DUAL BAND DIPOLE ANTENNA WITH HARMONIC SUPPRESSION CAPABILITY

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A project report is Submitted In partial

Fulfillment of the Requirements for the Award of The

Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering

University Tun Hussein Onn Malaysia

JULY, 2015

ABSTRACT

Wireless communication system has become very popular, and has been developed rapidly over last one and a half decade. Wireless devices that operate in multiband frequencies, with smaller size, are now used by almost everyone. In this work, multiband dipole antenna with harmonic suppression capability has been designed. The dual-band dipole antenna has been vigorous, since it is simple, easy to be designed and fabricated. However, higher order modes (HOM) in these multiband antennas gives problems when designing such type of antennas. The proposed antenna consists of two designs; first design is building single parasitic element which generates 0.8 GHz, 2.4 GHz and 4 GHz; while the second design was realized by adding three parasitic elements on both sides of the two arms of the design with same frequencies of the first design which generates another frequency component of 5.1 GHz. They are named as MDA1PE and MDA3PE, respectively. The unwanted frequencies have been suppressed by adding the stub. The first design has successfully eliminated frequency component of 4 GHz , while the second design has suppressed frequencies of 4 GHz and 5.1 GHz. The suppression leads to elimination of possible noise interference through removing the unwanted frequencies. Hence, the final design is dual band (0.8 GHz and 2.4 GHz) dipole antenna which is free from noise interference. The proposed concept has been investigated through simulation in CST Microwave studio and actual experimental works. The simulation and experimental results confirm the validity of the proposed antenna. There have been matching agreements between both simulation and measurements results.

ABSTRAK

Sistem komunikasi tanpa wayar menjadi semakin terkenal dan telah membangun dengan pesat sepanjang satu setengah dekad yang lalu. Peranti tanpa wayar yang beroperasi pada frekuensi jalur pelbagai, dengan saiz yang lebih kecil, kini telah digunakan oleh hampir semua orang. Dalam kerja ini antena dwikutub pelbagai jalur dengan keupayaan penindasan harmonik telah direka. Antena dwikutub jalur berkembar telah banyak digunakan kerana ianya mudah, senang untuk direkabentuk dan difrabrikasi. Walau bagaimanapun, Mod tertib tinggi (HOM) di dalam antena pelbagai jalur memberikan masalah merekabentuk antenna tersebut. Antena yang dicadangkan terdiri daripada dua rekabentuk. Rekabentuk pertama ialah membina elemen parasit tunggal yang menghasilkan 0.8 GHz, 2.4 GHz dan 4 GHz, manakala rekabentuk kedua dirialisasikan dengan menambah tiga elemen parasit pada kedua belah sisi lengan yang menghasilkan komponen frekuensi lain iaitu 5.1 GHz. Masing-masing dinamakan sebagai MDA1PE dan MDA3PE. Frekuensi harmonik telah ditindas dengan menambah puntung. Rekabentuk pertama berjaya menghapuskan frekuensi 4 GHz, manakala rekabentuk kedua telah menindas frekuensi 4 GHz dan 5.1 GHz. Penindasan frekuensi yang tidak diingini membawa kepada penghapusan gangguan hingar melalui pengeluaran frekuesi yang tidak diingini. Oleh itu rekabentuk akhir adalah antena dwikutub jalur berkembar (0.8 GHz dan 2.4 GHz) yang bebas daripada gangguan frekuesi harmonik. Konsep yang dicadangkan telah diselidiki melalui proses simulasi menggunakan CST Microwave studio dan eksperimen. Simulasi dan keputusan eksperimen membuktikan kesahihan cadangan antena. Terdapat kesepadanan antara simulasi dan keputusan pengukuran.

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LIST OF ABBREVIATIONS

PMA - Printed monopole antenna

WLAN - Wireless local area network

MHz - Mega hertz

GHz - Giga hertz

2-D - Two dimension

3-D - Three dimension

BW - Bandwidth

VNA - Vector network analyzer

GSM - Global system for mobile communication

mm - Millimeter

ISM - Industrial, scientific and medical

HOM - Higher order mode

HSA - Harmonic suppressed antenna

EBG - Electromagnetic bandgap

DGS - Defected ground structure

PBG - Photonic bandgap

E-Plane - Electric plane

H-plane	-	Magnetic plane
HPBW	-	Half-power beam width
VSWR	-	Voltage standing wave ratio
SPE	-	Single parasitic element
TPE	-	Three parasitic elements
RL	-	Return loss
CST	-	Computer simulation technology
%BW	-	Percentage bandwidth

LIST OF SYMBOLS

Pr - Receive Power

f_1 - lower frequency

f_2 - Higher frequency

λ - Wave length

$\varepsilon\, reff$ - Effective dielectric constant

D - Directivity

dB - Decibels

c - Speed of light

λ_g - Effective wavelength

r - Dielectric constant

f - Frequency

f_o - Operating Frequency

C - Capacitor

Z_o - Characteristic Impedance

$|S_{11}|$ - Magnitude of reflection loss

$|S_{21}|$ - Magnitude of insertion loss

h - Substrate height

CHAPTER 1

INTRODUCTION

1.1 Background study

Nowadays wireless communication systems have become very popular, and have been developed rapidly over the last one and a half decades. High data rate and physically reduced sized antennas are on high demand with new developments. Dual-band WLAN systems combining IEEE 802.11a/b/g standards have become more attractive. A single antenna is highly desirable if it can operate at these bands [1].

Printed monopole antenna (PMA) with microstrip feed line is an important class of broadband antennas. Because of the stripped ground plane on back side of the substrate, these types of antennas provide wider bandwidth. Dual-band operation can be achievable for these types of antennas by creating two independent resonating paths in the form of protruding stub in the ground plane and radiating element printed on the top of the substrate. Major challenge in designing these antennas is the tuning of the protruding stub in the ground plane with radiating element on the substrate to provide dual-band operation for RFID, WLAN, etc. These antennas are light weight, low profile, less fragile and can be easily integrated into hand held devices [2].

Moreover, multiband antennas are often used on satellite systems to reduce the number of on-board and ground antennas. These antennas allow combination of several applications on the same radiating element. However, the performances of multiband antennas are traditionally limited by the arrangement of their constitutive radiating elements especially on agility in terms of frequency allocation required. Moreover, the multiplicity of frequency bands dedicated to radio-navigation or broadcasting applications reveals the need for multiband antennas having flexible and low cost features, and offering performances equivalent to those obtained from mono-application/single-band antennas [3].

Printed dipole antennas are widely used in commercial and military applications, because they exhibit low profile, small size, light weight, low cost, and easy to integrate with other electronics [4]. In all of these applications, if dual band operations are desired, separate antennas are designed for each frequency band. However, it has become more and more important to use such systems in one setting, and therefore it is desirable to design a single antenna that covers both frequency bands [5-6].

Several types of dipole antenna designs are shown in Figure 1.1. Examples of such antennas including an inverted v, multiband parallel dipole, a sloping dipole (sloper), a folded dipole and a trap dipole. Dipoles of multiband parallel, trap and folded varieties can be installed on sloping or inverted-v configurations.

