NOVEL THREE DIMENSIONAL BANDPASSING BLOCK FILTERS

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A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor (Hons) of Electronic and Communications Engineering

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"NOVEL THREE DIMENSIONAL BANDPASSING BLOCK FILTERS"** was prepared by **Khoo Choon Shen** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Electronic and Communications Engineering (Hons.) at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ____________________________

Supervisor : Dr. Lim Eng Hock

Date : ____________________________

Specially dedicated to
my beloved parents and friends.

ACKNOWLEDGEMENTS

First of all, I would like to thank my supervisor, Dr Lim Eng Hock, for his valuable guidance and advice throughout all the stages of this research project. His stimulating conversation and discussion have been a constant source of valuable ideas in the development of these new devices. He is always ready to give consultation all the time.

Besides that, I would like to acknowledge to my seniors and friends who are and have been doing their research under the supervision of my project supervisor. They have shared their knowledge and experience with me and are willing to render a helping hand whenever I faced problems.

I would like to thank UTAR for preparing such a good environment for me. Finally, I am thankful to the laboratory assistants who helped me throughout the research project.

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ABSTRACT

Bandpass filter is a two-port device that couples the input power at Port 1 and output the power at Port 2. Bandpass filter is designed to passes the frequencies in certain range while to reject the frequencies outside the range. This device is important in the growing needs of communication systems. The first part of this project is to demonstrate a rectangular block filter with two-mode passband. The second part of this project is mainly about the side-coupled block filter with three-mode passband. Simulation software such as High Frequency Structure Simulator (HFSS) is used for simulation and optimization of amplitude response and phase response of both the proposed design. The design is confirm with the satisfying result and proposed designs are fabricated. Measurement is done by using the Vector Network Analyzer (VNA). The simulation and experimental result are compared and showing good agreement. Case studies have been conducted for better understanding on the microstrip bandpass filter. Discussion and recommendations have been made based on each of the case study. The proposed bandpass filters are novel and intended to be published in the international journals.

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LIST OF SYMBOLS / ABBREVIATIONS

λ	Wavelength, m
f	Frequency, Hz
c	Speed of light, m/s
ε_r	Dielectric constant
ε_{eff}	Effective dielectric constant
h	Thickness of substrate, mm
w	Width of microstrip lines, mm
Z_o	Characteristic impedance, Ω
Z_{in}	Input impedance, Ω
S_{11}	Reflection coefficient, dB
S_{21}	Insertion loss, dB
S_{31}	Insertion loss, dB
S_{41}	Isolation, dB

CHAPTER 1

INTRODUCTION

1.1 Background

Electromagnetic (EM) radiation is a form of energy that radiates at the speed of light. EM radiation is formed by both magnetic and electric field that travel in the same direction which oscillate at the right angle to each other. The propagation of electromagnetic wave is shown in Figure 1.1.

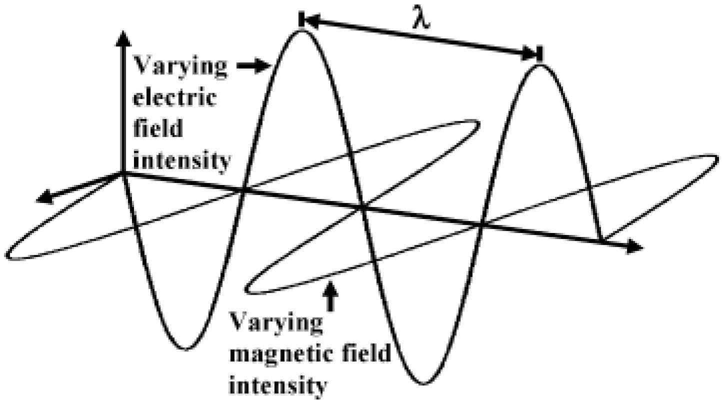

Figure 1.1: Schematic representation of electromagnetic wave.

Communication which uses electromagnetic radiation began very early in 19th century, most of the communication system used very long wavelength which travelled greater distances. There is wide range of microwave applications which used until today. The application includes microwave heating, communication, radio detection and ranging, electronic warfare, medical applications, scientific applications and industrial and commercial applications.

Microwaves is a form of EM spectrum with frequency spread from 300 MHz to 300 GHz and its wavelength ranging from 1m to 1mm respectively. Eventually, microwaves can be classified into three bands which are Ultra High Frequency (UHF) band with ranging from 300 MHz to 3GHz, the Super High Frequency (SHF) band with frequency spread from 3 GHz to 30 GHz and lastly the Extremely High Frequency (EHF) band with frequency of 30 GHz to 300 GHz. Table 1.1 and Table 1.2 shows the microwave frequency band in more details.

Table 1.1: The Electromagnetic Spectrum

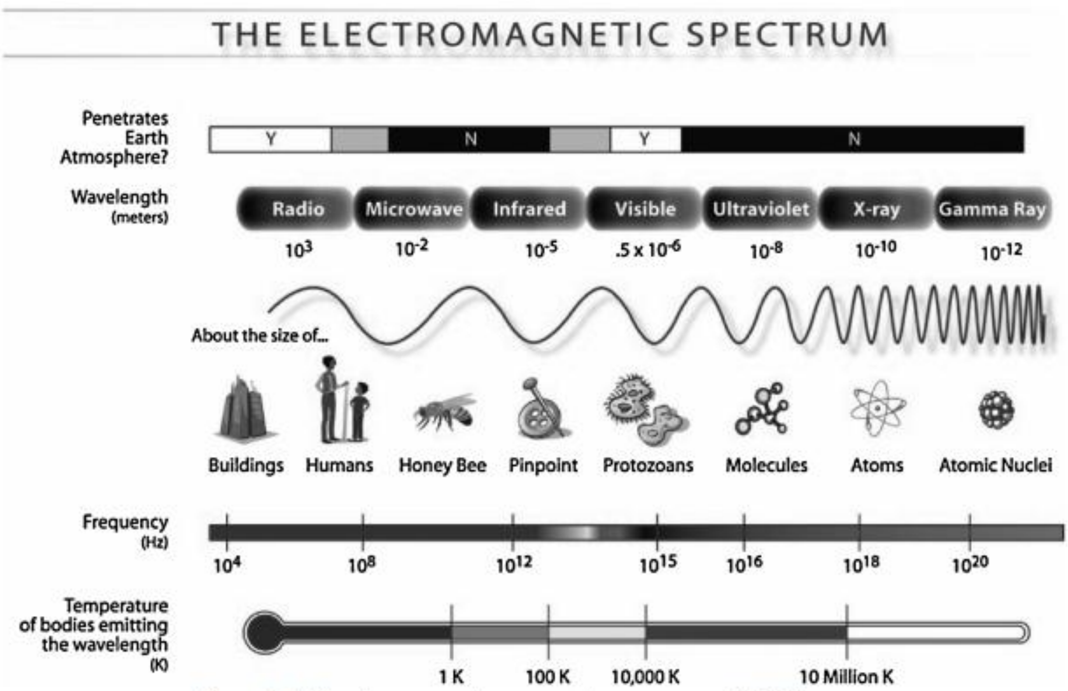

Figure 1.3 The electromagnetic spectrum (image courtesy of NASA)

Obtained from:

http://media.wiley.com/product_data/excerpt/24/04708227/0470822724-1.pdf

Table 1.2: Frequency band designation.

Frequency Band	Designation	Typical Services
3-30 KHz 100 km – 10 km	Very Low Frequency (VLF)	Navigation, time signal
30-300 KHz 10km – 1 km	Low Frequency (LF)	AM longwave broadcasts
300-3000 KHz 1 km – 100 m	Medium Frequency (MF)	AM broadcasting, Amateur radio
3-30 MHz 100 m – 10 m	High Frequency (HF)	Shortwave broadcasts
30-300 MHz 10 m – 1 m	Very High Frequency (VHF)	Television, FM Broadcast, Mobile communications, weather radio
300-3000MHz 1 m – 100 mm	Ultra High Frequency (UHF)	Television, satellite communications, microwave oven
3- 30 GHz 100 mm – 10 mm	Super High Frequency (SHF)	Airborne radar, microwave links, common-carrier land mobile communication, satellite communication
30-300GHz 10 mm – 1 mm	Extreme High Frequency (EHF)	Radio Astronomy

Obtained from: http://en.wikipedia.org/wiki/Radio_spectrum

From the table above, we have different applications that designated with different frequency band. The knowledge of microwave is so wide until many researchers still carrying on their research nowadays to explore more knowledge that benefits humankinds. Recently, many researches have been done in this few years to improve the communication system. One of the famous communication bands that being developed is the so called Long-term Revolution (LTE).

In Table 1.3, shows the microwave frequency band designations.

Table 1.3: Microwave frequency band designations.

Frequency	Band Designations
500 – 1000 MHz	C Band
1 -2 GHz	D Band
2 – 3 GHz	E Band
3 – 4 GHz	F Band
4 – 6 GHz	G Band
6 – 8 GHz	H Band
8 – 10 GHz	I Band
10 – 20 GHz	J Band
20 – 40 GHz	K Band
40 – 60 GHz	L Band

Obtained from: http://portronics.hubpages.com/hub/Frequency-Bands

The band designations are originated during World War II as a secret code. After the war, the codes were declassified and normally used in communication system which symbolizes the frequency range.

In this experiment, research, simulation, fabrication and documentation has been done on microstrip bandpass filter. The bandpass filter will have new concept which is using the metal block to couple the signal. Two bandpass filters have been designed which are rectangular block filter and side-coupled block filter.

1.2 Issues

In signal processing, filter is a sort of device which removes the unwanted signal from the original signal. There are many kinds of filter which are low-pass filter, high pass filter, band-pass filter, band-stop filter and many other filters. Various types of filters have been designed for their own function. In low pass filter, low frequencies are passed: In high pass filter, high frequencies are passed and vice versa. In filter, wider bandwidth is preferable because it allows more signal to pass thru the same frequency band.

