# DESIGN AND DEVELOPMENT OF SWITCHABLE MATCHED BANDSTOP TO BANDPASS FILTER USING RING RESONATOR

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## PROJEK SARJANA MUDA II

**Tajuk Projek** : DESIGN AND DEVELOPMENT OF SWITCHABLE MATCHED BANDSTOP TO BANDPASS FILTER USING RING RESONATOR

.

**Sesi Pengajian** : 2015/2016

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Supervisor's Name : PM. DR. BADRUL HISHAM BIN AHMAD

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# ABSTRACT

In the era of advancement in modern technologies, the growth of the modern wireless communication system is increasing exponentially. This automatically creates a high demand for filters that have the properties of compact-sized as well as being able to provide a high performance to the spectral cognitive systems. Moreover, a reconfigurable designed filters are now placed in demand especially in the modern wireless communication market where the filter can offer a very compact realization of having a reduced-sized and switchable mode of operations rather than having a number of filter banks in order to reduce the complexity of the system. Therefore this project aims to propose a new technique to design a reconfigurable filter that is based on a dual-mode ring resonator which has a switchable properties from being a matched bandstop filter, to bandpass filter and vice versa. This filter can be known as Switchable Matched Bandstop to Bandpass Filter and is proposed to achieve a high quality factor in order to provide high performance to the system. The switchable properties are able to be achieved simply by adding varicap diodes into the network topology. A brief overview on the methodology of this project includes conducting library research and literature reviews, designing and simulating the filter design and lastly fabricating the design and analyzing the measured results. Upon completion of this project, the outcome includes a fabricated switchable matched bandstop to bandpass filter with varicap diodes as its switching elements. The filter will have an operating frequency of 1GHz and is able to provide a high quality factor which results in high performance of the system as well as being a compact-sized filter.

# ABSTRAK

Pada masa kini, pertumbuhan sistem komunikasi tanpa wayar yang moden semakin meningkat dengan pesat. Ini secara automatik mewujudkan permintaan yang tinggi untuk penapis yang mempunyai ciri bersaiz kecil dan juga dapat memberikan prestasi yang tinggi. Selain itu, pembentukan semula penapis kini direka untuk memenuhi permintaan terutamanya dalam pemasaran komunikasi tanpa wayar yang moden di mana penapis boleh memberikan kesan sangat efektif yang mempunyai saiz yang kecil dan mod operasi yang boleh di ubah daripada menggunakan beberapa penyimpan penapis. Oleh itu projek ini bertujuan untuk mencadangkan satu teknik baru untuk mereka bentuk penapis yang menggunakan resonator ‘ring’ yang mempunyai ciri-ciri boleh diubah daripada menjadi penapis ‘matched bandstop’ kepada penapis ‘bandpass’ dan sebaliknya. Penapis ini boleh dikenali sebagai ‘Switchable Matched Bandstop to Bandpass Filter’ dan dicadangkan untuk mencapai kualiti faktor yang tinggi dan memberikan prestasi yang tinggi kepada sistem. Ciri-ciri boleh ubah dapat dicapai hanya dengan menambah diod varicap ke dalam topologi rangkaian. Satu gambaran ringkas mengenai metodologi projek ini ialah menjalankan penyelidikan perpustakaan dan ulasan kesusasteraan, mereka bentuk penapis dan proses simulasi reka bentuk penapis dan akhir sekali menjalankan fabrikasi reka bentuk penapis dan menganalisis keputusan yang telah diperoleh. Setelah projek ini dilengkapkan, hasil kajian projek ialah penapis ‘matched bandstop to bandpass’ yang telah difabrikasi yang mampu untuk bertukar antara dua mod operasi. Penapis ini akan beroperasi pada frekuensi 1GHz dan mampu untuk memberikan kualiti faktor yang tinggi, prestasi yang tinggi kepada sistem dan juga penapis bersaiz kecil.

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| | |
|---|---|
| ADS | Advanced Design System |
| FR4 | Flame Retardant Grade 4 |
| RF | Radio Frequency |
| Q | Quality |
| MCLIN | Microstrip Couple Line |
| MLIN | Microstrip Line |
| SMD | Surface Mount Device |
| DC | Direct Current |

# CHAPTER 1

# INTRODUCTION

## 1.1 PROJECT INTRODUCTION

The growth of the modern wireless communication market is increasing exponentially which creates a high demand for compact-size as well as providing high performance and reconfigurable designed filters. Therefore, the microstrip technology and its application offers a very compact realization for the demand of compact microwave reconfigurable filters. This project proposes a new technique used in the design of switchable matched bandstop to bandpass filters with high quality factor (Q). This filter design is realized by using a lossy low-Q resonator which is a dual-mode ring resonator in order to produce not only a high-Q bandstop filter but is also able to switch from matched bandstop response to bandpass response with operating frequency of 1GHz. The switching elements that will be used in this proposed technique are varactor diodes where the varactor diodes are incorporated into the network topology in order to exhibit either a matched bandstop or bandpass response. This filter will result in two modes of operation under two conditions which the first condition is where the filter will produce a matched bandstop response when the varactor diodes are turned on (ON state) and the second condition is where the filter will produce a bandpass response when the varactor diodes are turned off (OFF state). This project will present the theoretical analysis and implementation of the approach.

## 1.2 PROBLEM STATEMENT

As the modern wireless and microwave systems are progressing towards the spectral cognitive systems, it is necessary to produce more and more reconfigurable filter in order to enable the full potential of the system's performance while at the same time being small-sized and low-cost product. This project aims to propose a new technique of a reconfigurable filter using dual-mode ring resonator that allows the filter to switch its operation from being a matched bandstop filter to bandpass filter where varactor diodes are added into the network topology as the switching elements. This switchable filter operates at a frequency of 1GHz, able to provide a high quality factor (above 30) and is also compact in size.

## 1.3 OBJECTIVE

The purpose of this project is to propose a new technique of designing a switchable matched bandstop to bandpass filter by using a dual-mode ring resonator that is able to switch the filter's operation from being a matched bandstop filter to a bandpass filter. Therefore, for the purpose of this research, three objectives have been identified which are described as follows:

i. To design a switchable matched bandstop to bandpass filter with operating frequency of 1GHz with the help of Advanced Design System (ADS) Software by adding varactor diodes into the network topology as switching elements in order for the filter's ability to switch it's operation from bandstop to bandpass filter and vice versa.

ii. To analyze and improve the switchable matched bandstop to bandpass filter design in terms of achieving the highest quality factor and reduced in the filter's size as well as tuning the filter design in the simulation to obtain the best possible result before proceeding with the fabrication process.

## 1.4 SCOPE

The scope of this project will limit itself in designing the switchable matched bandstop to bandpass filter based on the design specifications as listed below:

i. Design of filter with the help of ADS software.
ii. Using the microstrip technology as models of fabrication.
iii. The designed filter is based on a dual-ring resonator.
iv. Fabrication of the filter design using FR-4 board.
v. Filter must have the ability to switch its operation from giving a matched bandstop response to a bandpass response.
vi. The operating frequency of the filter is at 1GHz.
vii. Varactor diodes are used as switching elements of the filter.
viii. The S11 response for the matched bandstop filter must be below than 15dB.
ix. The S21 response for the matched bandstop filter must be below than 20dB.
x. The filter must provide a high quality factor which is estimated to be at least above 30.

## 1.5 SIGNIFICANCE OF PROJECT DESIGN

There are many importance of realizing this project design. The main significance of this project design are described as follows:

i. The switchable matched bandstop to bandpass filter is a compact filter having two modes of operation in only one filter design. This means that instead of having a number of filter banks, this design reduces the complexity of the system by allowing filter re-configurability to switch from being a matched bandstop filter to a bandpass filter.

ii. The ability to produce a low cost filter that offers a high performance to the system. The switchable matched bandstop to bandpass filter uses a low cost substrate (FR-4) for fabrication. However, this design offers similar result to that of using an expensive substrate for the fabrication of the filter.

iii. The ability to offer better performance compared to a conventional bandstop filter. The switchable matched bandstop to bandpass filter is more selective, does not have any reflected signal in its response, low loss and has narrower bandwidth which results in high quality factor. Compared to a conventional bandstop filter, a conventional bandstop filter is quite lossy, has reflected signal in its response which means that it does not fully attenuate the signal, and also has a wider bandwidth which results in low quality factor.

## 1.6 BRIEF OVERVIEW ON THE METHODOLOGY OF THE PROJECT

The project methodology consists of three main parts. The first part is conducting the fundamental research of the project, second is the design and simulation process and lastly is the fabrication process. These processes are carried out not by order of sequence but are needed to be repeatedly done back and forth in order to obtain the best result and a functional design. For the first part, the fundamental research of the project includes conducting library research for background study and literature reviews. The second part which is the design and simulation process incudes the construction of the circuit design and simulation of the design using a specialized software called Advanced Design System

(ADS). The last part consist of the fabrication process of the designed filter onto the FR-4 board with fixed specifications and also analyzing the measured results obtained after fabrication has been done.

## 1.7 THESIS SCOPE

The overall thesis consists of five chapters namely, Chapter 1 (Introduction), Chapter 2 (Literature Review), Chapter 3 (Project Methodology) and Chapter 4 (Results and Discussions) and lastly Chapter 5 (Conclusion and Suggestions). In Chapter 1, the introduction on the proposed project will be briefly explained. This chapter also includes the problem statement, objectives, scope and importance of project design and lastly followed by a brief overview on the methodology of the project. Chapter 2 discusses on the literature reviews of the past researchers' works that are directly or indirectly related to this project. The literature reviews are mainly based on the journals made by previous researchers that may help in the design process of this project. Chapter 3 explains in detail about the methodology that have been carried out along the process of implementing this project. Chapter 4 discusses on the results and findings obtained after the project have been implemented. Lastly, Chapter 5 concludes the overall project and briefly explain the suggestions and future works that can be done in order to improve the project design.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 FUNDAMENTAL OF MICROWAVE FILTERS

A microwave filter can be described as a two-port network that is used mainly to control the frequency response at a certain point in an RF or microwave system. This is done by providing transmission at frequencies which is within the passband of the filter and attenuation in the stopband of the filter. The typical frequency responses include low-pass, high-pass, bandpass and bandstop (also known as band-reject or notch) characteristics. The application of microwave filters can be found in virtually any type of RF or microwave communication, radar, or even test and measurement system.

### 2.1.1 Conventional Bandstop Filters

Bandstop filters, also known as band-reject or notch filters are the kind of filter that passes all frequencies above and below a particular range set by the component values. Bandstop filters can be made out of a low-pass and a high-pass filter by connecting the two filter sections in parallel with each other as shown in Figure 2.1 below.