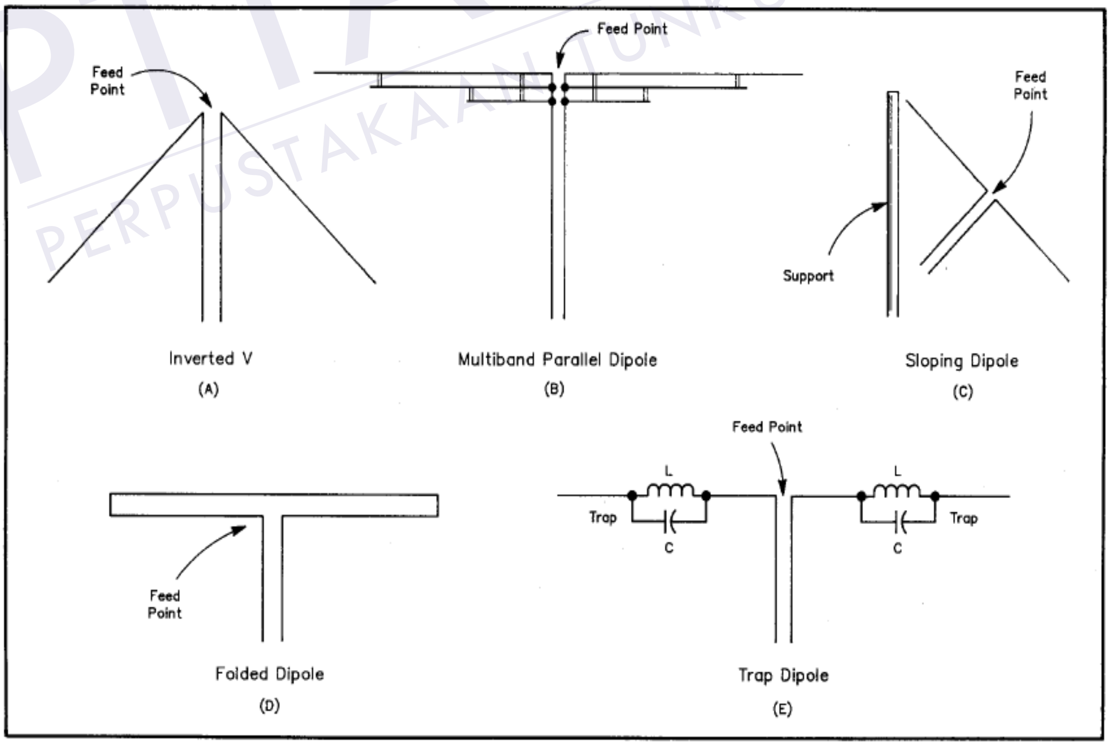


Figure1.1: Types of dipole antennas [7]

1.2 Problem statements

Wireless devices that operate at multiband frequencies with smaller physical sizes have now been used in many applications. The dual-band dipole antennas have been used vigorously, since they are simple, easy to be designed and fabricated. Appearances of higher order mode (HOM) in these multiband antennas is one of the problems that exist when designing such type of dual band dipole antennas.

In microwave and radio-frequency engineering, a stub is a transmission line which connects one end to the other. However, to overcome the higher order modes, problem dipole antenna with stub is proposed. These stubs reject the undesired frequencies and allow only the required frequencies. Therefore, it is expected to design dual band antenna with harmonic suppression capability.

1.3 Project objectives

The objective of this project is to fabricate and test a dual band dipole antenna with harmonic suppression capability for wireless communication system.

1.4 Scope of project

i. Design and simulate dual band dipole antenna operating at frequency 800 MHz and 2.4 GHz.
ii. Design and simulate a dual-band dipole antenna by employing stub to suppress higher order mode (HOM).
iii. The dual-band dipole antenna will be analyzed through simulation using CST and then experimented by using network analyzer.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses the dipole antenna and its types, general antennas parameters, harmonic suppression antenna and its techniques, and the previous research on designing dual-band dipole antenna with harmonic traps.

2.2 Half-wave dipole antenna

The half-wave dipole is formed from a conducting element, i.e. a wire or metal tube which is electrical half wavelength long. It is typically fed into the center where the impedance falls to its lowest. In this way, the antenna consists of a feeder connected to two quarter wavelength elements in line with each other as shown in Figure below 2.3 [8].

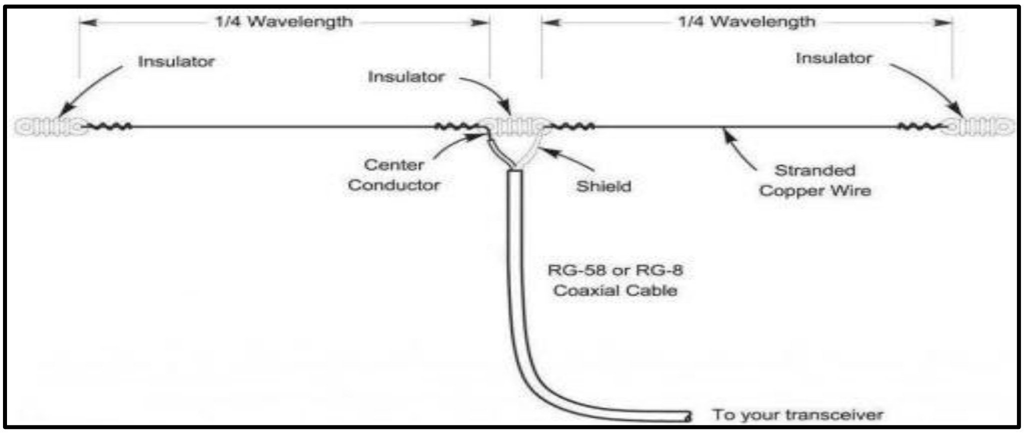


Figure 2.1: Half-wave dipole antennas [8]

The voltage and current levels vary along the length of the radiating section of the antenna. This occurs because standing waves are set up along the length of the radiating element. As the ends are open circuit, current at these points is zero, but the voltage is at its maximum. As the point at which these quantities are measured moves away from the ends, it is found that they vary in reverse pattern: the voltage falling, but the current rising. The current then reaches a maximum and the voltage a minimum at a length equal to an electrical quarter wavelength from the ends. As it is a half wave dipole, this point occurs in the center.

As the center point is where the current is a maximum and the voltage is a minimum, this makes a convenient point to feed the antenna as it presents low impedance. This is much easier to feed as high RF voltages can present many problems for feeders and matching units.

For a dipole antenna that is an electrical half wavelength long, the inductive and capacitive reactance cancels each other and the antenna becomes resonant. With the inductive and capacitive reactance levels cancelling each other out, the load become purely resistive and this makes feeding the half wave dipole antenna much easier. Coaxial feeder can easily be used as standing waves are not present, and it is also much easier to match it to a transmitter output that may only want to see a resistive load. Loads that include reactance’s lead at higher voltage level, that the transmitter might not be able to tolerate.

