DUAL MODE MICROSTRIP OPEN LOOP RESONATOR AND FILTER FOR WIRELESS LAN APPLICATIONS

NIK KHATIJAH BINTI NIK MUSTAFFA

A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical & Electronic Engineering
Universiti Tun Hussein Onn Malaysia

MARCH 2013

ABSTRACT

Bandpass filters play a significant role in wireless communication systems. Transmitted and received signals have to be filtered at a certain center frequency with a specific bandwidth. The major problem in design microstrip bandpass filter is to get a deeper and wider rejection bandwidth. In this thesis, a dual mode microstrip open loop resonators and filter is design to be operated at 5.7 GHz for wireless local area network (WLAN) using sonnet lite simulation software. Results have been analyzed in terms of reflection coefficient and transmission coefficient. The simulated filter performances are presented. The simulated result shows the performance of bandpass is better for resonator with contact feed compared with non contact feed.

ABSTRAK

Penapis jalur lulus memainkan peranan yang sangat penting dalam sistem komunikasi tanpa wayar.. Penghantaran dan penerimaan isyarat mestilah ditapis pada sesuatu frequency dengan lebar jalur yang tertentu. Masalah utama dalam merekabentuk penapis jalur lulus micro jalur adalah untuk mendapatkan kedalaman dan kelebaran penyingkiran lebar jalur. Dalam tesis ini, mode berkembar jalur lulus dengan penggetar dan penapis lingkaran terbuka direkabentuk untuk beroperasi pada frequency 5.7 GHz untuk diaplikasikan pada rangkaian tempatan tanpa wayar menggunakan perisian sonnet lite. Keputusan yang diperolehi dianalisa berdasarkan kecekapan pantulan dan kecekapan penghantan. Pencapaian penapis yang telah disimulasi turut dipersembahkan. Keputusan menunjukkan bahawa prestasi penapis jalur lulus semakin baik dengan hubungan kaki terus pada terminal berbanding tanpa hubungan kaki terus pada terminal.

CONTENTS

	TITLE	**i**
	DECLARATION	**ii**
	DEDICATION	**iii**
	ACKNOWLEDGEMENTS	**iv**
	ABSTRACT	**v**
	ABSTRAK	**vi**
	CONTENTS	**vii**
	LIST OF TABLES	**x**
	LIST OF FIGURES	**xi**
	LIST OF SYMBOLS / ABBREVIATIONS	**xiv**
CHAPTER 1	**INTRODUCTION**	
	1.1 Background	1
	1.2 Aims and objectives	3
	1.3 Project motivation	4
CHAPTER 2	**LITERATURE REVIEW**	
	2.1 Microstrip filter	5
	2.2 Microstrip lines	6
	2.2.1 Microstrip structure	7
	2.2.2 Losses in microstrip	8
	2.2.3 Dielectric constant	9
	2.2.4 Effective dielectric constant	9
	2.2.5 Characteristic Impedance	10
	2.2.6 Material	13

2.3 Scattering Parameters 13
2.4 Types of filter 16
2.4.1 Filter Characteristic 17
2.4.2 Filter Performance 18
2.5 Microstrip Resonators 19
2.5.1 Microstrip Open Loop Resonator 20
2.5.2 Coupling between resonators 21

CHAPTER 3 METHODOLOGY
3.1 Introduction 24
3.2 Sonnet Lite Software 25
3.2.1 Create New Project 26
3.2.2 Circuit Substrate 31
3.2.3 Display result on graph 34

CHAPTER 4 DATA ANALYSIS AND RESULT
4.1 Introduction 39
4.2 Analysis for port location 39
4.3 Analysis for varies the size of loading element (Y) 44
4.4 Analysis of varies transmission line gap of resonator 50
4.5 Analysis for coupling dual mode resonator with varies the gap between two resonators. 56
4.6 Analysis of varies the orientation of resonator 62
4.7 Analysis for non contact feed in term of variation the coupling gap 67
4.8 Analysis for direct contact feed and non contact feed. 71
4.9 Analysis for single n double resonator with direct contact feed. 72

CHAPTER 5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion 75

5.2 Recommendation 76

REFERENCES 77

LIST OF TABLES

4.1	Summary of result by compare the size of loading element	49
4.2	Summary of result by compare a coupling between resonator gap size	61
4.3	Summary of result	74

LIST OF FIGURES

2.1	The structure of microstrip	7
2.2	The open loop resonator can be obtained by folding a straight open resonator	20
2.3	Typical arrangements of a pair of square resonators with (a) magnetic coupling; (b) electric coupling; (c) and (d) mixed coupling	22
3.1	The Sonnet Lite welcome page	25
3.2	Select New Geometry	26
3.3	Sonnet Project Editor	27
3.4	Defining unit	28
3.5	Defining dielectric layer and thickness	28
3.6	Defining Cell and Box Size	29
3.7	Specify Metal Type	29
3.8	Project Frequencies	30
3.9	Circuit Substrate Window	31
3.10	Tool Box Window	31
3.11	Check the memory size	32
3.12	Estimate Memory Size	33
3.13	Example of Substrate Layout	33
3.14	Analyze project	34
3.15	Analysis Monitor	35
3.16	View Graph	35
3.17	Response Viewer	36
3.18	Add the Curve	37

