DESIGN OF MICROSTRIP BANDPASS FILTER

By

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FINAL REPORT

Submitted to the Electrical and Electronic Engineering Programme
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical and Electronic Engineering)

MAY 2012

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CERTIFICATION OF APPROVAL

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September 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Ridzuan Bin Zulkefli

ABSTRACT

Bandpass filters have a big role in wireless communication systems. This electronic device is widely used in the wireless transmitters and receivers. The function of filter in the transmitter is to limit the bandwidth of the output signal to the minimum necessary to convey data at desired speed and in the desired form. Meanwhile, in a receiver, a bandpass filter will only allows signals that want to be heard at the selected bandwidth of the frequencies and reject the unwanted signal to pass through it. A bandpass filter also optimizes the signal-to-noise ratio at a receiver. In designing of microstrip bandpass filters, firstly the approximated calculation based on the concentrated components like inductors and capacitors need to be done before the project going further. In this project, we will design the bandpass filters using the parallel-coupled technique.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Bandpass filter is an electronic device that will allows the specific range of frequencies to pass through it and will reject the frequencies which are out of its range by providing a large of attenuation for the stopband frequencies. In bandpass filters, there are two categories which are active bandpass filters and passive bandpass filters. Active bandpass filters are the filters which require an external source of power and employ active components such as transistors and integrated circuits. Meanwhile, other bandpass filters use no external source of power and consist only of passive components such as inductors and capacitors. This bandpass filters are called passive bandpass filters [1]. The research of the microstrip bandpass filter in the wireless communication technology is growing and trended to be raised continuously.

Nowadays, microstrip bandpass filters designed from coupled line have been widely used in many wireless communication applications. This design has the advantages in term of its planar structure, simple synthesis procedure, and good repetition [2]. The most popular structure is parallel-coupled microstrip filter because it does not require short circuits and is easy to design and implement. So, in this project, the structure of parallel-coupled mirostrip bandpass filter will be design and simulate using Ansoft Designer software before it goes to the fabrication process. The design and performance of parallel-coupled microstrip bandpass filter will be analyzed based on all of its parameters.

1.2 Problem Statement

1.2.1 Problem Identification

The microstrip bandpass filter has been extensively investigated and widely used in many microwave systems. This is due to the advances of telecommunication technology with the arising of the market demands. Bandpass filter is a passive component which is able to select signals at a certain center frequency passes through it and rejects the signals that out of the frequency region which have the potential to interfere the information signals.

In designing the bandpass filter, this question are faced, what is the maximal loss inside the pass region, the minimal attenuation in the reject/stop regions, and how the filter characteristics must look like in transition regions [3]. In the process to fulfil these requirements there are several strategies taken. For example, the choice of waveguide technology for the filter is preferred in respect to the minimal transmission loss (insertion loss). As the microstrip filter is fabricated on to the printed circuit board (PCB), it offers the advantages of easy and cheap in mass production [4]. In this project, the design of bandpass filter at the frequency of 2.4 GHz with parallel-coupled microstrip will be implemented.

1.2.2 Significance of Project

The main focus of this project is to design the microstrip bandpass filter at the frequency of 2.4 GHz. The aim is to produce the filter with compact of size and cheap in mass production. In order to do this, all the measurement and testing will be study through this project. Ansoft Designer and High Frequency Structure Simulator (HFSS) software will be fully-utilized to get the good design of the bandpass filter. Further work is the fabrication process which is on the Printed Circuit Board (PCB).

1.3 Objective and Scope of the Project

1.3.1 Main Objective

The main objective of this project is to come out with a design of the microstrip bandpass filter at the frequency of 2.4 GHz. Then analyzing the previous research on the microstip bandpass filter also will be the objectives of this project. Through this project, the basic skills in designing the microstrip bandpass filter using Ansoft Designer software and HFSS software also hope to be achieved.

1.3.2 Scope of Project

In starting the project, the literature review will be an important measure in giving the information and specifications of the microstrip bandpass filter that need to be designed. Then the designing of the filter will take part using the Ansoft Designer software and HFSS software which this part needs to give high attention. Further work is on the fabrication process of the bandpass filter onto the Printed Circuit Board (PCB). Lastly, the designed filter need to go through some measurement and testing process to make sure a good filter had been designed.

1.4 Relevancy of the Project

This project will produce a new microstrip bandpass filter which can be used in the UTP telecommunication lab. The design is based on the specification that is provided which is same with the filter that been used in the lab. So, with this new microstrip bandpass filter, it can replace the old one and the reliable of this filter can be maintained.

1.5 Feasibility of the Project

The project will be done in two semesters which include four areas which are research, design, simulation and also fabrication of the model itself. The objective is to design a new microstrip bandpass filter to replace the old design in the lab. The information about the filters will get by doing brief research about this topic. Besides that, Ansoft Designer software and HFSS software will be used to design and simulate the required design of the filter. PCB lab will be used to fabricate the designed filter. Based on the description above, it is very clear that this project will be feasible to be carried out within the time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 Fundamental of Bandpass Filters

In bandpass filters, there are two categories which are wideband and narrowband. Filters can be classified as wideband if their upper and lower passband cut-off frequencies are more than an octave apart. This is due to the upper frequency is over twice of the lower frequency. Besides that, wideband filters are also constructed from lowpass and highpass filters which are connected in series. Meanwhile, narrowband filters have upper and lower frequencies that are an octave or less apart.

2.1.1 Lowpass to Bandpass Transformation

The bandwidth of a bandpass filter and the normalized lowpass filter has a close relationship which can be seen from where it is derived. The bandwidth of a lowpass filter is come from DC to the cutoff frequency. Meanwhile the bandwidth of a bandpass filter is between the lower and upper cutoff frequencies. In order to obtain a particular bandwidth in a bandpass filter, first need to do is scale the normalized lowpass design to get the bandwidth and then transform this bandwidth into a bandpass filter design. The resultant bandwidth of the bandpass filter will be the same as the lowpass filter from which it was derived before [5]. Figure 1 below show the transformation.

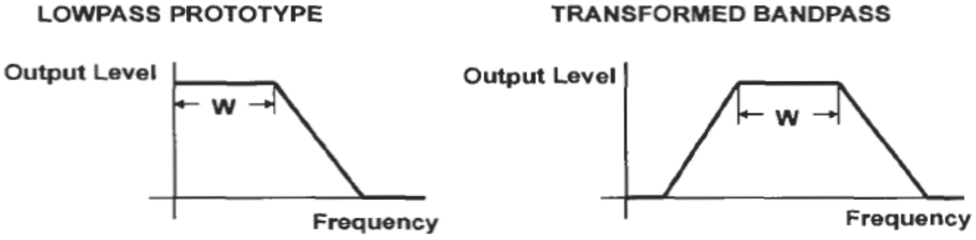


Figure 1 Lowpass to Bandpass Response Transformation

It is not restricted for only -3dB bandwidth for the relationship between the bandpass filter and its lowpass prototype. The width of the skirt in the lowpass filter response frequency, at which the same attenuation is achieved, will be equal to the width of the skirt in the bandpass filter response, at any given amount of attenuation.

As an example, a bandpass filter supposes has a center frequency of 10 kHz is desired. This filter must have a -3dB bandwidth of 6.8 kHz and 40dB attenuation at $F_c = \pm 10$ kHz, which is, the width of the skirt response at 40dB attenuation is 20 kHz. The bandpass filter must be based on a lowpass filter design that produces the same response. This is meant that it must have 40dB attenuation at a frequency of 20 kHz. The normalized stopband-to-passband frequency ratio of the lowpass filter is the same as that of the bandpass filter. So, 20 kHz divided by 6.8 kHz, which gives a ratio of 2.94. Therefore, 40dB attenuation is required at a frequency of 2.94rad/s in a normalized lowpass prototype with a 1 rad/s passband frequency, [6].

