VOT 74278

DESIGN AND DEVELOPMENT OF ACTIVE INTEGRATED ANTENNA FOR WIRELESS LAN APPLICATION

(MEREKABENTUK DAN MEMBANGUNKAN ANTENA AKTIF BERSEPADU UNTUK RANGKAIAN KAWASAN TEMPATAN WAYARLES)

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RESEARCH VOT NO:
74278

Fakulti Kejuruteraan Elektrik
Universiti Teknologi Malaysia

2007

UNIVERSITI TEKNOLOGI MALAYSIA

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MAY 2007

DECLARATION

I declare that this project entitled "*Design and Development of Active Integrated Antenna for Wireless Local Area Network Application*" is the result of my own research except as cited in the references.

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Date : 10 May 2007

ACKNOWLEDGEMENT

In the name of Allah, Most Gracious, Most Merciful. Praise be to Allah, the Cherisher and Sustainer of the Worlds. With His permission I have completed this thesis and hopefully this thesis will benefit the development of the Ummah all over the world.

Firstly I would like to give my heartiest gratitude to the Director of Wireless Communication Centre, who has given support me and my research team in providing the facilities and equipments for us to initiate our work. I would also like to thanks my colleagues who has spend a lot of their precious time to run this project. Your advice, guidance, kindness and support will always be my inspiration for the future. They have given me an inspiration to excel in the future.

Next, I would like to thanks my students which are Azhari, Thelaha, Mohd Haizal and Mohd Nazri, the undergraduate students and those who involve in this project which through discussion and exchanging ideas in this project which benefit all. Their support and friendship will always be treasured.

Lastly, I would also like to give my sincerest gratitude to my parent and family for their full support in this project. Their support and patience is a motivation to my work.

DESIGN AND DEVELOPMENT OF ACTIVE INTEGRATED ANTENNA FOR WIRELESS LAN APPLICATION

(Keywords: Active Microstrip antenna, dual band, WLAN)

Wireless local area network (WLAN) applications nowadays has become more popular especially those operating in the 2.4 GHz ISM band. Newer laptops incorporated WiFi and Bluetooth technologies to connect to portable devices such as handsets and palmtop or to fixed devices such as printers. Nowadays, there are a lot of efforts on combining the WLAN, IEEE 802.11 a/b/g bands together. Even though IEEE 802.11a is not allowed in Malaysia (for aeronautical navigation and fixed satellite communication), this frequency spectrum might be available in the future. Such new designs either provide inadequate coverage of the frequency band or not suitable for integration in some portable devices. This thesis describes the design of the dual band microstrip antenna using scaling factor technique and inset feed with the integration of active devices. Different shapes of patches have been used to investigate any improvements that can be achieved. The antennas were designed to operate in the ISM band at 2.4 GHz and lower UNII band at 5.2 GHz. The dimensions of each single element of the microstrip antenna, at these operating frequencies were calculated using transmission line model. Two elements of inset fed antenna were used for each frequency band. The simulation process was done using the Agilent Advanced Design System and Microwave Office software. The passive antennas show comparable results to the typical monopole antenna used for access point. The active antenna gives a broader bandwidth than the passive type antenna.

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MEREKABENTUK DAN MEMBANGUNKAN ANTENA AKTIF BERSEPADU UNTUK RANGKAIAN KAWASAN TEMPATAN WAYARLES

(Kata kunci: Antena Actif Mikrostrip, dwi jalur, WLAN)

Aplikasi-aplikasi bagi rangkaian kawasan tempatan wayarles (WLAN) pada masa kini telah menjadi lebih popular terutama yang beroperasi pada jalur frekuensi ISM 2.4 GHz. Komputer riba pada masa kini dilengkapi dengan peranti WiFi teknologi Bluetooth untuk dihubungkan dengan alat-alat mudah alih lain seperti telefon bimbit dan palmtop atau untuk alat-alat yang tetap seperti pencetak. Pada masa kini, terdapat banyak usaha untuk menggabungkan sistem WLAN, a/b/g bersama-sama. Walaupun IEEE 802.11a tidak dibenarkan di Malaysia (digunakan untuk panduan aeronotik dan komunikasi satelit tetap), frekuensi ini tetap mempunyai peluang pasaran dimasa hadapan. Rekabentuk yang direka sama ada tidak mempunyai liputan jalur frekuensi yang memadai atau rekabentuk itu tidak sesuai untuk diintegrasikan dalam sesetengah alat mudah alih. Tesis ini menerangkan tentang rekabentuk antena mikrostrip dwi-jalur menggunakan teknik penskalaan dan suapan sisipan serta intergrasi dengan komponen aktif. Bentuk-bentuk mikrostrip yang berlainan telah digunakan untuk mengenalpasti pembaikan yang boleh dicapai. Antena-antena direkabentuk untuk beroperasi pada jalur tertutup WLAN ISM pada frekuensi 2.4 GHz dan 5.2 GHz. Dimensi untuk setiap elemen-elemen tunggal telah dikira dengan menggunakan model talian penghantaran. Dua elemen antena telah digunakan bagi setiap jalur frekuensi. Proses simulasi telah dilakukan menggunakan perisian Agilent Advanced Design System dan Microwave Office. Antena pasif menunjukkan keputusan yang boleh dibandingkan dengan antena monopol yang biasa diguna pada peranti titik akses. Antena aktif mempunyai lebar jalur yang lebih besar dari antena pasif.

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LIST OF SYMBOLS

Z_o	-	Characteristic Impedance
Z_L	-	Load Impedance
Z_{in}	-	Input Impedance
RL	-	Return Loss
S_{11}	-	S parameter from port 1 to port 1
k_o	-	Complex propagation constant
k_m or k_n	-	Complex propagation constant of the m^{th} or n^{th} mode
$\acute{\omega}_{mn}$	-	Complex resonant frequency of the mn^{th} mode
λ	-	Wavelength
λ_g or λ_d	-	Dielectric guided wavelength
λ_o	-	Free space wavelength
$\tan\delta$	-	Dielectric loss tangent
μ_o	-	Permeability of free space
f_0 or f	-	Frequency
f_r	-	Resonant Frequency
f_c	-	Cutoff Frequency
f_u	-	Upper cut off frequency
f_l	-	Lower cut off frequency
G	-	Conductance
B	-	Susceptance

ε_{reff}	-	Effective dielectric constant
ε_o	-	Dielectric constant of free space
ε_r or ε_d	-	Relative Dielectric constant / permittivity
W or a	-	Conductor width
W_{eff}	-	Effective conductor width
L or b	-	Conductor length
L_{eff}	-	Effective conductor length
W/L	-	Patch conductor width over length ratio
t	-	Conductor thickness
h	-	Height of dielectric layer
R	-	Resistance
I	-	Current
C	-	Capacitance
L	-	Inductance
τ	-	Scaling factor
V	-	Voltage
pF / F	-	Piko Farade / Farade
D	-	Largest dimension of the physical aperture of the antenna
P_{AUT}	-	Power radiated from antenna under test
r_{ff}	-	Distance to AUT at the inner boundary of the far field region

LIST OF ABBREVIATIONS

AIA	-	Active Integrated Antenna
WLAN	-	Wireless Local Area Network
MoM	-	Method of Moments
TLM	-	Transmission Line Model
TM	-	Magnetic field transverse with respect to the interface normal
MMIC	-	Microwave Monolithic Integrated Circuit
MIC	-	Microwave Integrated Circuit
VSWR or S	-	Voltage Standing Wave Ratio
BW	-	Bandwidth
BW%	-	Bandwidth percentage
HPBW	-	Half-power beam width
CAD	-	Computer-aided Design
FR-4	-	Fire Retardant Type 4
DSSS	-	Direct Sequence Spread Spectrum
OFDM	-	Orthogonal Frequency Division Multiplexing
MIMO	-	Multiple Input Multiple Output
Wi-Fi	-	Wireless Fidelity
AFH	-	Adaptive Frequency Hopping
Mbps	-	Mega bit per second
EDR	-	Enhanced Data Rate
FS	-	Frequency Selection
TPC	-	Transmit Power Control

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Antenna design has become one of the most active fields in the communication studies. In the early years when radio frequency was ‘found’, simple antenna design was used as an apparatus to transmit electrical energy or radio wave through the air in all direction. This innovative way of communication to replace wired technology to wireless technology was first introduced by Guglielmo Marconi when he successfully initiated the first wireless telegraph transmission in 1895 [24]. And so, wireless technology has expanded rapidly not only for commercial but also for military purposes. Wireless technology provides less expensive alternative and a flexible way for communication. Just imagine the communication between an airport and an airplane in the air. How could the airport manager contact the captain to give instruction for landing without any means of communication?

Antenna is one of the important elements in the RF system for receiving or transmitting the radio wave signals from and into the air as the medium. Without proper design of the antenna, the signal generated by the RF system will not be transmitted and no signal can be detected for processing. Antenna engineering is a vibrant field which is bursting with activity and is likely to remain so in the foreseeable future [1]. Many types of antenna have been designed to cater with variable application and suitable for their needs. One of the types of antenna is the microstrip antenna. The microstrip antenna has been said to be the most innovative area in the antenna engineering, thanks to its low material cost and its easiness of fabrication which the process can be made inside universities or research institutes.

At international level, indoor WLAN frequency band has been allocated at two frequency bands [2], which are at 2.4000 GHz to 2.4835 GHz and 5.15 GHz to 5.25 GHz. In Malaysia, the frequency spectrum at 5.2 GHz is not allowed because it is reserved for aeronautical navigation and fixed satellite communication [2]. The standard for the 2.4 GHz frequency band is IEEE 802.11b has the data rates of 11 Mbps uses Direct Sequence Spread Spectrum (DSSS). IEEE 802.11b is the original Wi-Fi standards. The IEEE 802.11g is the improvement of the original standard uses Orthogonal Frequency Division Multiplexing (OFDM) and has a maximum data rate of 54 Mbps. With further improvements, IEEE 802.11n offers a maximum data rate over 100 Mbps which is contributed by the use of OFDM and Multiple Input Multiple Output (MIMO) technology. The IEEE 802.15 or Bluetooth also use the same frequency spectrum at 2.4 GHz. Bluetooth use spread spectrum, frequency hopping, full duplex signal which can also be called Adaptive Frequency Hopping (AFH) which offers data rate from 1 Mbps to 3 Mbps with Enhanced Data Rate (EDR). The 5 GHz band is catered for the IEEE 802.11a, also use the OFDM technology has a maximum data rate of 54 Mbps. The IEEE 802.11h also operates in 5 GHz band is the supplement to IEEE 802.11a in Europe which have the additional spectrum and power control management which are the dynamic Frequency Selection (FS) and Transmit Power Control (TPC). Some countries such as Malaysia limits the use of the 5 GHz frequency band to indoor use only to reduce the potential for harmful interference to co-channel Mobile Satellite systems. High power radars are allocated as primary users of the 5.25 – 5.35 GHz and 5.65 – 5.85 GHz bands. These radars could cause interference and/or damage to the access point device when used in countries that use this radar system.

Microstrip active integrated antenna (AIA) has been a fast growing area in the recent years as an effect of maturing microwave technology by introducing better material and monolithic integrated circuit [4]. Active integrated antenna can be classified by their different applications. Some of the classified types of AIA are the oscillator, transceiver, amplifier and phased array [4], [5].

Nowadays, there are a lot of efforts on combining the WLAN, a/b/g bands together as discussed in reference [25], [27], [28] and [29]. Such combinations will either provide inadequate coverage of the frequency band or not suitable for integration in some portable devices. Amplifying type of dual band antenna has been investigated to achieve higher gain as shown in reference [22].

1.2 Problem Statement

A WLAN access point device in the market commonly consists of a transceiver that uses one antenna for one frequency band. The use of one antenna for one frequency band increase the overall size of the access point device and the use of the monopole will have omni directional radiation pattern with some of the angle having unnecessary radiation from the antenna. The use of microstrip antenna will be an alternative to the omni directional monopole antenna which the microstrip antenna can be used in certain cases depends on the environment. The unnecessary radiation usually caused by the way the access point device is mounted. Access point device usually is mounted on the wall, where the area behind the wall is the region that does not need any coverage of the WLAN. Even if the access point is mounted on the ceiling, it is not intended that the upper floor will get the WLAN signal. The use of a unidirectional type of antenna helps to create a more controlled coverage area for the WLAN environment.

Monopole antenna has widely been used as the antenna for wireless access point because it has been a standard type of antenna for wireless devices (walkie-talkie, mobile phones, etc) and its design is less complicated than other type of antenna (only need a quarter wavelength of conductor such wire or metal rod). The monopole has less aesthetic value because of its difficulty to conceal itself inside the access point. A more aesthetic type of antenna will help to increase the price value of the access point device if the antenna can be incorporated on the device’s body.

Omni-directional means radiation at all angles. Larger beamwidth will results in lower gain. Decreasing the beamwidth will help increase the gain, thus increasing the coverage distance of the antenna. The use of a directional type of antenna will increase the gain but the antenna design must also consider a proper beamwidth angle so that it will not only radiate at certain angle only.

Two different set of frequencies have been allocated for the indoor WLAN application. One is at 2.4 GHz band and the other at 5.2 GHz band. Two different set of frequencies need two different set of antenna. It can be solved by using one antenna for two different systems. The integration of two band of frequencies can reduced the incompatibility to each other.

1.3 Objectives

The objectives of this research are as follows:

- To design, fabricate and analyze the performance of the dual band microstrip antenna using the scaling factor technique.
- To design and fabricate the dual band microstrip antenna and integrate with active device to enhance the bandwidth performance of the antenna.

1.4 Scope of Project

This project only concern on the physical layer of the OSI layer. The project focuses on the development of the antenna to meet the satisfied performance that can be used in WLAN system.

The first part of the project is to design the elements for both frequency bands. The elements are designed by using the basic shapes equations and will follows the log periodic technique for each frequency band.

In the second part of the project, the passive dual band antenna will be designed by joining the single elements and adjusting the distance between the single elements to obtain the matched impedance for both frequency bands.

The third part is the integration of amplifier to the passive antenna. Test and measurement is done to obtain the performance of the antenna in terms of bandwidth, gain, beamwidth and the radiation pattern.

The antenna is designed in Agilent Advanced Design System software to obtain the overall simulation performance of the antenna. AWR Microwave office software is also been used to view the electric current of the antenna.

The antennas are tested by using the Marconi Instruments to obtain the reflection coefficient of the antennas. The reflection coefficient will show the operating frequency of the antenna. The radiation patterns of the antennas are obtained in an indoor anechoic chamber, and the antenna is connected to either the spectrum analyzer or the signal generator as a transmitter or a receiver.

The designed antenna is designed for transmitter type of amplifying active integrated microstrip antenna for WLAN application. The type of antenna will affect the setup for the antenna measurement mainly the radiation pattern measurement.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Antenna is a means to transfer the electrical signal at a certain operating frequency to electromagnetic waves into the air. An antenna is an electronic component designed to transmit or receive radio signals (and other electromagnetic waves). The IEEE Standard Definitions of Terms for Antennas defines antenna as “the part of a transmitting or receiving system that is designed to radiate or to receive electromagnetic waves.” [3]. Antennas can be categorised into 9 types as proposed by Thiel [6]. Thiel proposed nine categories for antenna which are:

i. Wire antennas (such as dipoles and loops)
ii. Aperture antennas (such as pyramidal horns)
iii. Reflector antennas (such as parabolic dish antennas)
iv. Microstrip antennas (such as patches)
v. Dielectric antennas (such as dielectric resonant antennas)
vi. Active integrated antennas
vii. Lens antennas (sphere)
viii. Leaky wave antennas

ix. Antenna arrays (including smart antennas)

Among all these types of antennas, microstrip antenna has been one of the most variation in terms of feeding methods, shapes and architectures. Microstrip antenna is defined as “an antenna that consists of a thin metallic conductor bonded to a thin grounded dielectric substrate” [3]. The metallic conductor typically has some regular shape; for example, rectangular, circular, or elliptical. The commonly used feeding technique is a coaxial probe or a microstrip transmission line. Microstrip antenna has the advantages [1] of:

i. Can be made conformal to any surface. This allows the microstrip antenna suitable to be used for any wireless application for its ability to be concealed into the body of any device.
ii. Very low profile. As mentioned before, its ability to be easily concealed made microstrip antenna a low profile without sacrificing its aesthetic value.
iii. Can be fabricated using printed circuit technique (photolithographic). The photolithographic technique offers accurate dimension to be print out on the dielectric board.
iv. Potentially can be made with low cost. With photolithographic process, fabrication can be done the same as a photocopy machine because the mask of the design can be reused as many times as possible. The cost for making the mask is also cheap.
v. Easy fabrication into linear or planar arrays. Array structure requires incorporation of many passive elements. The fabrication requires accuracy despite of the complexity of the array organisation. The photolithography technique can handle this situation easily because the design is printed out and transferred to the dielectric board like a copier.
vi. Easy integration with microwave integrated circuit. Integration with microwave device can be realised because of the structure of the microstrip is also similar to a circuit board and the easiness to create a matching network for any microwave devices.

Although microstrip antenna possesses many advantages, it also has some disadvantages that made early designers think twice on researching in microstrip antenna. The disadvantages of the original microstrip antenna [1] are:

i. Narrow bandwidth
ii. Spurious feed radiation
iii. Poor polarisation purity
iv. Limited power capacity
v. Tolerance problem

So, many researches have been done to overcome these problems to satisfy the increasingly stringent systems requirements nowadays. A lot of work has been discussed in [7], [25], [31], [32], [33] and [34].

2.2 Microstrip Antenna Application

As discussed in the previous subtopic, due to the various advantages of the microstrip antenna, such as light weight and conformal, it has been use widely in many applications nowadays. In the early years of microstrip development, it is usually used for military purposes, such as in missiles, rockets, aircraft and satellites. With rapid changes and evolution of new technology of fabrication and new material, commercial sector also take part in utilizing the full potential of the microstrip antenna by replacing conventional antenna for most application.

As reported in [7], there are several applications that use microstrip antenna technology as its components which are the:

- Satellite communication and direct broadcast services (DBS)
- Doppler and other radars
- Radio altimeters
- Missiles and telemetry (sensors and weapon fusing)
- Satellite navigation receivers
- Mobile radio (pagers and telephones)
- Integrated antennas
- Biomedical radiators and intruder alarms

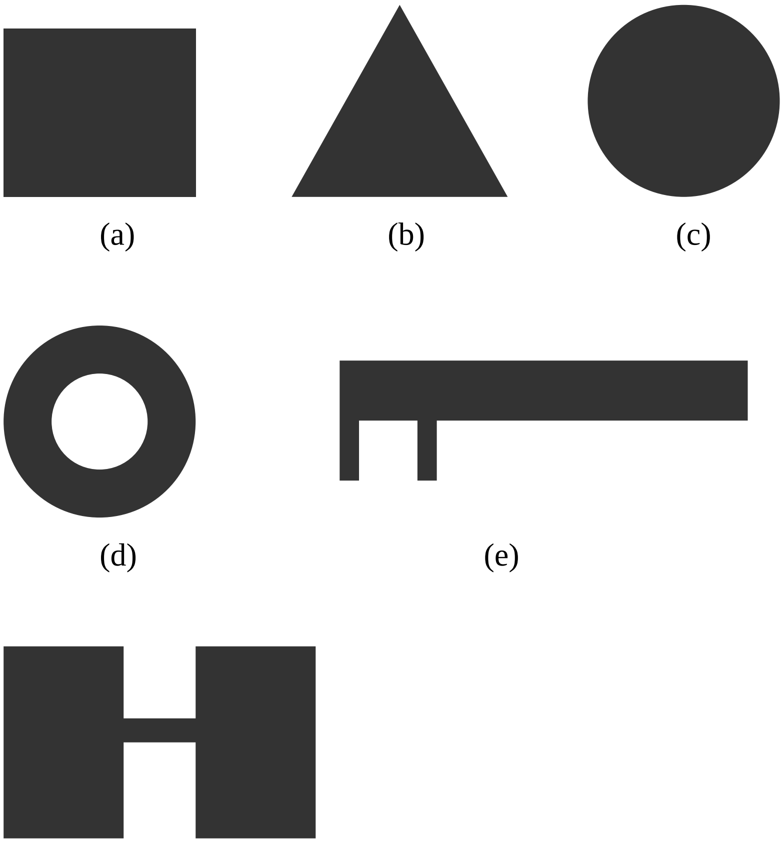
The most common use of the microstrip antenna in our every day life is in the mobile communication system as can be proven in [33]. Nowadays, the mobile phones in the market are getting smaller and smaller which also leads to the miniaturization of the antenna. The other application that benefits from the microstrip antenna is the global positioning system. The ground receiver antenna must be in circular polarized, omni-directional and wide-beam but has a low gain. These requirements can be achieved using the microstrip antenna. There are a lot more applications that can benefit from the improvements of the microstrip antenna which has been briefly discussed in this sub topic.

2.3 Improvements in Microstrip Antenna Design

Many researches have tried to overcome the disadvantages of a basic microstrip antenna as mentioned in sub section 2.1. There are several methods that have been commonly used for this purpose such as introducing various shapes [7], [31], feeding methods [2], architectures [31], [33], [34], arrays [23], [18], scaling factors technique [27] and integration with active devices [4], [5], [20], [21], [22], [29].

Certain feeding method could also improve the performance of the microstrip antenna. The proximity and the aperture-coupled feed has been claimed to be improving the bandwidth of the microstrip antenna to about 13% [7]. Even though this technique could produce a wide bandwidth, the modelling of the design cannot be done properly in the simulation software when involving array design such as the log periodic antenna.

The microstrip antenna can also have a different architecture from the usual, such as multi stacked patch which improves the bandwidth and could also introduce dual band feature, and other example of new architecture is the defected ground structure and band-gaps which could introduce a ‘filter’ like response and also improve the performance of the antenna.



(a) (b) (c)

(d) (e)

(f)

Figure 2.1: Shapes of microstrip antennas respectively; (a) square, (b) triangle, (c) circle, (d) circular, (e) PIFA, (f) H shaped.

Scaling technique can also be use to design a wide band or selective band antenna. While using the array technique, the directivity and the gain of the antenna can be increased and improved [24]. Microstrip array has been widely used in military for radar application, in air field and for satellite communication.

The microstrip antenna and common circuitry board have planar geometry which opens opportunities for the integration of antenna and circuits including MMICs. With integration of active devices onto the microstrip antenna, it helps to improve the performance of the antenna greatly.

2.4 Active Integrated Antennas

‘Active antenna’ can be defined as active devices employed in the passive antenna elements to improve the antenna performance. The term ‘active integrated antenna’ (AIA) indicates that the active and the passive elements are integrated on the same substrate [4]. The work and idea of active antenna has started from 1928 by developing a small antenna with an electron tube which is commonly used in radio broadcast receiver at 1 MHz [4]. With more developments on higher frequency active devices, the study on active antenna and active integrated antenna has been rapidly developed. The integration of active devices with the antenna can be a great advantages as it helps to increase the antenna bandwidth as also proven in the result in [22], decrease the mutual coupling between array elements and improve the noise factor, depends on the active elements that is being used [4].

Much research on AIA has been done over the years and the development of the AIA usually depends on the application that the antenna is going to be used such as for simple RF transceiver or a point to point communication will need different active element. Generally, the basic category of the AIA are transmitting and receiving type AIA, and some can have both functions of transmitting and receiving which is called transceivers as discussed in [20]. Other way to classify the AIA is according to the functions of active devices integrated in the AIA. The basic functions for the AIA are oscillating, amplifying and frequency conversion which leads to the assortment to these three types of AIA.

2.4.1 Oscillator type AIA

The oscillator type AIA integrates active devices that works as an oscillator so that it can generates a steady-state oscillation. By using the negative resistance characteristics of an active device, the AIA converts dc power to RF power. The selection of the actives elements is important for the operational performance. The active elements can be a two-terminal device such as Gunn Diodes or a three-terminal device such as MESFET.

The performance of the antenna is determined by the type of the solid-state source. Two-terminal elements are suitable for high power application for millimetre-wave frequencies but also low in DC-to-RF efficiency. Three-terminal elements have better DC-to-RF efficiency but a more complicated circuitry is needed. This complicated circuitry can be easily integrated with either hybrid or monolithic approaches which have planar geometry. Oscillator using transistor also has advantages such as flexible, better control of oscillation frequency, temperature stability and output noise. The oscillator type AIA is also discussed in [21].

2.4.2 Frequency Conversion type AIA

Frequency conversion AIA involves antenna with integrated active device with the purpose of either up-converting or down-converting the frequency. If it is for transmitting, this type of AIA can be used as oscillator/modulator and if it is for receiving, it can be used as oscillator/demodulator [4], [5].

Either two or three terminal active devices can be used for the integration. Using a three-terminal has greater advantages such as increase in conversion gain and the compatibility with MIC and MMIC technology. The application of this AIA is usually for short-distance communications, microwave identification systems and local area networks [4], [5].

2.4.3 Amplifier type AIA

Amplifying type of AIA integrates active device with the passive antenna at the input or the output port with the purpose of signal amplification. If the antenna is at the input port, it functions as a receiver and the antenna is considered as source impedance for the active device where this arrangement is usually called the low-noise amplifier design technique. If the antenna is placed at the output port of the active device, the antenna itself is the active device load impedance and the AIA works as a transmitter [4], [5].

The application of this type of AIA receives attention for the purpose of large phased arrays and spatial power combining amplifiers. The devices that can be used usually are the FETs, microwave integrated circuits (MICs) and the monolithic microwave integrated circuits (MMICs) which allow easy integration and low fabrication cost [4], [5].

The amplifier type AIA is the opposite of oscillator type AIA where the stability of the active device is important to avoid any oscillation. A direct integration of the microstrip antenna with the active device will direct to signal amplification for receiving or transmitting purposes which will leads to increase in the gain of the antenna.

The design objective of a transmitting type is to attain high gain over broad bandwidth while for the receiving type is to attain better noise performance and reasonable gain flatness.

The design of the amplifier type AIA that uses FETs, follows the design procedure of microwave transistor amplifier. The antenna acts as source impedance to the amplifier for the receiver type and as a load for the transmitter type. Other study on the amplifying type AIA can be found in [29].

2.5 Summary

The basic theory of microstrip antenna has been presented including the feeding method microstrip patch antenna. The parameters of the antenna have also been discussed along with the type of dual band antenna. The types of AIAs have been discussed along with the research done in the past until present.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The design of the AIA microstrip antenna started by designing the single elements that will cover a portion of the bandwidth required to cover the wireless LAN frequency band.

A direct feeding method using the inset feeding technique was used because of its easiness to analyze the electromagnetic properties of the microstrip compared to other technique which will involve difficult electromagnetic calculation. The representation of a common microstrip line can be easily represented in the ADS software compared to the other feeding technique. The Microwave Office software is also used to observe the current distribution of the microstrip antenna.

The design of the AIA cannot be done in EM simulation because it involves active elements that cannot be simulated in the EM simulation. The AIA is simulated in the circuit simulation that incorporates the active elements and the passive elements using the Momentum results obtained for each single element.

This chapter discusses the design process and the details on the dimensions and components that are being used in the simulation and experimental work of this project.

3.2 Shapes of Single Elements

Three shapes have been used for the designs which are the square, triangle and circle patch. The calculations for the three shapes are discussed in this sub section.

3.2.1 Square Patch Design Calculation for Single Frequency

The design of the square shape patch follows the equation for designing the rectangular shape patch. The same length and width of the patch of the antenna was made to ease the design steps. Inset feeding is introduced into the design to offset the feeding location to the point where matched impedance can be achieved.

First of all, the basic parameters of the microstrip has to be determined such the width and length and the feeding technique that is going to be used. The width of patch can be determined using the equation 3.1 [7].

$$W = \frac{1}{2f(\sqrt{\varepsilon_o \mu_o})} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{3.1}$$

The ε_0 and the μ_0 are the permittivity and the permeability in free space respectively. The equation $\frac{1}{\sqrt{\varepsilon_0 \mu_0}}$ can also be interpreted as the speed of light, c which is 3×10^8 m/s. The symbol f is the resonant frequency that the antenna intended to be operating and ε_r is the permittivity of the dielectric. The width of the antenna only is used in the calculation for the length of the antenna.