3.19	Edit Curve Group Window	38
4.1	Resonator with port at below	40
4.1(a)	Simulated Frequency Response for Resonator with port at below location	41
4.2	Resonator with port at above	42
4.2(a)	Simulated Frequency Response for Resonator with port at above	42
4.3	Response of case study 1	43
4.4	Resonator with loading element, Y= 6.0 mm	44
4.4(a)	Simulated Frequency Response of Resonator with loading element, Y= 6.0 mm	45
4.5	Resonator with loading element Y= 11.4 mm	46
4.5(a)	Simulated Frequency response for Resonator with loading element Y= 11.4 mm	47
4.6(a)	Response of Case Study 2 (S_{11}).	48
4.6(b)	Response of Case Study 2 (S_{21}).	48
4.7	Resonator with transmission line gap 2.5 mm	50
4.7(a)	Simulated Frequency Response of Resonator with transmission line gap 2.5 mm	51
4.8	Resonator with gap 0.2 mm	52
4.8(a)	Simulated Frequency Response of Resonator with gap 0.2 mm	53
4.9	Simulated Frequency Response Case Study 3.	54
4.10	Coupling Dual Mode Resonator with gap 0.6 mm	56
4.10(a)	Simulated Frequency Response for Coupling Dual Mode Resonator with gap 0.6 mm	57
4.11	Coupling Dual Mode Resonator with gap 1.0 mm	58
4.11(a)	Simulated Frequency Response for Coupling Dual Mode Resonator with gap 1.0 mm	58
4.12	Coupling Dual Mode Resonator with gap 0.2 mm	59
4.12(a)	Simulated Frequency Response for Coupling Dual Mode	59

	Resonator with gap 0.2 mm	
4.13	Response of Case Study 4	60
4.14	Filter with orientation 1	62
4.14(a)	Simulated Frequency Response for Filter with orientation 1	62
4.15	Filter with orientation 2	63
4.15(a)	Simulated Frequency response for Filter with orientation 2	63
4.16	Filter with orientation 3	64
4.16(a)	Graph S_{11} and S_{21}	64
4.17	Response for Case Study 5	65
4.18	Non Contact Feed Resonator with gap 0.2 mm	67
4.18(a)	Simulated Frequency Response for Non Contact Feed Resonator with gap 0.2 mm	67
4.19	Non Contact Feed Resonator with gap 0.6 mm	68
4.19(a)	Simulated Frequency Response for Non Contact Feed Resonator with gap 0.6 mm.	68
4.20	Non Contact Feed Resonator with coupling gap 1.0 mm.	69
4.20(a)	Simulated Frequency Response Non Contact Feed Resonator with coupling gap 1.0 mm	69
4.21	Compare for Direct Contact Feed Resonator and Non Contact Feed Resonator (Case Study 7)	71
4.22	Response for Case Study 8	73

LIST OF SYMBOLS AND ABBREVIATIONS

D, d -	Diameter
G Hz	Giga Hertz
h -	Thickness of substrate
L -	Length of microstrip
mm -	Milimeter
t	Thickness of conductor
W-	Width of microstrip
ε_{eff} -	Effective permittivity
ε_o -	Relative permittivity of free space
ε_r-	Relative permittivity of substrate
μ_o-	Permeability constant
λ_g -	Guided wavelength
λ_o-	Free space wavelength
f_1 -	Lower cutoff frequency
f_2 -	Upper cutoff frequency
f_c -	Center frequency
g	Prototype element value
S_{11}	Reflection coefficient
S_{21}	Transmission coefficient
TEM	Transverse electromagnetic
ω	Angular frequency in radian/s^{-1}
Z_o	Input Impedance
Φ	Phase angle or electrical length
Ω	Ohms

EM	Electromagnetic
FFT	Fast Fourier Transform
MB	Mega Byte
WLAN	Wireless Local Area Network
dB	Decibel

CHAPTER 1

INTRODUCTION

1.1 Background

With the rapid development of wireless and mobile communication systems, there is an increasingly demands for new technologies to meet the challenge for smaller size, high performance, multi-frequency and cheaper manufacturing cost. Filters are one of the most important components must be found in the transmitter or receiver. Filtering application is most crucial in a system as it will discriminate between wanted and unwanted signal frequencies. Bandpass filter is a passive component which is able to select signals inside a specific bandwidth at a certain center frequency and reject signals in another frequency region, which have the potential to interfere the information signals. In designing the bandpass filter, we are faced the question, what is the maximal loss inside the pass region, and the minimal attenuation in the reject or stop regions, and how the filter characteristic must look like in transition region. Thus, filter size is one of the concerns in the filter design. The filter is design to ensure that it can fit into the electronic devices. Besides, the losses of the filter are playing an important role because they will affect the performance of the filters.

Among all the filter technology, microstrip filters is widely used and apply in many RF/microwave circuits and systems [1] due to it ease of integration and compatibility with planar fabrication processes. Microstrip also favors miniaturization it is light, and occupies low volume. Furthermore, electronically tunable and reconfigurable filters, like the notch filters employed in ultra wideband applications can use surface mount varactors that are compatible with microstrip implementations. The main disadvantage of microstrip resonators is the low quality factors usually obtained. However, for applications that require negligible insertion loss (like front ends of satellite receivers), or very narrow relative bandwidths, the advent of high temperature superconductors have rendered microstrip resonators with quality factors above 30,000 .

