DUAL-BAND MICROSTRIP YAGI ANTENNA DESIGN AND ANALYSIS FOR 4G LTE COVERAGE IMPROVEMENT

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THIS REPORT IS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF ELECTRONIC ENGINEERING WITH HONOURS

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DEDICATION

This work is wholeheartedly dedicated to my beloved parents, Abu Bakar bin Fadzil and Roslida binti Abd Samat, to my respected supervisor, PM Dr Imran, and those in pursuit of knowledge.

ABSTRACT

Some areas, including those within a city, struggle with good internet speed due to network congestion especially band 3 (1.8GHz) and band 7 (2.6GHz) as they are widely used LTE bands in Malaysia. Moreover, a high gain and directional dual-band antenna is expected to overcome this problem while focusing in Yagi Uda design. However, a dual-band antenna using a conventional Yagi-Uda structure requires two sets of antennas, making it bulky and harder to maintain. Therefore, this project proposed the design and analysis of dual-band Quasi-Yagi antenna for 4G LTE band in 1.8GHz and 2.6GHz using FR4 as a substrate, to resolve this issue. Due to a lightweight microstrip antenna's properties and a low-cost antenna, it is perfect for this purpose. The antenna is first designed and simulated in CST software to achieve the desired resonance frequency followed by lab test and field test to validate the antenna's functionality. Result shows the proposed antenna has return loss below -10 dB, voltage standing wave ratio (VSWR) below than 2, gain of 4.625 dB and 5.4 dB, and directional radiation pattern at E-plane for 1.8 GHz and 2.6 GHz respectively. From the field test, it is proven that the proposed antenna able to improve overall network performance in term of speed and strength.

ABSTRAK

Beberapa kawasan termasuk berada di tengah bandar, menghadapi masalah kelajuan internet disebabkan oleh kesesakan rangkaian terutamanya di jalur band 3 (1.8GHz) dan band 7 (2.6GHz) kerana jalur band itu adalah jalur LTE yang banyak digunakan di Malaysia. Selain itu, dijangkakan bahawa sebuah antena dwi-frekuensi dengan gandaan dan arah yang tinggi dapat mengatasi masalah ini dengan reka bentuk tertumpu pada Yagi Uda. Walau bagaimanapun, sebuah antena dwi-frekuensi yang menggunakan struktur Yagi-Uda konvensional memerlukan dua set antena, menjadikannya besar dan sukar untuk diselenggara. Oleh itu, projek ini mencadangkan reka bentuk dan analisis antena dwi-frekuensi Quasi-Yagi untuk jalur 4G LTE pada 1.8GHz dan 2.6GHz menggunakan FR4 sebagai substrat, Disebabkan oleh sifat antena mikrostrip yang ringan dan berkos rendah, ia sesuai untuk tujuan ini. Antena direka terlebih dahulu dan disimulasikan dalam perisian CST untuk mencapai frekuensi resonans yang diinginkan, diikuti dengan ujian makmal dan ujian lapangan untuk mengesahkan fungsi antena. Hasil menunjukkan antena yang dicadangkan mempunyai kejatuhan balik di bawah -10 dB, nisbah gelombang berdiri voltan (VSWR) di bawah 2, gandaan sebanyak 4.625 dB dan 5.4 dB serta corak radiasi berarah pada medan E untuk kedua-dua frekuensi. Dari ujian

lapangan, terbukti bahawa antena yang dicadangkan dapat meningkatkan prestasi rangkaian keseluruhan dari segi kelajuan dan kekuatan.

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LIST OF SYMBOLS AND ABBREVIATIONS

LTE	:	Long Term Evolution
PCB	:	Printed Circuit Board
SDG	:	Sustainable Development Goals
VNA	:	Vector Network Analyzer
FR4	:	Flame Retardant 4
WLAN	:	Wireless Local Area Network
SMA	:	Subminiature Type-A
CPS	:	MS to coplanar strip
VSWR	:	Voltage Standing Wave Ratio
ε_r	:	Relative Permittivity
h	:	Thickness
CPW	:	Coplanar Waveguide Feed
f_c	:	Center Frequency
λ_G	:	Guide Wavelength
ε_{eff}	:	Effective Dielectric Constant
λ_o	:	Free-Space Wavelength

c	:	Speed Of Light
Z_{in}	:	Input Impedance
BW	:	Bandwidth
D_0	:	Directivity
U_{max}	:	Maximum Radiation Intensity
RL	:	Return Loss
Γ	:	Reflection Coefficient
RSRP	:	Reference Signal Received Power
RSRQ	:	Reference Signal Received Quality
SINR	:	Signal to Interference Noise Ratio
RSSI	:	Received Signal Strength Indicator
dxf	:	CAD data file format
2D	:	Two dimensional
CAD	:	Computer-Aided Design
UV	:	Ultraviolet
DUT	:	Device Under Test
Wi-Fi	:	Wireless Fidelity
ISP	:	Internet Service Provider
eNodeBs	:	Evolved Node B
eNB	:	Evolved Node B
PCI	:	Physical Cell Identity
IP	:	Internet Protocol
AP	:	Access Point
IoT	:	Internet of Things
HPBW	:	Half Power Beamwidth

H-plane	:	Magnetic Plane
E-Plane	:	Electric Plane
PKNM	:	Perbadanan Kemajuan Negeri Melaka
MITC	:	Melaka International Trade Centre
LoS	:	Line of Sight

CHAPTER 1

INTRODUCTION

This chapter provides an overall overview of the project, which includes project background, problem statement, objectives, scope of the project and organization.

1.1 Project Background

According to the data from Digital 2022: Malaysia [1], an analysis conducted by Kepios suggests that the number of Internet users in Malaysia increased from 2021 until 2022 by 365 thousand which equals to 1.3% of growth rate. The growth of internet users was significantly affected by the pandemic Covid-19 outbreak in 2019 as reported in Annual Report 2021 by MCMC [2]. Increased internet user causes an increase in data consumption has resulted in congestion. It leads the performance of the Internet to deteriorate especially in Internet speeds. The effect can be seen greatly when users are experiencing longer loading times during streaming high-definition content. This claim can be supported by the recent report on Mobile Experience during the COVID-19 pandemic: 4G Download Speed by Opensignal indicates that Malaysia's average 4G download speed decreased from 13.4Mbps in early February to an average of 8.8Mbps at the end of March 2020 [3].

In order to overcome the network congestion, a dual-band microstrip Quasi Yagi antenna can be fabricated for the user who experienced a lack of Internet quality. The proposed antenna works for 4G Long Term Evolution (LTE) with frequency of 1800MHz and 2600MHz in a single antenna instead of a separate antenna. Theoretically, Yagi antenna is a directional antenna that gives high gain and long-range coverage, improving Internet speed. Instead of a conventional Yagi antenna or a log periodic antenna, a microstrip Quasi Yagi antenna is considered as of its simplicity, lightweight, low fabrication cost and broad bandwidth [4]. Considering the high data rate these days, it becomes vital to have a high gain as a feature of this antenna to improve the Internet strength.

1.2 Problem Statement

Band 3 (1800MHz) and band 7 (2600MHz) in 4G LTE were widely used causing an increment in 4G usage. It led to network congestion and has affected the quality of user experience. Therefore, the network performance has dropped, especially in data rate speed.

1.3 Objectives

The main objectives of this project are listed below:

i. To investigate the working principle of dual-band microstrip Yagi antenna for 4G LTE Internet.

ii. To design the dual-band microstrip Yagi antenna for 1800MHz and 2600MHz.

iii. To validate antenna speed improvement using fabricated dual band microstrip Yagi antenna.

1.4 Scope of Project

The work scope of this project is mainly to design a dual-band microstrip Yagi antenna for 4G LTE coverage improvement which focuses on band 3 and band 7 of 4G LTE with frequencies of 1800MHz and 2600MHz respectively is studied to provide a solution for poor internet speed. Designing this antenna will require understanding the working principle of the antenna, design and simulation in CST Studio Suite software, fabrication of the antenna designed and testing on the fabricated antenna for field and lab testing. The antenna performance will be evaluated based on these parameters: return loss, gain, radiation pattern and efficiency of the antenna. Measurement of these parameters was first observed during simulation in CST before moving to lab testing which will be using Vector Network Analyzer (VNA) and anechoic chamber room. Moreover, field testing involved is to verify the functionality of the antenna based on the signal strength and internet speed test. All of the testing measurement data will be recorded for analysis purposes.

1.5 Importance and significant

Installing the dual-band Yagi antenna in schools will provide a quality education where the students can be involved in installing the antenna. Besides general knowledge of the antenna, they could also learn hands-on. Hence, this application will ensure inclusive and equitable quality education and promote lifelong learning opportunities for all as in Sustainable Development Goals (SDG)- 4 where the students in school involved will be exposed. Besides that, the proposed antenna is light weight and cost effective considering it only requires simple the fabrication method. It can also cater with two frequencies in a single antenna making it more practical. The project significant is summarized below.

i. The antenna is lightweight and cost effective in terms of fabrication process and maintenance.

ii. It can cater for two different frequencies for LTE band which is band 3 and band 7 in a single antenna.

iii. Improve Internet speed for band 3 and band 7 LTE band.

iv. Good Internet speed ensures inclusive and equitable quality education and promote lifelong learning opportunities for all.

1.6 Project Planning

In the first phase, that supposed to fulfill the first objective started with study on previous research regarding dual-band microstrip Yagi Antenna. This is to ensure the necessary knowledge particularly for designing the antenna including the calculations and formulation are acquired before designing the antenna in order to obtain the desired outcome. The research was done based on any related materials to the topic from articles, journals, books and websites.

Next, using the knowledge obtained during research was implemented on designing the antenna in CST software. The theory applied for designing the antenna will be tested by simulating the designated antenna in CST if it has the expected outcome. If the outcome does not meet the expectation, redesign should be made until satisfy all the requirements needed. This process is crucial as it will save time and reduce costs instead of fabricating and testing every design made.

If the design has passed CST, it is ready to be fabricated. The antenna will be printed on FR4 substrate which involves Printed Circuit Board (PCB) processes including etching. Another testing will take place after fabrication which is lab testing and field testing. Lab testing was conducted using VNA and anechoic chamber to test the return loss, radiation pattern and gain while for the lab testing, speed and strength of the Internet will be tested after installing the fabricated antenna.

Lastly, the last process in this project which cater objective 3 was data analysis and report writing. Data obtained from measurement during lab testing and field testing for all the design were collected to do the analysis. The analysis will be focused on its return loss, gain, radiation pattern and efficiency of the antenna.

1.7 Chapter Outline

There are 5 chapters in this project. Every detail about this project was summarised in the chapter outline for each of the chapter as shown below.

Chapter 1: The first chapter is the introduction of the project which describe the project background, problem statement, objectives, scope of project, importance and significant, project planning and chapter outlines.

Chapter 2: The second chapter focuses on previous work on dual-band microstrip antenna and comparison between previous project discussed to analyse which antenna is better for this project purpose.

Chapter 3: The third chapter is the project methodology that consists of project flow, project design, simulation, fabrication, antenna measurement, data analysis and preliminary result.

Chapter 4: The fourth chapter cover the result and discussion where result obtained from lab test and field test are analysed and explained in this chapter.

Chapter 5: The final chapter concludes overall project and finding during completion of project. It also includes the future recommendation for this project.

CHAPTER 2

BACKGROUND STUDY

This chapter will present a comprehensive literature review based on previous work which focuses on the design, performance, evaluation and applications of dual-band microstrip antennas.

2.1 Previous Related Work

In either the transmitting or receiving mode of operation, an antenna is a device that converts directed electromagnetic waves (signals) into radiating waves in an unbounded medium, often free space. Antennas are devices that depend on frequency. Each one of it is made for a certain frequency band. The antenna rejects signals that are outside of its working band. As a result, the antenna can be considered to be both a transducer and a bandpass filter. In communication systems, antennas are crucial components. Therefore, it is crucial to comprehend their working principle in order to design an antenna with parameters desired [5].

Many people utilize Yagi antennas because of their simple design and strong gain ever since 1928, when Yagi initially defined the antenna in the English language using his name[6]. The Yagi antenna has found various uses in both military and commercial applications due to its benefits of quick feeding, simple manufacture, outstanding directivity, and high gain performance. The standard Yagi antenna, however, has the drawbacks of relatively large size, narrow band (less than 5%), and tuning issue. As a result, there were minimal uses for this antenna[7]

In order to implement the Yagi-Uda antenna ideas in the microwave field, researchers are working hard to solve these drawbacks. By integrating the Yagi-Uda array concept and the microstrip radiator technology, an alternative antenna design is created [8]. The planar printed quasi-Yagi antenna has received a lot of interest for usage in microwave and millimeter wave applications since Huang initially proposed the microstrip-fed quasi-Yagi antenna in 1991. This is because of the benefits it produces, such as low profile, low weight, simplicity in production and installation, high radiation efficiency and high directivity [9].

Previous related works selected in this background study are focused on dual-band microstrip antenna which fabricated on FR4 substrate. The parameters of the antenna such as return-loss, gain and directivity are analyzed are compared to identify which antenna is best fitted to be implemented to current antenna project for LTE application. Therefore, the type of dual-band microstrip antenna to be compared are Quasi-Yagi antenna, log-periodic antenna, patch antenna and patch array antenna.

2.1.1 A Dual-band Microstrip fed Monopole Quasi - Yagi [10]

This paper proposed a dual-band microstrip fed monopole and quasi-Yagi antenna to be used with Wireless Local Area Network (WLAN) access point. The antenna comprised a printed circular monopole etched with a rectangular slot antenna as the driver fed by a microstrip transmission line, five metal patches as the directors and one reflector. It was designed for bandwidth of 2.09 to 2.07 GHz and 4.71 to 6.05 GHz. The goal of this project is to construct a dual-band Yagi antenna which is compact in size, low cost, efficient and simple to fabricate.

The proposed antenna is illustrated in Figure 2.1. It uses 2 sides of FR4 with permittivity, ε_r of 4.4, length and width of the same measurement which is 42.8 mm. A subminiature type-A (SMA) was used as a microstrip-to-coaxial line transition. Of all the 4 models designed, model 4 has the best result in terms of its return loss, radiation pattern and gain. All these coefficients are shown in Figure 2.2, Figure 2.3 and Figure 2.4. Based on all these results, the proposed antenna has dual-band property, high directivity (directional) and high gain (6.2 dB and 6.5dB).

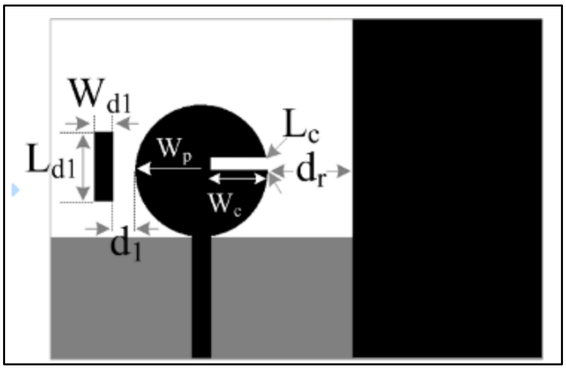


Figure 2.1: Geometry of the proposed antenna (model 4)

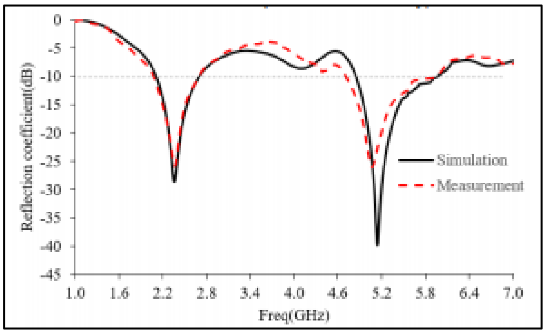


Figure 2.2: Simulated and measured reflection coefficients

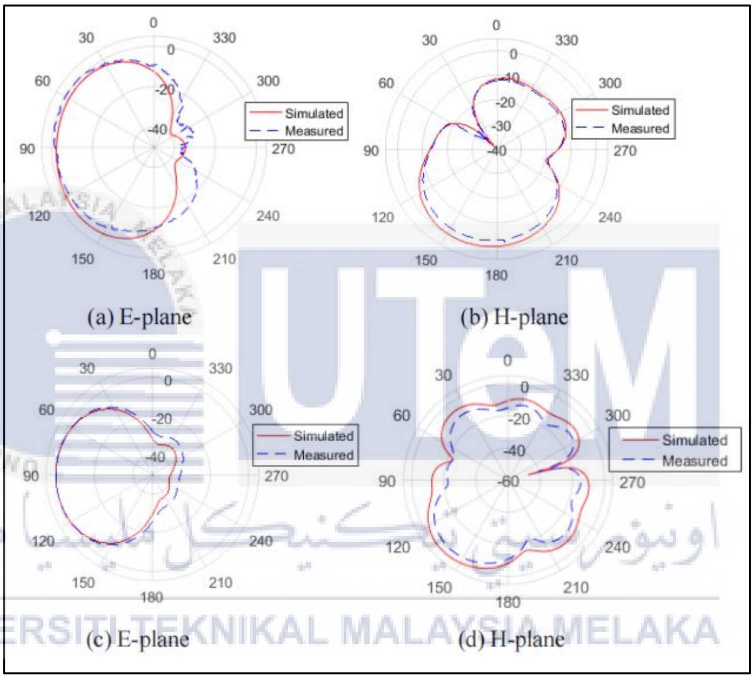


Figure 2.3: Simulated and measured radiation patterns of the propose antenna at (a),(b) 2.45 GHz and (c), (d) at 5.5 GHz

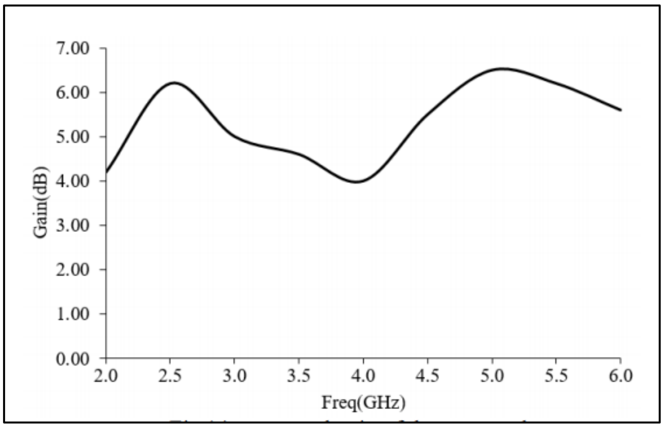


Figure 2.4: Measured gain of the proposed antenna.