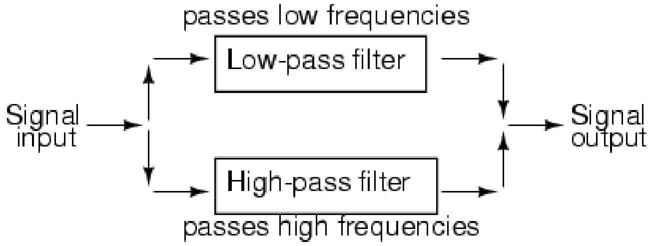


Figure 2.1: System Level Block Diagram of a Bandstop Filter

Figure 2.2 shows the structure of a bandstop circuit when constructed using two capacitive filter sections.

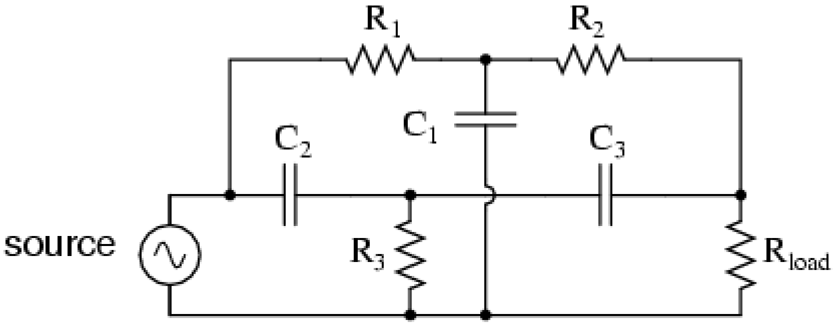


Figure 2.2: Bandstop Filter Circuit

The low-pass filter section is comprised of $R_1$, $R_2$ and $C_1$ in a "T" configuration while the high-pass filter section is comprised of $C_2$, $C_3$ and $R_3$ also in a "T" configuration. This arrangement is commonly known as a "Twin-T" filter, which gives sharp response when the component values are chosen in the following ratios:

$$R_1 = R_2 = 2(R_3) \qquad (2.1)$$

$$C_2 = C_3 = (0.5)C_1 \qquad (2.2)$$

Given these component ratios, the frequency of maximum rejection known as the notch frequency can be calculated using,

$$f_{notch} = \frac{1}{4\pi R_3 C_3} \tag{2.3}$$

### 2.1.2 Conventional Bandpass Filters

Bandpass filters are used for applications where a particular band, or spread, or frequencies are needed to be filtered from a wider range of mixed signals. A single filter comprises of a combination of low-pass and high-pass properties is called a bandpass filter. The bandpass filter circuit can be created from a low-pass and high-pass filter placed in series with each other as shown in Figure 2.3 below.

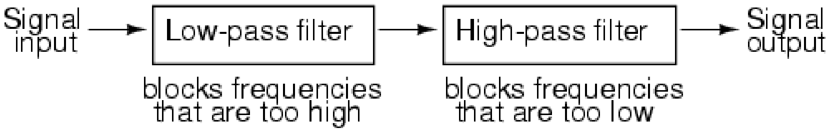


Figure 2.3: System Level Block Diagram of a Bandpass Filter

The series combination of these two filter circuits produces a circuit that will only allow passage of those frequencies that are neither too high nor too low. The typical schematic circuit of a bandpass filter can be seen as in Figure 2.4 and Figure 2.5.

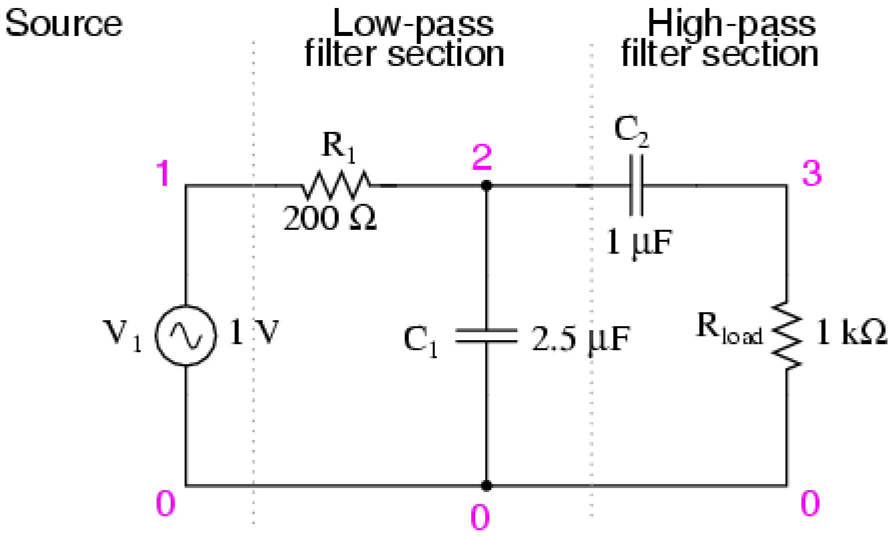


Figure 2.4: Capacitive Bandpass Filter Circuit

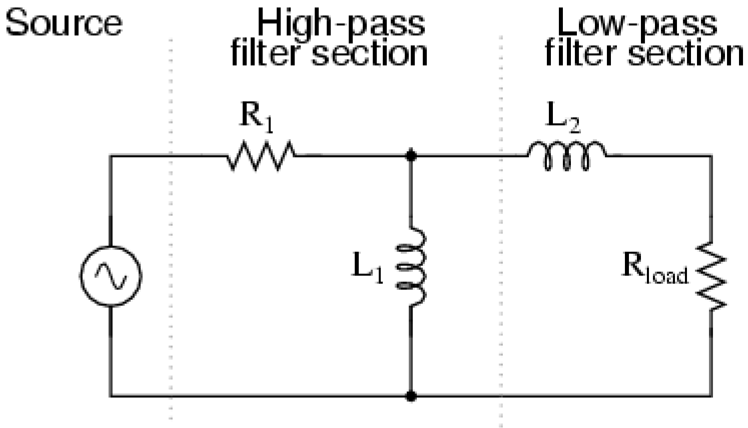


Figure 2.5: Inductive Bandpass Filter Circuit

As shown in the figures above, it can be seen that bandpass filters can be constructed using capacitors or using inductors. However, it is more suitable to use capacitors in the bandpass filter circuit as the reactive “purity: of the capacitors gives them a design advantage.

### 2.1.3 Application of RF and Microwave Filters

Nowadays, the modern society have been given an enormous impact by the microwave systems. Microwave systems applications are diverse. It may include any application from entertainment via satellite television, to civil and military radar systems. As conventional telephony are a widespread, the use of cellular radio systems are also increasing in the field of communications. Basically, microwave and RF filters are most widely used in all of these systems mainly to discriminate between wanted and unwanted signal frequencies. Cellular radio provides particularly demanding filter requirements both in the base stations and in mobile units. Figure 2.6 shows the block diagram of a typical filtering application which is the RF front end of a cellular radio base station.

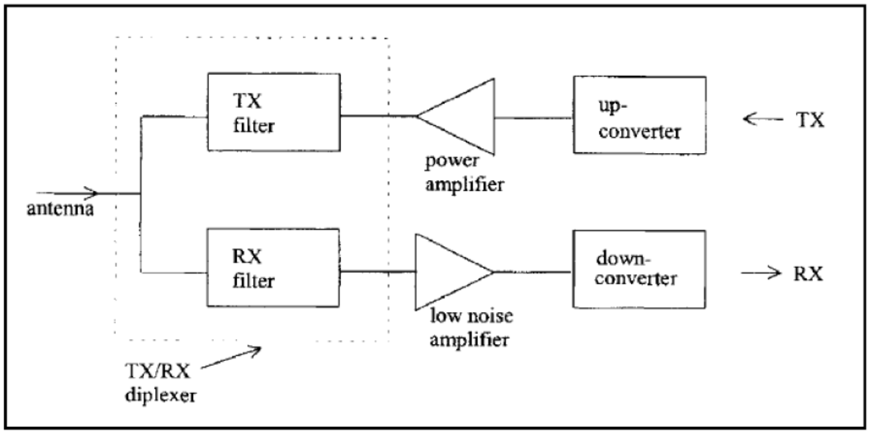


Figure 2.6: RF Front End of a Cellular Base Station

Since the GSM system uses a time division multiple access (TDMA) technique, the base station may simultaneously transmit and receive. The transmit filter must have a high level of attenuation in the receive band. This is because of the transmit power amplifier which produces an out-of-band intermodulation products and harmonics that must be filtered in order to prevent leakage into the receiver and therefore satisfy the regulatory requirements on an out-of-band radiation. Moreover, in order to satisfy the power amplifier linearity and efficiency requirements, the transmit filter must have a low passband insertion loss. The receiver must be protected by a filter with high attenuation in the transmit band in order to isolate the high power transmitter. The low passband insertion loss of the transmitter allows the preservation of the system sensitivity. In summary, the selectivity of filters properties is essential to achieve base station filters with remarkable performance.

## 2.2 THEORY ON MATCHED BANDSTOP FILTERS

A perfectly matched bandstop filters are realized at high frequencies where the lossy nature of microstrip makes it difficult to achieve a high quality factor. In order to improve the quality factor of a bandstop limiter, a perfectly notched concept is applied in this design. The perfectly notched concept makes use of two identical lossy resonators which are coupled to a 90° hybrid coupler with correct coupling factors based on the reflection mode filter. When the filer operate at the center frequency, the incident signals are critically coupled to the resonators and is absorbed into the resistive part of the resonator. This leaves no reflected signals at the output and thus achieving a theoretically infinite attenuation. A bandstop limiter is one of the most practical implementation of a lossy allpass network where the filter design implements the concept of a coupled-resonator model. The coupled-resonator model represents a matched bandstop filter based on L-shape resonator. By scaling the nodes of the admittance matrix of the 90° hybrid circuits, the generalized coupled-resonator model of a perfectly matched bandstop can be obtained. Figure 2.7 shows the generalized coupled-resonator model of a matched notch filter whereas the generalized equation for the even-odd admittance of a perfectly matched bandstop filter are as follows:

$$Y_{even}\,(p) = -j + \frac{K2}{Ysub + jK2} \qquad (2.4)$$

$$Y_{odd}\,(p) = \frac{1}{Yeven\,(p)} \qquad (2.5)$$

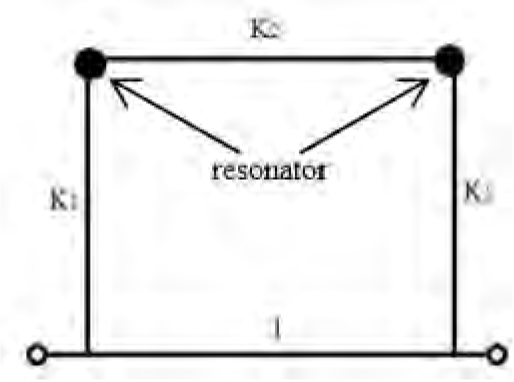


Figure 2.7: Generalized Coupled-Resonator Model of a Matched Bandstop Filter

## 2.3 DESIGN OF MATCHED BANDSTOP FILTERS USING LOSSY LOW-Q RESONATORS

### 2.3.1 Generalized Coupled-Resonator Model of a Matched Bandstop Filter

The quadrature hybrids are 3dB directional couplers with a 90° phase difference in the outputs of the through and coupled arms. This type of hybrid is often made in microstrip line or stripline form and is also known as a branch-line hybrid. Figure 2.8 below shows the hybrid circuit implementation of a perfectly-matched bandstop filter.