The patch's length can be calculated using the equations 3.2. The length's extension, ΔL and the effective permittivity, ε_{reff} have to be calculated before calculating the length of the microstrip patch as shown in equation 3.3 and 3.4. The h is the height of the substrate while the W is the width of the patch as calculated before.

$$L = \left(\frac{1}{2f\sqrt{\varepsilon_{reff}}\sqrt{\varepsilon_o \mu_o}} \right) - 2\Delta L \tag{3.2}$$

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{3.3}$$

$$\varepsilon_{reff} = \left(\frac{\varepsilon_r + 1}{2} \right) + \left[\left(\frac{\varepsilon_r - 1}{2} \right) \left[1 + 12\frac{h}{W} \right]^{-0.5} \right] \tag{3.4}$$

where:

f = Operating frequency

ε_r = Permittivity of the dielectric

ε_{reff} = Effective permittivity of the dielectric

ε_0 = Permittivity in free space

μ_0 = Permeability in free space

W = Patch's width

H = Thickness of the dielectric

The width of the patch is made to be in the same value with the length to ease the design process, so the patch will be a square patch. Actually, the determination of the patch's width is important because it affects the efficiency of the antenna. A small value of width compared to the calculated width will leads to low antenna efficiency while high value of width will leads to higher order modes [23].

The type of feeding technique that will be used is the inset feed technique. It is one of the easiest feeding techniques and it is also easy to control the input impedance of the antenna. The input impedance level of the patch can be control by adjusting the length of the inset. The calculation of the inset fed is shown in the equations 3.5 which show the resonant input resistance for the microstrip patch.

$$R_{in}(L = \ell) = \frac{1}{2(G_1 \pm G_{12})}\cos^2\left(\frac{\pi\ell}{L}\right) \tag{3.5}$$

L is the length of the patch, ℓ is the length of the inset, G_1 is the conductance of the microstrip radiator and G_{12} is the mutual conductance between the two slots. The conductance of the radiator is calculated using equation 3.6. I_1 is the current excited into the microstrip patch.

$$G_1 = \frac{I_1}{120\pi^2} \tag{3.6}$$

$$I_1 = \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 w}{2}\cos\theta\right)}{\cos\theta} \right]^2 \sin^3\theta \quad d\theta \tag{3.7}$$

The mutual conductance of the two slots (both sides of the feed) can be calculated using equation 3.8.

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 w}{2}\cos\theta\right)}{\cos\theta} \right]^2 J_0(k_0 L \sin\theta)\sin^3\theta \quad d\theta \tag{3.8}$$

The equations above need tedious effort to be calculated. As reported in [15], the calculations for finding the inset length can be simplified as shown in the equation below. This equation is valid for ε_r from 2 to 10. Using the equation below helps to ease the calculation for the inset length of the microstrip antenna.

$$\ell = 10^{-4}\begin{pmatrix} 0.001699\varepsilon_r^{\ 7} + 0.13761\varepsilon_r^{\ 6} - 6.1783\varepsilon_r^{\ 5} + 93.187\varepsilon_r^{\ 4} - \\ 682.69\varepsilon_r^{\ 3} + 2561.9\varepsilon_r^{\ 2} - 4043\varepsilon_r + 6697 \end{pmatrix}\frac{L}{2} \tag{3.9}$$

where:

ε_r = Permittivity of the dielectric

L = Length of the microstrip patch

3.2.2 Triangular Shape Patch Design Calculation for Single Frequency

The design of the square patch has been discussed earlier as it is the basic shape that is easy to analyze. The triangular and the circular shape design came after the expansion of improvements made to microstrip antenna which is motivated from the new design and the need to overcome the disadvantages of using microstrip antenna.

The sides of the triangle, *a* are made to be the same length as shown in figure 3.1.

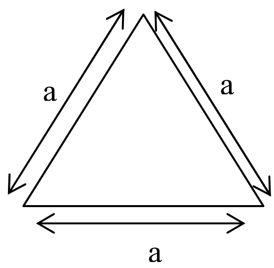


Figure 3.1: Triangle layout dimensions.

The length of the patch, *a* can be calculated using the equations below [7]. The mode that is used for the triangular shape is the TM_{10} which is the dominant mode for triangular shape patch.

$$f_r = \frac{2c}{3a\sqrt{\varepsilon_r}}\sqrt{m^2 + mn + n^2} \tag{3.10}$$

where:

c = Speed of light

a = Triangle side's length

ε_r = Permittivity of the dielectric

m, n = Number of modes

The equations given does not provide a direct calculation to the patch's length, so the calculation of the patch can be made by using the effective length, a_e of the patch as in equation 3.11 which does not vary much from the actual length of the patch.

$$f_{10} = \frac{2c}{3a_e\sqrt{\varepsilon_r}} \tag{3.11}$$

where:

c = Speed of light

a_e = Effective triangle side's length

ε_r = Permittivity of the dielectric

$$a_e = a\left[\begin{array}{l} 1 + 2.199\dfrac{h}{a} - 12.853\dfrac{h}{a\sqrt{\varepsilon_r}} + 16.436\dfrac{h}{a\varepsilon_r} \\ + 6.182\left(\dfrac{h}{a}\right)^2 - 9.802\dfrac{1}{\sqrt{\varepsilon_r}}\left(\dfrac{h}{a}\right)^2 \end{array}\right] \tag{3.12}$$

where:

a = Triangle side's length

ε_r = Permittivity of the dielectric

h = Substrate heigth

The calculation for different operating mode can be calculated using equation 3.13. To ease the calculation for the triangle's dimensions, equation 3.11 is used.

$$f_{mn} = f_{10}\sqrt{m^2 + mn + n^2} \tag{3.13}$$

3.2.3 Circular Shape Patch Design Calculation for Single Frequency

The calculation for circular shape patch microstrip antenna also needs tedious effort as shown in the given equations [7]. The dominant mode that is used for calculating the circular radius is TM_{11}. The radius of the circular patch as in figure 3.2 can be calculated using the equation 3.18.

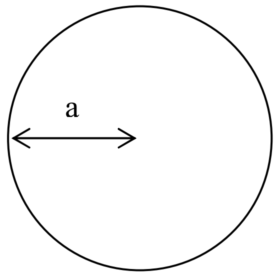


Figure 3.2: Circle layout dimensions.

$$a_e = \frac{87.94}{f_r\sqrt{\varepsilon_r}} \quad mm \qquad (f_r \ in \ GHz) \tag{3.14}$$

For different mode, equation 3.15 can be used to calculate the resonant frequency at radius a_e.

$$f_{nm} = \frac{x_{nm}c}{2\pi a_e\sqrt{\varepsilon_r}} \tag{3.15}$$

where:

$x_{nm} = ka$

$k = 2\pi\sqrt{\varepsilon_r/\lambda_0}$

a_e = Effective radius

ε_r = Permittivity of the dielectric

c = Speed of light

3.3 Single Element Design for Microstrip Antenna

Single elements of each shape are designed so that the elements can then be combined using the scaling method to achieve the dual band feature. The design of three shapes helps to compare the performance of the passive elements of antenna and determining the shapes that posses the best performance. The bandwidths of the elements simulated using the ADS software is shown in table 3.1.

Table 3.1: Simulated bandwidth summary of the elements.

Shapes	Frequency Range (GHz)	Bandwidth (%)
Square	2.25 – 2.30	2.02
	2.35 – 2.40	2.11
	4.81 – 4.95	2.77
	5.06 – 5.21	2.82
Triangle	2.25 – 2.30	1.85
	2.37 – 2.41	1.72
	4.80 – 4.92	2.47
	5.03 – 5.15	2.42
Circle	2.24 – 2.29	2.17
	2.31 – 2.34	2.18
	4.71 – 4.86	3.20
	4.95 – 5.11	3.08

From the bandwidth shown in table 3.1, the single elements have an average bandwidth of 2.4% which is not sufficient to the operating frequency from 2.4 GHz until 2.4835 GHz (bandwidth 83.5 MHz). So, the combination of two elements for the frequency band (2.4 – 2.4835 GHz and 5.15 – 5.25 GHz) is needed so that the bandwidth percentage will has at least 3.42%. The flow of the design is as shown in appendix A.

3.3.1 Square Shape Microstrip Antenna

The design calculation for the square patch has been discussed in section 3.2. The parameters that needed to be calculated are the length of the patch, the inset feed and the feed line's length as shown in figure 3.3.

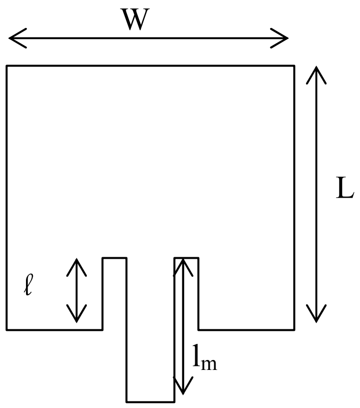


Figure 3.3: Layout of the square patch.

The calculated parameters of the patch have been calculated as shown in table 3.2. The resonant frequency of the antenna has been designed to be much lower than the expected frequency which at 2.4 GHz and 5.2 GHz as reported in reference [23]. The feed line is made to be a quarter wavelength of the operating frequency. The length of the feed line can be in any length.

Table 3.2: Calculated dimensions of the square patch.

Frequency (GHz)	L and W (mm)	Inset, ℓ (mm)
2.27	30.16	9.47
2.38	28.74	9.02
4.95	13.46	4.22
5.20	12.77	4.01

The dimension is then realized into the circuit simulation in the ADS software. The design of the square shaped patch in the schematic window is done to construct the patch with precise dimensions.

The design is then generated to the layout window to do the EM simulation. The simulation is done and the modification will be made so that the operating frequency will be at the desired frequency with acceptable bandwidth and return loss. The new dimensions of the square microstrip antenna are shown in table 3.3. The simulation input return loss of the elements can be viewed in appendix D.

Table 3.3: Modified dimensions of the square patch.

Frequency (GHz)	L and W (mm)	Inset, ℓ (mm)	l_m (mm)
2.27	30.70	10.00	18.36
2.38	29.30	9.50	17.47
4.95	14.30	4.90	8.40
5.20	13.60	4.70	8.00

3.3.2 Triangular Shape Microstrip Antenna

The unsymmetrical shape of triangle compared to square shape leads to different inset feed length and much different in the radiation pattern. As shown in figure 3.4, the feed line is connected to the patch at one side of the patch, and not at the tip of the triangle. The calculated dimensions are shown in table 3.4.

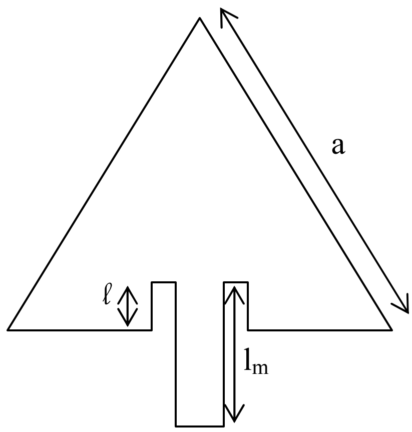


Figure 3.4: Layout of the triangle patch.

Table 3.4: Calculated dimensions of the triangle patch.

Frequency (GHz)	Sides length (mm)	Inset, ℓ (mm)
2.27	40.64	11.05
2.38	38.76	10.54
4.95	18.64	5.06
5.20	17.74	4.82

The inset feed length of the triangle patch is much less than the square and the circle shape because there is a huge difference in the shape structure. The small inset feed length is also affected by the feeding position of the feed line. The dimensions that have been used in the fabrication are as shown in table 3.5. The simulations are shown in appendix D.

Table 3.5**:** Modified dimensions of the triangle patch.

Frequency (GHz)	Sides Length (mm)	Inset, ℓ (mm)	l_m (mm)
2.27	40.35	5.9	17.41
2.38	38.43	5.7	16.59
4.95	18.50	3.1	7.98
5.20	17.60	3.1	7.60

3.3.3 Circular Shape Microstrip Antenna

Figure 3.5 shows the layout of the circle patch. The calculations of the patch can also be found in previous subtopic. The measured inset feed length of the patch is almost similar as calculated. The calculated length of the patch can be found in table 3.6**.**

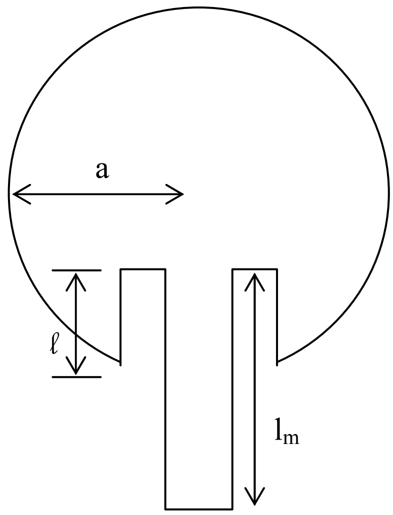


Figure 3.5: Layout of the circle patch.

Table 3.6**:** Calculated dimensions of the circle patch.

Frequency (GHz)	Radius (mm)	Inset, ℓ (mm)
2.27	17.87	11.22
2.38	17.04	10.70
4.70	8.63	5.42
4.90	8.28	5.20

The modified dimensions of the patch can be viewed in table 3.7. The diameter of the patch is less then the dimension of the square patch. It shows that by introducing different shapes will helps to miniaturize the size of the microstrip antenna.

Table 3.7**:** Modified dimensions of the circle patch.

Frequency (GHz)	Radius (mm)	Inset, ℓ (mm)	l_m (mm)
2.27	18.46	12.60	17.41
2.38	17.90	12.00	16.59
4.70	9.00	5.80	8.38
4.90	8.60	5.70	7.60

3.4 Dual Band Active Integrated Antenna Design

The dual band AIA design uses the same layout of the passive antenna but with the addition of the active element. The active element is placed at the centre between the 2.4 GHz elements and the 5.2 GHz elements as shown in figure 3.6. The specification for the amplifier can be found in appendix E. The amplifier operates from 0 to 6 GHz. Element 1 and 2 operate at 2.4 GHz band, while element 3 and 4 operate at 5.2 GHz. The amplifier is placed at the centre of the feed line as discussed in [23].

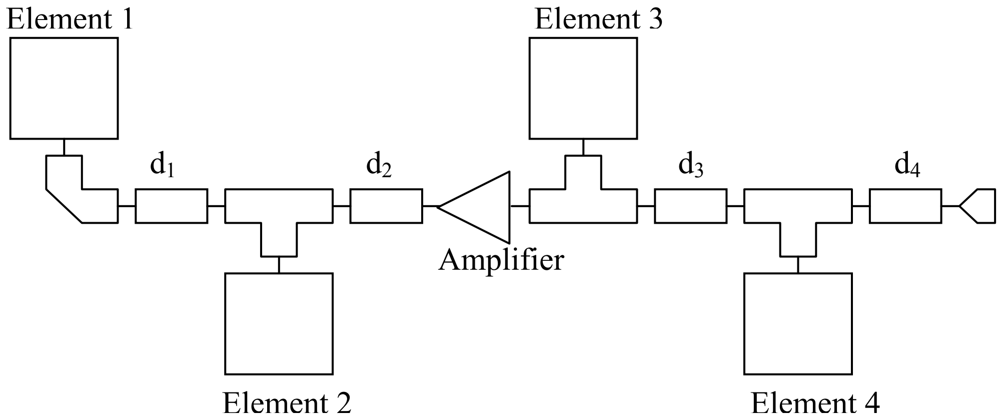


Figure 3.6: Data block layout of the AIA.

3.4.1 Circuit Simulation

The design of the dual band AIA can only be done in the schematic window. The amplifier that is going to be integrated with the passive elements will be represented with a data block in the schematic. The data block contains the S-parameter data of the amplifier that can be obtained from the developer's web site.

The amplifier that is being used is the Mini-Circuits amplifier, ERA-2 type that can amplify signal from 0 Hz to 6 GHz. The data sheets for the amplifier can be found in appendix E. Simulation is done after adding the amplifier data block into the design.

After some modification has been made to the length between the elements, d_m the best simulation results can be viewed in figure 3.7, 3.8 and 3.9**.** The simulation was done using the circuit simulator, so the result can be uncertain. So, the designs of the antenna are fabricated to see the performance of the antenna.

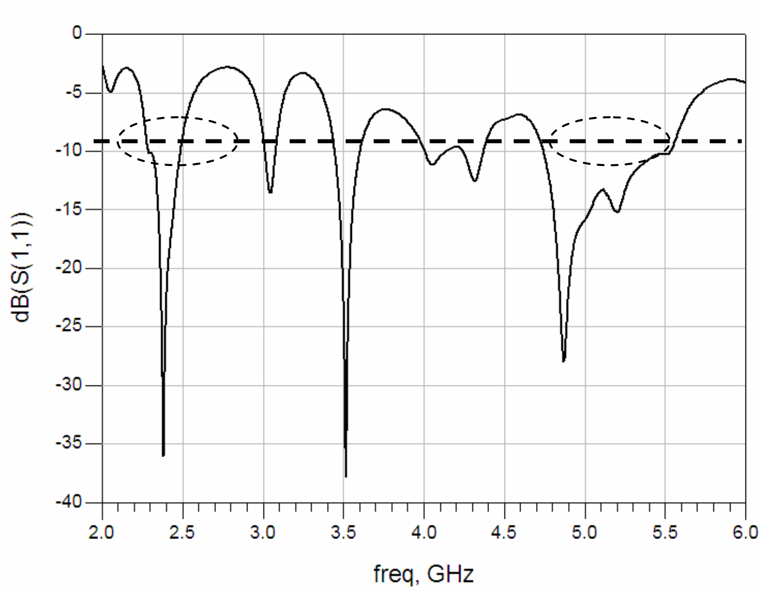


Figure 3.7: Circuit simulation return loss of the dual band square patch AIA.

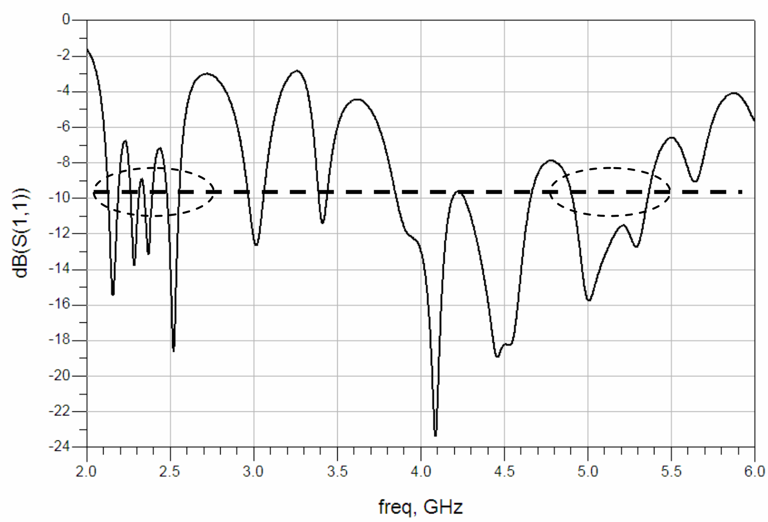


Figure 3.8**:** Circuit simulation return loss of the dual band triangle patch AIA.

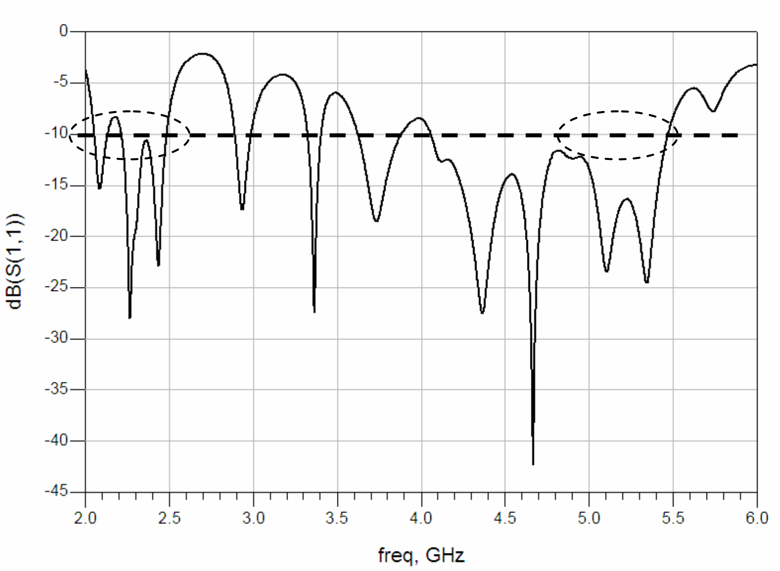


Figure 3.9: Circuit simulation return loss of the dual band circle patch AIA.

3.5 Prototype Fabrication

After designing and determining of the dimensions and parameters of the antenna, the design will be fabricated using the wet etching technique. The passive and the AIA design will undergo the same process except the addition of the active elements.

3.5.1 Materials Selection

Before doing the design and fabrication process, the materials used in the project should be determined first. The dielectric that is going to be used is the FR4 board, SMA connector and electronic components such as amplifier, capacitor and resistor. The selection of the capacitor and the resistor depends on the type of amplifier that will be used.

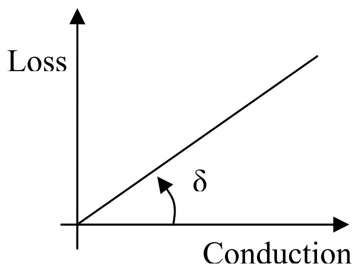
FR4 material has been chosen as it is one of the cheapest material in the market. The material is also easy to obtain in Malaysia.

3.5.2 PCB Board Selection

The dielectric that has been chosen for the antenna is the FR-4 (Fire Retardant – 4) board. The reasons for choosing this type of board are because of its low cost and ease of fabrication process. The FR-4 board has a dielectric constant of 4.7 and a tangent loss of 0.019. The thickness of the dielectric is 1.6 mm, while the thickness of the copper is 0.035 mm.

To choose the material of the substrate, designers should use low dielectric material at higher end of microwave spectrum. The reason is because the result will have much more reasonable length for transmission lines at high frequency. For low frequency, antenna designers should use high dielectric constant material, because the large wave length are easier to handle and can be put on a circuit board to maintain the architecture which have small and conform RF and microwave size constraints.

The dissipation factor (tangent loss, tan δ) which is the loss in the material to the RF and microwave energy is also a constraint in choosing the substrate material. A minimum value of tan δ will lower the losses and the better the material.



$$\tan\delta = \frac{Loss}{Conduction}$$

Figure 3.10: The relation between the loss and the conduction.

The dielectric constant generally was thought of as being constant and not a function of frequency. Actually, the tan δ is varied through the frequency spectrum in an exponential function.

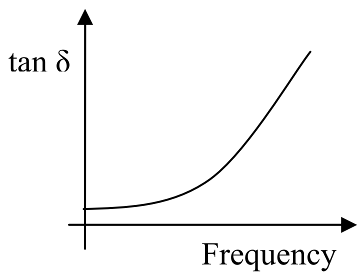


Figure 3.11: The relation between the dissipation loss and the frequency.

For designing multilayer microstrip antenna, such as the proximity, aperture coupled and the multi stacked antenna, the selection of substrates material should also be considered. For example, to design the proximity antenna, the lower substrate usually has higher dielectric constant, ε_r, because it will lower the size of the feed network. But the drawback of using high dielectric constant substrate will degrade the patch performance. With two substrates, overall ε_r seen by the patch will be lowered because of the upper substrate. It will reduce the surface wave excitation, increase the efficiency and the bandwidth and by using different ε_r substrate, it offers a way of meeting the often conflicting requirements of minimizing circuit size while maintaining good antenna performance.

3.5.3 Layout Design

In the AIA design, besides the amplifier, other components that are added to the design are the capacitor and the resistor. The capacitor is needed in the design so that no dc current will flow to the terminal port that might damage the equipments connected to the AIA. The resistor is added as the bias resistance which is needed so that the amplifier can work properly. The value of the resistance will affect the voltage needed to bias the amplifier. The bias configuration is also provided in the data sheet in appendix E.

Figure 3.12 shows the typical biasing configuration for the amplifier. The 2.44 GHz elements will be at the output port of the amplifier while the 5.2 GHz elements will be at the input port of the amplifier. The resistor that has been used is 150 Ω, so the voltage, V_{cc} should be at around 9.8 V. The value for the C_{block} is 100 pF. The typical operating current for the amplifier is 40 mA. So, the voltage is slowly increased from 0 V until the current passing R_{bias} should be 40 mA.

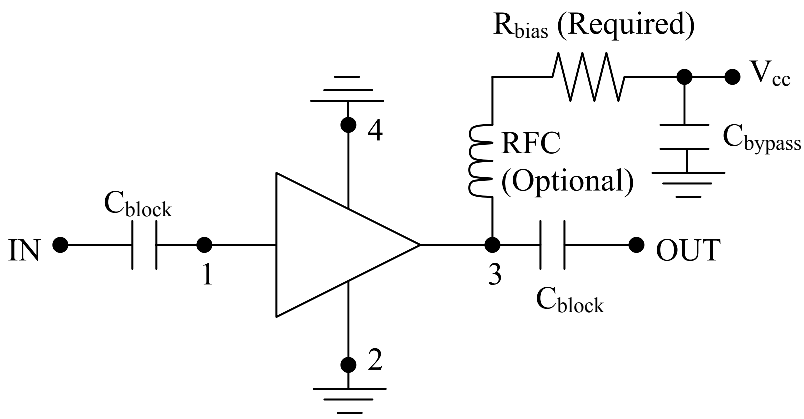


Figure 3.12: Typical biasing configuration of the amplifier.

The basic layout of the square patch passive antenna and AIA are as shown in figure 3.13 and 3.14 respectively. The layout design of all the shapes can be viewed in appendix F. The layout design for the amplifier base is also given, and can be viewed in appendix G. The measured results of the antennas can be viewed in the next chapter. The photographs of the fabricated antennas are shown in appendix H. The higher frequency elements are closer to the input port to reduce the loss that the higher frequency elements will experience when going through feed line [23]. The discussion for the biasing stub design can be found in [39].

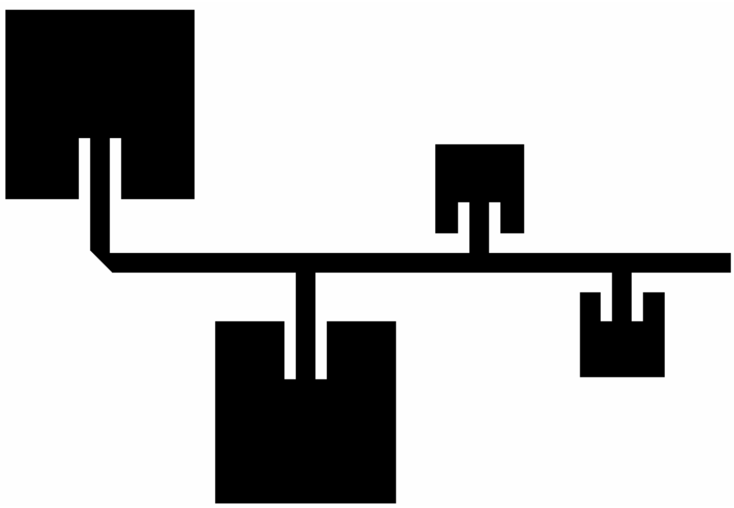


Figure 3.13: Layout mask of the square passive antenna.

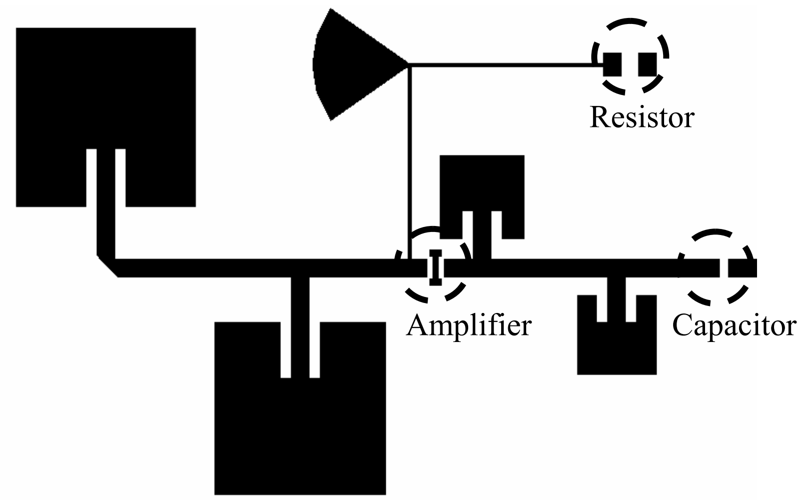


Figure 3.14: Layout mask of the square AIA.

