DESIGN OF 5.8 GHz QUASI-YAGI PATCH ANTENNA

HANI AQILAH WAHIDAH BINTI ABD MANAN

UNIVERSITI SAINS MALAYSIA

2017

DESIGN OF 5.8 GHz QUASI-YAGI PATCH ANTENNA

by

HANI AQILAH WAHIDAH BINTI ABD MANAN

Thesis submitted in partial fulfillment of the
requirements for the degree of
Bachelor of Engineering (Electronic Engineering)

MAY 2017

ACKNOWLEDGEMENTS

First of all, I would like to express my deepest gratitude to my supervisor, Prof. Dr. Widad Binti Ismail. Her constant guidance and support throughout the project that allow me to successfully finish this project are much appreciated. Under her supervision, I have gained new skills in antenna design and increase my basic knowledge on antenna theory.

I am also grateful to my project examiner, Dr. Nor Muzlifah Binti Mahyuddin, for her positive feedback and suggestions in completing the project.

Furthermore, I would like to give special thanks to the technicians, namely, Mr. Abdul Latip bin Hamid, Madam Zammira binti Khairuddin, and Mr. Elias bin Zainuddin, for their patience, and their willingness to assist me in the practical part of this project.

Finally, I would like to thank my family and friends for giving me motivation and strength in order to complete this project. Without their support, all the efforts cannot be accomplished.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

Symbol:

cm	Centimeter
mm	Milimeter
Hz	Hertz
G	Giga
M	Mega
dB	Decibel
λ_g	Guided wavelength
c	Speed of light

Abbreviation:

PCB	Printed Circuit Board
VSWR	Voltage Standing Wave Ratio
AUT	Antenna Under Test
SMA	SubMiniature Version A (SMA)

ABSTRAK

Disertasi ini membincangkan rekabentuk antena segi empat sama kuasi-Yagi untuk komunikasi tanpa wayar. Kebanyakan kajian mengenai reka bentuk antena kuasi-Yagi telah menggunakan dwikutub sebagai elemen pemacu. Terdapat juga kajian mengenai bentuk-bentuk pemacu antena yang berbeza. Kajian ini memfokuskan tentang penggunaan pemacu mikrojalur segi empat dalam antenna kuasi-Yagi yang telah terbukti menghasilkan jalur lebar yang lebih luas dan corak radiasi yang lebih baik, iaitu antara keperluan untuk aplikasi komunikasi tanpa wayar. Rekabentuk antena yang dicadangkan ialah antenna kuasi-Yagi dengan pemacu slot mikrojalur beroperasi pada frekuensi 5.8 GHz sebelum membentuk antenna jajaran. Ukiran slot pada pemacu segi empat adalah untuk menigkatkan jalur lebar antena, selain daripada mengaplikasikan antena jajaran, yang juga menigkatkan corak radiasi antena tersebut. Jenis papan litar bercetak (PCB) yang digunakan ialah ROGERS 4003, dengan pemalar dielektrik 3.38 dan ketebalan 0.813mm, telah digunakan dalam kajian ini. CST Microwave Studio ialah peralatan simulasi yang digunakan untuk model dan mensimulasikan rekabentuk antena sebelum menterjemahkan hasil keluaran kepada pembuatan perkakasan PCB. Antena yang telah direka diuji menggunakan peralatan RF untuk mengukur prestasi antena dan hasilnya dibandingkan dengan hasil simulasi. Antena segi empat sama kuasi-Yagi konvensional, antena segi empat sama kuasi-Yagi dengan slot, dan antena jajaran segi empat sama kuasi-Yagi dengan slot menghasilkan jalur lebar dengan gandaan yang tinggi. Penambahan slot dan antenna jajaran telah meningkatkan jalur lebar antena dan mencapai corak sinaran yang baik. Antena yang diusulkan dan jajarannya adalah sesuai untuk aplikasi jalur SHF dan system komunikasi tanpa wayar.

ABSTRACT

This dissertation discussed the design of 5.8 GHz quasi-Yagi patch antenna for wireless communications. Most of the researches on the quasi-Yagi antenna designs used a dipole as the driver element. There are also studies conducted on different driver shapes of the antenna. This research focused on the use of patches driver in the quasi-Yagi antenna as it is proven to give the antenna a wider bandwidth and a better radiation pattern which are the needs for the wireless communication applications. The proposed antenna design is a quasi-Yagi antenna with slotted microstrip driver operating at a frequency of 5.8 GHz before forming antenna arrays. The etching of slot on the patch driver is to increase the bandwidth of the antenna, aside from applying antenna arrays, which also enhances the radiation pattern of the antenna. Printed Circuit Board (PCB), ROGERS 4003, dielectric material with relative permittivity of 3.38 and thickness of 0.813 mm, is used in this research. CST Microwave Studio is the simulation tool used to model and simulate the antenna design before translating the output results to PCB hardware fabrication. The fabricated antenna is tested using RF equipment to measure the antenna performance parameters and the results are compared to the simulated results. The conventional quasi-Yagi patch antenna, slotted quasi-Yagi patch antenna, and slotted quasi-Yagi patch antenna array resulted in a broad bandwidth and a high gain. The addition of slots and antenna array have enhance the bandwidth of the antenna and achieve a good radiation pattern. The proposed antenna and its array is suitable for SHF band applications and wireless communication system.