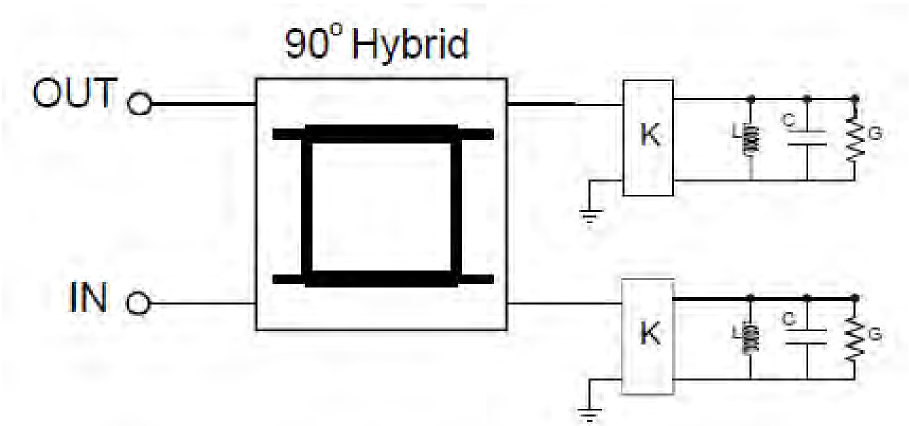


Figure 2.8: Hybrid Circuit Implementation of a Perfectly-Matched Bandstop Filter

Based on the 90° hybrid circuit, a generalized coupled-resonator model of a matched bandstop filter is then produced as shown in Figure 2.9.

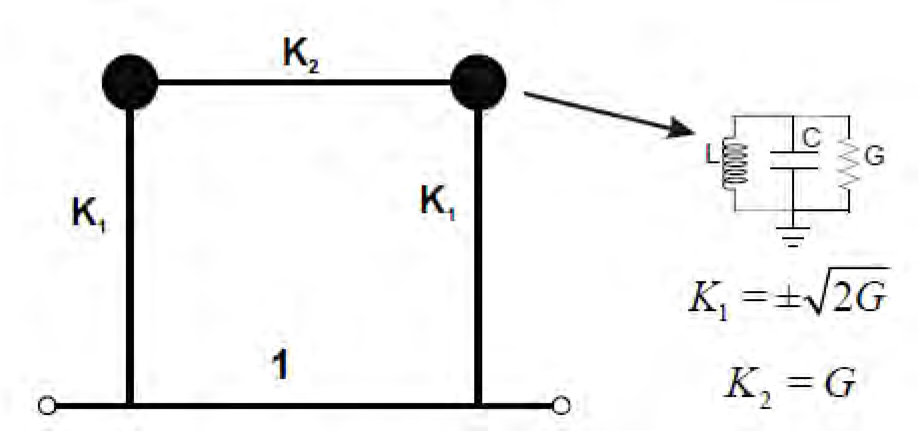


Figure 2.9: Generalized Coupled-Resonator Model of a Matched Bandstop Filter

### 2.3.2 Matched Bandstop Filter using L-Shape Resonator

The design of a matched bandstop filter consists of two parallel-coupled half-wavelength resonators. The short transmission lines that produced a nominally-90$^0$-phase shift element between the resonator couplings in a single structure. Figure 2.10 shows the transformation of the general coupled resonator model to become an L-shape resonator with the desired parameter for the matching bandstop filter.

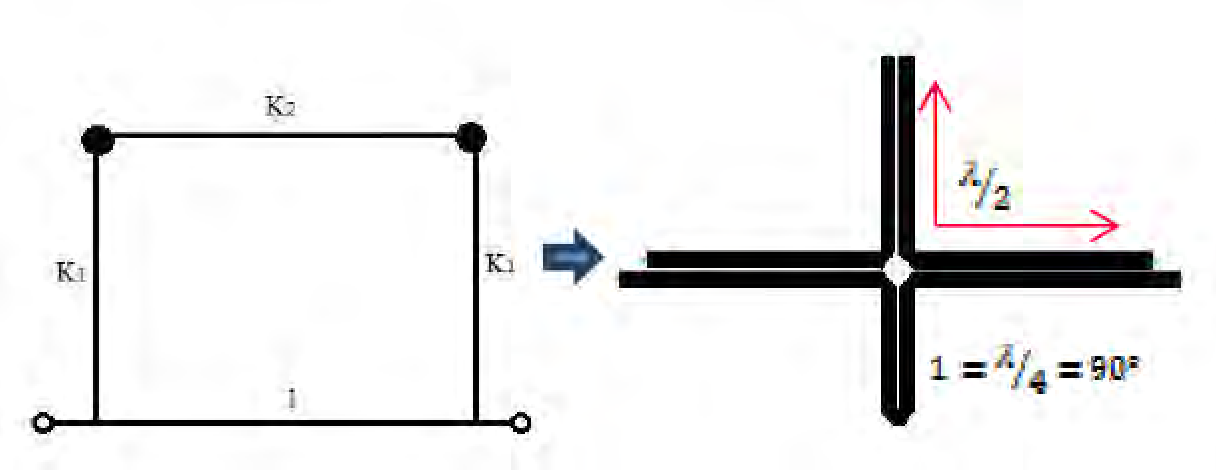


Figure 2.10: Coupled Resonator Design with the Desired Parameter for the Matching Bandstop Filter

The design of the matched bandstop filter using the L-shape resonator is based on the FR4 substrate specifications as shown below.

| Dielectric Constant, $\varepsilon_r$ | Substrate Thickness, H | Metal Thickness, T | Loss Tangent, D |
|---|---|---|---|
| 4.7 | 1.6mm | 0.035mm | 0.019 |

Table 2.1: Design Specification of FR4 Substrate

This specification is used for the reconfigurable matched bandstop filter which is designed at the center frequency of 1GHz. In order to achieve a matched bandstop response between the S11 and S21 at one resonant frequency, a perfectly notch topology with lossy resonator is implemented. K2 equals to 1 where 1 is considered as $90^{o}$ length. To ensure that the two modes can be overlapped with each other and achieve cancellation, the value of K1 gap will be tuned gradually to produce a notch bandstop. By adding the switching elements such as PIN diodes into the filter, the reconfigurable matched bandstop filter can be designed.

### 2.3.3 Matched Bandstop Filter using Ring Resonator

Based on the generalized coupled-resonator model, a dual mode design consisting of a ring resonator which is coupled with a thru line can be obtained. The dual mode design is coupled into the two modes which is $90^{o}$ and this will effectively set up a single wave circulating around the resonator. At resonance, the power coupled off from the resonator at the output is equal the in power and is $180^{o}$ out of phase with the signal that is exiting the thru-line. A perfect notch is then produced. Figure 2.11 shows the travelling wave interpretation of the dual-mode ring resonator notch where the two modes of the resonator are excited at $90^{o}$ out of phase, resulting in a single circulating wave.

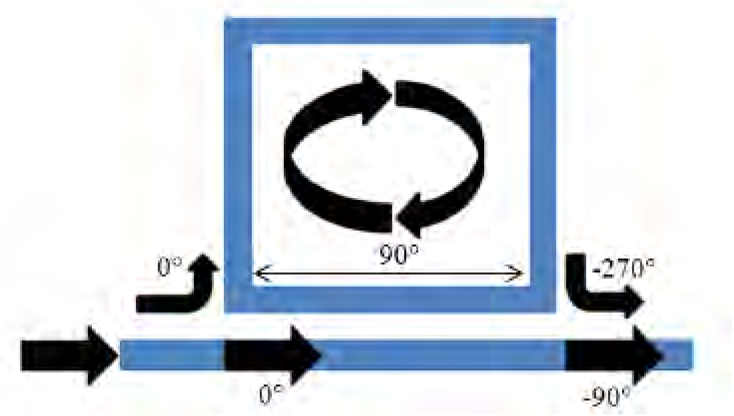


Figure 2.11: Travelling-Wave Interpretation of the Dual-Mode Ring Resonator Notch

The dual mode ring resonator structure consists of two degenerate modes or splitting resonant frequencies. The modes can be excited by using perturbing stubs, notches or symmetrical feed lines. The ring resonator with a perturbing stub or notch can be placed at 45°, 135°, 225° or 315° and can be shown in Figure 2.12.

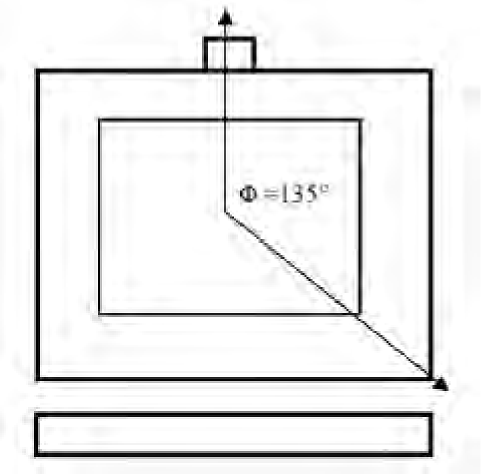


Figure 2.12: Perturbing Stub Placed At 135°

Basically, a ring resonator is two identical half-wavelength resonator that is connected in parallel. The identical resonators are excited to produce the same frequency response. If the ring does not have any perturbing and is excited by symmetrical feed lines, the frequency response may overlap with each other. However, two different frequency modes are excited and coupled to each other if one of the half-wavelength resonator is perturbing out of balance with the other.

Based on the literature reviews that have been carried out, the Switchable Matched Bandstop to Bandpass filter is designed using a dual-mode ring resonator and the switching elements used in the design are varicap diodes. Varicap diodes are used rather than the PIN diodes because it gives a much more precise matched bandstop response compared to when using the PIN diodes. However, PIN diode are also used in the circuit where it is placed at the stub of the filter. The method of adding PIN diode into the stub of the filter provides a better bandpass response compared to when not using any PIN diode.

# CHAPTER 3

# PROJECT METHODOLOGY

This chapter explains the methodology that have been conducted throughout the implementation of designing the project from the beginning until upon completion of the project. This chapter is essential in order to provide an outline process of the project and ensure that it will run smoothly and efficiently. The methodology of this project is not a step by step process but it is more to a back and forth process where each steps of the methodology may be done repeatedly until the most desirable result have been obtained. In the first semester of the Bachelor Degree Project (PSM 1), the project mainly focuses on obtaining the matched bandstop response of the filter. Then this project further its research into the second semester of the Bachelor Degree Project (PSM 2) by including varactor diodes into the coupling of the network topology in order to achieve a switchable matched bandstop to bandpass filter response where the varactor diodes will act as switching elements to indicate the filter's operation whether it operates as a bandstop filter or a bandpass filter. Included in this chapter are the three main parts of the methodology that have been carried out which are described as follows.