This research also did a parameter study on model 4 design in Figure 2.1 with parameters listed in Table 2.1 along with the effect when the parameter changes.

Table 2.1: Comparison of parameters effect

No.	Parameter	Effect
1	Length of driver (W_p)	If W_p increases, the lower band hardly change while the higher band decrease. Therefore, W_p determine the resonant frequency of lower band.
2	Width of Slot (W_c)	If W_c increases, the lower band does not change while the impedance matching of notched band decreases.
3	Length of director (L_{d1})	Increasing L_{d1} will increase the resonance of lower band while the center frequency of higher band insignificantly changes.

In conclusion, the dual-band microstrip antenna was successfully fabricated on a FR4 substrate with a relative permittivity of 4.4 and a thickness of 1.6 mm. The measured and simulated reflection coefficient demonstrated shows clear correlation where the measured bandwidth of the optimized antenna was found to be 2.09 - 2.70 GHz and 4.71 - 6.05 GHz for the -10 dB reflection coefficient, almost identical to simulated bandwidth of 2.12 - 2.72 GHz and 4.82 - 6.08 GHz. This wide bandwidth fulfills the specifications for WLAN operation in the 2.45 GHz and 5.5 GHz bands. Significant gains of 6.2 dB and 6.5 dB indicate the antenna's ability to provide enhanced signal strength and reception efficiency. Thus, the excellent performance of fabricated dual-band microstrip antenna in term of wide bandwidth coverage, accurate radiation patterns, and high gains at the desired frequencies validate the effectiveness of the antenna design for WLAN applications.

2.1.2 Parametric study of a dual-band quasi-Yagi antenna for LTE application [11]

This paper presented a quasi-Yagi antenna for LTE application resonating at 1.8 GHz and 2.6 GHz is portrayed in Figure 2.5. The antenna consists of eight director elements, driven element and truncated ground plane. The ground plane is made of cooper metal and is used as a reflector element. It was fabricated on FR-4 substrate with a MS to coplanar strip line (CPS) transition feeding technique. CPS technique is preferred than conventional feeding technique as it has unbalanced characteristics which will affect the radiation of a printed dipole element. The aim is to achieve high gain and broad bandwidth which make it suitable for LTE spectrum.

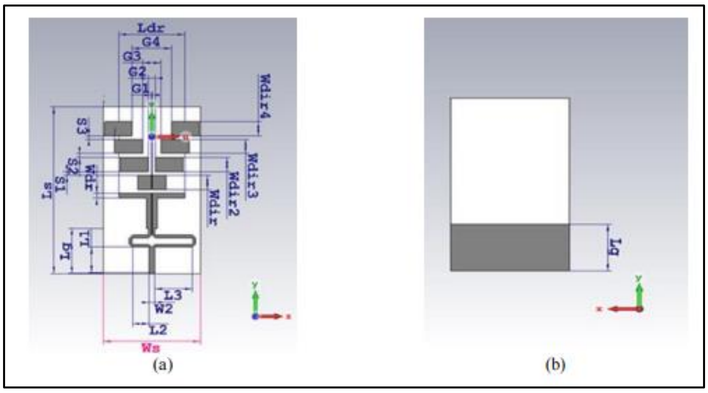


Figure 2.5: Geometry of proposed quasi-Yagi antenna. (a) front view and (b) back view.

Based on the simulated result from CST software in Figure 2.6 (a), the return-loss is -65.23 dB and -31.55 dB for frequency resonant of 1.8 GHz and 2.6 GHz respectively. The return loss with magnitude lower than -10 dB shows that the antenna reflects minimal energy. Moreover, from Figure 2.6 (b), the VSWR measures less than 2 for the least variance which indicate most power from transmitter is being radiated by the antenna than being reflected toward the source. Both return loss and VSWR obtained show that the antenna has good performance with minimal signal losses as it ensures efficient power transfer.

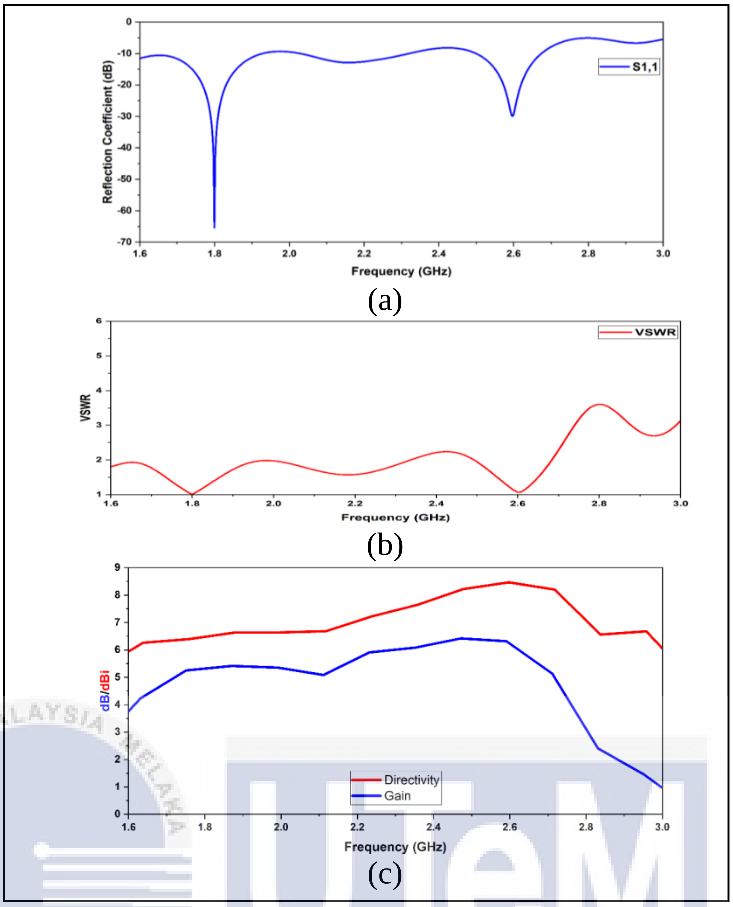


Figure 2.6: Coefficients of the proposed antenna. (a) return-loss, (b) VSWR and (c) Gain and directivity

According to this research, the effectiveness of the proposed antenna depends on substrate's thickness, length of the feed and parasitic components and the spacing between it. The best result obtained from the proposed antenna is when it has more directors, low ground plane length, high tuning length of driven element and low thickness of FR4 substrate. Manipulating these parameters has demonstrated good antenna characteristic with good reflection coefficient, gain, directivity, (F/B) ratio and VSWR for both operating bands of 1.80 GHz and 2.60 GHz as in Figure 2.6.

2.1.3 Dual-band Microstrip Antenna for 4G-LTE Handheld Devices [12]

This research showcased a dual-band antenna with operating frequency of 1780 MHz and 2610 MHz for 4G-LTE handheld devices such as mobile phones. To ensure it fits the casing of the device, the dimension used for FR4 substrate is 20 mm × 50 mm × 1.2 mm. The designed is as illustrated in Figure 2.7.

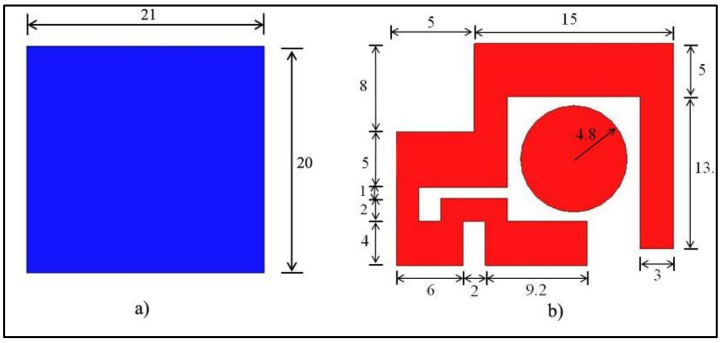


Figure 2.7: Antenna design: a) bottom view and b) top view

Comparison between simulated and measured results gives good agreement where it only has slight difference in bandwidth and return loss as in Figure 2.8.

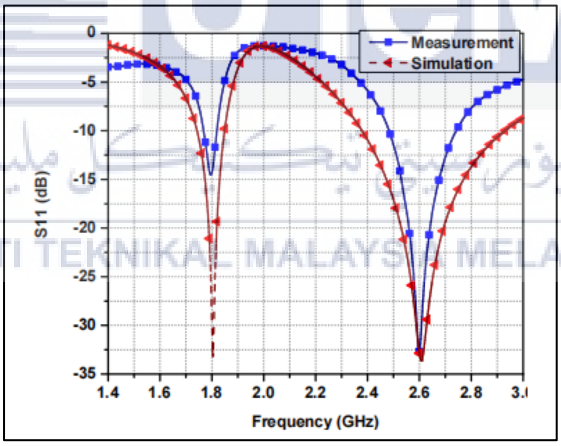


Figure 2.8: Simulation and measured result of return loss

Therefore, a microstrip antenna capable of operating in two frequency bands, 1780 MHz and 2610 MHz for 4G LTE handheld devices has been successfully designed and constructed. The antenna design demonstrates promising simulation results, including wide bandwidth and favorable gain at both low and high resonant frequencies.

2.1.4 A Log-Periodic Microstrip Patch Antenna Design for Dual Band Operation in Next Generation Wireless LAN Applications [13]

In this paper, a dual-band inset-fed log-periodic microstrip patch antenna for next generation WLAN is proposed. The goal is to design an antenna with operating frequency of 2.4 GHz and 5 GHz. The proposed antenna comprises of four radiating elements and two inset-fed, each one for each frequency band. Furthermore, standard FR4 substrate is used. An array of four elements is created to cover the full WLAN band, which includes frequencies at 2.4 GHz and 5 GHz. For each frequency band, two square patch elements are used, and the design uses a feeding technique called inset feeding. By utilizing the log-periodic technique, a single antenna element has been transformed into an array configuration as in Figure 2.9.

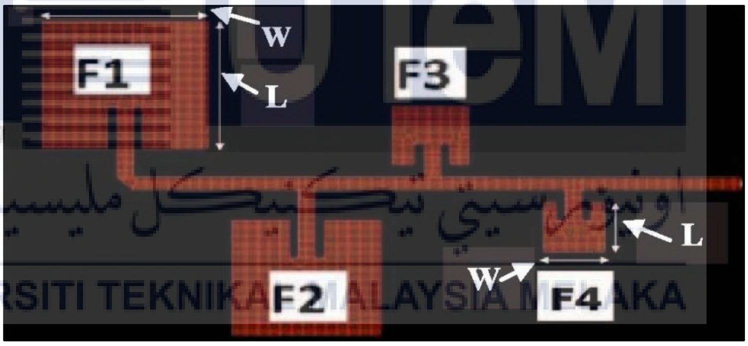


Figure 2.9: Dual-band log-periodic antenna array

Based on result in Figure 2.10, simulated return loss obtained is at desired which is below -10 dB for both frequencies, 2.4 GHz and 5 GHz. Return loss of -22.5 dB and -19 dB at 2.4 GHz and 5 GHz respectively shows that the reflected signal is less than 10% of the transmitted signal. However, there are also other frequencies available beside the desired frequencies due to log-periodic nature of the antenna. The result of the proposed antenna reveals the directivity is 7.05 dBi and 7.6 dBi while the gain of is 2.75 dBi and 0.6 dBi at 2.4 GHz and 5 GHz respectively.

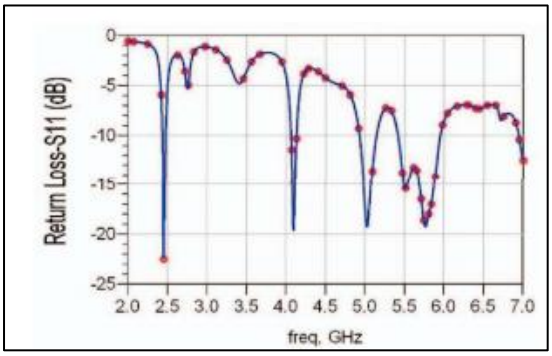


Figure 2.10: Return loss of proposed antenna.

It can be concluded that wider bandwidth can be obtained when using log-periodic antenna. Increment in number of patch element will increase the bandwidth. Moreover, the spacing between the elements does not exhibit consistent periodicity. In order for the signal at a particular frequency to reach the correct antenna element, the branch lines of the following element should have an open circuit impedance.

2.1.5 Dual Band Microstrip Patch Array Antenna for LTE Applications in Malaysia [14]

A single element antenna resonates at 1.8 GHz and 2.6 GHz was proposed in this research. The proposed antenna consists of a radiating patch, inset feed line, substrate and ground plan. Furthermore, SMA connector is used along with the antenna to connect the inset to feed line. Based on the geometry of proposed antenna in Figure 2.11, the U-shaped cut will provide the frequency of 2.6 GHz.

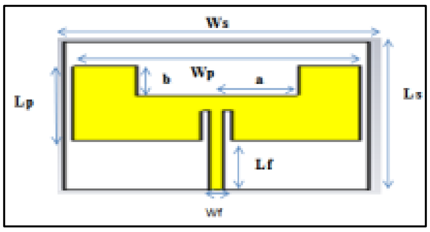


Figure 2.11: Single element dual band microstrip patch antenna

Two and four numbers of elements are used with antenna arrays to achieve higher directivity while feeding each element with microstrip feed line using 3 dB divider. The antenna directivity depends on the number of array elements. Different numbers of array elements are tested for 2×1 array and 4×1 array antenna with corporate T-junction feeding technique in this research. By referring to Figure 2.12, it shows that only the single element has accurate operating frequency of 1.8 GHz and 2.6 GHz as desired compared to 2 elements and 4 elements due to fringing effect. However, all antenna appears to have reflection coefficient below -10 dB at resonance frequency, which is desirable.

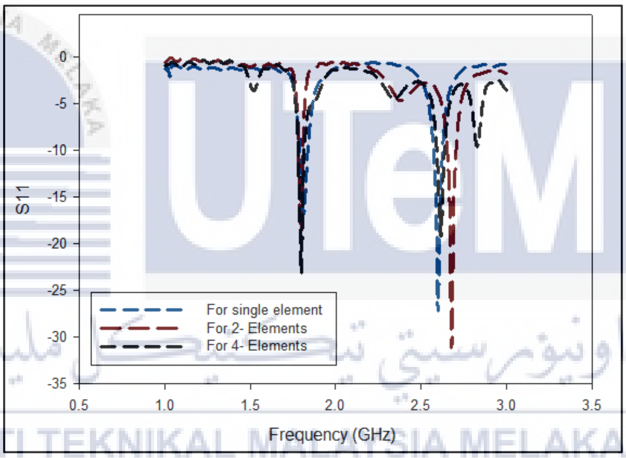


Figure 2.12: Reflection coefficient result of different number of elements.

Figure 2.13 shows that the directivity for 4 × 1 elements antenna array has the most directional radiation pattern.