The impedance for a half-wave dipole antenna in free space is dipole 73 Ω which presents a good match to a 70Ω coaxial feeder and this is one of the reasons why coax with this impedance was chosen for many applications.

2.3 Antenna parameters

2.3.1 Impedance bandwidth

Impedance bandwidth is used to describe the bandwidth over which the antenna has acceptable losses due to mismatch. In Figure 2.6, the bandwidth of broadband antenna can be calculated using the equation (2.-1)[9].

$$B.W=\frac{f_2-f_1}{f_o}\mathrm{x}100\% \tag{2.1}$$

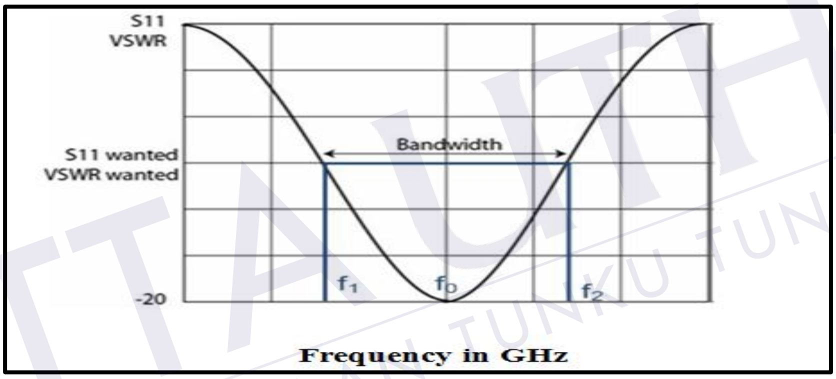


Figure 2.2: Bandwidth measurement

Where f_0 is the centre frequency,

f_1 is the lower frequency

f_2 is the upper frequency

2.3.2 Return loss

Return loss is an important parameter when connecting an antenna. It is a way to characterize the input and output of signal sources. The return loss is related to impedance matching and maximum transfer of power. When a load is mismatched, not all the available power from generator is delivered to the load. This return loss is also a measure of the effectiveness of an antenna to deliver power from the source to the antenna.

The return loss, RL shows the level of the reflected signal with respect to the incident signal in dB. It is defined by the ratio of incident power of the antenna Pin to the power reflected back from the antenna of the source Pref. Its mathematical expression is:

$$RL=-20\log_{10}|\Gamma|(dB) \tag{2.2}$$

Where $|\Gamma|$ is determined by:

$$|\Gamma|=\frac{Pin}{Pref}=\frac{Zl-Zo}{Zl+Zo} \tag{2.3}$$

Where Zl and Zo are the load and characteristic impedance respectively.

For good power transfer, the ratio Pin/Pref shall be high. If the return loss is low, standing wave phenomena's or resonances might occur, and it will end up in the frequency ripple or gain. During design process of micro strip patch antenna, there is a response taken from the magnitude of S11 versus the frequency which known as return loss. In most practical circuits, a return loss value of -10 dB is good enough [10].

2.3.3 S-parameters

In Vector Network Analyzer (VNA), data are normally presented in the form of S-parameters and they are defined by measuring voltage travelling waves between N-ports as shown in Figure 2.7. S-parameters describe the response of an N-port network to voltage signals at each port [11, 12].

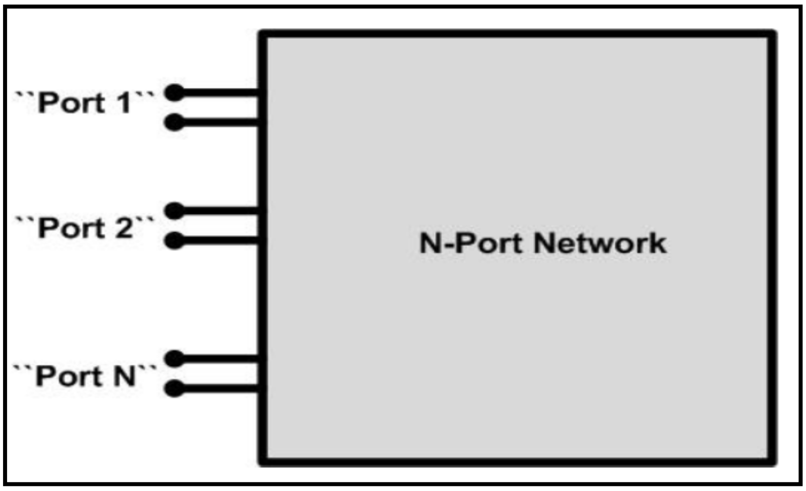


Figure 2.3: An N – port Network [11]

The responding port is the first number in the subscript and the incident port is the second number. Thus, S_{12} means the response at port 1 due to a signal at port 2 and S_{21} means the response at port 2 due to a signal at port 1. In microwave engineering, the most common "N-port" are single port, dual-port or three-port network [13]. To discuss this in more detail, dual ports are used as an example as shown in Figure 2.8.

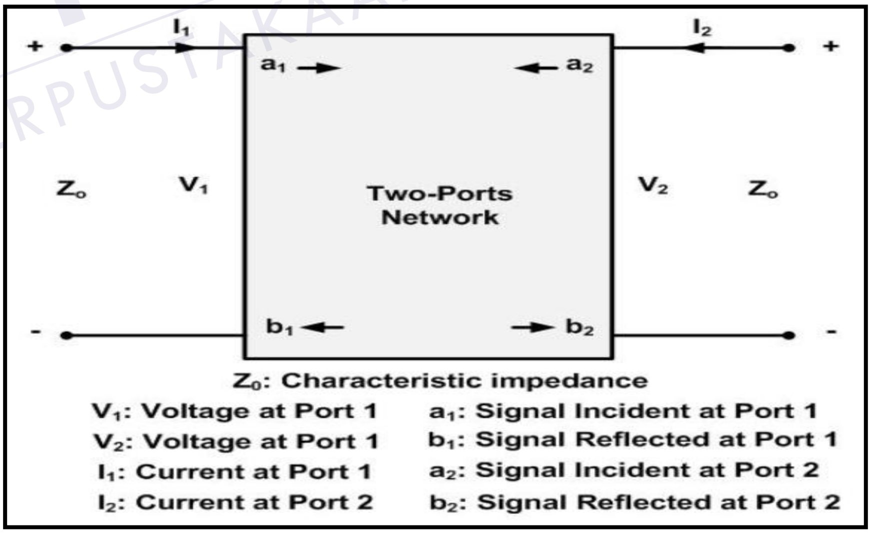


Figure 2.4: Two-Port Networks [13]

S-Parameters for such a network are defined as:

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} s_{11} \; s_{12} \\ s_{21} \; s_{22} \end{pmatrix} \text{x} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \tag{2.4}$$

If we assume that each port is terminated at impedance Z_0, we can define the four S-parameters of the 2-port as:

$$s_{11} = \frac{b_1}{a_1} \; |a_{2=0} \tag{2.5}$$

$$s_{21} = \frac{b_2}{a_1} \; |a_{2=0} \tag{2.6}$$

$$s_{12} = \frac{b_1}{a_2} \; |a_{1=0} \tag{2.7}$$

$$s_{22} = \frac{b_2}{a_1} \; |a_{1=0} \tag{2.8}$$

In this case, if S_{11} is to be measured, the port one would be used to inject the signal so the reflected signal will be measured. a_2 will be equal to 0 as there is no signal injected at port 2.

