

INVERTED KOCH FRACTAL DUAL BAND DIPOLE ANTENNA WITH HARMONIC SUPPRESSION CAPABILITY

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ABSTRACT

Mobile telecommunication is certainly one of the major breakthroughs of this millennium. Fractal antenna is an essential for modern telecommunication technology for more effective implementation. Koch fractal dual band dipole antenna that is integrated with the Defected Ground Structure (DGS) and tapered balun has been designed and experimentally validated in this project. The Koch dipoles are double-sided structure while the tapered balun is triangular with linear transition. The Koch fractal geometry has been used to reduce the length of main dipole arms. This antenna is capable to operate for Global System for Mobile Communication (GSM) at 900 MHz as well as for Wireless Local Area Network (WLAN) at 2.4 GHz by using Computer Simulation Technology (CST) software. The harmonic frequencies which are 3.6 GHz and 4.7 GHz were eliminated by the used DGS. The properties of antennas such as return loss, S_{11} , bandwidth, VSWR, gain, current distribution and radiation pattern have been investigated through simulation and measurement. The developed antenna can reduce the size of the conventional dipole antenna and electromagnetic interference and provide other additional characteristic for multiband antenna. Hence, the aim of this project has been achieved.

ABSTRAK

Telekomunikasi mudah alih merupakan salah satu daripada penemuan utama di alaf ini. Antena fraktal adalah penting untuk teknologi telekomunikasi moden bagi pelaksanaan yang lebih berkesan. Antena dwikutub Koch fractal dwi-jalur yang disepadukan dengan struktur gangguan bumi dan balun tirus telah direka dan dibuktikan melalui uji kaji dalam projek ini. Koch dwikutub adalah struktur dua bahagian manakala balun yang tirus adalah segi tiga dengan peralihan linear. Geometri fraktal Koch telah digunakan untuk mengurangkan panjang lengan dwikutub utama. Antena ini mampu beroperasi untuk Sistem Komunikasi Bergerak sejagat pada kadar 900 MHz dan juga untuk rangkaian wayarles kawasan tempatan pada kadar 2.4 GHz dengan menggunakan perisian teknologi simulasi komputer. Frekuensi harmonik 3.6 GHz dan 4.7 GHz telah dihapuskan menggunakan DGS. Ciri-ciri antena seperti kehilangan balikan, S_{11} , lebar jalur, nisbah voltan gelombang berdiri, VSWR gandaan, pengaliran arus dan corak sinaran telah dikaji melalui simulasi dan pengukuran. Antena yang telah dibangunkan ini boleh mengurangkan saiz antena dwikutub konvensional dan gangguan elektromagnet. Oleh itu, matlamat projek ini telah berjaya dicapai.

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LIST OF SYMBOLS AND ABBREVIATIONS

WLAN	-	Wireless local area network
GSM	-	Global system for mobile communication
CST	-	Computer simulation technology
BW	-	Bandwidth
SWR	-	Standing wave ratio
S_{11}	-	Return loss
IFS	-	Iterated function systems
DGS	-	Defected ground structure
v	-	Speed of EM propagate through a dielectric (ms^{-1})
c	-	Speed of light (ms^{-1}) [$c = 3 \times 10^8 ms^{-1}$]
f_o	-	Operating frequency (GHz)
λ	-	Wavelength inside of the dielectric
λ_o	-	Free space wavelength
λ_g	-	The guide wavelength
h	-	Substrate thickness (mm)
Z_{in}	-	Input impedance (Ω)
Z_o	-	Characteristic impedance (Ω)
μ_o	-	Permeability of vacuum (Hm^{-1}) [$\mu_o = 4\pi \times 10^{-7} N/A^2$]
μ_r	-	Relative permeability of the substrate. (For FR-4, $\mu_r = 1$)
ϵ_o	-	Permittivity of the vacuum (F/m) [$\epsilon_o = 8.8542 \times 10^{-12} F/m$]
ϵ_r	-	Relative dielectric constant
ϵ_{reff}	-	Effective dielectric constant

n	-	Number of iterations
L_{koch}	-	Effective length for each koch fractal dipole
Γ	-	Reflection coefficient
f_r	-	Center frequency
f_l	-	Lower cutoff frequency
f_h	-	Upper cutoff frequency

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CHAPTER 1

INTRODUCTION

1.1 Background

Over the last fifteen years, mobile communications have been developed in a very significant way in order to make life easier or more enjoyable [1]. In today's modern communication industry, antennas are the most significant components required to create a communication link. Moreover, important components required to create a communication link with the rapid progress of wireless communication systems, which come in variety size ranging from small handheld devices to wireless local area networks.

Furthermore, wireless communication devices and systems are generally handheld or are part of portable laptop computers. Thus, the antenna must be physically very small dimensions in order to fit the appropriate device. A single antenna is highly desirable if it can operate at multiple frequencies. It should be in planar form, lightweight and compact, so that it can easily be embedded in the cover of communication devices [2]. The systems are used for general communication, Radio Frequency Identification (RFID) and as well as for wireless local area network (WLAN) systems, dipole antennas have been used in these systems because they are physically small and can be tuned to the appropriate frequencies [3], printed dipole antenna [1, 4] has the advantages of low profile, light weight and low cost. Furthermore, it is very suitable for installation into notebook computer. [5]. Thus the

antenna which can operate at one or two frequency bands is most desirable and convenient. As a result, the design of a dual band dipole antenna becomes an essential technique.

Moreover, Fractal Antenna Systems designs and manufactures world-class antennas. Its proven capabilities and versatile approach result in the world's most compact and powerful antennas. Fractal antennas have received much attention from the antenna designers since Nathan Cohen introduced the fractal antenna in 1988 [6]. Several Fractal geometry has been introduced for antenna applications and has been successful in improving antenna characteristics [7] [8].

Fractal antennas are a particular design of small antennas that approaches the limits for small antennas when the number of iterations is increased. The self-similarity properties of fractals make them especially suitable to design multiband antennas. Some fractals have complex; highly convoluted shapes that can enhance radiation when being used as antennas. Fractals can improve the performance of antenna or antenna arrays. Fractals have a short-range disorder and long-range order. In antennas design, the use of fractal shapes makes the operational frequency of an antenna which depends on the ratio of the electromagnetic signal's wavelength to the physical size of the antenna – independent of its scale. This means that a fractal antenna can be constructed in small sizes, yet possessing a broad frequency range. Additionally, there are many different forms of antenna structures can bring about high gain and directional radiation [2]. Hence, for these advantages the Koch fractal dipole antenna will be designed with harmonic suppression capability. The figure shown below shows a type of a fractal dipole (Koch fractal dipole antenna).