2.1.2 Passive Filters

For the passive bandpass filters, they are derived from the normalized lowpass model. The model is terminated with a 1 Ω load resistance which is normalized for a passband that extends from DC to 1 rad/s. First of the process that need to do is scale the lowpass model for the desired cutoff frequency. Then transform it into a bandpass filter and lastly the process that needs to do is scale for the correct load impedance.

Starting of the process is identifying the lowpass prototype. This could be Butterworth, Chebyshev, or any other design. Then, the filter order must also be determined. From previous example, the filter design that be needed is a 6.8 *kHz* 3dB bandwidth and with 40dB attenuation at $\pm 10kHz$. Besides that, the filter will let to have a center frequency, F_o, of 198*kHz*. Lastly, a design of Butterworth bandpass filter is make that achieves this specification [7].

As referring to the previous example, the stopband-to-passband ratio is 20/6.8 = 2.94. A fifth-order filter will provide the required performance based on the attenuation versus frequency curves for Butterworth filters. First, start with a lowpass prototype, as shown in below.

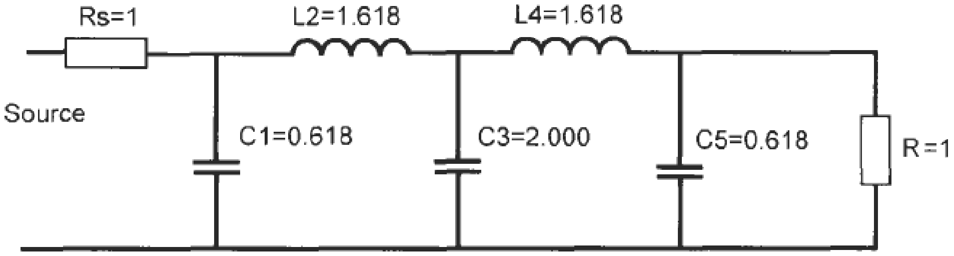


Figure 2 Normalized Fifth-Order Butterworth Lowpass Model

After that, the lowpass model must be frequency scaled to have a cutoff frequency of 6.8 kHz**.** This will be done by the same way that lowpass filters are scaled which is the inductors and capacitors are divided by $2\pi F_C$, where F_C is the cutoff frequency. The result of the divisor factor is therefore 42,725.66 which make results in the component values are shown in Figure 3.

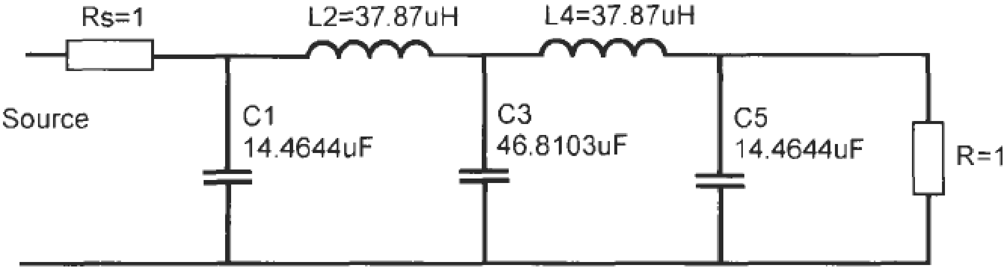


Figure 3 Scaled Fifth-Order Butterwoth Lowpass Filter

Resonate each branch of the ladder at the center frequency, *Fo* need to be done in order to frequency translate the scaled lowpass prototype into a bandpass model. This will make series inductors become series *LC* circuits, and shunt capacitors become parallel tuned *LC* circuits. But the capacitor and inductor values in the lowpass model are unchanged [8].

For a tuned circuit at resonance, $F_O = \dfrac{1}{2\pi\sqrt{LC}}$. By manipulating this equation, the inductor and capacitor values can be found. So, from manipulating the equation, we get this equation $L_{BP} = \dfrac{1}{4\pi^2 {F_O}^2 C_{LP}}$, for inductor in order to tune the lowpass capacitor. For the equation of capacitor that required to tune the lowpass inductor becomes $C_{BP} = \dfrac{1}{4\pi^2 {F_O}^2 L_{LP}}$.

The frequency translating factor is $4\pi^2 {F_O}^2 = 1.547712 \times 10^{12}$ for the bandpass filter tuned to 198 kHz. Based on this information, the bandpass circuit component values are given like Table 1.

Table 1 Bandpass Component Values

Lowpass Component	**Lowpass Value**	**Bandpass Component**	**Bandpass Value**
C1	14.4644×10^{-6}	L1	44.669×10^{-9}
L2	37.87×10^{-6}	C2	17.0614×10^{-9}
C3	46.8103×10^{-6}	L3	13.8028×10^{-9}
L4	37.87×10^{-6}	C4	17.0614×10^{-9}
C5	14.4644×10^{-6}	L5	44.669×10^{-9}

So, the circuit of the bandpass filter is shown below in Figure 4.

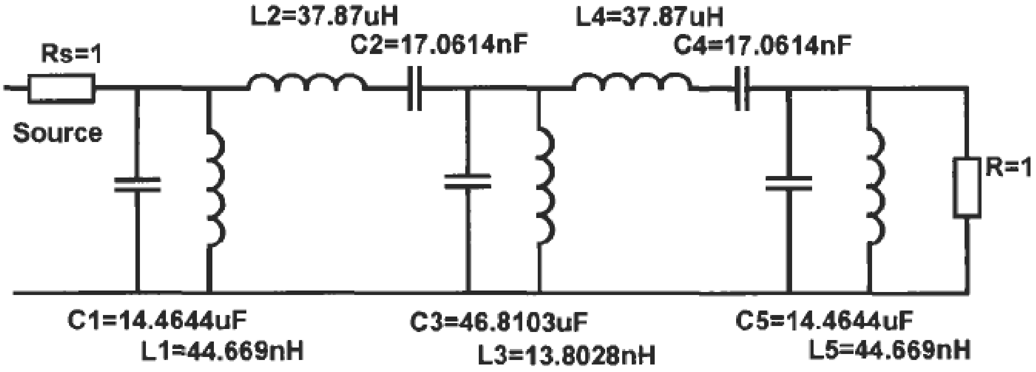


Figure 4 Bandpass Filter, with 1 Ω Load Resistance

2.2 Fundamental of Filter Design

2.2.1 Bandpass Filter

Superhigh frequency filter is a 2-port circuit that used to control the frequency response of superhigh frequency system. It is control by the transmission within pass frequency band and attenuation in cut-off band. Typical filter types are classified into low pass filter, high pass filter, band pass filter and band rejection filter based on pass characteristics. There are two filter design methods which are image parameter method and insertion loss method. First is image parameter method. This method is featured by master-slave configuration of simple 2-port filters to represent cut-off frequency and attenuation characteristics. But for this method the specific frequency response over the entire operating range is not taken into consideration [9].

Therefore, the filter design using this image parameter method can be consider simple but to get desired result the same process should be repeated several times. The second method is insertion loss method. This method applied network synthesis technique in order to design a filter with desired frequency response. So, we can say that the insertion loss method synthesizes band pass filter, high pass filter or band rejection filter by converting prototype low pass filter normalized with reference to impedance and frequency.

There are several types of filter such as Chebyshev filter, Butterworth filter, Elliptic function filter and linear phase filter. These filters are classified based on frequency and phase response characteristics [10]. Figure 5 and 6 show frequency and phase response characteristics by filter.