CHAPTER 1

INTRODUCTION

1.1 Overview

The modern wireless communication consist of a vast amount of technologies, including mobile cell system, mobile personal services, satellites, specialized mobile radios and WLANs. In recent years, the need of wireless communications has grown and the antenna design has developed itself, searching wideband and better radiation pattern characteristics. The antennas should have specific requirements for their viability such as light weight, low cost, and easy manufacture [2].

Quasi-Yagi antennas was introduced as a class which presents better characteristics than the others. It is simple to construct and has a high gain. The design of quasi-Yagi antenna is based on the classic Yagi-Uda antenna with a dipole as the antenna driver. Since then, quasi-Yagi antennas are widely used in wireless communication system and explored in several papers [2]-[8].

The antenna consists of a single 'feed' or 'driven' element, typically a dipole or a folded dipole antenna [1]. Aside from the quasi-Yagi dipole driver, other different shapes are developed such as patch driver, meander driver, long periodic director array and multi-director array. Each shape has its own characteristics and a different calculation technique [2].

This project will focus on the microstrip or patch driven quasi-Yagi antenna since it has a broader bandwidth and radiation pattern than the others. The bandwidth is expected to be further increased with the addition of slot on the patch driver and array formation. Thus, it is suitable for a wideband application in the wireless communication systems.

1.2 Problem Statement

Antennas with wideband and better radiation pattern are essential in wireless communications. Applications such as radar, mobile phones and satellites, typically uses Super High Frequency (SHF) band, which operates from 3 GHz to 30 GHz.

In this research, a quasi-Yagi antenna with slotted microstrip driver which operates in 5.8 GHz is proposed to determine whether it is suitable to be used in wireless communication application. The radiation pattern of a conventional patch driven quasi-Yagi patch antenna is more isotropic and broader compared to the classical quasi-Yagi antenna [3]. Both of the classical and patches driver of quasi-Yagi antenna have a wide frequency bandwidth, 42% measured [4].

The bandwidth can be widened by cutting a slot on the driver [15]. In this project, slots would be etched on the patch driver of the antenna to see if the bandwidth can be further increased. The resulting bandwidth of the quasi-Yagi patch antenna is expected to be broader and a better radiation pattern should be achieved.

A single antenna will be designed first before making it into an array element. According to [7], the proposed classical quasi-Yagi antenna arrays achieves a measured 48% frequency bandwidth and excellent radiation properties. Therefore, this project will determine whether the slotted quasi-Yagi patch antenna and its array are suitable for wireless communication application.

1.3 Aim of the Project

The aim of this project is to model, simulate and fabricate a quasi-Yagi patch antenna at 5.8GHz and explore its benefits for wireless communication applications.

1.4 Objectives

The objectives of this project are:

I. To design and simulate a single quasi-Yagi patch antenna and a quasi-Yagi patch antenna array operating at 5.8GHz.

II. To fabricate a single quasi-Yagi patch antenna and a quasi-Yagi patch antenna array with the requirements needed for wireless communication applications.

III. To test, characterize and analyze the performance of quasi-Yagi patch antenna and its array to fulfill 5.8 GHz wireless communication application.

1.5 Scope and Limitation of the Project

In this project, 5.8 GHz quasi-Yagi patch antenna is proposed. The antenna will be designed and simulated using CST Microwave Studio. The antenna is enhanced by forming an array and adding a slot on the microstrip driver. The finalized design will be fabricated with ROGERS 4003 as the substrate used.

The quasi-Yagi patch antenna has three elements which are director, driver and reflector. This research will not only focus on all of the parts in designing the antenna, but also the feeding method, antenna slot, and antenna array.

The performance of the proposed antenna which consists of gain, return loss, bandwidth and radiation pattern will be measured by using laboratory RF equipment such as network analyzer, signal generator and spectrum analyzer. A full anechoic chamber with measurement equipment is not available to test the antenna performance. Therefore, far-field radiation pattern and return loss will be measured by using the indoor laboratory equipment setup.

1.6 Thesis Organization

Chapter 2 reviews the information from previous researches which is related to quasi-Yagi antenna. It describes the concept of the antenna and the important design parameters.

Chapter 3 provides the discussion of methods applied in this project. The flow charts, block diagrams, design procedure of quasi-Yagi patch antenna and the explanation of the measurement procedure.

Chapter 4 focuses on the results and analyses. This chapter will show the simulated and measured results from simulation tool and laboratory RF equipment respectively and also the comparison between simulated and measured results of the proposed antenna.

Chapter 5 concludes the project from the beginning stage until the stage of implementation. The limitations of the antenna and future works will also be discussed and suggested.

CHAPTER 2

Literature Review

2.1 Introduction

This chapter discusses the previous studies and researches about the quasi-Yagi antenna and how it is developed by using different types of driver element. The review is to gain more information and understanding of the concept of the antenna. The studies on the design of quasi-Yagi patch antenna are to make this research to be more effective and efficient.