In general, microstrip bandpass filters can be designed using single or dual mode resonators. Band pass filter require precise transmission characteristics that allow a desired band of signals to pass through the two port network. Thus, between a transmitter and transmitting antenna, a band pass filter may be used to attenuate unwanted signals and harmonic components that may cause interference to other users of the electromagnetic spectrum. Conversely, between an antenna and a receiver, a band pass filter will reject out of band signals that may cause interference within the receiver, especially if they are at a high signal level in comparison with the desired signals. Dual mode resonators are attractive because each dual mode resonator can be used as a doubly tunable resonant circuit. Therefore the number of resonators in a filter can be reduced by half, thus resulting in a compact configuration. Various kinds of dual mode resonators have been investigated, including the circular ring [2], square loop [3], and triangular patch [4]. Meanwhile, several new types of dual mode resonators [5] have been reported for filter applications recently. Practically, some special applications require high selectivity on only one side of the pass band, but less or none on the other side. In such cases, using filters with asymmetric frequency responses would be desirable [6].

In this project, the type of miniature microstrip dual-mode open loop resonator for filter applications is introduced. The dual-mode open loop resonator is developed. The open-loop resonator is well known for its flexibility to design cross-coupled resonator filters, as well as its compact size, which amount to $\frac{\lambda}{8} by \frac{\lambda}{8}$, where λ is the guided wavelength at the fundamental resonant frequency. It will be shown that the proposed dual-mode open-loop resonator has a size that is the same as the single-mode open-loop resonator, which, however, is much smaller than the conventional dual-mode loop resonator [3]. The size of the dual-mode open-loop resonator is only approximately one-quarter of the dual-mode loop resonator, which is a significant size reduction. There have some different of distinct characteristics between the dual-mode open-loop resonator and the conventional dual-mode loop resonator.

The frequency response for non contact feed dual mode open loop resonator and direct contact feed dual mode open loop resonator are investigated. The frequency shift for variation of port location for resonator and variation of resonator orientations are reported. The study of filter parameters and the effect to filter response was also presented. This information is important especially for circuit optimization work.

In this project bandpass filters based on dual-mode open loop resonator are design at 5.7 *GHz* and verified using SONNET LITE software to optimized and simulate the circuits. All results obtained are analyzed based on transmission coefficient, reflection coefficient and the bandwidth.

1.2 Aims and objectives

There are several objectives that have been outline to complete this analysis of dual mode microstrip open loop resonators and filters at 5.7 *GHz* for *WLAN* applications. This project is to designs a dual-mode microstrip open loop resonators and filters at 5.7 *GHz* by using SONNET Lite simulation software. This objective helps to gain fundamental knowledge in microstrip filter. This project also to simulate and analyze the performance of bandpass filter operating at frequency range of 5 *GHz* to 6 *GHz* and to measure the frequency responses of the dual mode resonator and filter.

The project aims to design a dual mode microstrip open loop resonator bandpass filter which is simple and have a good performance of frequency response. The design filter should be a dual mode bandpass device that resonates in the frequency range of 5 *GHz* to 6 *GHz*. On the other hand, this project aims to design a dual-mode microstrip open loop resonators and filters at 5.7 *GHz* where the filter will be unique, simple, and high-performing. Through this project, we will have a better understanding of the microstrip bandpass filter properties.

1.3 Project motivation

The project motivation is to design the dual mode microstrip open loop resonator and bandpass filters that are to fulfill the master's project requirement**.** After completing the literature review throughout the journals, knowledge in filter design has widen. The goal of this project is to design a simple, high performing, and small size microstrip bandpass filter that has results comparable to those published.

CHAPTER 2

LITERATURE REVIEW

2.1 Microstrip filter

In modern wireless and mobile communication systems, Radio Frequency (RF) and microwave filter are important and essential components. No doubt, filters are playing an important role in the RF and microwave applications. A microwave filter is a two port network used to control the frequency response at a certain point in a microwave system by providing transmission at frequencies within the passband of the filter and attenuation in the stopband of the filter [6]. Generally there are four types of frequency response include low-pass, high pass, bandpass and bandstop characteristics.

Filters with smaller size, lighter weight, higher performance, and lower insertion loss are of high demand. Microstrip filters can fulfill the requirements stated above. Besides wireless and mobile communication systems, low-temperature co fired ceramics (LTCC), high temperature superconductor (HTS), monolithic microwave integrated circuits (MMIC), micro electromechanic system (MEMS) and micromachining technology, have driven the rapid development of the new microstrip filter than other microwave and RF filters.

Microstrip filters can be designed and manufactured with remarkable predictable performance in various patterns depending on different requirements. Each microstrip filter consists of its individual properties and characteristics. The common microstrip designs that available in market are such as rectangular patch filter, circular patch filter, triangular patch filter and etc. Filters are then incorporated to set the system response precisely.

2.2 Microstrip lines

Microstrip line is one of the most popular types of planar transmission line that basically consists of a thin-film strip in intimate contact with one side of a flat dielectric substrate, with a similar thin-film ground-plane conductor on the other side of the substrate. It is similar to stripline and coplanar waveguide, and it is possible to integrate all three on the same substrate. According to Encyclopedia, microstrip was developed by ITT laboratories by Grieg and Engelmann in December 1952 as a competitor to stripline. According to Pozar, the early microstrip work used fat substrates, which allowed non-TEM7 waves to propagate which makes results unpredictable. In the 1960s the thin version of microstrip started became popular. Microstrip can be fabricated using printed circuit board (PCB) technology and is used to convey microwave frequency signals. It consist of a conducting strip separate from a ground plane by a dielectric layer which known as substrate.