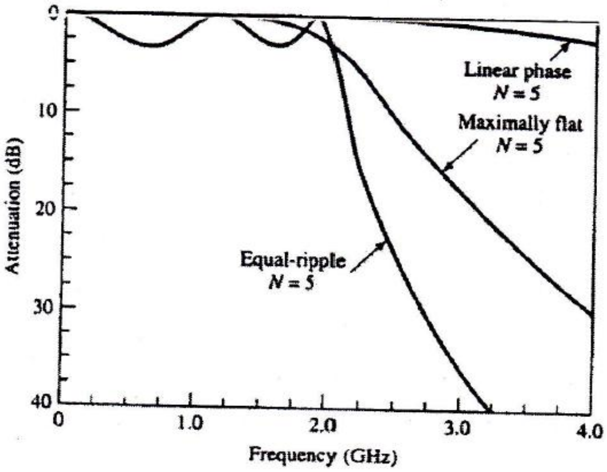


Figure 5 Attenuation characteristic vs. frequency

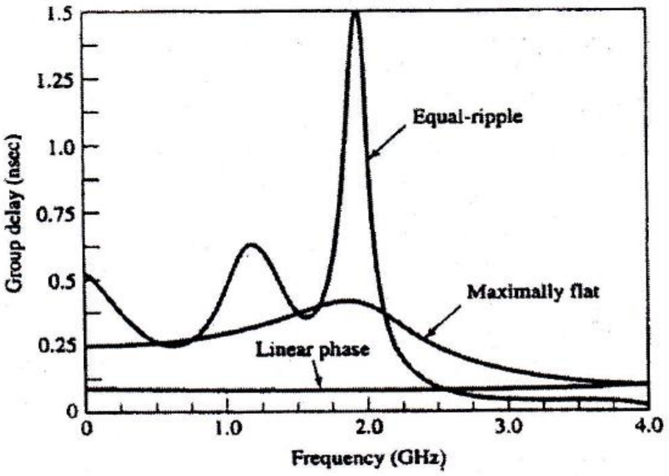


Figure 6 Group delay characteristics vs. frequency

Chebyshev or equal-ripple filter generates some degree of ripple at passband but shows good cut-off characteristics at stopband. Butterworth or maximally flat filter has flat insertion loss at pass band but shows slow cut-off characteristics at stopband. Meanwhile, linear phase filter has slow cut-off characteristics at stopband compared with Chebyshev filter or Butterworth filter but shows linear change in phase at passband. Therefore, it is desirable to design a proper filter according to application. Microstrip line filter is used for superhigh frequency band, which allows implementation of compact size and integration, compared to integrated device filter. Microstrip line filter types include stub filter, step impedance filter and coupled line filter.

2.2.2 Coupled Microstrip Line Filter

Below is the figure of 2-port coupled lines with band pass response.

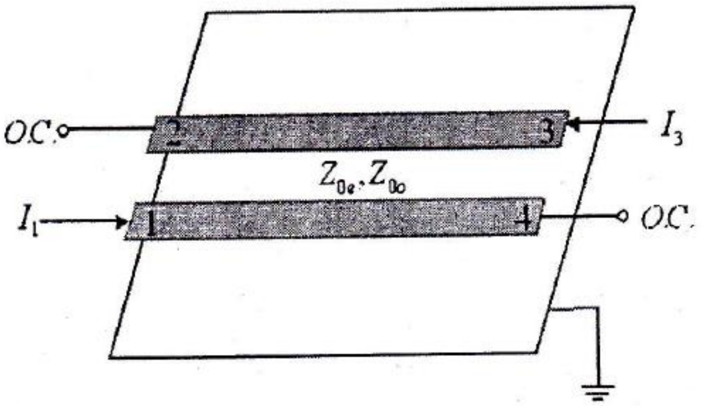


Figure 7 2-port coupled lines with band pass response

This coupled line band pass filter can be manufactured by connecting the coupled lines shown in Figure 8. One coupled line is modelized into equivalent circuit shown in Figure 9 in order to induce the design equation for this type of filter. The propagation constant of the equivalent circuit and also the image impedance can be calculated from this design. It also can be seen that these values approach to the values of coupled lines for $\theta = \frac{\pi}{2}$, which corresponds to the center frequency of band pass response [11]. The ABCD parameters of the equivalent circuit can be represented as below:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\theta & jZ_O \sin\theta \\ \dfrac{j\sin\theta}{Z_O} & \cos\theta \end{bmatrix} \begin{bmatrix} 0 & \dfrac{-j}{J} \\ -jJ & 0 \end{bmatrix} \begin{bmatrix} \cos\theta & jZ_O \sin\theta \\ \dfrac{j\sin\theta}{Z_O} & \cos\theta \end{bmatrix}$$

$$= \begin{bmatrix} \left(JZ_O + \dfrac{1}{JZ_O}\right)\sin\theta\cos\theta & j\left(JZ_O{}^2 \sin^2\theta - \dfrac{\cos^2\theta}{J}\right) \\ j\left(\dfrac{1}{JX_O{}^2}\sin^2\theta - J\cos^2\theta\right) & \left(JZ_O + \dfrac{1}{JZ_O}\right)\sin\theta\cos\theta \end{bmatrix} \tag{2.1}$$

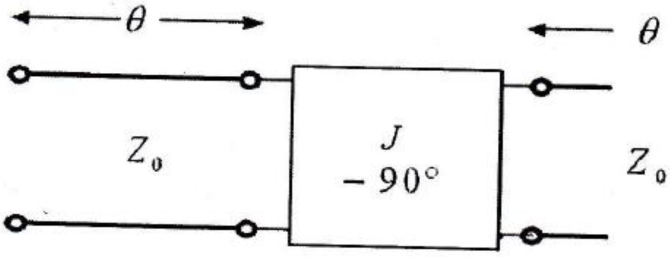


Figure 8 Equivalent circuit of coupled lines in Figure 7

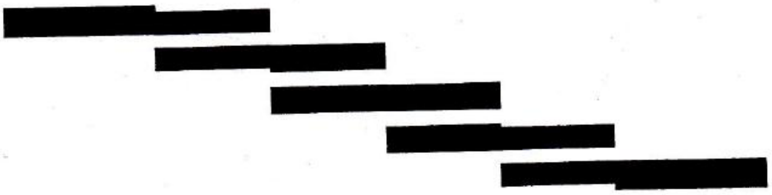


Figure 9 Microstrip coupled line band pass filter

The image impedance of the equivalent circuit is:

$$Z_i = \sqrt{\frac{AB}{CD}} = \sqrt{\frac{JZ_O{}^2 \sin^2\theta - 1/J\cos^2\theta}{\left(1/JZ_O{}^2\right)\sin^2\theta - J\cos^2\theta}} \tag{2.2}$$

At the center frequency $\theta = \frac{\pi}{2}$, the above equation reduces to,

$$Z_i = JZ_O{}^2 = \frac{1}{2}\left(Z_{0e} - Z_{0o}\right) \tag{2.3}$$

The propagation constant is as below,

$$\cos\beta = A = \left(JZ_0 + \frac{1}{JZ_0}\right)\sin\theta\cos\theta = \frac{Z_{0e} + Z_{0o}}{Z_{0e} - Z_{0o}}\cos\theta \tag{2.4}$$

So, it is assumed that $\sin\theta = 1$, if $\theta = \pi/2$. Then this equation can be analyzed to give even and odd mode line impedances as below.

