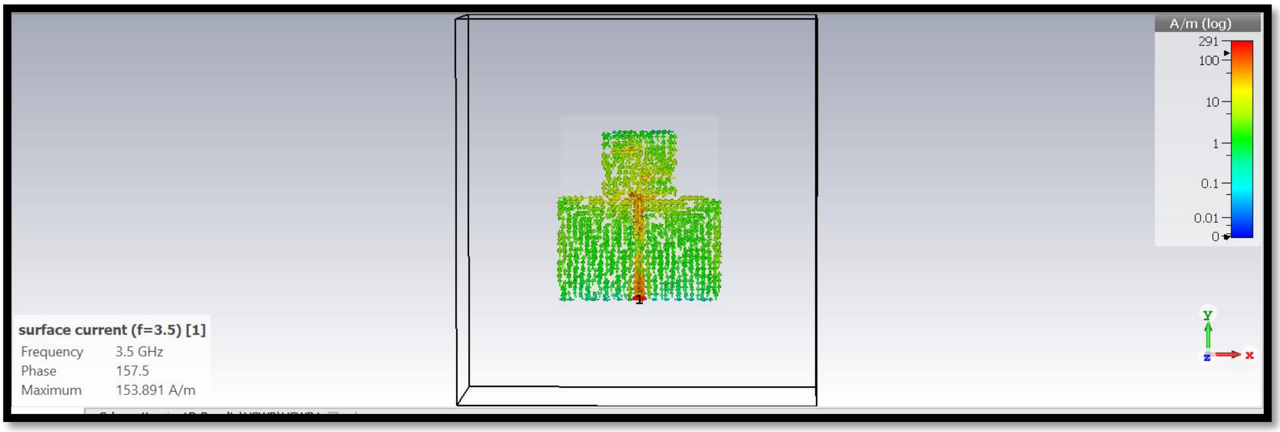

surface current (f=2) [1]
Frequency 2 GHz
Phase 202.5
Maximum 291.137 A/m

Figure 4.15: The surface current density of non-resonance frequency with Polyimide substrate

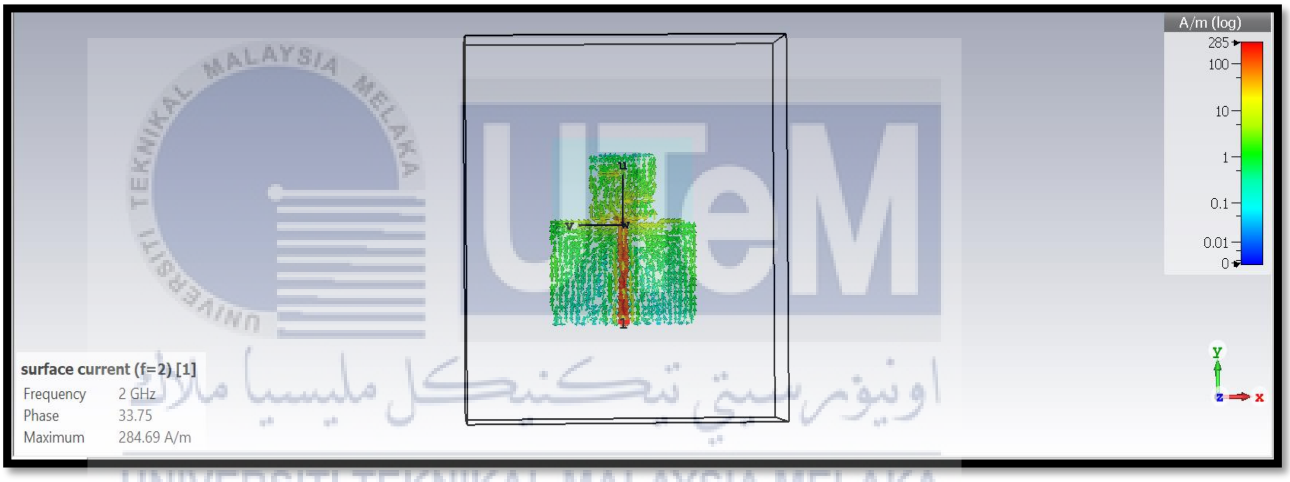

surface current (f=3.5) [1]

Frequency 3.5 GHz

Phase 157.5

Maximum 153.891 A/m

Figure 4.16: The surface current density of resonance frequency with Polyimide substrate


surface current (f=2) [1]