2.3.4 Radiation patterns

Radiation pattern is a representation of how the signal propagates from the antenna. In other words, the radiation pattern is a graphical representation of the relative field strength transmitted from or received by the antenna. Radiation patterns of an antenna are usually measured in the far field region in most cases where the distributions of radiated power are independent to distance. It can be determined in the 2-D or 3-D plots.

Elevation pattern means the radiation pattern is looking from the side, y-z plane, known as H plane, and an azimuth pattern when looking for above, x-y plane, known as E plane. The combination of both patterns gives a 3D graphic of the radiation. The E-plane is the plane containing electric field vector, meanwhile the H-plane is the plane containing magnetic field. Figure 2.9 below shows the radiation pattern of the antenna [14].

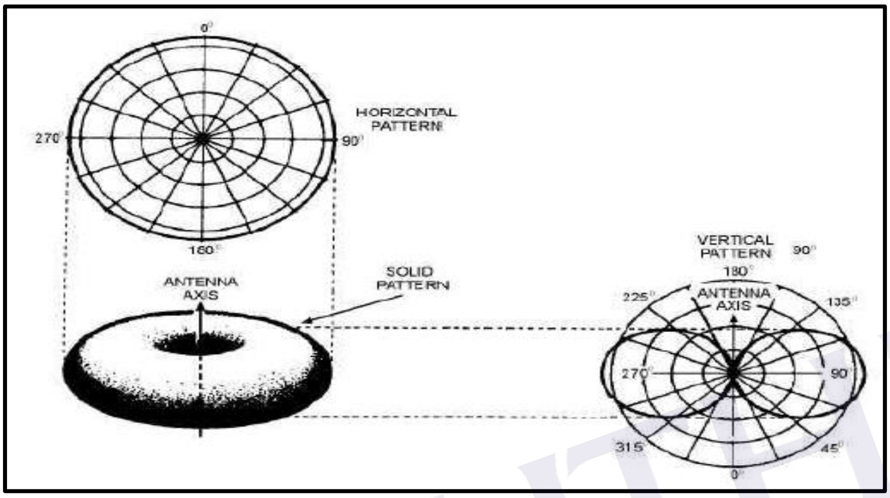


Figure 2.5: Radiation Pattern of the dipole antenna [14]

2.3.5 Gain

Gain is a useful parameter describing an antenna's performance. Although the gain of an antenna is closely related to directivity, it is a measure that takes into account on the efficiency of the antenna as well as its directional capabilities. Antenna gain is usually expressed in dB, simply refers to the direction of maximum radiation. Mathematically, the maximum gain, G is obtained by using equation 2.9 [10].

$$G = \eta D \tag{2.9}$$

Where, η = efficiency and D = directivity

2.4 Harmonic suppression antenna

Harmonic suppression antennas (HSAs) are used to suppress power radiation at harmonic frequencies from active integrated antennas (AIA). An antenna that presents a good impedance match at the fundamental design frequency (f_o) and maximized reflection at harmonic frequencies is said to be a harmonic suppression antenna. AIAs are very popular, but they suffer undesired harmonics which needs to be eliminated or suppressed. The unwanted harmonics are critical because they degrade the antenna performance. In the conventional AIAs, harmonic suppression filters were employed and these create additional insertion loss and increase the antenna size. In addition, the input impedance of any HSA design has to have minimized resistance at the harmonic frequencies and hence will be largely reactive [15].

Furthermore, the active integrated antenna has been attractive area of research more recently, due to their compact size, low cost, and multiple functionalities. The AIA can be regarded as an active microwave circuit where the input or output port is free space. The main applications of active integrated antenna are wireless communication systems in both civilian and military purposes. The design and fabrication of such components may involve several steps and procedures, depending on the area of application and technology as well as material characterization. In all cases, the antenna is fully or closely integrated with the active device to form a subsystem on the same board and can provide particular circuit functionalities such as resonating, duplexing filtering as well as radiating that describe its original role.

Several techniques have been proposed to control harmonics such as photonic band-gap (PBG), electromagnetic band gap structures (EBG), meta- materials, defected ground structure (DGS) and stubs. Thus, in radio-frequency engineering and microwave, a stub is a transmission line which connects one end to the other. Besides, stubs are commonly used in frequency selective filters, antenna impedance matching circuits, and resonant circuits for UHF electronic oscillators and RF amplifiers [16]. In this thesis, stubs were employed to eliminate the unwanted frequencies and this increases the antenna radiation performance.

2.4.1 Harmonic suppression techniques

2.4.1.1 Photonic band-gap (PBG)

Photonic band-gap (PBG) structures are effective in microwave applications that provide an effective control of electromagnetic (EM) waves along specific direction and performance. The term PBG is introduced as a structure which influence or even changes the electromagnetic properties of materials. Recently a Photonic band gap structure consisting of small metal pads with grounding via which used to improve the performance of a patch antenna. The PBG structure provides a certain frequency bands which cannot propagate. PBG structures are most widely used in various applications like microwave filters, antenna and other devices [17].

2.4.1.2 Electromagnetic band gap structures (EBG)

EBG structures are used to suppress spurious pass band at high harmonics. However, the structures are etched on ground plane with specific gaps which has harmonic suppression characteristics. It will bring packaging problem and realization in Microwave Monolithic Integrated Circuit [18].

2.4.1.3 Meta materials

Meta materials are artificial structure which is unusual in nature. Meta based ring resonators are investigated using various physical configurations. Sometimes, the shape of resonators has been modified to achieve better performance in terms of harmonic suppression, quality factor, size reduction, design flexibility, and so on (Choon Sik et al 2005).

2.4.1.4 Defected ground structure (DGS)

Microstrip line with defected ground structures can provide two distinct properties, namely slow wave propagation in pass band and distinct bandstop characteristics, which is recognized as having potential application in harmonic suppression on RF circuits [18].

2.4.1.5 Stub

In microwave and radio-frequency engineering, a stub or resonant stub is a length of transmission line or waveguide that is connected at one end only. The free end of the stub is either left open-circuit or as (always in the case of waveguides) short-circuited as shown in Figure (2.6). Neglecting transmission line losses, the input impedance of a stub is purely reactive; either capacitive or inductive, depending on the electrical length of the stub, and on whether it is open or short circuit. Stub may thus function as capacitors, inductors and resonant circuits at radio frequencies.