$$Z_{oe} = Z_0\left[1 + JZ_0 + \left(JZ_0\right)^2\right] \tag{2.5}$$

$$Z_{oo} = Z_0\left[1 - JZ_0 + \left(JZ_0\right)^2\right] \tag{2.6}$$

The first step is the order of the filter that wants to be designed should be determined. This can be done through attenuation graph for the normalized frequency like in Figure 10. After that, the parameter value (gn) of low pass filter (LPF) prototype can be determined using the Table 2. From this parameter value, admittance conversion constant (Jn) is calculated using the formula (2.6) and (2.10). For even mode and odd mode impedances are calculated using the formula (2.5) and (2.6) respectively. The next step is manufacturing of the filter by connecting coupled lines. This step is done after obtaining the even mode and odd mode impedances. Lastly, the attenuation graphs and parameter value (gn) for LPF prototype can be found in order to describe the microwave electronics [12].

$$Z_o J_1 = \sqrt{\frac{\pi\Delta}{2g_1}} \tag{2.7}$$

$$Z_o J_n = \frac{\pi\Delta}{2\sqrt{g_{n-1}g_n}} \tag{2.8}$$

For n = 2, 3, 4,…, N

$$Z_o J_{N+1} = \sqrt{\frac{\pi\Delta}{2g_N g_{N+1}}} \tag{2.9}$$

For n = N+1

$$\Delta = \frac{\left(\omega_2 - \omega_1\right)}{\omega_0} \tag{2.10}$$

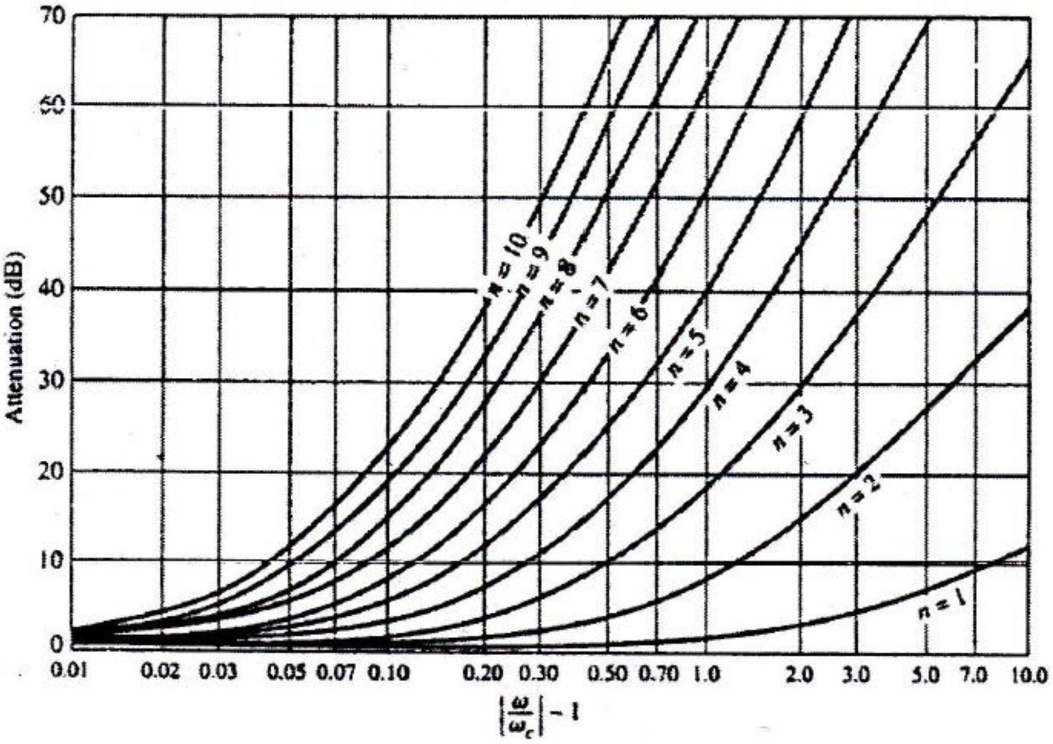


Figure 10 Attenuation curves for normalized frequency of Chebyshev (0.5 dB ripple) filter prototype

Table 2 Parameter values of low pass prototype for Chebyshev filter

0.5 dB ripple								
N	**g1**	**g2**	**g3**	**g4**	**g5**	**g6**	**g7**	**g8**
1	0.6986	1.0000						
2	1.4029	0.7071	1.9841					
3	1.5963	1.0967	1.5963	1.0000				
4	1.6703	1.1926	2.3661	0.8419	1.9841			
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000		
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841	
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000

CHAPTER 3
METHODOLGY

3.1 Research Methodology

In order to achieve the main objective of this project, the goals for the sub-objectives highlighted in the Chapter 1 need also to be accomplished. To develop a fully functional microstrip bandpass filter, background study and literature review need to be done on the selected papers that concentrate on the designing process. The relevancy between selected papers and project objectives need to be taken into account to ensure the credibility of the project.

The High Frequency Structure Simulator (HFSS) and Ansoft Designer software also need to be studied since this software will be used to design and simulate the design later. The result of the simulation will be used in the fabrication process onto the Printed Circuit Board (PCB). Then this designed model will go through the measurement and testing process to ensure the good design had been produce.

3.2 Flow Chart

The following flow chart explains the methodology in executing the project.