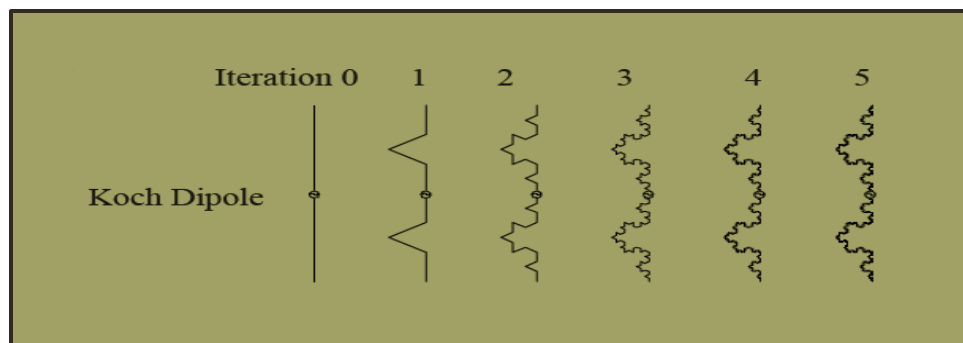


Figure1.1: Koch fractal dipole antenna

1.2 Problem Statements

Dipole antennas usually suffer from undesirable harmonic frequencies which can make the signal at the operating frequency corrupt and jeopardise its quality. In order to suppress the undesirable frequencies, it can be achieved by adding an external filter that can be used to reject the harmonic frequencies. This method does increase the complexity and the size of the antenna.

To overcome that problem, it is proposed to use defect ground structure (DGS) to act as the internal filter, because it is easy to be designed and fabricated. Moreover, the DGS gains much more attention over the last few years for its ability in effectively suppressing undesirable frequencies. The fractal curve is used to reduce the antenna size.

1.3 Objective

- (i) To design, simulate and test a dual band dipole antenna for wireless communications.
- (ii) To simulate, develop and test a dual band dipole antenna with harmonic suppression capability using defected ground structure (DGS).

1.4 Scope Of Project

- (i) The proposed antenna operates at Global System Mobile Communication (GSM) at 900MHz as well as for Wireless Local Area Network (WLAN) at 2.4 GHZ by using CST software.
- (ii) Defected ground structure (DGS) is used in order to suppress harmonic frequencies.
- (iii) Fractal configuration was used for multiband antenna physical size reduction.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this modern communication age, mobile phones and other personal communication devices are becoming physically smaller and lightweight. Printed antennas are well exploited in these compact applications because of its features like low profile, small size, conformal to the mounting host. [9]. Almost all printed antennas are developed based on microstrip configuration or its modifications. Moreover, The Koch dipoles can be appreciated as a series of curves and bends, these Fractal dipole antennas are no longer having the same impedance as a common dipole antenna. The explanation of the advantages of each antenna also makes clear. All the related formulas and their characteristic of the antennas are shown.

2.2 Microstrip Dipole Antenna

Printed dipole antenna came into use only after successfully demonstrated of the operation of the rectangular patch antenna. The rectangular microstrip antenna can be classified into two main categories depending on their length and width ratio. An antenna with narrow

rectangular strip is called a microstrip dipole, whereas a broad rectangular antenna is called a microstrip patch [10]. Center-fed dipole is a printed version of the free-space cylindrical dipole and will be called a printed dipole. Fig. 2.1 shows the basic layout of a microstrip dipole antenna. This is always a good place to start when designing an antenna. There are a few variables, and it is easy to get good results. Moreover, the dipole antenna has several characteristics, which are:

- (i) Omni directional - A dipole antenna has transmitted and receives in all directions.
- (ii) Low gain - Since the dipole antenna is radiated in all directions, it has a low gain because all the power radiated is equally distributed in all space and direction instead of radiation at one specific direction.
- (iii) Easy to build - Since the dipole antenna consists of two collinear wires (conductor), it is easy to build such as just by using copper wire.

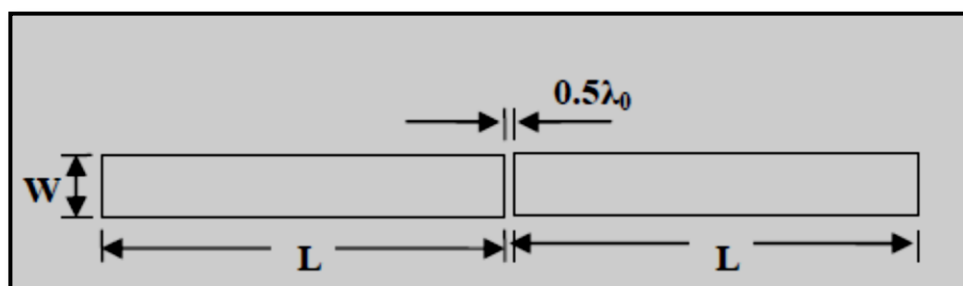


Figure 2.1: Microstrip dipole antenna

The main consideration in the design of a dipole antenna is the length, L of the element required for resonance. The dielectric substrate used for this project is FR-4 with a relative dielectric constant $\epsilon_r = 4.8$ and a thickness of 1.6mm. However, at a frequency of 900MHz, radiation losses are expected to be negligible [11]. When the electromagnetic waves propagate through a dielectric, they travel at a speed of light that is given by:

$$v = \frac{1}{\sqrt{\mu\epsilon}} \quad (2.1)$$

Where : $\mu = \mu_o$ and $\epsilon = \epsilon_o$ and μ_o and ϵ_o are the permeability and permittivity of vacuum, respectively.