Stub work by means of standing waves of radio waves along their length. Their reactive properties are determined by their physical length in relation to wavelength of the radio waves. Therefore, stubs are most commonly used in UHF or microwave circuits in which the wavelengths are short enough that the stub is conveniently small. They are often used to replace discrete capacitors and inductors, because at UHF and microwave frequencies lumped components perform poorly due to parasitic reactance. Stubs are commonly used in antenna impedance matching circuits, frequency selective filters, and resonant circuits for UHF electronic oscillators and RF amplifiers.

Stub can be constructed with any type of transmission line: parallel conductor line (where they are called Lecher lines), coaxial cable, strip line, waveguide, and dielectric waveguide [19].

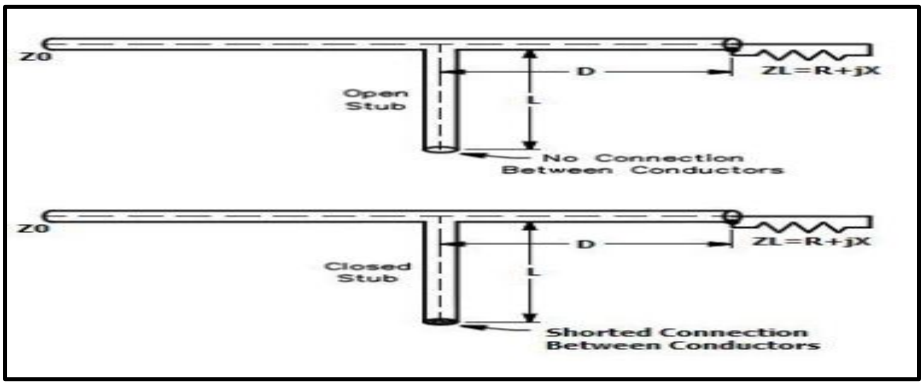
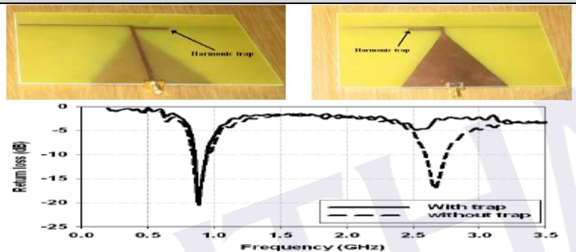
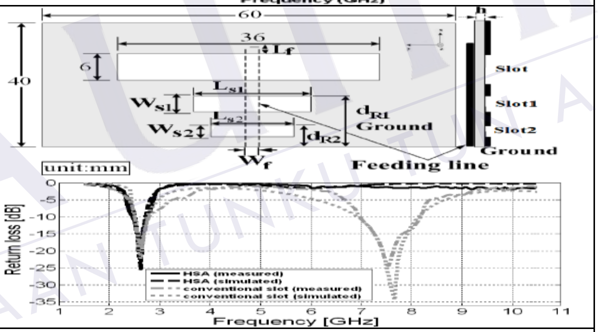
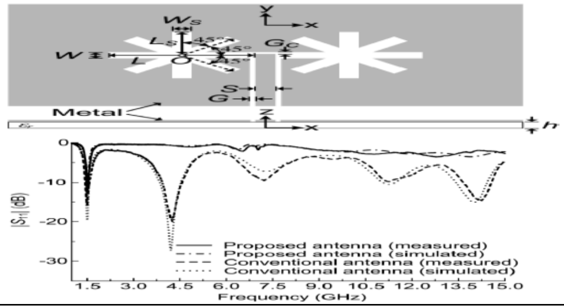
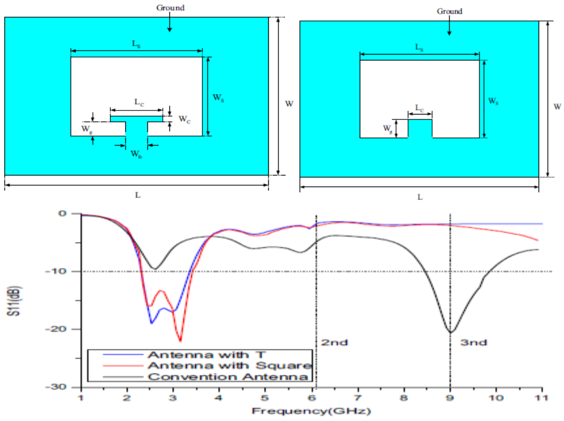


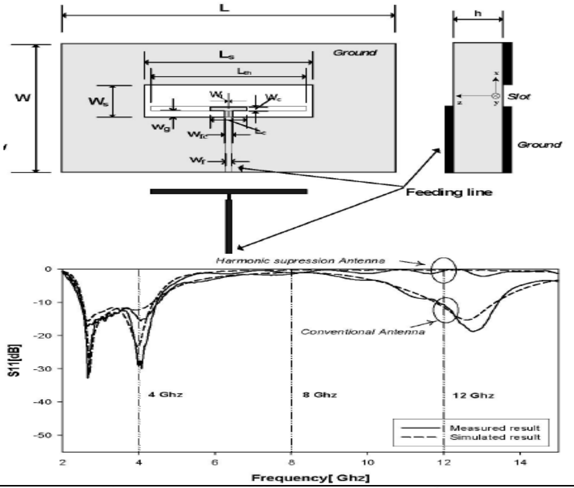
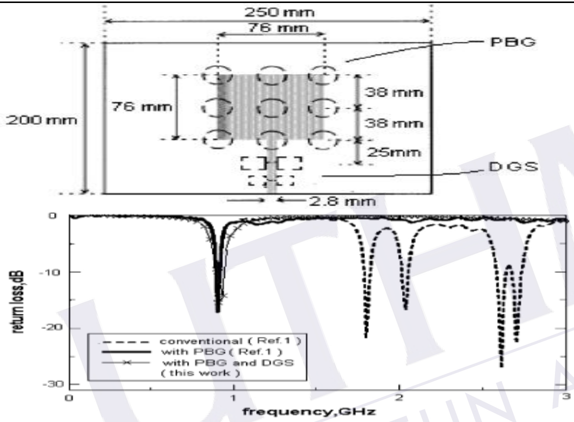
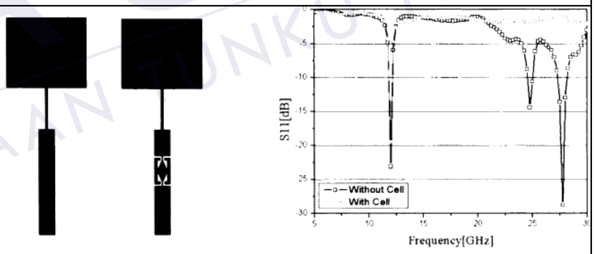
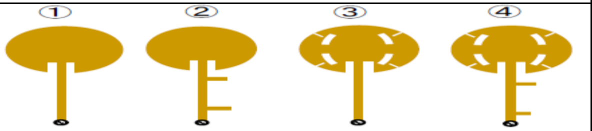
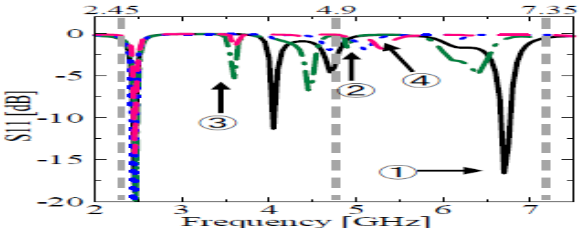
Figure 2.6: open and short circuit stub [19]

2.5 Previous research

Previous researches that have been done are one of the important resources to understand the study. They can help to understand the concept of the project and give several ways in identifying the problems. Table 2.1 shows some previous researches that give the theoretical information that relate to the study.