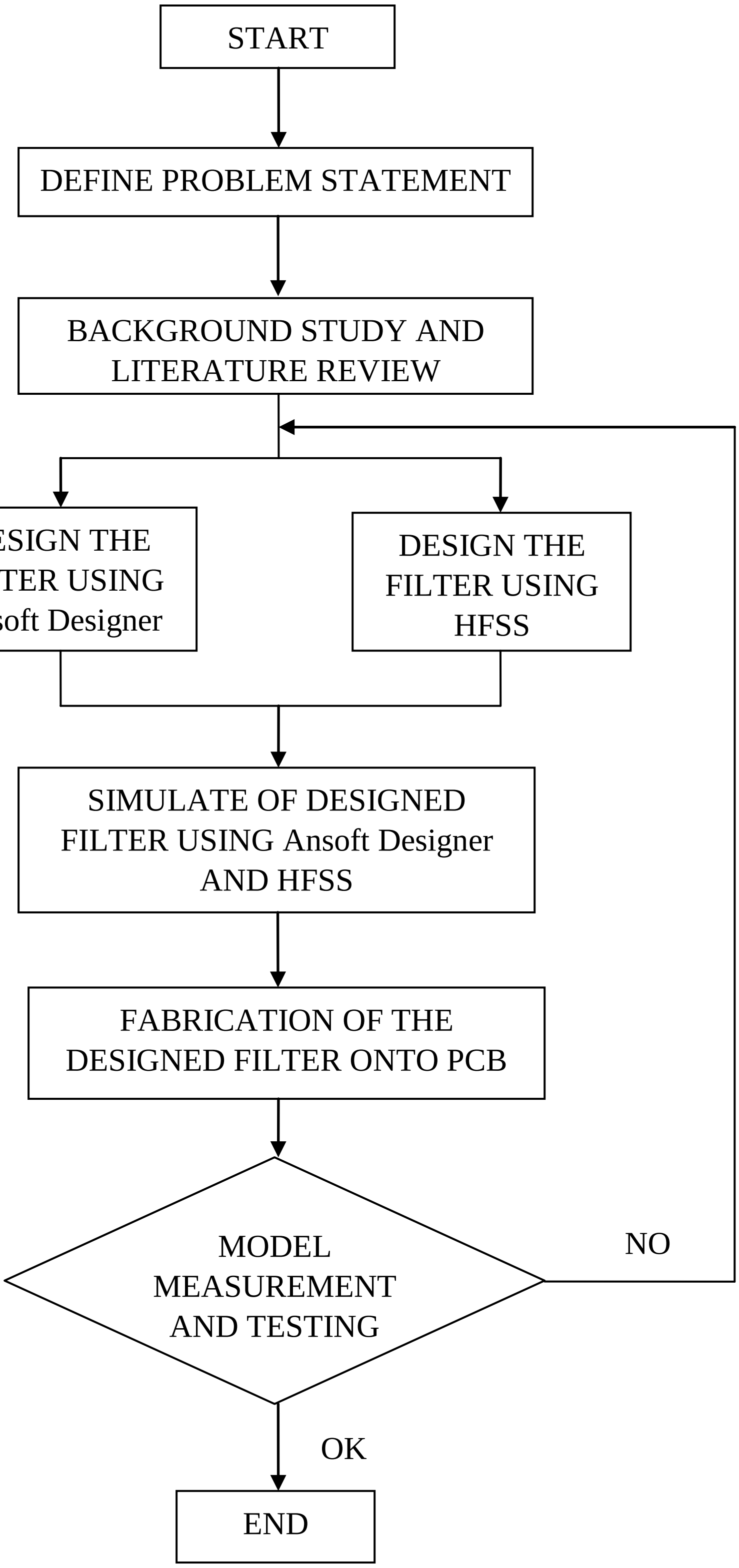


Figure 11 Project Methodology

This is the elaboration of the flow chart.

- **Define Problem Statement**
  - First and foremost, problem statement needs to be defined. One design of filter to be developed using Ansoft Designer and HFSS is decided.

- **Background Study and Literature Review**
  - Once design has been decided, background study and literature review is done to gain more knowledge and information regarding the project to determine the feasibility of the project.

- **Design the Filter Using Ansoft Designer software**
  - The filter structure will be designed using Ansoft Designer software. This software helps to give basic knowledge in order to design the filters.

- **Design the Filter Using HFSS**
  - Then the filter structure will be designed using HFSS software. This is the real design that will be used for further process.

- **Simulate of the Designed Filter Using Ansoft Designer and HFSS**
  - In this step, the designed filter will be simulated to obtain the result which will be use in the fabrication process.

- **Fabrication of the Designed Filter onto PCB**
  - Once the result of the designed filter had obtained, the fabrication process can be done. All the parameters that used to design the filter will be used in this fabrication process.

- **Model Measurement and Testing**
  - After finished with the fabrication, the model will be through the measurement and testing process in order to make sure the model is a well designed.

3.3 Gantt Chart and Milestones

3.3.1 Gantt Chart for Final Year Project (FYP) I

Below is the Gantt chart for Final Year Project I:

ACTIVITIES	**FINAL YEAR PROJECT I**													
	WEEK NO.													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Literature Review and Background Study	→	→	→	→	→	→	→							
Design the filter using Ansoft Designer software						→	→	→	→	→				
Design the filter using HFSS software						→	→	→	→	→				
Simulation the filter using Ansoft Designer software and HFSS sofware									→	→	→	→	→	→
Report Writing										→	→	→	→	→

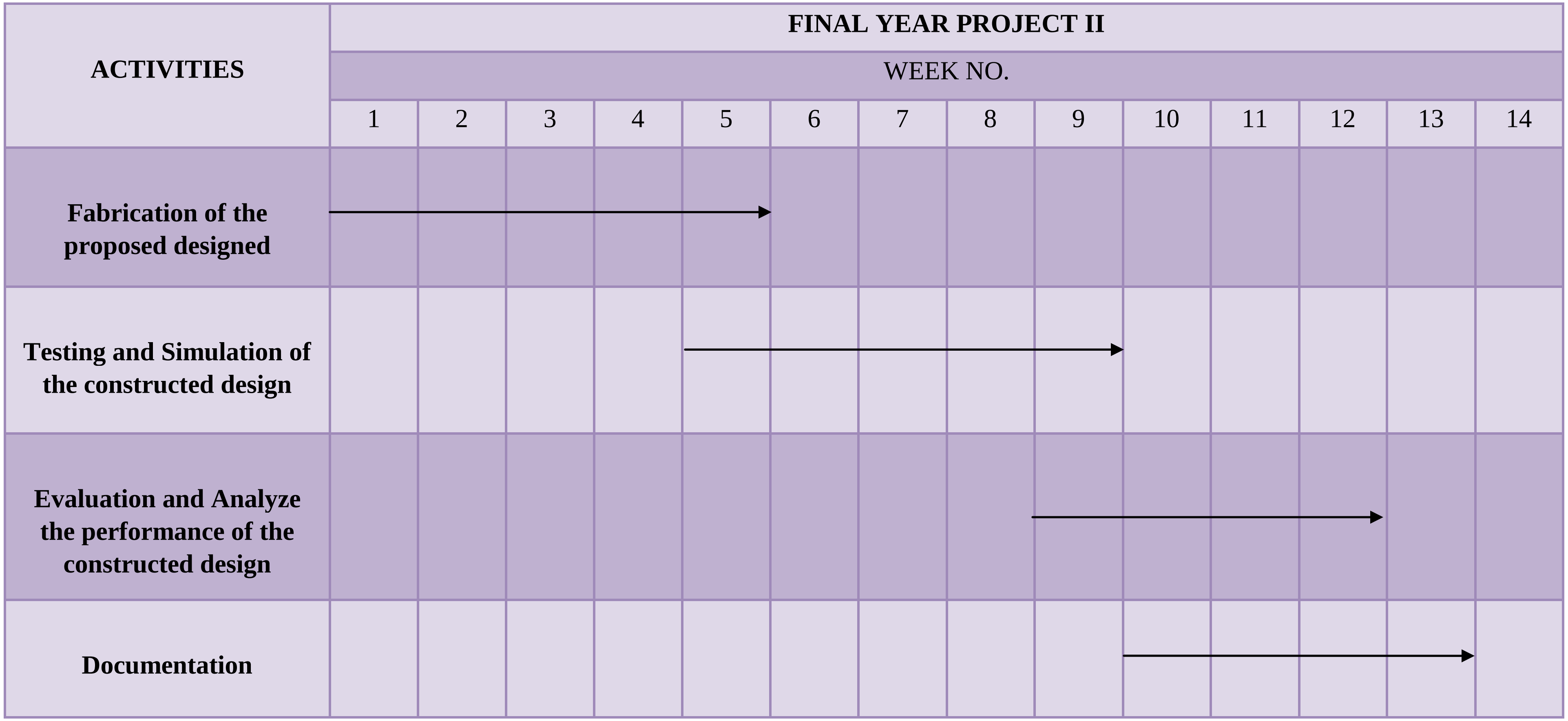
3.3.2 Milestone for Final Year Project (FYP) I

Below is the milestone for Final Year Project (FYP) I:

Component Submission	**Time (Week)**
Completion of Literature Review and Background Study	Week#7
Completion of design of the filter using Ansoft Designer software	Week #10
Completion of design of the filter using High Frequency Structure Simulator (HFSS) software	Week #10
Completion of Simulation of the filter using Ansoft Designer software and High Frequency Structure Simulator (HFSS) software	Week#14
Documentation	Week#14

3.3.3 Gantt Chart for Final Year Project (FYP) II

Below is the Gantt chart for Final Year Project II:



ACTIVITIES	FINAL YEAR PROJECT II													
	WEEK NO.													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Fabrication of the proposed designed	→	→	→	→	→									
Testing and Simulation of the constructed design					→	→	→	→	→					
Evaluation and Analyze the performance of the constructed design									→	→	→	→		
Documentation										→	→	→	→	

3.3.4 Milestone for Final Year Project (FYP) II

Below is the milestone for Final Year Project (FYP) II:

Component Submission	Time (Week)
Completion of fabrication of the proposed designed	Week#5
Completion of testing and simulation of the constructed design	Week #9
Completion of evaluation and analyze the performance of the constructed design	Week #12
Documentation	Week#13

3.4 Tools

The main software used for the designing of the filter is Ansoft Designer software as it provides necessary tools in the whole of designing process. Other than that, the High Frequency Structure Simulator (HFSS) software also used in order to give more knowledge and information towards the designing the filter. Printed Circuit Board (PCB) also will be used in the fabrication of the design in this project.