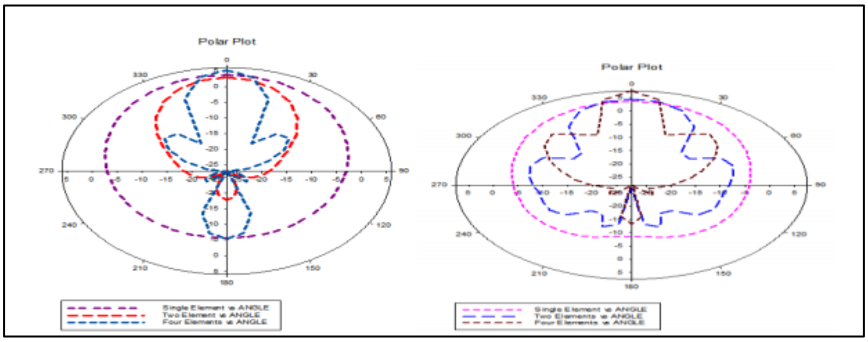


Figure 2.13: Simulated polar plot of the single element, 2 x 1 and 4 x 1 at 2.6GHz

From the finding, it shows that increasing the number of array elements will improve the directivity. However, this increment will also increase the complexity of the antenna. To attain higher gain and directivity, various forms may be used. In order to achieve a larger gain, multiple antenna elements can be added simultaneously. Additionally, the antenna's bandwidth needs to be improved. To increase the antenna bandwidth, a variety of methods could be used, including slot coupling, stacked patches, and parasitic patches on the same plane. Future dual band microstrip antennas should be designed for greater frequencies of operation for mobile communications since the antenna's size is purely dependent on its frequency. The dual band microstrip antenna's frequency is inversely proportional to its size.

2.2 Antenna Summary of Literature Review

All the proposed antenna in selected literature review previously can be summarized in Table 2.2. Not all parameters are stated clearly in their research. In general, all of these antennas are dual-band which mostly have resonance frequency of 1.8 GHz and 2.6 GHz which is LTE band while the other has 2.4 GHz and 5 GHz.

All of the antennas were fabricated on FR4 substrate and majority has relative permittivity, ε_r of 4.4 with thickness, h equal to 1.6 mm. Overall, all of the antenna has good return-loss value which is below -10 dB. Comparing all of the antennas that operate in resonance frequency of 1.8 GHz and 2.6 GHz, Quasi-Yagi type antenna has quite high gain. Moreover, the gain from log-periodic is very low when compared to quasi-yagi antenna that operates at the same resonant frequency which is 2.45 GHz and 5.5GHz. Thus, from collected data in Table 2.2, dual-band microstrip Quasi-Yagi antenna has the best peak gain which will result in higher signal strength.

Table 2.2: Parameters of proposed antenna in literature review

Antenna design	Description	Resonance frequency (GHz)	Return-loss (dB)	Gain (dB)	Directivity (dBi)
Dual-band microstrip fed monopole Quasi-Yagi Antenna	• 5 metal patches (director) • 1 reflector • circular monopole with rectangular slot • FR4 substrate • ε_r= 4.4 • h=1.6mm • type-A (SMA) connector	2.45	-30	6.2	N/A
		5.5	-40	6.5	N/A
Dual-band Quasi-Yagi Antenna	• FR4 substrate • Coplanar strip line transition feeding • 8 directors • truncated ground plane as reflector (cooper plate) • ε_r= 4.3 • h=1.56mm	1.8	-65.23	5.5	6.5
		2.6	-31.55	5.8	8.5

Dual-band microstrip antenna	• FR4 substrate • Dimension of 20×50×1.2 mm • ε_r= 4.4 • h=1.2 mm	1.78	-33.7	2.64 dBi	N/A
		2.61	-34	3.48 dBi	N/A
Log-periodic dual-band Microstrip patch antenna	4 radiating element 2 inset-fed amtenna 2x1 elements frequency band • FR4 substrate • ε_r= 4.5 • h=1.6 mm	2.4	-22.5	2.75 dBi	7.05
		5	-19	0.6 dBi	7.6
Dual-band microstrip patch array antenna	Corporate feed with T-jungtion power divider Slot for 1.8GHz u-shaped cut for 2.6GHz SMA connector 2- element • FR4 substrate • ε_r= 4.6 • h=1.6 mm	1.8	-16.14	4.49	9.16
		2.6	-31.11	5.14	8.91

After identifying the best design structure, comparison on antennas' performance is narrowed to this type of design only. Several past works are compared in Table 2.3.

Table 2.3: Comparison of previous work on microstrip Quasi Yagi Antenna

Ref	Substrate	Resonance Frequency (GHz)	S_{11} (dB)	Gain (dB)	Directivity (dBi)	VSWR
[15]	Rogers 4003C ε_r= 4.6 h=1.6 mm	9.62	<10	8	--	--
		11.15	<10	8	--	--
[16]	Rogers R04350b ε_r= 3.48 h=0.25mm	2.45	-38	6.75	6.8	--
		5	-18	4.84	5.3	--

[17]	FAF-4D-SKL ε_r= 2.5 h=1.5mm	1.98	-27	--	--	--
		2.43	-17	--	--	--
[18]	FR4 ε_r=4.4 h=1mm	4.2	-23	3.5	--	--
		7.1	-20	4.2	--	--
[19]	FR4 ε_r= 4.4	2.45	-34	--	--	--
		3.6	-30	--	--	--
[20]	FR4 ε_r= 4.4 h =0.4mm	0.9	-15	0.1	--	--
		2.45	-20	3.4	--	--
[21]	Cooper laminated ε_r= 4.5 h =1.25mm	0.9	-26	4.95	--	--
		2.4	-24	7.26	--	--
[22]	--	0.868	-25	1.4	--	--
		2.45	-15	2.03	--	--
[22]	FR4 ε_r= 4.4 h =1.6 mm	2.3	-10	4.9	--	--
		3.5	-15	8	--	--
[23]	FR4 h =1.6 mm	2.3	-20.38	5	--	--
		3.6	-24.49	5	--	--
[24]	FR4 ε_r= 4.4 h =1.6 mm	2.4	-20	6.5	--	--
		3.5	-25	8.3	--	--
[25]	FR4 ε_r= 4.4 Rogers 5880 ε_r= 2.2	2.6	-15	4.43	--	--
		5.5	-30	4.79	--	--
[26]	FR4 ε_r= 4.3 h =1.6 mm	1.8	-65.23	5.3	6.5	1
		2.6	-31.55	6.2	8.3	1.2

CHAPTER 3

METHODOLOGY

This chapter focuses on method and considerations taken during the process of accomplishing the objectives of this project from designing until testing the fabricated antenna. This chapter combine the knowledge on theoretical principles, practical method and measurement procedures as comprehensive approach to successfully develop the dual-band microstrip Yagi Antenna.

3.1 Project Flowchart

Project process flow can be seen in Figure 3.1. This illustration is important to give project outline in completing this project. Hence, it will be more organize and clear on the things that should be done. There are 3 phases in this project which cater the objectives. In the first phase, it focuses on designing the antenna using appropriate method before going into phase 2 which is simulation and testing the fabricated antenna. The last phase is to validate the fabricated antenna. Therefore, it will focus on analysis on the fabricated antenna to verify the functionality of the proposed antenna.

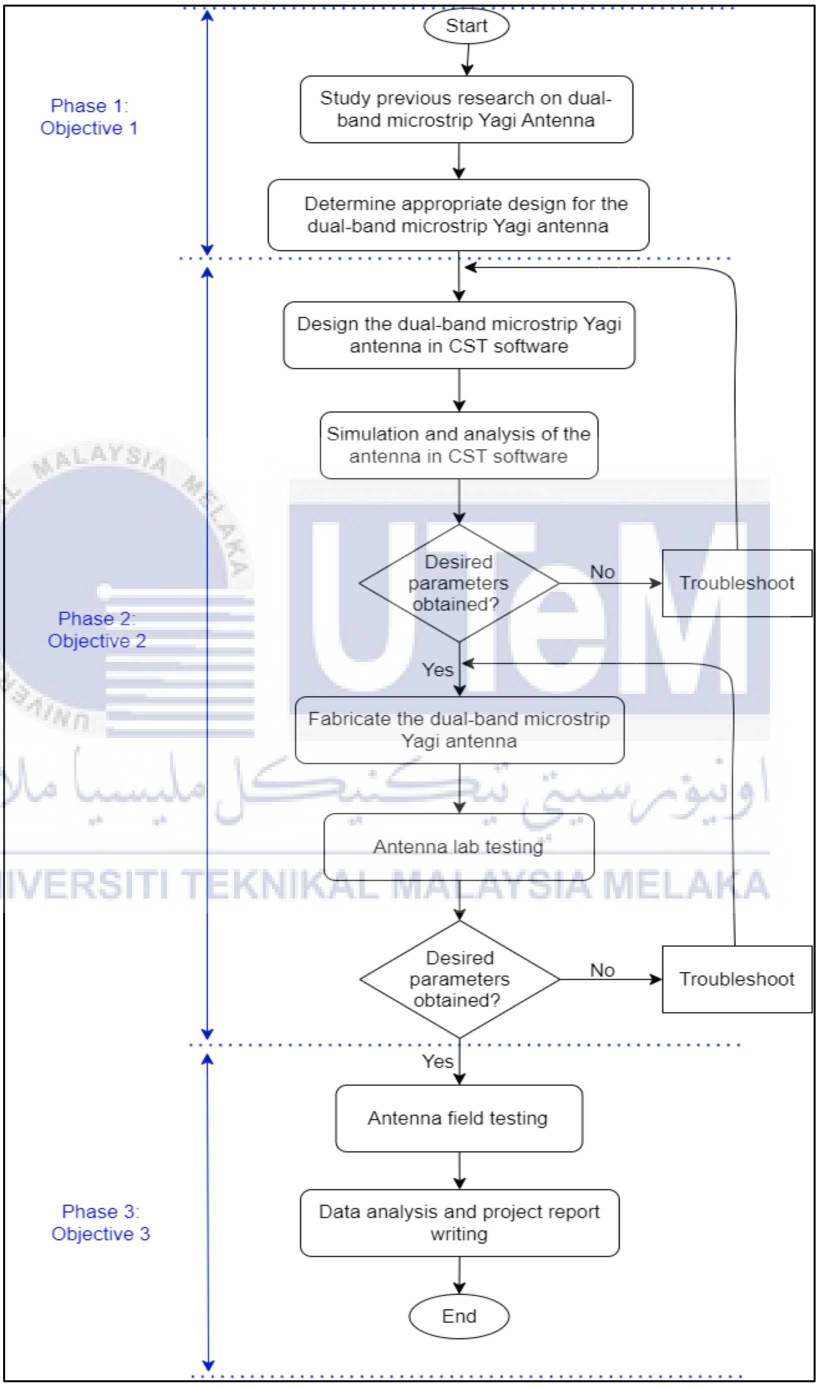


Figure 3.1: Flowchart of Project Planning

3.2 Designing Process

In the design process, the software that will be used is CST software to design antenna operates at 1.8 GHz and 2.6 GHz. Three steps are required to be taken in producing a well-developed antenna which include design structure and material, design parameters and design process.

3.2.1 Design Structure and Material

The structure and materials of an antenna is a crucial part in designing an antenna as it will affect the performance and frequency range that will determine the successfulness of an antenna.

A microstrip patch antenna with quasi-Yagi design techniques is proposed as the structural design for this project as in Figure 3.3. The microstrip patch antenna is widely used in wireless applications due to its compact size, lightweight nature, and cost-effectiveness. However, it has a limitation in terms of narrowband performance [27]. Therefore, the proposed design incorporates a quasi-Yagi antenna layout for the patch, derived from the conventional dipole Yagi-Uda antenna known for its high gain and narrower bandwidth [11]. The conventional Yagi antenna in Figure 3.2 consists of driven elements and non-driven parasitic elements, including reflector and director elements. Similarly, the quasi-Yagi antenna retains these characteristics but utilizes a different feeding technique [28].

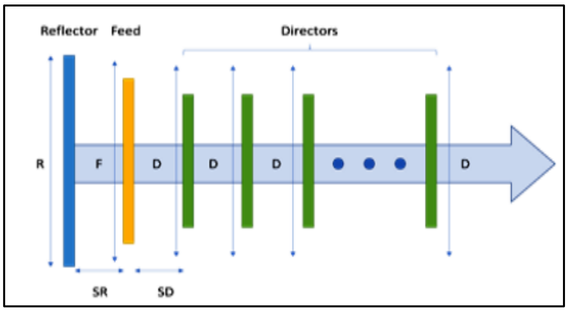


Figure 3.2: Geometry of Conventional Yagi-Uda Antenna [11]

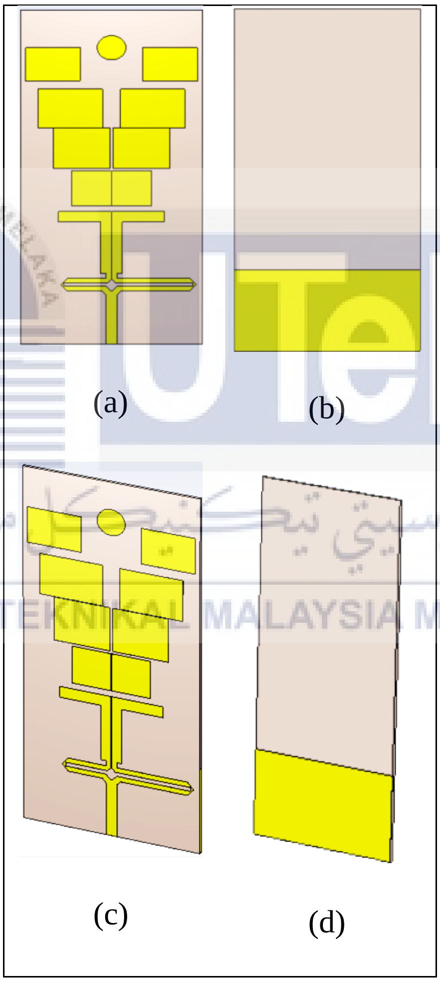


Figure 3.3: Proposed dual-band Quasi-Yagi antenna view: (a) front, (b) back, (c) front perspective, (d) back perspective.

While for the selection of material, FR4 substrate is selected for fabrication materials of this antenna. FR4 is a type of fiberglass-reinforced epoxy laminate material. It is used as it has relatively low and stable dielectric constant, cost-effective and conveniently easy to find. Moreover, this material gives more flexibility in design as it is available in different thicknesses. Hence, for this project, FR4 substrate used has 1.56 mm thickness with relative dielectric of 4.3.

3.2.2 Feeding Technique

Quasi Yagi antenna can be designed using several different types of feeding technique such as microstrip-to-coplanar, stripline transition (MS-to-CPS), coplanar waveguide feed (CPW) and Tapereded balun. The proposed antenna specifically used MS-to-CPS feeding technique as it provides the highest bandwidth compared to the three feeding techniques [28].

3.2.3 Design Parameters

Design parameters refer to the dimensions of the antenna structure. The performance of an antenna is directly influenced by its dimensions. The size, shape and proportions of antenna will affect the antenna's radiation pattern, gain, directivity, and bandwidth. Therefore, careful consideration is taken to achieve desired antenna performance. The parameters in the **Figure 3.4** are calculated and some are assumed.