Microstrip can be used to design antennas, couplers, filters, power dividers and etc. Microstrip filters are very suitable for wideband applications and were demand on selectivity is not severe. Various kind of filters can be realized using microsrip type structures such as parallel coupled line, interdigital, combline, hair pin line, stubs and many more. The advantages of microstrip line are low cost, small size, light weight, high reliability, improved reproducibility and improved performance more. The material costs are lower than the traditional waveguides since the entire microstrip is just a patterned metal and a ground plane only, and it also much lighter and more compact than the waveguides. Since microstrip is not enclosed as a waveguide, it is susceptible to crosstalk and unintentional radiation. Unlike stripline, microstrip can mount all the active components on top of the board. However, the disadvantages are that microstrip generally has lower power handling capacity and higher losses. External shield may be needed for circuits that require higher isolation such as switches.

In this project, microstrip has been chosen for the filter design because it is a proven technology and the shielding problem can be solved easily by encapsulating the filter in a metallic box. Besides, crosstalk and unintentional radiation are not an issue in this project as well.

2.2.1 Microstrip Structure

A microstrip structure consists of a top conductor strip, dielectric substrate and conductor ground plane. The top conductor strip, dielectric material and infinite ground plate form a microstrip transmission line which acts as a guide to the transmission electromagnetic waves. Important parameter of a microstrip are the thickness of the conductor strip (t), the width of the conductor strip (w), the thickness of the substrate (h), and the relative permittivity of the substrate (ε_r). The medium above the substrate, usually air which have the dielectric constant ε_o, where $\varepsilon_r = 1$ and $\varepsilon_o = 808542 \times 10^{-12}$ F/m. The relative dielectric medium of the substrate is ε_r. The substrate will be assumed to be magnetic with permeability constant, $\mu_o = 4\pi \times 10^{-7}$H/m.

Figure 2.1 The structure of microstrip

Microstrip is used over a frequency range of 1 GHz to 40 GHz. Below 1 GHz, circuit dimension become very large while above 40 GHz, circuit dimension is very small while the circuit losses become high. In practice the range of frequencies that are widely used are from 2 GHz to 12 GHz. At frequencies where the electrical distance in the dielectric material between the strip and the ground plane is much less than a wavelength, microstrip behaves as non dispersive transverse electromagnetic (TEM) line. Unlike moding in pure TEM lines, the transition in microstrip from TEM to quasi-TEM is not sudden. With increasing frequency, as the substrate thickness of microstrip becomes appreciable, the propagation velocity and the characteristic impedance of the line increase.

2.2.2 Losses in microstrip

Losses are a fact of life, no matter how carefull a circuit is designed, a part of the signal is transformed into useless heat and lost as far as communication is concerned. Given sufficient time, any response eventually dies out. The amplitude of the signal decrease as it travels along the line, the signal is attenuated [7].

Basically, losses are resulted from three mechanisms; conduction, dissipation and radiation in dielectric and magnetic materials.

- Conductor losses – due to resistive losses in strip
- Dissipation in the dielectric of the substrate – due to polarization by the time varying field in the substrate
- Radiation – due to the antenna action of microstrip. Bend, open stubs and discontinuities on transmission line excite order modes which can radiate energy.

Conduction losses and dissipation effect, where as radiation loss and surfacewave propagation are essentially parasitic phenomenon. Other than the above mentioned losses there are also insertion losses. Thus, this loss can be seen of microstrip resonator which might due to:

i. Reflection at the filter ports or mismatch loss
ii. Dissipation within the filter or unloaded Q induced loss
iii. Radiation from the filter or radiation loss.

2.2.3 Dielectric constant

Microstrip can be fabricated on different substrates based on the requirement of the design. For a lower cost, microstrip devices can be built on the ordinary Duroid 6006 substrate. Dielectric constant is a measure of the extent to which it concentrates electrostatic lines of flux. For example, FR-4 has a dielectric constant of 4.4 and R6006 duroid has 6.15 at frequency of 10 GHz. And by definition, the dielectric constant of vacuum is equal to 1. Dielectric constant is frequency dependent. In this project, dielectric constant is 10.8.

2.2.4 Effective dielectric constant

In general, the dielectric constant of the substrate will be different (and greater) than air, so the wave is travelling in an inhomogeneous medium. In consequence, the propagation velocity is somewhere between the speed of radio waves in the substrate, and the speed of radio waves in air. This behavior is commonly described by stating the effective dielectric constant of the microstrip. Effective dielectric constant is an equivalent dielectric constant of an equivalent homogeneous medium. As part of the fields from the microstrip conductor exists in air, the effective dielectric constant is less than the substrate's dielectric constant.

2.2.5 Characteristic impedance

The characteristic impedance, Z_o is important in microstrip lines design, it will affects the reflection loss, S_{11}. The reflection loss is related to the characteristic impedance and also load impedance by formula, $S_{11} = \frac{Z_{in} - Z_o}{Z_{in} + Z_o}$. In order to minimize the reflection loss at the input port, the characteristic impedance of microstrip must be equal to the input of the impedance. Most of the input ports are designed at 50 ohm to prevent any reflections. The characteristic impedance is also a function of height (H) and width (W) of microstrip lines. Note that effective dielectric constant value is required for the microstrip characteristic impedance calculation. The characteristic impedance of microstrip lines can be calculated by using formulas below.