3.5 Project Schedule

The planned schedule for Final Year Project (FYP) I and Final Year Project (FYP) II are as follows:

Table 3 Project Schedule for FYP I

Component Submission	Time (Week)
Title Selection	Week 1
Extended Proposal	Week 6
Proposal Defense	Week 9
Draft Report	Week 13
Final Report	Week 14

Table 4 Project Schedule for FYP II

Component Submission	Time (Week)
Pre-EDX	Week 8
Draft Report	Week 13
Final Report	Week 14
VIVA	Week 15

3.6 Design Process

3.6.1 BPF Design Specification

Below is the specification for the proposed design of microstrip bandpass filter:

Table 5 BPF Design Specification

Center Frequency	2.4 GHz
Filter Type	Chebyshev
Filter Structure	Parallel Egde Coupled
Bandwidth	3 %
Ripple	0.5dB
Stopband Attenuation	45 dB @ 2.5 GHz

3.6.2 Order Calculation

Firstly, stopband frequency was converted to normalized frequency $(\omega_c = 1)$ of Chebyshev prototype LPF.

$$\Delta = (\omega_2 - \omega_1)/\omega_0 = 3\% = 0.03$$

$$\omega_s = \frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) = \frac{1}{0.03}\left(\frac{2.5}{2.4} - \frac{2.4}{2.5}\right) = 2.72 rad/\sec$$

Using the value above to substitute in formula below to calculate order of Chebyshev Prototype Low Pass Filter (LPF),

$$n \geq \frac{\cosh^{-1} X}{\cosh^{-1} \omega_s} = \frac{\log\left(X + \sqrt{X^2 - 1}\right)}{\log\left(\omega_s + \sqrt{\omega_s^2 - 1}\right)}$$

$$X = \sqrt{\left(K_p^{-2} - 1\right)^{-1}\left(K_s^{-2} - 1\right)}$$

$$= \sqrt{\left(10^{0.1\alpha_p} - 1\right)^{-1}\left(10^{0.1\alpha_s} - 1\right)}$$

Since Passband Ripple $\alpha_p = 0.5dB$ and Stopband Attenuation $\alpha_s = 45dB$,

$$n = 4.18$$

Therefore, the order of the filter is determine as 5th-order filter $(n > 4.18)$.

3.6.3 Determination of normalized parameter values

Using the table below in order to determine Chebyshev Prototype LPF parameter values:

Table 6 Chebyshev Prototype LPF $(g_0 = 1, \omega_c = 1, 0.5dBripple)$

0.5 dB ripple								
N	**g1**	**g2**	**g3**	**g4**	**g5**	**g6**	**g7**	**g8**
1	0.6986	1.0000						
2	1.4029	0.7071	1.9841					
3	1.5963	1.0967	1.5963	1.0000				
4	1.6703	1.1926	2.3661	0.8419	1.9841			
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000		
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841	
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000

3.6.4 Calculation of even mode and odd mode impedance

Using the below calculation step in order to calculate for the even mode and odd mode impedance of the filter model.

$$Z_0 J_1 = \sqrt{\frac{\pi\Delta}{2g_1}}$$

$$Z_0 J_n = \frac{\pi\Delta}{2\sqrt{g_{n-1} g_n}} \qquad \text{For n = 2, 3, 4,..., N}$$

$$Z_0 J_{N+1} = \sqrt{\frac{\pi\Delta}{2g_N g_{N+1}}} \qquad \text{For n = N+1}$$

$$Z_{0e} = Z_0 \left[1 + JZ_0 + (JZ_0)^2\right]$$

$$Z_{0o} = Z_0 \left[1 - JZ_0 + (JZ_0)^2\right]$$

This is the simplified table after the calculation had been made:

Table 7 Simplified table of the parameters

n	g_n	$Z_0 J_n$	Z_{0e}	Z_{0o}
1	1.7058	0.1752	60.30	42.78
2	1.2296	0.0362	51.87	48.26
3	2.5408	0.0296	51.53	48.56
4	1.2296	0.0296	51.53	48.56
5	1.7058	0.0362	51.87	48.26
6	1.0000	0.1752	60.30	42.78

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Result

The design model is simulated to determine the result of the design of microstrip bandpass filter using Ansoft Designer software. Below is the design schematic of the microstrip bandpass filter.

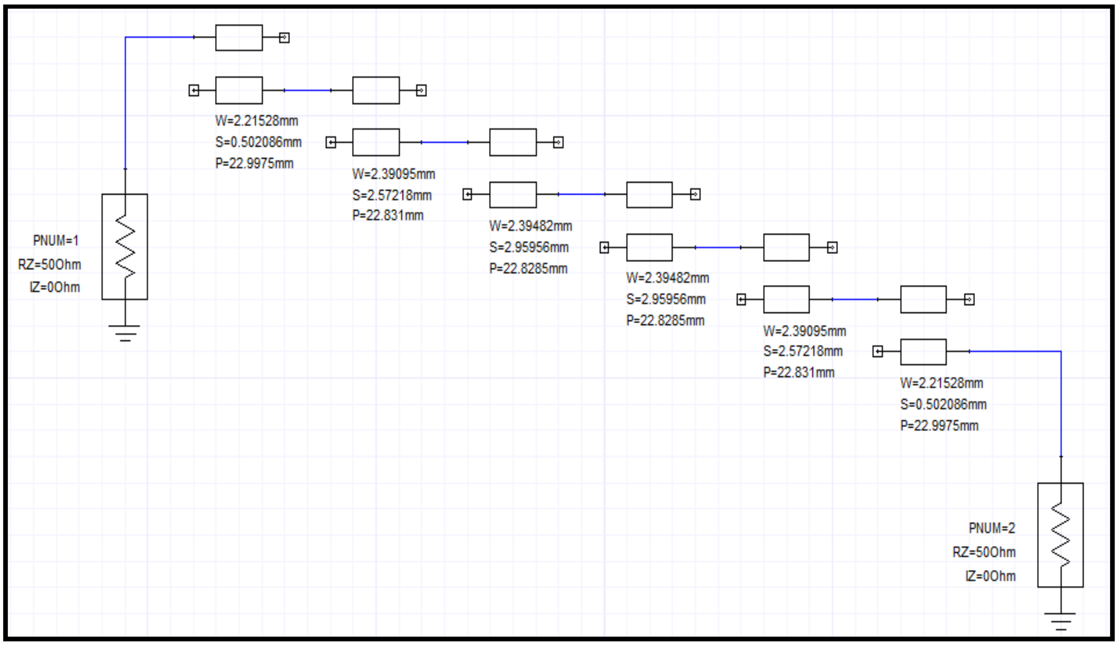


Figure 12 Simulation design of the microstrip filter

The order of the filter is 5th which had been calculated before in the design process. From the schematic diagram, it can be seen the parallel coupled had the 5th-order filter.

Below is the graph that shows the result of the simulation design of the microstrip bandpass filter.