ϵ_r is the relative dielectric constant of the substrate. Since $\lambda = v/f$, the wavelength inside of the dielectric is given by:

$$\lambda = \frac{v}{f} \quad (2.2)$$

$$= \frac{1}{\sqrt{\mu\epsilon_r\epsilon_0}f} \quad (2.3)$$

This relationship is used to determine the required length of the dipole in order to radiate at 900 MHz while completely immersed in the FR-4 dielectric. The dipole length, L_{MD} is then:

$$L_{MD} = \frac{\lambda}{2} \quad (2.4)$$

$$= \frac{1}{2\sqrt{\mu\epsilon_r\epsilon_0}f} \quad (2.5)$$

2.3 Fractal antenna

Fractal antennas are a particular design of small antennas that approaches the limits for small antennas when the number of iterations is increased. The self-similarity properties of fractals make them especially suitable to design multiband antennas. Some fractals have complex; highly convoluted shapes that can enhance radiation when used as antennas. Fractals can improve the performance of antenna or antenna arrays. They have a short-range disorder and long-range order. In antennas design, the use of fractal shapes makes the operational frequency of an antenna which depends on the ratio of the Electromagnetic signal's wavelength to the physical size of the antenna – independent of its scale. This means that a fractal antenna can be constructed in small sizes, yet possessing a broad frequency range.

2.4 Introduction of fractal geometry

The term fractal from the Latin *fractus*, means 'broken' refers to the images captured the popular imagination; many of them were based on recursion. In 1975, Mandelbrot coined the word fractal to denote an object whose Hausdorff-Besicovitch dimension is greater than its topological dimension. He illustrated this mathematical definition with striking computer-constructed visualizations [29]. Two examples of naturally occurring fractal geometries are snow-flakes and boundary of geographic continents. Several naturally occurring phenomena such as lightning is better analyzed with the aid of fractals. One significant property of all these fractals is indeed their irregular nature. Some examples of fractals are given in Fig. 2.2. Most of these geometries are infinitely sub-divisible, with each division a copy of the parent. This special nature of these geometries has led to several interesting features uncommon with Euclidean geometry [7].

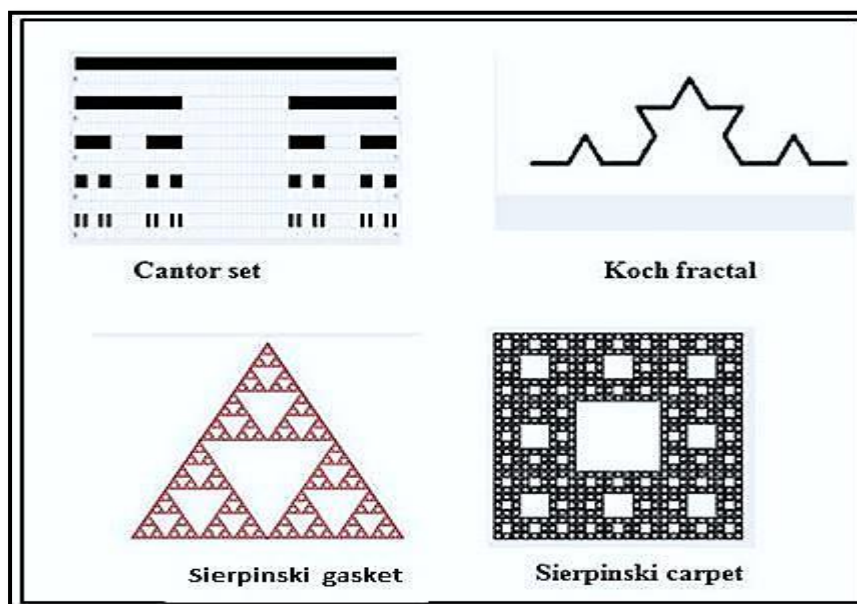


Figure 2.2: Some common examples of fractals [7]

Fractal theory offers methods for describing the inherent irregularity of natural objects. In fractal analysis, the Euclidean concept of 'length' is viewed as a process. This process is characterized by a constant parameter, D , that is known as the fractal dimension.

The fractal dimension can be viewed as a relative measure of complexity, or as an index of the scale-dependency of a pattern. To obtain this value, the geometry is divided into scaled down, but identical copies of itself. If there are no such copies of the original geometry scaled down by a fraction, f the similarity dimension, D is defined as [7].

$$D = \frac{\log n}{\log 1/f} \quad (2.6)$$

For example, a square can be divided into 4 copies of $1/2$ scale, 9 copies of the scale, 16 copies of $1/4$ scale, or n copies of $1/n$ scale. By using equation (2.6), the dimension of fractal geometries shown in Figure 2.2 are listed in Table 2.1.

Table 2.1: Fractal dimension of some geometry in figure 2.2

Geometry	n	f	Dimension
Cantor set	2	1/3	0.6309
Koch fractal	4	1/3	1.2619
Sierpinski gasket	9	1/4	1.5850
Sierpinski carpet	64	1/16	1.8928

2.5 Application of fractal geometry

Fractal geometry has permeated many areas of science, such as astrophysics, biological sciences, computer graphics, and has become one of the most important techniques in telecommunication - antenna. The geometry of the fractal antenna encourages its study both as a multiband solution and also as a small antenna. This is because one should expect a self-similar antenna, which contains many copies of itself at several scales, to operate in a similar way at several wavelengths. That is, the antenna should keep similar radiation parameters through several bands. And the space-filling properties of some fractal shapes, the fractal dimension, might allow fractal shaped small antennas to better take advantage of the small surrounding space [30]. In antennas design, the use of fractal shapes makes the

operational frequency of an antenna which depends on the ratio of the electromagnetic signal's wavelength to the physical size of the antenna – independent of its scale. This means that a fractal antenna can be constructed in small sizes, yet possessing a broad frequency range.

2.6 Introduction to Koch fractal geometry

The Koch fractal geometry used in this project is a mathematical curve, and one of the earliest discovered fractal curves. It appeared in 1904 by the Swedish mathematician Helge von Koch. It starts with a line segment instead of an equilateral triangle. The geometric construction of the basic curve is shown in figure 2.3.