2.2 Quasi-Yagi Antenna

2.2.1 Overview

The Yagi-Uda antenna is first published in an English language journal in 1928 [1]. Since then, it has been used extensively as an end-fire antenna and further development has been done. The antenna has wide applications in wireless communication systems, radar systems, power combining, phased arrays, and active arrays, as well as millimeter-wave imaging arrays [2].

A quasi-Yagi antenna is a printed antenna based on the classic Yagi-Uda antenna. It is commonly used in microwave and millimeter-wave applications because of the low manufacturing cost, low profile, broadband, high gain, ease of integration with monolithic microwave integrated circuits (MMIC), and the ability to be mounted on planar, nonplanar, and rigid exteriors [6]. Generally, a quasi-Yagi antenna consists of four parts which are reflector, driver, director and feeding structure.

Referring to [3], the antenna is constructed on a single piece of substrate with metallization on both sides. The top metallization consists of microstrip feed, two microstrip arms, driver, and director elements. The metallization on the bottom plane is a truncated microstrip ground, which is used as a reflector element for the antenna.

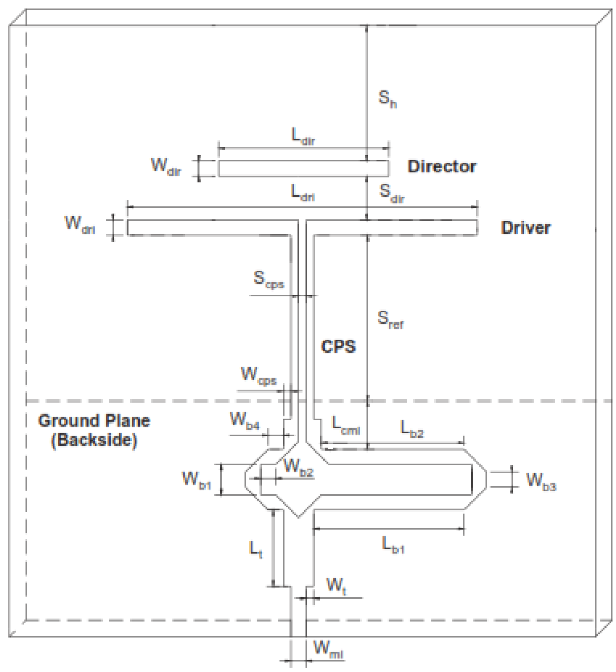

Figure 2.1: Schematic of the quasi-Yagi antenna with dipole driver [3].

Based on [2], the design of quasi-Yagi antenna requires careful optimization of the driver, director, and reflector parameters, which include element spacing, length, and width. By choosing the antenna parameters properly, the quasi-Yagi antenna demonstrates good performances [2] as shown in Table 2.1 below.

Table 2.1: Performance of quasi-Yagi antenna designed in [2].

Characteristics	Value	
Bandwidth Percentage	10-20%	40-50%
Gain	~4dB	~6.5dB
Front-to-back Ratio	>12dB	
Cross Polarization	<-15dB	
Acceptable Absolute Gain	3-5dB	
Nominal Efficiency	93%	

2.2.2 Parameters

Acquired from [6], there are five design parameters considered in the study include: parameter 1 – length of the director, parameter 2 – distance between the director and the driver, parameter 3- distance between the coupled microstrip lines, parameter 4 – length of the driver, parameter 5 – distance from the driver to the reflector, as shown in Figure 2.2 below.

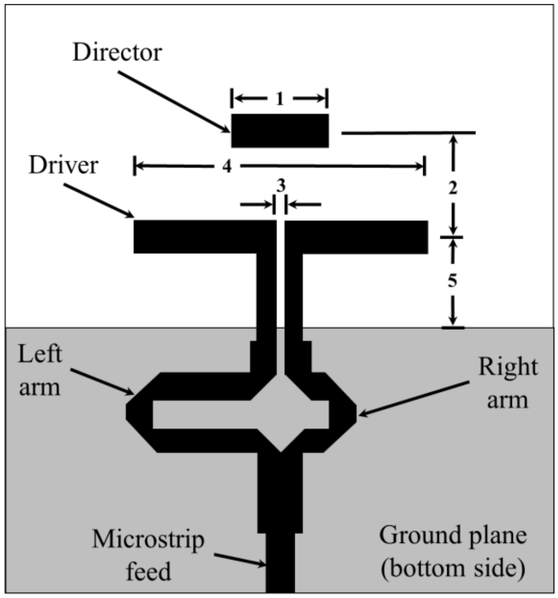

Figure 2.2: Configuration of uniplanar quasi-Yagi antenna [5].

The study in [5] concluded that the design frequency and the operational bandwidth are insensitive to the changes in the length of the director (parameter 1) and the distance between the director and the driver (parameter 2). The length of gap between the coupled microstrip lines (parameter 3) affects the bandwidth moderately. It is found that the length of the driver (parameter 4) and the distance from the driver to the reflector (parameter 5) are the most sensitive parameters of the quasi-Yagi antenna since they affect both antenna's design frequency and its operational bandwidth.