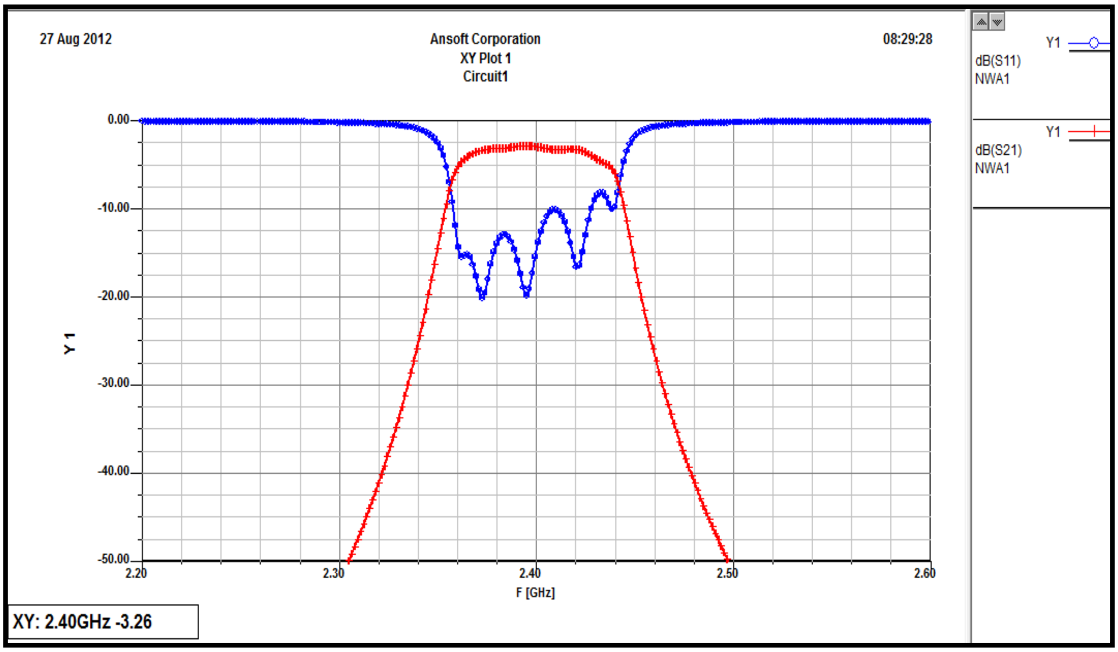


Figure 13 Result for simulation design of the microstrip filter

After the design and simulation had been finished, the design had sent for the fabrication process. The fabrication took place in the PCB lab. Below is the pictures of the microstrip bandpass filter that been fabricated:

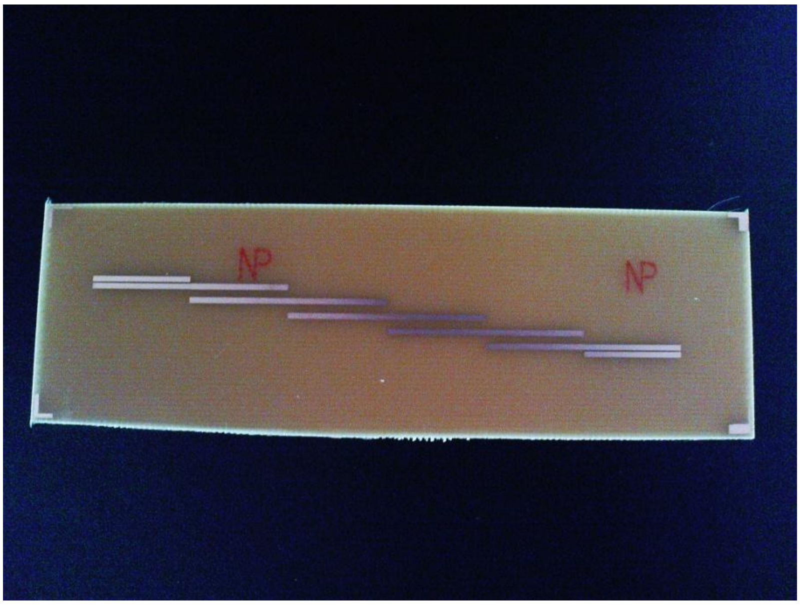


Figure 14 Fabrication of filter on FR4

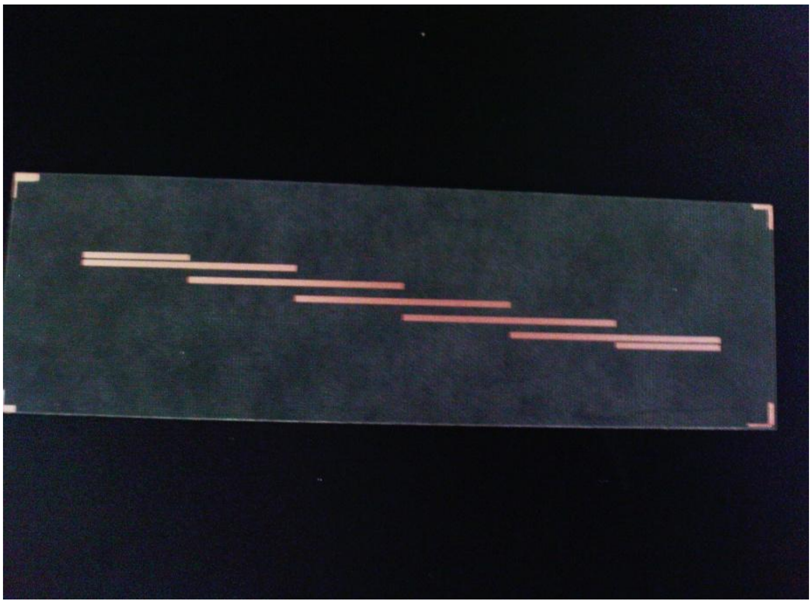


Figure 15 Fabrication of filter on Roger Duroid 5880

Now, the fabrication of parallel-coupled microstrip bandpass filter will be testing and measurement will also been analyze. The test that will be used is network analyzer.