When $\left(\frac{W}{H}\right) < 1$

$$Z_0 = \frac{60}{\sqrt{\varepsilon_{eff}}} \ln\left(8\frac{H}{W} + 0.25\frac{H}{W}\right) ohms \tag{2.1}$$

When $\left(\frac{W}{H}\right) \geq 1$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff} \times \left[\frac{W}{H} + 1.393 + \frac{2}{3}\ln\left(\frac{W}{H} + 1.444\right)\right]}} ohms \tag{2.2}$$

The very first step in this project is to design the microstrip lines that can achieve 50 ohm of characteristic impedance, Z_o. From the formulas above, there are three variables in the calculation which are $\varepsilon_{eff,}$ Width (W) and Height (H). Since the ε_{eff} and height is constant for the substrate, the only variable is the width of the microstrip line.

Since the formula is quite complicated, we have to substitute different W value in order to get 50 ohm characteristic impedance. At first, it has to verify the ratio of W/H and determine which formula to be used. It is time consuming for the calculation on different substrate. Fortunately, some of the web application and software are able to calculate the width of the microstrip lines by entering the desire characteristic impedance, height of the substrate and dielectric constant of the substrate. Then the software will perform the calculation within seconds and shows the value. It has simplified the microstrip lines design work and most importantly consume less time. For instance, one of the useful software was used for characteristic impedance calculation is MATLAB. The software is easy to control and able to get the width value easily by key in height of the substrate, thickness of the strip, and dielectric constant of the substrate. The microstrip width calculation of the microstrip line can be found as [8].

For narrow strips $(Z_o > 44 - 2\varepsilon_r)$

$$\frac{W}{h} = \frac{8e^{A}}{e^{2.A} - 2} \tag{2.3}$$

and for wide strips $(Z_o < 44 - 2\varepsilon_r)$

$$\frac{W}{h} = \frac{2}{\pi}\left[B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left(\ln(B - 1) + 0.293 - \frac{0.517}{\varepsilon_r}\right)\right] \tag{2.4}$$

Where

$$A = \sqrt{\frac{\varepsilon_r + 1}{2}} \cdot \frac{Z_o}{60} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.226 + \frac{0.12}{\varepsilon_r}\right) \tag{2.5}$$

$$B = \frac{377\pi}{2Z_o \cdot \sqrt{\varepsilon_r}} \tag{2.6}$$

The line length, L, for a 90^o phase shift is found as

$$\phi = 90^o \tag{2.7}$$

Where

$$\phi = \beta L \tag{2.8}$$

And

$$\beta L = \sqrt{\varepsilon_{eff}}\, k_o . L \tag{2.9}$$

$$k_o = \frac{2\pi f}{c} \tag{2.10}$$

So, the line length, L

$$L = \frac{90^o . \left(\frac{\pi}{180^o}\right)}{\sqrt{\varepsilon_{eff}}\, k_o} \tag{2.11}$$

The effective dielectric constant of a microstrip line is given approximately by

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \cdot \frac{1}{\sqrt{1 + 12 . \frac{h}{w}}} \qquad (2.11)$$

2.2.6 Material

The important step for the design of microstrip bandpass filter is to choose the kind of material for the dielectric substrate, its thickness and then the relative permittivity. This step is very important where a suitable dielectric substrate of appropriate thickness must be chosen. Many manufactures offer suitable substrates in various thicknesses and in a variety of claddings. The table in Table 2.1 shows a specification of substrate that used in this design.

2.3 Scattering parameters

Scattering parameters (S-parameters) are important in microstrip design because they are easier to measure and work with high frequencies than other kind of parameters. They are conceptually simple, analytically convenient, and capable of providing a great insight into a measurement or design problem. S-parameters have earned a prominent position in RF circuit design, analysis and measurement. Other parameters such as Y, Z and H parameters require open and short circuits on port during measurement [9].This pose serious practical difficulties for broadband high frequency measurement.

S-parameters are defined in terms of travelling waves because matched loads are used in determination and the position of the reference planes only affects the phase of the scattering parameter.

Two ports S-parameters are defined by considering a set of voltage waves. When a voltage wave from a source is incident on a network, a portion of the voltage wave is transmitted through the network, and a portion is reflected back toward the source [9]. Incident and reflected voltages waves may also be present at the output of the network. New variable are defined by dividing the voltage waves by the square root of the reference impedance.

The square of the magnitude of these new variables maybe viewed as travelling power waves [9].

$$|a_1|^2 = \text{incident power wave at the network input} \quad (2.12)$$

$$|b_1|^2 = \text{reflected power wave at the network input} \quad (2.13)$$

$$|a_2|^2 = \text{incident power wave at the network output} \quad (2.14)$$

$$|b_2|^2 = \text{reflected power wave at the network output} \quad (2.15)$$

These variables and the network S-parameters are related by;

$$b_1 = a_{11}s_{11} + a_2 s_{12} \quad (2.16)$$

$$b_2 = a_{11}s_{21} + a_2 s_{22} \quad (2.17)$$

The S-parameters S_{11}, S_{22}, S_{12}, and S_{21} are:

$$S_{11} = \left. \frac{b_1}{a_1} \right|_{a_2=0}$$ input reflection coefficient with the output port terminated by a match load (Z_L=Z_o) (2.18)

$$S_{22} = \left. \frac{b_2}{a_2} \right|_{a_1=0}$$ Output reflection coefficient with the input port terminated by a match load (Z_L=Z_o) (2.19)

$$S_{21} = \left. \frac{b_2}{a_1} \right|_{a_2=0}$$ Forward transmission (insertion) gain the output terminated in a matched load. (2.20)

$$S_{12} = \left. \frac{b_1}{a_2} \right|_{a_1=0}$$ Reverse transmission (insertion) gain the input port terminated in a matched load.