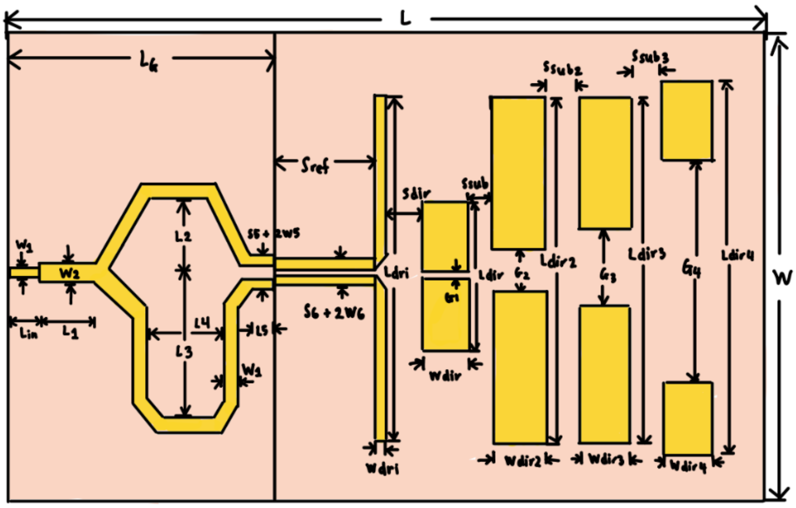


Figure 3.4: Parameters of proposed antenna (Preliminary Design)

Center frequency of this antenna can be defined using Equation (3.1). As the proposed antenna has 1.8 GHz and 2.6 GHz for minimum frequency and maximum frequency respectively, its center frequency is 2.2 GHz.

$$f_c = \frac{f_{max} + f_{min}}{2} \tag{3.1}$$

The properties of FR4 substrate for relative permittivity, ε_r and thickness, t is determined before doing any calculation. The guide wavelength, λ_G can be obtain only after finding its effective dielectric constant,ε_{eff} based on the Equation (3.4) and Equation (3.3).

$$\lambda_G = \frac{\lambda_o}{\varepsilon_{eff}} \tag{3.2}$$

$$\lambda_o = \frac{c}{f_c} \tag{3.3}$$

$$\varepsilon_{eff} = \left(\frac{\varepsilon_r+1}{2}\right) + \left(\frac{\varepsilon_r-1}{2}\right)\left[\frac{1}{\sqrt{1+\frac{12d}{Wdr}}}\right] \tag{3.4}$$

$$W_{dr} = \frac{c}{2f_c\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{3.5}$$

Where λ_G=Waveguide length, λ_o=free-space wavelength, c=speed of light, ε_{eff}= effective permittivity, d= substrate thickness, W_{dr}= width driven element

All parameters of the antenna in **Figure 3.4** is calculated based on Equation listed below [29]. The lengths calculated are in millimeters (mm) and the center frequency, f_c is considered in GHz. Hence, before doing the calculation, make sure all the units are correct.

$$L_1 = 35.4{f_c}^{-1} \tag{3.6}$$

$$L_2 = 20.5{f_c}^{-1} \tag{3.7}$$

$$L_3 = 61.5{f_c}^{-1} \tag{3.8}$$

$$L_4 = 2L_2 \tag{3.9}$$

$$L_5 = 15.4{f_c}^{-1} \tag{3.10}$$

$$W_1 = 3 \tag{3.11}$$

$$W_2 = 5.15252 \tag{3.12}$$

$$S_5 = 2 \tag{3.13}$$

$$W_6 = 2.6 \tag{3.14}$$

$$S_6 = 1.8 \tag{3.15}$$

$$Z_0 = 50\Omega \quad (3.16)$$

$$L_{dri} = 135.2{f_c}^{-1.165} + 4.843 \quad (3.17)$$

$$L_{dir} = 0.421L_{dri} \quad (3.18)$$

$$L_G = L_{in} + L_1 + L_4 + L_5 \quad (3.19)$$

$$L = L_G + S_{ref} + S_{dir} + S_{sub} \quad (3.20)$$

$$W = 1.5L_{dri} \quad (3.21)$$

$$S_{ref} = 60.2{f_c}^{-1.315} + 5.798 \quad (3.22)$$

$$S_{dir} = 0.636S_{ref} \quad (3.23)$$

$$S_{sub} = 0.379S_{ref} \quad (3.24)$$

$$W_{dri} = 5.29{f_c}^{-1.315} + 0.5095 \quad (3.25)$$

$$W_{dir} = W_{dri} \quad (3.26)$$

3.2.4 Design Process

The design process for this project involves identifying the value of the design parameters to have desired antenna performance. Some methods that can be considered are using equations, assumption or using parametric studies. The specification of the antenna is depicted in Table 3.1.

Table 3.1: Specification of proposed antenna

Substrate type	FR4
Substrate thickness (mm)	1.56
Relative permittivity, ε_r	4.3

Cooper thickness (mm)	0.02
Center frequency (GHz)	2.2

For this proposed antenna, some parameters are calculated in Table 3.2 based on calculation in 3.2.3 and some are determined based on assumption.

The assumption method in determining the remaining structure dimension is based on previous study from *Parametric study of a dual-band quasi-Yagi antenna for LTE* [11] and *Design Equations for the Quasi Yagi-Uda Antenna Operating in the UHF band* [29]. Table 3.3 show the assumption values for remaining parameter. All of the values for parameters in this part are the initial values. Parametric studies are implemented to obtain the best value to achieve the desired result.

Table 3.2: Parameters value

Parameter	Value (mm)
$\boldsymbol{L_1}$	16.0909
$\boldsymbol{L}_2$	9.3182
$\boldsymbol{L}_3$	27.9545
$\boldsymbol{L}_4$	18.6364
$\boldsymbol{L}_5$	7
$W_{\mathbf{1}}$	3
W_2	5.15252
W_6	2.6
S_5	2
S_6	1.8

L_{dir}	24.755
L_{dri}	58.8
L_G	49.7727
L	104.4673
W	88.2
S_{ref}	27.144
S_{dir}	17.264
S_{sub}	10.288
W_{dri}	2.385
W_{dir}	2.385

Table 3.3: Parameter value assumed.

Parameter	Value (mm)
L_{in}	8.0455
W_{dir2}	15.38
W_{dir3}	15.38
W_{dir4}	15.38
L_{dir2}	56.99
L_{dir3}	57. 52
L_{dir4}	56.48
S_{sub2}	4.18
S_{sub3}	4.29
G_1	0.50

G_2	7.47
G_3	18.88
G_4	40.34

3.3 Antenna Simulation

The platform used for simulating the proposed antenna is CST software as it provides accurate visual representation of antenna behavior. The design in **Figure 3.4** is constructed in this software to monitor the performance of the antenna based on parameters such as impedance, bandwidth, directivity and gain, radiation pattern, return loss and VSWR. During this process, parameter sweep function is used to obtain the best performance.

3.3.1 Impedance

Input impedance, Z_{in} of an antenna is known as instantaneous impedance of the input terminals of antenna that determine the efficiency of radiation. In order to obtain the most efficient electromagnetic radiation, the antenna should be a matching line between transmission line impedance and free space impedance where this concept is clearly illustrated in Figure 3.5.

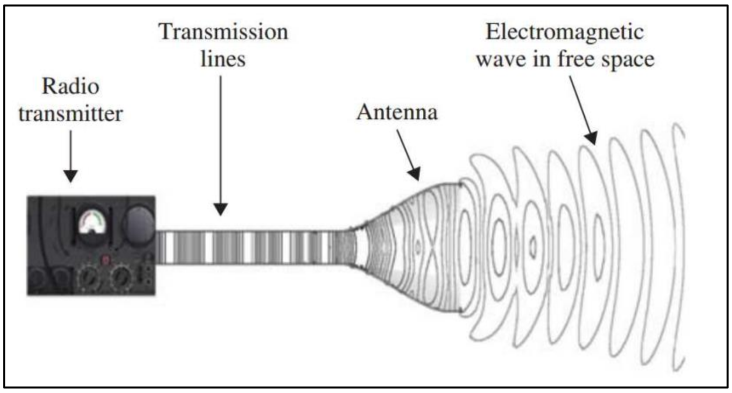


Figure 3.5: Basic concept of matching line between transmission line impedance and free space impedance [30]

. Therefore, the antenna should have a matching line approximately 50 Ω as the transmission lines impedance is 50 Ω. If not, mismatch will happen and as a result, radiation efficiency will be reduced [30].

3.3.2 Bandwidth

An antenna only allows specific frequency band to be transmitted or received which operates similar to band pass filter. The amount of information transmitted depends on the system's bandwidth [30]. The bandwidth of the antenna is actually the frequency range of antennas' resonance frequency. Bandwidth, BW can be calculated using Equation (3.27).

$$BW = \frac{f_{upper} - f_{lower}}{f_0} \times 100\% \tag{3.27}$$

3.3.3 Directivity and Gain

Directivity, D_0 of an antenna is calculated using Equation (3.28) where U_{max} is maximum radiation intensity. It is the ability of an antenna to focus its energy in a particular direction during transmission or receiving. In this case, a static antenna radiated more energy in a particular direction desired which known as directional antenna and radiated less energy in other direction.

$$D_0 = \frac{U_{max}}{P/4\pi} \tag{3.28}$$

Gain is a dimensionless ratio that defined amount of energy radiated in one direction while comparing it to the energy radiated by isotropic antenna in the same direction. The antenna gain is written as dB but written as dBi for isotropic antenna Only the maximum gain is considered where it shows the most power radiated in particular direction [31].

3.3.4 Radiation Pattern

Radiation pattern is the relative strength of radiated field from the antenna in many directions at a constant distance. It is measured in the farfield of the antenna. The radiation pattern can visualize the radiated power distributed in space with respect to antenna. Even though the radiation pattern is three dimensional, it is typically measured in two dimensions in a polar format in horizontal and vertical planes. For polar coordinates, it has two classes which is linear and logarithmic. Plotting in CST used the logarithmic polar coordinates system [31].

3.3.5 Return Loss

Besides impedance, return loss is also a method that identifies mismatch. Mismatch that occur will reflect the signal back to it source such that the signal unable to be transmitted through space as an electromagnetic wave. The return loss, RL of antenna is denoted in logarithmic form of reflection coefficients as in

Equation (3.30) while the reflection coefficient, Γ is calculated in Equation (3.29). Reflection coefficient is also known as S_{11} in S-parameters [30].

$$\boldsymbol{\Gamma} = \frac{\boldsymbol{Z_{in} - Z_0}}{\boldsymbol{Z_{in} + Z_0}} \tag{3.29}$$

$$\boldsymbol{RL = -20\log\ |\Gamma|[dB]} \tag{3.30}$$

To have a good antenna performance, the antenna should have return loss more than 10 dB in the interest band. It indicates that the antenna accepts 90% of the received power while reflecting the remaining 10% back to the source. However, it is normal to have 6 dB for electrically small antenna.

3.3.6 Voltage Standing Wave Ratio (VSWR)

VSWR can be referred to Standing Wave Ration (SWR). It defines power reflected from antenna. VSWR that is also a function of reflection coefficient can be calculated using Equation (3.31). The value calculated is always real and positive number [32].

$$\boldsymbol{VSWR} = \frac{\boldsymbol{1 + |\Gamma|}}{\boldsymbol{1 - |\Gamma|}} \tag{3.31}$$

VSWR is desired to be less than 2 to have a good performance. Ideally, VSWR is equal to 1, where there will be no reflected power and the voltage is constant value in the transmission line.

3.4 Antenna Fabrication

Fabrication starts when the optimized parameter values satisfy the desired performance specification. Firstly, the design needs to be exported in dxf format as this format keeps the 2D data of the design. This step can be done directly from CST software. Since the film used is a negative photoresist film, annotate the areas not intended for copper with black color. This file can be opened in any suitable CAD software such as CorelDraw. This step is very important and crucial in photoresist patterning.

Figure 3.6 illustrate a simplified flow diagram of the main steps involved in antenna fabrication process.

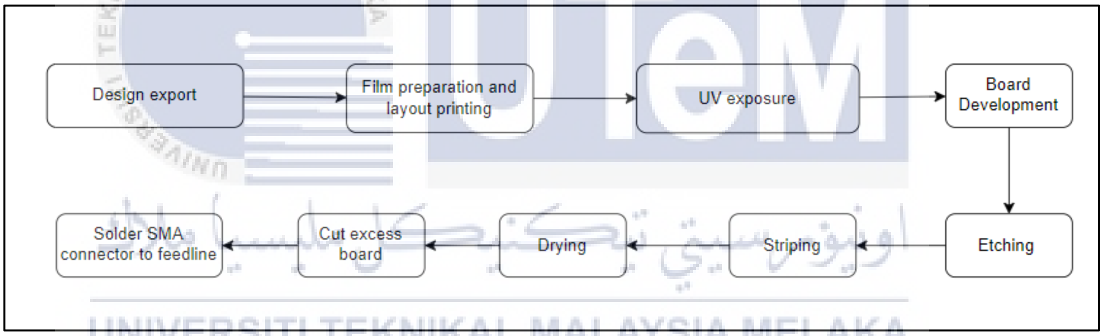


Figure 3.6: Antenna fabrication process flow

The adjusted layout from before is printed on a transparent film using a laser printer. Prepare the FR4 board by laminating both top and bottom surfaces with photo-sensitive film. Followed by printing the inner layer, the printed film for top and bottom layers are aligned together to ensure proper positioning with the board before exposing it to UV light. This step hardens the cooper coverage area under the transparent area of printed film that allows light to pass through. Meanwhile, the black area is protected from hardening because the black area prevents light from reaching the photo-resist film. The process continues with board development where the unhardened parts on the board are washed away by an alkaline developer solution, leaving the hardened pattern behind. The board is then immersed into an etching solution to dissolve unprotected copper which is not covered by photoresist. The remaining photoresist is removed with stripper solution, revealing the final circuit pattern in bare cooper. To achieve clean and finished product, the excess board area is trimmed. Finally, SMA connector is soldered to the feedline. The fabrication process is a success as pictured in Figure 3.7.

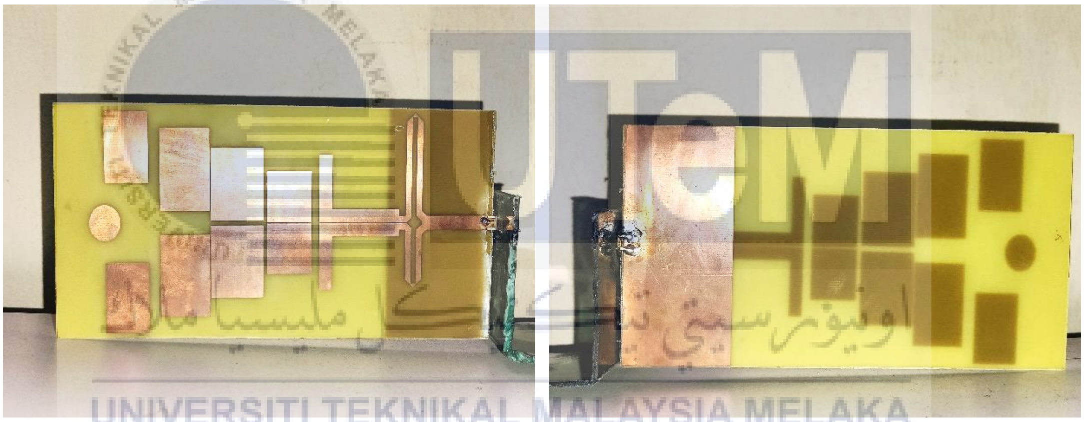


Figure 3.7: Fabricated Antenna

3.5 Antenna Measurement

Antenna measurement is vital for determining the project’s success. The measurements taken from two types of testing incorporate lab testing and field testing which are controlled environment and real environment respectively. Lab test is conducted under objective 2 whereby it is the final stage in designing a dual-band antenna. Field test on the other hand, falls under objective 3. It validates the functionality of the antenna within actual operating condition.

3.5.1 Lab test

During lab test, several parameters are monitored such as return-loss (S_{11}), radiation pattern and gain. Measurement for S_{11} is taken from vector network analyzer (VNA). Moreover, both radiation pattern and gain are measured within an anechoic chamber.

3.5.1.1 Vector network analyzer

Vector network analyzers (VNA) is a common tool used to verify design performance by measuring S-parameters [33]. Reflection coefficient, S_{11} is one of the S-parameters and an essential parameter that affects the power transmitted by the antenna directly. Figure 3.8 shows S_{11} test on the fabricated antenna by connecting the antenna port to the VNA port.

As depicted in Figure 3.9, incident waves are the waves entering the device under test (DUT) while the reflected waves are the waves exiting DUT. Both incident and reflected waves are used to characterize a DUT by applying the equation shown. In S-parameter theory view, S_{11} can be obtain from Forward case where it correlates with reflection coefficient at Port 1. Forward case happens when a_1 signal transmitted from Port 1 matches with load applied to Port 2, the signal reflection at the load is equivalent to zero [34].