Frequency 2 GHz

Phase 33.75

Maximum 284.69 A/m

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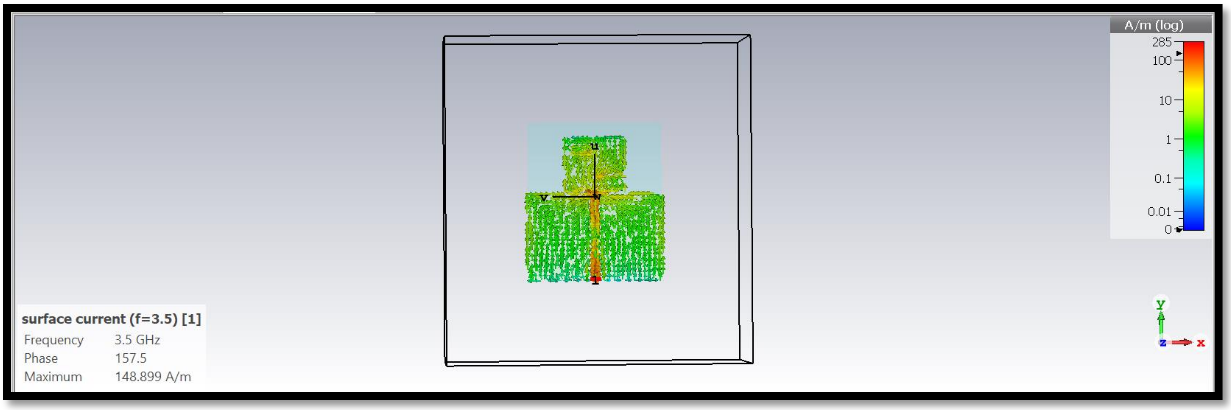
Figure 4.17: The surface current density of non-resonance frequency with PET substrate



surface current (f=3.5) [1]
Frequency 3.5 GHz
Phase 157.5
Maximum 148.899 A/m

Figure 4.18: The surface current density of resonance frequency with PET substrate

Substrate	Surface Current Density, A/m	
	Non-resonance frequency 2.0 GHz	Resonance frequency 3.5 GHz
Rogers 3003	107.877	58.116
Polyimide	291.137	153.891
PET	284.690	148.899

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Table 4.3: The comparison of surface current density of three substrate

From table 4.3, the proposed antenna with Polyimide substrate has the highest value of surface current density 291.137 GHz at non-resonance frequency and 153.891 A/m at resonance frequency. The surface current density of PET substrate is 284.690 A/m at non-resonance frequency and 148.899 A/m at resonance frequency. Although the value of surface current density at non-resonance is higher than the surface current density at resonance frequency, but the current does not flow in all the patch in non-resonance frequency. In resonance frequency, the current flow in all the patch.

`The follow parameters to be seen are the radiation properties for Polyimide substrate and PET substrate. Figure 4.19 refer to the 3D radiation pattern of the proposed antenna with Polyimide substrate. It is an omni-directional radiation pattern with the maximum realized gain of 2.44 dB at 3.5 GHz. Figure 4.20 represent the 3D radiation pattern of the proposed antenna with PET substrate. The maximum realized gain of the proposed antenna with PET substrate is 2.257 dB which lower compare to Polyimide substrate. The omni-directional radiation pattern of the proposed antenna can be justified by observing 2D polar pattern. Figure 4.21 and figure 4.22 show the 2D polar pattern of proposed antenna with Polyimide substrate and proposed antenna with PET substrate respectively. The circular represents the E-plane where it cut 0 degree of the radiation pattern and the H-plane is the bidirectional 2D patterns whereby it cut 90 degree of the radiation pattern.

Figure 4.23 represents realized gain of the proposed antenna of three different substrate in the range of 3 GHz to 4GHz. The highest realized gain is 2.50 dB for the proposed antenna with Rogers 3003 substrate, follow by the proposed antenna with Polyimide substrate have the realized gain of 2.44 dB and 2.257 dB of realized gain for the proposed antenna with PET substrate. The efficiency of the proposed antenna with three substrates is shows in figure 4.24. In the range of the BW, the efficiency of the antenna with Polyimide substrate is 96% which is the highest efficiency. The proposed antenna with Rogers 3003 substrate contributes 95% efficiency, slight lower than the Polyimide substrate and proposed antenna with PET substrate provide 92% efficiency. Hence, the proposed antenna with the three substrates have good quality by observing the radiation parameters.