3.6 Measurement Setup

After the fabrication has been done, the prototype antenna can then be tested to investigate the performance of the antennas. Two measurement setups can be made for both passive and active antenna.

3.6.1 Input Return Loss Measurement Setup

After the soldering between the connector and the board is done, testing will be made to determine its functionality. The types of parameters that will be taken are the input return loss, and the radiation pattern of the antenna. The return loss can be measured using the Marconi Instruments Microwave Test Set 6204, while the radiation pattern is taken inside an anechoic chamber using the signal generator and the Agilent Spectrum Analyzer.

The Marconi Instruments consist of two part, first is the instrument/analyzer itself which can measure from 10 MHz to 46 GHz and the second is the Marconi Instruments Transmission Line Test Head Type 6583 which can be use for 10 MHz to 26.5 GHz. At the test head, there are two outputs which are the Fault Location and the Return Loss. To measure the return loss, the antenna is connected to the Return Loss connector. Using the Marconi Instrument, the first step is to set the frequency span that will be analyzed, for instant from 2 GHz until 3 GHz.

The next step is to do the calibration. Calibration has to be made every time when the frequency span is changed to ensure the precision of the instrument for any spectrum. The calibration is done by connecting the short and open connection to the return loss connector on the Marconi Instruments. After it is done, the antenna under test (AUT) will be connected to the Marconi Instruments.

3.6.2 Radiation Pattern Measurement Setup

After calibration, the AUT will be set up on the inside the anechoic chamber to measure the radiation pattern of the AUT. As shown in figure 3.15 and 3.16, the antenna under test (AUT) will be placed on the rotating machine. For passive antenna, the AUT will be the transmitting antenna while the reference antenna which is a horn antenna will be the receiver. While for the AIA, the AUT will be transmitting and the horn antenna will be receiving. The parameters of the horn antenna are shown in appendix C.

Both the AUT and the reference antenna will be aligned in the anechoic chamber and will be rotated depends on the polarization that is going to be measured. The data collection can be eased by reducing the angle interval of the rotation at 2°.

The minimum distance for far field measurement can be calculated in equation 3.20 [35].

$$r_{ff} = \frac{2D^2}{\lambda} \quad (m) \tag{3.20}$$

where

r_{ff} = Distance to AUT at the inner boundary of the far field region (m)

λ = Wave length (m)

D = Largest dimension of the physical aperture of the antenna (m)

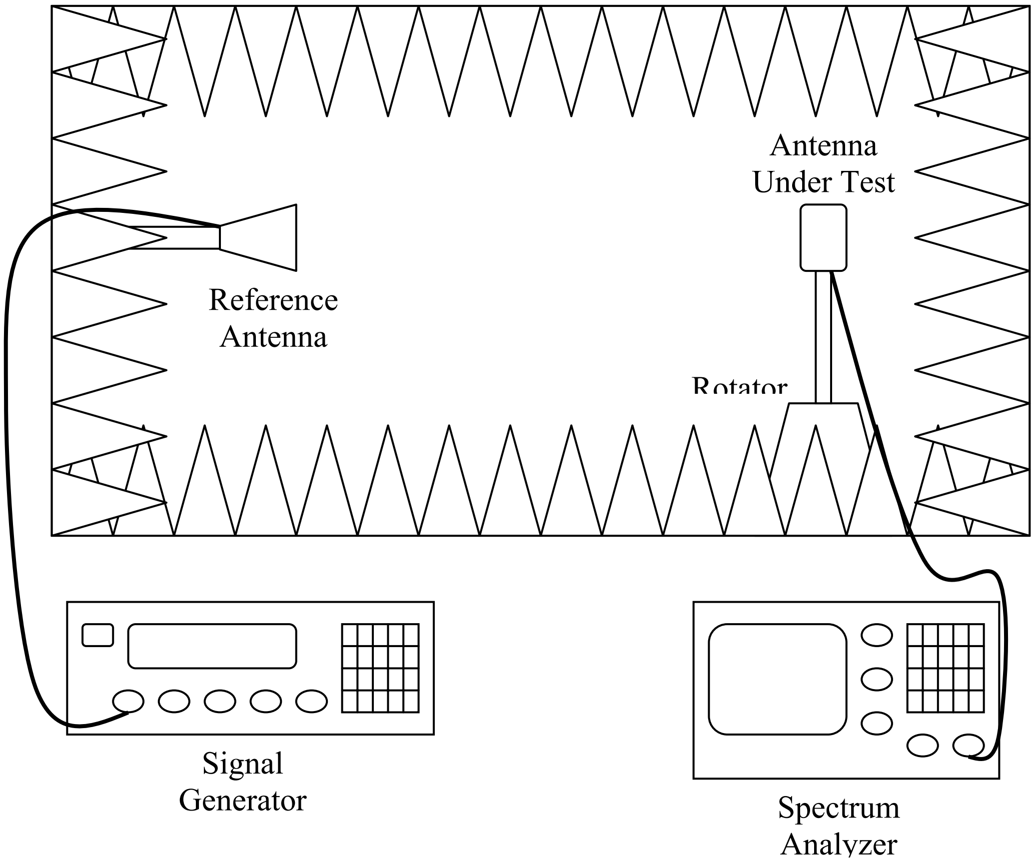


Figure 3.15: Radiation pattern measurement setup in the anechoic chamber for passive antenna.

As can be seen in figure 3.16, the setup for the AIA's radiation measurement is the opposite of the passive's setup. The passive's setup does not concern which antenna is the transmitter or the receiver, but for the AIA's setup the AUT should be the transmitter because the antenna is an amplifying type and is used for the transmitting purposes. In addition to the passive's setup is the power supply for the amplifier's biasing. The voltage is increased little by little until the biasing current is 40 mA.

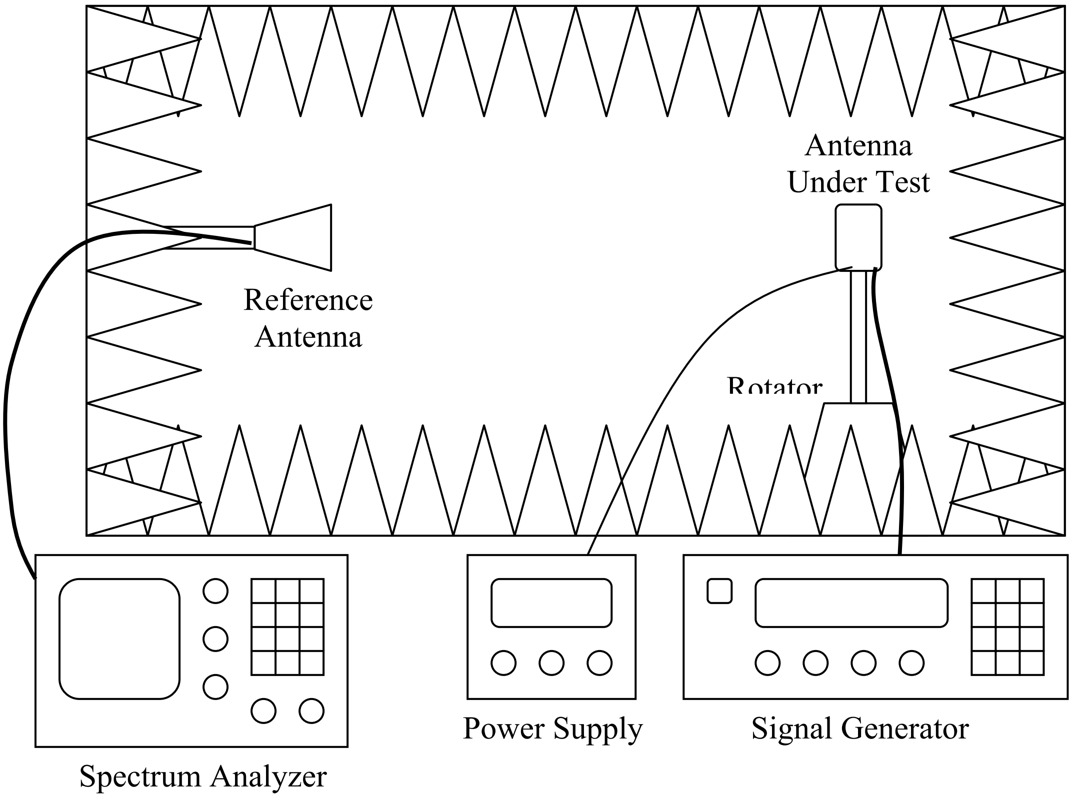


Figure 3.16**:** Radiation pattern measurement setup in the anechoic chamber for active integrated antenna.

3.7 Summary

This chapter discusses the design of the single elements, the dual band antennas and the AIAs. The circuit simulations and the EM simulations show almost similar results which show a good agreement between the two simulations. At the end of the fabrication, the antenna is tested to study the performance of the prototype antenna. The results of the fabricated antennas are presented in chapter 4.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The results for passive antenna designs such as the return loss and the radiation pattern can be obtained by using the ADS software. The results for the integrated active antenna simulation does not accurately give similar result as measured. It is because the simulation of MoM can only be done for passive structure. So, MoM simulation of the passive structure such as the transmission line and the microstrip patch must be done first before the active element is integrated with the passive antenna. Close approximation with measured result has been observed in the circuit simulation for the return loss of active integrated antenna.

4.2 Passive Antenna Results

The results obtained and compared for the three different shapes of the antennas are the input return loss (S_{11}), the radiation pattern, half power beamwidth (HPBW) and the gain of the antenna. These results determine the performance of each antenna developed.

4.2.1 Bandwidth Comparison

4.2.1.1 Square Patch

The dual band feature on the square patch shows a good return loss at both frequency bands. As shown in the figure 4.1, at the 2.4 GHz band, the bandwidth percentage for the simulation result is about 8.34% and for the measured result is about 7.78%. For the 5.2 GHz band, the percentage bandwidth for the simulation is about 15.53% and for the measured result is about 17.08%.

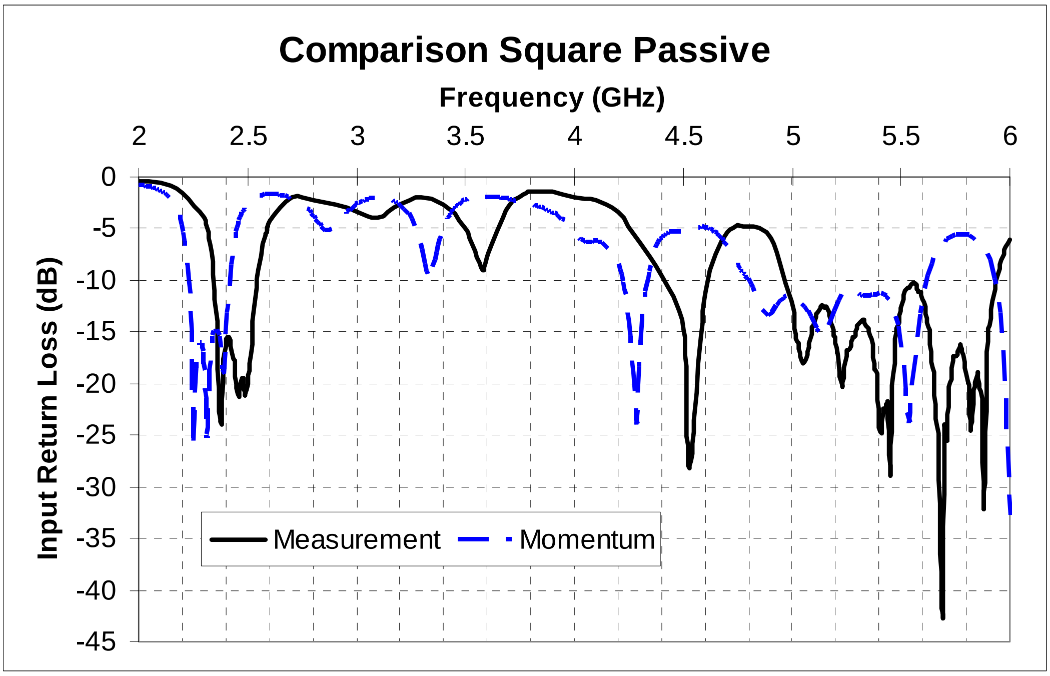


Figure 4.1: Input return loss for the square patch passive antenna.

4.2.1.2 Triangular Patch

The result for the triangular shaped patch shows an almost similar result as the square shaped patch; with slightly decrease in the bandwidth percentage. As shown in figure 4.2, the bandwidth percentage for the 2.4 GHz band in simulation is about 6.59% and for the measurement is about 6.51%. For the 5.2 GHz band, the bandwidth achieved is about 10.66% for the simulation, while in measurement, the bandwidth is about 9.76%.

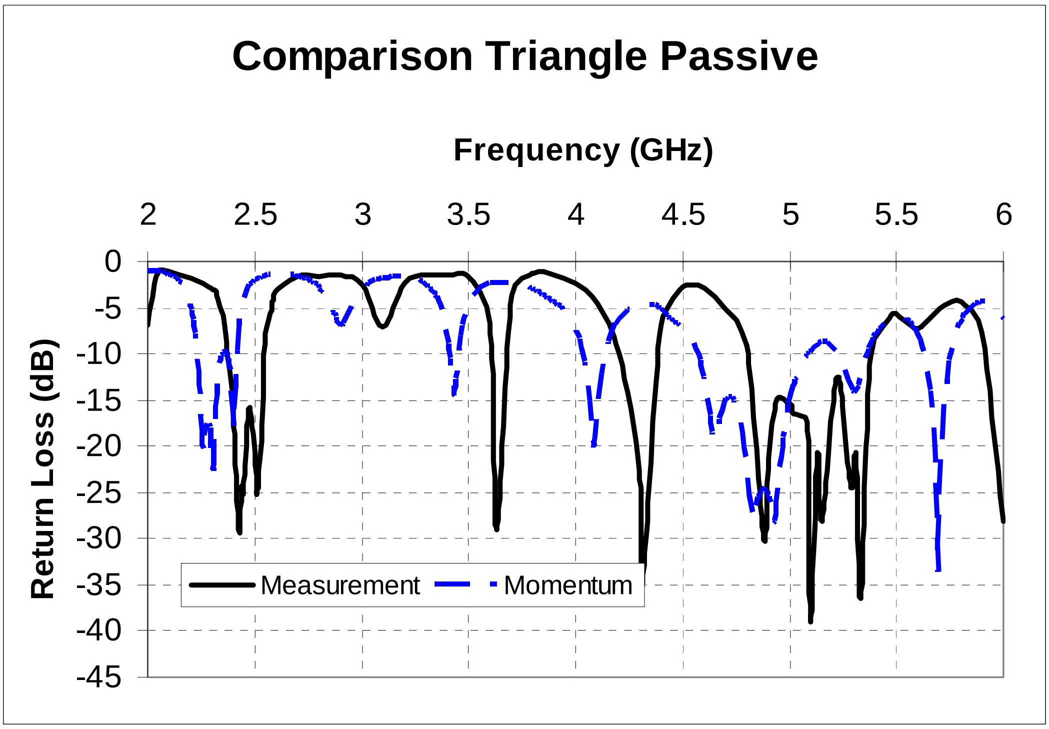


Figure 4.2: Input return loss for the triangular patch passive antenna.

4.2.1.3 Circular Patch

The dual band feature on the circular patch also shows a good return loss at both frequency bands. As shown in the figure 4.3, at the 2.4 GHz band, the bandwidth percentage for the simulation result is about 7.82% and for the measured result is about 8.21%. For the 5.2 GHz band, the percentage bandwidth for the simulation is about 11.01% and for the measured result is about 3.85%.

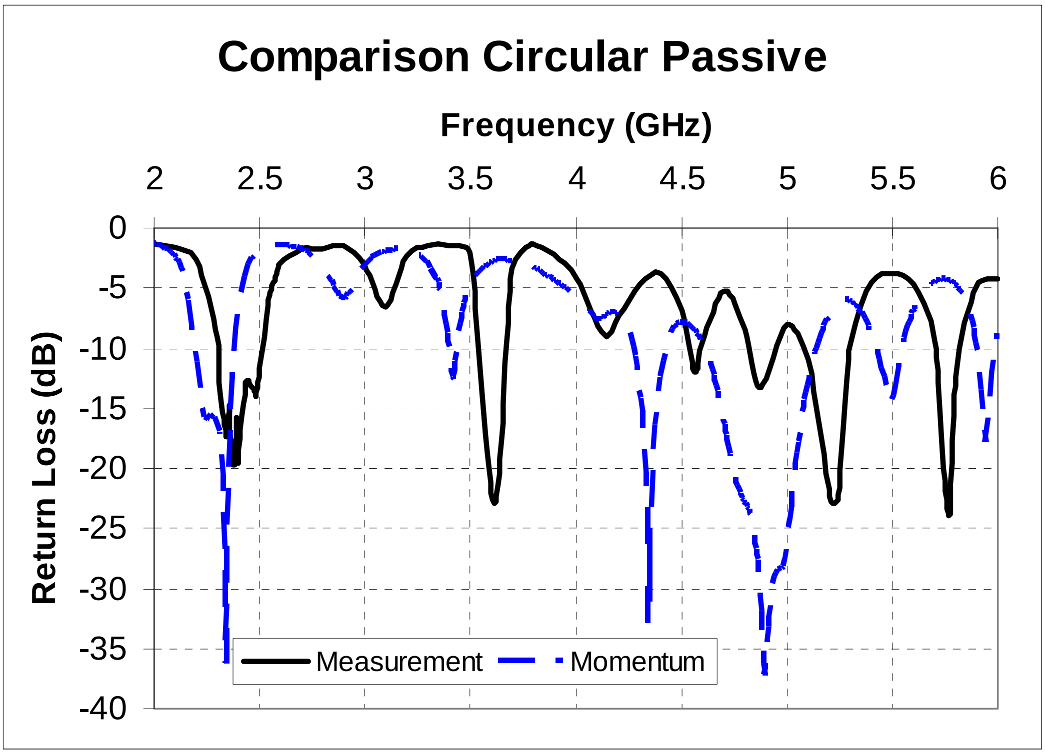


Figure 4.3: Input return loss for the circular patch passive antenna.

4.2.1.4 Bandwidth Overall

The overall results for the three patches are shown in Table 4.1. From the table, it can be observed that for the 2.4 GHz band, the circular shaped patch gives a greater bandwidth than the other two shapes, while the square shaped patch gave the greatest bandwidth for the 5.2 GHz band.

Table 4.2 shows the minimum simulated and measured input return loss of the antennas for each band. The triangular shape patch gave the best return loss for the 2.4 GHz band and 5.2 GHz band.

The bandwidth difference is caused by the difference of each element shape which contribute to different excitation mode and difference in input port position which leads to different results. The inconsistent bandwidth and return loss occurs because of the different length of the feed line between the single antenna elements could reduce the matching between the antenna and input port.

From Table 3.1, the bandwidths of the single elements are different from each other. This would also contribute to the difference of the bandwidth between the three shapes. For 2.4 GHz band, the sum of bandwidth for the two circular shaped antenna elements would be the broadest when compared to the other shapes bandwidth’s sum. But for 5.2 GHz band, it can be observed that even though that the total of bandwidth for circular patch is the broadest, the frequency range of the circular elements is different from the other shapes. So, the square shape element would give the best bandwidth at 5.2 GHz.

From the input return loss figures too, inconsistency of the bandwidth difference between the measurement and simulation could also caused by difference of the feed length, d_m between the antenna elements too.

From the input return loss figures, it can be observed that there are some additional resonant frequencies at 3.5 GHz and at 4.5 GHz. The resonant frequency could be caused by higher order excitation mode of the antenna as also been experienced by Wong in [34] and [40].

The comparison of the input return loss of the dual band antennas with different shapes can be viewed in figure 4.4.

Table 4.1: Comparison of the bandwidth percentage of the different shapes passive antenna.

	2.4 GHz band		5.2 GHz band	
	Simulation	Measurement	Simulation	Measurement
Square	8.34%	7.78%	15.53%	17.08%
Triangle	6.59%	6.51%	10.66%	9.76%
Circular	7.82%	8.31%	11.01%	3.85%

Table 4.2: Comparison of the minimum return loss of the different shapes of passive antenna.

	2.4 GHz band		5.2 GHz band	
	Simulation	Measurement	Simulation	Measurement
Square	-26.21 dB	-24.01 dB	-23.84 dB	-32.20 dB
Triangle	-22.68 dB	-29.37 dB	-28.22 dB	-38.95 dB
Circular	-36.18 dB	-19.68 dB	-37.25 dB	-22.84 dB

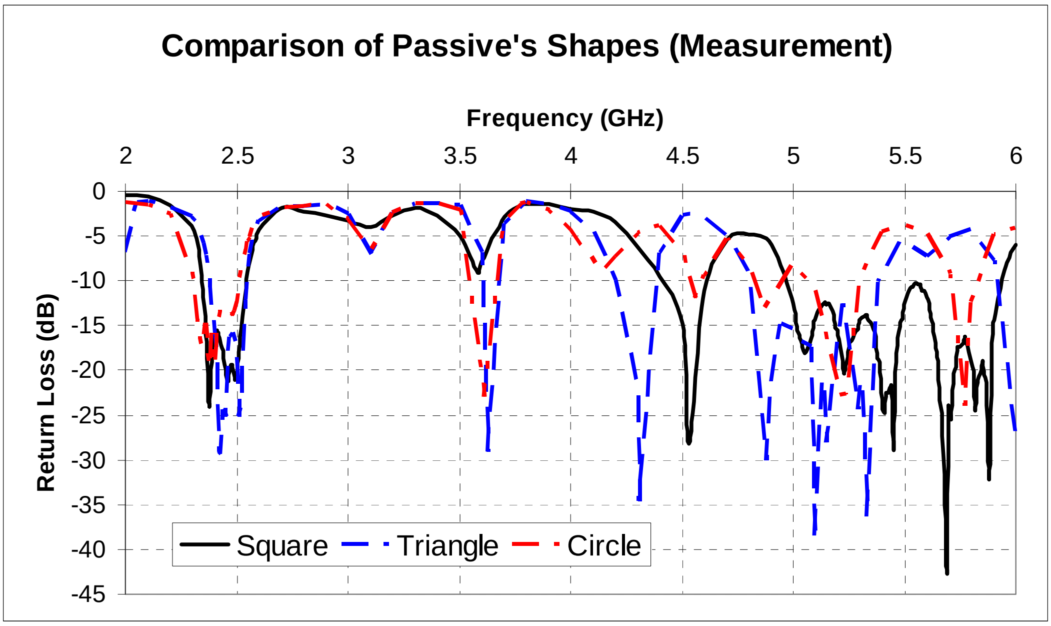


Figure 4.4: Comparison of the input return loss for the three shapes of passive antennas.

4.3 Active Integrated Antenna Results

The measurement setup for the AIA is also the same as the passive antenna's setup. Improvement of the AIA performance is observed throughout the measurement.

4.3.1 Bandwidth Comparison

The input return loss of the AIA improved much from the same passive structure when the active components was introduced as can be seen in figure 4.5, 4.6 and 4.7. After adding the amplifiers to the transmission line, the bandwidth of the square patch antenna in figure 4.5 increase to 17.39% for the 2.4 GHz band, while at 5.2 GHz band, the bandwidth is much bigger at about 38.31%. Simulation results show a much lesser bandwidth of 8.34% for the 2.4 GHz band, while for the 5.2 GHz band at about 15.39%.

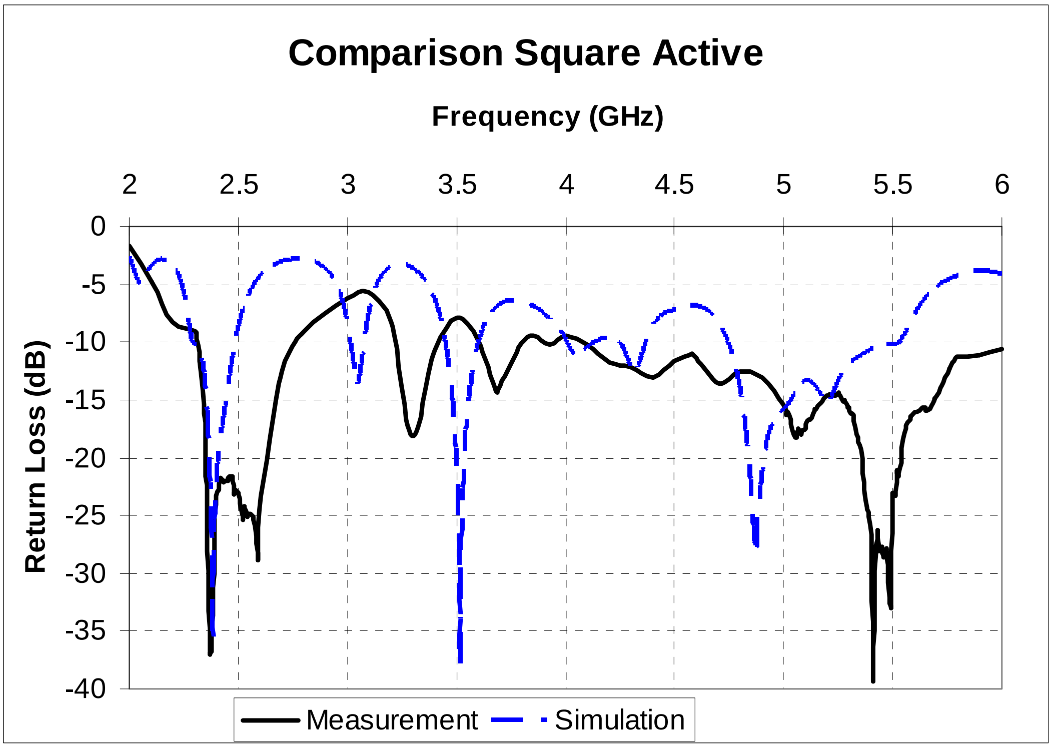


Figure 4.5: Input return loss for the square patch AIA.

Figure 4.6 shows the return loss of the triangle shape patch which from the simulation shows bandwidth at about 5.54% at 2.4 GHz band, while at 5.2 GHz the bandwidth percentage is about 8.77%. When measured, the bandwidth at 2.4 GHz band is about 13.65% and at 5.2 GHz band, the bandwidth is about 7.09%.

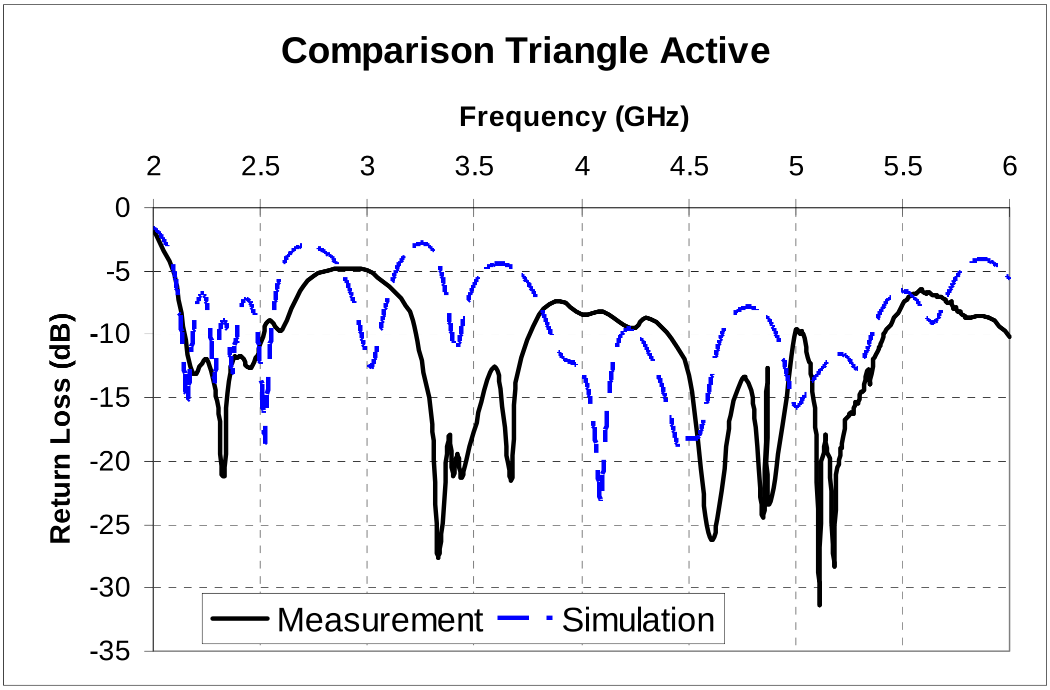


Figure 4.6: Input return loss for the triangle patch AIA.