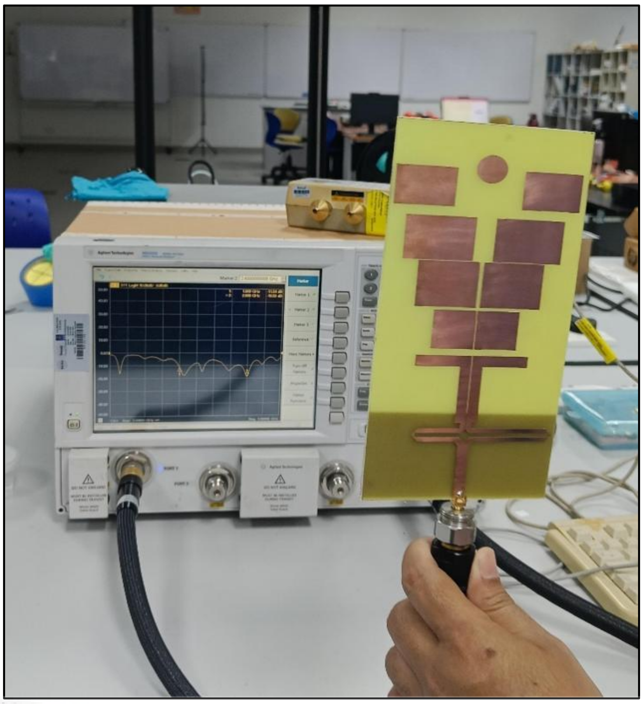


Figure 3.8: Testing S_{11} of an antenna using VNA

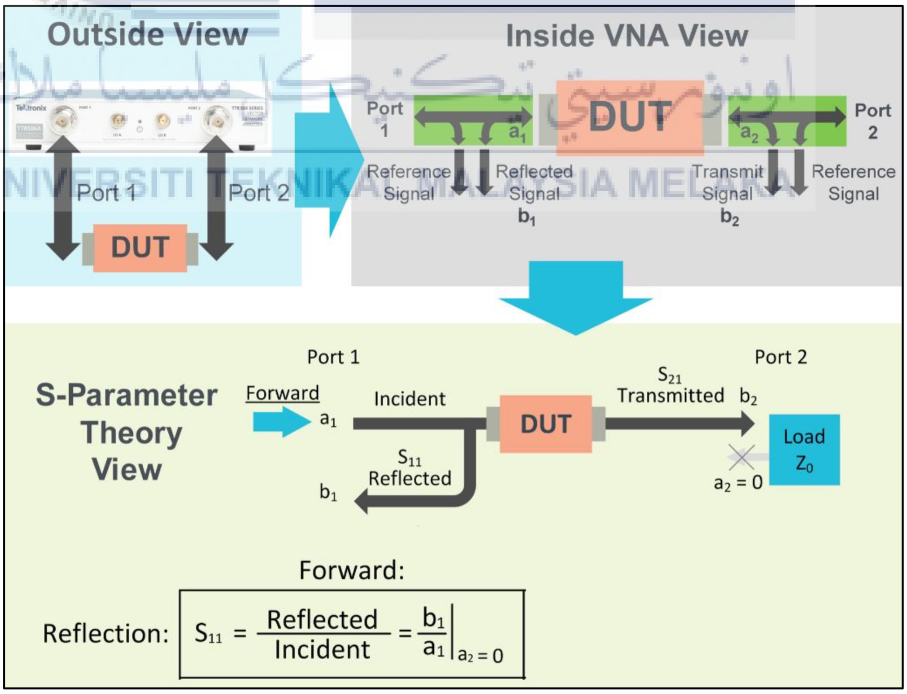


Figure 3.9: Overview of VNA working to measure S_{11} [34]

3.5.1.2 Anechoic Chamber

Anechoic chamber is used to test fabricated antenna as it provides a controlled indoor setting for the fabricated antenna. The antenna connection within the chamber is depicted in Figure 3.10 This setting is crucial to obtain accuracy in measurement required as conventional indoor setting will cause the generated wave to be reflected by walls and ceiling. Thus, resulting in a complicated measurement. Therefore, the antenna can be isolated from extraneous signal in anechoic chamber. Since the chamber's walls are lined with pyramidal-shaped absorbed, reflection within the chamber can be minimized. As a result, the measured antenna characteristics accurately reflect its performance in a free-space environment where it is free from external interference [35].

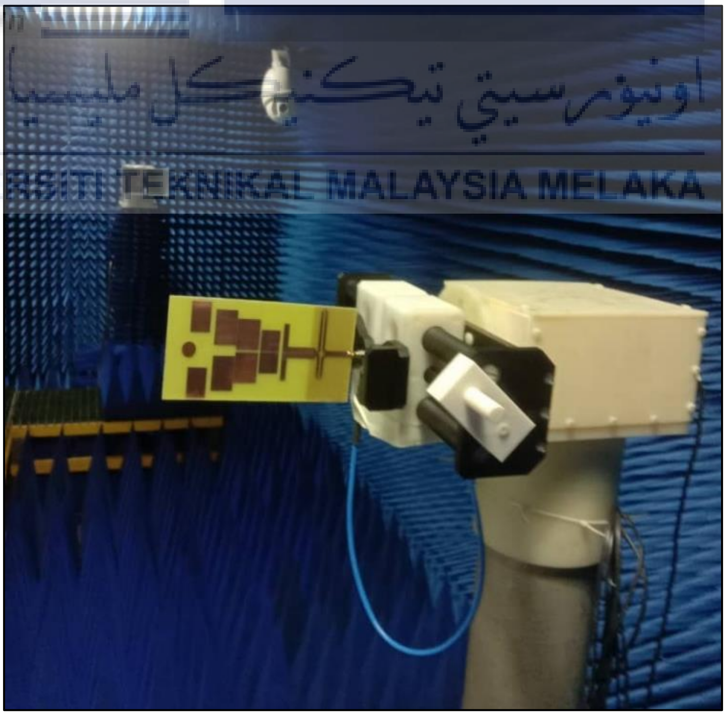


Figure 3.10: Fabricated antenna undergo lab test in anechoic chamber.

3.5.2 Field Test

Field tests are as crucial as lab tests. Apart from ideal condition in lab test, the real-world environment during field test validates the functionality and performance of the fabricated antenna in the intended environment where it includes the interference and reflections. Field test involves testing the speed test and signal strength of mobile Wi-Fi 4G. For this project, the fabricated antenna was tested under the same condition successively where the measurement is taken at Pangsapuri Taman Tasik Utama with coordinate 2°16'04.8"N 102°16'47.3"E between 10:00 am to 5:00 pm. Moreover, the Internet service provider used (ISP) during the test is Maxis, one of the most leading ISP. The hardware connection to carry out the field test is as shown in Figure 3.11.

Figure 3.11: Hardware connection for field test

In general, the whole field test measurement flow is simplified in flowchart in Figure 3.12. The process is repeated for band 3, band 7 and combination of both band 3 and band 7.

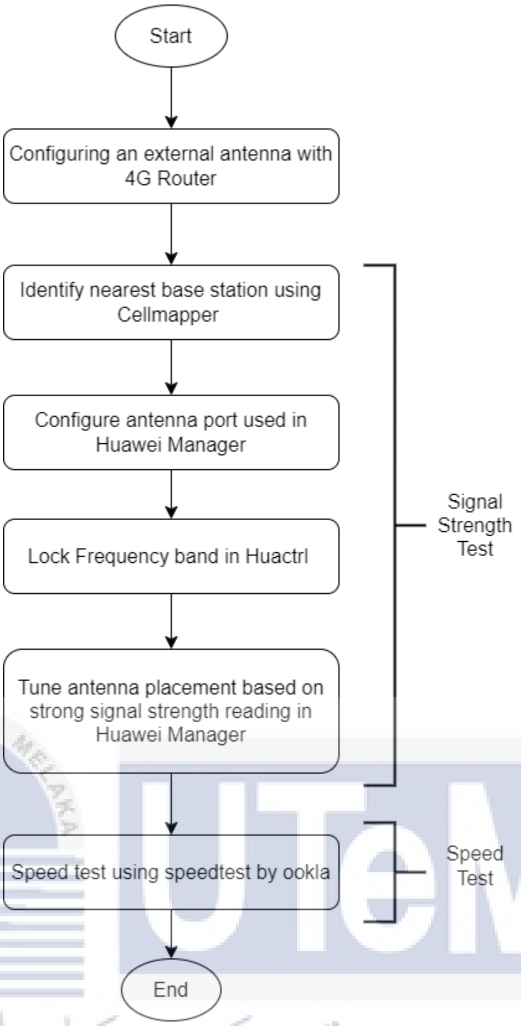


Figure 3.12: Field test measurement process

3.5.2.1 Signal Strength Test

Signal Strength measurements are taken directly from Huawei Manager. Careful observations are made on RSSI, RSRQ, RSRP and SINR. However, a few factors need to be considered first before relying on those parameters' reading. This includes identifying the nearest base station using Cellmapper and locking specific band using HuaCTRL to ensure the measurement reflects its optimal performance.

3.5.2.1.1 Location of Base Station

Cellmapper offers cellular tower including 2G, 3G, 4G and 5G base stations and coverage mapping service. The search of base station can easily be filtered by any providers used. In this case, provider used is Maxis. This application can be accessed from a website or by installing from Playstore. Having this application in mobile phone certainly help to detect which base station eNodeBs the mobile network is connected to as depicted in Figure 3.13. Keep in mind, this feature will only works when the simcard is inserted in the mobile phone.

Figure 3.13: Nearest base station from site location

Moreover, Cellmapper also provides information on all channels available along with mapped cell coverage of a base station as in Figure 3.14. Referring to the base station with eNB ID 360023 in Figure 3.13, the base station covers band 1, band 3 and band 7. As this base station supports band 3 and band 7 particularly, it can be used as a reference point for orienting the fabricated antenna. To be more specific, the antenna should be directed to the nearest PCI (Physical Cell Identity) where in this case, the nearest PCI to site location which support both cell 2 and cell 12 for band 3 and band 7 respectively is 160 (53/1).

Selection of base station location to point the antenna is important because it will directly impact the user's network performance in terms of coverage and signal strength [36]. Information on cell 2 and cell 12 is shown in Figure 3.15.

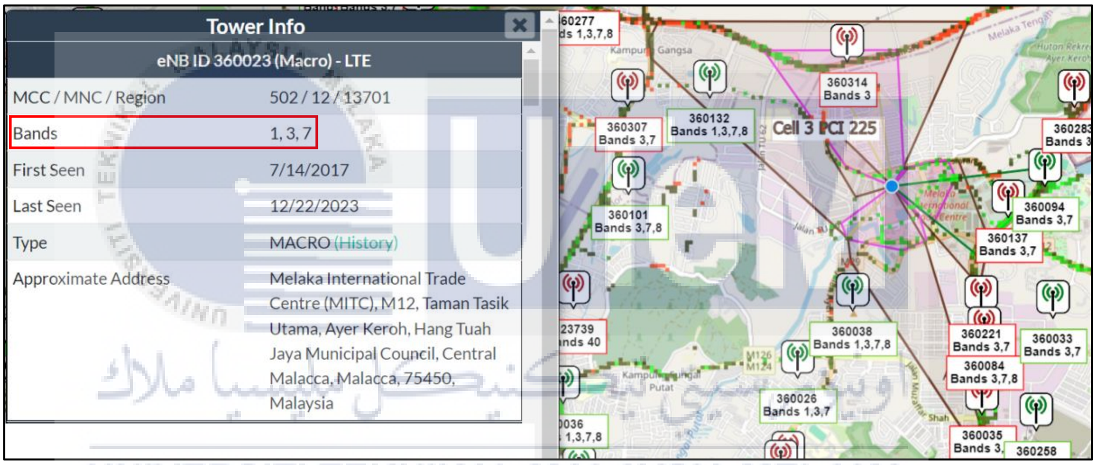


Figure 3.14: Base station information in Cellmapper.

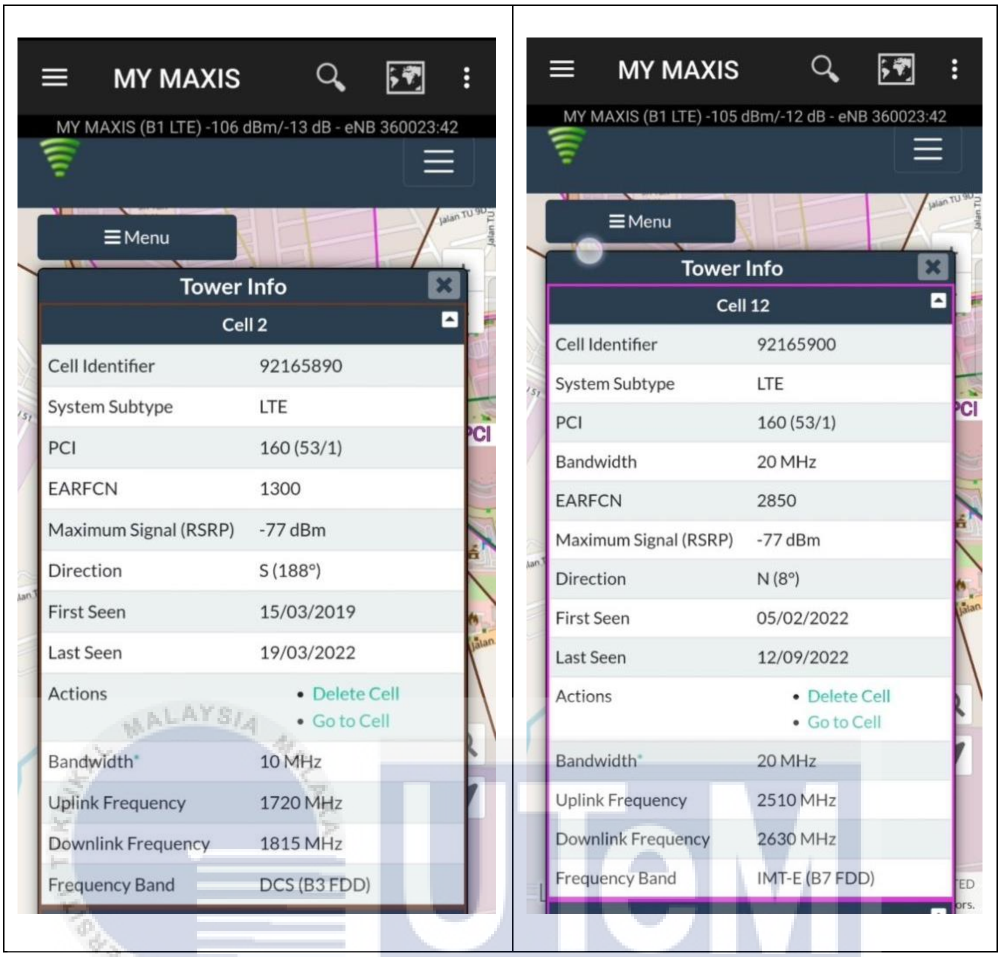


Figure 3.15: Cell information for enB 360023

3.5.2.1.2 Lock Frequency Band

HuaCTRL has a very similar function as Huawei Manager, except it is easier to lock a specific band. Hence, it is actively used during data measurement to switch band locking from band 3 to band 7, and combination of both bands. Locking specific band can improve signal quality as the fabricated antenna works only at band 3 and band 7. The setting can be accessed from set band setting in HuaCTRL as depicted in Figure 3.16.

Figure 3.16: Band lock setting in HuaCTRL

3.5.2.1.3 Huawei Manager

Huawei Manager is a primary software used to measure the signal strength parameter. Data visualization of Huawei Manager as in Figure 3.17 is better than HuaCTRL making it easier to monitor the measurement.

Figure 3.17: Interface of Huawei Manager

Moreover, this software allows the user to directly make any configuration on router's antenna port setting instead of assessing IP address web interface of the router. The router's antenna setting in Figure 3.18 can be chosen either both ports built-in, external port 1 or external both port 1 & 2. For testing purposes, the antenna port setting alternately changed from built-in to external port 1 only because fabricated antenna only has a single port. The data collection also includes when both ports are built-in antenna as initial value to compare the data before and after utilizing external antenna.

In case where a problem occurred to change the antenna port setting, user can access this IP address: 192.168.8.1 to make any changes to the router's setting.

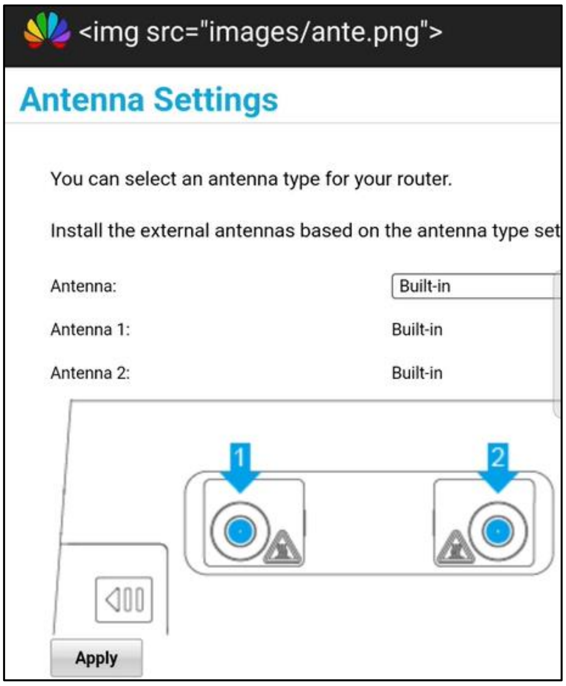


Figure 3.18: Antenna setting for router B310 in Huawei Manager

3.5.2.2 Signal speed Test

Active measurement of speed test is a better option than passive as it is introducing new traffic into the network during measurement. The test is conducted using Speed test by Ookla which is the most popular application for speed test [37]. Running the speed test from web browser and through its application installed in the device will differ in term of accuracy where using the application gives more accurate result [38]. Besides that, the type of device used, and Wi-Fi Access Point (AP) will affect the test results. Hence, the same device which is Realme 9 Pro+ and the distance of 1 meter from router is fixed during testing. The key factors for network performance include download speed, upload speed and latency (ping) [37]. Sample of detailed result from Speed Test by Ookla is shown in Figure 3.19.