Taken from [4], the design of quasi-Yagi antenna can obtain reasonably good initial dimensions for the length of the dipole driver element, L_{dri}, being equal to the guided wavelength, λ_g, where:

$$L_{dri} = \lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{eff}}} \tag{2.1}$$

and ε_{eff} is the permittivity of the structure which is given in the equation (2.2) [17].

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} \tag{2.2}$$

where ε_r is the dielectric constant of the substrate.

The wavelength, λ, can be calculated as follows:

$$\lambda = \frac{c}{f} \tag{2.3}$$

where c is the speed of light, c = ($3x10^8$ m/s) and f is the design frequency.

The length for the director element is $\lambda_g/2$. The optimized dimensions of the antenna can be found through trial and error method. The director element is shorter than the classical Yagi-Uda antenna design and this contributes to the antenna wideband characteristic [4].

The microstrip line at the input port is connected to a microstrip-to-CPS transition. The two branches of the microstrip lines, or the right and left arms of the quasi-Yagi antenna are adjusted so that their lengths will be $l_1 - l_2 = {}^{\lambda_g}/_4$. In this way, the propagation mode in the coupled microstrips can be easily transferred into the CPS mode after the ground plane is truncated [20].

2.3 Quasi-Yagi Antenna with Microstrip (Patch) Driver

2.3.1 Antenna Design

The traditional dipole driver element of quasi-Yagi antenna is changed to a pair of microstrip patch elements. The name patches is due to the square approach shape at each monopole, but precisely for patch configuration, a ground plane is required and, in this case, the square patches operate without ground plane under them. In spite of this, the name is keeping due to the easy identification [3].

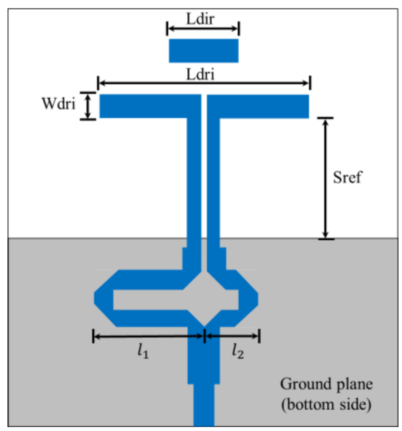

Figure 2.3: Classical structure of quasi-Yagi antenna [4].

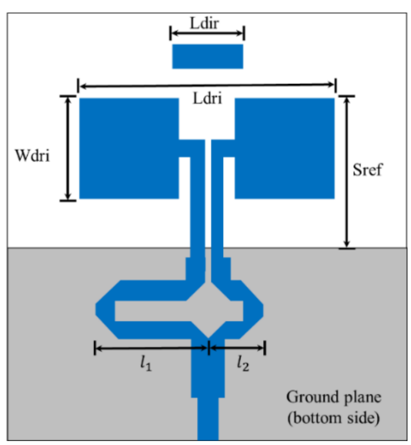

Figure 2.4: Quasi-Yagi antenna structure with patches as the driver [4].

The patches were designed with length equal to half a dipole driver and the width equal to the length, acquiring a square form. Many simulations have shown that the length may be larger, about 15%, while the width is kept equal [6]. The fabricated antennas are shown in Figure 2.5 and Figure 2.6.

Figure 2.5: Quasi-Yagi antenna with dipole driver [3].

Figure 2.6: Quasi-Yagi antenna with patch driver [3].

Theoretically, the inset feed technique for the patch elements could refine the impedance matching. However, referring to [3], the use of inset feed does not improve the performance when the patch is designed as the driver of the quasi-Yagi antenna. Simulation with this technique shows a bad impedance matching, thus it maintain the patch structure without inset feed.

2.3.2 Return Loss and Bandwidth of Antenna

From [4], the simulated and measured results of the return loss of the antenna are shown in Figure 2.7.

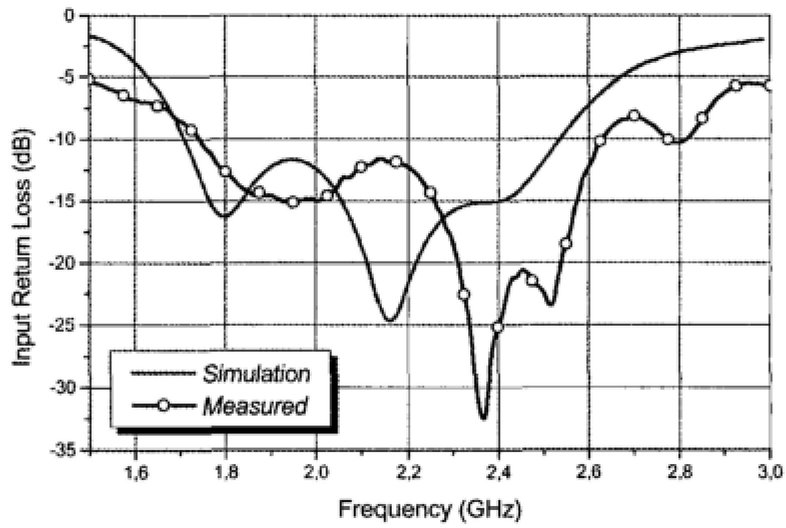

Figure 2.7: Simulated and measured results of the designed quasi-Yagi patch antenna [4].