Input VSWR and S_{11} are related by the equation below;

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|} \tag{2.21}$$

The output VSWR is related to S_{22} by an analogue equation. The complex input impedance is related to the input reflection coefficient by the expression below;

$$Z_{input} = Z_o \frac{1+S_{11}}{1-S_{11}} \tag{2.22}$$

The output impedance is defined by an analogous equation using S_{22}.

2.4 Types of filters

Generally, there are four most common types of filter response; Low pass, High-pass, Bandpass and Bandstop.

i. Low-Pass filter
   - A filter that block fight frequencies and allows low frequencies to pass through the output.

ii. High-Pass filter
   - A filter that allows high frequencies and block low frequencies.

iii. Bandpass filter
   - A filter that passes the frequencies between the specified ranges and rejects those unwanted frequencies.

iv. Bandstop filter
   - A filter that blocks the frequencies between specified range and allows the others.

2.4.1 Filter Characteristics

In order to design a filter, a few factors on filter characteristic must be considered such as;

i. Bandwidth

Bandwidth is commonly defined as a difference between the upper and the lower cutoff frequency (f_1 and f_2) of the circuit. Its amplitude response is 3 dB below the pass band response. It is often called the half power bandwidth.

ii. Q Factor

Defined as ratio of the center frequency to its bandwidth, also defined as

$$Q = \frac{f_c}{(f_2 - f_1)} \tag{2.23}$$

Q is measured of the selectivity of a resonant circuit. Basically, higher Q would contribute to a narrower bandwidth and a higher selectivity.

2.4.2 Filter Performance

In designing a filter, there are some important parameters that must be taken into consideration.

- Bandwidth

  It is the differences between the maximum and minimum frequency of the filter at which its amplitude response is 3 dB below the pass band.

- Q factor

  The ratio of power stored to the power dissipation. It is also a measure of the selectivity of a filter. Higher Q will give a higher selectivity of a filter.

- Selectivity

  The ability to select wanted and unwanted frequency for filtering process. It is also a measure of steepness or sharpness of the cutoff slope.

- Stopband Rejection

  The ratio of the amplitude of unwanted frequency components before filter insertion to the amplitude existing after filter insertion. It is measured of the extent to which it rejects unwanted energy.

- Return Loss

  The ratio of reflected signal to incident signal where it is measured in dB. In the pass band, a smaller return loss is desirable. In S-parameter, return loss is represented by S_{11}.

- Insertion Loss

  When a component or group of component is inserted between a generator and its load, some of the signal from the generator is absorbed in those component due to their inherent resistive losses. Thus, not as much of the transmitted signal is transferred to the load as when the load is connected directly to the generator. The attenuation that result is called insertion loss. In S-parameter, the insertion loss is represented by S_{21}.

- Ripple

  A measure of the flatness of the pass band of a resonant circuit and it is expressed in decibels. Physically, it is measured in the response characteristic as the difference between the maximum attenuation in the pass band and the minimum attenuation in the pass band.

- Resonance frequency

  The exact frequency at which the filter response is resonated.

2.5 Microstrip resonators

Microstrip resonators can be designed in various patterns. Before designing the microstrip band pass filter, it has to do some literature studies through IEEE Xplore about the microstrip resonators. Besides, it is also to ensure that the effort spent in design has not been researched by others nor published in the IEEE Xplore before. The types of resonators that covered are dual mode microstrip open loop resonator.

2.5.1 Microstrip open loop resonators

The microstrip open loop resonator can be obtained by folding a straight open resonator as shown in Figure 2.2. Due to the corners and the fringing capacitance between the open ends, a rigorous calculation of the electromagnetic fields in the square resonator is impractical. However, it is possible to study the main characteristics of the resonant modes of the open loop resonator by analogy to those of the straight resonator. This qualitative analysis can shed some light on the behavior of the resonator with minimum effort. The conclusions drawn using this approach can then be compared for validation against the actual distribution of the electromagnetic fields obtained with the aid of full wave simulators.

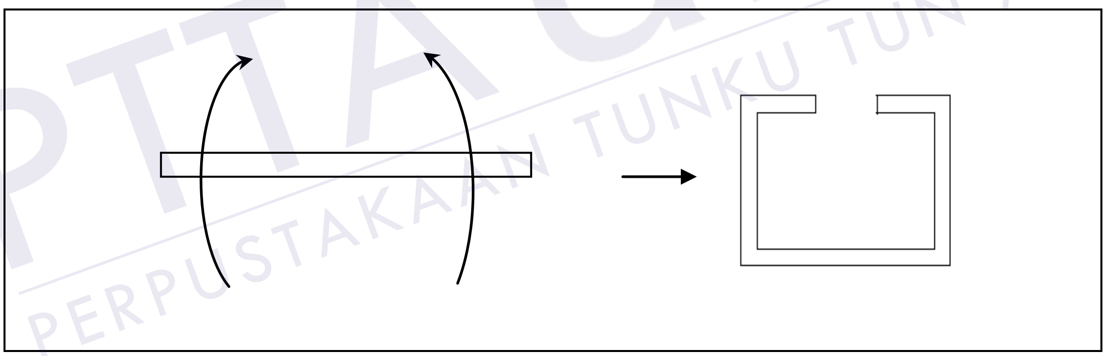

Figure 2.2: The open loop resonator can be obtained by folding a straight open resonator.