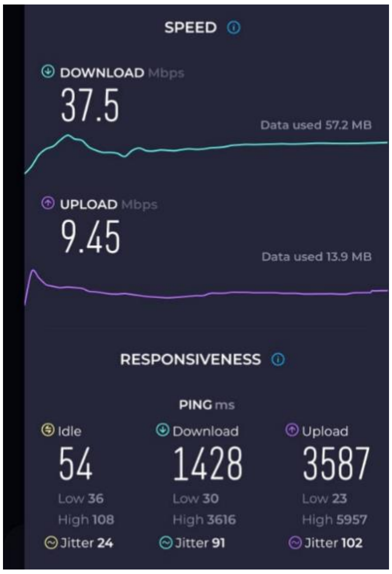


Figure 3.19: Example result from Speedtest

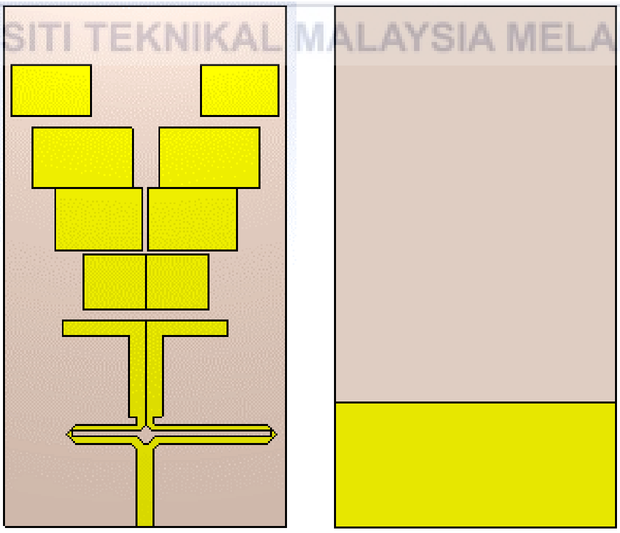
3.6 Data analysis

According to project planning flowchart in Figure 3.1, the final stage of this project is data analysis and report writing. In order to effectively project the result, Origin Lab is used to plot majority of the data including radiation pattern generated from simulation and from lab test. All the data is saved in Excel file before importing into Origin Lab for plotting. It is important to visualize the result in a clear and informative manner as it will greatly affect the analysis and discussion of this project. Hence, the analysis will focus on the outcome from simulation, lab test and field test to validate the performance of the fabricated antenna as a dual band LTE Quasi-Yagi antenna.

3.7 Preliminary Result

Preliminary results are crucial in antenna design since it gives early insight and on how the antenna design perform in term of return loss, radiation pattern, gain and efficiency.

The preliminary antenna design is constructed in CST as illustrated in Figure 3.20 with the optimal parameter listed in Table 3.4. The antenna design employs the method mentioned in 3.2 above for designing process where the antenna design structure was inspired from Parametric study of Dual-Band Quasi Yagi antenna [39]. Meanwhile, the dimension and each value of the design structure is calculated in MATLAB by referring to calculation in research paper Design Equations for Quasi Yagi-Uda Antenna Operating in UHF Band [40]. Moreover, the optimization stage uses parameter sweep and optimizer in obtaining the most favorable design outcome. Then, the design structure is further enhanced and refined by adding certain elements to improve antenna's return loss, radiation pattern and gain. Designing Process



(a) (b)

Figure 3.20: Quasi Yagi antenna structure view in CST; (a) Front View, (b) Back View

Table 3.4: Parameter's value of preliminary antenna design

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
ws	99.59	wdir1	19.255	L1	29.34	s0	-10.78
ls	184.13	wdir2	22.408	L2	25.5	s1	1.064
Lg	44	wdir3	21.057	L3	44	s2	0.093
t	0.02	wdir4	18.37	L4	28.413	s3	4.161
h	1.56	ldir1	44.193	g1	0.372	p1	4.5
w2	6.0125	ldir2	64.372	g2	1.766	p2	2.006
wdr	5.646202	ldir3	80.66752	g3	9.324294	p3	5.133
ldr	57.86831	ldir4	94.286	g4	38.69258	p4	6

Return loss magnitude, S_{11} was obtained by simulating the antenna design in CST time domain solver as shown in Figure 3.21. The return loss obtained is desirable for frequency band of interest, 1.8 GHz and 2.6 GHz at -19.795 dB and -18.121 dB respectively. Both measured impedance bandwidth defined by $S_{11} < -10\ dB$ are in good agreement with simulation. While the antenna is designed to operate at band 3 and band 7 in LTE, it also functions in Band 1 (2.1 GHz) and Wi-Fi frequency (2.4 GHz). However, further discussion will only cover band 3 and band 7.

As for VSWR in Figure 3.22, both frequencies have values lower than 2 which match with standard set for an antenna. Having VSWR less than 1.5 is ideal in real time RF field as it able to evade the mismatch between an antenna and feed line [41]. The VSWR obtained from simulation for 1.8 GHz and 2.6 GHz are 1.228 and 1.284 respectively. The simulated antenna peak gain reach 6.638 dB at 1.8 GHz and 6.979 dB at 2.6 GHz as displayed in Figure 3.23.

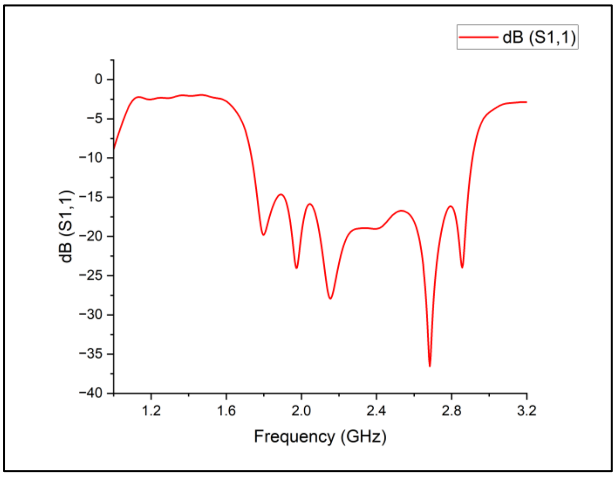


Figure 3.21: S_{11}Parameter of preliminary antenna design

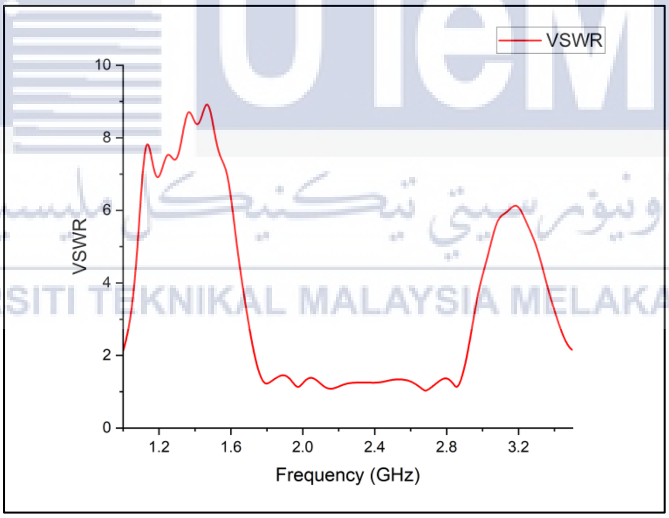


Figure 3.22 : VSWR of preliminary antenna design

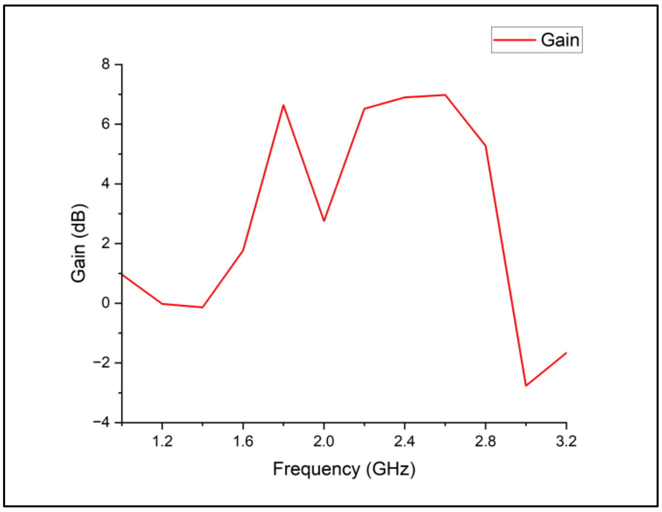
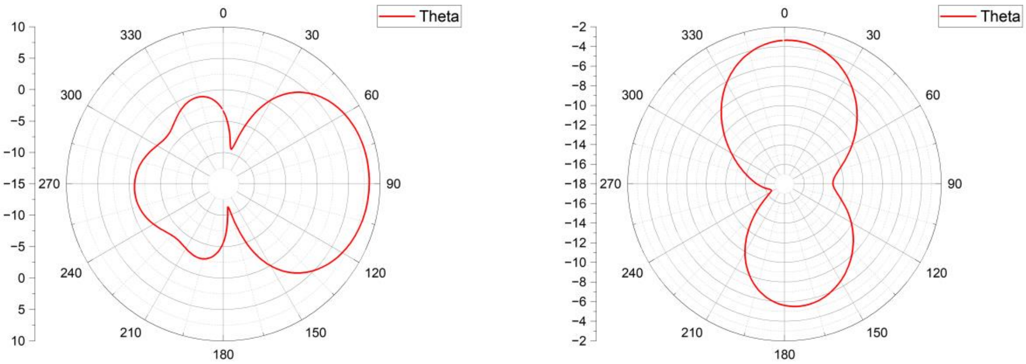


Figure 3.23: Simulated Gain of preliminary antenna design

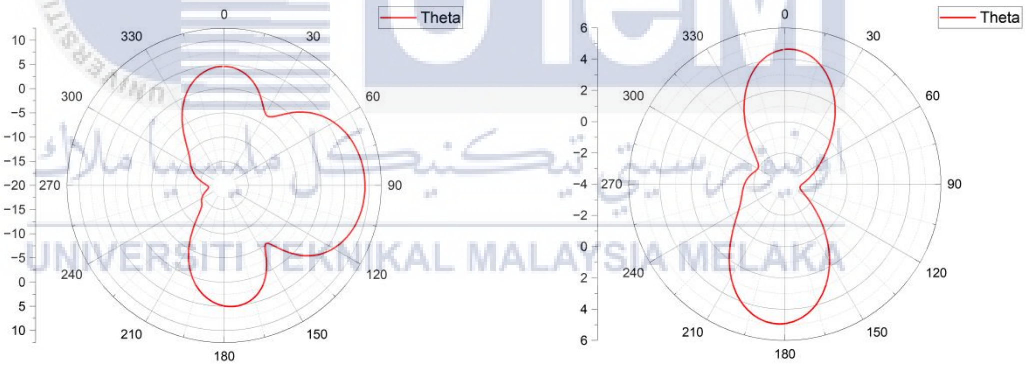
Figure 3.24 and Figure 3.25 illustrates the far field radiation pattern of the antenna at its resonant frequency, 1.8GHz and 2.6GHz respectively. Referring to both Figure, the radiation pattern at E-plane for both resonant frequencies display directional pattern while the H-plane pattern form 'figure-8' which is a common radiation pattern for dipole antennas. At 1.8GHz, the radiation pattern in E-plane show that the antenna has directional pattern with half power beamwidth (HPBW) of 86.6° and peak gain of 8.29 dBi. The H-plane radiation pattern's gain is -3.35 dBi with HPBW of 68.6°. Meanwhile for 2.6GHz, the HPBW of the main lobe in E-plane gives 60° with directivity of 9.13 dBi. Moreover, the H-plane for 2.6GHz has HPBW of 65.3° and 4.95 dBi directivity.

In comparison, E-plane radiation pattern for both resonance frequencies gives directional pattern. However, the directivity and the gain are much higher at 2.6 GHz compared to radiation pattern at 1.8GHz. Both frequencies' radiation patterns in H-plane gives similar 'figure-8' radiation pattern. In addition, smaller HPBW indicates more focused and concentrated beam which make the antenna focuses more on frequency 2.6GHz than 1.8GHz. Since it does differ much, it is considered acceptable.



(a) (b)

Figure 3.24: Radiation Pattern for 1.8GHz preliminary antenna design (a) E-plane and (b) H-plane

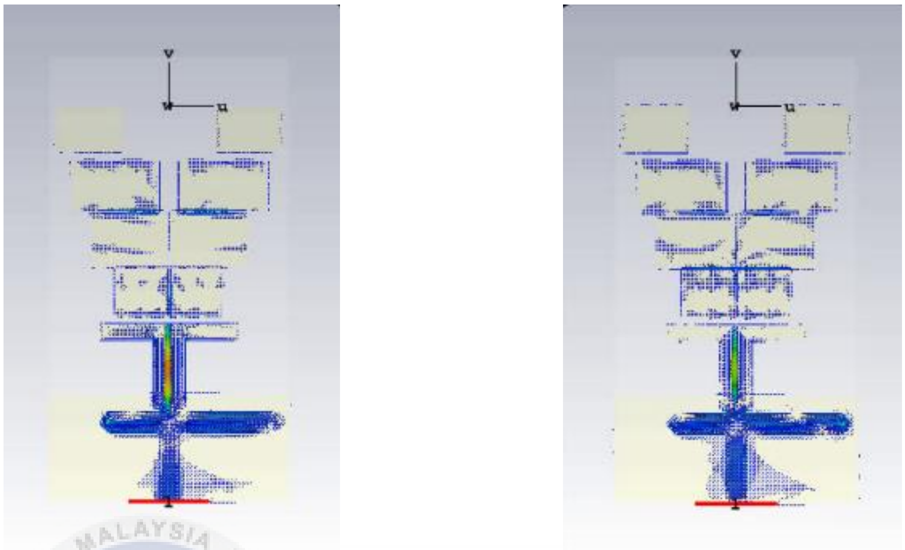


(a) (b)

Figure 3.25: Radiation Pattern for 2.6GHz preliminary antenna design (a) E-plane and (b) H-Plane

By referring to the surface current in Figure 3.26, the current flow at the antenna's elements becoming fainter toward the end of the last director. The surface current at 1.8GHz is 158.659 A/m while 2.6GHz obtained maximum of 142.505 A/m.

However, adding more directors does not improve the surface current. Therefore, an adjustment needs to be made to improve this situation.



(a) (b)

Figure 3.26: Surface Current at, (a) 1.8GHz and (b) 2.6GHz

3.8 Summary of Methodology

Designing a directional antenna that performs at band 3 and band 7, 1.8 GHz and 2.6 GHz respectively requires well defined methodology. This project starts with calculations from MATLAB and some assumptions based on previous research. Parameter sweep is used to have the best value for antenna's parameter to have an optimized result. Followed by fabrication, lab test and field test to validate the functionality the antenna in improving network performance. Based on the simulation result, the proposed antenna has obtained objective 2 where it can operate at dual frequency. Although the preliminary results are desirable, some improvements need to be considered for the antenna's elements to work as intended.