There are many kinds of transmission line configurations which are available in the market. The three most common transmission line configurations which use stripline technology are microstrip line, stripline and co-planar stripline. In this experiment, we use microstrip line because it is cheap and can be easily fabricated. The substrate that is used for the microstrip line is the semiconductor which has different dielectric constant. The semiconductors that usually used are such as epoxy resin, glass fibre (FR-4), aluminium oxide and many more.

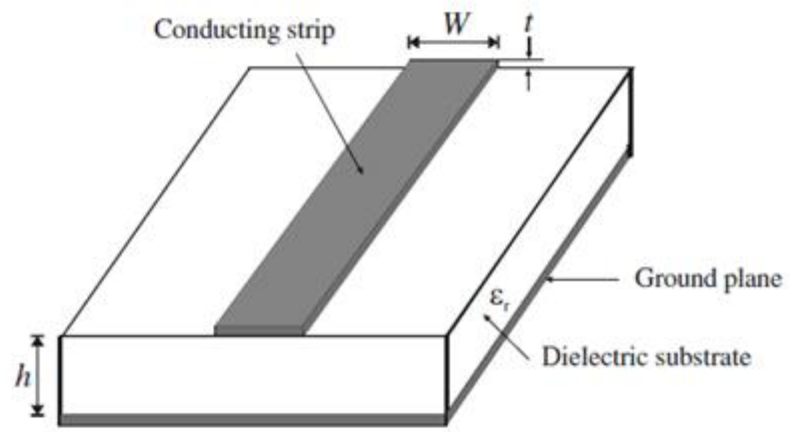

Figure 1.2: General microstrip structure.

Figure 1.2 shows the cross section view of a microstrip. It is designed that the conducting strip stays at the top of the substrate. W is the width of the conducting strip while h represents the height of the substrate. ε_r is the dielectric constant of the semiconductor. Microstrip structure consist of more advantage as compare to stripline and co-planar stripline because the conducting strip which stays at the top of the substrate make it the most easy structure to be fabricated. In addition, it will be easier for performing measurement on amplitude response and phase response.

Every microstrip has different characteristic impedance. The characteristic impedances that usually used are 30Ω, 50Ω and 75Ω. Different characteristic impedance of the port to the microstrip transmission line can cause severe impedance mismatch. This will affect the S_{11}, which is also known as the return loss – loss of signal power resulting from the reflection caused at a discontinuity in a transmission line. In order to minimize the return loss in the design, port and microstrip transmission line has to been to same characteristic impedance which is 50Ω.

1.3 Research Aim and Objectives

The main objective of this project is to design and construct a new microstrip bandpass filter that proves the side coupling effect. Normally, larger gap does not allow the signal to couple along the neighbouring stripline. However, by increasing the height of the stripline, we can observe that the signal is coupled successfully.

The first proposed idea is to design a rectangular block filter on microstrip with two-mode passband effect. It has an operating frequency of 3 GHz. The number of gap is used to determine the number of mode in the bandpass filter. Eventually, it has wider bandwidth since it is a two-mode passband filter.

In the second part of the experiment, a side-coupled block filter with three-mode passband effect is designed to further prove the side coupling effect that was examined in first idea. It has an operating frequency of 3.25 GHz. It has wider bandwidth since it is a three-mode passband filter. Both of the proposed idea has been designed, analysed and demonstrated by the author.

By doing this project, the author has gained the precious knowledge and better understanding on the passband filter that operate at microwave frequency. In addition, both of the proposed idea is a breakthrough since they are the very first three-dimension microstrip filters that perform successfully. The two ideas are intended to be submitted to the IEEE transaction Microwave Theory and Techniques and IEEE Microwave and Wireless Components Letters respectively.

1.4 Project Motivation

During this 2 semester, author has fully and wisely spent most of the time in doing the research with the help of supervisor and course mate. The research is highly motivated by the availability of the various testing equipment such as a powerful Vector Network Analyzer (VNA) and etching machine in laboratory. The availability of various type of substrate also eases the author in microstrip fabrication.

In this project, various skills have been acquired such as problem solving skill, designing skill, and also testing skills. These skills are very useful in author's future path to be a skilful design engineer. By having all these skills, author can processed with a better understanding on microstrip technology and also the knowledge of microstrip filter.

1.5 Thesis Overview

In this thesis, literature review on the theory, issues, design considerations and recent development of microwave components will be presented on Chapter 2. The microwave component that will be discussed in Chapter 2 is the wideband branch-line coupler. Besides that, some of the simulation tools will be introduced in Chapter 2 as well.

In Chapter 3 and Chapter 4, a rectangular block filter and side-coupled block filter will be discussed separately in different chapter. Firstly, some brief background of the filter will be introduced in both of the chapter. The design parameter and configuration of the filter will be shown and discussed. Then, the simulation part of the filter will be analysed. Here, the simulation is done by using the Ansoft HFSS software. The transmission line model of the side-coupled block filter will only be analysed. After that, some of the important parameters were also be analysed respectively. The result and performances of the block filter will be discussed and compared with the measurement result. Fractional bandwidth will be calculated for both of the chapter. Finally, discussion on the filter will be made. From the simulation and measurement, author can confirm that the rectangular block filter and side-coupled block filter are performing successfully.

In Chapter 5, achievement of the whole project will be summarized. Future work and improvement of the block filter will be discussed as well.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

In this chapter, some basic knowledge of microwave components and circuits will be discussed. Then, the design methodology of some design considerations and issues will be discussed. Few recent developments about the microstrip filter will be discussed in this chapter for better understanding. Last but not least, the simulation tools, Ansoft HFSS software and Microwave Office which used to simulate the project will be introduced.

2.2 Coupled Line Filter

A microwave filter is a two port network used to control the frequency response at a certain point in a microwave system by providing transmission of frequencies within the passband of the filter and attenuation in the stopband of the filter. Typical frequency response include low-pass, high-pass, bandpass and band reject characteristics. Application can be found in virtually any type of microwave communications such as radar, or test and measurement system. (David M. Pozar, 2005).

In microwave circuits, we often see the waveguide which guide the signal to the linear N-port network and the signal will either reflected or transmitted through the port of the networks. It may define up to n-number of port as required. In Figure 2.1 shows the normalized scattering matrix of microwave circuit. V_i^+ and V_i^- are propagating voltage waves which can be the actual voltage for TEM modes or the equivalent voltages for non-TEM modes.

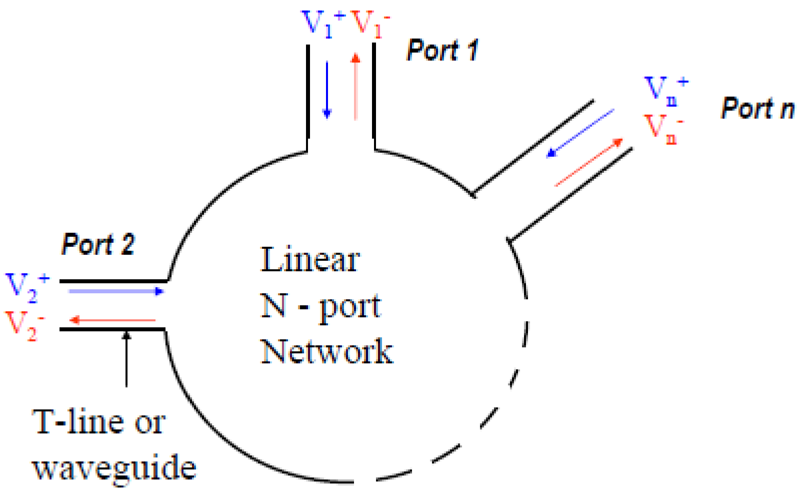

Figure 2.1: Normalized scattering matrix.

S-parameter or scattering parameters is used to describe the electrical behaviour of linear electrical networks when undergoing various steady states which stimuli by electrical signals such as insertion loss, return loss and etc. Equations below show the s-parameter for 2-port devices such as microstrip filter, oscillator, and etc.

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{11} = \frac{b_1}{a_1}|_{a_2=0}$$

$$S_{21} = \frac{b_2}{a_1}|_{a_2=0}$$

$$S_{22} = \frac{b_2}{a_2}|_{1=0}$$

$$S_{12} = \frac{b_1}{a_2}|_{a_1=0}$$

$a_i = 0$ implies that we terminate i^{th} terminal with its characteristic impedance. Zero reflection which eliminates standing waves.

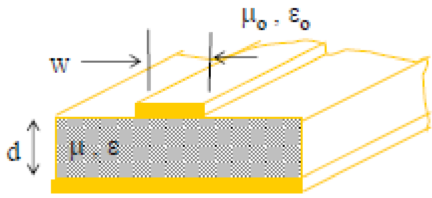

Figure 2.2: Cross section of microstrip.

Below shows the design equations for microstrip line, first we obtain the ε_{eff} and Z_0 of the equations,

$$\varepsilon_{eff} = 1 + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{1}{\sqrt{1+\frac{10d}{w}}}\right],$$

$$Z_o = \frac{377}{\sqrt{\varepsilon_{eff}}}\left[\frac{w}{d} + 1.98\left(\frac{w}{d}\right)^{0.172}\right]^{-1},$$

Given characteristic impedance, find the width of microstrip line,

$$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right),$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}},$$

$$\frac{w}{d} = \begin{cases} \dfrac{8e^{A}}{e^{2A}-2} & for\,\frac{w}{d}<2 \\ \frac{2}{\pi}\left[B-1-\ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left(\ln(B-1)+0.39-\frac{0.61}{\varepsilon_r}\right)\right] & for\,\frac{w}{d}>2 \end{cases},$$

Many of the filters can be designed by using the parallel coupled transmission lines theory. It is easier to fabricate the bandpass and band stop coupled line filter on microstrip or stripline form. Generally, the wider bandwidth filter will require highly tight coupled lines, which are difficult to fabricate.