As shown in figure 4.7, it can be observed that the simulation bandwidth at 2.4 GHz is about 11.47% and at 5.2 GHz is about 14.25%. When measured, the bandwidth for the 2.4 GHz band is about 8.84% and at 5.2 GHz is about 9.91%.

Table 4.3 and 4.4 shows the summary of the bandwidth percentage and the minimum input return loss of the antennas. The tables show that there are similarity between the simulation results and the measurement results. But the input return loss's graph shows a difference between the simulated and the measured results.

The difference in terms of the bandwidth and the minimum input return loss could has been caused by the same reason as mentioned in section 4.2.1.4. Compared to Table 4.1, the measured result of the AIA's bandwidth has increased due to the integration of the amplifier. The same effect has also occurred in [22].

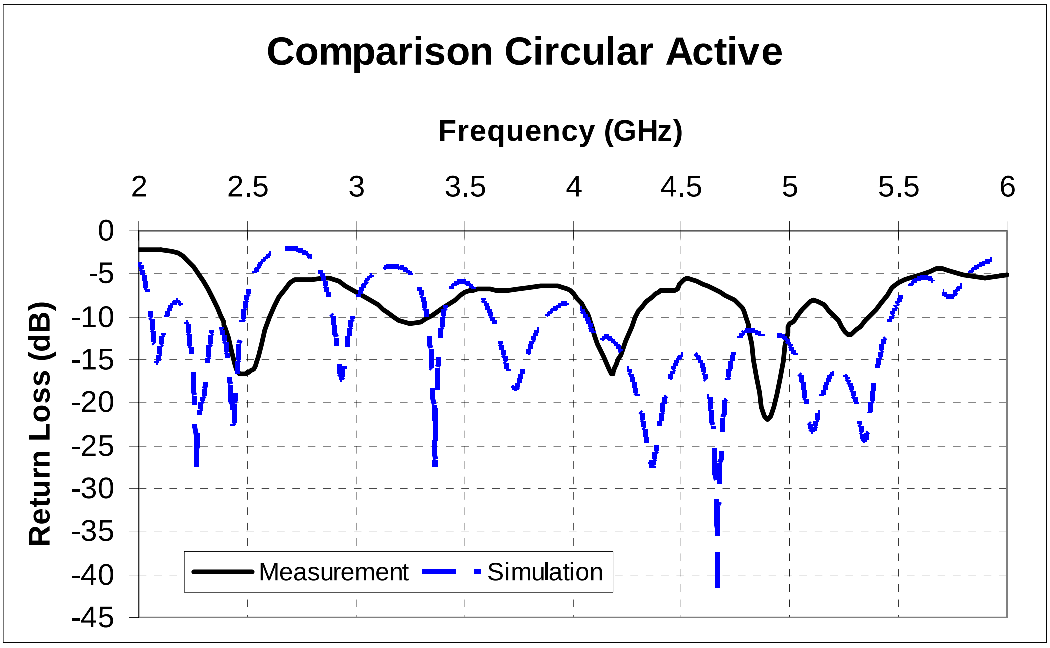


Figure 4.7: Input return loss for the circular patch AIA.

Table 4.3: Comparison of the bandwidth percentage of the different shapes of the AIA.

	2.4 GHz band		5.2 GHz	
	Simulation	Measurement	Simulation	Measurement
Square	8.34%	17.39%	15.39%	38.31%
Triangle	5.54%	13.65%	8.77%	7.09%
Circular	11.47%	8.84%	14.25%	9.91%

Table 4.4: Comparison of the minimum return loss of the different shapes of the AIA.

	2.4 GHz		5.2 GHz	
	Simulation	Measurement	Simulation	Measurement
Square	-36.02 dB	-37.06 dB	-27.99 dB	-39.29 dB
Triangle	-13.80 dB	-21.19 dB	-15.76 dB	-31.36 dB
Circular	-28.03 dB	-16.51 dB	-42.36 dB	-21.93 dB

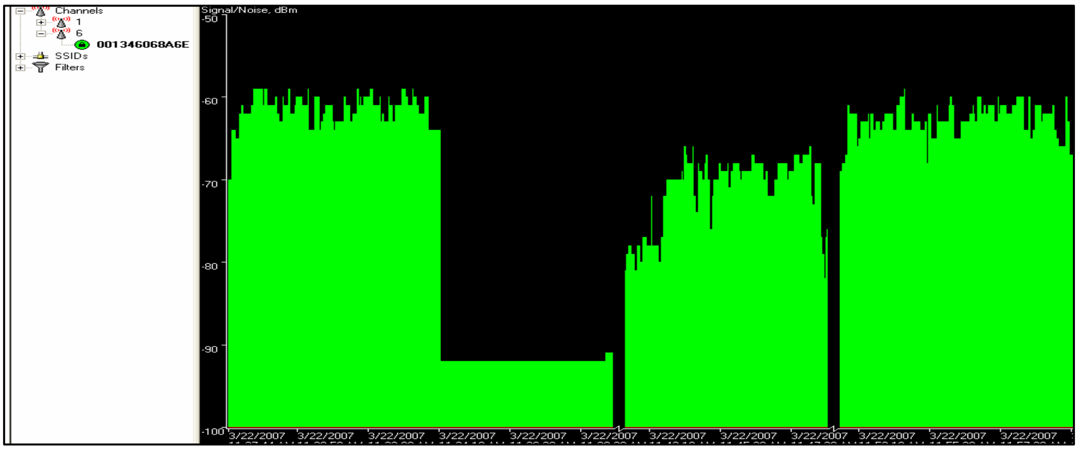


Figure 4.8: SNR Of AIA

4.3.2 Radiation Pattern

The measurement for the AIA also uses the same method as the passive antenna only with the addition of a power supply connected to the biasing circuit of the amplifier.

4.3.2.1 Square Patch AIA

Figure 4.9 and 4.10 shows the radiation pattern of the square patch AIA for E plane and H plane respectively. Overall, for the three shapes, the cross isolation for the active antenna has decreased. The cross isolation at 2.44 GHz for E plane is about 7 dB only, while at H plane is about 4 dB. The HPBW achieved for the E plane and the H plane is about 54° and 82° respectively.

At 5.2 GHz as shown in figure 4.23 and 4.24, the cross isolation in E plane is about 19 dB while in H plane, the cross isolation is about 9 dB. The HPBW for the E plane is about 58° and for the H plane is about 94°.

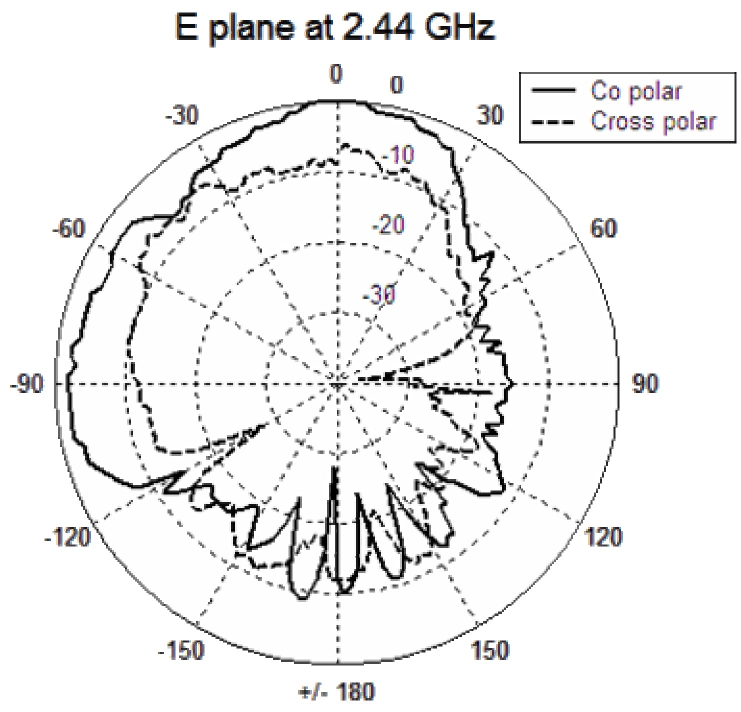


Figure 4.9: Radiation pattern for square patch AIA at 2.44 GHz in E plane.

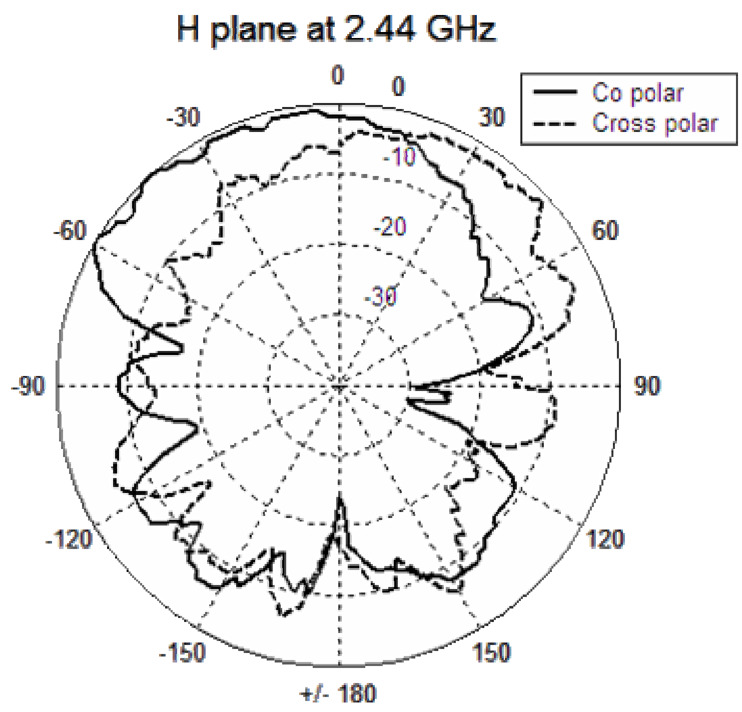


Figure 4.10: Radiation pattern for square patch AIA at 2.44 GHz in H plane.

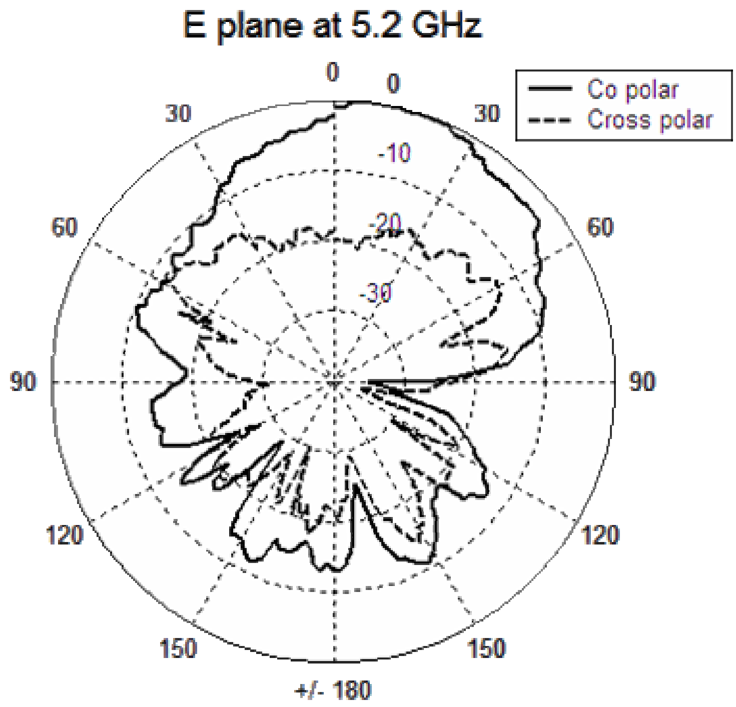


Figure 4.11: Radiation pattern for square patch AIA at 5.2 GHz in E plane.

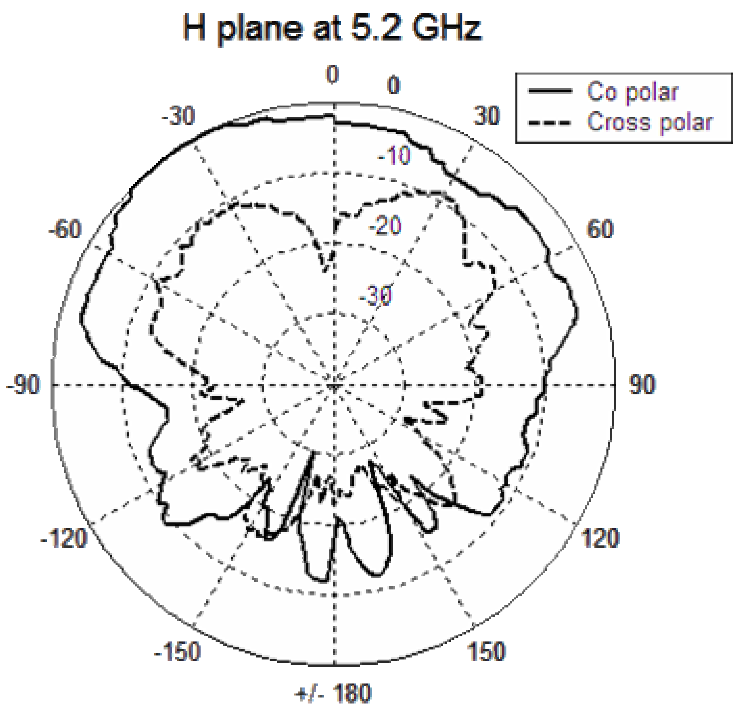


Figure 4.12: Radiation pattern for square patch AIA at 5.2 GHz in H plane.

4.3.2.2 Triangular Shape AIA

The result for the triangular shape AIA also shows almost the same pattern as the square shape AIA. Figure 4.13 and figure 4.14 shows the radiation pattern of the triangle shape AIA at 2.4 GHz. The cross isolation for E plane is about 7 dB while for H plane is about 12 dB. The HPBW for E plane is about 42° and for H plane is about 52°.

While at 5.2 GHz as shown in figure 4.15 and figure 4.16, the cross isolation for E and H plane is about 2 dB. The HPBW for E plane is about 18° and for H plane is about 36°.

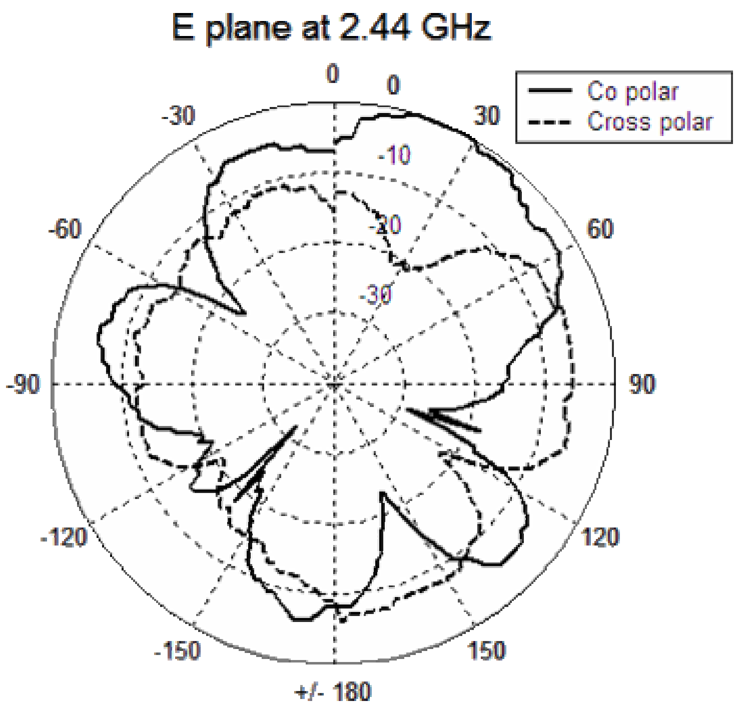


Figure 4.13: Radiation pattern for triangle patch AIA at 2.44 GHz in E plane.

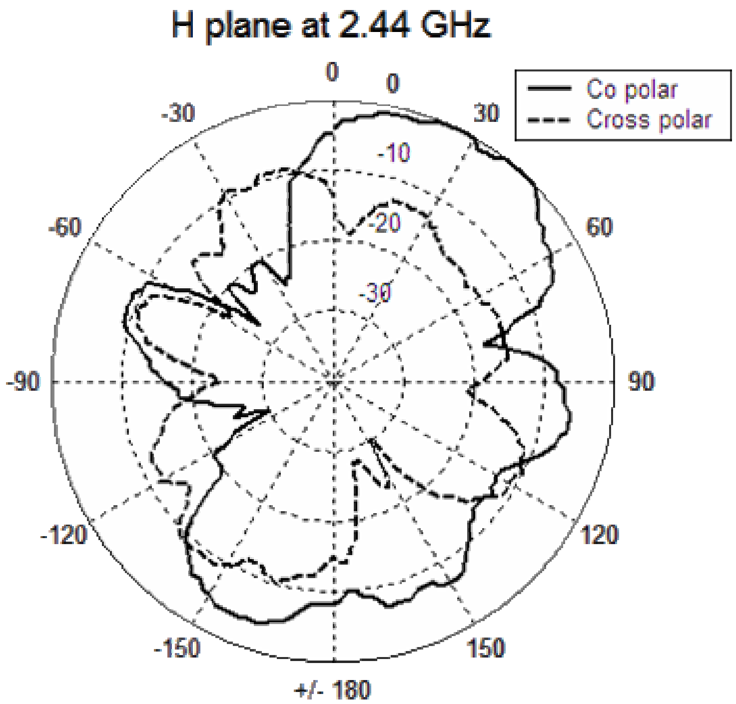


Figure 4.14: Radiation pattern for triangle patch AIA at 2.44 GHz in H plane.

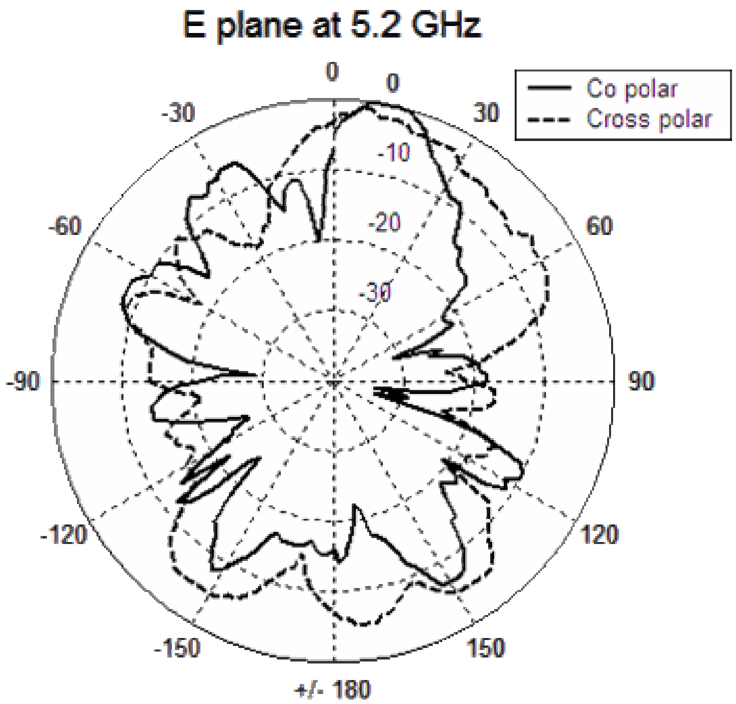


Figure 4.15: Radiation pattern for triangle patch AIA at 5.2 GHz in E plane.

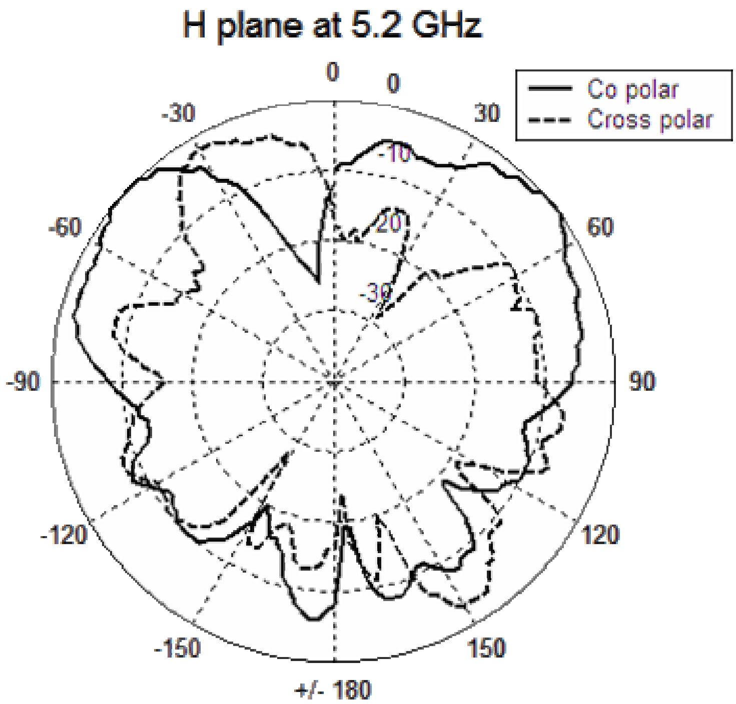


Figure 4.16: Radiation pattern for triangle patch AIA at 5.2 GHz in H plane.

4.3.2.3 Circular Patch AIA

Figure 4.17 and figure 4.18 shows the radiation pattern for the circular patch AIA in E plane and H plane respectively at 2.44 GHz. The HPBW for the E plane is about 78° and the cross isolation is about 5 dB. For the H plane, the HPBW is about 74° and the cross isolation is about 8 dB.

As shown in figure 4.19 and 4.20, the radiation pattern at 5.2 GHz has a HPBW of 56° for E plane and 26° for H plane. The cross polarization for both planes is about 4 dB.

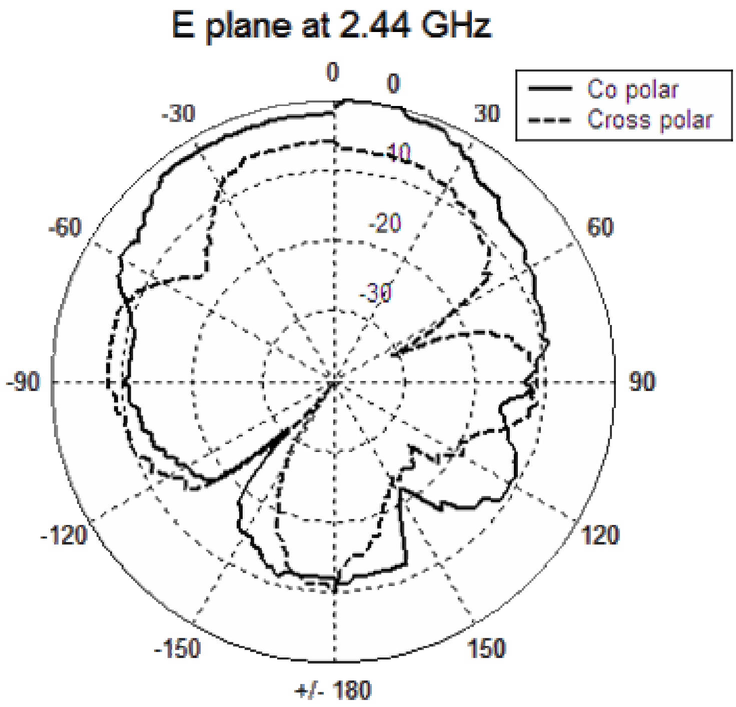


Figure 4.17: Radiation pattern for circular patch AIA at 2.44 GHz in E plane.

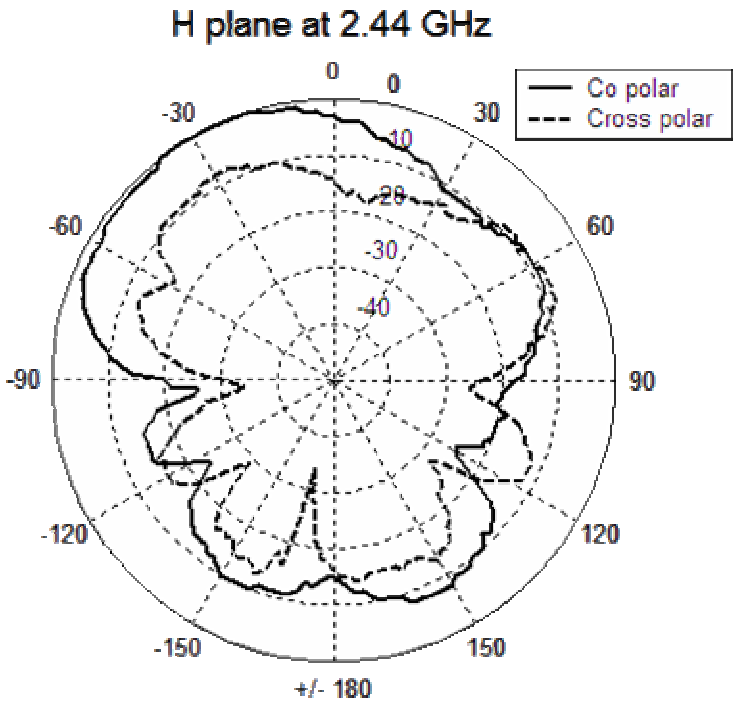


Figure 4.18: Radiation pattern for circular patch AIA at 2.44 GHz in H plane.

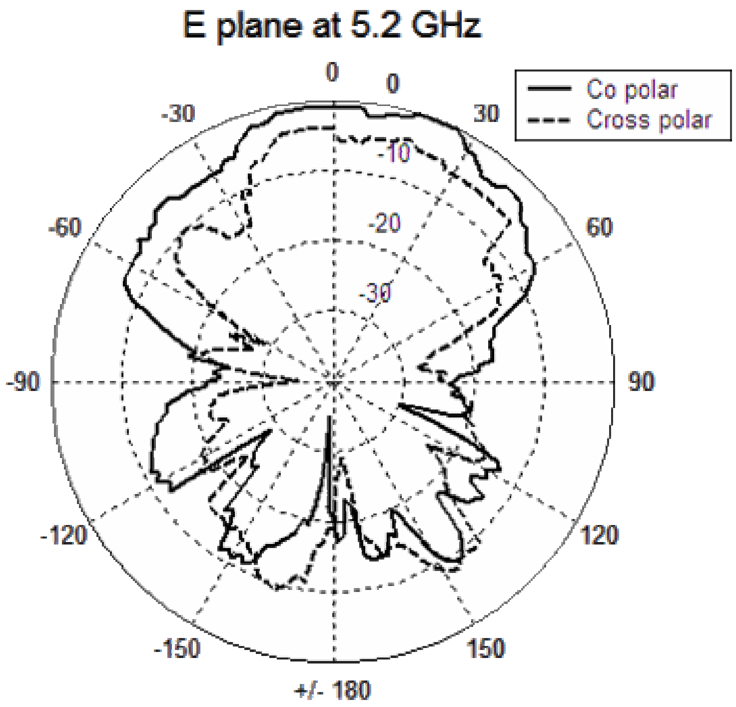


Figure 4.19: Radiation pattern for circular patch AIA at 5.2 GHz in E plane.

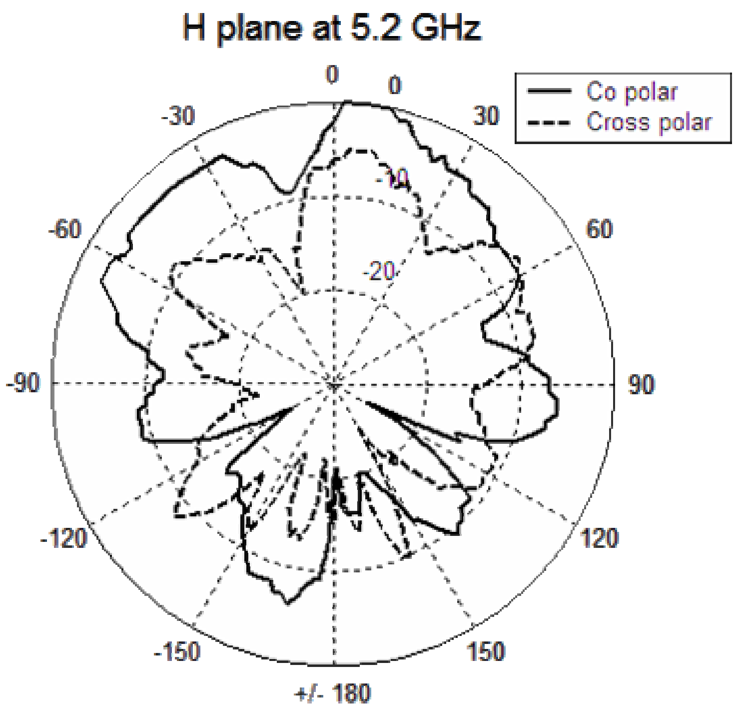


Figure 4.20: Radiation pattern for circular patch AIA at 5.2 GHz in H plane.