Table 2.1: previous researches

Ref	Comments	Antenna configuration and results
[20]	Stubs are used to eliminate 2.7GHz, f_o = 900 MHz	
[21]	DGS(RDGS),to suppress 7.8 GHz, f_o = 2.6 GHz	
[22]	Twelve slots stub to eliminate from 4.5 GHz to 15 GHz (approximately 4 stop bands), f_o = 1.5 GHz	
[23]	T- and square-shaped conductor lines connected to the ground plane to eliminate 9 GHz, f_o = from (2.4 GHz to 3.4 GHz)	

[24]	T-shaped conductor line, to eliminate 12GHz, f_{o} = (3.4 GHz and 4 GHz)	
[25]	PBG and DGS, to eliminate from 1GHz to 3GHz (approximately 4 stop bands), f_{o} = 900 MHZ	
[26]	1-dimensional PBG, to suppress 25GHz and 28GHz, f_{o} = 12.2 GHz	
[27]	Slits and stub, to eliminate from 3.8 GHz to 6.5 GHz, f_{o} = 2.4 GHz	 without slits and stubs, with slits and without stubs, wit stubs and without slits. 

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter summarizes and explains in details the methodology of this project to ensure the objectives of the project could be are achieved. It includes the simulation work by using CST microwave studio, the measurement and fabricating the design. The simulation part contains designing and simulating the antenna in CST microwave studio, while the measurement part contains fabrication and measuring the antenna using network analyzer. Therefore, at the beginning of the project, work plan has been established so that the design is well organized to ensure good and smooth coordination of the work so that the task can be finished in time. Initially, the work was started by implementing more to the understanding of the basic principles and operation of dipole antenna with harmonic traps. The design and simulation is done by using the CST microwave studio, the simulation results will be optimized to get the best performance of the antenna, and then the antenna will be fabricated on the FR-4 board with dielectric constant (ε_r) of 4.6 and a height of 1.6 mm.

The Flow chart for this project is shown in Figure 3.1, it explains the steps for both designs, initially, the dipole antenna with single parasitic element (with and without stubs) by making some optimization, while the second design of dipole antenna with three parasitic elements (with and without stubs), also with making optimization of parametric study for parasitic elements and stub.

3.2 Flow chart of the project work

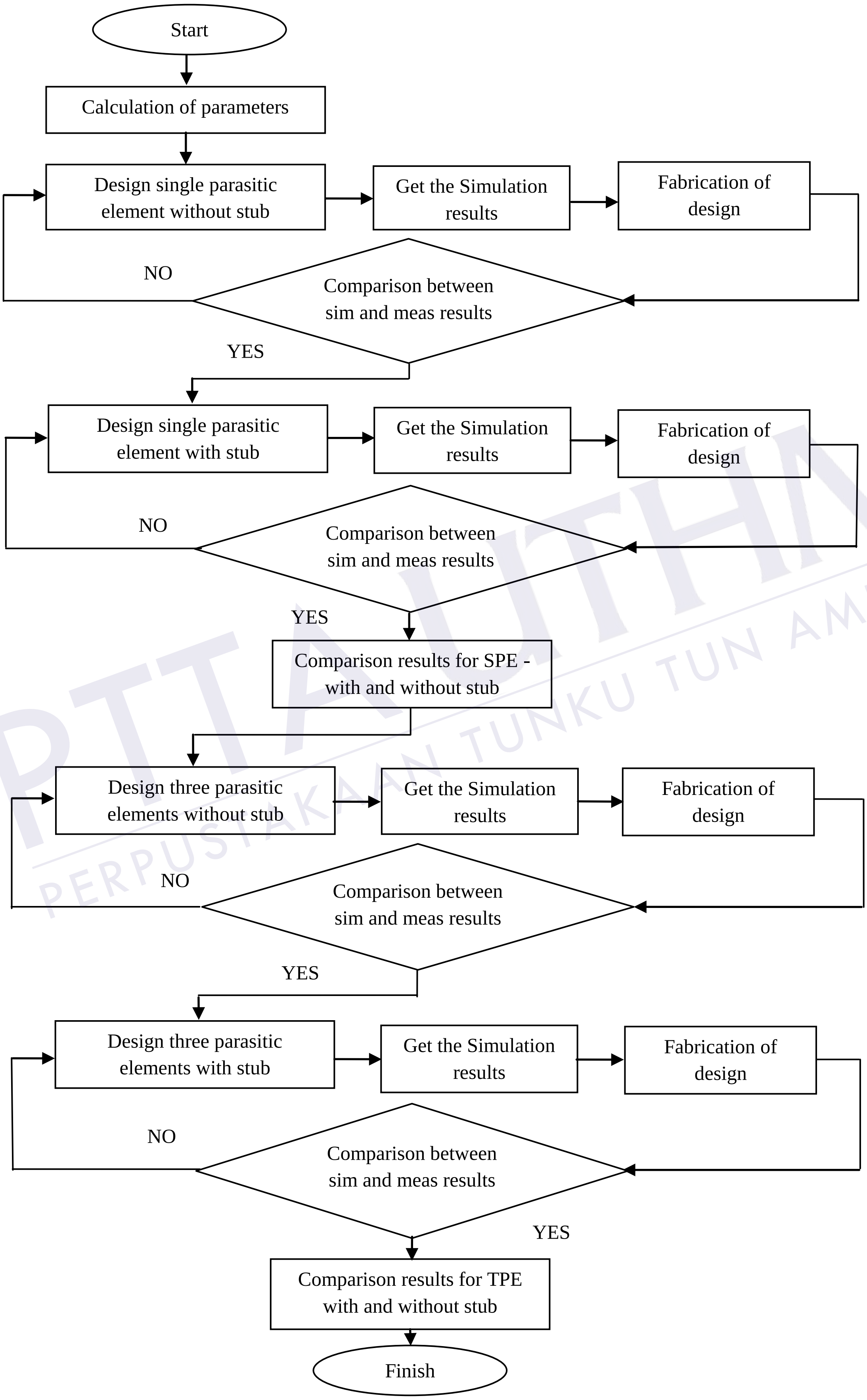


Figure 3.1: The flow chart of the project

3.3 Antenna design structure

In this section, the proposed design of dipole antenna is divided into two parts. Firstly, the dipole antenna is designed with single parasitic element (with and without stub). Secondly, the dipole antenna designed with three parasitic elements (with and without stub).