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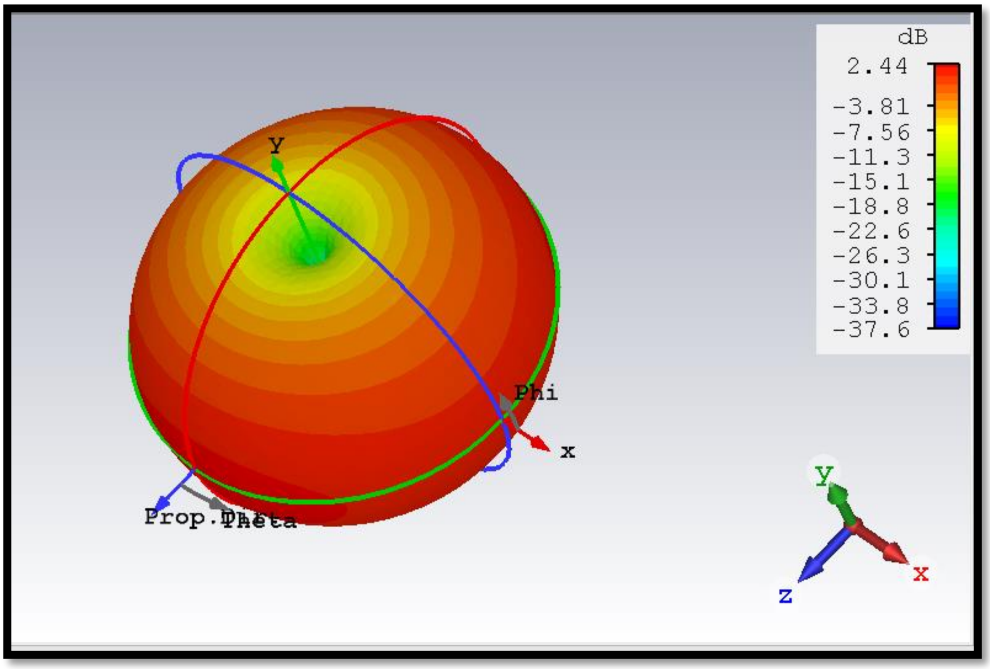

Figure 4.19: The 3D radiation pattern of the proposed antenna with Polyimide substrate

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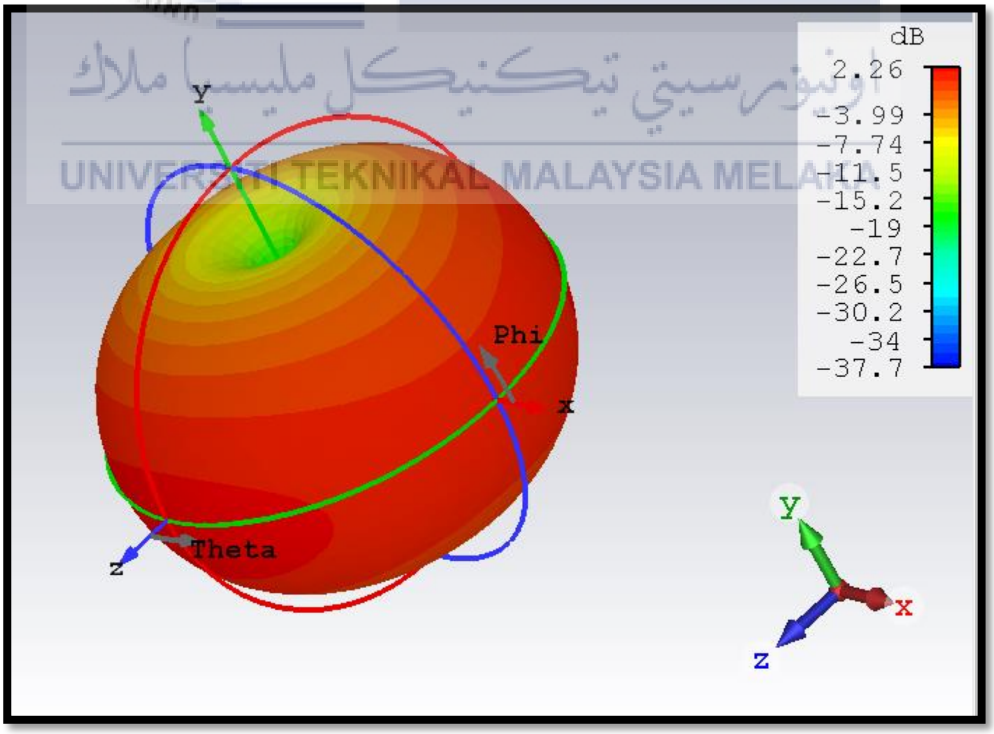

Figure 4.20: The 3D radiation pattern of the proposed antenna with PET substrate

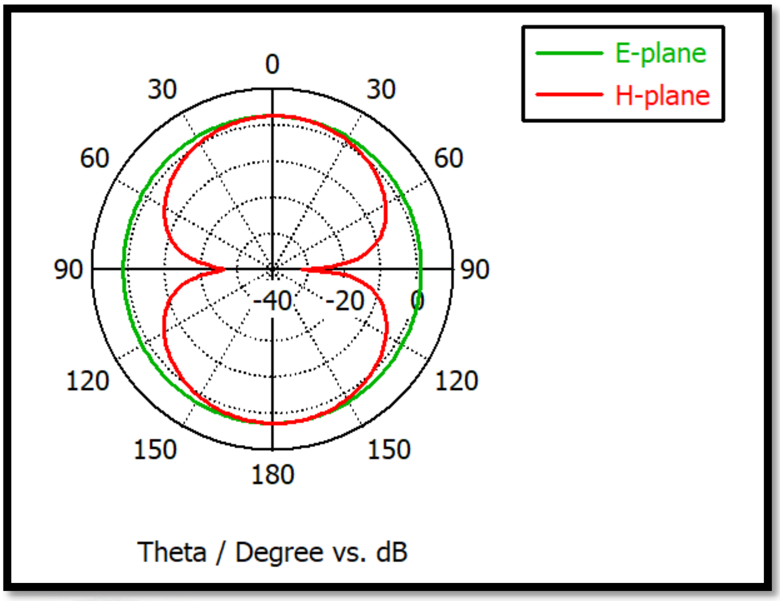

Figure 4.21: The 2D radiation pattern of the proposed antenna with Polyimide substrate