## 3.1 FUNDAMENTAL RESEARCH

This part mostly includes the process of conducting library research and literature reviews. The library research are conducted in order to have a clear view on the background study of the proposed project which is the Switchable Matched Bandstop to Bandpass Filter. Before designing the filter, student must first be familiarize and understand the fundamentals and the basic operations of any filter-related materials such as the bandstop filters, bandpass filters, and how both of these filters can be related in order to produce a whole new configuration of a switchable matched bandstop to bandpass filter. The concept of the matched bandstop filters are needed to be entirely familiarized in order to have a deeper understanding on how to construct the reconfigurable filter and how it can be done just by adding the varactor diodes as switching elements. From conducting the library research for this project, student were able to obtain the mathematical equations needed to calculate the theoretical values of the important parameters that will be used in the filter design. Literature reviews on previous researchers' works that are related with this project are conducted in order to collect any important and useful data that may assist the student throughout the process of designing the switchable filter.

### 3.1.1 Fundamental of the Filter Design

The basic fundamental of the filter design is based on the hybrid circuit implementation of a perfectly-matched bandstop filter as shown in Figure 3.1 below.

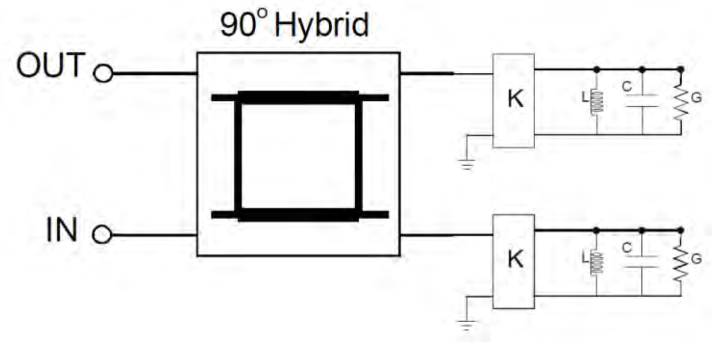


Figure 3.1: Hybrid Circuit Implementation of a Perfectly-Matched Bandstop Filter

The filter design implements the concept of coupled-resonator model which represents a matched bandstop filter based on dual-mode ring resonator. A ring resonator, as shown in Figure 3.3 is composed of two identical half-wavelength resonators connected in parallel where it is coupled with a thru-line. The dual mode designs of the ring resonator is coupled into the two modes 90° out of phase. At resonance, the power coupled off from the resonator at the output is equal the in power and 180° out of phase with the signal exiting the thru-line. The circuit then performs phase cancellation to effectively set up a single wave to circulate around the resonator in order to produce a perfectly matched bandstop filter.

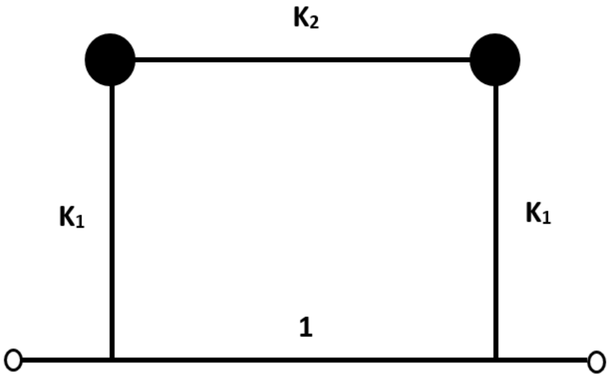


Figure 3.2: Generalized Coupled-Resonator Model of a Matched Bandstop Filter

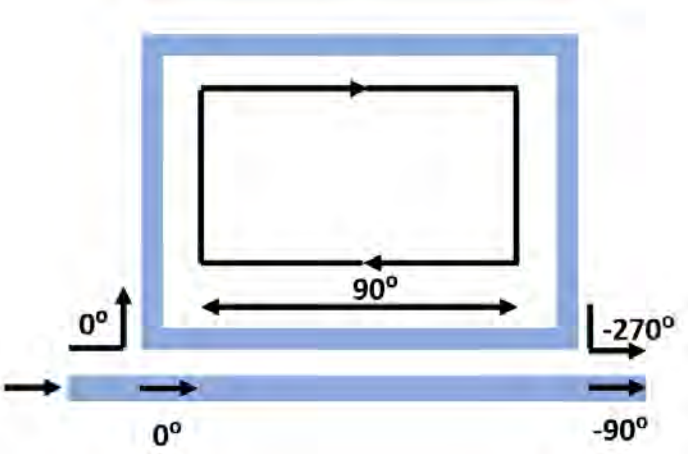


Figure 3.3: Implementation of Ring Resonator Based on the Coupled-Resonator Model

## 3.2 DESIGN AND SIMULATION

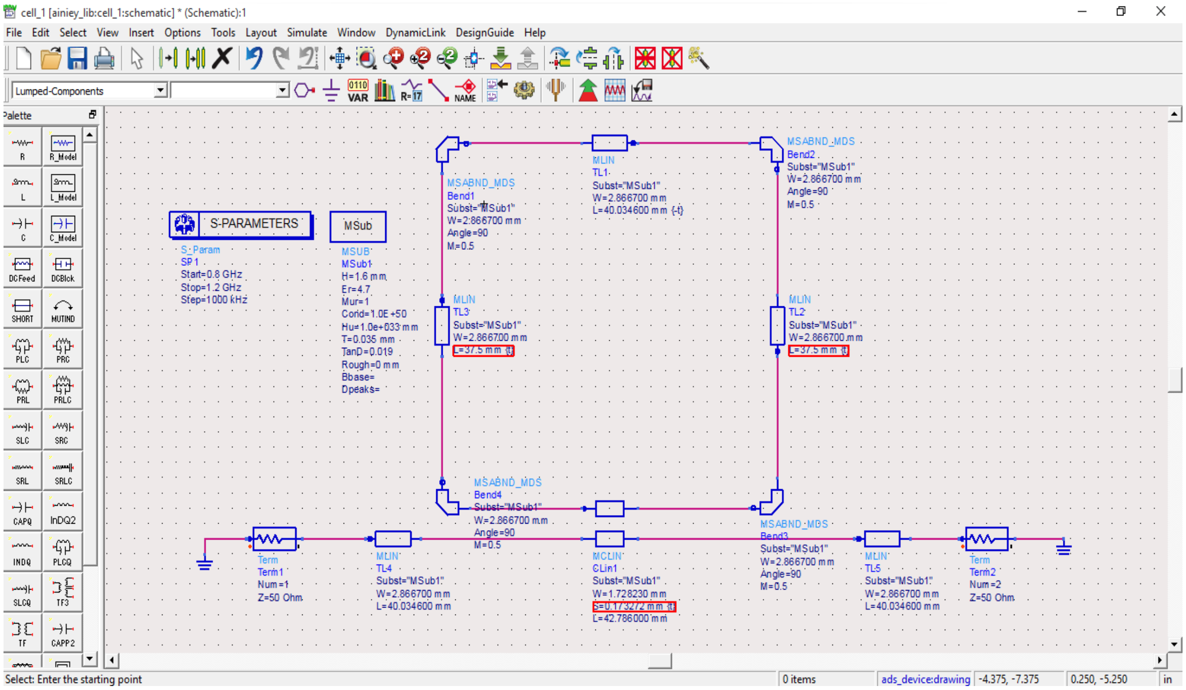
This part explains the design and simulation process of the switchable matched bandstop to bandpass filter. Firstly, the circuit of the filter is constructed using the Advanced Design System (ADS) which is a special software primarily used to design any type of filters. By using the mathematical equations obtained from the library research, the values of the parameters that will be used in the design circuit are calculated. The calculated values of each parameters are then used in order to do the simulation of the circuit design. The output response for the matched bandstop filter will be produced after simulation had been taken place. From the output response, the Q factor can be calculated. The circuit design and simulation then undergo tuning and optimization process to ensure that the filter's operating frequency is 1GHz where both the S11 and S21 response must match at that frequency. The S11 and S21 response must be below than -15dB and -20dB respectively where their values follow the ideal specification of a matched bandstop filter. When a perfectly matched bandstop response have been obtained through simulation, and the S11 and S21 response are under -15dB and -20dB respectively, the layout of the schematic diagram is then generated. However, when updating the layout from the schematic diagram of the circuit design, the response may be different than what had been obtained before. Therefore, further tuning is required using the design layout where the parameters such as the length of the stub and the gap between the MCLIN are tuned in order to obtain a much more narrow S11 and S21 response. By tuning the length of the MLIN, the frequency where the S11 and S21 matches can be shifted where the longer the length of the MLIN, the matched response shifts to a lower frequency and if the length of the MLIN is shorter, the matched response shifts to a higher frequency. The main parameter that needs constant tuning and really affects the S11 and S21 response are the gap of the MCLIN and the length of the stub. These two parameters determines the best possible matched bandstop response that can be obtained. The smaller that gap of the MCLIN, the narrower the S21 response will be and therefore the smaller the bandwidth is which results to a high quality factor.

### 3.2.1 Schematic Circuit Design for Matched Bandstop Filter

The schematic circuit of the matched bandstop filter is designed using the Advanced Design System (ADS) Software. When designing the circuit, it is important to determine all of the important parameters needed to be included into the circuit in order to obtain the desired results. The schematic circuit design consists of:

i. Microstrip Coupled Line (MCLIN) for the gap of the coupled resonator
ii. Microstrip Line (MLIN)
iii. Microstrip Bend (Bend)
iv. Terminal (Term) for the input/output port

Using the substrate specifications and also the values for each parameters obtained earlier, we can determine the width and height of each MLIN and also the width, height and gap of the MCLIN. Another alternative of determining the width, height and length of each MLIN and MCLIN is by using the LineCalc (Line Calculate) option given by the ADS software to speed up the process. The substrate specifications and the S-Parameters are defined where the start and stop frequency are 0.8GHz and 1.2GHz respectively. Figure 3.4 below shows the schematic circuit design of the Matched Bandstop Filter.



cell_1 [ainiey_lib:cell_1:schematic] * (Schematic):1

S_Param
SP1
Start=0.8 GHz
Stop=1.2 GHz
Step=1000 kHz

MSUB
MSub1
H=1.6 mm
Er=4.7
Mur=1
Cond=1.0E+50
Hu=1.0e+033 mm
T=0.035 mm
TanD=0.019
Rough=0 mm
Bbase=
Dpeaks=

MSABND_MDS
Bend1
Subst="MSub1"
W=2.866700 mm
Angle=90
M=0.5

MLIN
TL1
Subst="MSub1"
W=2.866700 mm
L=40.034600 mm {-t}

MSABND_MDS
Bend2
Subst="MSub1"
W=2.866700 mm
Angle=90
M=0.5

MLIN
TL3
Subst="MSub1"
W=2.866700 mm
L=37.5 mm {t}

MLIN
TL2
Subst="MSub1"
W=2.866700 mm
L=37.5 mm {t}

MSABND_MDS
Bend4
Subst="MSub1"
W=2.866700 mm
Angle=90
M=0.5

MSABND_MDS
Bend3
Subst="MSub1"
W=2.866700 mm
Angle=90
M=0.5

Term
Term1
Num=1
Z=50 Ohm

MLIN
TL4
Subst="MSub1"
W=2.866700 mm
L=40.034600 mm

MCLIN
CLin1
Subst="MSub1"
W=1.728230 mm
S=0.173272 mm {t}
L=42.786000 mm

MLIN
TL5
Subst="MSub1"
W=2.866700 mm
L=40.034600 mm

Term
Term2
Num=2
Z=50 Ohm

Select: Enter the starting point
0 items
ads_device:drawing
-4.375, -7.375
0.250, -5.250
in

Figure 3.4: Schematic Circuit Design for Matched Bandstop Filter

### 3.2.2 Simulation of the Circuit Design

The desired result after simulation of the circuit design are as follows:

i. The S11 and S21 response must match at 1GHz
ii. The S11 response must be below than -15dB
iii. The S21 response must be below than -20dB

If the result as describes above was not obtained, then further tuning of the circuit design must be done in order to meet the required design specifications. The easiest way to tune the circuit design is by tuning the length of the MLIN and the gap of the MCLIN as it has shown that a matched response of S11 and S21 at 1GHz is possible after tuning these parameters. The desired output response of the matched bandstop filter is as shown in Figure 3.5 below.