The patterns parameters are compared as shown in table 4.5 and 4.6. From the tables, it seems that the performances in terms of beamwidth and cross isolation for the AIAs are lower than the passive antenna. It may be caused by the addition of the active elements onto the transmission line.

From the radiation patterns, the beam of the antennas might slightly tilt to left or right. This is caused by the coupling between the single elements and the stray radiation from the feed line [23]. Some of the patterns also show that the co and cross polarization of the antennas are quite close to each other. There are two possibilities that might cause it. First, the amplifier could also contribute additional radiation to the overall radiation pattern. So, even though it is the cross polarization setup which the signal detected is low, the amplifier could also radiate in the same polarization. The second possibility is the antenna has radiated in circular polarization. Even though these patterns lead to these possibilities, the first option is more preferable.

Table 4.5: HPBW comparison of the different shapes of the AIA.

	2.44 GHz		5.2 GHz	
	E plane	H plane	E plane	H plane
Square	54°	82°	58°	94°
Triangle	42°	52°	18°	36°
Circular	78°	74°	56°	26°

Table 4.6: Cross isolation comparison of the different shapes of the AIA.

	2.44 GHz		5.2 GHz	
	E plane	H plane	E plane	H plane
Square	7 dB	4 dB	19 dB	9 dB
Triangle	7 dB	12 dB	2 dB	2 dB
Circular	5 dB	8 dB	4 dB	4 dB

4.3.3 Gain Comparison

The gains of the AIAs are slightly greater than the passive antenna except for the circular AIA. Compared to the horn antenna, it is found that the square patch passive antenna at 2.44 GHz and 5.2 GHz has a gain of 22 dB and 4 dB respectively. The gain for the triangle patch passive at 2.44 GHz is about 21 dB while at 5.2 GHz the gain is about 4 dB. Lastly, the gain for the circular patch passive at 2.44 GHz is about 20 dB while at 5.2 GHz the gain is about 6 dB.

The gain difference at 2.44 GHz and at 5.2 GHz has been discussed in section 4.2.3 previously.

4.4 Comparison Between Passive and Active

In terms of bandwidth the passive antennas offer an adequate bandwidth that can be use in the WLAN system, but by using the active element, the bandwidth of the AIA increase as shown in table 4.7.

The square shape AIA shows a greater bandwidth than the passive antenna for both frequency bands. On the other hand, the triangle shapes AIA improvements of the bandwidth can be seen at 2.4 GHz frequency band and slightly less at 5.2 GHz compared to the passive antenna. The circular shape AIA shows a slight increase of bandwidth at the 2.4 GHz band while at 5.2 GHz band, the bandwidth increase almost three times than the passive’s bandwidth.

Table 4.7: Comparison of the bandwidth percentage of the different shapes between the passive antenna and the AIA.

	2 GHz band		5.2 GHz band	
	Passive	AIA	Passive	AIA
Square	7.78%	17.39%	17.08%	38.31%
Triangle	6.51%	13.65%	9.76%	7.09%
Circular	8.31%	8.84%	3.85%	9.91%

The comparison of HPBW between the passive and the active antenna as shown in table 4.8, shows an almost similar result, but does give minor improvement to the antenna's beamwidth. The square patch AIA gives a greater HPBW only at the H plane, but in the E plane the passive antenna gives a greater beamwidth. The triangle shape passive antenna gives a greater beamwidth than the AIA. The circular patch AIA improve the HPBW compared to the passive antenna except for 5.2 GHz band in H plane.

Table 4.8: HPBW comparison of the different shapes between the passive antenna and the AIA.

	2.44 GHz				5.2 GHz			
	E plane		H plane		E plane		H plane	
	Passive	AIA	Passive	AIA	Passive	AIA	Passive	AIA
Square	64°	54°	72°	82°	110°	58°	68°	94°
Triangle	66°	42°	72°	52°	20°	18°	48°	36°
Circular	58°	78°	72°	74°	56°	56°	72°	26°

The cross isolations of the passive antenna as shown in table 4.9 give better results than AIA. It happens because the active device increases the co and cross polarization radiation of the AIAs simultaneously.

Table 4.9: Cross isolation comparison of the different shapes between the passive antenna and the AIA.

	2.44 GHz				5.2 GHz			
	E plane		H plane		E plane		H plane	
	Passive	AIA	Passive	AIA	Passive	AIA	Passive	AIA
Square	17 dB	7 dB	15 dB	4 dB	12 dB	19 dB	18 dB	9 dB
Triangle	14 dB	7 dB	17 dB	12 dB	1 dB	2 dB	1 dB	2 dB
Circular	20 dB	5 dB	18 dB	8 dB	15 dB	4 dB	13 dB	4 dB

The gain of the antennas can be viewed in table 4.10. From the table, it shows that the integration of active device does improve the gain of the antenna compared to the passive antenna. Further improvements on the placement of the active device on the transmission line may help to increase the gain of the antenna even further.

Table 4.10: Gain comparison of the different shapes between the passive antenna and the AIA.

	2.44 GHz		5.2 GHz	
	Passive	AIA	Passive	AIA
Square	19 dB	22 dB	4 dB	4 dB
Triangle	15 dB	21 dB	3 dB	4 dB
Circular	21 dB	20 dB	4 dB	6 dB

4.5 Summary

This chapter has presented the results of all the antennas fabricated that serve the purpose of the project. The AIAs have shown a slightly similar result compared to the passive antennas in terms of the HPBW and the cross isolation. But, in terms of bandwidth, the AIA have outshined the passive antennas.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The design of the dual band Microstrip active integrated antenna for WLAN application has been presented. The utilization of the softwares involves in the production process help to minimize the processing time for the calculation and the simulation of the design. Seven antennas, that are three passive antennas and three AIA with different shapes consist of square, triangular and circular shape have been developed and manually fabricated in the facility in Wireless Communication Centre, Universiti Teknologi Malaysia.

The integration of the active device onto the same surface structure of the passive elements, improve the bandwidth of the microstrip antenna. The antennas that have been tested are proven to be operational, operating with sufficient return loss and radiation characteristics.

The performance of the dual band microstrip antenna, that incorporates the 3 basic shapes, has been investigated. The easiest shape to be analyzed and characterized is the square shaped patch, which in overall, shows a good result compared to the other two shapes.

By implementing the log periodic technique, the author was bounded to the rules of the log periodic technique where the design of the elements should be from the lowest frequency to the highest frequency, periodically. Using the scaling technique, some elements were cut-off from the design, and it becomes a frequency selective antenna or in this case a dual band antenna. This improves the physical size of the antenna as only a selected frequency element is needed to be designed.

As an overall conclusion, all the planned works and the objectives of this project have been successfully implemented and achieved even though the performance for the 5.2 GHz band has not been fully optimized because of time constraint and the lack of suitable equipment. The best prototype recommended from this project is the square shaped AIA, which give consistent performance in terms of bandwidth, HPBW and the gain. The AIA prototype is a transmitting type of antenna, so they are not suitable to be fixed to the access point device. The passive prototype can be used as the access point device’s antenna replacing the existing dipole antenna, as the flat and planar microstrip antenna prototype can be conform to the access point device’s housing.

5.2 Proposed Future Work

Further works should be carried out in order to improve the performance of the dual band AIA as suggested below:

i. Different feeding method can be used for the integration of active devices. Potential feeding methods are the proximity feed and the CPW feed. The proximity feed offer a greater bandwidth while the CPW feed allow easy integration with MICs or MMICs.

ii. Different architecture such by stacking or defected ground structure can also be used in the design to improve the performance of the antenna.

iii. Different position of the integrated active device can be also studied.

iv. Propagation study using the antennas onto an access point can be done to study the effectiveness of the designed antennas.

v. Improvements on the test and measurement facilities need to be done so that more accurate measurement could be carry out in the future.

vi. Simultaneous transmit and receive can be studied for further improvement of the antenna.

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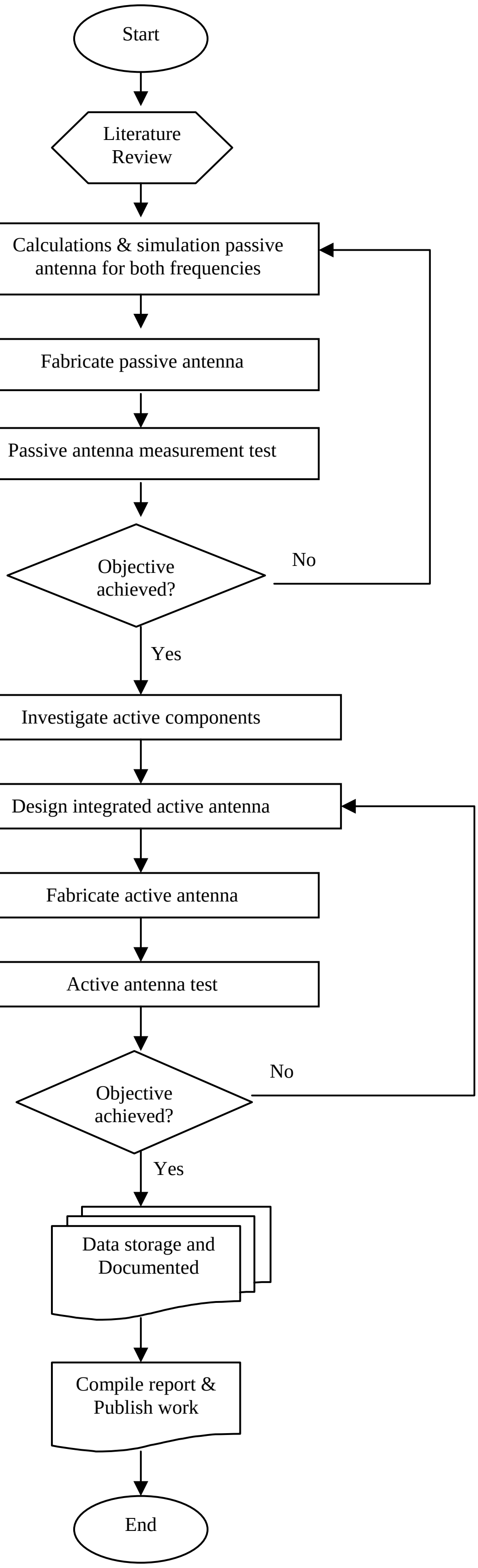
APPENDIX A

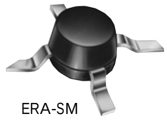
FLOW CHART OF THE PROJECT



MONOLITHIC AMPLIFIERS 50Ω

BROADBAND DC to 8 GHz

ERA



ERA-SM

low power, up to +13.5 dBm output

all specifications at 25°C

MODEL◆ NO.	✪ FREQ. GHz f_L - f_U	GAIN, dB Typical over frequency, GHz 0.1	1	2	3	4	6	8	Min.@ 2 GHz	MAXIMUM POWER (dBm) at 2 GHz* Output (1 dB Comp.) Typ.	Output (1 dB Comp.) Min.	Input (no dmg)
ERA-1	DC-8	12.3	12.1	11.8	10.9	9.7	7.9	8.2	9	12.0	10.0	15
ERA-2	DC-6	16.2	15.8	15.2	14.4	13.1	11.2	—	13	13.0	11.0	15
ERA-3	DC-3	22.1	21.0	18.7	16.8	—	—	—	16	12.5	9.0	13
ERA-1SM	DC-8	12.3	12.1	11.8	10.9	9.7	7.9	8.2	9	12.0	10.0	15
ERA-21SM	DC-8	14.2	13.9	13.2	12.2	10.8	8.7	8.9	11.2	12.6	10.6	15
ERA-2SM	DC-6	16.2	15.8	15.2	14.4	13.1	11.2	—	13	13.0	11.0	15
ERA-33SM	DC-3	19.3	18.7	17.4	15.9	—	—	—	15	13.5	11.5	13
ERA-3SM	DC-3	22.1	21.0	18.7	16.8	—	—	—	16	12.5	9.0	13
ERA-8SM	DC-2	31.5	25.0	19.0	15.0	12.0	—	—	17	12.5	—	13

MODEL◆ NO.	DYNAMIC RANGE at 2 GHz* NF (dB) Typ.	IP3 (dBm) Typ.	VSWR (:1) Typ. In DC-3 GHz	In 3-f_U** GHz	Out DC-3 GHz	Out 3-f_U** GHz	ABSOLUTE MAX. RATING[3] I (mA)	P (mW)	DC OPERATING POWER[4] at Pin 3 Current (mA)	Device Volt. Typ	Min	Max	THERMAL RESISTANCE θjc Typ. °C/W	CASE STYLE Note B	CONNECTION	PRICE $ ea. Qty. (30)
ERA-1	4.3	26	1.5	1.8	1.5	1.9	75	330	40	3.4	3.0	4.1	178	VV105	cb	1.37
ERA-2	4.0	26	1.3	1.4	1.2	1.6	75	330	40	3.4	3.0	4.1	155	VV105	cb	1.52
ERA-3	3.5	25	1.5	—	1.4	—	75	330	35	3.2	3.0	4.1	154	VV105	cb	1.67
ERA-1SM	4.3	26	1.5	1.8	1.5	1.9	75	330	40	3.4	3.0	4.1	183	WW107	cb	1.42
ERA-21SM	4.7	26	1.1	1.4	1.3	1.9	75	330	40	3.5	3.0	4.1	194	WW107	cb	1.57
ERA-2SM	4.0	26	1.3	1.4	1.2	1.6	75	330	40	3.4	3.0	4.1	160	WW107	cb	1.57
ERA-33SM	3.9	28.5	1.6	—	1.25	—	75	330	40	4.3	3.8	4.8	140	WW107	cb	1.72
ERA-3SM	3.5	25	1.5	—	1.4	—	75	330	35	3.2	3.0	4.1	186	WW107	cb	1.72
ERA-8SM	3.1	25	1.4	1.8	1.8	2.2	65	250	36	3.7	3.2	4.2	140	WW107	cb	1.22

see suggested PCB layout PL-075 for ERA models

features

- low thermal resistance
- miniature microwave amplifier
- frequency range, DC to 8 GHz, usable to 10 GHz
- up to 18.4 dBm typ. (16.5 dBm min) output power

absolute maximum ratings

operating temperature: -45°C to 85°C
storage temperature: -65° to 150°C

model identification

Model	marking (see note below)	demo board
ERA-1, ERA-1SM	1	ERA-01TB
ERA-2, ERA-2SM	2	ERA-02TB
ERA-21SM	21	ERA-21TB
ERA-3, ERA-3SM	3	ERA-03TB
ERA-33SM	33	ERA-33TB
ERA-4,-4SM	4	ERA-04TB
ERA-4XSM	4X	ERA-04TB
ERA-5, ERA-5SM	E5	ERA-05TB
ERA-50SM	50	ERA-50TB
ERA-51SM	51	ERA-51TB
ERA-5XSM	5X	ERA-05TB
ERA-6, ERA-6SM	6	ERA-06TB
ERA-8SM	E8	ERA-08TB

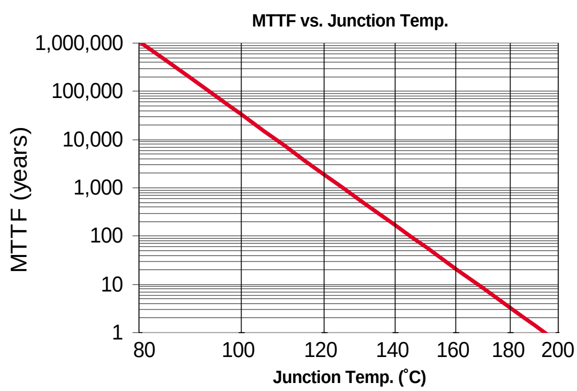
Note: Prefix letter (optional) designates assembly location. Suffix letters (optional) are for wafer identification.

_ _ _

prefix letter
number
suffix letter

NOTES:

◆ Aqueous washable
* at 1 GHz for ERA-4,5,6, 4SM,4XSM ,5SM,5XSM, 50SM, 51SM, 6SM, 8SM.
** f_u is the upper frequency limit for each model as shown in the table; for ERA-8SM VSWR (In & Out) is specified at DC-1GHz & 1-4 GHz.
*** Gain and VSWR are specified at 1.5 GHz.
✪ Low frequency cutoff determined by external coupling capacitors.
A. Environmental specifications and re-flow soldering information available in General Information Section.
B. Units are non-hermetic unless otherwise noted. For details on case dimensions & finishes see "Case Styles & Outline Drawings".
C. Prices and Specifications subject to change without notice.
D. For Quality Control Procedures see Table of Contents, Section 0, "Mini-Circuits Guarantees Quality" article. For Environmental Specifications see Amplifier Selection Guide.
1. Model number designated by alphanumeric code marking.
2. ERA-SM models available on tape and reel.
3. Permanent damage may occur if any of these limits are exceeded. These ratings are not intended for continuous normal operation.
4. Supply voltage must be connected to pin 3 through a bias resistor in order to prevent damage. See "Biasing MMIC Amplifiers" in minicircuits.com/application.html. Reliability predictions are applicable at specified current & normal operating conditions.



051014

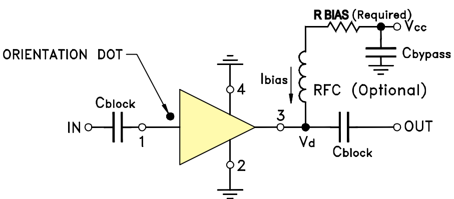
medium power, up to +18.4 dBm output

all specifications at 25°C

MODEL◆ NO.	✪ FREQ. GHz f_L - f_U	GAIN, dB Typical over frequency, GHz 0.1	1	2	3	4	Min.@ 2 GHz	MAXIMUM POWER (dBm) at 2 GHz* Output (1 dB Comp.) Typ.	Output (1 dB Comp.) Min.	Input (no dmg)	DYNAMIC RANGE at 2 GHz* NF (dB) Typ.	IP3 (dBm) Typ.	VSWR (:1) Typ. In DC-3 GHz	In 3-f_U** GHz	Out DC-3 GHz	Out 3-f_U** GHz	ABSOLUTE MAX. RATING[3] I (mA)	P (mW)	DC OPERATING POWER[4] at Pin 3 Current (mA)	Device Volt. Typ	Min	Max	THERMAL RESISTANCE θjc Typ. °C/W	CASE STYLE Note B	CONNECTION	PRICE $ ea. Qty. (30)
ERA-6	DC-4	12.6	12.5	12.2	11.7	11.3	10.5	17.9	16	20	4.5	36	1.3	1.2	1.6	1.8	120	650	70	5.0	4.6	5.6	170	VV105	cb	3.85
ERA-4	DC-4	14.3	14.0	13.4	12.7	11.8	11	17.3	15	20	4.2	34	1.2	1.2	1.3	1.8	120	650	65	4.5	4.2	5.5	163	VV105	cb	3.85
ERA-5	DC-4	20.2	19.5	18.5	16.7	14.3	16	18.4	16.5	13	4.3	32.5	1.3	1.3	1.2	1.3	120	650	65	4.9	4.2	5.5	133	VV105	cb	3.85
ERA-6SM	DC-4	12.6	12.5	12.2	11.7	11.3	10.5	17.9	16	20	4.5	36	1.3	1.2	1.6	1.8	120	650	70	5.0	4.6	5.6	143	WW107	cb	3.90
ERA-4SM	DC-4	14.3	14.0	13.4	12.7	11.8	11	17.3	15	20	4.2	34	1.2	1.2	1.3	1.8	120	650	65	4.5	4.2	5.5	196	WW107	cb	3.90
NEW ERA-4XSM	DC-4	14.7	14.2	13.5	12.0	11.8	12	17.0	15.0	20	4.2	35	1.2	1.2	1.2	1.4	100	650	65	4.5	4.2	5.5	196	WW107	cb	1.69
NEW ERA-5XSM	DC-4	20.5	19.5	17.6	15.5	13.7	16	17.8	16.5	13	3.5	33	1.2	1.3	1.2	1.4	120	650	65	4.9	4.2	5.5	133	WW107	cb	1.69
ERA-51SM	DC-4	18.0	17.4	16.1	14.8	12.5	14	18.1	16.5	13	4.1	33	1.1	1.2	1.2	1.9	120	650	65	4.5	4.2	5.5	154	WW107	cb	3.90
ERA-5SM	DC-4	20.2	19.5	17.6	15.6	14.0	16	18.4	16.5	13	4.3	32.5	1.3	1.3	1.2	1.3	120	650	65	4.9	4.2	5.5	133	WW107	cb	3.90
ERA-50SM***	DC-1.5	20.7	19.4	18.3	—	—	16	17.2	16.0	13	3.5	32.5	1.3	—	1.2	—	120	650	60	4.4	4.0	4.9	177	WW107	cb	2.95

see suggested PCB layout PL-075 for ERA models

typical biasing configuration



R BIAS

"1%" Resistor Values (ohms) for Optimum Biasing of ERA Models

Vcc	ERA-1 ERA-1SM	ERA-2 ERA-2SM	ERA-21SM	ERA-3 ERA-3SM	ERA-33SM	ERA-4, 4SM,4XSM	ERA-5, 5SM,5XSM	ERA-50SM, -51SM	ERA-6, ERA-6SM	ERA-8SM
7	90.9	88.7	88.7	107	69.8	38.3	33.2	40.2	30.1	88.7
8	113	113	113	133	93.1	52.3	48.7	53.6	43.2	118
9	137	137	137	162	115	66.5	63.4	68.1	56.2	143
10	162	162	162	191	140	80.6	78.7	82.5	69.8	174
11	187	187	187	221	165	95.3	95.3	97.6	84.5	200
12	215	215	215	249	191	110	110	113	97.6	226
13	237	237	237	280	215	127	124	127	113	255
14	261	261	261	309	243	143	140	143	127	280
15	287	287	287	340	267	158	158	158	140	309
16	309	309	316	365	287	174	174	174	154	340
17	332	332	340	392	316	187	187	191	169	365
18	357	365	365	422	340	205	205	205	182	392
19	383	392	392	453	365	221	221	221	196	422
20	412	412	412	475	392	237	232	237	210	453

designers kits available

KIT NO.	Model Type	No. of Units in Kit	Description	Price $ per kit
K1-ERA	ERA	30	10 of each 1,2,3	49.95
K2-ERA	ERA	20	10 of each 4,5	69.95
K1-ERASM	ERA-SM	30	10 of each 1SM, 2SM,3SM	49.95
K2-ERASM	ERA-SM	20	10 of each 4SM, 5SM	69.95
K3-ERASM	ERA-SM	30	10 of each 4SM, 5SM, 6SM	99.95

pin connections

PORT	cb
RF IN	1
RF OUT	3
DC	3
CASE GND	2,4
NOT USED	—

NSN GUIDE

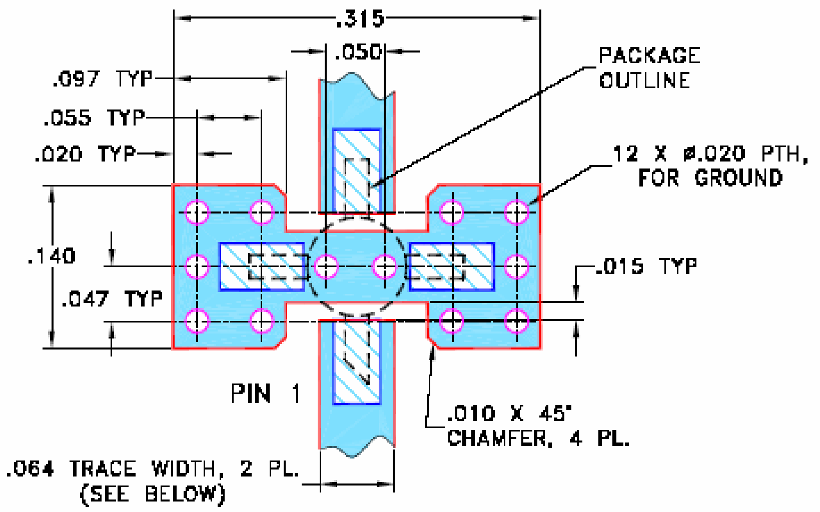
MCL NO.	NSN
ERA-1SM	5962-01-459-9075
ERA-3SM	5996-01-516-5438
ERA-4SM	5962-01-459-7410
ERA-5SM	5962-01-459-9314

051018

APPENDIX C

BASE OF THE AMPLIFIER

SUGGESTED MOUNTING CONFIGURATION FOR
WW107 CASE STYLE, "cb" PIN CONNECTION



NOTES:

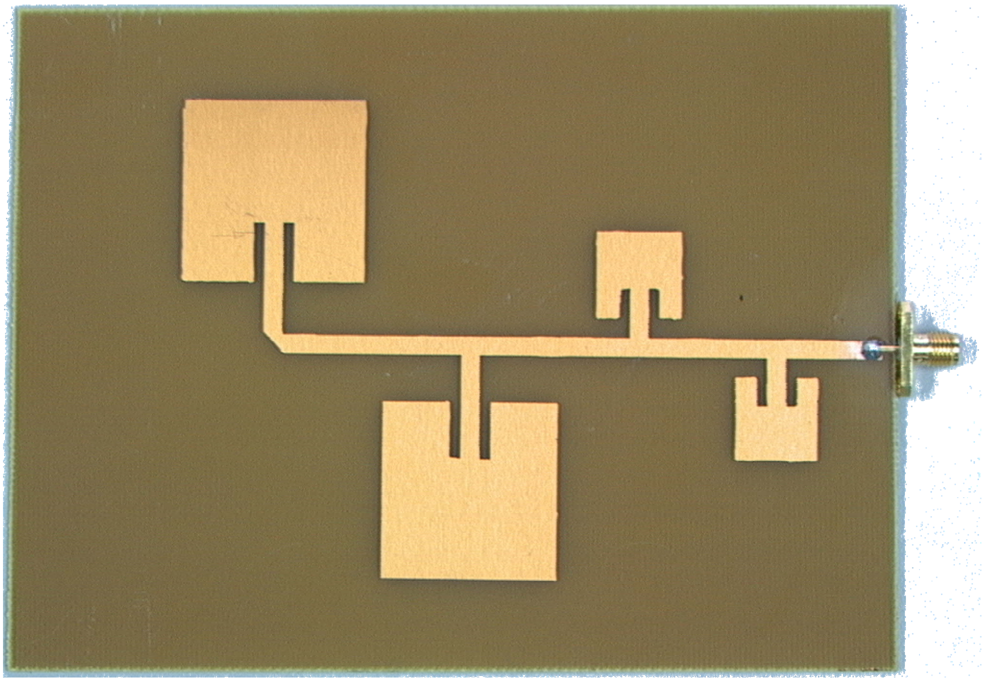
1. TRACE WIDTH IS SHOWN FOR ROGERS RO4350B WITH DIELECTRIC THICKNESS .030" ± .002"; COPPER: 1/2 OZ. EACH SIDE. FOR OTHER MATERIALS TRACE WIDTH MAY NEED TO BE MODIFIED.
2. BOTTOM SIDE OF THE PCB IS CONTINUOUS GROUND PLANE.
3. IF PCB DESIGN RULES ALLOW, PLACE GROUND VIAS UNDER THE LAND PATTERN FOR BETTER RF PERFORMANCE. OTHERWISE PLACE GROUND VIAS AS CLOSE TO LAND PATTERN AS POSSIBLE.