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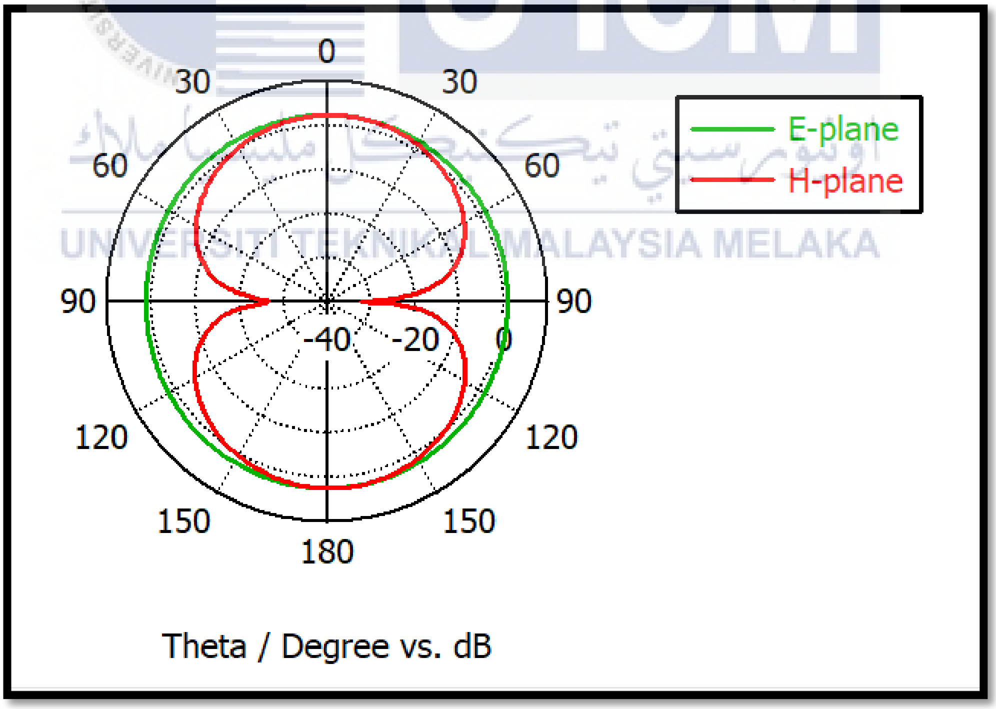