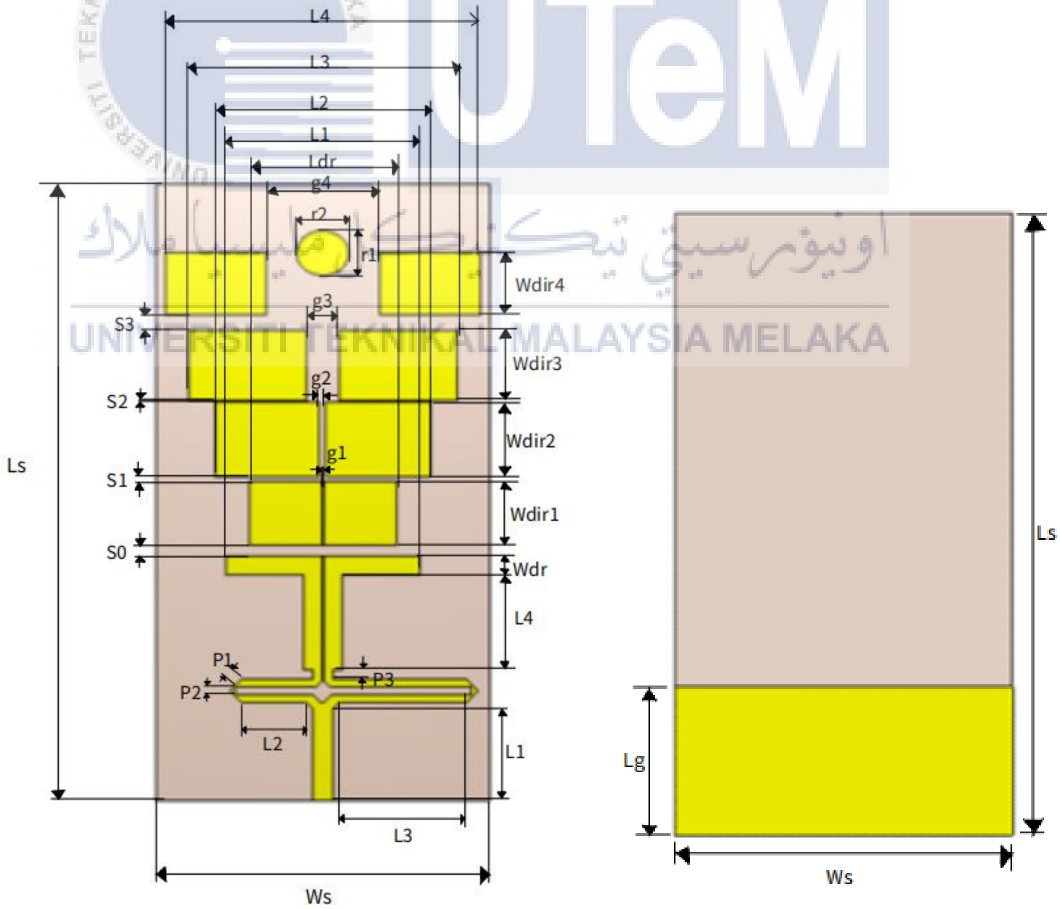
CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the findings of the project's investigation on dual band microstrip Yagi antenna design and analysis for 4G LTE coverage improvement. The first section introduces a new, improvised design from preliminary result in Chapter 3.7. The next section compares the measurement result from lab test with simulation test and then delves into a comprehensive discussion of these results in terms of return loss, gain and radiation pattern to explore their implications and limitations. The last section discusses the field test and overall network improvement which validate the antenna's functionality. Throughout this chapter, the results obtained are investigated and analyzed to shed light on effectiveness of the fabricated dual band antenna on network performance.

4.1 Fabricated antenna design

Final design of antenna is visualized as in Figure 4.1. The improvement is made from preliminary design to improve the surface current flow of the antenna by adding additional element in between the last director. The additional element is an oval shape with an optimize dimension highlighted in Table 4.1. The structure's dimension of driven elements, eights directors and truncated ground plane is listed in the same Table and visualized by labelling all the parameters in Figure 4.1. Giving it a final design, the project proceeds with fabrication and testing in both lab and field test as mentioned in methodology part. The fabrication is done on an FR4 with thickness of 1.56 mm.



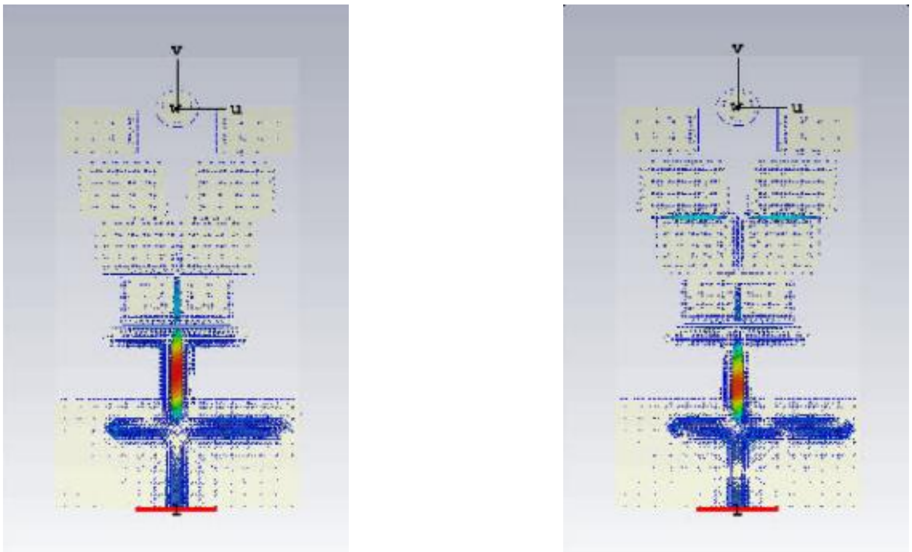
(a) (b)

Figure 4.1: Final Design Antenna (a) front view and (b) back view

Table 4.1: Parameter's value for final design antenna

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
ws	99.59	ldr	58.08331	wdir3	21.0571	g4	33.80903
ls	184.13	wdr	5.646202	wdir4	18.36969	p1	4.5
Lg	44	ldir1	44.19344	s0	-11.7205	p2	2.005701
t	0.02	ldir2	64.372	s1	1.373075	p3	5.1333
h	1.56	ldir3	80.66752	s2	0.247827	p4	6
L1	29.34	ldir4	94.286	s3	4.562506	r1	7.868476
L2	25.5	wdir1	19.25516	g1	0.307457	r2	6.685404
L3	44	wdir2	22.40787	g2	1.867003	-	-
l4	28.4125	ldr	58.08331	g3	9.955578	-	-

The maximum surface current for 1.8 GHz has improved significantly to 215.536 A/m and 188.781 A/m at 2.6 GHz. As depicted in Figure 4.2, adding oval-shaped additional element which act as a reflector, the surface current distribution is more balanced especially on the last director compared to without additional element in Figure 3.26.



(a) (b)

Figure 4.2: Surface current for final design at (a) 1.8GHz and (b) 2.6GHz

4.2 Lab Test Result

The lab measurement from VNA and anechoic chamber are observed after fabricating antenna with its final design in **Error! Reference source not found.**. The first lab test is return loss and the result is plotted in Figure 4.3. Compared to the simulation, the measured return loss at 1.8 GHz is -10.801 dB, the lowest value observed. However, the measured return loss at 2.6 GHz is -19.620 dB, slightly higher than the simulated values. Both resonant frequency 1.8 GHz and 2.6 GHz have return loss lower than -10 dB which is desirable. The difference between lab test measurements and simulations are multifaceted where it is influenced by many factors including measurement technique, real-word complexities and potential benefits of simulations.

Return loss, S_{11} is the key performance metric that indicated the amount of power reflected back to the source. A good antenna should reflect less than 10% of the incoming signal achieving a return loss below -10dB. In addition, return loss of final design simulation improves 30% (-19.795 to -26.558 dB) at 1.8 GHz and meets the desired threshold of -10 dB at 2.6 GHz when compared to preliminary design at both target frequencies. Besides the initial frequency, 1.8 GHz and 2.6 GHz, it also covers 2.1 GHz (Band 1) and 2.4 GHz (Wi-Fi), making it suitable for most-used LTE bands.

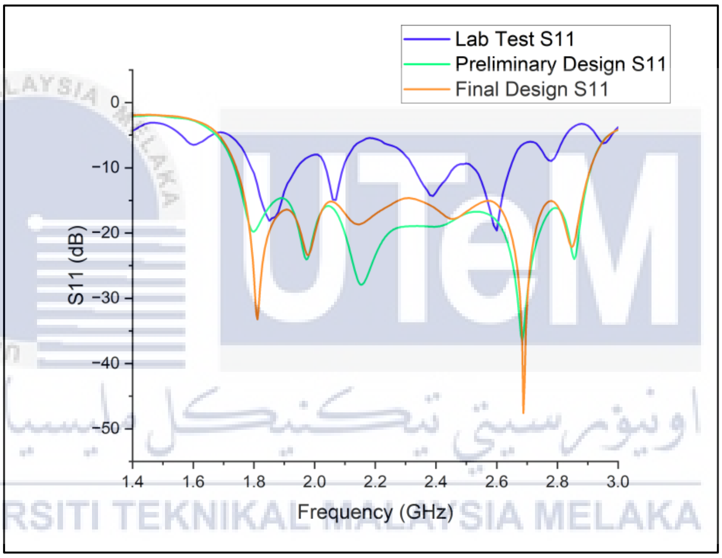


Figure 4.3: Return loss comparison between lab test measurement and simulations

Figure 4.4 unveils the measured and simulated result for gain and efficiency of the antenna. The measured gain of the antenna is 4.625 dB with efficiency of 69.7% at 1.8 GHz and 5.4 dB gain and 52.9% efficiency at 2.6 GHz. Further analysis demonstrates, the measured gains fall slightly below the simulated values at both frequencies, while the efficiencies remain below 80%. Interestingly, the efficiency at 1.8 GHz surpasses simulated efficiency but lower efficiency at 2.6 GHz. Despite that, it is an acceptable value for this project application since higher efficiency is a critical parameter if the application is to have a high-power radiation while this project application does not radiate any signal [42].

The efficiency improvement should be made if the intended application is IoT application. Even though it is good to have high efficiency, it is considered high enough when it is able to compromise with other important parameters to have a network performance improvement. As for the gain, higher gain allows longer receiving distance [43]. In addition, higher gain results in narrower bandwidth and at the same will improve the signal strength and quality by enhancing the signal to noise ratio [44]. The fabricated gain having approximately 5 dB gain in both frequencies is sufficient as the project focus does not cover high gain application. However, during field testing, a distance of 700 m is still in range for the antenna to receive signal from the base station. This topic will be further discussed in following section, field testing.

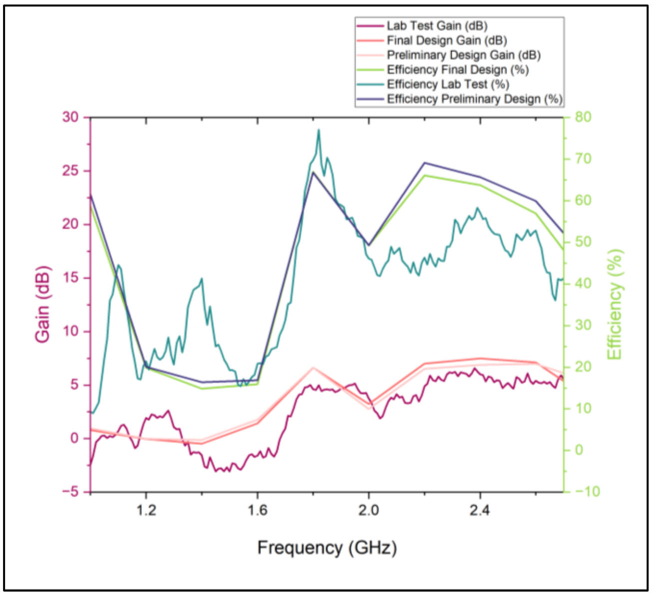
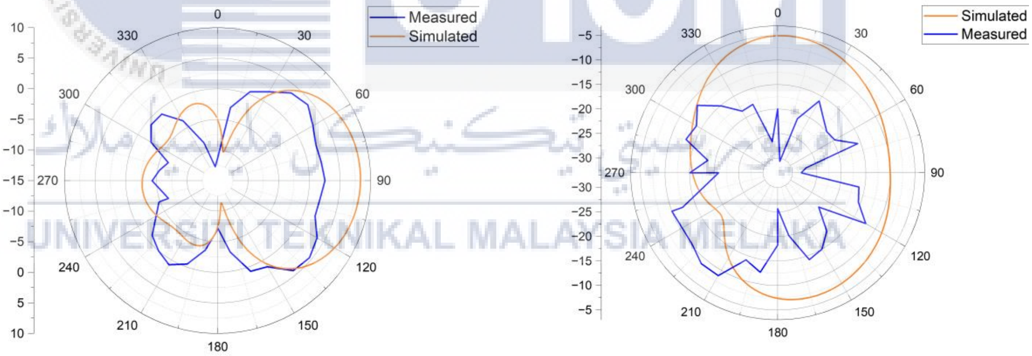


Figure 4.4: Gain and Efficiency comparison between lab measurement and simulations

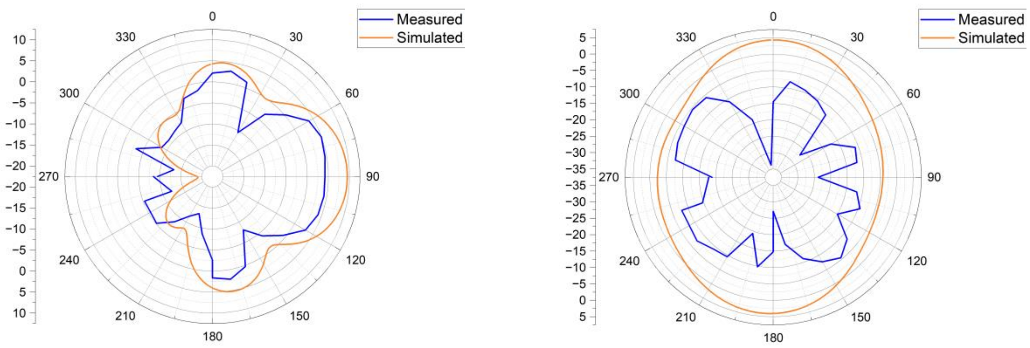
Figure 4.5 and Figure 4.6 visualize the simulated and measured radiation patterns at 1.8 GHz and 2.6 GHz in both E-plane and H-plane. The simulation of this design shows the radiation patterns for both planes are similar in terms of shape in preliminary result. From measurement result, the radiation pattern in both planes also in a good term with simulation result where E-plane radiation pattern is directional while H-plane is omnidirectional. The HPBW and directivity results for both frequencies in E-plane and H-plane are summarized in Table 4.2. In the E-plane, the measured HPBW values closely match the simulated values at both 1.8 GHz and 2.6 GHz, indicating a consistency in beamwidth except for their directivity where the measured values are almost half of the simulated value. In the H-plane, disagreement between measurement and simulation is observed where both HPBW and directivity exhibit significant difference. It seems the results in H-plane have less accurate prediction of the antenna's behavior. However, further investigation is not necessary as the project focused only on the E-plane due to the fabricated antenna polarized vertically.

Comparing the simulation and measurement result on E-plane, 2.6 GHz has higher directivity than 1.8 GHz. The HPBW values explain that 1.8 GHz has broader coverage by 20% compared 2.6 GHz where it has a more focused beam. This characteristic is desirable since higher frequency needs more focused beam than lower frequency. This is because higher frequency has shorter wavelength and is more susceptible to interference and energy loss if the beam is not focused [45]. Hence, having higher directivity potentially enhances the signal concentration in the desired direction.



(a) (b)

Figure 4.5: Comparison radiation pattern for 1.8 GHz at (a) E-plane and (b) H-plane



(a) (b)

Figure 4.6: Comparison radiation pattern for 2.6 GHz at (a) E-plane and (b) H-plane

Table 4.2: HPBW and directivity of 1.8 GHz and 2.6 GHz at E-plane and H-plane

Method	Frequency (GHz)	E-plane		H-plane	
		HPBW	Directivity (dBi)	HPBW	Directivity (dBi)
Simulation	1.8	88°	8.33	78.5°	-4.99
	2.6	57.5°	9.47	59°	4.31
Measurement	1.8	81°	4.246	45°	-41.751
	2.6	51°	4.987	45°	-46.243

4.3 Field Test Validation

Field test is performed at site location as depicted in Figure 4.7, Pangsapuri Taman Tasik Utama with a distance of nearly 700m to the base station near PKNM, MITC. During the test, the same device is used to measure the signal strength and speed. The Internet Service Provider (ISP) used for this test is Maxis.

Figure 4.7: Location of field testing

Firstly, the placement of the antenna is adjusted toward the base station based on signal strength values without locking to any band. The antenna is placed within Line of Sight (LOS) where there is no obstacle in between the antenna and the cell tower. Having the best parameter of signal strength, the band is locked and measured separately for band 3, band 7 and combination of band 3 and 7 through HuaCTRL software. The result of signal strength when using antenna and without using it is summarized in Table 4.3 with color indicator based on Table 4.4.

The most basic measurement in Long Term Evolution (LTE) are Received Signal Strength Indicator (RSSI), the Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ). Meanwhile, the channel quality is measured based on Signal to Interference plus Noise Ratio (SINR) [46]. From the result overview, using antenna has increased the signal strength and quality especially when both band 3 and 7 are combined. Most practical applications imply that the higher SINR, the higher the RSRP. Higher RSRP means stronger signal which also indicates that the signal is strong with less distance attenuation. Even though SINR correlates with RSRP, it does not directly impact RSRP unlike LoS. If there is a clear LoS, it generally led to stronger signal as the signal travel directly from cell tower with minimum interference. Moreover, better RSRQ is achieved when there is lesser difference between RSRP and RSSI where RSRP always have lower value than RSSI.