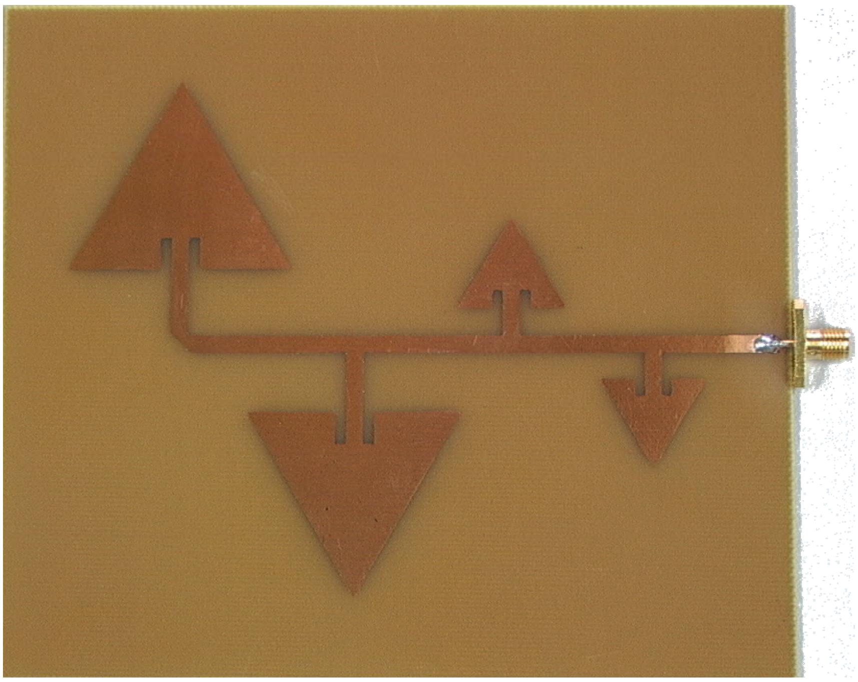
DENOTES PCB COPPER LAYOUT WITH SMOBC (SOLDER MASK OVER BARE COPPER)

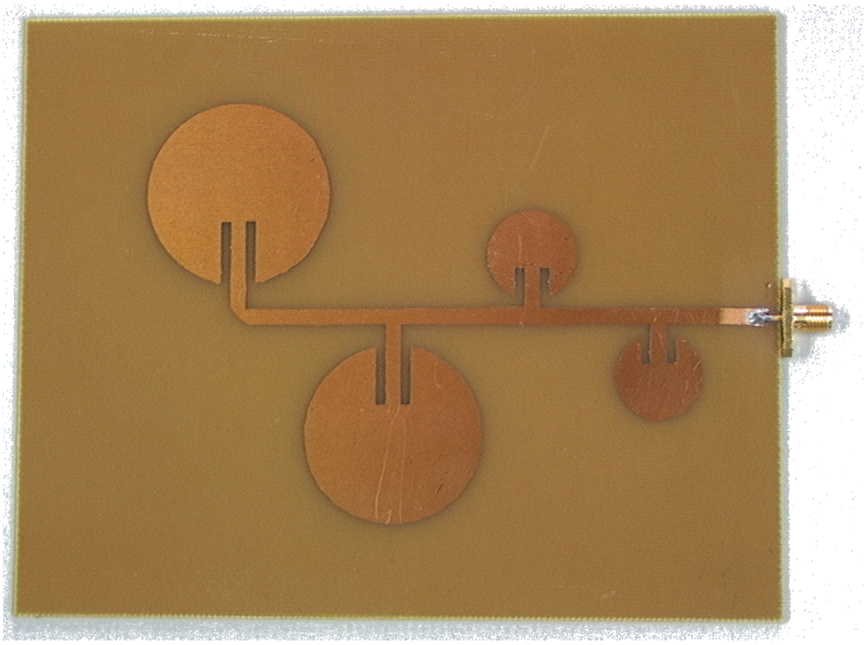
DENOTES COPPER LAND PATTERN FREE OF SOLDER MASK

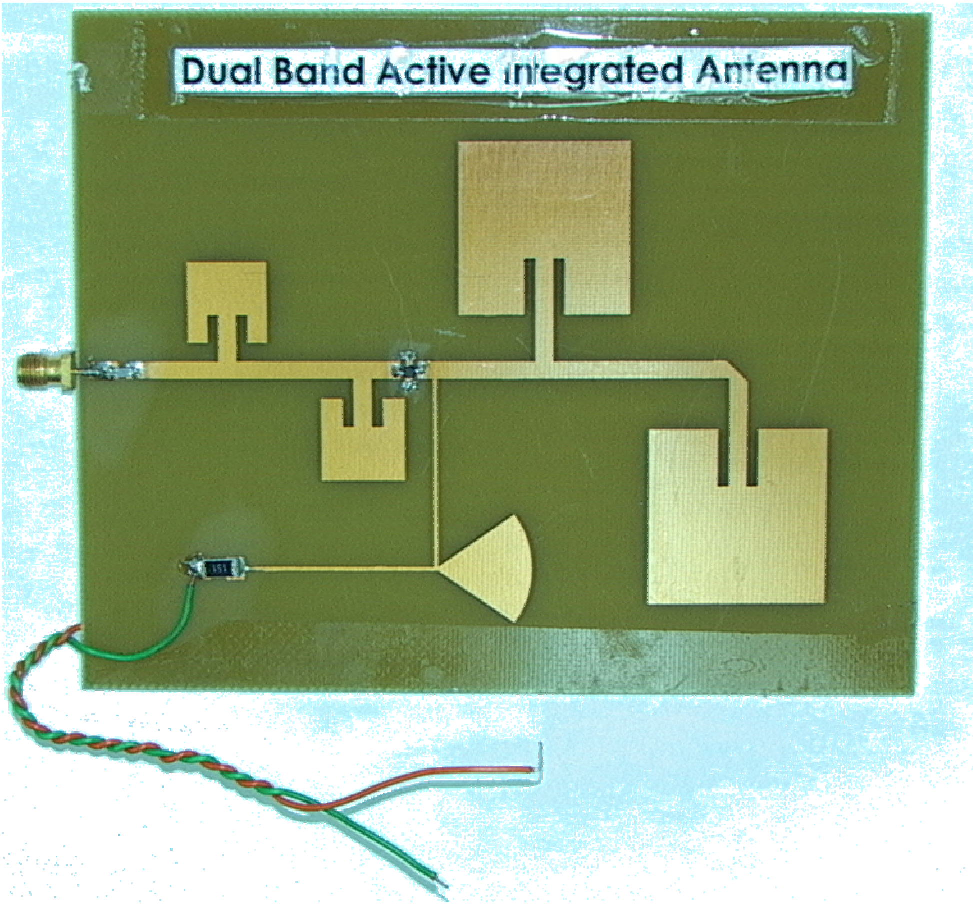
APPENDIX D

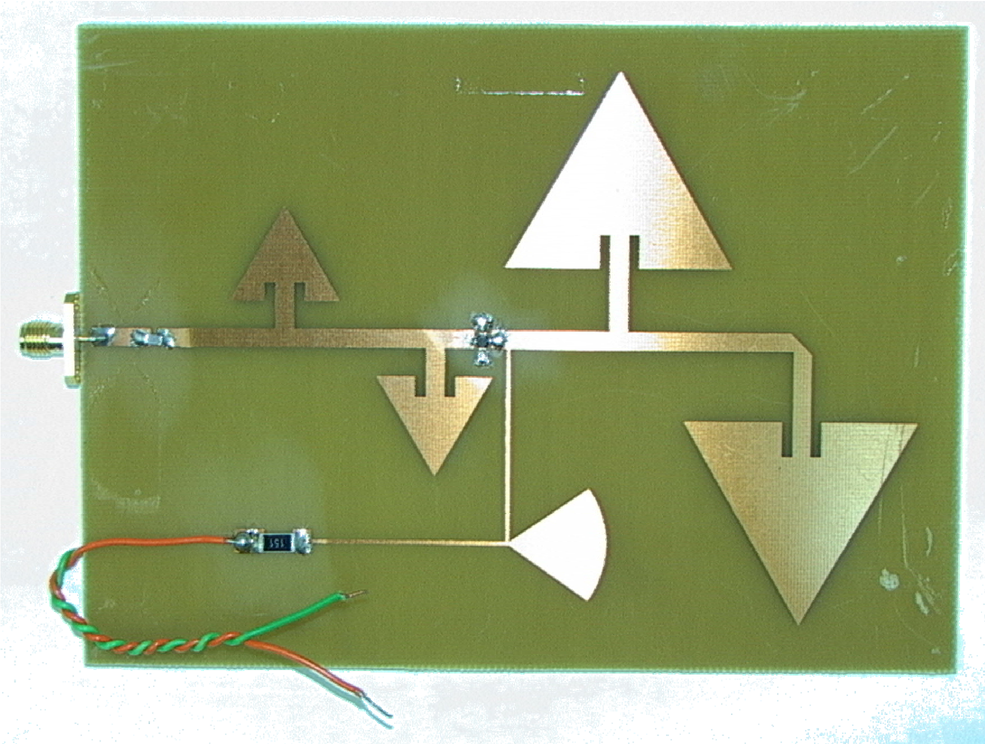
PICTURE OF THE FABRICATED ANTENNA

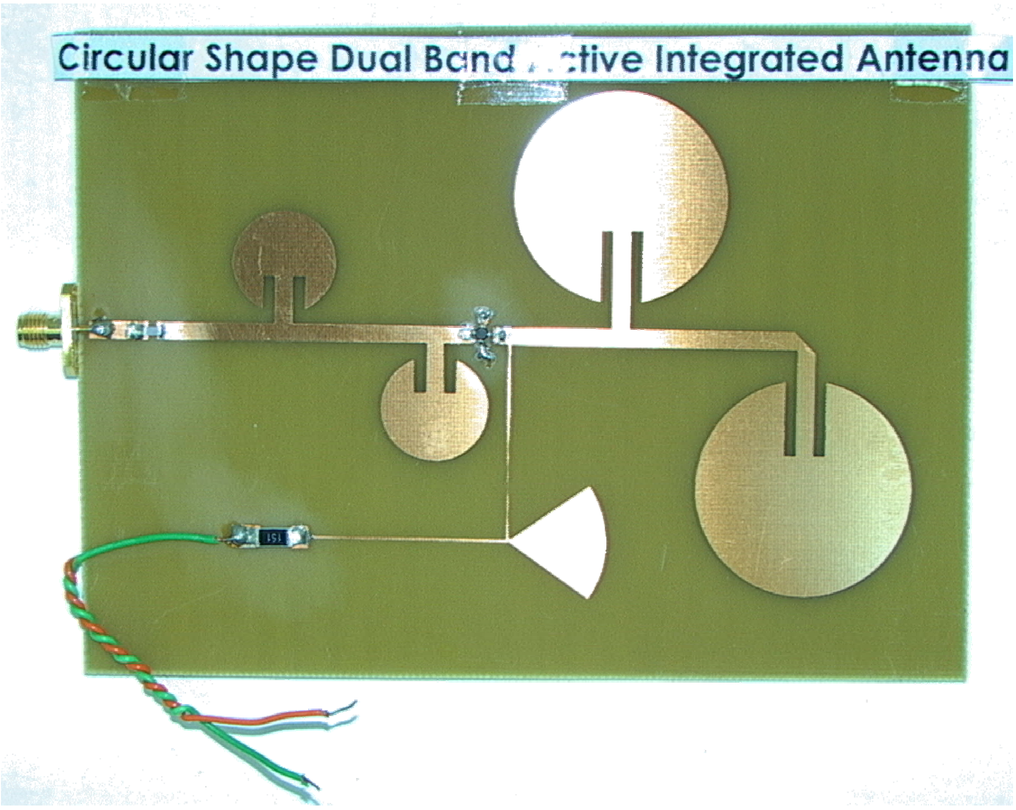







Dual Band Active Integrated Antenna




Circular Shape Dual Band
ctive Integrated Antenna

Active and Passive Aperture Coupled Microstrip Antenna Design

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Abstract

Microstrip antennas has a few feeding technique applicable to them. One of them is the non-contacting feeds, which is the aperture-coupled feed techniques. The main mechanism of power transfer between its feed line and patch is the coupling mechanism through the aperture. This work is an effort to design, simulate, fabricate and measurement of passive and active rectangular patch with aperture coupled feed techniques. Simulation is being done using the Method of Moments (MoM). This is simulated in Microwave Office software. This design intends to focus on studying the differences in simulated and measured parameters of the antenna on its return loss, bandwidth and radiation pattern..

I. INTRODUCTION

The wireless industry has experienced a significant growth in the past several years. There is an essential need for a light weight with a low profile and a good performance antenna for wireless application. In order to meet these demands, printed circuit patch antenna is one of the solutions to it. There are four feedings for microstrip antenna which can be categorized in contacting feed and non-contacting feed. For contacting feed, there are microstrip feed and coaxial feed while non-contacting feed are proximity feed and aperture coupled feed. However, for microstrip feed and coaxial feed, these antennas are characterized by bandwidth limitation, which is about 1-2% [1]. To overcome this problem, aperture coupled microstrip antenna is discovered by the researchers for the purpose to improve antenna performance features such as bandwidth.
Their features have met the essential need for wireless application which requires a light weight with a low profile and a good performance antenna. The structure consists of two substrates, one containing the radiating patch and other containing the feed network [2]. A small aperture located under the patch allows coupling of the patch to the feed line which has the form of an open-circuited stub [3]. The input impedance can be controlled by its size, position, and shape of the aperture and open-ended stub length. Besides that, its performance will also affected by the type of the antenna which comprise of active or passive. In this paper, the aperture coupled microstrip antenna for active and passive are investigated in terms of its return loss, bandwidth and radiation pattern. The antenna structure has been design at 2.4 GHz frequency.

II. ANTENNA STRUCTURE AND DESIGN

The main objective of this work is to design the active aperture coupled microstrip antenna to resonate at the frequency of 2.4 GHz. Since a suitable and similar substrate must be chosen in order to provide a general platform for the shapes to be simulated, the chosen substrate is FR-4, which has a dielectric constant (ε_r) of 4.5, dielectric loss tangent ($tan\delta$) of 0.019 and substrate height (h) of 1.6mm.

The first design is the active aperture coupled microstrip antenna. The patch of the antenna is calculated based on the equation in [4] and the dimension is adjusted for optimization. For the calculated patch, the dimension is 37.7 mm for the width and 29.1 mm for the length but after optimization the patch for the width is 38 mm for the width and 28 mm for the length. This design is according to the normal feed width in FR-4 for 50 ohm microstrip line which is 3 mm. The feed line has a width and length of 3mm x 57.5mm starting from the stub, where 28 mm of the length is overlapped under the ACMA patch. The antenna's full dimension is shown in Fig. 1 and the schematic of the active antenna is shown in Fig. 2. The schematic of the active antenna is using the transmission line circuit simulator from Microwave office software. The capacitor choosen for the dc block is 100 pF. The current for the transistor is biased at 40 mA.

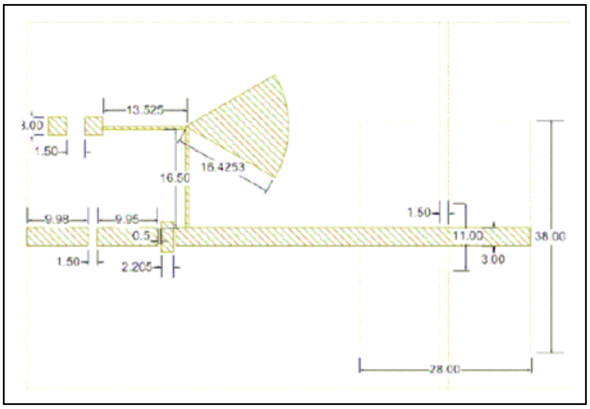


Fig. 1: Dimension of active aperture coupled microstrip antenna

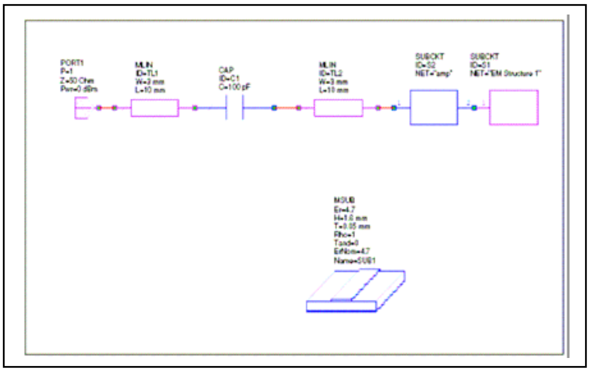


Fig. 2: Schematic view of active aperture coupled microstrip antenna

Fig. 1 shows the radial stub used for the amplifier biasing. The biasing voltage is depend on the amplifier data sheet. Fig. 2 shows the schematic diagram using microstrip line and capacitor with 100 pF. The following is the microstrip line connecting the ERA-2sm amplifier from mini-circuit and the right most ended is the ACMA. All the microstrip line in the active antenna design is in 3 mm wide except the stub line is using only 1 mm wide feed line.

The passive aperture coupled microstrip antenna and the dimension for the antenna is fixed except the feed line width for the comparison purpose. The overall dimension for the feed line of the passive ACMA is 8 mm x 57.7 mm. Its patch is 37 mm x 28 mm while the aperture slot is in 11 mm x 1.5 mm. The full dimension for the passive aperture coupled microstrip antenna is shown in Fig. 3.

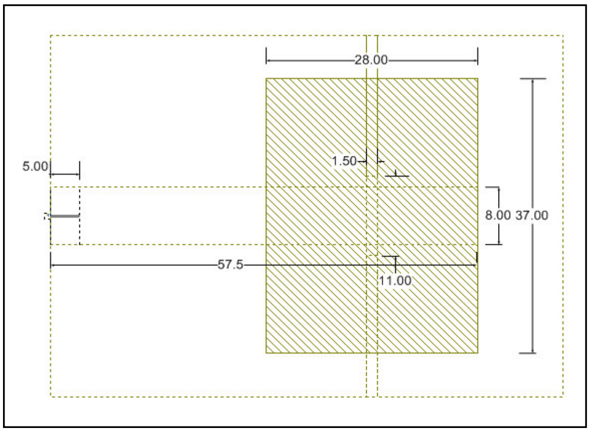


Fig. 3: Dimension of 8mm feed line width aperture coupled microstrip antenna

III RESULT

The designs shown in the previous section have been simulated and fabricated. Then the simulated result and the fabricated result are compared. The simulated and measured return loss result for the passive aperture coupled microstrip antenna is shown in Table 1 while the simulated and measured bandwidth is shown in Table 2.

The simulated passive design resonates at 2.41 GHz while the fabricated resonates at 2.435 GHz. This yields a variation of 0.025 GHz or 1.04% which shows a good approximation for the simulated and fabricated design in its real operation. However, the return loss varied by 6.95 dB or 27%. The return loss graph is shown in Fig. 4. From the data, bandwidth for the rectangular design is 190 MHz in simulation while only 110 MHz in measurement. The summarized result is shown in Table 1 and Table 2.

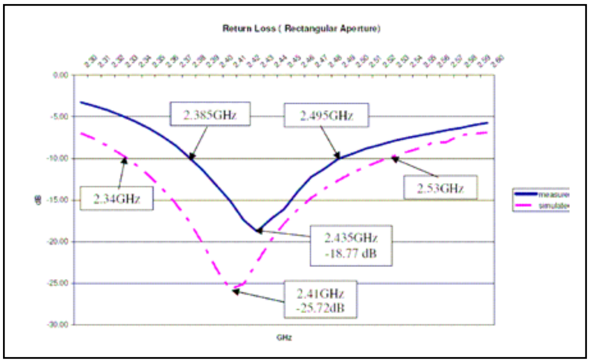


Fig. 4: Comparison of simulated and measured return loss graph for 8mm feed line width

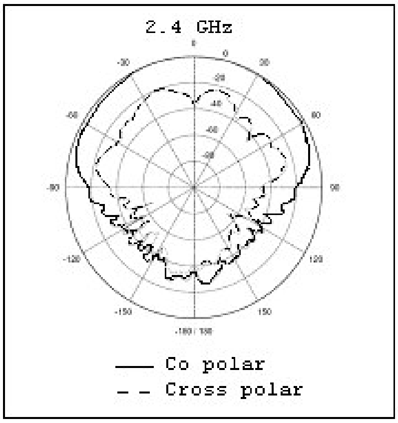
TABLE 1: SUMLATION AND MEASUREMENT OF RETURN LOSS

Feed Line Width	Model	Return Loss (dB)	Res. Freq (GHz)	Res. Freq Var. (GHz)	Res. Freq Var. (%)
active	Sim	-21.9	2.336	0.214	9.2
	Meas	-38	2.55		
passive	Sim	-25.72	2.41	0.025	1.04
	Meas	-18.77	2.435		

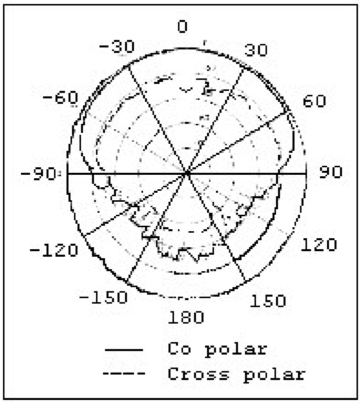
TABLE 2: SIMULATION AND MEASUREMENT OF BANDWIDTH

Feed Line Width	Model	BW Range (GHz)	BW (MHz)	BW (%)	BW Var. (%)
active	Sim	2.131- >3.1	969		
	Meas	2.24-2.68	440		
passive	Sim	2.34-2.53	190	7.88	42.11
	Meas	2.385-2.495	110	4.52	

The radiation pattern for passive aperture coupled microstrip antenna give a good HPBW (half power beam width), it has a simulated Half Power Beam Width (HPBW) of 110.28º for H-plane and 81.8º for E-plane while has a measured HPBW of 98º for E-plane and 117º for H-plane. The rectangular aperture coupled feed technique produced a relatively moderate HPBW values and acceptable isolation level (Isolation < -20dB). The measured radiation pattern of the passive aperture coupled microstrip antenna is shown in Fig. 5



(a) E Plane



(b) H Plane

Fig. 5: Polar plot radiation pattern for passive antenna

The simulated and measured result for active aperture coupled microstrip antenna is summarized in Table 1 and Table 2. The optimal resonant frequency is varied by 0.214 GHz or 9.2%. However, the return loss is suffering a very large variation than the simulated one. Both of the simulated and measured return loss shapes are different. The simulated active antenna gives a very wide bandwidth starting from 2.131 GHz to over 3.1 GHz which comprise more than 0.969 GHz. However, in the real world, the bandwidth is just 0.44 GHz. It is significant drop if compare to the simulated active antenna. The measurement result for active antenna is shown in Fig. 6.

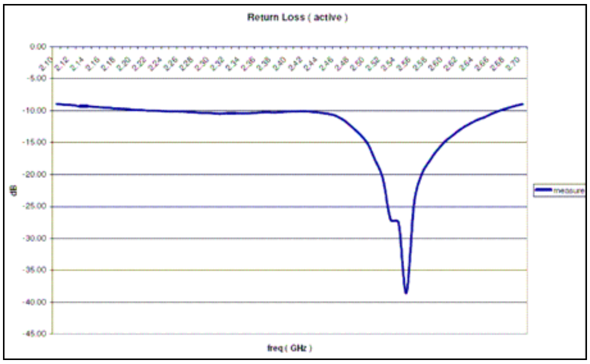
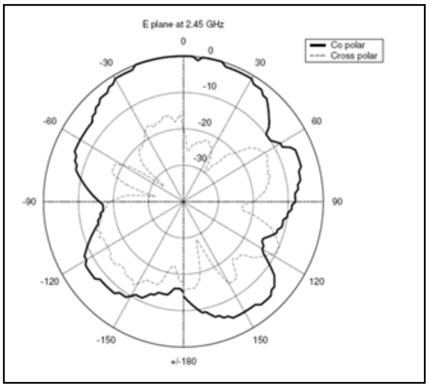
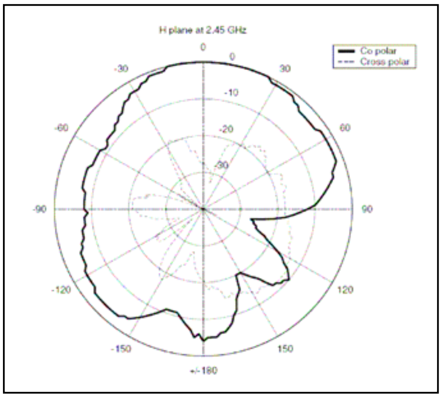


Fig. 6: Measured return loss graph for active ACMA

The radiation pattern of the active antenna design yields simulation results of 100.7º for E-plane and 95.8º for H-plane. The measured result varied from the simulation with 72º for E-plane and 92º for H-plane. The summarized radiation pattern result is shown in Table 3. Figure 7 shows the polar plot of E-plane and H-plane for active aperture coupled microstrip antenna. The HPBW and isolations results are shown in Table 3.



(a) E Plane



(b) H Plane

Fig. 7 : Radiation Pattern for active antenna

TABLE 3: RADIATION PATTERN RESULT

Feed Line Width	Active		Passive	
	E-plane	H-plane	E-plane	H-plane
HPBW (deg) sim	100.7	95.8	110.3	110.7
HPBW (deg) meas	104	80	117	94
Cross Isolation (dB)	27	20	35.92	15
Gain (dB)	3		0	

IV DISCUSSION

Two comparisons results are made in this paper. Typically, the 3 mm feed line width is designed for 50 ohm line for ordinary microstrip feed antenna and it is applied in the active ACMA. However, the 8 mm feed line width is chosen for the passive ACMA because this width gives the best optimize results after adding the feed line width from 3 mm. In addition, the 3 mm feed width does not make the design works. The 3 mm design resonates at the desired frequency but it does not meet the specification that return loss exceed -10 dB. But, the 8 mm feed width does work with the same dimension for the passive ACMA.

The 3 mm feed line width does work with the active ACMA. One of the reasons of the working is because the active circuit such as the amplifier is added in the antenna. The current which is pumped into the feed is amplified by the amplifier before propagated into the feed line. It makes the coupling power strong enough to couple through the aperture to the patch.

For the variation on return loss, resonant frequency and bandwidth, the main factor is the simulation software constraint. The constraint is the conductor is not able to draw under the substrate. Since the aperture coupled antenna needs the feed to be on the same layer with the ground plane or the aperture, thus one more substrate is defined so that the feed can be drawn on the substrate. On the other hand, the simulation for the active antenna is done by using the schematic only. The air gap existed between the patch with the aperture is a factor as well. In simulation, the design is ideal and no air gap exists between the patch and the ground plane. With the use of adhesive to stick the patch with the ground plane, the variation is affected more as the adhesive will affect the effective dielectric constant and contribute some height to the gap.

In practical, nothing is perfect and this includes the dielectric material. The dielectric material used in this work, which is the FR-4, has a relative dielectric constant that varies from 4.0 to 4.8 depending on the operating frequency. In simulation, the substrate is assumed to a constant value of dielectric constant. In practice, this definition is unrealistic, as the dielectric constant has certain amount of variation along the length, width and even thickness of the structure.

The usage of adhesive will worsen the situation as this adhesive will contribute dielectric constant as well and contribute to the variation. Other than that, Electromagnetic coupling is one of the important mechanisms to aperture coupled microstrip antenna. But in the simulation, the electromagnetic coupling to the environment is not modeled. While doing return loss measurement, the antenna is not tested in the cleanest environment, thus there will always exists a level of coupling to surrounding objects or even parts of human body.

V. CONCLUSION

A comparison is made between active and passive aperture coupled microstrip antenna. The dimension, return loss graph and polar plot for radiation pattern of the design are shown in this paper. Both designs achieved the best return losses at the desired frequency as well. The active aperture coupled microstrip antenna gives a very outstanding BW and return loss. All the variation issues on the design is discussed, the factors of the variation are pointed out as well.