Figure 4.22: The 2D radiation pattern of the proposed antenna with PET substrate

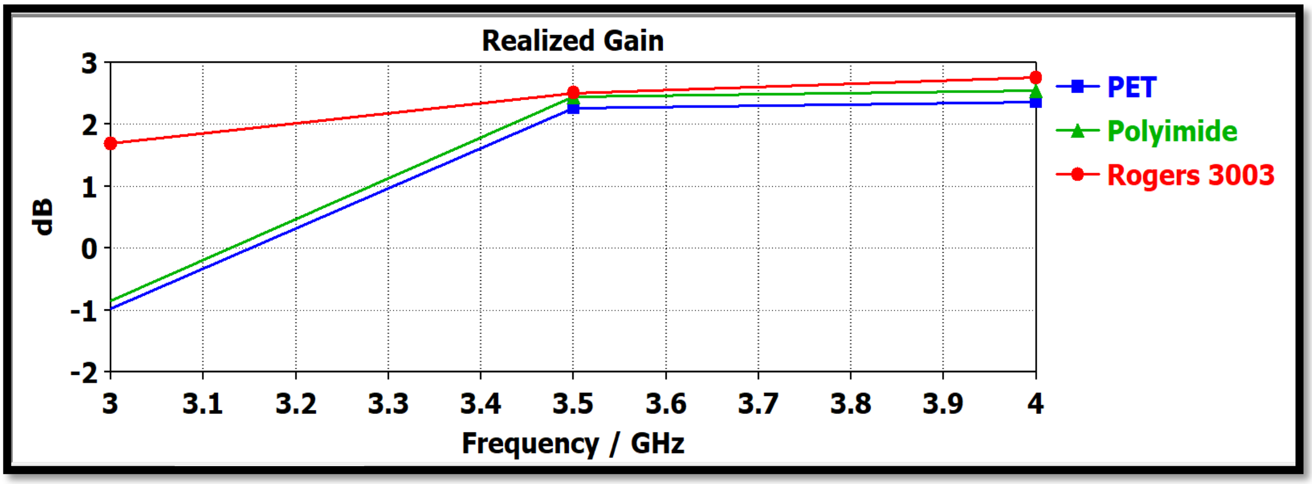

Figure 4.23: The comparison of realized gain of the three substrates

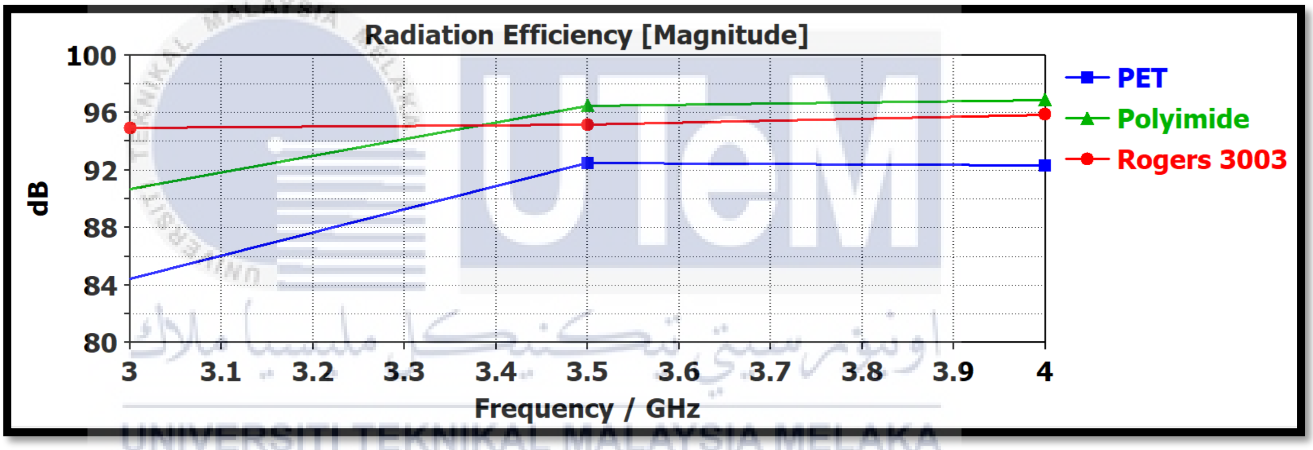

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Figure 4.24: The comparison of radiation efficiency of the three substrates

4.4 The characterization of the planar antenna and bent antenna

The proposed antenna is implemented by bending the antenna to observe the different and the changes on the simulation result. The Polyimide and PET substrate are flexible substrate that can apply the bending application. Figure 4.25 and Figure 4.26 show the antenna is bend 90 degree in XZ plane and YZ plane for Polyimide substrate.