By superposition, we can see that the total port current can be expressed in even and odd mode current as show below,

$$I_1 = i_1 + i_2,$$

$$I_2 = i_1 - i_2,$$

$$I_3 = i_3 - i_{42},$$

$$I_4 = i_3 + i_4,$$

First, consider the line as being driven in the even mode by the i_1 current sources. If the other ports are open-circuited, the impedance seen at port 1 or 2 is,

$$Z_{in}^{e} = -jZ_{0e}cot\beta\ell,$$

So the voltage at port 1 or 2 is,

$$v_a^1(0) = v_b^1(0) = 2V_e^+ cos = i_1 Z_{in}^e,$$

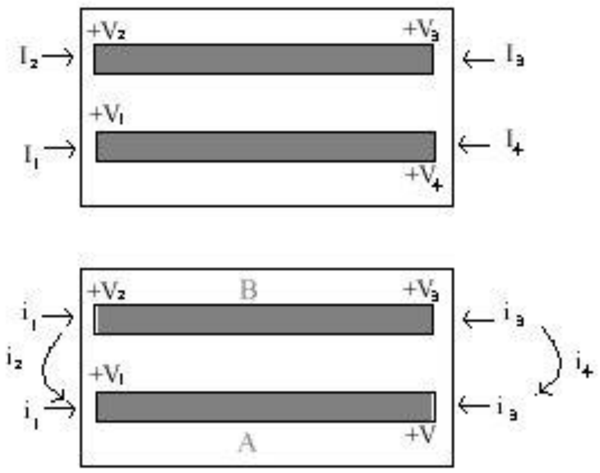

Figure 2.3: Parallel coupled line (even and odd mode current)

In our design, i_2 and i_4 are set to open circuit since open circuits are easier to fabricate than the short circuits. In this case, $I_2 = I_4 = 0$, so the four-port impedance matrix equations will be greatly reduce to two-port coupled line filter as shown below,

$$V_1 = Z_{11}I_1 + Z_{13}I_3,$$

$$V_3 = Z_{31}I_1 + Z_{33}I_3,$$

And hence, we can analyse the filter characteristics of this circuit by calculating the image impedance (which is the same at port 1 and 3), and the propagation constant. The image impedance in terms of Z-parameters is,

$$Z_i = \sqrt{Z_{11}^2 - \frac{Z_{11}Z_{13}^2}{Z_{33}}},$$

$$= \frac{1}{2}\sqrt{(Z_{0e} - Z_{0o})^2 csc^2\theta - (Z_{0e} + Z_{0o})^2 cot^2\theta},$$

When the coupled line section is $\lambda/4$ long ($\theta = \pi/2$), the image impedance reduces to,

$$Z_i = \frac{1}{2}(Z_{0e} - Z_{0o}),$$

To design a coupled line bandpass filter, a narrowband bandpass filter can be made with cascaded coupled line sections form as shown in Figure 2.4. To derive the design equations for filters, we will calculate the image impedance and propagation constant of the equivalent circuit by showing that they are approximately equal to those of the coupled line section for $\theta = \pi/2$, which will correspond to the centre frequency of the bandpass response. (David M. Pozar, 2005)

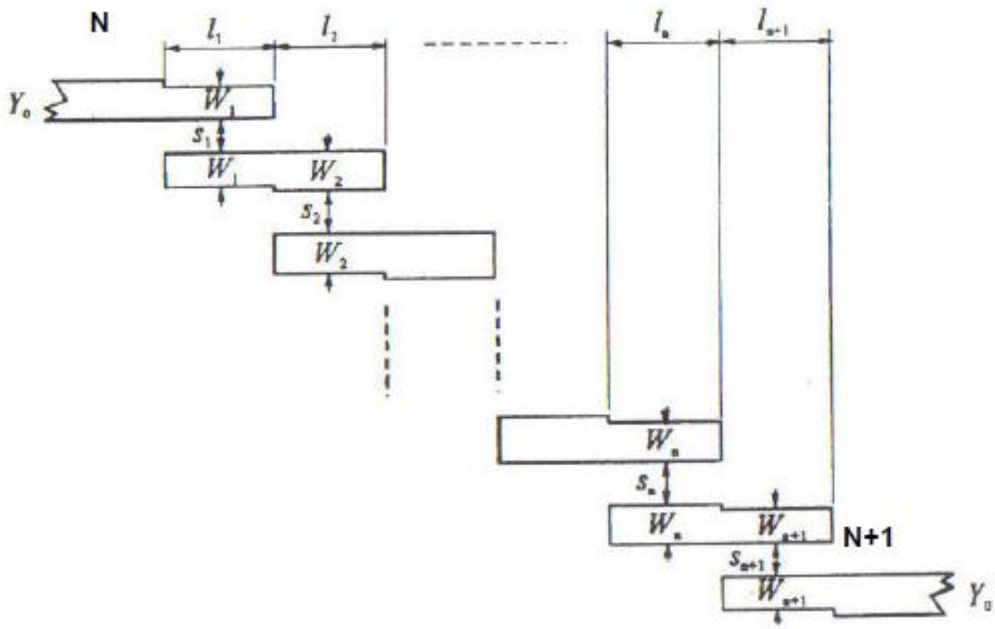

Figure 2.4: Parallel coupled microstrip bandpass filter.

From the figure above, l_n shows the quarter-wavelength for max coupling. For wider gap, the implementation of the bandpass filter on microstrip can be lot easier. Usually, wider range of bandwidth in bandpass filter is always realizable.

2.3 Recent Developments

To understand more on the coupled line bandpass filter, a number of journal regarding bandpass filter have been reviewed. Different method and different design has been implemented in order to improve the performance of the microstrip bandpass filter such as wider bandwidth, low insertion loss and low return loss. In these sections, several techniques that are commonly used in industry will be reviewed.

2.3.1 New Ultra Wideband Parallel Coupled Line Microstrip Bandpass Filter

Parallel coupled-line microstrip filters have been found to be one of the most commonly used microwave filters in many practical wireless systems for several decades. In addition to the planar structure itself and quite wide bandwidth, the major advantage of this kind of filters is that its design procedure is relatively simple. Based on insertion loss method, the filter functions of maximally flat and Chebyshev type can be easily synthesized. Moreover, the filter performance can be improved in a straightforward manner by increasing the order of the filter. (Thirumalaivasan K and Nakkeeran R, 2011).

When these filters are to be realized by parallel coupled microstrip lines, one of the main limitations is the small gap size of the first and the last coupling stages. The more fractional bandwidth, the smaller gap size is required to increase the coupling. Obviously, shrinking the gap size is not the only way to increase coupling of coupled lines. The proposed bandpass filter in this paper is based on parallel coupled line microstrip structure. The filter is designed to cover upper band of the UWB range. The obtained scattering parameter characteristics of UWB bandpass filter convey optimal performance in terms of insertion and return loss. It is distinctive in its structure and it has simple design with less number of design parameters compared to the existing filter designs in the literature. (Thirumalaivasan K and Nakkeeran R, 2011). Figure 2.5 shows the proposed UWB bandpass filter.

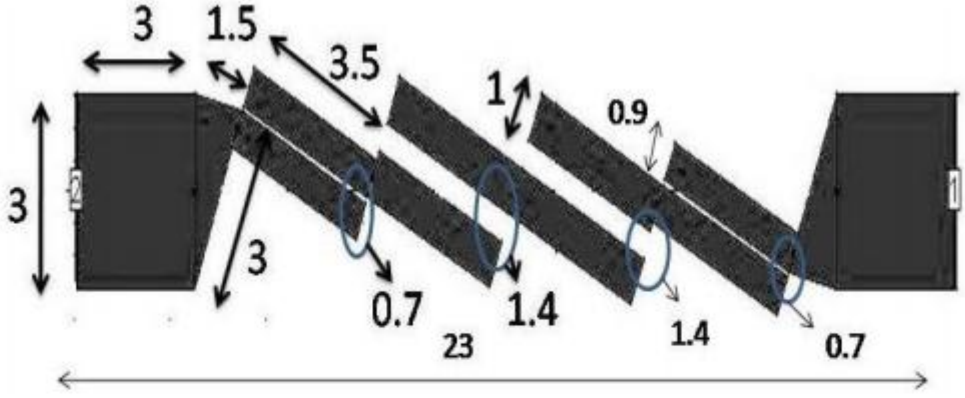

Figure 2.5: Geometry of the proposed UWB bandpass filter

It consists of transmission line sections having the length of half wavelength at the corresponding centre frequency. Half wavelength line resonators are positioned so that adjacent resonators are parallel to each other along half of their length. This parallel arrangement gives relatively large coupling for the given spacing between the resonators, and thus, this filter structure is particularly convenient for constructing filters having larger bandwidth as compared to the other structure. The gap between the resonators is introducing a capacitive coupling between the resonators, which can be represented by a series capacitance. The gap of coupled lines and the widths are optimized to have fixed values i.e., 0.7 mm, 1.4 mm, 1 mm and 0.9 mm respectively.

Using this configuration, higher coupling is obtained and therefore wider bandwidth is achieved. This structure is used to generate a wide passband and expected to achieve a tight coupling and lower insertion by reducing both strips and slot widths. (Thirumalaivasan K and Nakkeeran R, 2011).