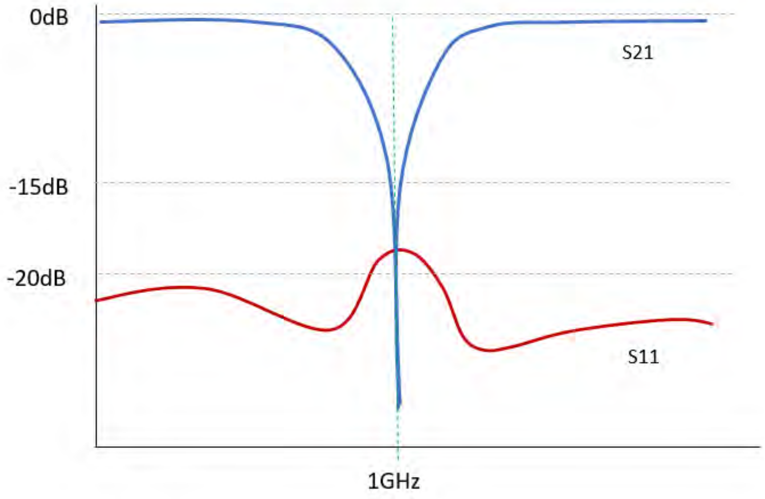


Figure 3.5: Desired Output Response for the Matched Bandstop Filter After Tuning

When a perfectly matched bandstop response have been obtained through simulation, and the S11 and S21 response are under -15dB and -20dB respectively, the layout of the schematic diagram is then generated. However, when updating the layout from the schematic diagram of the circuit design, the response may be differ from what had been obtained earlier. Therefore, further tuning is required using the design layout where the parameters such as the length of the stub and the gap between the MCLIN are tuned in order to obtain a much more narrow S11 and S21 response. The layout that had been generated from the schematic circuit design is shown in Figure 3.6.

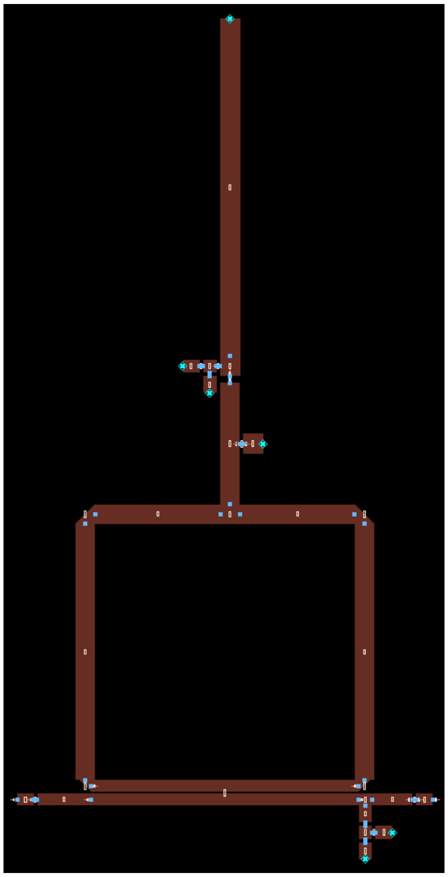


Figure 3.6: Layout Design

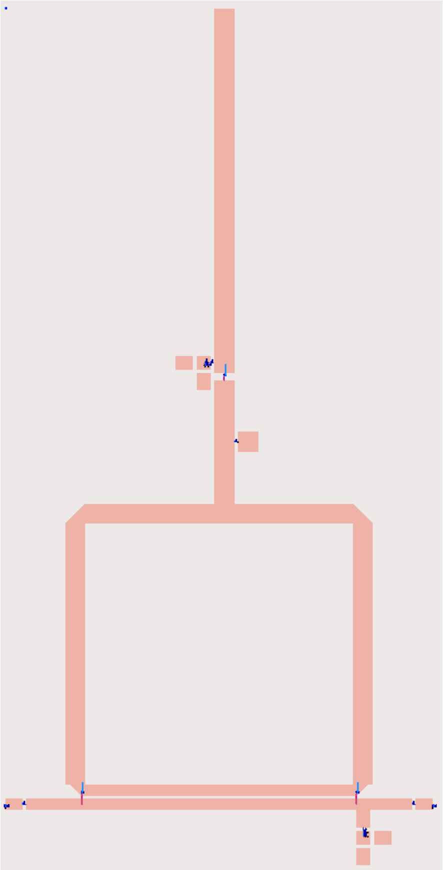


Figure 3.7: Schematic Design

By tuning the length of the MLIN, the frequency where the S11 and S21 matches can be shifted where the longer the length of the MLIN, the matched response shifts to a lower frequency and if the length of the MLIN is shorter, the matched response shifts to a higher frequency. The main parameter that needs constant tuning and really affects the S11 and S21 response are the gap of the MCLIN and the length of the stub. These two parameters determines the best possible matched bandstop response that can be obtained. The smaller that gap of the MCLIN, the narrower the S21 response will be and therefore the smaller the bandwidth is which results to a high quality factor. When the desirable matched bandstop response have been obtained after tuning the layout design, another schematic design of the filter design is generated as shown in Figure 3.7. This schematic design shows the active components such as the varactor diodes, PIN diodes, inductors, capacitors, resistors that are present in the filter design. This schematic design also allows the switching of the filter in order to see both the matched bandstop response and the bandpass response. When the voltage supply is turned off for both varactor diodes and PIN diode, a matched bandstop response can be seen and when the voltage supply is turned on for both varactor diodes and PIN diode, the output response shows a bandpass response. The PIN diode at the stub is added in order to give a more precise bandpass response compared to when no PIN diode is added. From the simulation of the layout design and the schematic, it have been proven that the filter now have switchable mode of operations where the switching properties is based on the conditions of the varactor diodes whether it is turned on or turned off to give a bandpass response or a matched bandstop response respectively. The design circuit can then be proceeded for fabrication process.

## 3.3 FABRICATION

After the circuit design of the switchable matched bandstop to bandpass filter have been successfully produced and the desirable simulation results have been achieved, the fabrication process may take place. The microstrip circuit design is fabricated onto an FR-4 Board with a standard specification as described in Table 3.1 below.

| Dielectric Constant, $\varepsilon_r$ | Substrate Thickness, H | Metal Thickness, T | Loss Tangent, D |
|---|---|---|---|
| 4.7 | 1.6mm | 0.035mm | 0.019 |

Table 3.1: Substrate's Specification

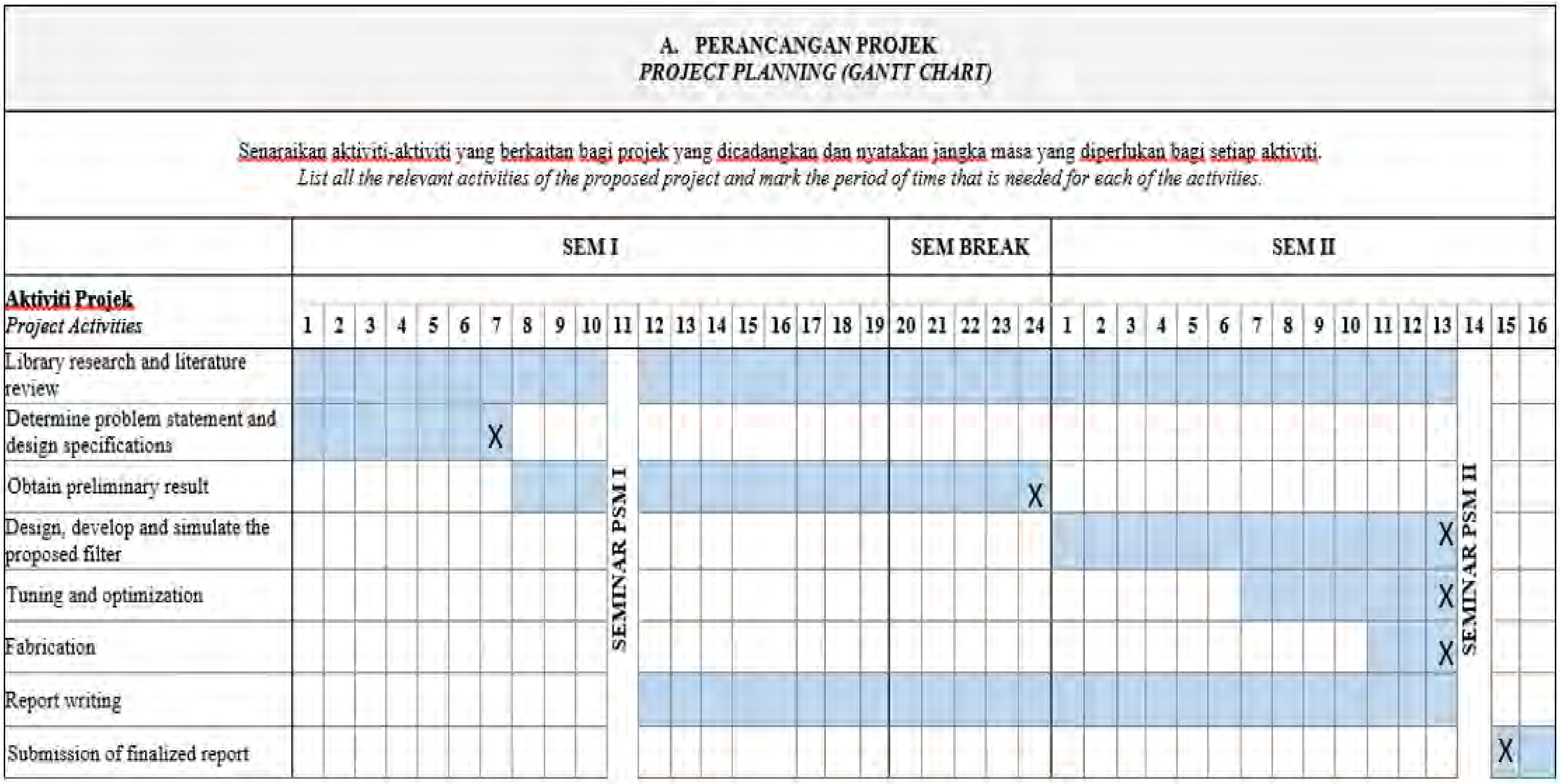
As shown in the table above, the FR-4 Board will have the dielectric constant of 4.7, substrate thickness of 1.6mm, metal thickness of 0.035mm and a loss tangent of 0.019. Surface Mount Device (SMD) such as varactor diodes, PIN diode, capacitors, inductors, resistors and ports are soldered onto the fabricated circuit. When the fabrication process have been finished, the Network Analyzer is used to measure the fabricated circuit for its S11 response, S21 response and also the quality factor of the filter. The measured results are recorded and compared with the simulation results in terms of S11, S21 and Q factor. The measured results may vary and are not exactly the same as the results obtained from simulation which may be due to some factors during the fabrication process. The difference between the measured results and simulation results may be caused by the etching process where the copper on the FR-4 board is not properly etched, difference in material dielectric across the FR-4 board, active components which varies the readings of the measurement, inaccurate soldering where the components may not be fully connected to the copper and also lossy substrate since the FR-4 board is a low cost substrate.