2.5.2 Coupling between resonators

The main interaction mechanism between resonators for filter application is due to proximity coupling. This coupling can be characterized by a coupling coefficient that depends upon the ration of coupled energy to stored energy as follows:

$$k = \frac{\int \varepsilon E_a E_b dv}{\sqrt{\int \varepsilon E^2{}_a dv \int \varepsilon E^2{}_b dv}} + \frac{\int \mu H_a H_b dv}{\sqrt{\int \mu H^2{}_a dv \int \mu H^2{}_b dv}} \tag{2.24}$$

Where E_a and H_a are, respectively the electric and magnetic fields produced by the first resonator, and E_b, H_b are the corresponding fields of the second resonator. The first term on the right hand side of equation 2.3 represents the coupling due to the interaction between the electric fields of the resonators, or more simply the electric coupling. Similarly, the second term represents the magnetic coupling between the resonators. Depending on which term dominates the sum the coupling is said to be electric, magnetic, or mixed.

The nature of the coupling between open loop resonators is related to the relative orientation of both resonators. Four canonical arrangements are shown in the Figure 2.3. When the resonators are operating near their first resonant frequency, the pair of resonators depicted in Figure 2.3a interact mainly through their magnetic fields, this is because the magnetic field is maximum near the center of the resonator opposite to its open ends, maximizing the numerator of the second term of equation 2.3. The configuration of Figure 2.3b produces, in turn, an electric coupling since the electric field is maximum near the open ends, maximizing the numerator of the first term of equation 2.23. The coupling produced by the two configurations of Figure 2.3c and 2.3d are collectively referred as mixed coupling because neither the electric fields nor the magnetic fields dominate the interaction between the resonators.

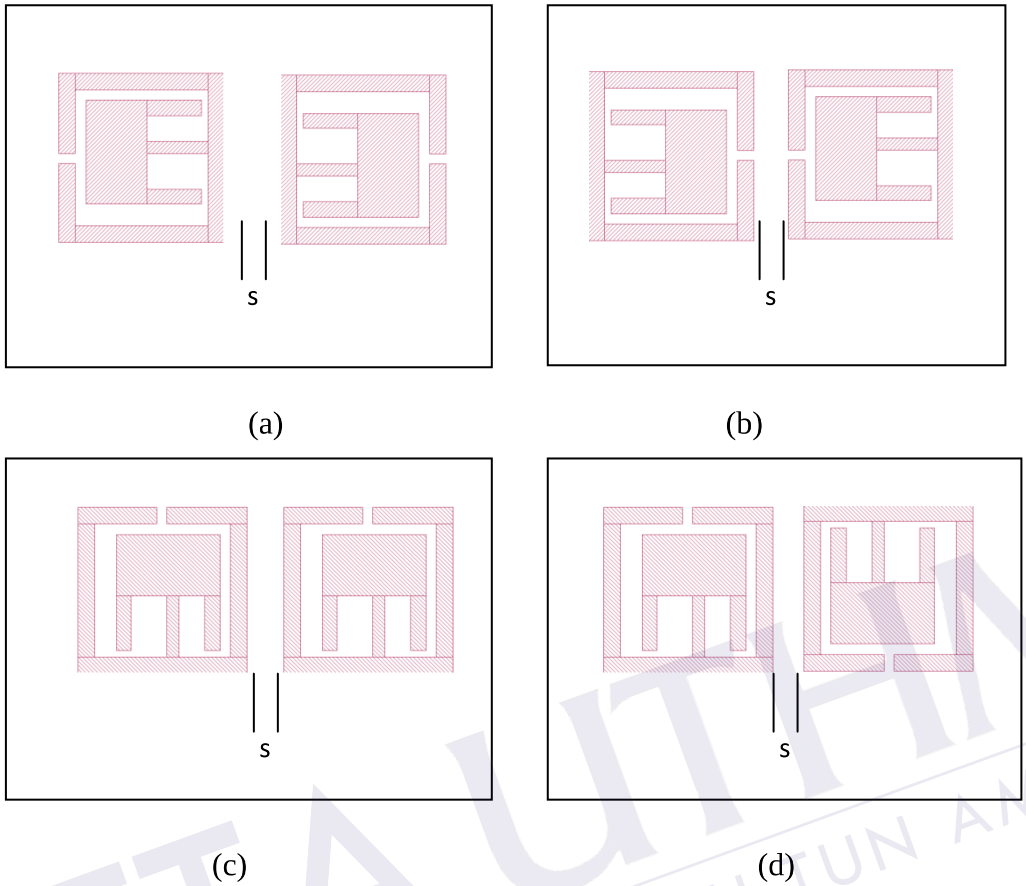

Figure 2.3: Typical arrangements of a pair of square resonators with (a) magnetic coupling; (b) electric coupling; (c) and (d) mixed coupling.

The definition of *k* given in equation 2.3 is not practical for calculation purposes since it requires the knowledge of the electromagnetic fields everywhere. A useful alternative expression for k can be obtained from a well known fact in physics, when two resonators are coupled to each other they resonate together at two frequencies f_1 and f_2, that are in general different from their original resonant frequency f_o. Furthermore, these two frequencies are associated with two normal modes of oscillation of the coupled system, and their difference increases as the coupling between the resonators increases. A formula giving the exact relationship between these quantities is derived in [21] and is given by;

$$k = \frac{f_2^{\,2} - f_1^{\,2}}{f_1^{\,2} + f_2^{\,2}} \qquad (2.25)$$

To find coupling between a pair of resonators like any of those of Figure 2.5, they are excited with a pair of loosely coupled feed lines to obtain a transmission parameter S_{21} from which the two resonant frequencies f_1 and f_2 can be obtained. These procedures can then be repeated for several separations s between resonators in order to produce design plot that gives *k* Vs *s*.