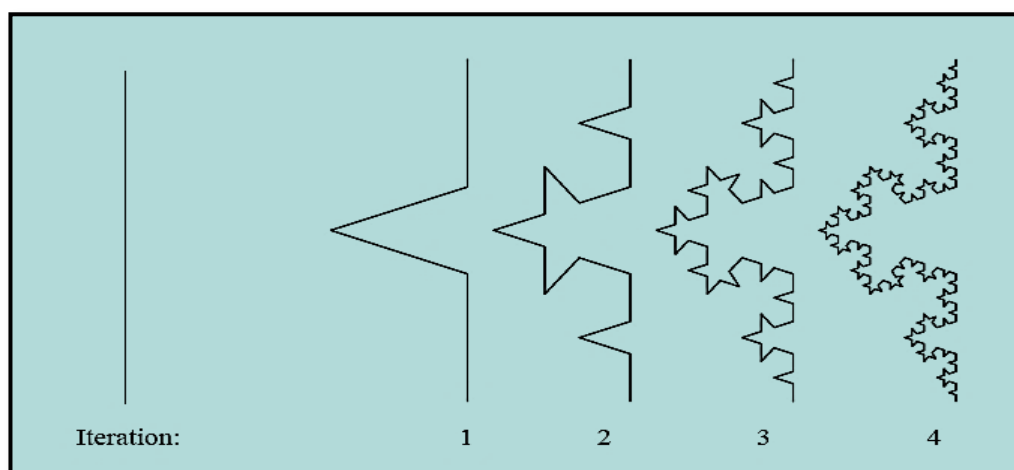


Figure 2.3: Standard Koch curve [12]

The geometric construction of the standard Koch curve is fairly simple. One star with straight line is called the initiator. This is partitioned into three equal parts and the segment in the middle is replaced with others of the same length as shown in Fig 2.3. This is the first iterated version of the geometry and is called the generator. The process is reused in the generation of higher iterations [7]. Refer to Figure 2.4; the first iteration form by an affine transform w_1 scales a straight line to one-third of its original length. The

transform w_2 scales to one-third and rotates by 60° but the third transform, w_3 is similar to but rotating by -60° . Finally the fourth transform, w_4 is the same with w_1 .

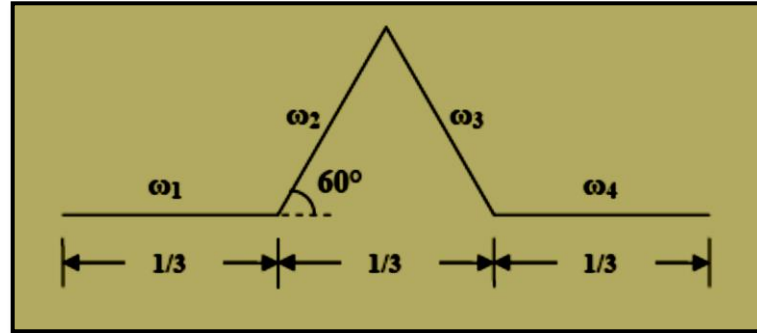


Figure 2.4: The four segments that form the basis of the Koch fractal antenna.

Each iteration adds the length of the total curve. This can be seen from the Fig 2.4 that depicting the generating process. It may recalled that each segment in the first iterated curve is $1/3$ the length of the initiator. There are four such segments. Thus, for n^{th} iterated curve the unfolded (to stretch out) length of the curve is $(4/3)^n$. This is the one an important property that would be useful in the design of the antennas of this geometry Furthermore, The effective length for each Koch fractal dipole antenna would be:

$$L = \frac{c}{2f} \quad (2.7)$$

$$Length_{koch} = h \left(\frac{4}{3} \right)^n \quad (2.8)$$

Where n is the number of iterations and h is the height of the straight starting generator.

The variation of the indentation angle determines how rapidly the wire length increases with the iteration. In this way, the length of the n^{th} iteration of the dipole with indentation angle θ is given by

$$L_{\theta,n} = \left(\frac{2}{1 + \cos \theta} \right)^n L_0 \quad (2.9)$$

With L_0 being the length of the linear dipole with the same end-to-end length. In the end, it is this wire length $L_{\theta,\text{and}}$ that really produces the reduction in the resonant frequency of the antennas.

The geometry of the fractal is important because the effective length of the fractal antenna can be increased while keeping the total special area relatively the same. As the number of iterations of the fractal increases, the effective length increases. When designing a small antenna, it is important to have a large effective length because the resonant frequency would be lower.

2.7 Iterative function system (IFS)

The shape of the fractal antenna is formed by an iterative mathematical process. This process can be described by an Iterative Function System (IFS) algorithm, which is based upon a series of affine transformations [13]. An affine transformation in the plane ω can be described by:

$$W_1 \begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{s} & 0 \\ 0 & \frac{1}{s} \end{bmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \quad (2.10)$$

$$W_2 \begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{s} \cos \theta & -\frac{1}{s} \sin \theta \\ \frac{1}{s} \sin \theta & \frac{1}{s} \cos \theta \end{bmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{1}{s} \\ 0 \end{pmatrix} \quad (2.11)$$

$$W_3 \begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{s} \cos \theta & \frac{1}{s} \sin \theta \\ -\frac{1}{s} \sin \theta & \frac{1}{s} \cos \theta \end{bmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{1}{2} \\ \frac{1}{s} \sin \theta \end{pmatrix} \quad (2.12)$$

$$W_4 \begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{bmatrix} \frac{1}{s} & 0 \\ 0 & \frac{1}{s} \end{bmatrix} \begin{pmatrix} x \\ y \end{pmatrix} + \begin{pmatrix} \frac{s-1}{s} \\ 0 \end{pmatrix} \quad (2.13)$$

Where the scale factors are the angle dependent and is given by

$$\frac{1}{s} = \frac{1}{2(1 + \cos \theta)} \quad (2.14)$$

2.8 Antenna properties

All the parameters that involved in antenna are important to fabricate a stable and efficient antenna. The important parameters of an antenna are radiation pattern, gain, impedance and VSWR, bandwidth, return loss, and Fundamentals of Transmission Line

2.8.1 Return loss

Return loss is defined as the ratio of the amplitude of the reflected wave to the amplitude of the incident wave [17]. The return loss value describes the reduction in the amplitude of the reflected wave, compared to the forward energy. This return loss also can be used to determine the matching condition has been achieved. Figure 2.5 below shows the return loss graph. It can be seen that the resonant frequency is 94.25 MHz where it falls below -20dB and the bandwidth is 2.1MHz. An antenna is considered functioning well when its returns loss falls below than -10dB.