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Circular Dual Band Microstrip Antenna for WLAN Application

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***Abstract* - Wireless local area network (WLAN) applications nowadays has become more popular especially those operating in the 2.4 GHz ISM band. There have been a lot of efforts on combining the WLAN, a/b/g bands together. The designs either provide inadequate coverage of the frequency band or not suitable for integration in some portable devices. This paper describes the design of a circular dual band microstrip antenna using scaling factor technique and inset feed. The antenna was designed to operate in the indoor WLAN ISM band at 2.4 GHz and 5.2 GHz. A scaling factor of 1.05 has been chosen for the design, starting from the lowest resonating frequency at each band. The antenna has been fabricated on the FR4 microstrip board with ε_r = 4.7, substrate height of 1.6 mm and tan δ = 0.019 using the wet etching technique.**

***Index Terms:* Circular, Microstrip antenna, Dual band, WLAN, Scaling factor technique**

I. INTRODUCTION

Wireless Local Area Network (WLAN) access point devices in the market commonly consists of a transceiver that use one antenna for one frequency band, and some use monopole antenna which has dual band feature. The use of one antenna for one frequency band increase the physical size of the access point device and the use of the dual band monopole will have omni directional radiation pattern with some of the angle having unnecessary radiation from the antenna. The unnecessary radiation is usually caused by the way the access point device is mounted. Access point device is usually mounted on the wall, where the area behind the wall is the region that does not need any coverage. Even if the access point device is mounted on the ceiling, it is not intended that the upper floor will get the WLAN signal. The use of a directional type of antenna helps to create a more controlled coverage area for the WLAN.

Monopole antenna has been widely used as the antenna for wireless access point because it has been a standard type of antenna for wireless devices and its design is less complicated than the other type of antenna (only need a quarter wavelength of conductor such wire or metal rod). The monopole has less aesthetic value because of its difficulty to conceal itself inside the access point. A more aesthetic type of antenna might increase the price value of the access point device if the antenna can be incorporated on the device's body. Monopoles antenna is an omni-directional antenna that radiates EM wave at all angles, omni directionally. Its wide beamwidth resulted in lower gain. If the beamwidth of an antenna can be decreased, it will help increase the gain, thus increasing the coverage distance of the antenna.

In Wireless LAN applications or systems, two different set of frequencies (ISM & UNII Band) have been allocated where one is at 2 GHz band and the other is at 5 GHz band. It is possible to simultaneously use these two frequencies for WLAN application at one time, but two different set of antenna is also needed. This can be solved by using one antenna for two different systems. The integration of these two bands of frequencies/systems can reduced the incompatibility to each other.

Dual band antennas have not received much attention because of the complexity of the feeding method for array applications [1]. Because of the lightness and the surface conformal property of the microstrip antenna, the dual band antenna is suitable for systems that are used to be mounted on airborne platforms like the synthetic-aperture radar (SAR) and scatterometers [1] but the antenna design must also consider a proper beamwidth angle so that it will not only radiate at certain angle only. .So, in this paper, we propose the usage of a dual band, directional type of microstrip antenna for the WLAN application.

II. ANTENNA DESIGN

The design calculation for circular shape patch microstrip antenna is given in the equations below [2]. The dominant mode that is used for calculating the circular radius is TM_{11}. The radius of the circular patch as shown in figure 1 can be calculated using the equation (1).

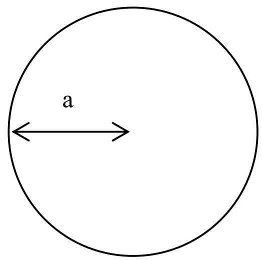


Figure 1: Circle layout dimensions.

$$a_e = \frac{87.94}{f_r\sqrt{\varepsilon_r}} \quad mm \qquad (f_r \text{ in GHz}) \qquad (1)$$

For different mode, equation below can be used to calculate the resonant frequency at radius a_e.

$$f_{nm} = \frac{x_{nm}c}{2\pi a_e\sqrt{\varepsilon_r}} \qquad (2)$$

where:

$x_{nm} = ka$

$k = 2\pi\sqrt{\varepsilon_r}/\lambda_0$

a_e = Effective radius

ε_r = Permittivity of the dielectric

c = Speed of light

III. SINGLE ELEMENT DESIGN

Figure 2 shows the layout of the circular microstrip antenna. The type of feeding technique that will be used is the inset feed technique. It is one of the easiest feeding techniques and it is also easy to control the input impedance of the antenna. The input impedance level of the patch can be control by adjusting the length of the inset. The calculation of the inset fed is shown in the equation 3 which show the resonant input resistances for the microstrip patch [3].

$$\ell = 10^{-4}\begin{pmatrix} 0.001699\varepsilon_r^{\,7} + 0.13761\varepsilon_r^{\,6} - 6.1783\varepsilon_r^{\,5} + 93.187\varepsilon_r^{\,4} - \\ 682.69\varepsilon_r^{\,3} + 2561.9\varepsilon_r^{\,2} - 4043\varepsilon_r + 6697 \end{pmatrix}\frac{L}{2} \qquad (3)$$

The fabricated inset feed length of the patch is almost similar as the calculated inset length. The calculated length of the patch can be found in table 1.

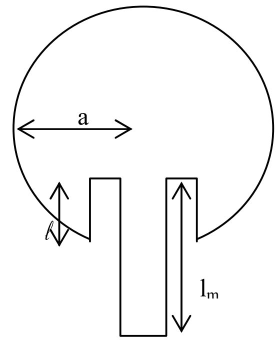


Figure 2: Layout of the circle patch.

Table 1: Calculated dimensions of the circle patch.

Element	Frequency (GHz)	Radius (mm)	Inset, l (mm)
1	2.27	17.87	11.22
2	2.38	17.04	10.70
3	4.70	8.63	5.42
4	4.90	8.28	5.20

The modified dimensions of the patch are shown in table 2. The diameter of the patch is less then the dimension of the square patch. It shows that by introducing different shapes will helps to miniaturize the size of the microstrip antenna.

Table 2: Modified dimensions of the circle patch.

Element	Frequency (GHz)	Radius (mm)	Inset, l (mm)	l_m (mm)
1	2.27	18.46	12.60	17.41
2	2.38	17.90	12.00	16.59
3	4.70	9.00	5.80	8.38
4	4.90	8.60	5.70	7.60

IV. DUAL BAND DESIGN

After designing both of the elements, they will be combined to form the dual band feature antenna. Each of the single elements can be represented as a data block as shown in figure 3. A preliminary simulation can be made using the circuit simulation in the schematic window. The width of each block other than the data block is made to be 3 mm, an approximately 50 Ω (48 to 49 Ω) feed line.

The scaling factor technique is used to determine the operating frequencies of each of the single element of the antenna and the length of the transmission lines connecting each element. The design of the dual band patch antenna needs four elements because a single element cannot covers the whole frequency band of the WLAN. So, with two elements for each frequency band and with proper matching between the elements, it will help to achieve the dual band feature.

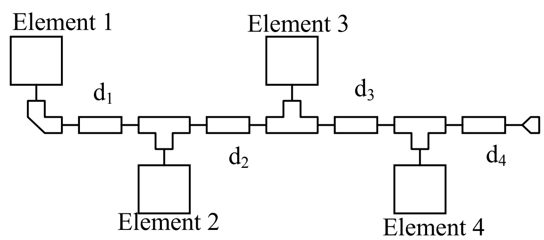


Figure 3: Data block layout of the passive antenna.

Usually, the length of the d_m is made to be the half wave length of the operating frequency of the element as shown in the equation below. But, to be more precise, in this project, the length d_m is determined first in order to make sure that the input impedance from the subsequent element (m+1) will be open circuit (high impedance) [4].

$$d_m = \lambda_0/2 \tag{4}$$

V. SCALING FACTOR TECHNIQUE

The scaling factor technique is similar to the log periodic technique which involves the scaling of the dimensions, period by period, which makes the performance of the antenna periodic to the logarithm of the frequency [4], [5].
The dimensions such as the length, L the width, W and the inset feed, ℓ of the antenna can be related to the scaling factor, τ as shown in the equation below.

$$\tau = \frac{L_{m+1}}{L_m} = \frac{W_{m+1}}{W_m} = \frac{\ell_{m+1}}{\ell_m} \tag{5}$$

As shown in figure 4, the arrangement of the patch in the scaling method can be related to the factor τ. The dimension of the array is multiplied by the scaling factor τ to the elements itself starting from element *m* which will then generate the element *m+1*, *m+2* and so on.

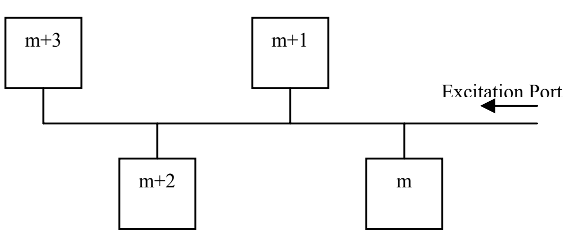


Figure 4: The model of the combination of the elements.

From this technique, the operating frequency will also be scaled to the factor τ. The relation of the scaled frequency is shown in the equation below.

$$f_1, \quad f_2 = \tau f_1, \quad f_3 = \tau^2 f_1, \quad f_4 = \tau^3 f_1 \tag{6}$$

The relations can also be viewed as shown below, thus it is called log periodic.

$$\ln\frac{f_2}{f_1} = \ln\tau, \quad \ln\frac{f_3}{f_1} = 2\ln\tau, \quad \ln\frac{f_4}{f_1} = 3\ln\tau \tag{7}$$

The log periodic technique has been modified to serve the purpose of frequency selective antenna. For example, the indoor wireless LAN system uses the ISM and UNII frequency band at 2.4 GHz and 5.2 GHz. If the log periodic technique is used, the bandwidth of the antenna will go along from the 2.4 GHz band up to 5.2 GHz band as shown in figure 5. But by modifying the log periodic technique, the selective band can be achieved as shown in figure 6. This method uses the scaling method rules, but with frequency selection technique. The operating frequency that will be used is selected to cover both frequency bands.

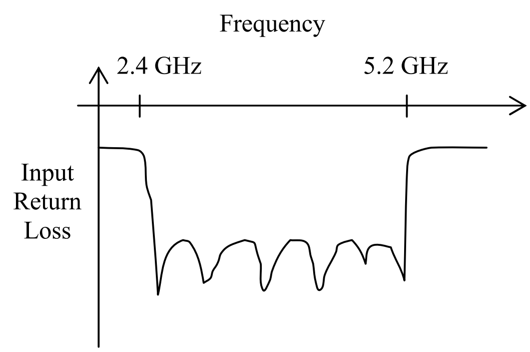


Figure 5: Input return loss example from a log periodic antenna.

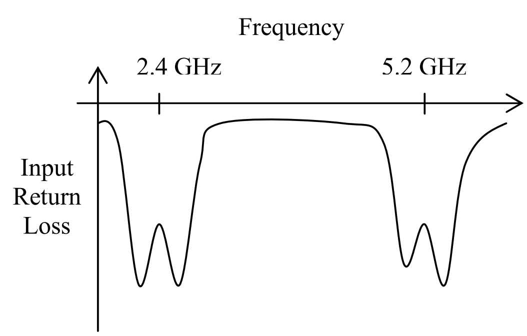


Figure 6: Input return loss from the scaling factor technique.

VI. RESULTS

The dual band feature on the circular patch also shows a good return loss at both frequency bands. As shown in the figure 7, at the 2.4 GHz band, the bandwidth percentage for the simulation result is about 7.82% and for the measured result is about 8.21%. For the 5.2 GHz band, the percentage bandwidth for the simulation is about 11.01% and for the measured result is about 3.85%.

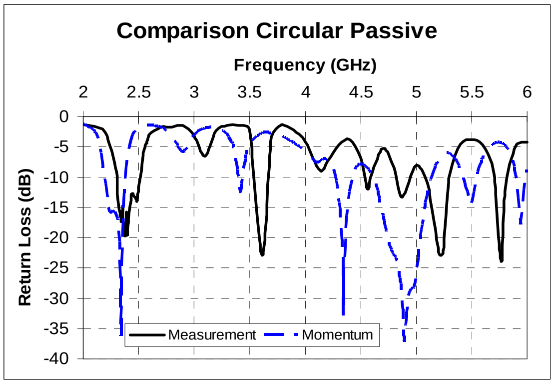
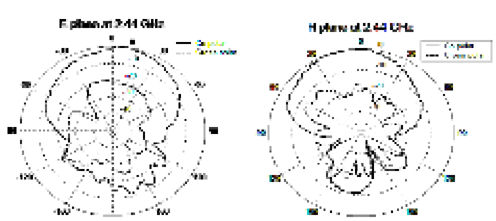


Figure 7: Input return loss for the circular patch passive antenna.

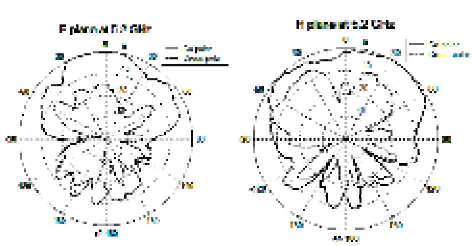
Two sets of radiation pattern are taken at 2.44 GHz and 5.2 GHz for each shape of antenna patch. The frequency 2.44 GHz and 5.2 GHz are chosen because the frequencies are at the centre at each frequency band (2.4 – 2.48 GHz and 5.15 – 5.25 GHz). The radiation pattern was made in an indoor anechoic chamber using the Gigatronics Signal Generator and the Agilent Spectrum Analyzer.

Figure 8 (a) and (b) shows the radiation patterns for the circular patch in E plane and H plane respectively at 2.44 GHz and 5.2 GHz. At 2.44 GHz, The HPBW for the E plane is about 58° and the cross isolation is about 20 dB. For the H plane, the HPBW is about 72° and the cross isolation is about 18 dB.

At 5.2 GHz, the HPBW for the E plane is about 56° and the cross isolation is about 15 dB. For the H plane, the HPBW is about 72° and the cross isolation is about 13 dB.



(a)



(b)

Figure 8: Radiation patterns of the circular dual band microstrip antenna at (a) 2.4Ghz and (b) 5.2Ghz

The gain is compared to a horn antenna which has gain from 6 to 10 dBi and the range of frequency between 1 to 18 GHz. When compared to the horn antenna, the gain for the circular patch passive at 2.44 GHz is about 12 dBi while at 5.2 GHz the gain is about -3 dBi.

VII. Conclusion

By implementing the log periodic technique, the author was bounded to the rules of the log periodic technique where the design of the elements should be from the lowest frequency to the highest frequency, periodically. Using the scaling factor technique, some elements were cut-off from the design, and it becomes a frequency selective antenna or in this case, a dual band antenna. This improves the physical size of the antenna as only a selected frequency element is needed to be designed. The use of circular shape for the design add up as an alternative to other shapes commonly used for microstrip antenna design.

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Square Shaped Dual Band Active Integrated Antenna and Passive Antenna

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Abstract

Wireless local area network (WLAN) applications nowadays has become more popular especially those operating in the 2.4 GHz ISM band. Nowadays, there are a lot of efforts on combining the WLAN, a/b/g bands together. Research on dual band and multiband antennas has gone tremendous development throughout the century. This paper describes the design of the dual band microstrip antenna using scaling factor technique and inset feed with the integration of active devices. The antennas were designed to operate in the indoor WLAN ISM band at 2.4 GHz and 5.2 GHz. The dimensions of each single element of the microstrip antenna, at these operating frequencies were calculated using transmission line model and their individual S-parameter data. The scaling factor of 1.05 has been chosen for the design. The antennas have been fabricated on the FR4 microstrip board with ε_r = 4.7, substrate thickness of 1.6 mm and tan δ = 0.019 and proved to be operating with adequate bandwidth and radiation characteristics.

1. Introduction

Antenna is one of the important elements in the RF system for receiving or transmitting the radio wave signals from and into the air as the medium. Without proper design of the antenna, the signal generated by the RF system will not be transmitted and no signal can be detected for processing. Antenna engineering is a vibrant field which is bursting with activity and is likely to remain so in the foreseeable future [1]. Many types of antenna have been designed to cater with variable application and suitable for their needs. One of the types of antenna is the microstrip antenna. The microstrip antenna has been said to be the most innovative area in the antenna engineering because of its low material cost and its easiness of fabrication which the process can be made inside universities or research institutes.

Active antenna can be defined as an active devices employed in the passive antenna elements to improve the antenna performance [2]. The active integrated antenna (AIA) means that the active device is being incorporated on the same substrate with the passive antenna elements. The implementation of active devices with passive antenna shows some advantages such as increasing the effective length of short antenna, bandwidth increment and noise factor improvement.

The power amplifier is the most power-hungry component in a transmitter designs, so high-efficiency power amplifier is an important aspect for designing the amplifying type active integrated antenna [3]. The implementation of the amplifier in a passive antenna may increase the antenna gain and bandwidth and will improve the noise performance [2].

2. Antenna Design

The design of the AIA cannot be done in EM simulation because it involves active elements that cannot be simulated in the EM simulation. The AIA is simulated in the circuit simulation that incorporates the active elements and the passive elements using the Momentum results obtained for each single element.

A. Square Patch Design Calculations

The design of the square shape patch follows the equation for designing the rectangular shape patch. The same length and width of the patch of the antenna was made to ease the design steps. Inset feed is being introduced into the design to offset the feeding location to the point where matched impedance can be achieved.

The basic parameters of the microstrip has to be determined such the width and length and the feeding technique that is being used. The width of patch can be determined using the equation 1.

$$W = \frac{1}{2f(\sqrt{\varepsilon_o \mu_o})}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

The ε_0 and the μ_0 are the permittivity and the permeability in free space respectively. The equation $\frac{1}{\sqrt{\varepsilon_0 \mu_0}}$ can also be interpreted as the speed of light, c which is 3×10^8 m/s. The symbol f is the resonant frequency that the antenna intended to be operating and ε_r is the permittivity of the dielectric. The width of the antenna is used for the calculation of the antenna's length.

The patch's length can be calculated using the equations 2. The length's extension, ΔL and the effective permittivity, ε_{reff} have to be calculated before calculating the length of the microstrip patch as shown in figure 1. The h is the height of the substrate while the W is the width of the patch as calculated before.

$$L = \left(\frac{1}{2f\sqrt{\varepsilon_{reff}}\sqrt{\varepsilon_o \mu_o}} \right) - 2\Delta L \quad (2)$$

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

$$\varepsilon_{reff} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left[\left(\frac{\varepsilon_r - 1}{2}\right)\left[1 + 12\frac{h}{W}\right]^{-0.5}\right] \quad (4)$$

where:

- f = Operating frequency
- ε_r = Permittivity of the dielectric
- ε_{reff} = Effective permittivity of the dielectric
- ε_0 = Permittivity in free space
- μ_0 = Permeability in free space
- W = Patch's width
- H = Thickness of the dielectric

The width of the patch is made to be in the same value with the length to ease the design process, so the patch will be a square patch. Actually, the determination of the patch's width is important because it affects the efficiency of the antenna. A small value of width compared to the calculated width will leads to low antenna efficiency while high value of width will leads to higher order modes [4].

The type of feeding technique that is being used is the inset feed technique. It is one of the easiest feeding techniques and it is also easy to control the input impedance of the antenna. From figure 1, the input impedance level of the patch can be control by adjusting the length of the inset. The calculation of the inset fed is shown in the equations 5 which show the resonant input resistance for the microstrip patch [5].

$$\ell = 10^{-4}\left(\begin{array}{l} 0.001699\varepsilon_r^7 + 0.13761\varepsilon_r^6 - 6.1783\varepsilon_r^5 + 93.187\varepsilon_r^4 - \\ 682.69\varepsilon_r^3 + 2561.9\varepsilon_r^2 - 4043\varepsilon_r + 6697 \end{array} \right)\frac{L}{2} \quad (5)$$

B. Single Element Design

The design calculation for the square patch has been discussed earlier. The parameters that needed to be calculated are the length of the patch, the inset feed and the feed line's length as shown in figure 1.

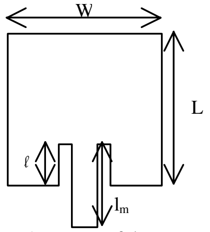


Figure 1: Layout of the square patch.

The calculated parameters of the patch is shown in Table 1. The resonant frequency of the antenna has been designed to be much lower than the expected frequency which at 2.4 GHz and 5.2 GHz as reported in reference [4]. The feed line is made to be a quarter wavelength of the operating frequency. The simulation and modification were done so that the operating frequency will be at the desired frequency with acceptable bandwidth and return loss. The new dimensions of the square microstrip antenna are shown in table 2.

Table 1: Calculated dimensions of the square patch.

Element	Frequency (GHz)	L and W (mm)	Inset, ℓ (mm)
1	2.27	30.16	9.47
2	2.38	28.74	9.02
3	4.95	13.46	4.22
4	5.20	12.77	4.01

Table 2: Modified dimensions of the square patch.

Element	Frequency (GHz)	L and W (mm)	Inset, ℓ (mm)	l_m (mm)
1	2.27	30.70	10.00	18.36
2	2.38	29.30	9.50	17.47
3	4.95	14.30	4.90	8.40
4	5.20	13.60	4.70	8.00

C. Dual Band Passive Antenna Design

After the design of the single elements, the elements were combined to form the dual band feature antenna. The width of the transmission line is made to be 3 mm, an approximately 50 Ω (48 – 49 Ω) feed line. The scaling factor design involves in determining the operating frequencies of the single element of the antenna and the length of the transmission lines connecting each elements. The design of the dual band patch antenna needs four elements because a single element cannot covers the whole frequency band of the WLAN. So, with two elements for each frequency band and with proper matching between the elements, it will help to achieve the dual band feature.

Usually, the length of the d_m is made to be the half wave length of the operating frequency of the element as shown in equation 6. But, to be more precise, in this project, the length d_m is determined to make sure that the input impedance from the subsequent element (m+1) will be open circuit (high impedance) [6].

$$d_m = \lambda_0 / 2 \qquad (6)$$

The scaling factor technique is the same technique as the log periodic technique which involves the scaling of the dimensions period by period which will make the performance of the antenna periodic to the logarithm of the frequency [6], [7].

The scaling factor technique The dimensions such as the length, L the width, W and the inset feed, ℓ of the antenna can be related to the scaling factor, τ as shown in the equation 7.

$$\tau = \frac{L_{m+1}}{L_m} = \frac{W_{m+1}}{W_m} = \frac{\ell_{m+1}}{\ell_m} \qquad (7)$$

As shown in figure 2, the arrangement of the patch in the scaling method can be related to the factor τ. The dimension of the array will be multiplied by the scaling factor τ to the elements itself starting from element *m* which will then generate the element *m+1*, *m+2* and so on.

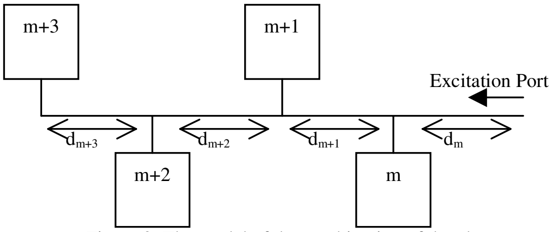


Figure 2: The model of the combination of the elements.

From this technique, the operating frequency will also be scaled to the factor τ. The relation of the scaled frequency be viewed as shown below, thus it is called log periodic.

$$\ln\frac{f_2}{f_1} = \ln\tau, \quad \ln\frac{f_3}{f_1} = 2\ln\tau, \quad \ln\frac{f_4}{f_1} = 3\ln\tau \qquad (3.19)$$

The log periodic technique has been modified to serve the purpose of frequency selective antenna. For example, the indoor wireless LAN system uses the ISM and UNII frequency band at 2.4 GHz and 5.2 GHz. If the log periodic technique is used, the bandwidth of the antenna will go along from the 2.4 GHz band up to 5.2 GHz band as shown in figure 3. But by modifying the log periodic technique, the selective band can be achieved as shown in figure 4. This method uses the scaling method rules, but with frequency selection technique. The operating frequency that will be used is selected to cover both frequency bands.

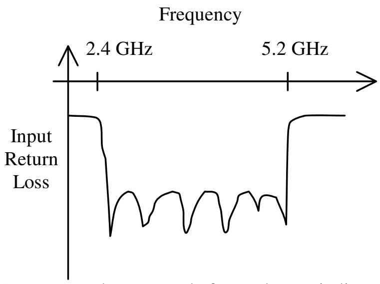


Figure 3: Input return loss example from a log periodic antenna.

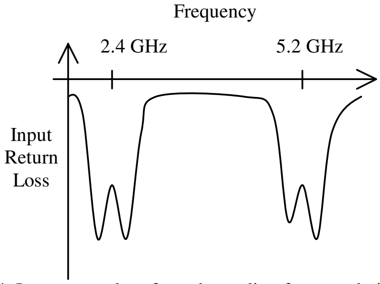


Figure 4: Input return loss from the scaling factor technique.

D. Active Integrated Antenna Design

The dual band AIA design uses the same layout of the passive antenna but with the addition of the active element. The active element is placed at the centre between the 2.4 GHz elements and the 5.2 GHz elements as shown in figure 5.

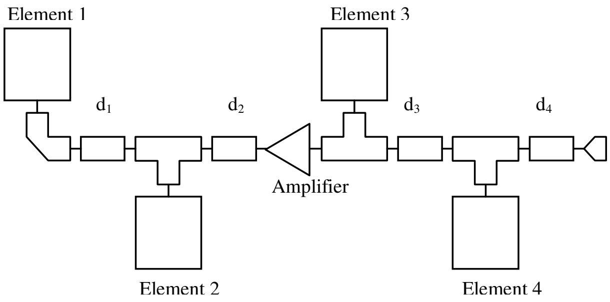


Figure 5: Data block layout of the AIA.

Figure 6 shows the typical biasing configuration for the amplifier. The 2.44 GHz elements will be at the output port of the amplifier while the 5.2 GHz elements will be at the input port of the amplifier. The resistor that has been used is 150 Ω, so the voltage, V_{cc} should be at around 9.8 V. The value for the C_{block} is 100 pF. The typical operating current for the amplifier is 40 mA. So, the voltage is slowly increased from 0 V until the current passing R_{bias} should be 40 mA.

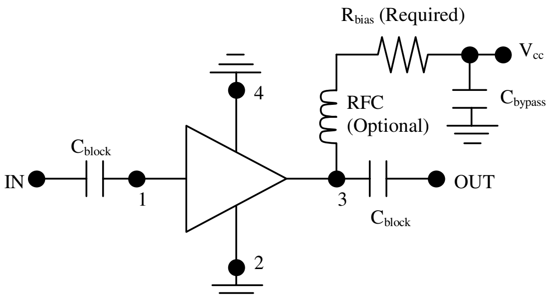


Figure 6: Typical biasing configuration of the amplifier.

The basic layout of the square patch passive antenna and AIA are as shown in figure 7 and 8 respectively.

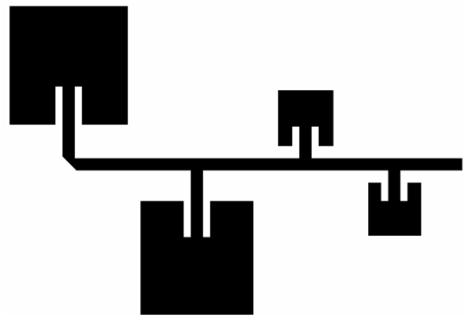


Figure 7: Layout mask of the square passive antenna.

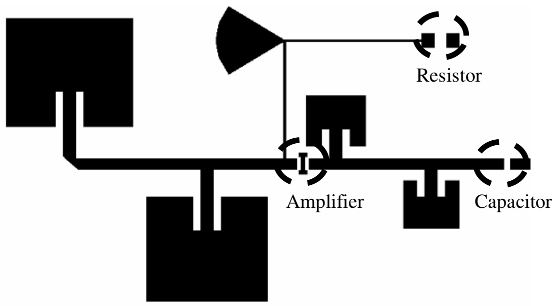


Figure 8: Layout mask of the square AIA.

3. Result and Discussion

A. Return Loss

The dual band feature on the square patch shows a good return loss at both frequency bands. As shown in the figure 9, at the 2.4 GHz band, the bandwidth percentage for the simulation result is about 8.34% and for the measured result is about 7.78%. For the 5.2 GHz band, the percentage bandwidth for the simulation is about 15.53% and for the measured result is about 17.08%.

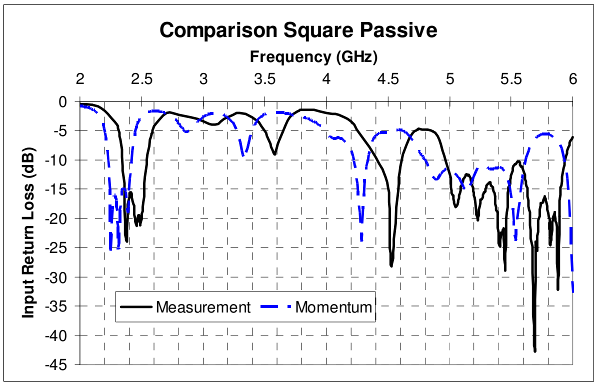


Figure 9: Input return loss for the square patch passive antenna.