Therefore, some of the design consideration and specifications must be set first, such as the PCB board. The operating frequencies are 0.8 GHz and 2.4 GHZ. Table 3.1 tabulates some specifications of antenna design.

Table 3.1: Design specifications

Design properties	**Specification**
Range of frequencies	0 GHZ- 6 GHZ
Operating frequencies	Band 1 = 0.8 GHz, Band 2 = 2.4 GH
Return loss(S11)	Lower than RL≤ -10
Gain(dBi)	1(dBi) - 3.5(dBi)
Radiation patterns	Omni-directional
Voltage standing wave ratio (VSWR)	VSWR≤ 2
Dielectric substrate	-Fire-Retardant4(FR-4) -Thickness substratec-1.6mm Dielectric constant, ε_r = 4.6

3.3.1 Single parasitic element dipole antenna with and without stub (Design 1)

Figure 3.2 shows geometry of the dual-band dipole antenna with single parasitic element and stub. The antenna consists of transmission line, balun, stub and dipoles arms. The parasitic element is located at the centered on the arms. The antenna is simulated using CST micro wave studio.

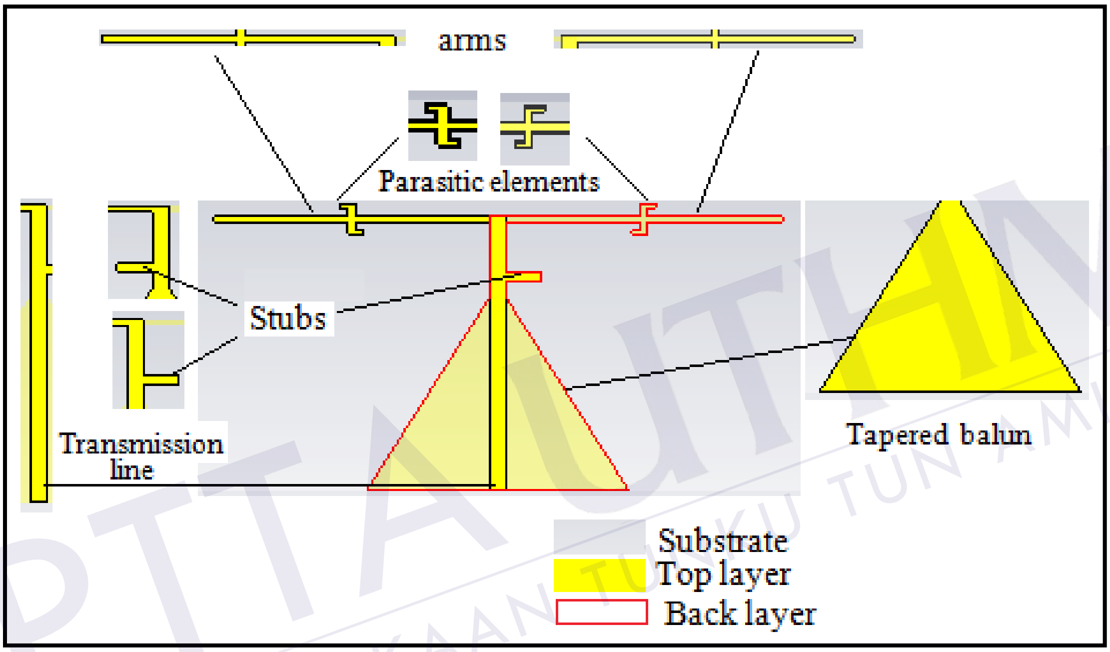


Figure 3.2: Geometry of dipole antenna with single parsitic element (SPE)

3.3.2 Three parasitic elements dipole antenna with and without stub (Design 2)

The geometry of the dipole antenna with three parasitic elements with stub is shown in Figure 3.3. It consists of the transmission line, tapered balun, two stubs, and parasitic elements located on both arms. These parasitic elements are located on the arms by doing parametric study.

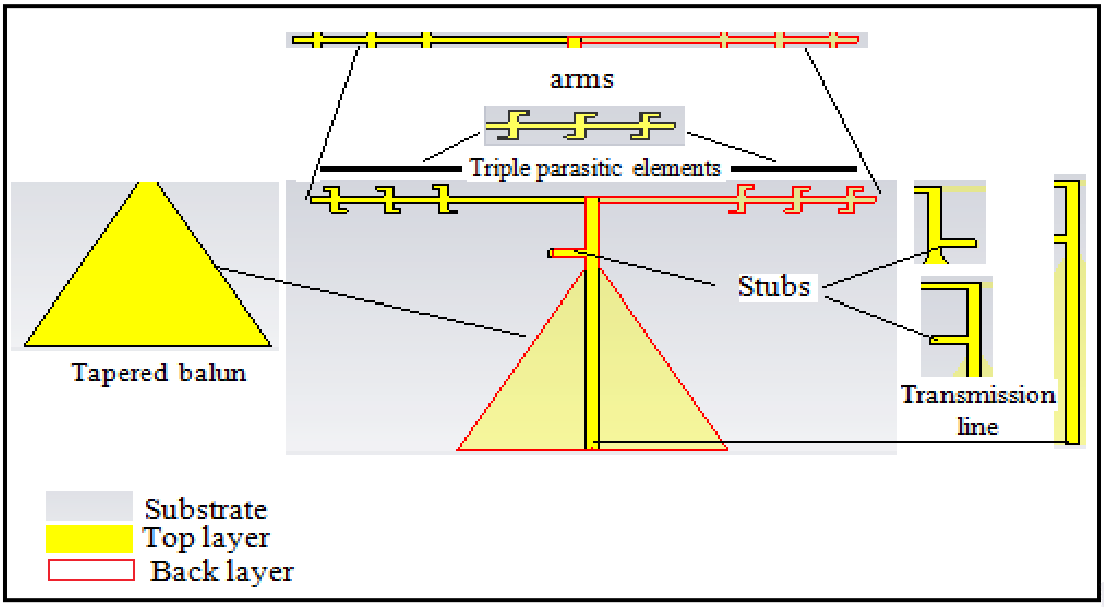


Figure 3.3: Gemeotry of dipole antenna with three parasitic elements (TPE)

a. Design Consideration

- The three essential parameters for the design of a dual-band dipole antenna are:
    - Frequency of operation (f_r): The resonant frequencies are selected as 0.8 GHz and 2.4 GHz respectively.
    - The dielectric constant of substrate (ε_r): The dielectric material selected for my design is FR-4 with a dielectric constant of 4.6.
    - Height of dielectric substrate (*h*): The height of the dielectric substrate selected is 1.6 mm.