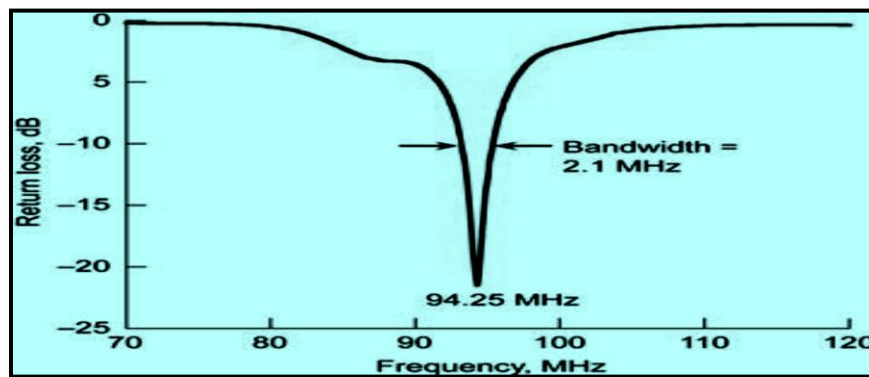


Figure 2.5: Return Loss Graph [21]

$$\text{Return loss} = -20 \log (\Gamma) \text{dB}. \quad (2.15)$$

2.8.2 VSWR

For efficient energy transfer, the impedance of the radio, the antenna, and the transmission line connecting the radio to the antenna must be the same. Radios typically are designed for 50Ω impedance and coaxial cables (transmission lines) used with them also have 50Ω impedance. Efficient antenna configurations often have an impedance other than 50Ω, some sort of impedance matching technique is then required to transform the antenna impedance to 50Ω.

The Voltage Standing Wave Ratio (VSWR) is an indication of how good the impedance match is. A high VSWR is an indication that the signal is reflected prior to being radiated by the antenna [15]. Higher VSWR gives a greater mismatch. A VSWR of 2.0:1 or less is considered good. It is represented as:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \quad (2.16)$$

Where Γ is called the reflection coefficient.

2.8.3 Bandwidth

The bandwidth of an antenna is the range of usable frequencies within which the performance of the antenna [16]. For broadband antenna, the bandwidth is usually expressed as the ratio of upper-to-lower operating frequencies. Meanwhile, for narrowband antenna, it can be expressed as in term of percentage of bandwidth, which is upper frequency minus lower frequency divide by the square root of upper frequency multiply lower frequency.

$$fr = \frac{f_l + f_h}{2} \quad (2.17)$$

$$BW = f_h - f_l \quad (2.18)$$

$$BW\% = \frac{f_h - f_l}{\sqrt{f_h * f_l}} * 100\% \quad (2.19)$$

Where:

f_c is the center frequency

f_l is the lower cutoff frequency

f_h is the upper cutoff frequency

2.8.4 Radiation Pattern

The radiation pattern is a graphical depiction of the relative field strength transmitted from or received by the antenna. It is a 3D plot of an antenna radiation far from the source.

or received by the antenna. It is a 3D plot of an antenna radiation far from the source. It provides the information that describes how the antenna directs the energy it radiates. Antenna radiation patterns are taken at one frequency, one polarization and one plane cut. Figure 2.6 shows a radiation pattern of a dipole antenna.

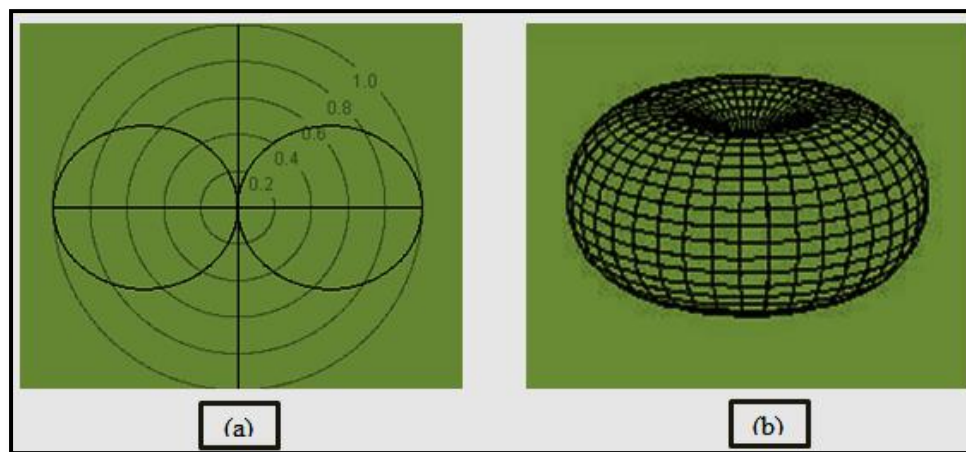


Figure 2.6: Radiation pattern of dipole antenna (a) 2D view (b) 3D view

2.9 Harmonic suppression techniques

Harmonic Suppressed Antenna (HSA) is an alternative solution. Several techniques have been proposed to control these harmonics, such as slots and short-pins [20], resonator [21], PBG (Photonic Band-Gap) [22], EBG (Electromagnetic Bandgap structures)[23],and DGS (Defected Ground Structure) [24]. The term defected ground structure (DGS), specifically implies a single or very limited number of defects .Additionally, deliberately created defects in the form of etched out patterns on the ground plane of microstrip circuits and transmission lines have been familiar to microwave engineers for a long time, although their applications to the antennas are relatively new .DGS have interesting properties in terms of size miniaturization, suppression of surface waves and the ability to introduce distinctive stop bands. The antenna designers initially employed DGS underneath printed feed lines to suppress higher harmonics. During 2005-2006, DGS was directly integrated with antennas to improve the radiation characteristics and to suppress mutual coupling between adjacent elements. They have been used in many applications such as low pass filters, band pass filters and antennas. A DGS may come in a variety of geometries and sizes .Depending upon their mode of application, as well as the frequency of operation. These shapes include: rectangular dumbbell, circular dumbbell, spiral, 'U', 'V', 'H', cross and concentric rings.

To sum up, the harmonic suppressed antenna is an antenna that is impedance matched at the desired operating frequency while producing maximum reflections at harmonic frequencies. The antenna has a capability to suppress the radiation power at these unwanted harmonics by applying a harmonic traps technique to the antenna.