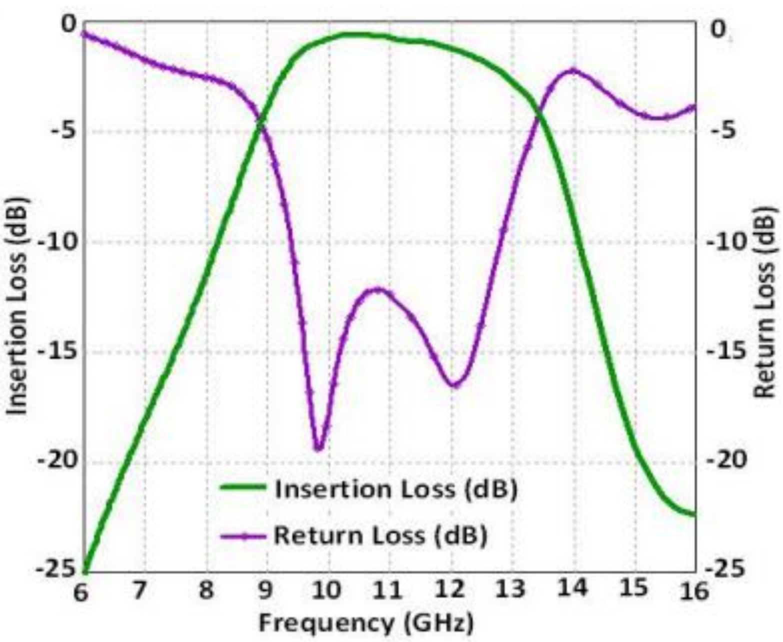

Figure 2.6: Simulation S-parameter.

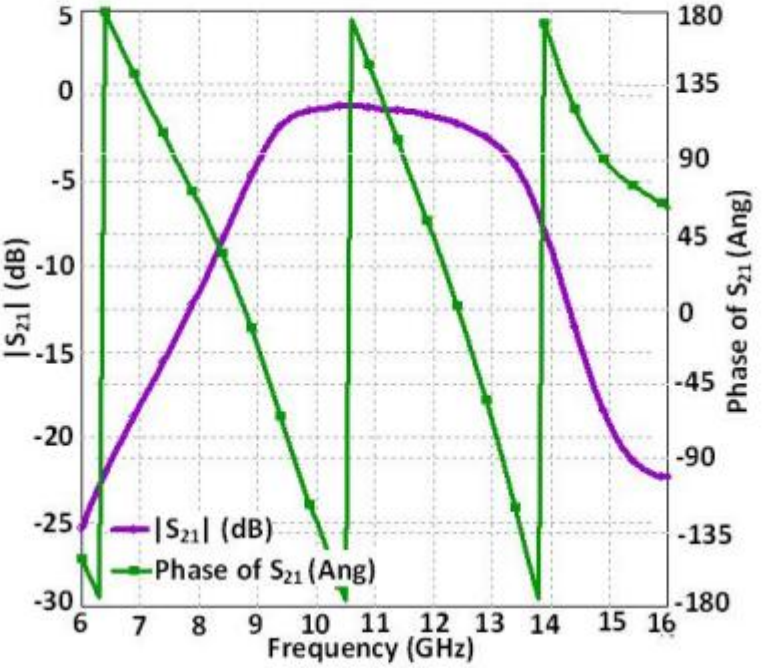

Figure 2.7: Simulation result of phase of S_{21}.

The simulation S parameters of the proposed UWB bandpass filter using parallel coupled line are shown in Figure 2.6. It is clear from the response that the proposed filter has better insertion loss of -1.2 dB and the low return loss of about -

19.42dB. The -10 dB fractional bandwidth computed from the response is about 52.17 %.Simulation of bandpass filter delivers excellent scattering parameters with the magnitude of insertion loss, |S21| lower than -1.2 dB and return loss better than -19.42dB. The group delay obtained for the filter is below 0.15 ns. (Thirumalaivasan K and Nakkeeran R, 2011).

2.3.2 Wideband Microstrip Bandpass Filter Based on Modified Parallel-Coupled Line Topology

Parallel-coupled line bandpass filter is combined using cascaded single filter. This structure consists of two parallel-coupled line sections connected in cascade and a shunt open stub is connected at the middle of them. The length of each parallel-coupled line has a quarter-wavelength at the centre frequency (f_0) and that of the stub has a half-wavelength resonator. To study the performance of Figure 2.8, the characteristic impedance of the system is 50 Ω whereas Z_{0e} and Z_{0o} are 150Ω and 50Ω, respectively. The shunt open stub is adjusted to 58 Ω for improving the return loss. (K. Srisathit* and W. Surakumpontorn**, 2010).

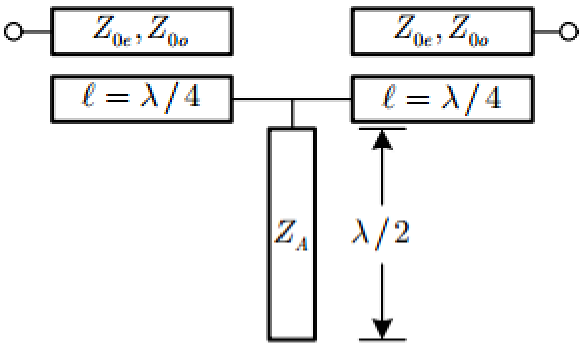

Figure 2.8: The proposed bandpass filter schematic.

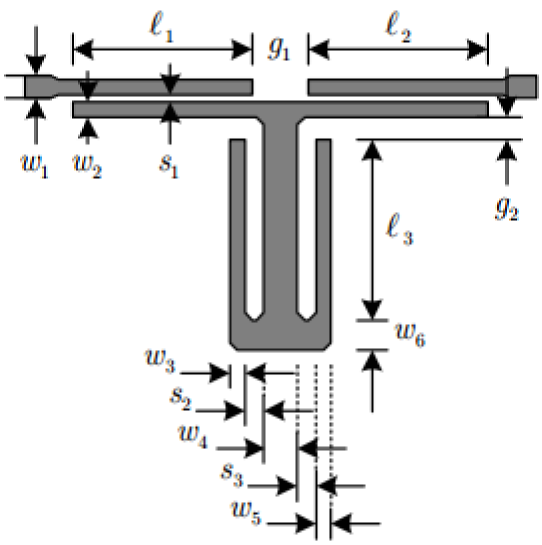

Figure 2.9: The proposed BPF with three-line conductor layout.

The physical parameters of this parallel-coupled BPF filter were synthesized on an FR-4 substrate with the substrate thickness of 1.52 mm and dielectric constant of 4.4. The centre frequency and fractional bandwidth are designed at 2 GHz and 75 percentages, respectively. In addition, when the symmetrical layout of the schematic becomes a cause for practical concern, a three-line conductor is thus required. (K. Srisathit* and W. Surakumpontorn**, 2010). Figure 2.9 above shows the physical layout of the proposed wideband BPF with a three-line conductor.

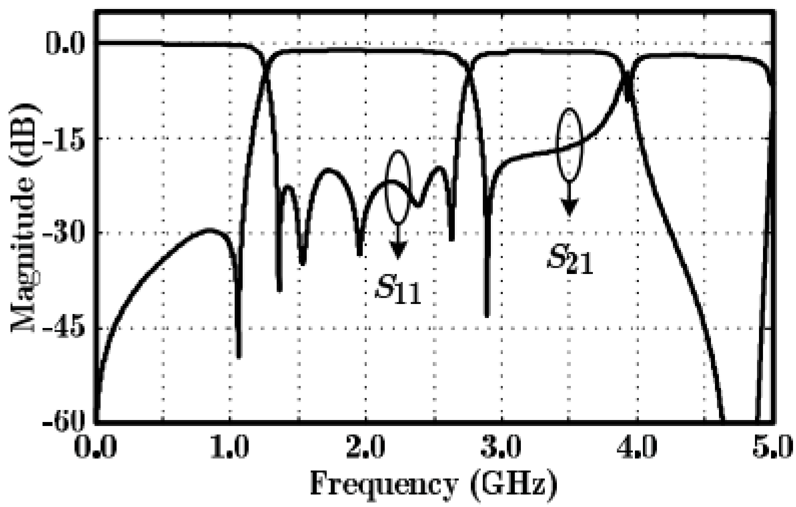

Figure 2.10: Simulated S-parameter of the proposed BPF.

The simulated performances have been shown in Figure 2.10. The simulated center frequency is at 2 GHz whereas the factional bandwidth is about 79.5 percentages. The insertion loss (S_{21}) at the center frequency is less than 1.0dB. The return loss (S_{11}) exceeds 19.8 dB in the whole passband, and gives five transmission poles inside the passband. Though the parallel-coupled BPF with shunt stub can present a wider bandwidth than the BPF without the stub, the spurious response can be seen at 3.92 GHz as also shown in Figure 2.10 due to the differences of even- and odd-mode electrical lengths. (K. Srisathit* and W. Surakumpontorn**, 2010).

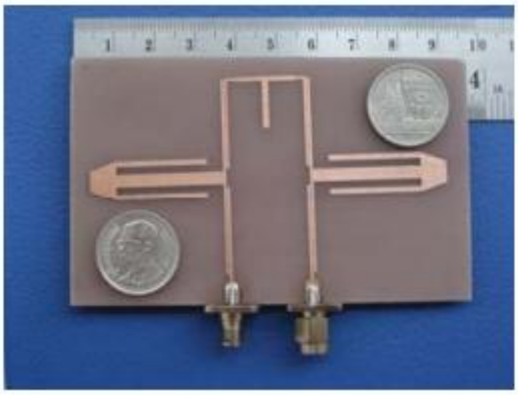

Figure 2.11: Cascaded BPF with first spurious suppression.