Table 4.3: Signal strength for with and without antenna

	Without Antenna			With Antenna		
Band	3	7	3 + 7	3	7	3 + 7
RSSI (dBm)	-69	-69	-77	-75	-73	-51
RSRP (dBm)	-104	-95	-100	-82	-78	-75
RSRQ (dB)	-13	-6	-7	-8	-8	-6
SINR (dB)	-6	17	16	2	22	22

Table 4.4: Indicator of network quality level

Excellent	Good	Fair	Poor

4.3.1 Signal Throughput

Maintaining the same field test location and antenna placement as before, the signal speed test is measured 20 times continuously while outliers are removed. The test is taken during the daytime from 10 a.m to 5 p.m using Speedtest by Ookla. While conducting the test, the data of download and upload speed and latency are taken. Figure 4.8, Figure 4.9 and Figure 4.10 visualize the upload and download speed at band 3, band 7 and combination of band 3 and 7 respectively. The average value download speed, upload speed and ping are shown in Figure 4.11, Figure 4.12 and Figure 4.13.

From Figure 4.8, the upload and download speed for Band 3 when using antenna is higher than without using antenna. However, the upload speed when using antenna improved significantly from an average of 9.320 Mbps to 39.17 Mbps. The average upload speed is higher than download speed in any condition either using antenna or not. The average download speed for without using antenna and with antenna is 4.44 Mbps and 6.1 Mbps respectively where both values are lower than the upload speed. Hence, it is more suitable to use this band when the user frequently creates and shares large files.

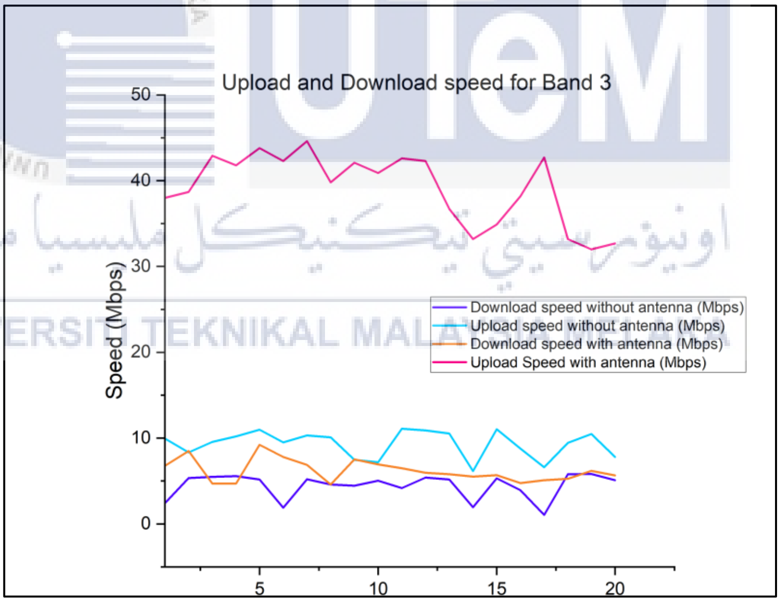


Figure 4.8: Upload and Download Speed for Band 3 with and without antenna.

The upload and download speed are visualize for band 7 and combination of band 3 and band 7 in Figure 4.9 and Figure 4.10. Both results show that download speed with and without using antenna are higher than upload speed. This condition is suitable for daily usage where users usually stream videos, browse web, download files or online gaming. Higher download speeds let the user have a good experience when browsing online. For basic usage, 10 Mbps is required for a seamless online experience and 5 Mbps for upload speed.

The trend in both band 7 and combination band are quite similar in any case. For example, with antenna, the average download speed for band 7 and combination band is 37.72 Mbps and 37.71 Mbps respectively. Band 7's average upload speed improves by 10.51 Mbps and its download speed improves by 94% (18.3 Mbps). Meanwhile for combination band, the upload speed improves by 6.57 Mbps and download speed improves by 17.73 Mbps. Hence, it shows that installing antenna has enhanced the overall performance of the upload and download speed for band 3, band 7 and combination band 3 and 7.

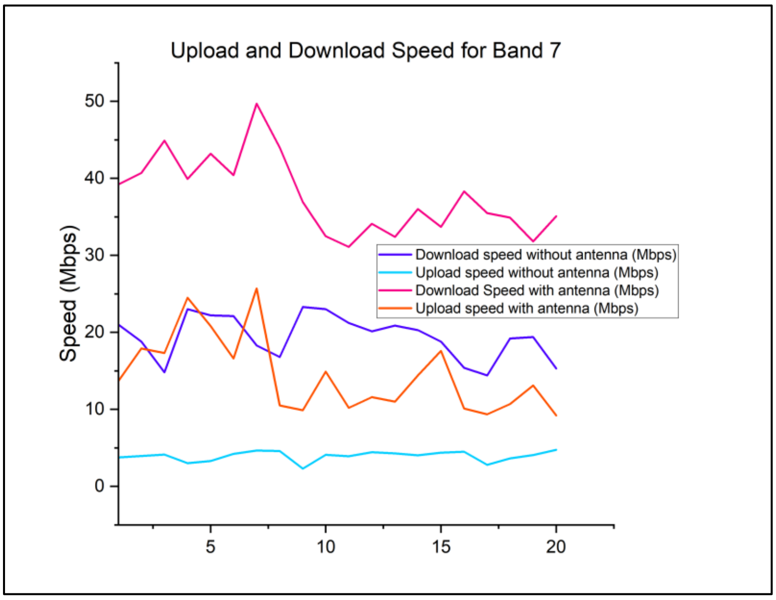


Figure 4.9: Upload and Download Speed for Band 7 with and without antenna.

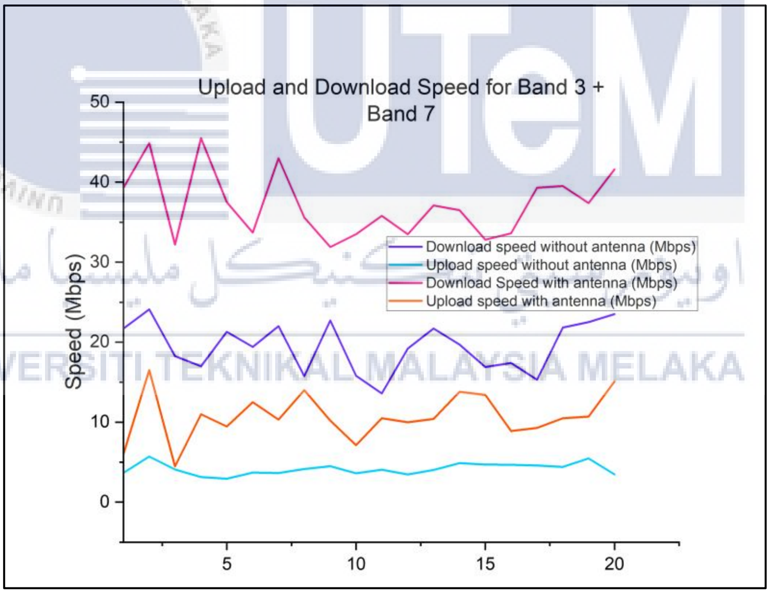


Figure 4.10: Upload and Download Speed for combination frequency of Band 3 and Band 7 with and without antenna.

The comparison between average result of the download speed, upload speed and latency for all band is shown separately in Figure 4.11, Figure 4.12 and Figure 4.13.

All the parameters measured are higher when using the antenna. Therefore, the following comparison is made when using the antenna when comparing between band. To summarize, the highest average download speed is band 7 with 0.02% (0.01 Mbps) difference with combination band 3 and 7. For the upload speed, Band 3 has the highest value of 39.17 Mbps. Meanwhile for the latency (ping), the range vary between 35.2 to 44.85 ms where the lowest latency is band 3 and the highest is combination band. Therefore, overall performance of band 7 and combination band are better than when using band 3 for daily usage. Despite that, the user can easily switch to band 3 electronically without the need to modify the antenna position 3 using HuaCTRL.

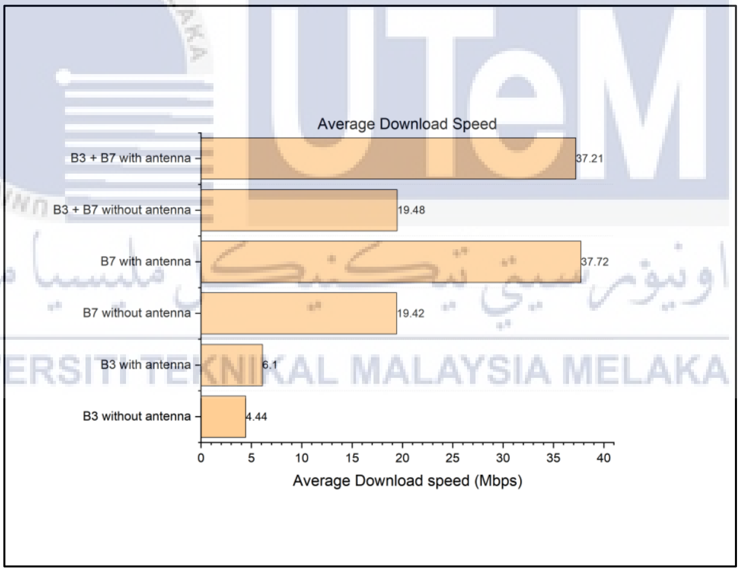


Figure 4.11: Average download speed for band 3, 7 and combination band 3 and 7

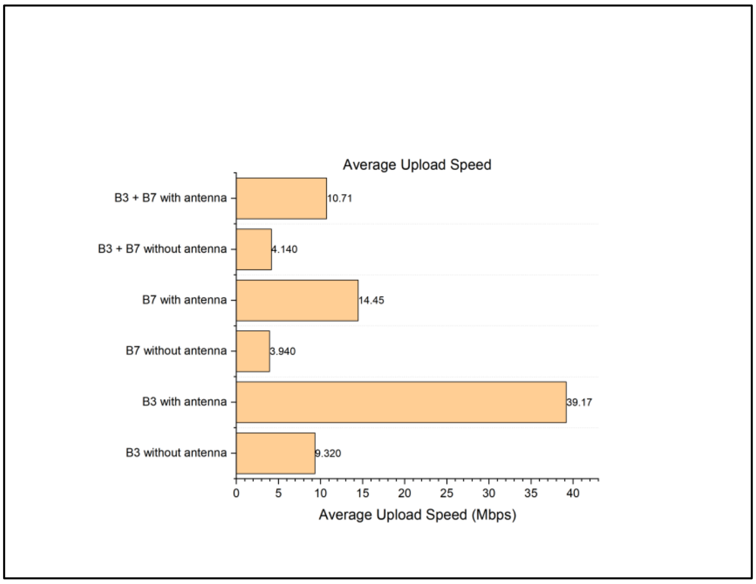


Figure 4.12: Average upload speed for band 3, 7 and combination band 3 and 7

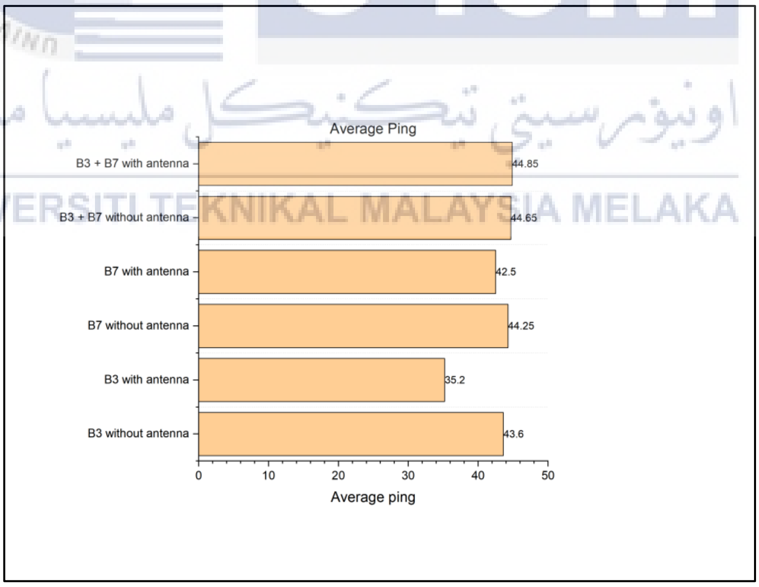


Figure 4.13: Average ping for band 3, 7 and combination band 3 and 7

4.4 Comparison between previous and current research

This research is compared to previous research where it has similar design with dual band frequency. Based on the comparison in Table 4.5, the gain has improved, indicating stronger signal transmission and reception in both frequency band by 25% and 18% for 1.8 GHz and 2.6 GHz respectively.

Table 4.5: Comparison previous and current research

	Substrate	Resonance Frequency (GHz)	S_{11} (dB)	Gain (dB)	Directivity (dBi)	VSWR
Simulation (Previous Research)	FR4 ε_r= 4.3 h =1.6 mm	1.8	-65.23	5.3	6.5	1
		2.6	-31.55	6	8.3	1.2
Simulation (Current Research)	FR4 ε_r= 4.3 h =1.6 mm	1.8	-26.557	6.639	8.34	1.0986
		2.6	-15.586	7.131	9.47	1.3987

For the directivity, it has improved by 28% and 14% at 1.8 GHz and 2.6 GHz respectively. This demonstrates a more focused signal beam and reduced interference. However, the comparison can only be made on simulation part as previous research does not cover lab measurement. Hence, improvement is seen in gain and directivity but does not further validated through lab and field testing.

4.5 Summary of Result and Discussion

By incorporating an optimized oval element into the antenna design, noticeable improvements can be seen in both lab and field tests. Lab measurements confirmed measured return loss at both target frequencies has efficient signal absorption. While gain and efficiency measurement values are slightly below simulations, both remained acceptable for the project's objectives. Measurement radiation pattern focusing on E-plane which is directional signal transmission is desirable for vertical polarization. The lab test results show that the antenna is fully functional in enhancing the network performance in term of network strength and speed which validated by field testing.

Moreover, the field tests can be concluded with all bands 3, 7, and their combination experiencing significant improvement in signal strength, quality, and speed. Band 7 and the combined option have become the best option for daily usage, delivering high speed and allowing smooth online experiences. Band 3, though slightly slower in download, it is best in uploading tasks, offering a substantial advantage for users sharing large files or engaging in video calls. This flexibility highlights the final design's effectiveness, catering to diverse needs and scenarios. In conclusion, the optimized antenna design, validated by both lab and field tests, demonstrably enhances network connectivity. Whether seeking seamless streaming, rapid uploads, or a mix of both, users can choose the ideal band based on their priorities.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

This chapter concludes the research which successfully tackled the issue of declining 4G performance due to network congestion by designing a dual-band Yagi antenna for bands 3 and 7 (1.8GHz and 2.6GHz respectively). Suggestion on potential study also mentioned in this chapter.

5.1 Conclusion

The proposed antenna with additional element of an oval is lightweight and cost-effective. It also caters to two frequencies in one antenna while addressing the need for increased capacity and speed. The analyzed result from lab test in term of return loss, gain and efficiency has been validated its effectiveness by significantly improved signal strength, quality, and speed across all bands during the field test.

The versatility of the antenna allows the user to optimize their usage as band 7 and the combined option is best for daily usage, band 3 excels in uploads. This innovative solution not only enhances network connectivity but also promotes digital inclusion and lifelong learning opportunities, aligning with SDG-4 goals where the target community is school.

Moreover, this solution follows the rules and regulations as it is not a booster. This dual-band Microstrip Yagi antenna falls under the category of directional antennas which are specifically designed to focus on capturing signals from certain frequencies and directions. It does not amplify the signal but rather improves its reception by being more efficient at picking it up. If booster is to be made, it should be certified by the Commission. Otherwise, legal action could be taken where in mention in the guideline from MCMC, “the purchase, use or possession of non-compliant cellular booster is strictly prohibited” [47].

5.2 Future works

Based on the simulation result, the gain obtained for both frequencies are 6.639 dB and 7.131 dB respectively. Following the lab test, the gain are almost half from the simulation where 1.8 GHz has 4.625 dB gain and 2.6 GHz’s gain is 5.4 dB. Considering this case, simulated gain value should be higher than the targeted gain. As the gain is not very high during lab measurement, the future work should improve the gain to be more than 10 dB. Hence, longer distance can be covered by the antenna.

Moreover, during the field test, there is no distance test covered to verify the maximum distance of the antenna coverage. The field test can be conducted by measuring the network strength and speed from several distance away from the base station at the same angle the antenna is positioned. Therefore, further investigation should be made to prove the effectiveness to a greater extent.

Furthermore, the antenna return loss and gain shows that there are other frequencies available in this design especially 2.4 GHz for Wi-Fi and 2.1 GHz in another frequency of 4G LTE. Another field test can be performed to verify the frequencies functionality. The next study can design an antenna to be functional in all LTE bands.

Last but not least, the size of the proposed antenna is quite big even though it is less bulky than the disc antenna. Further improvements should focus in minimizing the size to a smaller and compact design.

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