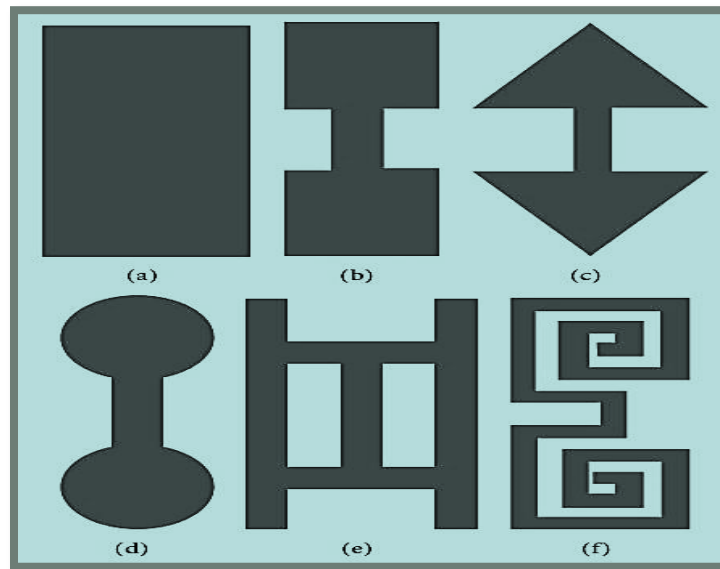


Figure 2.7: Different slots for DGS: (a) rectangular DGS, (b) square head DGS (dumbbell shape), (c) triangular DGS, (d) circular DGS, (e) H shape DGS, and (f) spiral DGS [26]

2.10 Previous Work

This section describes the importance of several previous researches and projects that are related to the design, dual band antenna with harmonic traps.

A harmonic suppression for a wide band reconfigurable printed dipole antenna is reported in [25]. Moreover, the open circuit stub is used to eliminate the third harmonic frequency at 2.7 GHz, whereas the operating frequency was 900 MHz. The results showed that the fabricated antenna with harmonic trap can select one of the lower frequency bands without selecting the higher frequency bands by eliminating higher order modes.

Rectangular and Circular Defected Ground Structures (RDGS), (CDGS) are used to eliminate the third harmonic frequency at 7.86 GHz in a 2.6 GHz slot antennas [26]. According to the measured results, these antennas with the simple harmonic suppression structures are quite effective for harmonic suppression.

A non-uniform cascaded bowtie Defected Ground Structure (DGS) unit cells has been presented with a wideband antenna to eliminate the second and the third harmonics bands, which are generated above 5 GHz (5.5 GHz-20 GHz), while the antenna operates in the frequency range between 2 GHz and 5.4 GHz [27]. The results illustrated that, the

proposed compact antenna with wideband harmonic suppression is very useful for ultra wideband (UWB) antenna operating in the frequency range of 3.1 GHz to 5.2 GHz.

Reported harmonic suppressed compacted reconfigurable slot antenna slot antenna is available in [28]. A band stop filter for harmonic suppression is integrated in the middle of the slot. Furthermore, the antenna operates in the frequency range between 5 GHz to 6 GHz. This antenna is suitable choice for portable devices since it has a good radiation pattern and compact size about 30 mm × 20 mm. To conclude, the previous discussed techniques are summarized in the table 2.3 below.

Table 2.2: Different Suppression Techniques.

Ref	Authors	Antenna Structure	Suppression Technique	Operating Frequency	Suppressed Frequency
[25]	Mirkamali, A.et.al. (2006) (University of Birmingham, Edgbaston, UK)	Dipole Antenna	Stubs	900MHZ	2.7GHZ
[26]	Ghaffarian, M.et.al. (2012) (University of Tehran, Iran).	Slot Antenna	Rectangular and Circular (DGS)	2.6GHZ	7.86GHZ (Contd.)
[27]	Damaj, L.et.al. (2012) (Institut Mines-Télécom, Télécom ParisTech,France)	Wideband Antenna	DGS	2 GHz and 5.4 GHz	5.5GHZ-20GHZ
[28]	Erfani, E.et.al. (2013) (Institut National de la RechercheScientifique ,Canada)	Reconfigurable Slot Antenna	Band Stop Filter	5 GHz - 6 GHz	Above 6GHZ

CHAPTER 3

METHODOLOGY

3.1 Introduction

First of all, the methods are used in order to obtain the optimum result of the project will be explained in this chapter, starting from the designing process to the testing process. Apart from this, CST microwave software is used in simulating the antenna characteristics. Furthermore, the real antenna will be tested using the network analyzer in the next stage of this project to obtain its input return loss. All the antenna experiment and simulation characteristics can be used in later chapters for the analysis of the performance of the antennas. Figures 3.1 to 3.2 show the project planning flow from the beginning until to the end.

3.2 Flow chart

The Figure 3.1 and Figure 3.2 display the flow chart for the project1 and project 2 respectively.