The input return loss of the AIA improved much from the same passive structure when the active component was introduced as can be seen in figure 10. After adding the amplifiers to the transmission line, the bandwidth of the square patch antenna increase to 17.39% for the 2.4 GHz band, while at 5.2 GHz band, the bandwidth is much bigger at about 38.31%. Simulation results show a much lesser bandwidth of 8.34% for the 2.4 GHz band, while for the 5.2 GHz band at about 15.39%.

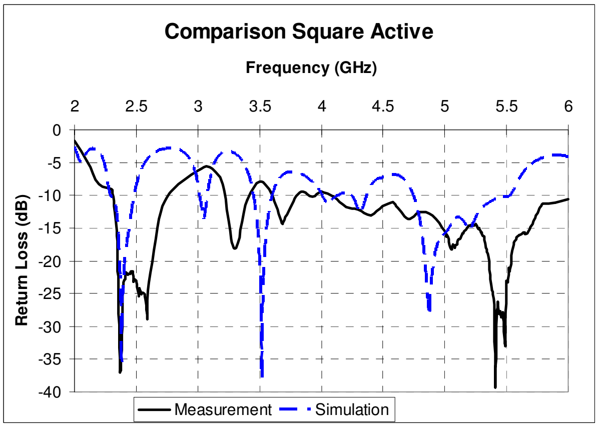


Figure 10: Input return loss for the square patch AIA.

B. Radiation Pattern

As shown in figure 11, the half power beamwidth (HPBW) at 2.44 GHz for the square patch at E plane at about 64° with cross isolation at 0° is about 17 dB. In H plane, the HPBW is about 72° with cross isolation of 15 dB.

At 5.2 GHz, the HPBW in E plane is about 110° with cross isolation of 12 dB. The radiation pattern in H plane, the HPBW is about 68° with cross isolation of 18 dB.

Compared to the horn antenna, it is found that the square patch passive antenna at 2.44 GHz has a gain of 8 dB, while at 5.2 GHz, it is -6 dB.

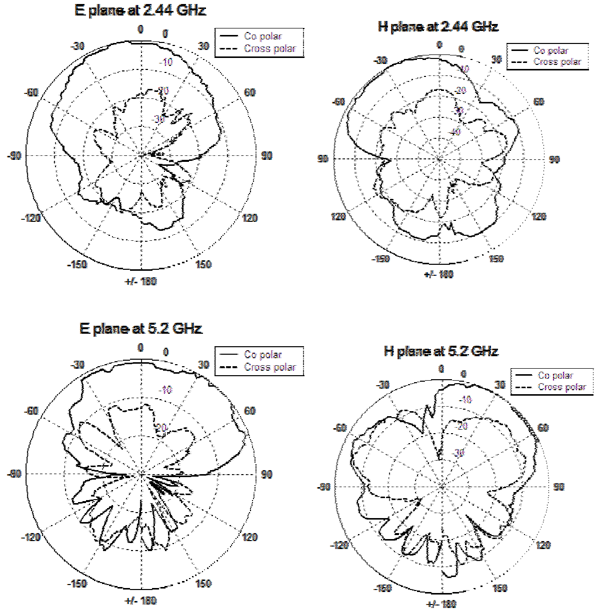
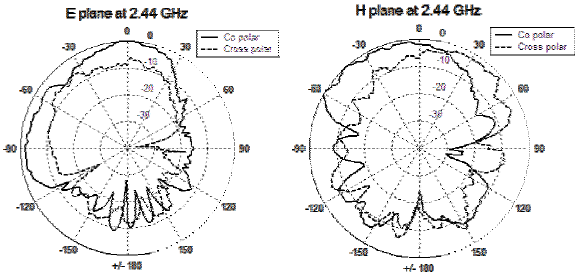


Figure 11: Radiation pattern for square patch passive antenna.

Figure 12 shows the radiation patterns of the square patch AIA. The cross isolation for the active antenna has decreased. The cross isolation at 2.44 GHz for E plane is about 7 dB only, while at H plane is about 4 dB. The HPBW achieved for the E plane and the H plane is about 54° and 82° respectively.

At 5.2 GHz, the cross isolation in E plane is about 19 dB while in H plane, the cross isolation is about 9 dB. The HPBW for the E plane is about 58° and for the H plane is about 94°.

The gains of the AIA are slightly greater than the passive antenna. Compared to the horn antenna, it is found that the square patch passive antenna at 2.44 GHz and 5.2 GHz has a gain of 10 dB and -3 dB respectively.



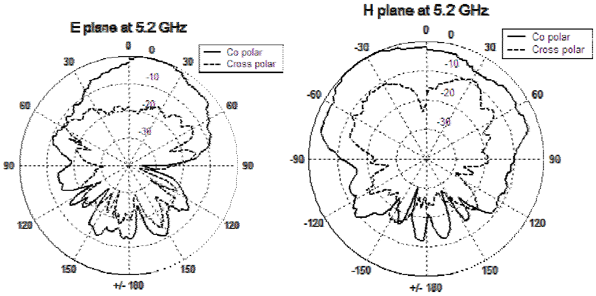


Figure 12: Radiation pattern for square patch AIA.

In terms of bandwidth the passive antennas offer an adequate bandwidth that can be use in the WLAN system, but by using the active element, the bandwidth of the AIA increase as shown in table 3. The square shape AIA shows a greater bandwidth than the passive antenna for both frequency bands.

Table 3: Comparison of the bandwidth percentage between the passive antenna and the AIA.

2 GHz band		5.2 GHz band	
Passive	AIA	Passive	AIA
7.78%	17.39%	17.08%	38.31%

The comparison of HPBW between the passive and the active antenna as shown in table 4, shows an almost similar result, but does give minor improvement to the antenna's beamwidth. The square patch AIA gives a greater HPBW only at the H plane, but in the E plane the passive antenna gives a greater beamwidth.

Table 4: HPBW comparison between the passive antenna and the AIA.

2.44 GHz				5.2 GHz			
E plane		H plane		E plane		H plane	
Passive	AIA	Passive	AIA	Passive	AIA	Passive	AIA
64°	54°	72°	82°	110°	58°	68°	94°

The cross isolations of the passive antenna as shown in table 5 give better results than AIA. It happens because the active device also increase the cross polarization of the AIAs.

Table 5: Cross isolation comparison between the passive antenna and the AIA.

2.44 GHz				5.2 GHz			
E plane		H plane		E plane		H plane	
Passive	AIA	Passive	AIA	Passive	AIA	Passive	AIA
17 dB	7 dB	15 dB	4 dB	12 dB	19 dB	18 dB	9 dB

The gain of the antennas can be viewed in table 6. From the table, it shows that the integration of active device does improve the gain of the antenna compared to the passive antenna. Further improvements on the placement of the active device on the transmission line may help to increase the gain of the antenna even further.

Table 6: Gain comparison of the different shapes between the passive antenna and the AIA.

2.44 GHz		5.2 GHz	
Passive	AIA	Passive	AIA
8 dB	10 dB	-6 dB	-3 dB

4. Conclusion

The design of the dual band microstrip antenna for WLAN application has been presented. The utilization of the softwares involve in the production process help to minimize the processing time for the calculation and the simulation of the design. Two antennas have been developed and manually fabricated in the facility in Wireless Communication Centre, Universiti Teknologi Malaysia.

The integration of the active device onto the same surface structure of the passive elements, improve the bandwidth of the microstrip antenna. The antennas that have been tested are proven to be operational, operating with sufficient return loss and radiation characteristics.

The performance of the dual band microstrip antenna, that incorporates the 3 basic shapes, has been investigated. The easiest shape to be analyzed and characterized is the square shaped patch, which in overall, shows a good result compared to the other two shapes.

By implementing the log periodic technique, the author was bounded to the rules of the log periodic technique where the design of the elements should be from the lowest frequency to the highest frequency, periodically. Using the scaling technique, some elements were cut-off from the design, and it becomes a frequency selective antenna or in this case a dual band antenna. This improves the physical size of the antenna as only a selected frequency element is needed to be designed.

Acknowledgement

This paper was done as part of the project funded by the Government of Malaysia under the Ministry of Science, Technology and Innovation (MOSTI) through the IRPA programme.

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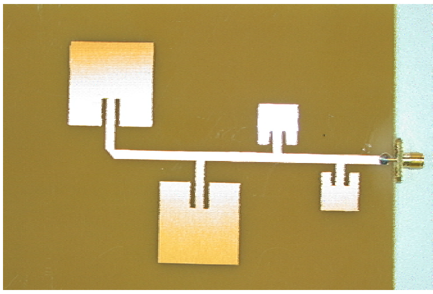

Figure 13: Photograph of the passive circular dual band antenna.

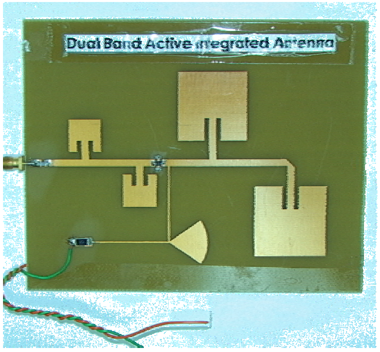

Figure 14: Photograph of the active integrated circular dual band antenna.

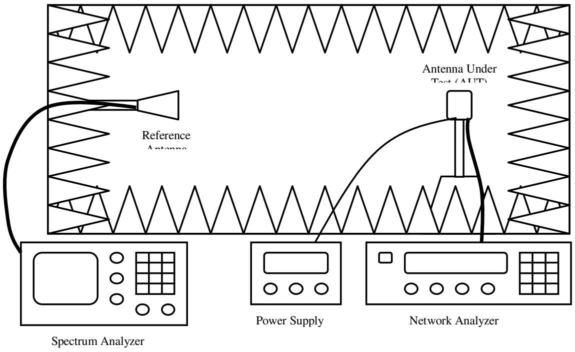

Figure 15: Radiation pattern measurement setup inside the anechoic chamber.

Triangular and Circular Dual Band Microstrip Antenna for WLAN Application

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Abstract **-** Wireless local area network (WLAN) applications nowadays has become more popular especially those operating in the 2.4 GHz ISM band. There are a lot of efforts on combining the WLAN, a/b/g bands together. Such new designs either provide inadequate coverage of the frequency band or not suitable for integration in some portable devices. This paper describes the design of the triangular and circular dual band microstrip antenna using scaling factor and inset feed technique. The antennas were designed to operate in the indoor WLAN ISM band at 2.4 GHz and 5.2 GHz. The scaling factor of 1.05 has been chosen for the design starting from the lowest resonating frequency at each band. The antennas have been fabricated on the FR4 photoboard with ε_r = 4.7, substrate height of 1.6 mm and tan δ = 0.019 using the wet etching technique.

Keywords: Triangular, circular, microstrip antenna, dual band, WLAN

1. Introduction

Two different set of frequencies have been allocated for the indoor WLAN application. One is at 2.4 GHz band and the other at 5.2 GHz band. Two different set of frequencies need two different set of antenna. It can be solved by using only one antenna for two different systems. The integration of two frequency band can reduced the incompatibility to each other.

Dual band antennas have not received much attention because of the complexity of the feeding method for array applications [1]. Because of the lightness and the surface conformal property of the microstrip antenna, the dual band antenna is suitable for systems that can be mounted on airborne platforms such as the synthetic-aperture radar (SAR) and scatterometers [1].

2. Antenna Design

The triangular and the circular shape design came after the expansion of improvements made to microstrip antenna which is motivated from the new design and the need to overcome the disadvantages of using microstrip antenna.

The sides of the triangle, *a* are made to be the same length as shown in figure 1.

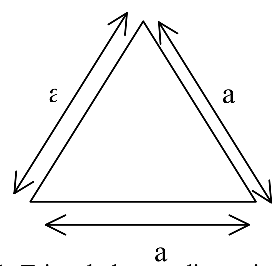

Figure 1: Triangle layout dimensions.

The length of the patch, *a* can be calculated using the equations below [2]. The mode that is used for the triangular shape is the TM_{10} which is the dominant mode for triangular shape patch.

$$f_r = \frac{2c}{3a\sqrt{\varepsilon_r}}\sqrt{m^2 + mn + n^2} \qquad (1)$$

where:

c = Speed of light
a = Triangle side's length
ε_r = Permittivity of the dielectric
m, n = Number of modes

The equations given does not provide a direct calculation to the patch's length, so the calculation of the patch can be made by using the effective length, a_e of the patch as in the equation below which does not vary much from the actual length of the patch.

$$f_{10} = \frac{2c}{3a_e\sqrt{\varepsilon_r}} \qquad (2)$$

where:

c = Speed of light
a_e = Effective triangle side's length
ε_r = Permittivity of the dielectric

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$$a_e = a\begin{bmatrix} 1+2.199\frac{h}{a}-12.853\frac{h}{a\sqrt{\varepsilon_r}}+16.436\frac{h}{a\varepsilon_r} \\ +6.182\left(\frac{h}{a}\right)^2-9.802\frac{1}{\sqrt{\varepsilon_r}}\left(\frac{h}{a}\right)^2 \end{bmatrix} \quad (3)$$

where:

a = Triangle side's length
ε_r = Permittivity of the dielectric
h = Substrate height

The calculation for circular shape patch microstrip antenna also needs tedious effort as shown in the given equations [2]. The dominant mode that is used for calculating the circular radius is TM_{11}. The radius of the circular patch as in Figure 2 can be calculated using the equation:

$$a_e = \frac{87.94}{f_r\sqrt{\varepsilon_r}} \quad mm \quad (f_r \text{ in GHz}) \quad (4)$$

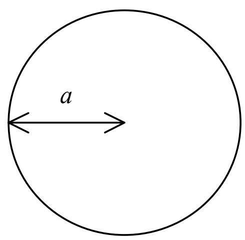

Figure 2: Circle layout dimensions.

For different mode, equation below can be used to calculate the resonant frequency at radius a_e.

$$f_{nm} = \frac{x_{nm}c}{2\pi a_e\sqrt{\varepsilon_r}} \quad (5)$$

where:

$x_{nm} = ka$
$k = 2\pi\sqrt{\varepsilon_r/\lambda_0}$
a_e = Effective radius
ε_r = Permittivity of the dielectric
c = Speed of light

The type of feeding technique that will be used is the inset feed technique. It is one of the easiest feeding techniques and it is also easy to control the input impedance of the antenna. The input impedance level of the patch can be control by adjusting the length of the inset. The calculation of the inset fed's length is shown in the equation 6 [3].

$$\ell = 10^{-4}\begin{pmatrix} 0.001699\varepsilon_r^{\,7}+0.13761\varepsilon_r^{\,6}-6.1783\varepsilon_r^{\,5}+93.187\varepsilon_r^{\,4}- \\ 682.69\varepsilon_r^{\,3}+2561.9\varepsilon_r^{\,2}-4043\varepsilon_r+6697 \end{pmatrix}\frac{L}{2} \quad (6)$$

2.1 Single Element Design

The unsymmetrical shape of triangle compared to other shape leads to difference in inset fed's length and much different in the radiation pattern. As shown in figure 3, the feed line is connected to the patch at one side of the patch, and not at the tip of the triangle. The calculated dimensions are shown in table 1.

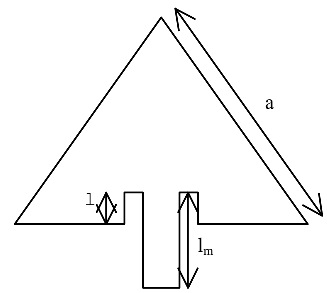

Figure 3: Layout of the triangle patch.

Table 1: Calculated dimensions of the triangle patch.

Element	Frequency (GHz)	Sides length (mm)	Inset, l (mm)
1	2.27	40.64	11.05
2	2.38	38.76	10.54
3	4.95	18.64	5.06
4	5.20	17.74	4.82

The inset feed length of the triangle patch is much less than the square and the circle shape because there is a huge difference in the shape structure. The small inset feed length is also affected by the feeding position of the feed line. The dimensions that have been used in the fabrication are as shown in table 2.

Table 2: Modified dimensions of the triangle patch.

Element	Frequency (GHz)	Sides Length (mm)	Inset, l (mm)	l_m (mm)
1	2.27	40.35	5.9	17.41
2	2.38	38.43	5.7	16.59
3	4.95	18.5	3.1	7.98
4	5.20	17.6	3.1	7.60

Figure 4 shows the layout of the circle patch. The calculations of the patch can also be found in previous subtopic. The measured inset feed length of the patch is almost similar as calculated. The calculated length of the patch can be found in table 3.

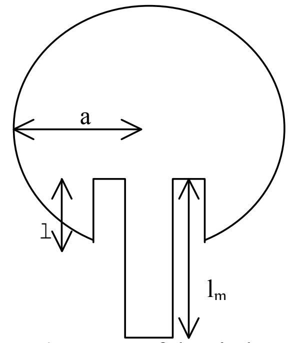

Figure 4: Layout of the circle patch.

Table 3: Calculated dimensions of the circle patch.

Element	Frequency (GHz)	Radius (mm)	Inset, l (mm)
1	2.27	17.87	11.22
2	2.38	17.04	10.70
3	4.70	8.63	5.42
4	4.90	8.28	5.20

The modified dimensions of the patch can be viewed in table 4. The diameter of the patch is much smaller when compared to the dimension of a square patch. It shows that by introducing different shapes will helps to miniaturize the size of the microstrip antenna.

Table 4: Modified dimensions of the circle patch.

Element	Frequency (GHz)	Radius (mm)	Inset, l (mm)	l_m (mm)
1	2.27	18.46	12.60	17.41
2	2.38	17.90	12.00	16.59
3	4.70	9.00	5.80	8.38
4	4.90	8.60	5.70	7.60

2.2 Dual Band Design

After the design of the single elements, the elements will be combined to form the dual band feature antenna. The single elements can be represented as a data block as shown in figure 5. A preliminary simulation can be made using the circuit simulation in the schematic window. The width of each block other than the data block is made to be 3 mm, an approximately 50 Ω (48 – 49 Ω) feed line.

The scaling factor design involves in determining the operating frequencies of the single element of the antenna and the length of the transmission lines connecting each elements. The design of the dual band patch antenna needs four elements because a single element cannot covers the whole frequency band of the WLAN. So, with two elements for each frequency band and with proper matching between the elements, it will help to achieve the dual band feature.

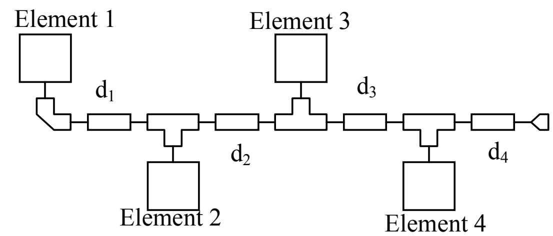

Figure 5: Data block layout of the passive antenna.

Usually, the length of the d_m is made to be the half wave length of the operating frequency of the element as shown in the equation below. But, to be more precise, in this project, the length d_m is determined to make sure that the input impedance from the subsequent element (m+1) will be open circuit (high impedance) [4].

$$d_m = \lambda_0/2 \tag{7}$$

2.3 Scaling Factor Technique

The scaling factor technique is the same technique as the log periodic technique which involves the scaling of the dimensions period by period which will make the performance of the antenna periodic to the logarithm of the frequency [4], [5].

The dimensions such as the length, L the width, W and the inset feed, ℓ of the antenna can be related to the scaling factor, τ as shown in the equation below.

$$\tau = \frac{L_{m+1}}{L_m} = \frac{W_{m+1}}{W_m} = \frac{\ell_{m+1}}{\ell_m} \tag{8}$$

As shown in figure 6, the arrangement of the patch in the scaling method can be related to the factor τ. The dimension of the array will be multiplied by the scaling factor τ to the elements itself starting from element *m* which will then generate the element *m+1*, *m+2* and so on.

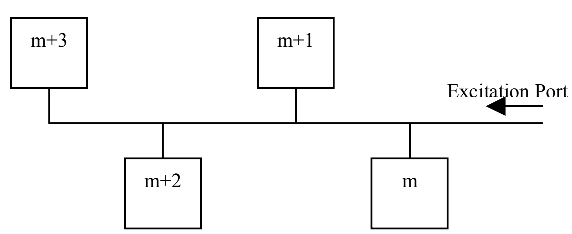

Figure 6: The model of the combination of the elements.

From this technique, the operating frequency will also be scaled to the factor τ. The relation of the scaled frequency is shown in the following equation:

$$f_1, \quad f_2 = \tau f_1, \quad f_3 = \tau^2 f_1, \quad f_4 = \tau^3 f_1 \qquad (9)$$

The relations can also be viewed as shown below, thus it is called log periodic.

$$\ln\frac{f_2}{f_1} = \ln\tau, \quad \ln\frac{f_3}{f_1} = 2\ln\tau, \quad \ln\frac{f_4}{f_1} = 3\ln\tau \qquad (10)$$

The log periodic technique has been modified to serve the purpose of frequency selective antenna. For example, the indoor wireless LAN system uses the ISM and UNII frequency band at 2.4 GHz and 5.2 GHz. If the log periodic technique is used, the bandwidth of the antenna will go along from the 2.4 GHz band up to 5.2 GHz band as shown in figure 7. But by modifying the log periodic technique, the selective band can be achieved as shown in figure 8. This method uses the scaling method rules, but with frequency selection technique. The operating frequency that will be used is selected to cover both frequency bands.

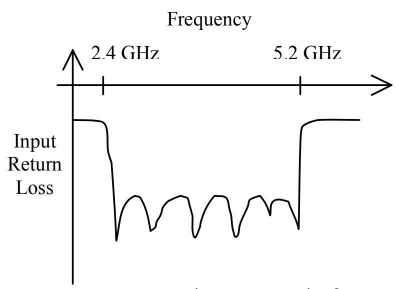

Figure 7: Input return loss example from a log periodic antenna.

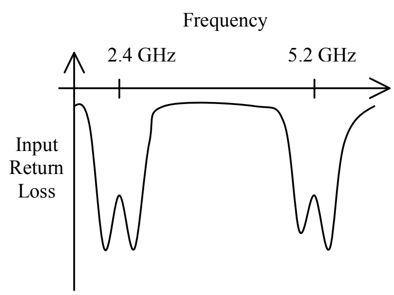

Figure 8: Input return loss from the scaling factor technique.

3. Results

The result for the triangular shaped patch is as shown in figure 9; the bandwidth percentage for the 2.4 GHz band in simulation is about 6.59% and for the measurement is about 6.51%. For the 5.2 GHz band, the bandwidth achieved is about 10.66% for the simulation, while in measurement, the bandwidth is about 9.76%.

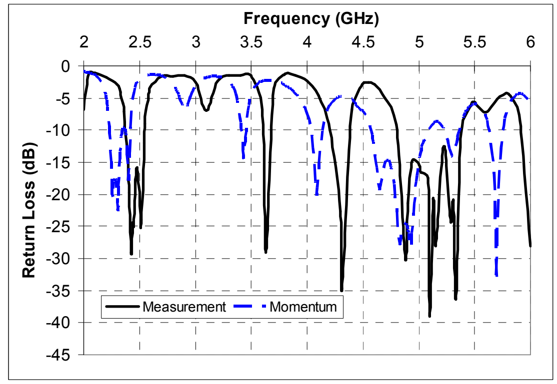

Figure 9: Input return loss for the triangular patch passive antenna.

The dual band feature on the circular patch also shows a good return loss at both frequency bands. As shown in the figure 10, at the 2.4 GHz band, the bandwidth percentage for the simulation result is about 7.82% and for the measured result is about 8.21%. For the 5.2 GHz band, the percentage bandwidth for the simulation is about 11.01% and for the measured result is about 3.85%.

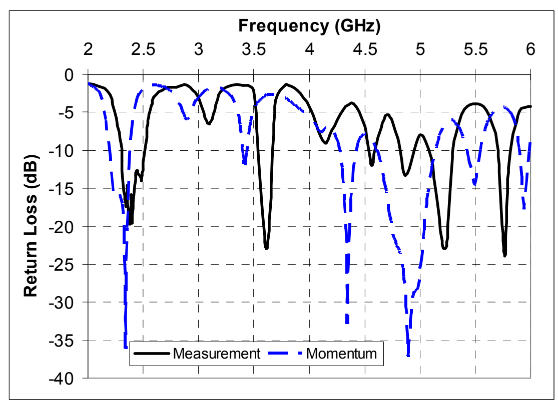

Figure 10: Input return loss for the circular patch passive antenna.

Figure 11 shows the radiation patterns of the triangular antenna. At 2.44 GHz, the HPBW for the E plane is about 66° with the cross isolation of 14 dB. The HPBW for H plane is about 72° with cross isolation of 17 dB.

At 5.2 GHz, the HPBW for E plane is about 20° with cross isolation of 1 dB. For the H plane, the HPBW is about 48° with cross isolation of 1 dB.

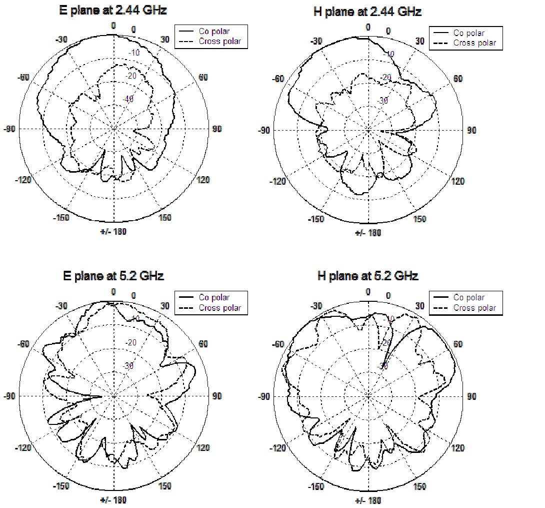

Figure 11: Radiation pattern for triangle patch passive antenna.

Figure 12 shows the radiation patterns for the circular patch in E plane and H plane respectively at 2.44 GHz and 5.2 GHz. At 2.44 GHz, The HPBW for the E plane is about 58° and the cross isolation is about 20 dB. For the H plane, the HPBW is about 72° and the cross isolation is about 18 dB.

At 5.2 GHz, the HPBW for the E plane is about 56° and the cross isolation is about 15 dB. For the H plane, the HPBW is about 72° and the cross isolation is about 13 dB.

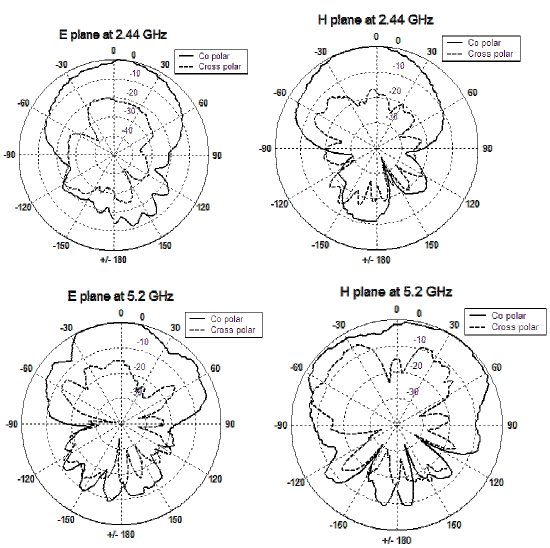

Figure 12: Radiation patterns of the circular dual band microstrip antenna.

The gain is compared to a horn antenna which has the gain from 6 to 10 dBi and the range of frequency between 1 to 18 GHz. When compared to the horn antenna, the gain for the triangular dual band antenna at 2.44 GHz is about 8 dB while at 5.2 GHz the gain is about -7 dB. The gain for the circular dual band antenna at 2.44 GHz is about 12 dB while at 5.2 GHz the gain is about -3 dB.

4. Conclusion

By implementing the log periodic technique, the author was bounded to the rules of the log periodic technique where the design of the elements should be from the lowest frequency to the highest frequency, periodically. Using the scaling technique, some elements were cut-off from the design, and it becomes a frequency selective antenna or in this case a dual band antenna. This improves the physical size of the antenna as only a selected frequency element is needed to be designed. The use of circular shape for the design add up as an alternative to other shapes commonly used for microstrip antenna design.

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