Table 3.2: The parameters of the proposed design

Item	Value
Central frequency, *fr*	0.8 GHz (GSM) &2.4 GHz (ISM)
Central , ε_r	3.25
Substrate thickness, *h*	4.6 mm

b. Calculation

The propagation of electromagnetic field is usually considered in a free space, where it travels at the speed of light c ($3 * 10^8$ m/s). Lambda, λ is the wavelength, expressed in meters.

a. Formula to determine the width and the length of a dipole antenna arms

i. Width, *W*

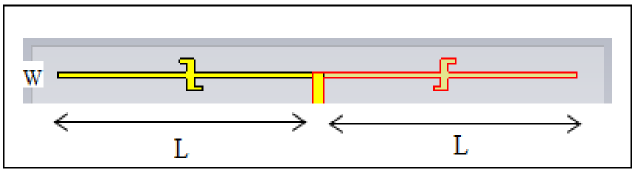
Ratio for w/d where w is the width and (h (1.6mm)), is the thickness:

$$\frac{W}{h} = \frac{8e^{A}}{e^{2A} - 2} \tag{3.1}$$

Where A:

$$A = \frac{Z_o}{60}\sqrt{\frac{\varepsilon r+1}{2}} + \frac{\varepsilon r-1}{\varepsilon r+1}\left(0.23 + \frac{0.11}{\varepsilon r}\right) \tag{3.2}$$

ii. Length, *L*



$$= 0.47\frac{v}{f} \tag{3.3}$$

$$v = \frac{c}{\sqrt{\varepsilon eff}} \tag{3.4}$$

$$\varepsilon_{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[\frac{1}{\sqrt{1+12\left[\frac{h}{w}\right]}}\right] \tag{3.5}$$

b. The formula to determine transmission line

i. Width, *W*

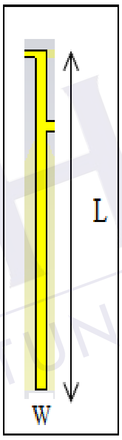
$$\frac{W1}{h} = \frac{8e^{A}}{e^{2A}-2}\frac{W_1}{h} < 2 \qquad (3.6)$$

Where

$$A = \frac{Z_o}{60}\sqrt{\frac{\varepsilon r+1}{2}} + \frac{\varepsilon r-1}{\varepsilon r+1}\left(0.23+\frac{0.11}{\varepsilon r}\right) \qquad (3.7)$$

ε_r = 4.6, h = 1.6 mm,

Z_0 =50 ohm



ii. Length, *L*

Effective dielectric, ε_{eff} :

$$= \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[\frac{1}{\sqrt{1+12\left[\frac{h}{w}\right]}}\right] \qquad (3.8)$$

Then

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon eff}} \qquad (3.9)$$

λ = wavelength

c = velocity of light

f = frequency

$$L = \frac{\lambda_g}{4} \qquad (3.10)$$

c. Formula to determine tapered balun

The length $a = \frac{\lambda_g}{4}$ (3.11)

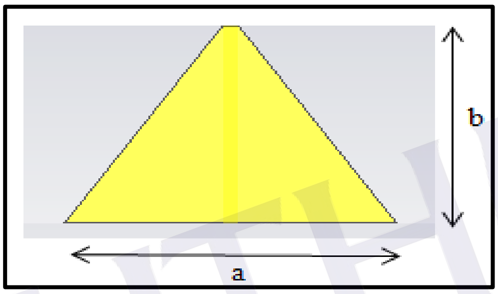
the length $b = \frac{\lambda_g}{4}$ (3.12)

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon eff}} \quad (3.12)$$

Where

$\lambda =$ Wave length

c = velocity of light



d. Parasitic elements

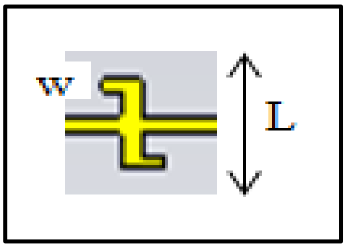
Parasitic element to generated triple band frequencies for the first design, it can be adjusted the middle arms of the dipole antenna towards right or left in order to get best results, furthermore, same calculation of parasitic elements for the second design to generate fourth band.

The wave length is

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

The length is

$$L = \frac{\lambda}{4}$$



Where is

λ Wave length

c Velocity of light

e. Calculation of Stubs

Stubs are located on the transmission line and the length of stub is $\frac{\lambda}{4}$. They are used to eliminate higher order modes.

Quarter-wave transformer line length is

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

$$L = \frac{\lambda}{4}$$

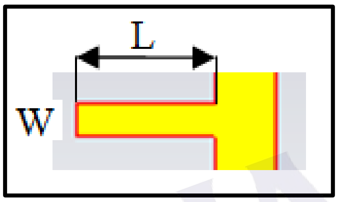


Figure 3.4 below shows the design of a dipole antenna with completed dimensions.

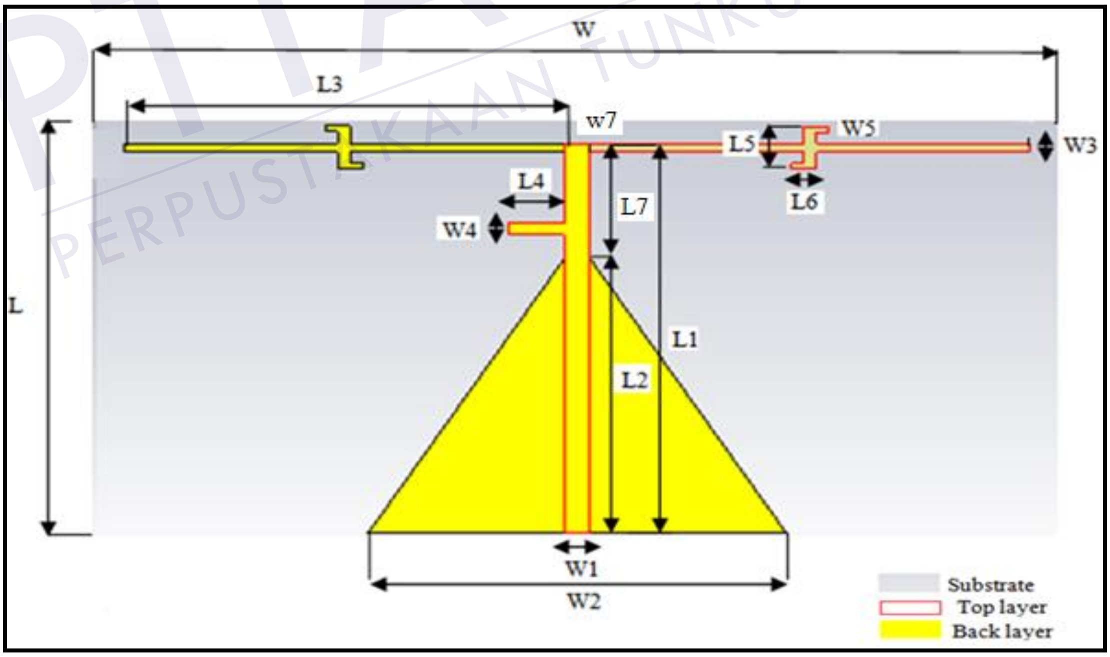


Figure 3.4: Dipole antenna design with dimension parameters

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