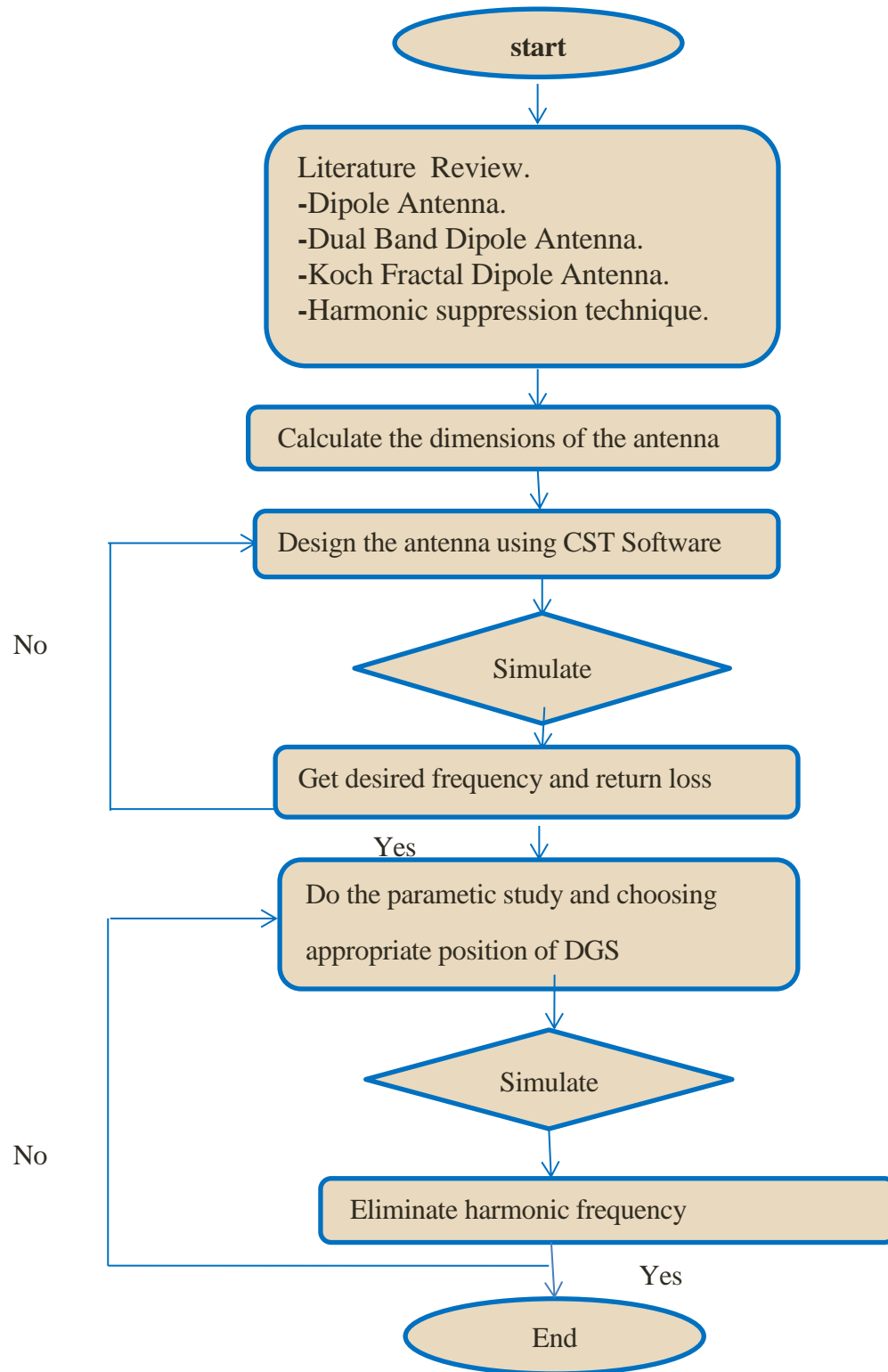


Figure 3.1: Planned progress of Project 1

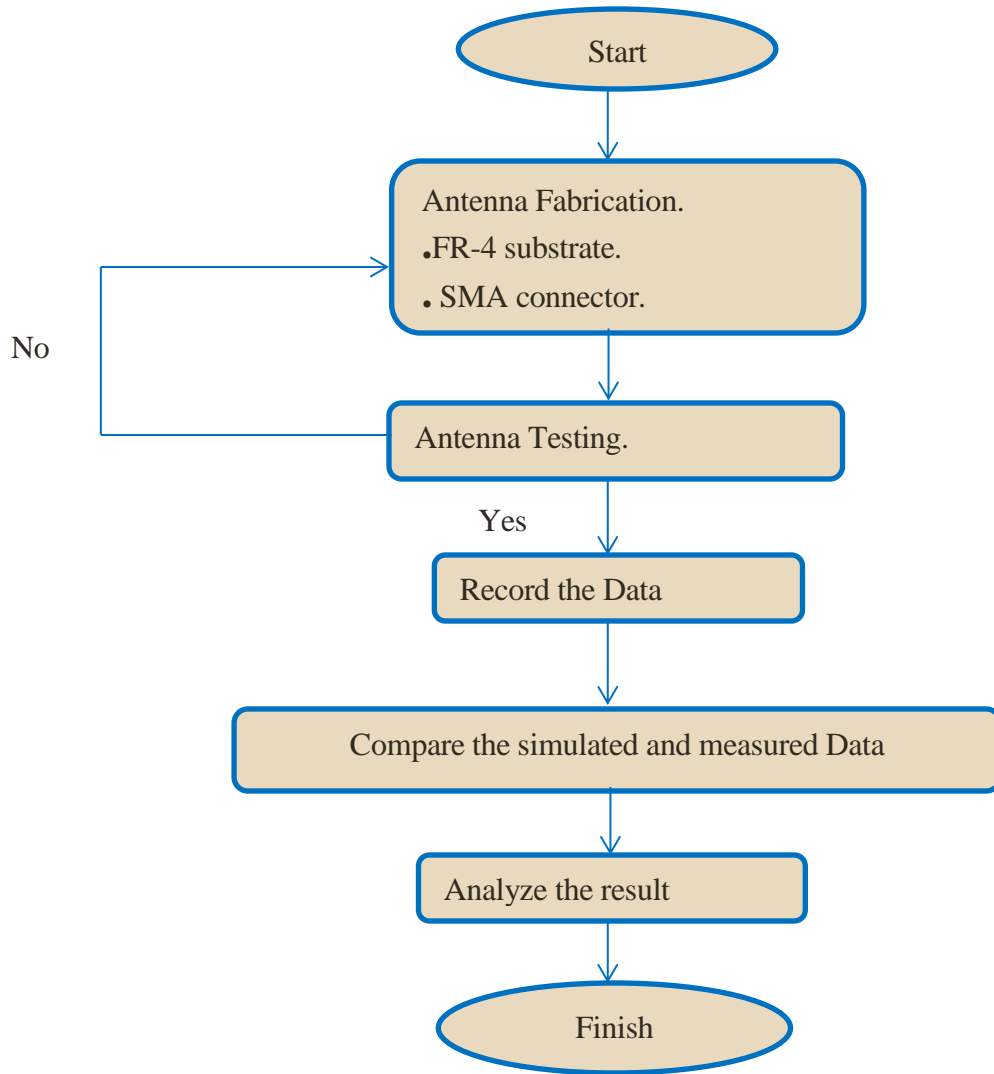


Figure 3.2: Planned progress of Project 2

3.3 Design procedures

This part explains about the design and specifications of the Invert Koch fractal dipole antenna with harmonic suppression. Moreover, there are some important parameters for the design Invert Fractal dipole antenna and must be known before starting the design, they are the resonant frequency (f_0), the dielectric constant (ϵ_r) of the substrate and the substrate thickness (h).