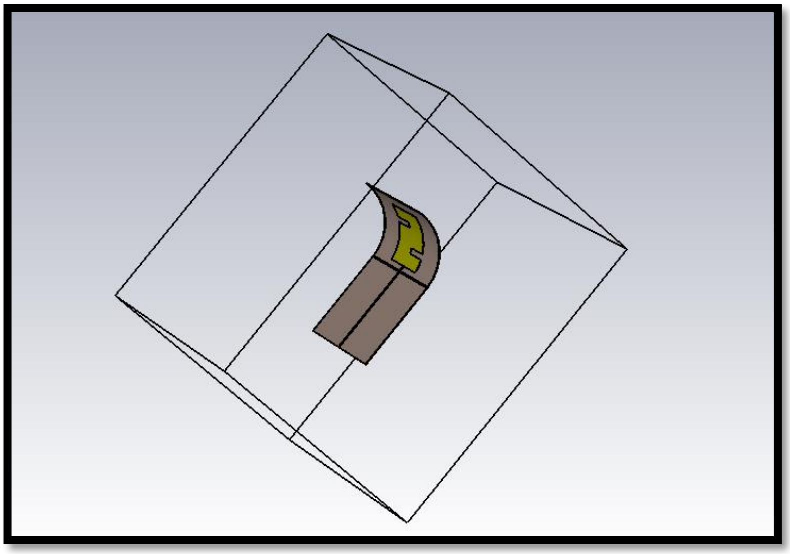

Figure 4.25: Bending in XZ plane for Polyimide substrate

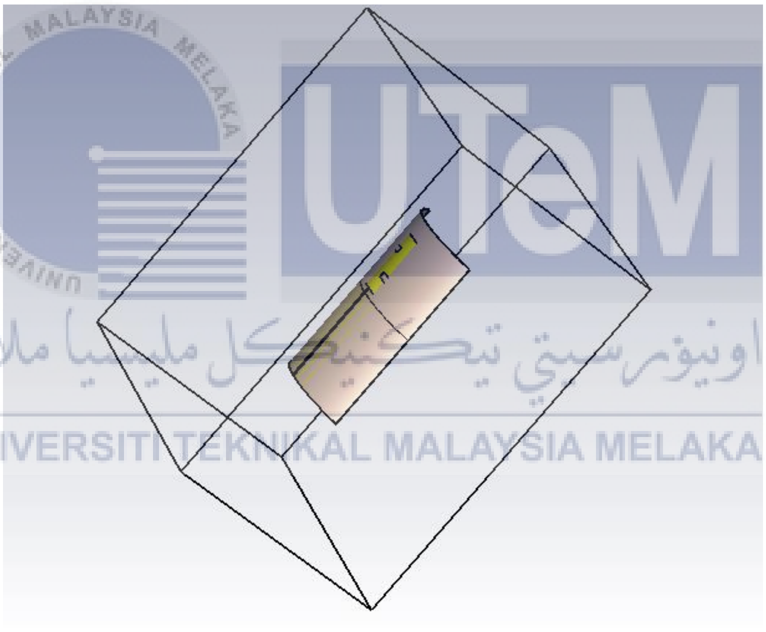

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Figure 4.26: Bending in YZ plane for Polyimide substrate

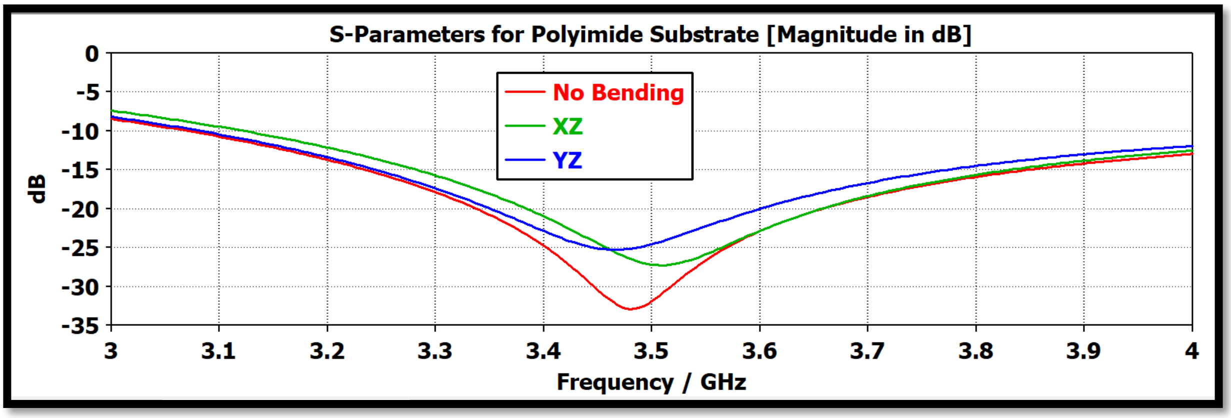

Figure 4.27: S-parameters for Polyimide Substrate with different bending condition

Figure 4.28 show S11 response for different bending conditions, there is a slightly changes in the resonance and return loss for the bending in XZ plane but it still below -10dB. For the YZ plane bending condition also show the changes in resonance and return loss, but it is still in acceptable condition because the resonance frequency is around 3.5 GHz. This result shows that the proposed antenna is stable not only in normal condition, and in bending application

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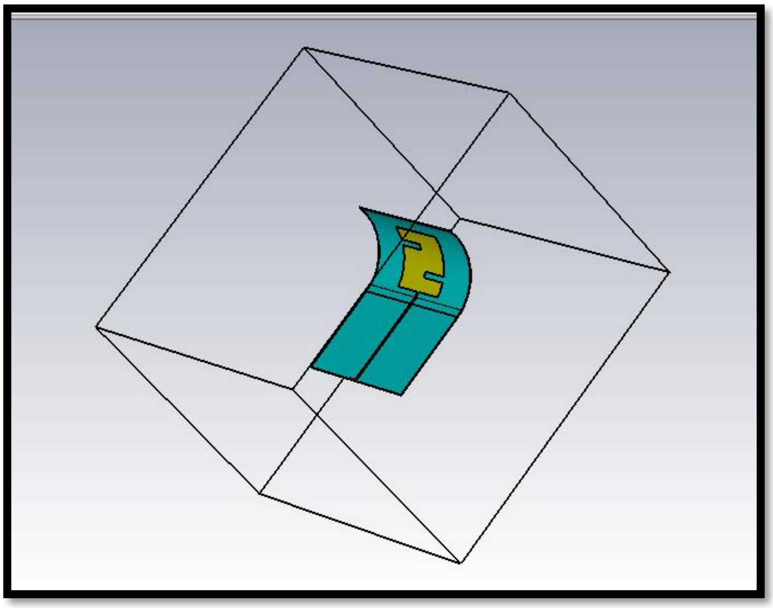