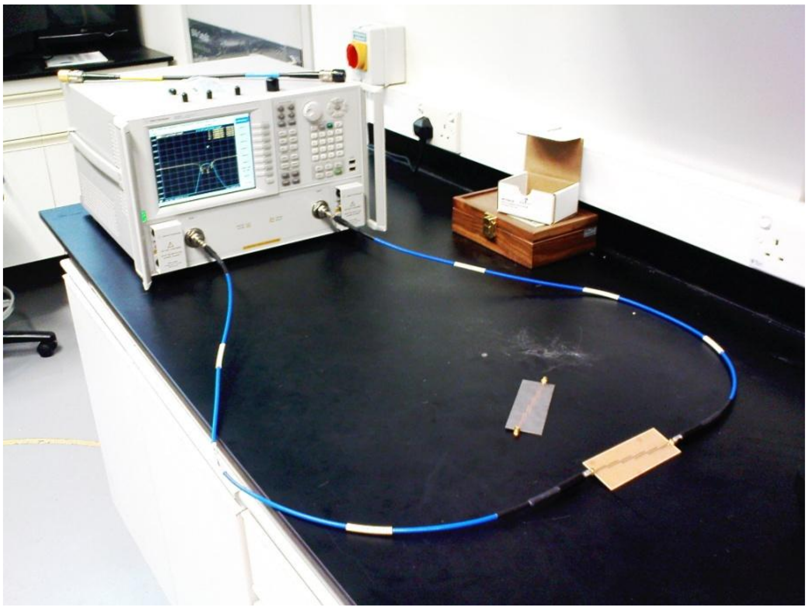
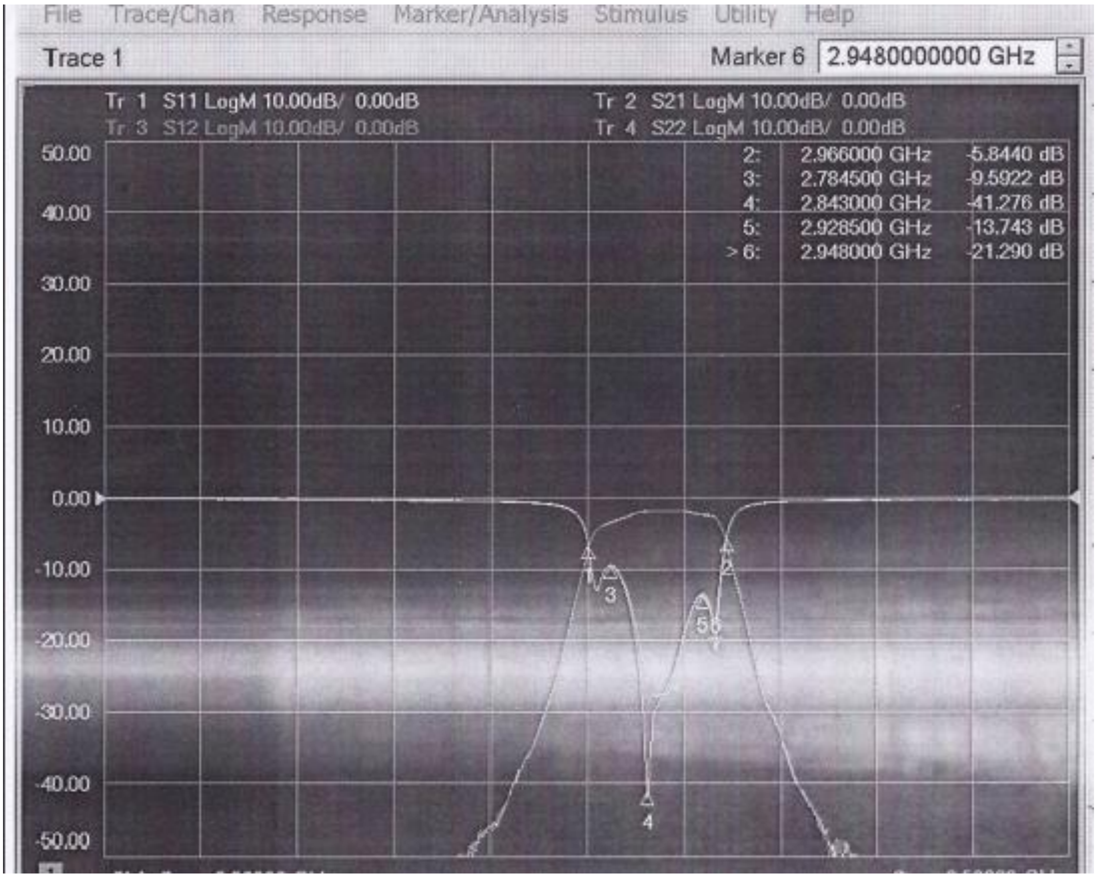


Figure 16 Testing and Measurement Process Using Network Analyzer

Below is the result of the testing of the fabricated parallel-coupled microstrip bandpass filter:



Marker 6 2.9480000000 GHz

Tr 1 S11 LogM 10.00dB/ 0.00dB
Tr 2 S21 LogM 10.00dB/ 0.00dB
Tr 3 S12 LogM 10.00dB/ 0.00dB
Tr 4 S22 LogM 10.00dB/ 0.00dB

```
  2:   2.966000 GHz   -5.8440 dB
  3:   2.784500 GHz   -9.5922 dB
  4:   2.843000 GHz   -41.276 dB
  5:   2.928500 GHz   -13.743 dB
> 6:   2.948000 GHz   -21.290 dB
```

Figure 17   Result of Network Analyzer

4.2 Discussion

Simulation

The simulation result which is the graph is analyzed to get the final result of the simulation. The final result of the simulation is as below:

Center Frequency	2.4 GHz
Bandwidth	70 MHz
Insertion Loss	3.26dB @ 2.4GHz
Stopband Attenuation	53 dB @ 2.5 GHz

As the comparison been made of the final result with the design specification, this design can be accepted due to the only slightly different that been get from the result.

Fabrication, Testing and Measurement

In the fabrication process, this parallel-coupled microstrip bandpass filter had been fabricated on the two different materials. One is on the FR4 and the other one is on the Rogers Duroid 5880. After done with the fabrication, the testing and measurement had been gone through. The process to test and measure this fabricated filter is called network analyzer.

After finished doing the network analyzer, the results of the fabricated filter had been compared with the design in the simulation process. It had been found that the results for both filters are slightly different. The center frequency that we get from the fabricated filter is 2.85 GHz which is different from the simulation which is 2.4 GHz. In order to make them same, the tuning process need to be done.

CHAPTER 5

CONCLUSION

5.1 Conclusion

In conclusion, microstrip bandpass filters have a big role in wireless communication systems. This electronic device is widely used in the wireless transmitters and receivers. The function of filter in the transmitter is to limit the bandwidth of the output signal to the minimum necessary to convey data at desired speed and in the desired form. Meanwhile, in a receiver, a bandpass filter will only allows signals that want to be heard at the selected bandwidth of the frequencies and reject the unwanted signal to pass through it.

From this project, the basic principle on how to design a microstrip bandpass filter can be learnt. The different results that get from the simulation and fabrication process also can be investigate in order to make sure the results will be same at last. If we get the same results, it is meaning that this project is successful.

REFERENCES

[1] Bandpass Filter, *http://searchcio-midmarket.techtarget.com.*

[2] D. M. Pozar, "*Microwave Engineering,"* 2nd ed., New York : Wiley, 1998.

[3] G. Matthaei, L.Young, and E.M.T. Jones, *"Microwave Filters, Impedance-matching Networks, and Coupling Structures,"* Artech House, Norwood, MA : 1980.

[4] M. Alaydrus**,** **"***Designing Microstrip Bandpass Filter at 3.2 GHz,"* International Journal on Electrical Engineering and Informatics, Vol. 2, Jakarta, Indonesia : 2010.

[5] B. A. Shenoi, **"***Introduction to Digital Signal Processing and Filter Design,"* New Jersey: John Wiley & Sons, 2006.

[6] A. B. Williams and F. Taylor, **"***Electronic Filter Designer's Handbook,"* New York: McGraw-Hill, 1988.

[7] A. S. Sedra and P. Brackett, "*Filter Theory and Design: Active and Passive,"* New York and London: Pitman, 1979.

[8] W. K. Chen, **"***Passive and Active Filters: Theory and Implementations,"* New York: John Wiley & Sons, 1986.

[9] J. S. Hong, and M. J. Lancaster, "*Microstrip Filters for RF/Microwave Application,"* New York: Wiley, 2001.

[10] R. Mongia, P. Bhartia and I. J. Bahl, "*RF and Microwave Coupled-line Circuits," 2nd ed.,* Artech House, Boston: 2007.

[11] D. Puttadilok, D.Eungdamrong, and W. Tanacharoenwat, "*A Study of Narrow-Band and Compact Size Microstrip Bandpass Filter for Wireless Communications,"* SICE Annual Conference, Thailand : 2007.

[12] Jen-Tsai Kuo, *"Design of Parallel-Coupled Microstrip Filters With Suppression of Spurious Resonances Using Substrate Suspension,"* IEEE Trans. Microwave Theory Tech., vol. 52, no.1, January 2004.