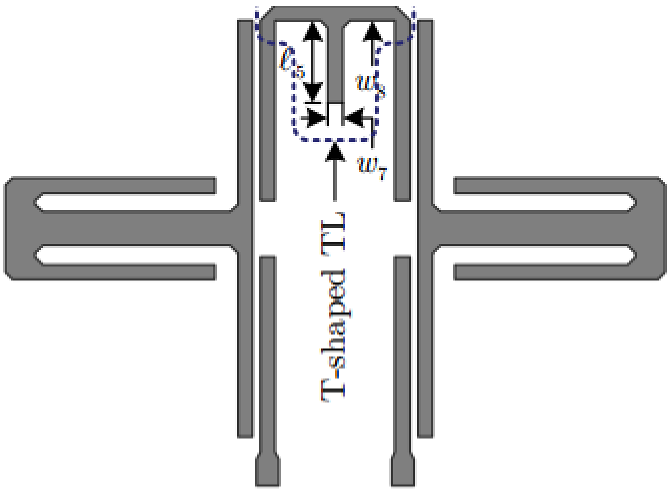

Figure 2.12: Layout of cascaded BPF.

To achieve sharp rejection response, a cascaded structure of an identical single BPF though the TL is required. Although the spurious frequency at $2f_0$ has significantly effect in the single BPF, its response in cascaded BPF can be suppressed by using a T-shaped TL with the characteristic impedance of Z_0. (K. Srisathit* and W. Surakumpontorn**, 2010). Figure 2.11 and Figure 2.12 show the layout of cascaded BPF with first spurious suppression.

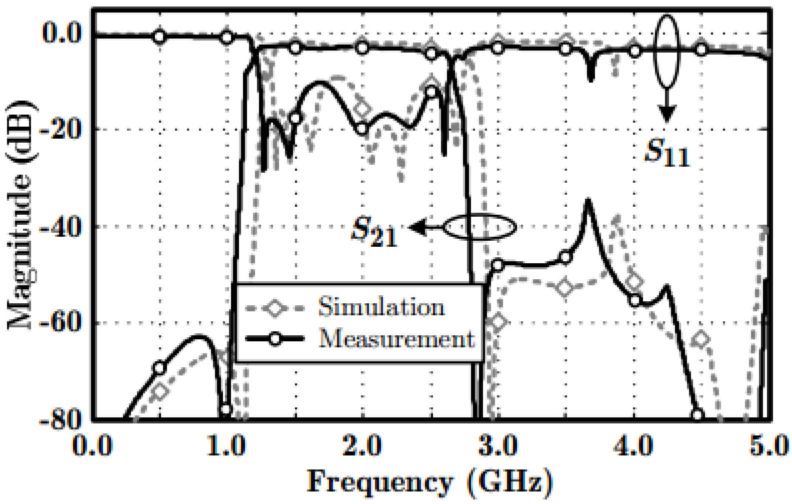

Figure 2.13: S-parameter of cascaded BPF.

In the Figure 2.13, the broadband BPF is observed at the center frequency of 1.92 GHz with the fractional bandwidth of 73.4 percentages. The measured insertion loss (S_{21}) is better than 2.5 dB at the center passband frequency, whereas the return loss (S_{11}) is kept below 12 dB over the frequency from 1.143 GHz to 2.678 GHz. The spurious frequency around 3.7 GHz is improved about 30.2 dB (35.6 – 5.4 = 30.2 dB), and the proposed filter shows an excellent stopband response below 1.1 GHz, and between 2.77 to 5 GHz with the better suppression of 38dB. Moreover, the attenuation level is better than 62.3dB at the below frequency of 1.02 GHz. (K. Srisathit* and W. Surakumpontorn**, 2010).

2.3.3 Parallel Coupled Microstrip Line Bandpass Filter on the R04003C Substrate

Coupled microstrip lines that utilize half wavelength line resonators are widely used for implementing microstrip filters. Adjacent resonators are parallel to each other along half of their length to construct the filter. The structure is inhomogeneous as the fields in the microstrip extend within two media, dielectric below and air above. Due to this nature, the microstrip does not support a pure transverse electromagnetic wave, making microstrip line dispersive. Both impedance and effective dielectric constant vary with the frequency. Hence, their propagation will depend not only on material properties, but also on the physical dimensions of the microstrip. (Goh Chin Hock and Chandan Kumar Chakrabarty, 2006). Figure 2.14 and Figure 2.15 show the physical layout of the parallel coupled microstrip line bandpass filter.

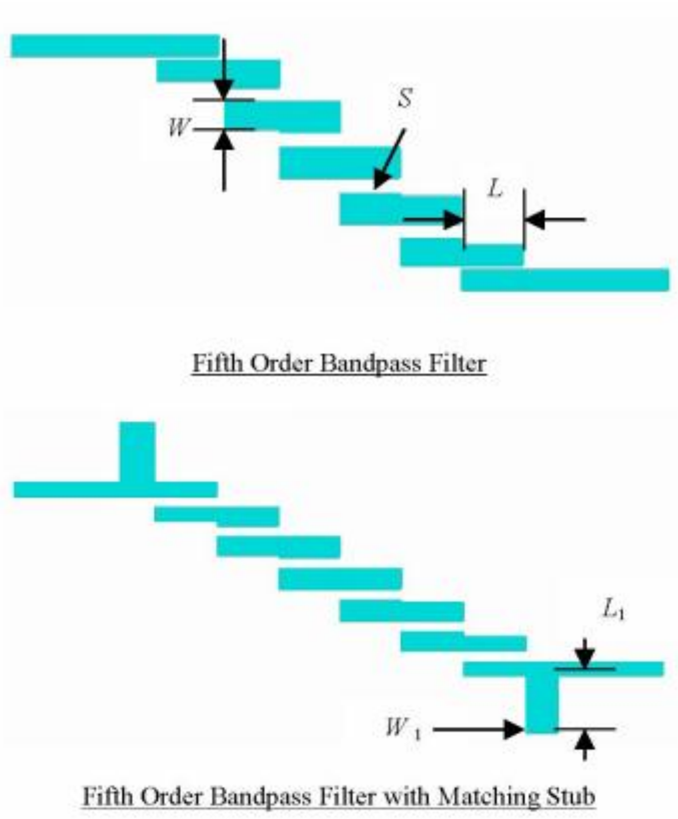

Figure 2.14: Physical layout of bandpass filter.

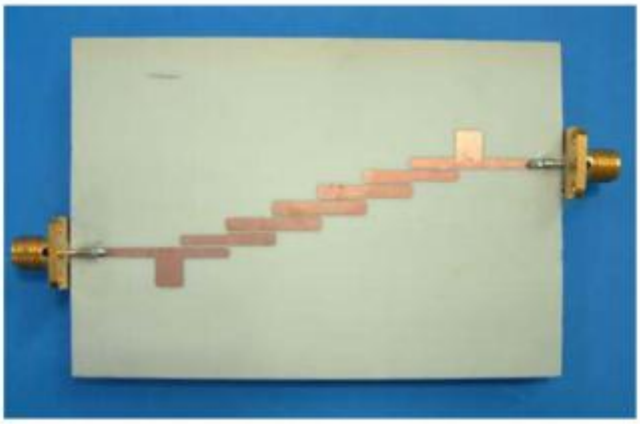

Figure 2.15: Physical Layout of the Fabricated Fifth-order Bandpass Filter with Matching Stub.

In designing the parallel coupled microstrip line bandpass filter, R04003C and FR4 substrate is used. The gap of the fifth order bandpass filter is very small and may not be practically fabricated. The gaps of the fifth order filter have been broadening after the two matching stubs are added at the input and the output port. (Goh Chin Hock and Chandan Kumar Chakrabarty, 2006).

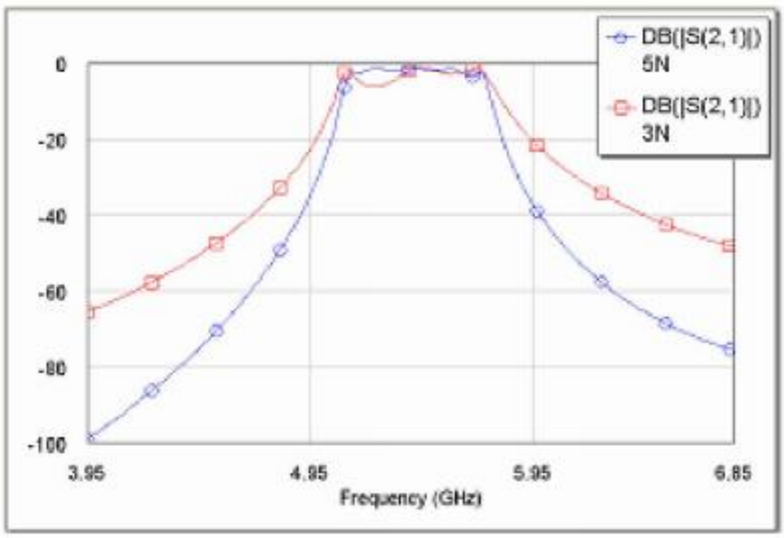

Figure 2.16: S_{21} of third and fifth order filter.

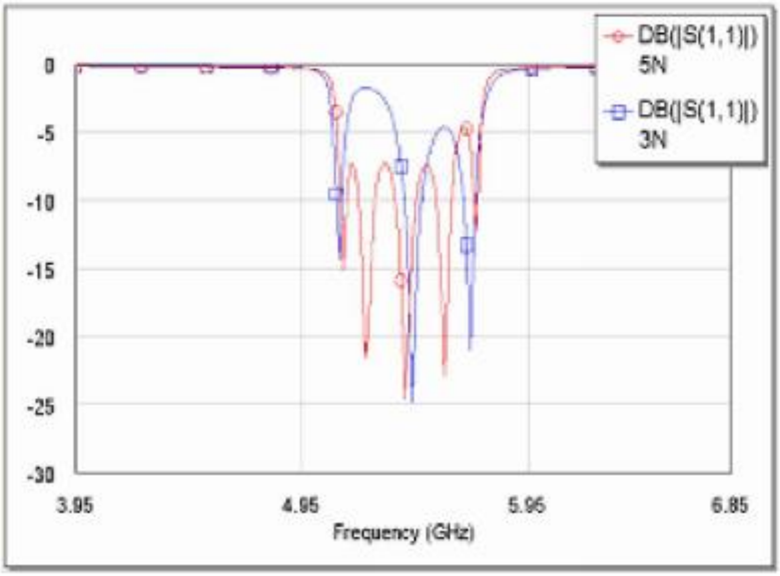

Figure 2.17: S_{11} of third and fifth order filter.