Figure 4.28: Bending in XZ plane for PET substrate

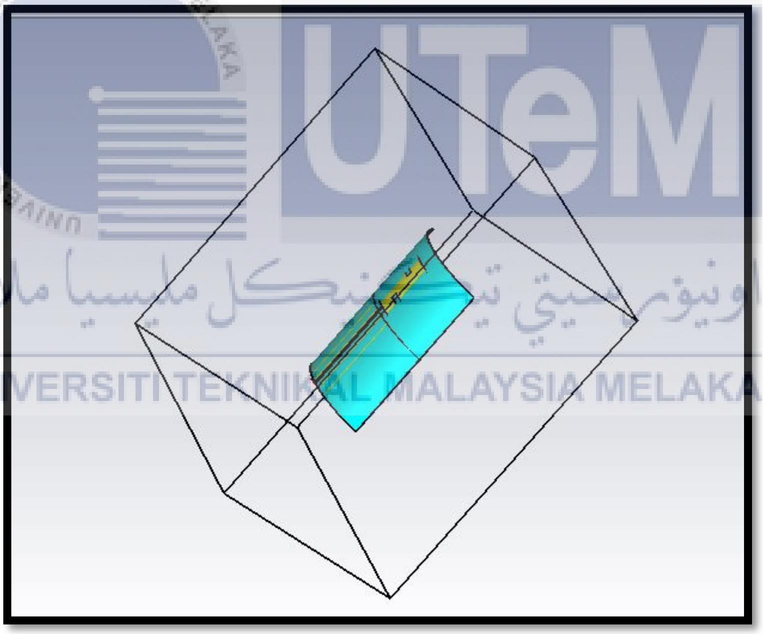

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Figure 4.29: Bending in XZ plane for PET substrate

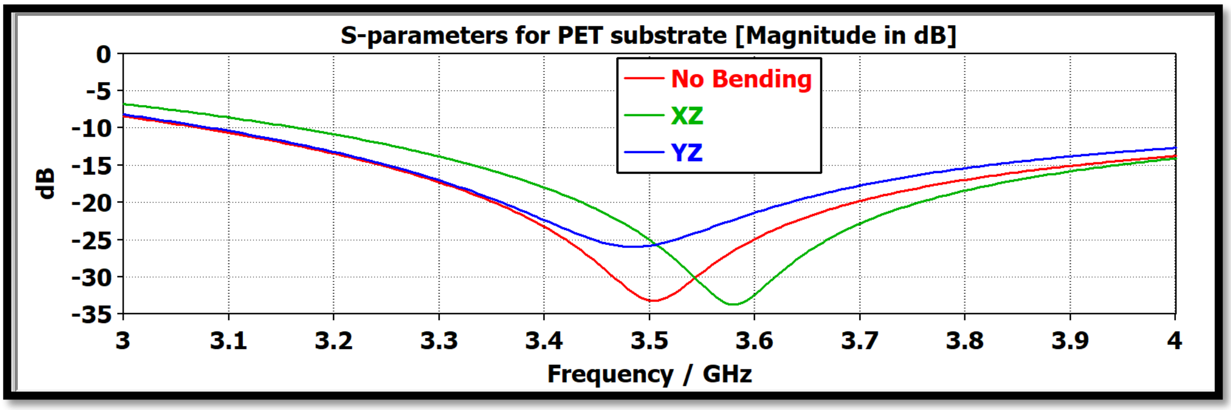

Figure 4.30: S-parameters for PET Substrate

Figure 4.27 and Figure 4.28 show the antenna is bended 90 degree in XZ plane and YZ plane for PET substrate. Figure 4.29 show the S11 for different bending condition. In XZ plane bending condition, the frequency is shift to the right with same return loss value. For the YZ plane bending condition, the resonance frequency is shift to the left and the return loss value decrease to -25 dB. The bandwidth is decreasing compare to normal condition. It can be acceptable because it is resonating in 3.5 GHz. In conclusion, the proposed antenna is stable in term of impedance matching.

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CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter discusses about the conclusion and the future work that can be improve for this proposed antenna. This chapter also determine the performance of the proposed antenna and recommendation and suggestion for this project.

5.2 CONCLUSION

A sub-6GHz Z-shaped planar antenna for 5G application was introduced in this project. The project was split into software and hardware. In the software part, the Z-shaped planar antenna was designed in CST Studio Suite. The proposed antenna showed good performance in terms of bandwidth that was large and covered the 3.5 GHz which is frequency 5G band in Malaysia. The omni-directional radiation pattern shows the good stability and realized gain of the proposed antenna were in good performance. The efficiency of the antenna was 95% which was high efficiency that could be applied in RFID application. The proposed antenna also showed that when designed in Polyimide and PET substrate, it also performed the good result in term of bandwidth and radiation pattern. The bending technique was applied for the antenna designed on polyimide substrate and PET substrate. The simulation results showed good performance for the two substrates. Hence, it had proved that the proposed antenna was stable to apply in RFID application.

5.3 Recommendation

The bending technique was applied to the proposed antenna and simulated in the CST Studio Suite. It showed that the results in terms of S-parameters, surface current density, radiation pattern and gain are in good performance. The fabrication of the bent antenna can be implemented in the future work so that it can be used in other application.