## 3.4 PROJECT PLANNING

This part shows the planning of the project implementation and the duration needed for each processes that have to be carried out until the completion of this project as discussed in the methodology section but in the form of flow chart and Gantt chart.

### 3.4.1 Gantt Chart

The purpose of creating this Gantt chart is to plan the minimum or maximum duration needed to implement the activities throughout the whole of the project design. This Gantt chart also helps to clearly set the deadline of each activities in order to assist the student to undergo a smooth and efficient research.



**A. PERANCANGAN PROJEK**
***PROJECT PLANNING (GANTT CHART)***

Senaraikan aktiviti-aktiviti yang berkaitan bagi projek yang dicadangkan dan nyatakan jangka masa yang diperlukan bagi setiap aktiviti.
*List all the relevant activities of the proposed project and mark the period of time that is needed for each of the activities.*

| | SEM I | | | | | | | | | | | | | | | | | | | SEM BREAK | | | | | SEM II | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aktiviti Projek**<br>*Project Activities* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| Library research and literature review | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | SEMINAR PSM I | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | SEMINAR PSM II | | |
| Determine problem statement and design specifications | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | X | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Obtain preliminary result | | | | | | | | ▨ | ▨ | ▨ | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | X | | | | | | | | | | | | | | | | |
| Design, develop and simulate the proposed filter | | | | | | | | | | | | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | X | | | |
| Tuning and optimization | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | X | | | |
| Fabrication | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ▨ | ▨ | X | | | |
| Report writing | | | | | | | | | | | | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | ▨ | | | |
| Submission of finalized report | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | X | ▨ |

Figure 3.8: Gantt Chart for Project Planning

### 3.4.2 Flow Chart

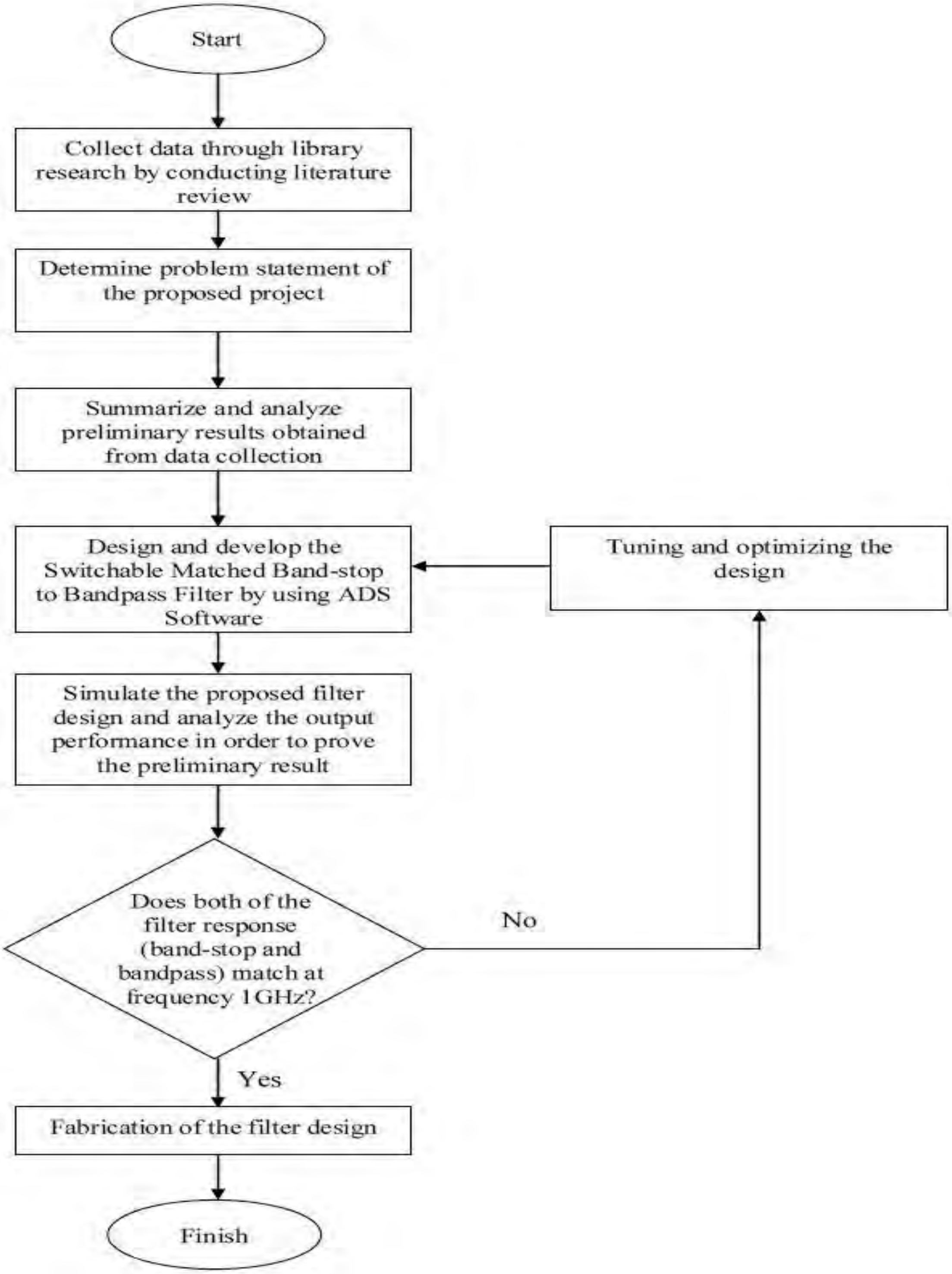


Figure 3.9: Flowchart of the Methodology Process

# CHAPTER 4

# RESULTS AND DISCUSSION

This chapter discusses on the results that have been obtained during the simulation process of the switchable matched bandstop to bandpass filter design and also the measured results after fabrication had been taken place. Firstly the design and simulation results from both the schematic circuit design and layout design are shown and analyzed. The fabricated product are also shown in this chapter in order to show the size of the filter. Moreover, the measured results after fabricating the filter design are also analyzed. Lastly, both of the results from the simulation and measurement are compared to see whether it shows good agreement between them. The challenges and complications that had been overcome during the process of obtaining the results are stated.

## 4.1 DESIGN AND SIMULATION RESULTS

### 4.1.1 First Schematic Design

The first schematic circuit design of the switchable matched bandstop to bandpass filter shows the components and elements that are required in order to design this filter. These components includes MLIN, MCLIN, MSABND, MTEE, TERM and varactor diode. Since the center frequency is at 1GHz, the start and stop frequency that was set at the S-parameters is 0.8GHz and 1.2GHz respectively. The MTEE represent the stub of the filter and the MCLIN represents the coupling gap of the filter that can be tuned in order to achieve the filter's specification. The schematic circuit design of the filter is as shown in Figure 4.1 below.

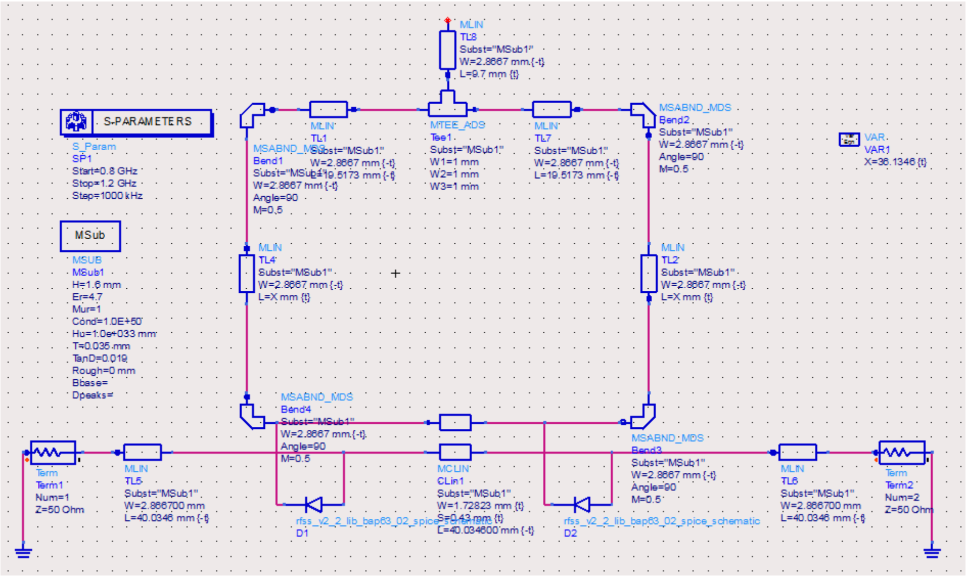


Figure 4.1: First Schematic Circuit Design for the Matched Bandstop to Bandpass Filter

After all of the components have been placed correctly and are properly connected with each other, the circuit can then be simulated in order to see if this design is able to produce a matched bandstop response. The circuit is tuned and optimized until the desirable output response is obtained. This schematic circuit design only produce a matched bandstop response which is shown in Figure 4.2. In order to see both of the matched bandstop and bandpass response, this schematic circuit design must be converted into a layout design.