The third-order bandpass filter as well as the fifth order bandpass filter with matching stub were measured in the frequency range 4-8 GHz. In general, matching stubs are used as impedance transformer in order to match mismatched transmission lines. It can also be used as a tool to ease the fabrication of the passive device such as bandpass filter. In most practical cases, the gap of the coupled line bandpass filter is too small to be fabricated. Moreover, as the gaps are getting smaller, the error becomes worst. (Goh Chin Hock and Chandan Kumar Chakrabarty, 2006). Figure 2.16 and Figure 2.17 show the S_{11} and S_{21} of the third and fifth order of filter.

2.4 Introduction of Simulation Tools

Various kinds of tools and software have been used in order to carry out this experiment. The software that is being used includes Ansoft HFSS (High Frequency Structure Simulator), Microwave Office, CST Design Environment, Freelance Graphics, Microsoft Excel, TXLine and many more. The software that is used to simulate the bandpass filter design is Ansoft HFSS and Microwave Office. For documentation of the data, Freelance Graphics is used since it provides variety of options and easy to use.

2.4.1 High Frequency Structure Simulator

Ansoft Corporation has developed a very useful simulation tool called High Frequency Structure Simulator (HFSS). It is the registered trademark of Ansoft Corporation and it has a high performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modelling that has a great graphical user interface (GUI). Ansoft HFSS employs the Finite Element Method (FEM) with adaptive meshing to give unparalleled performance and insight to all three dimension (3D) EM problems. In addition, Ansoft HFSS has evolved over a period of years with the industries. This software is selected as the simulation tools in this experiment of its high productivity research, development and virtual prototyping.

The analysis of the s-parameter (X, Y, Z parameter) and the virtualization of the 3-D electromagnetic fields (near field and far field) can be done easily with the rapid advancement of HFSS. It helps to determine the signal quality, transmission path losses, and reflection coefficients due to impedance mismatch, parasitic coupling and radiation across the substrate.

2.4.2 Microwave Office

In microwave office, we can perform transmission line modelling to represent the equivalent circuit of the proposed design. This software is registered under the trademark of the AWR Corporation, which Microwave Office is also known as AWR. This software provides several Free Online Training Courses which allows user to have some basic guidelines before using. Users can also browse through the courses and tutorial to get familiar with the software.

Author has found the Microwave Office is fairly easy to use as it has a user friendly graphical user interface (GUI). Besides that, it also includes Variable Tuner which helps in the optimization process. Users have to input the maximum value, minimum value and step to control the resolution when sliding the tuner. By using the Microwave Office, we can easily simulate the proposed design and it is as accurate as other simulation software.

CHAPTER 3

RECTANGULAR BLOCK FILTER

3.1 Background

A bandpass filter is a device that passes the frequencies in certain range while to reject the frequencies outside the range. An ideal and perfect bandpass filter will have a completely flat passband which is in range and completely attenuate the frequencies which located outside the passband. In this chapter, a rectangular block filter was analysed with further experiment such as simulations, measurements and parameter analysis. To further prove the performance of block filter, a side-coupled filter is proposed, experimented and discussed.

3.2 Configuration

From the discussed earlier, a bandpass filter should have good VSWR, desired Q-factor and able to pass and reject certain frequencies over wide bandwidth. Various types of bandpass filter have been made to pass and reject desired frequencies. In this experiment, a rectangular block filter is designed to stimulate a situation where more signals that coupled through the wall of the substrate along the air gap.

First and foremost, a rectangular block filter is designed by using wall coupled theory. The proposed design was drawn by using Ansoft HFSS. Figure 3.1 shows the top-down view of the proposed rectangular block filter.

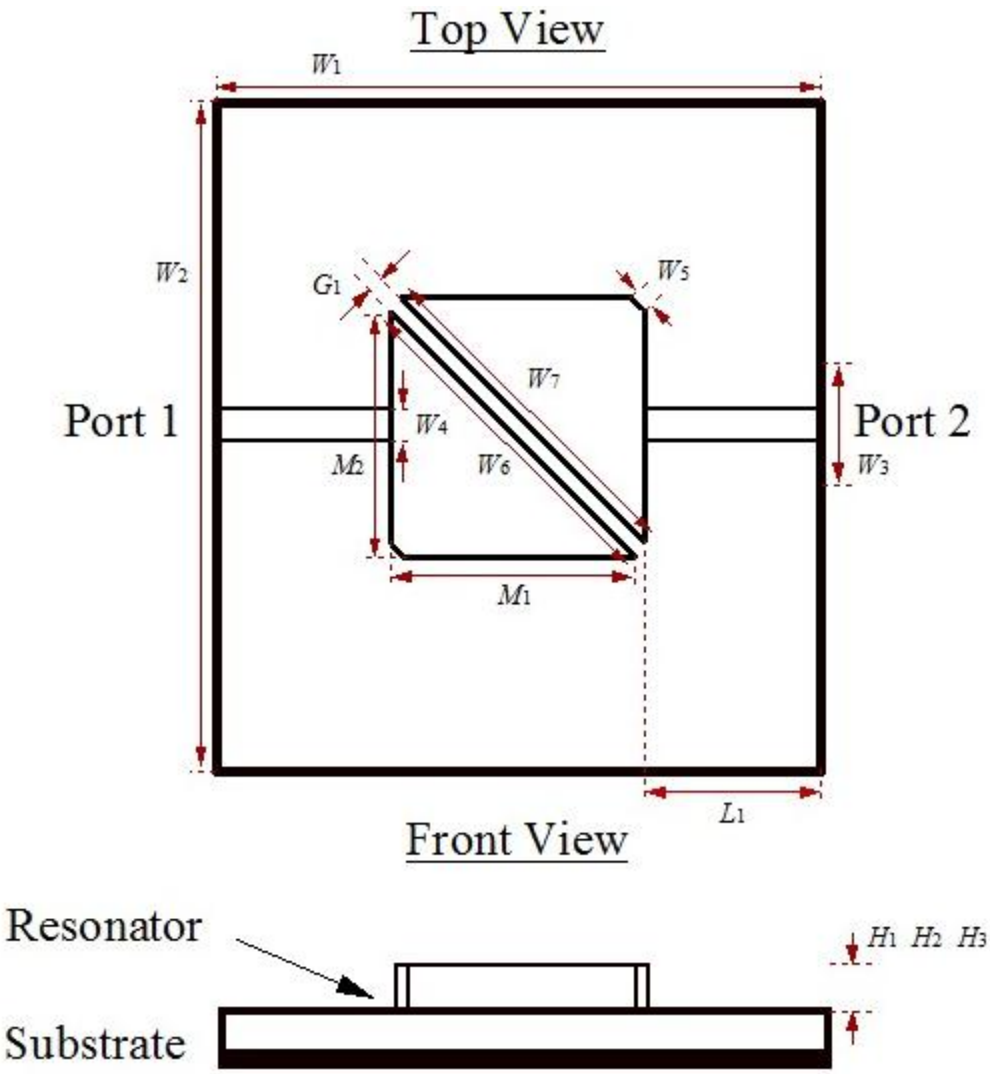

Figure 3.1: Top-down view and front view of proposed Rectangular Block Filter.

The detailed design parameters are given by: G_1 = 2.82 mm, H_1 = 2.00 mm, L_1 = -13.00 mm, M_1 = 12.00 mm, M_2 = -13.00 mm, W_1 = 25.00 mm, W_2 = 20.00 mm, W_3 = 6.45 mm, W_4 = 2.15 mm, W_5 = 1.00 mm, W_6 = 24.00 mm, and W_7 = 24.00 mm.

Rectangular Block Filter have been successfully proposed and constructed in this research project. Basically, this proposed design was fabricated on the FR-4 substrate (with a dielectric constants of ε_r = 4.4 and a thickness of 1.57mm). It is a two-port rectangular block filter where Port 1 functions as an input port, and Port 2 defined as an output port of the filter.

All microstrip feed lines have the characteristic impedance of 50Ω. The proposed rectangular block filter is designed in three dimensions where more signals are coupled from metal 1 to metal 2 through the metal plate. The area of the metal plate is equal to the area where the signal coupled. By using the three dimensions design, the gap between the metal, $g1$ can be made larger compare to the conventional microstrip filter. The bandpass signal is inversely proportional to the gap, $g1$. The bandpass signal decreases when the gap between the metal increases.

The top-down view and side view of the proposed bandpass-filtering directional is shown in Figure 3.2.