CHAPTER 3

METHODOLOGY

3.1 Introduction

There are different method carrying out research in the field of RF/Microwave system, like experiment and simulation. The building of a design and the testing of it in practical experiment is an expensive and time-consuming method. To minimize time and cost, this project focus on simulation experiment based on Sonnet Lite simulation software in order to simulate frequency response for resonators and filters.

The Sonnet *EM* analysis is based on a method-of-moments technique. The circuit metal is first meshed into small subsections. The *EM* coupling between each possible pair of subsections is calculated and this fills a big matrix. The matrix is inverted, yielding all currents everywhere in the circuit metal. This, in turn, determines things like S-parameters, which can be used in other analysis programs.

The Sonnet analysis has very high accuracy because it calculates all couplings between subsections using a 2-D Fast Fourier Transform (*FFT*). In signal processing, application of the *FFT* requires uniform time sampling of a signal. In EM analysis, the *FFT* requires uniform space sampling across the two dimensions of the substrate surface. Thus the analyzed circuit metal falls on a uniform underlying *FFT* mesh. The *FFT* approach also requires the circuit to exist inside a conducting, shielding box.

REFERENCES

1. J.S. Hong and M. J. Lancaster, Microstrip Filters for RF/Microwave Applications. New York: Wiley, 2001.
2. I.Wolff, Microstrip bandpass filter using using degenerate modes of a microstrip ring resonator, Electron.Lett, vol. 8, no.12, pp.302-303, Jun. 1972.
3. J.S. Hong and M.J. Lancester, Bandpass characteristics of new dual mode microstrip square loop resonators, Electron. Lett, vol.31, no.11. pp. 91-892, Nov. 1995.
4. J.S. Hong and S.Li, Theory and Experiment of dual mode microstrip triangular patch resonators and filters, IEEE Trans. Microw. Theory Tech, vol. 52, no. 4, pp. 1237-1243, Apr. 2004.
5. C. Lugo and J. Papapolymero, Bandpass filter design using a microstrip triangular loop resonator with dual mode operation, IEEE Microw. Wireless Compon. Lett, vol 15, no.7 pp. 75-477, Jul. 2005.
6. David M. Pozar.Microwave Engineering, Second Edition. John Wiley & Sons, Inc.pp.442;1998.
7. David M. Pozar.Microwave Engineering, Second Edition. John Wiley & Sons, Inc.pp.160-162;1998.
8. Wen Hua Tu and kai Chang. Compact Microstrip Bandstop Filter Using Open Stub and Spurline. IEEE Microwave and Wireless Components Letters, vol.15, No.4, pp.268-270;April 2005.
9. Fred Gardiol. Microstrip Circuits. John Wiley & Sons, Inc.pp.51;1994
10. Wolf.Microstrip *Bandpass Filter Using degenerate Modes of a Microstrip Ring Resonator*, “Electronic Lett.Vol.8, No.12, 302.

11. Hong, J-S and M.J Lancaster, *Bandpass Characteristic of New Dual Mode Microstrip Square Loop Resonators,* “Electronics.Lett, Vol.30,.No.11,891;1995
12. Hong,.J-S,.H.Shanman, and Y.H.Chun, *Dual Mode Microstrip Open Loop Resonators and Filters*, “IEEE. Trans.Microw. Theory Tech., Vol.55, No.8, 1764{1770, 2007.
13. Song, K and Q Xue, *Novel Broadband Bandpass Filters using Y-shaped dual mode microstrip resonators,* “IEEE Microw. Wire. Compon, Lett, Vol.19, No.9,548 {550,.2009
14. Wang, Y.-X., B.-Z. Wang, and J. Wang, A *compact square loop dual-mode bandpass Filter with wide stop-band*," Progress In Electromagnetics Research, Vol. 77, 67{73, 2007.
15. Chen, Z.-X., X.-W. Dai, and C.-H. Liang, *Novel dual-mode dual-band bandpass Filter using double square-loop structure*," Progress In Electromagnetics Research, Vol. 77, 409{416, 2007.
16. Hong, J.-S. and M. J. Lancaster, *Microstrip cross-coupled trisection bandpass filters with asymmetric frequency characteristics,*"IEE Proc. Microw. Antennas Propag., Vol. 146, No. 1, 84{90,1999.
17. 11. Kurzrok, R. M., *General three-resonator Filters in waveguide*,"IEEE Trans. Microw. Theory Tech., Vol. 14, No. 1, 46{47, 1966.
18. Chang, C.-Y. and C.-C Chen, *A novel coupling structure suitable for cross-coupled filters with folded quarter-wave resonators*,"IEEE Microw. Wirel. Compon. Lett., Vol. 13, No. 12, 517{519,2003.
19. Mongia, R., I. Bahl, and P. Bhartia, *RF and Microwave Coupled-line Circuits*, Artech House, Norwood, MA, 1999.
20. Matsuo, M., H. Yabuki, and M. Makimoto, Dual-*mode stepped impedance ring resonator for bandpass fillter applications*," IEEE Trans. Microw. Theory Tech., Vol. 49, No. 7, 1235 {1240, 2001.
21. Pozar, D. M., *Microwave Engineering*, 3rd edition, Wiley, New York, 2005.