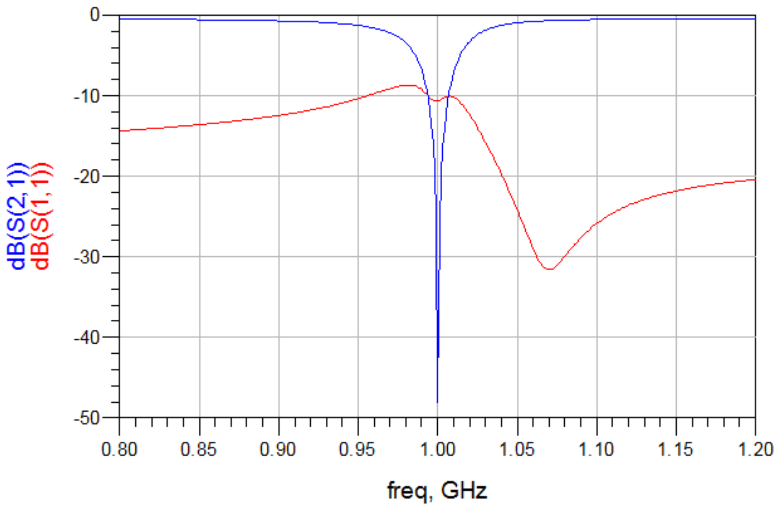


Figure 4.2: Matched Bandstop Response from Simulation of the Schematic Circuit Design

### 4.1.2 Layout Design and Second Schematic Design

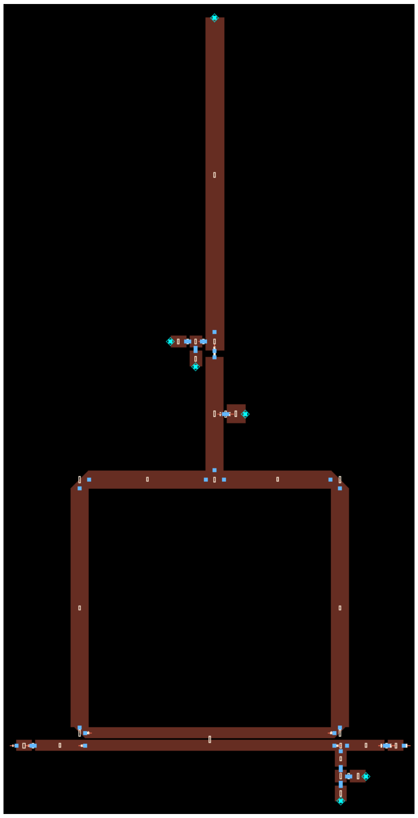


Figure 4.3: Layout Design

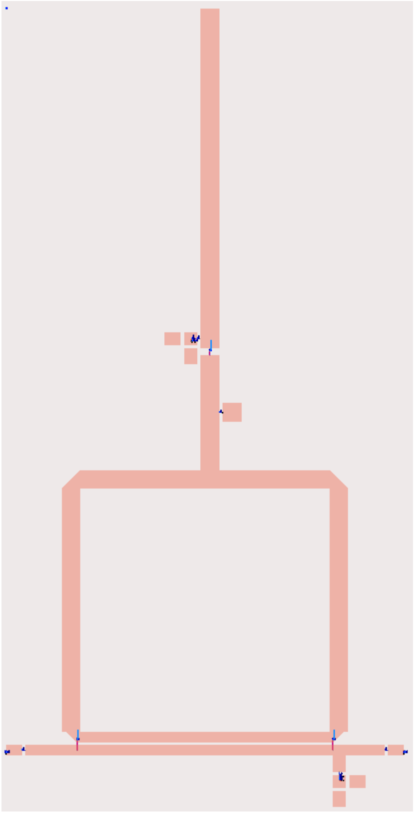


Figure 4.4: Second Schematic Design

Figure 4.3 shows the layout design of the switchable bandstop to bandpass filter which was converted from the first schematic diagram. The layout is again tuned in order to obtain the best simulation result since the result may differ from the first schematic diagram. In order to see the bandpass response, the second schematic design is produced as shown in Figure 4.4. When the layout is tuned and updated, the second schematic design is also automatically updated. This schematic design provides the response for both matched bandstop and bandpass filter by simply turning on or turning off the vltage supply in the circuit. The matched bandstop and bandpass response obtained after tuning the layout and second schematic design can be seen in Figure 4.5 and Figure 4.6.

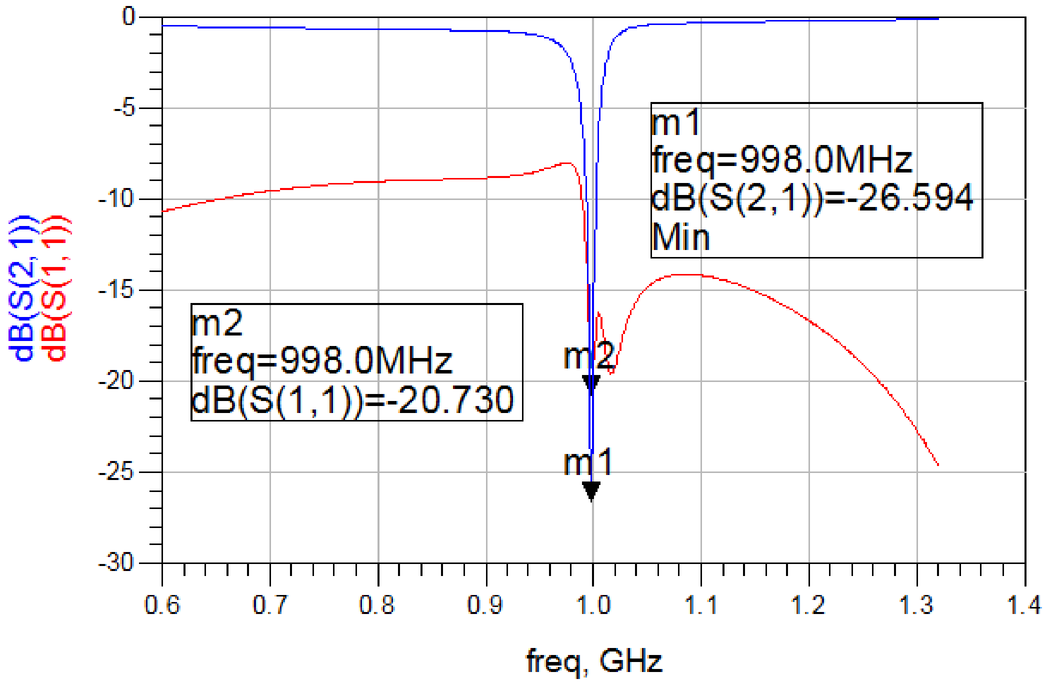


Figure 4.5: Matched Bandstop Response from the Layout and Second Schematic Design

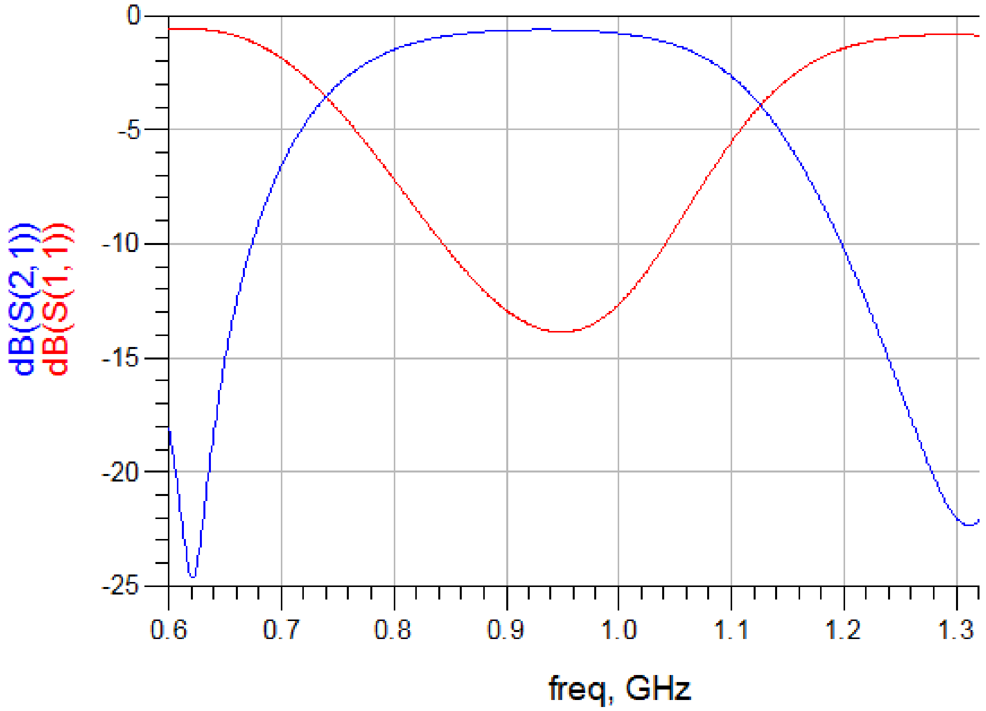


Figure 4.6: Bandpass Response from the Layout and Second Schematic Design

## 4.2 FABRICATION OF THE FILTER DESIGN

Figure 4.7: Fabricated Switchable Matched Bandstop to Bandpass Filter

After the circuit design of the switchable matched bandstop to bandpass filter have been successfully produced and the desirable simulation results have been achieved, the fabrication process may take place. The microstrip circuit design is fabricated onto an FR-4 Board with a standard specification. The FR-4 Board will have the dielectric constant of 4.7, substrate thickness of 1.6mm, metal thickness of 0.035mm and a loss tangent of 0.019. Surface Mount Device (SMD) such as varactor diodes, PIN diode, capacitors, inductors, resistors and ports are soldered onto the fabricated circuit. When the fabrication process have been finished, the Network Analyzer is used to measure the fabricated circuit for its S11 response, S21 response and also the quality factor of the filter. The measured results are recorded and compared with the simulation results in terms of S11, S21 and Q factor. The measured results may vary and are not exactly the same as the results obtained from simulation which may be due to some factors during the fabrication process. The difference between the measured results and simulation results may be caused by the etching process where the copper on the FR-4 board is not properly etched, difference in material dielectric across the FR-4 board, active components which varies the readings of the measurement, inaccurate soldering where the components may not be fully connected to the copper and also lossy substrate since the FR-4 board is a low cost substrate. The fabricated switchable matched bandstop to bandpass filter is as shown in Figure 4.7.

## 4.3 MEASURED RESULTS

The fabricated filter is measured by using the Network Analyzer. Before starting the measurement of the filter, student must first calibrate the equipment to be used during the measurement process. Once all of the equipment have been calibrated, the filter ports are connected to port 1 and port 2 of the network analyzer. The DC supply is connected to each resistor at the stub and also at the bottom right of the filter. This is to control the on and off of the varactor diodes and the PIN diode.