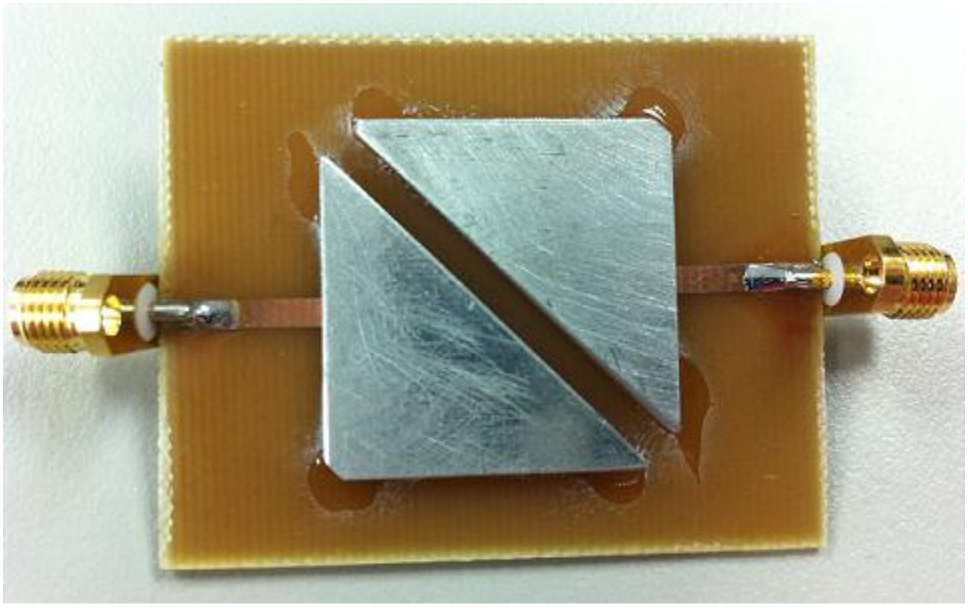

Figure 3.2: Top-down view of the proposed rectangular block filter.

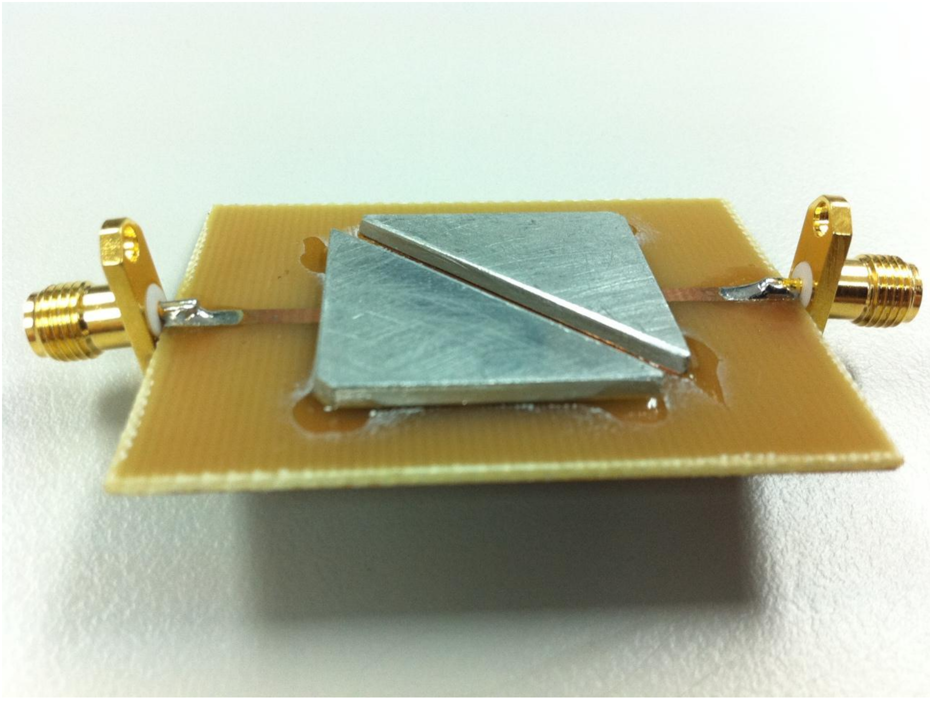

Figure 3.3: Side view of the proposed rectangular block filter.

3.3 Simulation

The configuration was simulated using Ansoft HFSS with all the parameters above. Figure 3.4 shows the performance of the proposed rectangular block filter. As can be seen from the amplitude response of the rectangular block filter, the operating frequencies of the bandpass filter are ranging from 2.25 GHz to 3.75 GHz with a total operating bandwidth of 1.5 GHz. It is a two-mode bandpass filter where the first pole locates at 2.8 GHz, and the second pole locates at the frequency of 3 GHz. In addition, the fractional bandwidth of the bandpass filter can be calculated as the following:

Centre Frequency

$$= \frac{Lower\ Frequency\ +\ High\ Frequency}{2}$$

$$= \frac{2.7375\ GHz + 3.1188\ GHz}{2}$$

$$= 2.928\ GHz$$

Fractional Bandwidth

$$= \frac{High\ Frequency - Lower\ Frequency}{Center\ \ Frequency} \times 100\%$$

$$= \frac{3.1188\ GHz - 2.7375\ GHz}{2.928\ GHz} \times 100\%$$

$$= 13\%$$

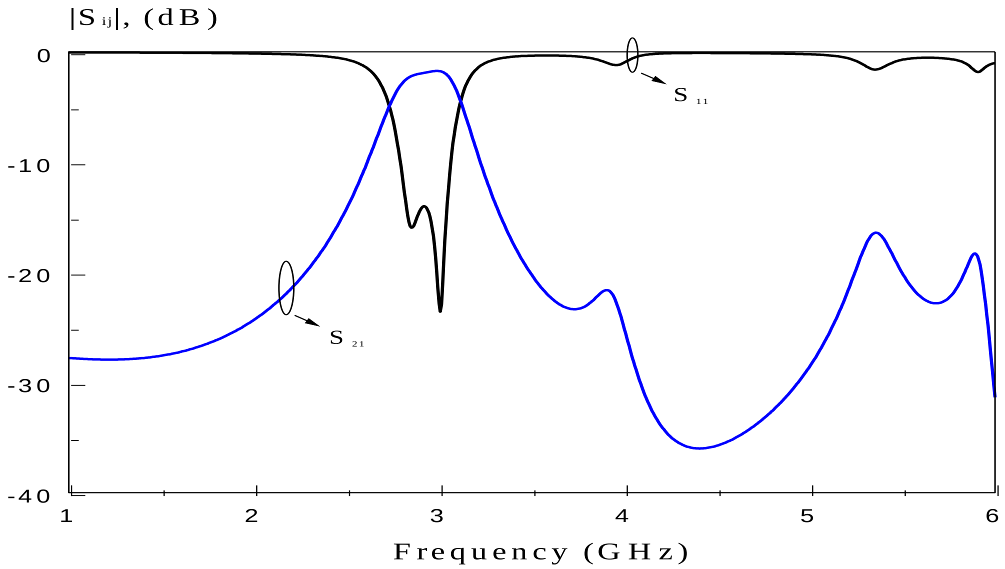

Figure 3.4: S-parameter of the proposed Rectangular Block Filter.

3.4 Parameter Analysis

Parameter analysis is so important since every parameter change make count. In order to obtain the optimal configuration of the proposed rectangular block filter, all the parameters were stepped up and stepped down to analyse the effect of every parameter by using Ansoft HFSS. Overall, the key parameter to analyse for the proposed rectangular block filter is the height and gap between each metal. However, the other parameters such as width, metal position, length will be discussed in detail according to the configuration in Figure 3.1.

Analysis 1

- Parameter : g_1
- Optimum value : 2.848 mm
- Step-down value : 1.414 mm
- Step-up value : 4.242 mm

Results:

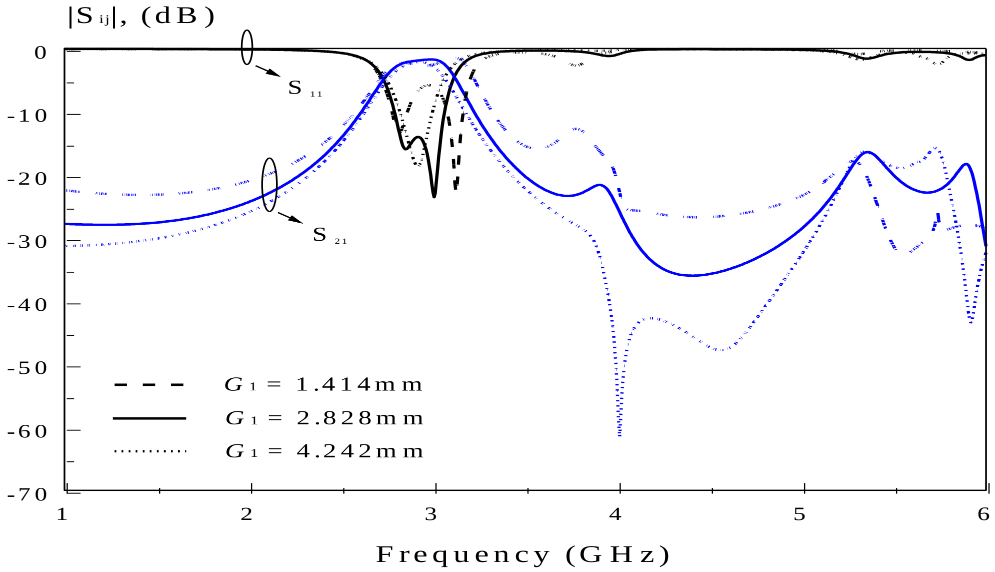

Figure 3.5: Effect of gap, g_1 on the rectangular block filter.

Description:

The parameter g_1 caused significant change on the proposed rectangular block filter. It affects the amplitude response of the rectangular block filter and eliminates the 2nd harmonic of the design. According to Figure 3.5, the optimal value of g_1 gives the best two-mode bandpass effect with a matching level below -20dB across the operating frequency band. Decreasing the gap between the metal can caused the signal to not operate at 3GHz of center frequency. In addition, it also eliminates the 2nd harmonic that we wish to observe. Increasing the gap will caused fewer signals to couple between both metal, the matching level is at -20dB which is not as good as the optimal result.