- The frequencies of operation (f_r): 0.9 GHz and 2.4 GHz are the two resonant frequencies which are chosen for this design, which are laying at the range from 0 to 4.5 GHz. The designed antenna must operate at these frequencies to be achieved.
- The dielectric constant and the thickness of the substrate (ϵ_r) and (h) respectively: The dielectric material selected for this design is FR-4 with a constant of 4.3 and its thickness is 1.60 mm. The substrate with a high dielectric constant has been selected since it reduces the dimensions of the antenna.

Table 3.1: The essential parameters for the design

Parameters	Dimension	Unit
Resonant frequencies (f_o)	0.9 , 2.4	GHz
Substrate thickness (h)	1.60	mm
Dielectric constant (ϵ_r) of the substrate	4.3	-

3.4 Calculation of the antenna parameters

3.4.1 Transmission line

The ratio for w/d where w is the width and d is the substrate thickness

$$\frac{w}{d} = \frac{8e^A}{e^{2A}-2} \quad (3.1)$$

Where

$$A = \frac{Z_0}{60} \sqrt{\frac{\epsilon_r+1}{2}} + \frac{\epsilon_r-1}{\epsilon_r+1} \left[0.23 \frac{0.11}{\epsilon_r} \right] \quad (3.2)$$

Substitution the value of $Z_0 = 50$, $\epsilon_r = 4.3$ into the above equation :

Hence $A = 1.544$

Then substitute value A into the equation 3.1

$$\frac{W}{d} = \frac{8e^{1.544}}{e^{2(1.544)-2}}$$

The thickness, d for FR4 board is 1.6mm, so the width of transmission line is

$$W=3\text{mm}$$

The length, L is :

$$L = \frac{c}{2fr\sqrt{\epsilon_r}} \quad (3.3)$$

$$L= 64 \text{ mm}$$

Where:

c = is the speed of light

fr = first resonant frequency of the antenna

ϵ_r = effective dielectric constant of the microstrip line

3.4.2 Effective dielectric constant

The effective dielectric constant , ϵ_{reff} is :

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2} \left[\frac{1}{\sqrt{1+12\left[\frac{h}{w}\right]}} \right] \quad (3.4)$$

Substituting $\epsilon_r=4.3$, $W=3 \text{ mm}$, $h=1.6 \text{ mm}$ into eq. (3.3)

$$\epsilon_{reff} = 3.256$$

3.4.3 Dipole arms

This proposed antenna was designed based on iterated Koch fractal geometrical principals using Microwave Office software with rotation angle = 60°, scaling factor 1/s = 1/9 since the second iteration was used.

$$\Delta L = 0.412h \frac{(\epsilon_{\text{reff}}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{\text{reff}}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (3.5)$$

Substituting $W = 3\text{mm}$, $h = 1.6\text{mm}$, $\epsilon_{\text{reff}} = 3.25$

$$\Delta L = 0.622 \text{ mm}$$

For the microstrip dipole, resonant length, L is given by

$$L = \frac{c}{2f_r \sqrt{\epsilon_{\text{reff}}}} - 2\Delta L \quad (3.6)$$

Substituting $C = 3 \times 10^8 \text{m/s}$, $\epsilon_{\text{reff}} = 3.25$, for is the resonant frequency

$$L = 91.206 \text{ mm}$$

Hence the length for second iteration Koch fractal arm equal to

$$L_{\text{Koch}} = \frac{l}{\left(\frac{4}{3}\right)^2} \quad (3.7)$$

Substituting $L = 91.206 \text{ mm}$

$$\text{Then } L_{\text{Koch}} = 51.303 \text{ mm}$$

For the second iteration the length of each segment is equal to

$$l_{\text{seq}} = \frac{L_{\text{Koch}}}{9} = 6 \text{ mm}$$

Then, Pythagoras' theorem is used to draw the Koch fractal arms in CST software. Finding the missing side of a right triangle is a pretty simple matter if two sides are known. One of the most famous mathematical formulas is $A^2 + B^2 = C^2$ which is known as the Pythagorean Theorem.

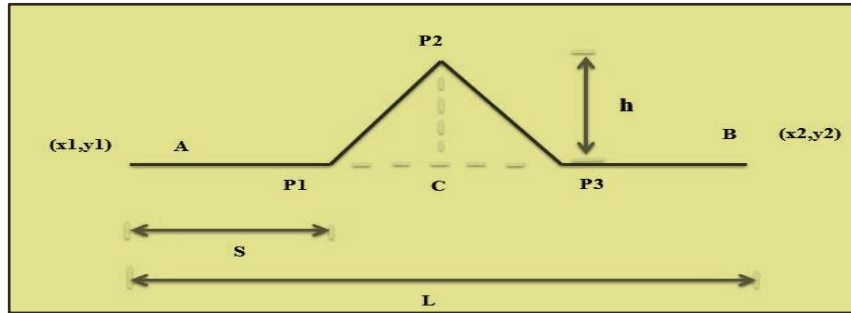


Figure 3.3: First iteration geometry

$$C = \frac{L}{2} \quad (3.8)$$

$$S = \frac{L}{3} \quad (3.9)$$

$$h = \frac{\sqrt{3}}{2} * S \quad (3.10)$$

$$P1 = \left(\frac{(2x1+x2)}{3}, \frac{2y1+y2}{3} \right) \quad (3.11)$$

$$P2 = \left(\frac{(y1-y2)}{l}, \frac{x2-x1}{l} \right) \quad (3.12)$$

$$P3 = \left(\frac{(x1+2x2)}{3}, \frac{y1+2y2}{3} \right) \quad (3.13)$$

$$S = \frac{L}{3} \quad (3.14)$$

3.4.4 Tapered balun

The width (a) and height (b) for the tapered balun can be obtained using the following equations:

$$a = \frac{\lambda g}{4} \quad (3.15)$$

$$b = \frac{\lambda g}{4} \quad (3.16)$$

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