The measured bandwidth of 42% is exceptionally wide for the antenna, compared to its simulated bandwidth, which is 38%.

2.3.3 Radiation Pattern

The radiation pattern of the results measured in [3] indicates a well-defined endfire with a front-to-back ratio around 10 dB. The radiation pattern of quasi-Yagi patch antenna is more isotropic than the others, due to characteristics of the patch element added into the structure. Quasi-Yagi patch antenna also has a broader radiation pattern compared to the others.

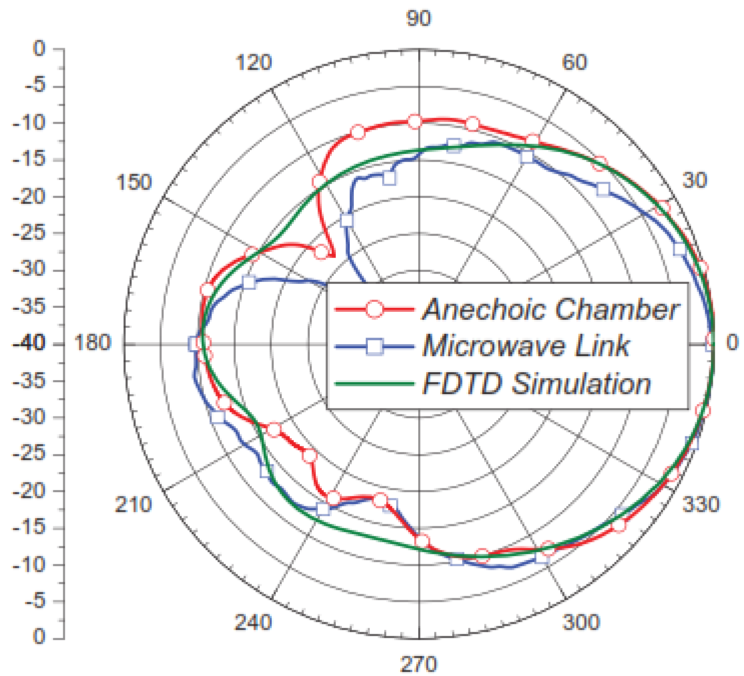

Figure 2.8: Radiation pattern of quasi-Yagi patch antenna [3].

2.4 Slot

2.4.1 Effects of Slot

The etching of a slot on a microstrip patch offers a better antenna performance. Based on [21], slots help to increase the bandwidth and enhance the gain of the antenna. Return loss can also be reduced by increasing the length and width of the slot.

Among the shapes of slot that will be implemented in the design of the quasi-Yagi antenna are U-shaped slot, E-shaped slot, H-shaped slot and single slot.

2.4.2 Position of Slot

Positioning of the slot is crucial for the efficiency of a microstrip antenna. The output characteristics of a slot antenna are evaluated in [22]. It may be concluded that if the slot is moved towards a fixed feeding point along the x-axis, then the antenna gives a maximum bandwidth and gain with slot is placed near the feed point.

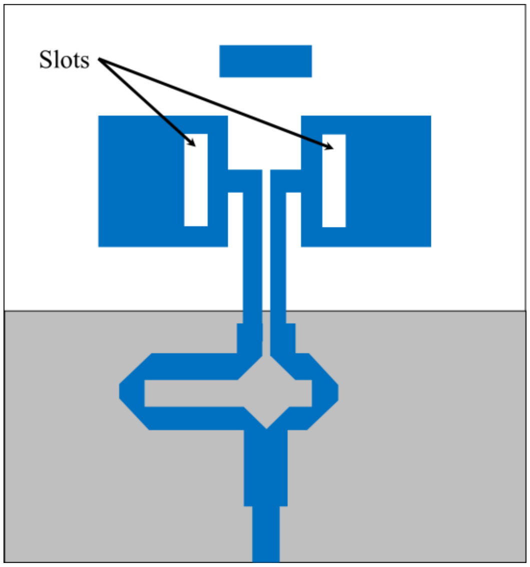

Figure 2.9: The best position for slot.

2.5 Quasi- Yagi Antenna Array

2.5.1 Design of Array

In reference to [7], the quasi-Yagi antenna can be configured into a two-dimensional (2-D) array by simply stacking multiple cards of subarrays as shown in Figure 2.10. This will form a sharp main beam useful for adaptive arrays for communications, spatial power combining or phased array radar, or millimeter-wave imaging.