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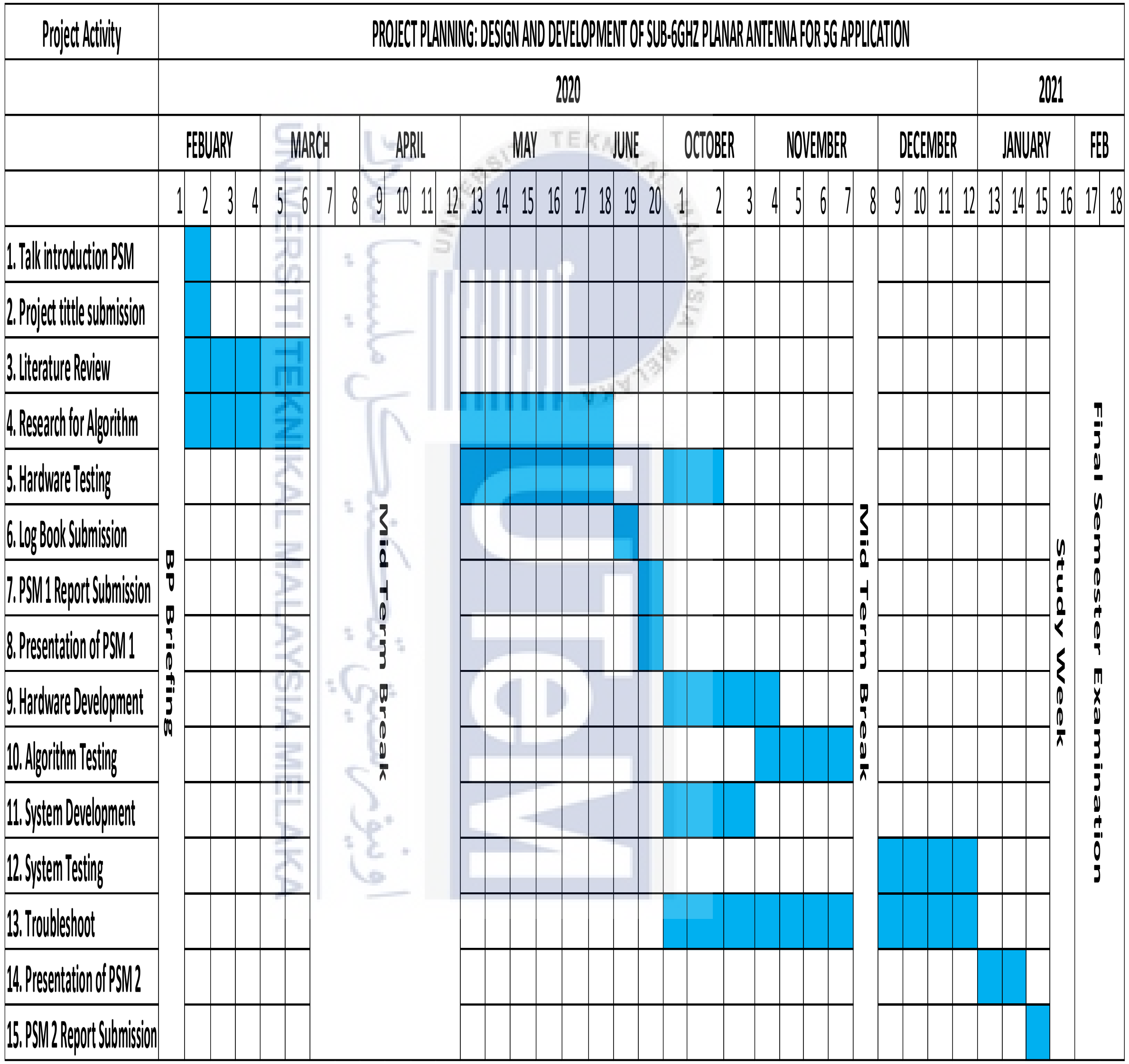
APPENDIX

Appendix 1 : Grant chart of the project



Project Activity	PROJECT PLANNING: DESIGN AND DEVELOPMENT OF SUB-6GHZ PLANAR ANTENNA FOR 5G APPLICATION																																					
	2020																																2021					
	FEBUARY				MARCH				APRIL				MAY					JUNE			OCTOBER			NOVEMBER					DECEMBER				JANUARY				FEB	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Talk introduction PSM	BP Briefing	■					Mid Term Break																						Mid Term Break								Study Week	Final Semester Examination	
2. Project tittle submission		■																																				
3. Literature Review		■	■	■	■	■																																
4. Research for Algorithm		■	■	■	■	■							■	■	■	■	■	■																				
5. Hardware Testing													■	■	■	■	■	■			■	■																
6. Log Book Submission																			■																			
7. PSM 1 Report Submission																				■																		
8. Presentation of PSM 1																				■																		
9. Hardware Development																					■	■	■	■														
10. Algorithm Testing																								■	■	■	■											
11. System Development																					■	■	■															
12. System Testing																													■	■	■	■						
13. Troubleshoot																					■	■	■	■	■	■	■		■	■	■	■						
14. Presentation of PSM 2																																	■	■				
15. PSM 2 Report Submission																																			■			

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