### 4.3.1 Matched Bandstop Response

When the DC supply is turned off, the varactor diodes and the PIN diode is in the OFF state and therefore produces a matched bandstop response as shown in Figure 4.8.

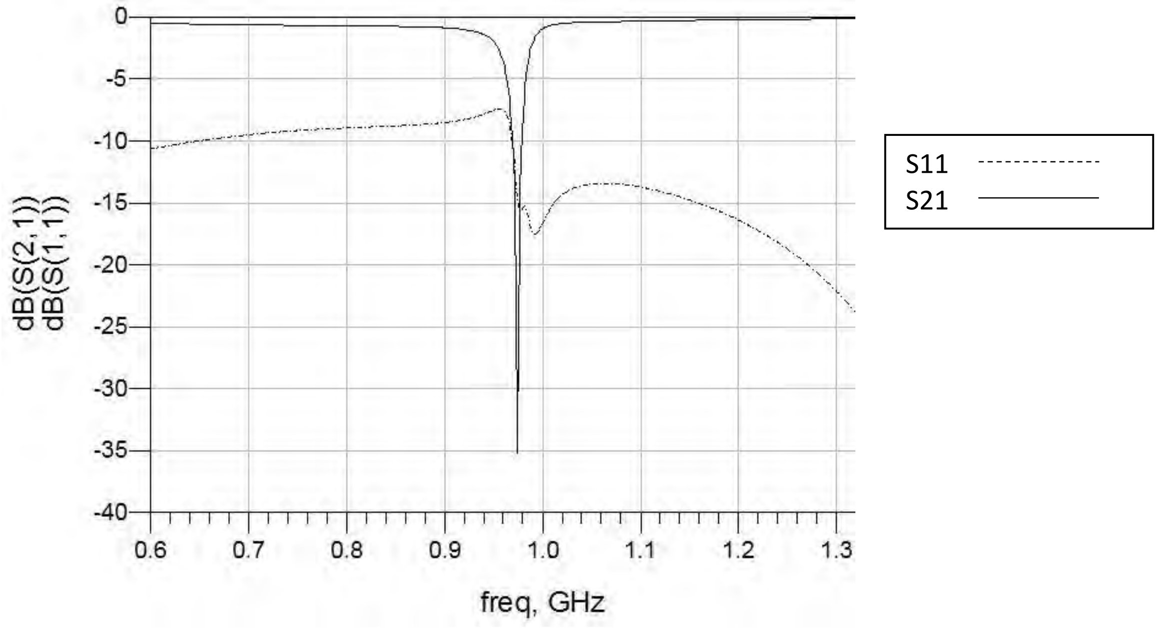


Figure 4.8: Measured Matched Bandstop Response using Network Analyzer

### 4.3.2 Bandpass Response

When the DC supply is turned on, the varactor diodes and the PIN diode is in the ON state and therefore produces a bandpass response as shown in Figure 4.8.

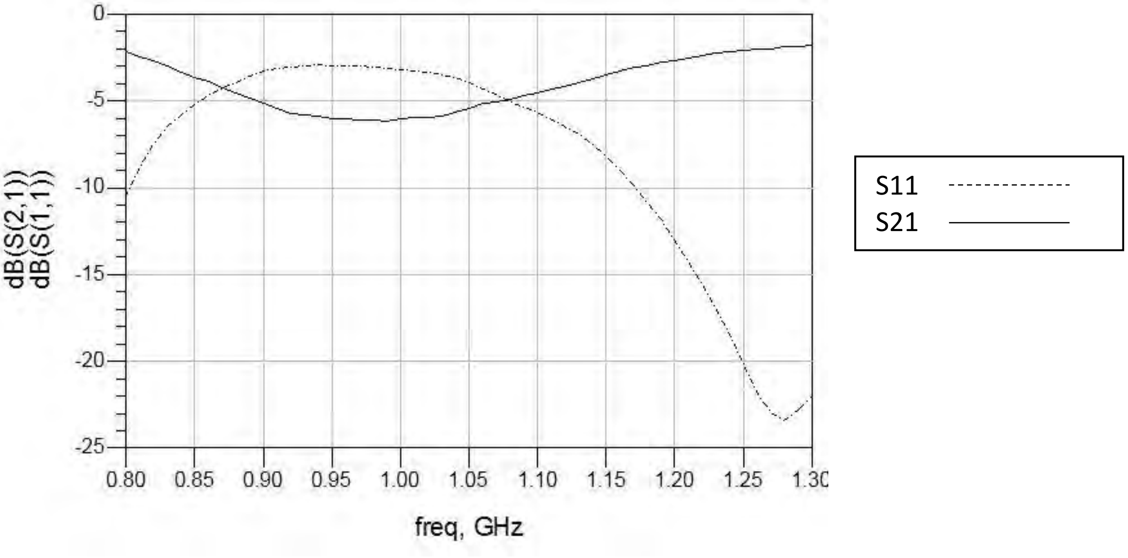


Figure 4.9: Measured Bandpass Response using Network Analyzer

## 4.4 COMPARISON BETWEEN SIMULATION RESULTS AND MEASURED RESULTS

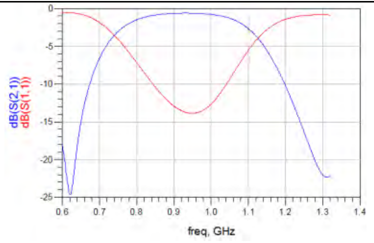
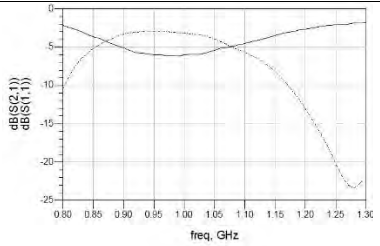
| Parameter | Matched Bandstop Filter based on Ring Resonator (size = 7cm x 13cm) | |
|---|---|---|
| | Simulation | Measurement |
| Bandstop Response (S11), dB | -20.730 (< -15) | -15.420 (< -15) |
| Bandstop Response (S21), dB | -26.594 (< -20) | -35.214 (< -20) |
| Bandpass Response (S11), (S21) |  |  |
| Q factor | 35.643 (> 30) | 27.083 |

Table 4.1: Comparison between Simulation and Measured Results

Looking at Table 4.1, the simulation result for the S11, S21 and Q factor follows the required specifications of the switchable matched bandstop to bandpass filter where the S11 must be below than -15dB, S21 must be below than -20dB and the Q factor must be at least more than 30. When simulated, the readings for the S11 is -20.730dB (below -15dB) and S21 is -26.594dB (below -20dB). This means that the simulation for the filter design follows the specifications given at the beginning of the project. Looking at the measurement results, the S11 and S21 response also follows the requirements of the filter where the S11 is -15.42dB (below -15dB) and S21 is -35.214dB (below -20dB). However the Q factor for the measurement is slightly below than 30 and does not follow the specifications given. This may due to the factors during fabrication process where the ideal Q factor was not achieved and may be caused by the etching process where the copper on the FR-4 board is not properly etched, difference in material dielectric across the FR-4 board, active components which varies the readings of the measurement, inaccurate soldering where the components may not be fully connected to the copper and also lossy substrate since the FR-4 board is a low cost substrate. The calculation of Q factor for both simulated and measured matched bandstop response is shown in equation (4.1) and (4.2) respectively.

Simulation: $$\frac{fc}{BW\,(3dB)} = \frac{0.998GHz}{1.010GHz - 0.982GHz} = 35.643 \qquad (4.1)$$

Measured: $$\frac{fc}{BW\,(3dB)} = \frac{0.975GHz}{0.984GHz - 0.948GHz} = 27.083 \qquad (4.2)$$

# CHAPTER 5

# CONCLUSION AND SUGGESTIONS

## 5.1 CONCLUSION

At the end of this project, student was able to design a Switchable Matched Bandstop to Bandpass Filter with the help of Advanced Design System (ADS) Software. The switchable filter properties where the filter can operate in two modes of operation which is being a matched bandstop filter or a bandpass filter and vice versa is achieved by simply adding varactor diodes as switching elements into the network topology. Other than that, the operating frequency of the filter where the S11 and S21 of the matched bandstop response matches is at 1GHz. Moreover, the specifications of designing the switchable filter where the S11 and S21 of the matched bandstop response must be below than -15dB and -20dB is achieved for both simulation and measurement process. Furthermore, the requirement of the Q factor where it must be above than 30 is achieved in the simulation but was not achieved in the measurement after fabrication process. This may due to some factors during the fabrication of the switchable filter since the substrate used for fabrication of the filter is a lossy substrate. Overall, the Switchable Matched Bandstop to Bandpass filter is successfully fabricated with correct filter functionality and can be improved for future work.

## 5.2 IMPORTANCE OF PROJECT DESIGN

There are a lot of importance of designing the switchable matched bandstop to bandpass filter are. Firstly, is having to design a compact filter having two modes of operations in only one filter design. This means that instead of having a number of filter banks, the switchable matched bandstop to bandpass filter reduces the complexity of a system by allowing the filter's re-configurability to switch from being a bandstop filter to a bandpass filter. Secondly is designing a low cost filter that offers a high performance to the system. This filter uses FR-4 as its substrate which is actually a low cost substrate. However, it offers a high quality factor and gives similar result to that using an expensive substrate. Other than that, this switchable matched bandstop to bandpass filter have better performances compared to a conventional bandstop filter. Compared to a conventional bandstop filter, the switchable matched bandstop to bandpass filter provides a matched bandstop response with a much narrower bandwidth which results to a high Q factor, has no reflected signal and is much more selective. A conventional bandstop filter is quite lossy, has reflected signals in its response which means that it does not fully attenuate the signal and also has a wider bandwidth which results in low quality factor.

## 5.3 POTENTIAL OF COMMERCIALIZATION

Since bandstop and bandpass filters are used in various applications with the purpose of suppressing and rejecting unwanted signals as well as allowing the passing of wanted signal, the potential commercialization of the switchable matched bandstop to bandpass filter includes the RF front end, military telecommunication systems, mobile base stations and Wi-Fi.

## 5.4 SUGGESTIONS FOR FUTURE WORK

At the end of this project, it can be concluded that the project of designing and developing a matched bandstop to bandpass filter which is based on a dual-mode ring resonator is a success as all of the objectives, specifications and requirements in designing this filter were achieved. However, future work can be done in order to improve the filter's design to give a much better performance to the system. The future work includes:

1. Repeat the fabrication of the existing design with correct and proper fabrication steps which includes the etching and soldering process and repeat the measurement for the Q factor.
2. Further tuning of the length of the stub and the gap of the MCLIN in order to obtain narrower and lower value of the S11 and S21 response to provide a perfect signal attenuation, no loss and no reflected signal.
3. Use the same concept and method of this filter design to come up with another design of the switchable matched bandstop to bandpass filter that operates at a different operating frequency.
4. Design a multi-mode filter where it has the ability to switch from being a matched banstop to allpass to bandpass filter and vice versa.

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