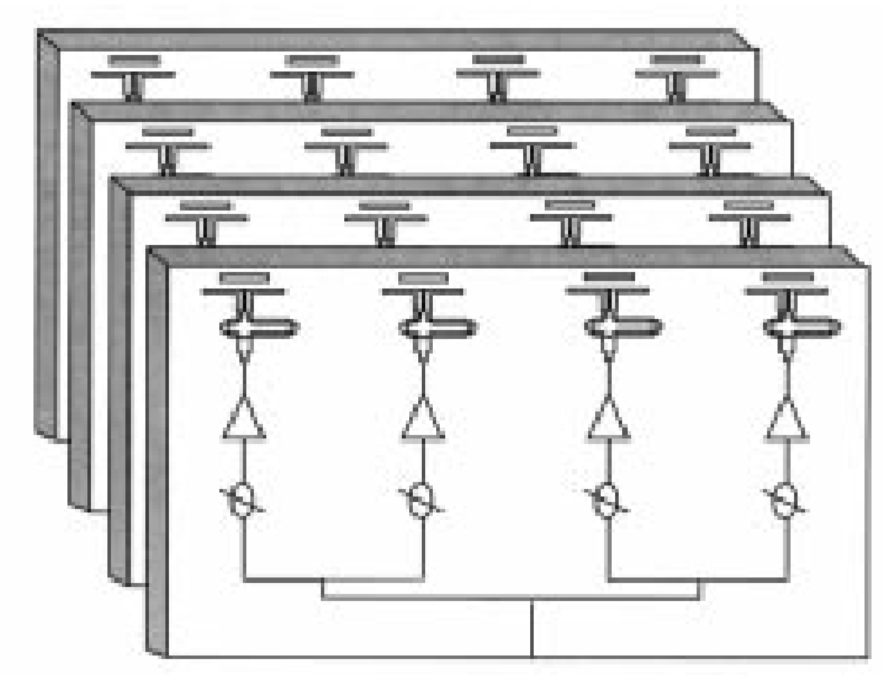

Figure 2.10: Proposed card-based architecture of 2-D array using quasi-Yagi antenna [7].

However, proceeding from [8], further research are currently being conducted to prove the designed compact endfire array is useful as a single "card" in large 2-D arrays. The fabricated eight element linear array with the main beam at endfire is shown in Figure 4. The demonstrated arrays has a front-to-back ratio better than 20 dB and cross polarization better than 15 dB in the operating bandwidth.

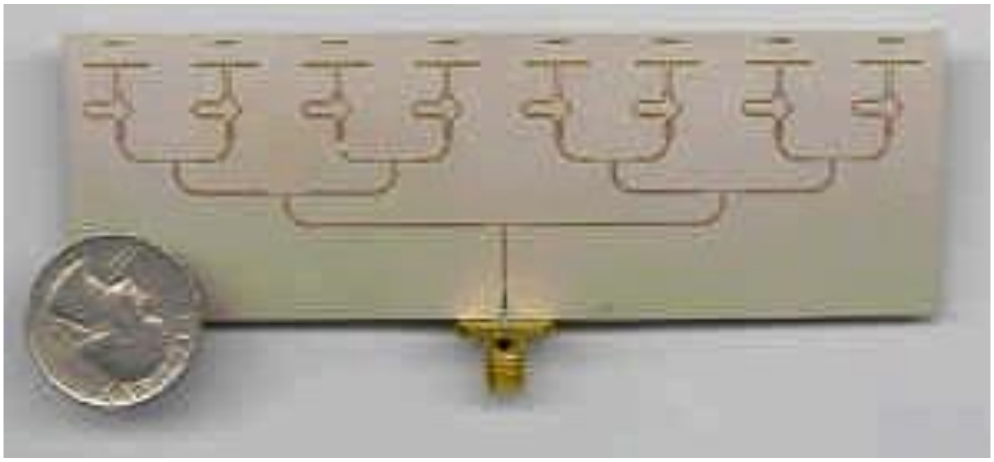

Figure 2.11: Picture of eight-element endfire array [8].

The low mutual coupling between adjacent quasi-Yagi elements (<-22.4 dB across the entire band) and the narrow physical width of the antenna gives great flexibility in array spacing not available with other endfire antennas, such as the Vivaldi, which are typically much wider.

The feed network is an important part in designing antenna array. It involves of the overall antenna which connects it individually into a network by using a transmission line. The feed network consists of series and parallel feed. Figure 2.12 shows the parallel feed network which uses simple power split.

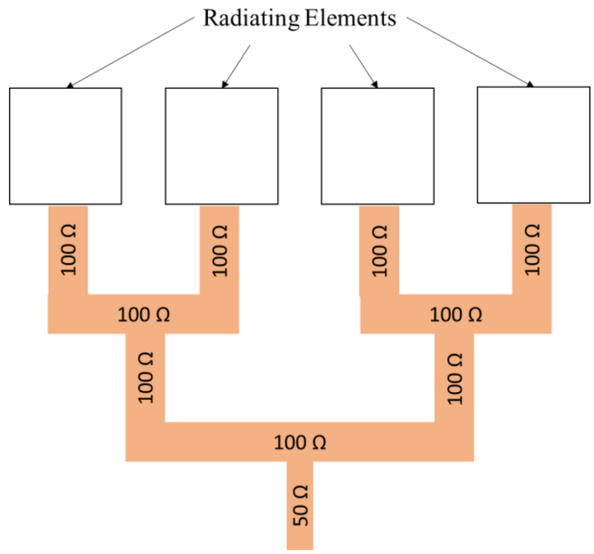

Figure 2.12: Parallel Feed Network [19].

2.5.2 Mutual Coupling

One of the important parameter in antenna array is the mutual coupling between elements within the array environment, which may complicate the design [7]. The quasi-Yagi antenna demonstrates relatively low mutual coupling when placed in an array environment despite its compact design. Possible source of mutual coupling include free-space coupling, coupling by surface waves excited by the feed networks of adjacent elements, and surface-wave coupling through the elements.

2.6 Previous Researches on Quasi-Yagi Antenna

Table 2.1 shows the summarized comparison between the previous designs of quasi-Yagi antenna in terms of frequency, simulated and measured bandwidth, radiation pattern, and application.

Table 2.2: Comparison between quasi-Yagi antenna designs from previous works.

Reference		[4]	[3]
Frequency		2.2 GHz	1.85-2.7 GHz
Bandwidth Percentage	Simulated	38%	38.5%
	Measured	42%	41.2%
Radiation Pattern		Broader compared to classical quasi-Yagi antenna	More isotropic and broader compared to other shapes of driver elements of quasi-Yagi antenna
Application		Wireless systems such as power combining and phase arrays.	Wireless systems with benefit of easy integration with other circuit components for its planar structure.

2.7 Summary

Based on the recent works, it can be seen that many researches on the quasi-Yagi antenna have been done, including various shape of the driver element, parameter study, and antenna array. Besides that, there are also studies on slots that will be added on the driver element of the quasi-Yagi patch antenna which includes the shapes of slot and the position of slots from the feeding point. Every design aspects of the antenna in previous works are compared in order to determine the scope and limitation in designing the proposed.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will describe the methods and steps used in constructing a 5.8 GHz quasi-Yagi patch antenna that is suitable for wireless communication system. Figure 3.1 shows the flow chart of the project from the beginning until the end.

The first step is studying the established theoretical framework and methodological focus on summaries of the research topics, which is reviewed in Chapter 2. It includes the geometry of the antenna, important parameters, radiation pattern and antenna gain. Based on the researches done, the design and specifications of quasi-Yagi patch antenna can be defined. After the parameters have been finalized, the antenna can be designed and simulated with CST simulation tool.

Next, the simulation results from the simulated antenna design are used to analyze the antenna requirements. Fine tuning and optimization cycles of the antenna are repeated if the simulation results do not meet the design requirements.

Once the simulation results are satisfying, the antenna is passed to the fabrication process. The desired parameters of the fabricated antenna will be tested with RF equipment. The simulation and measured data will be used to analyze the design of the proposed antenna.

3.2 Flow Chart

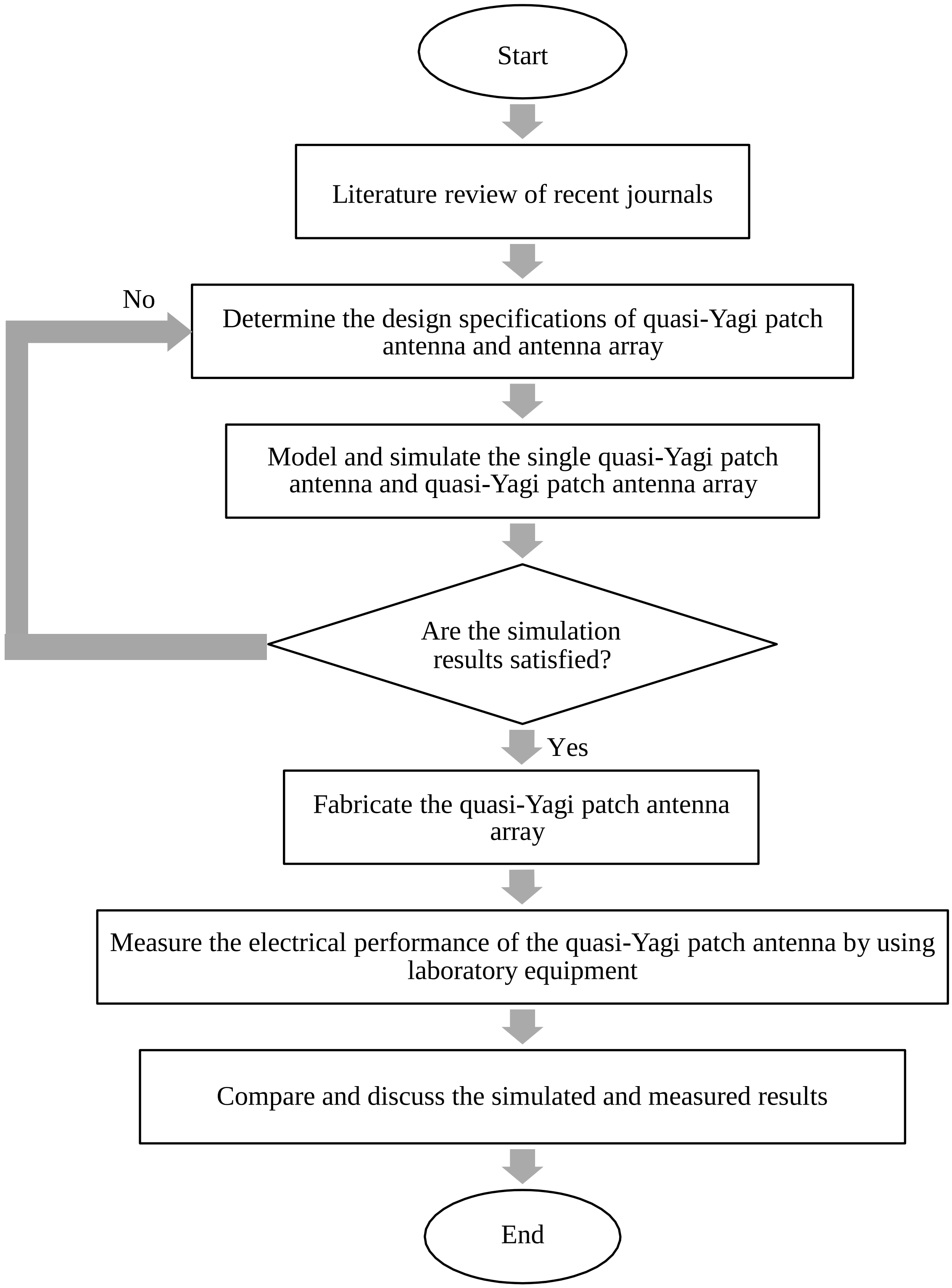

Figure 3.1: General design flow chart.

3.3 Design Specifications

The design specifications of the antenna involve frequency selection, patch architecture, antenna characteristics, antenna array, software used in design and simulation process, and hardware used for the fabricated antenna.

3.3.1 Frequency Selection

An operational frequency of 5.8 GHz has been chosen for the quasi-Yagi patch antenna as it is categorized in the Super High Frequency (SHF) band as shown in Appendix A. This frequency band is typically used in wireless communication system such as radar, mobile phones and satellites.

3.3.2 Patch Architecture

The dimension of the patch driver does not need to be calculated by using the theoretical formulas since the length of the driver is calculated based on the length of the driver of the classical quasi-Yagi patch antenna which is a folded dipole. For the width of the patch driver, it is equal to half of the length of the driver in order to acquire a square shape.

3.3.3 Antenna Characteristics

The design specification for the quasi-Yagi patch antenna and the parameter of ROGERS4003 substrate which is used in this project is shown respectively in Table 3.1 and Table 3.2 below.

Table 3.1: Design specification of quasi-Yagi patch antenna.

Antenna Characteristics	Specification	
Operating frequency	5.8 GHz	
Substrate	ROGERS 4003	
Return loss	-10dB or less	
Bandwidth	40-50%	10-20%
Gain	4dB	6.5dB

Table 3.2: Parameter of ROGERS4003 substrate.

Parameter	Value
Dielectric constant of substrate	3.38
Height of substrate	0.813 mm
Height of copper	0.035 mm

3.3.4 Array

The array for the proposed antenna consists of two elements of the single antenna. This is because the dimension of the antenna array is expected to be quite large. If the elements are made to be more than two, it is afraid that the antenna will not be conventional to be tested using the laboratory equipment.

3.3.5 Software

The software used in designing the antenna is CST (Computer Simulation Technology) Microwave Studio 2013. The antenna will be designed according to the calculated parameters, which depend on the operating frequency. The microstrip line for the antenna feed is determined by using Line Calculation (LineCalc) tool, which is provided in the Advanced Design System (ADS) 2014. The tool will calculate the length and width of the microstrip line according to the operating frequency, input impedance, parameters of substrate, and the thickness of copper.

3.3.6 Hardware

After the simulation results are found to be satisfying, the antenna is fabricated on a Printed Circuit Board (PCB). Then, the fabricated antenna is soldered with a SMA connector at its feeding point. The testing and measurement process used Vector Network Analyzer (VNA), Spectrum Analyzer, and Signal Generator to determine the return loss, bandwidth, radiation pattern, and gain.

3.4 Conventional Quasi-Yagi Patch Antenna Design

Before designing the antenna, the dimensions must be chosen correctly. The important design parameters include the length of the director, distance between the director and the driver, distance between the coupled microstrip lines, length of the driver, and distance from the driver to the reflector [5].

By using Equation (2.2), the effective permittivity can be calculated as:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}$$

$$\varepsilon_{eff} = \frac{3.38 + 1}{2} = 2.19$$

The obtained value of the effective permittivity is then inserted to equation (2.1) to get the guided wavelength, λ_g.

$$\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{eff}}}$$

$$\lambda_g = \frac{c/f}{\sqrt{\varepsilon_{eff}}}$$

$$\lambda_g = \frac{(3 \times 10^8 m/s)/5.8 \times 10^9 Hz}{\sqrt{2.19}} = 34.94mm$$

The length for the director element is $\lambda_g/2$. Thus,

$$L_{dir} = \frac{\lambda_g}{2} = \frac{34.94mm}{2} = 17.47mm$$