Analysis 2

- Parameter : h_1
- Optimum value : 2 mm
- Step-down value : 0.5 mm
- Step-up value : 4 mm

Results:

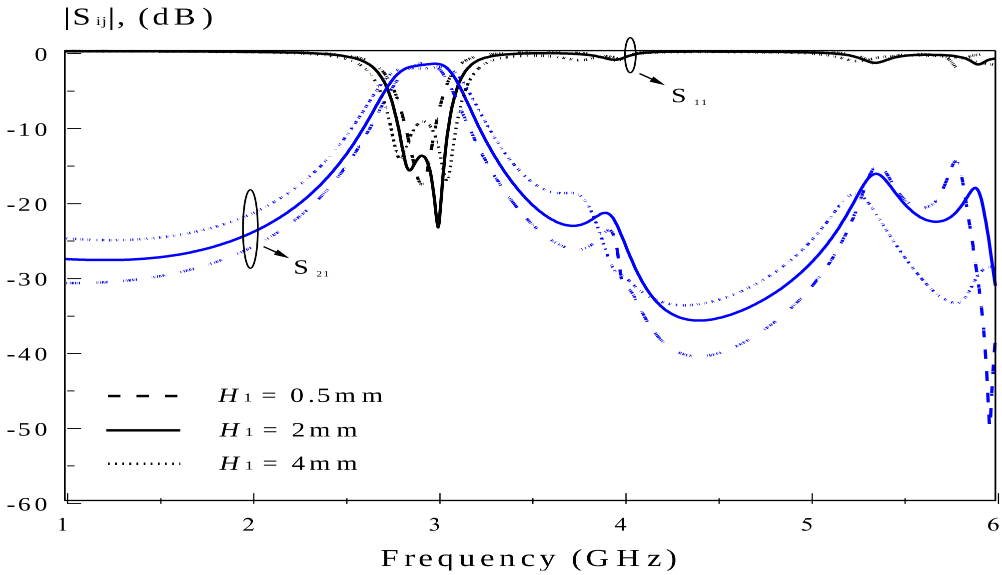

Figure 3.6: Effect of height, h_1 on the rectangular block filter.

Description:

By varying the parameter h_1, the signal of the proposed rectangular block filter changed across 2.7GHz to 3.1GHz. Aluminium is used as the metal since it has a good conductivity. The height is set to 2mm as it is easier to make compare to 0.5mm. The optimal parameter also gives maximum amplitude response in the design. When the height is reduced, the matching level at 3 GHz frequency is -17dB which is not good as the optimal parameter. When the height is increased, the 2nd harmonic is eliminated.

Analysis 3

- Parameter : h_2
- Optimum value : 2 mm
- Step-down value : 0.5 mm
- Step-up value : 4 mm

Results:

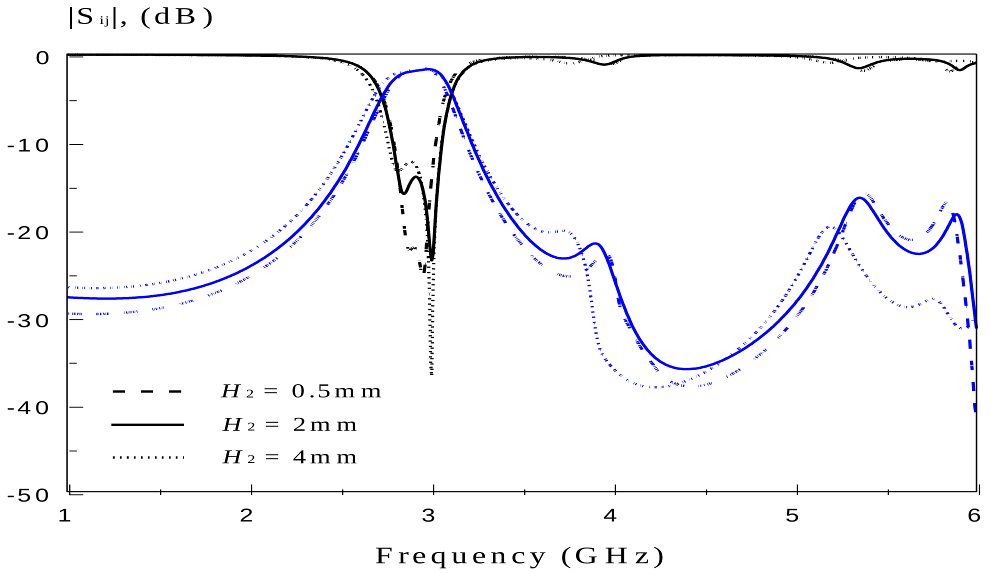

Figure 3.7: Effect of height, h_2 on the rectangular block filter.

Description:

In this parameter analysis, the height of both metal blocks has been set differently. The height of metal block at left is stepped down to 0.5mm and stepped up to 4mm respectively. From Figure 3.7, we do not observe big changes on the result. By stepping down the metal block, two-mode passband are combined together. By stepping up to 4mm, it has a lower return loss at 3 GHz with approximately -40dB.

Analysis 4

- Parameter : h_3
- Optimum value : 2 mm
- Step-down value : 0.5 mm
- Step-up value : 4 mm

Results:

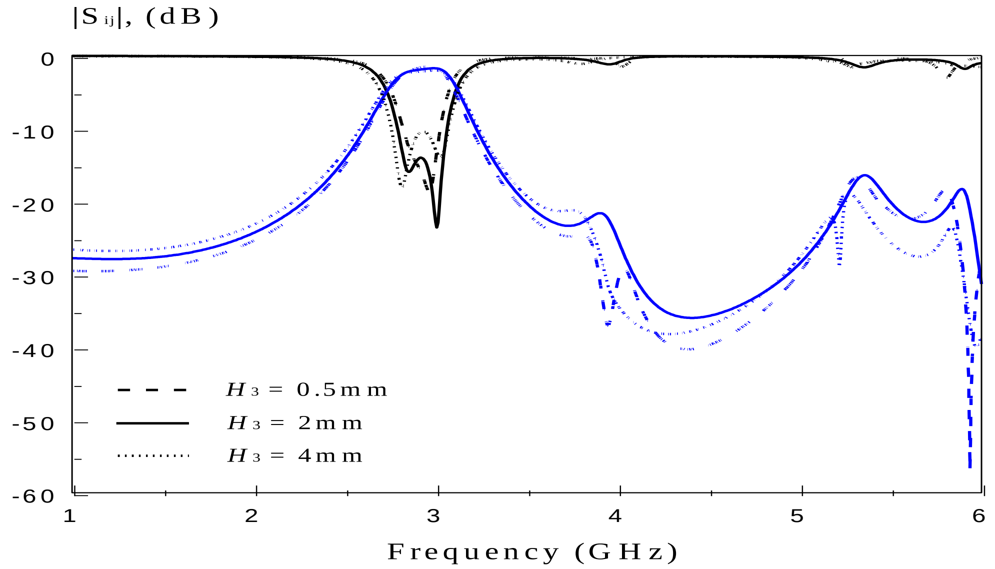

Figure 3.8: Effect of height, h_3 on the rectangular block filter.

Description:

Parameter analysis has been done by changing the height of metal block at right. By changing the height of 2nd metal block, it does not contribute too many changes to the result. It only causes the return loss of the rectangular block filter to goes higher as around -20dB. From Figure 3.8, the optimal value is giving the best result still.

Analysis 5

- Parameter : l_1
- Optimum value : -13 mm
- Step-down value : -12 mm
- Step-up value : -14 mm

Results:

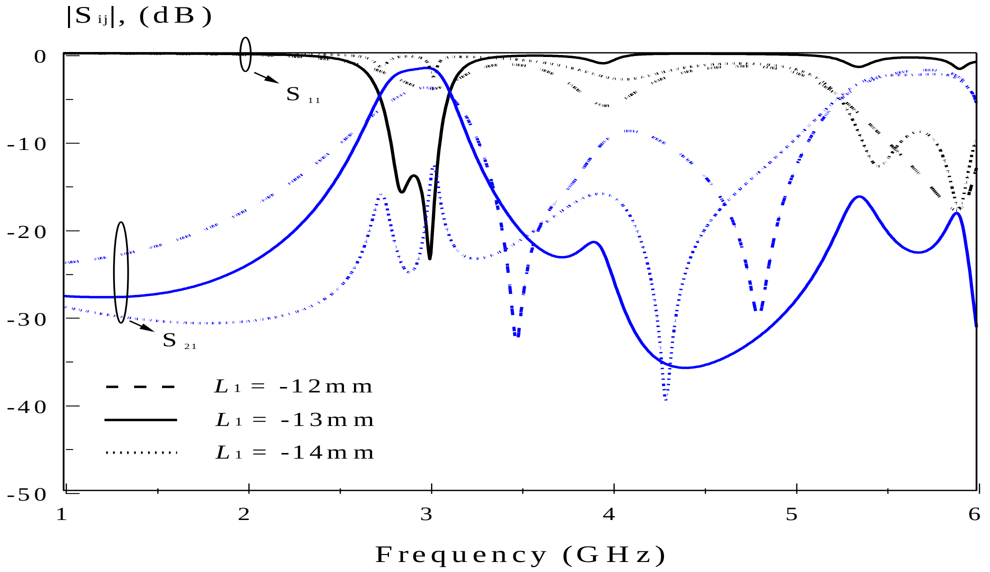

Figure 3.9: Effect of feeding position, l_1 on the rectangular block filter.

Description:

In analysis 5, length, l_1 shows the effect of different feed in position for the transmission line which caused different result on the analysis. The feed in position create a significant effect on the rectangular block diagram. With moving the feed in position away from the optimal value, the result is greatly affected until we are not able to get the bandpass filtering effect.

Analysis 6

- Parameter : m_1
- Optimum value : 12 mm
- Step-down value : 11 mm
- Step-up value : 13 mm

Results:

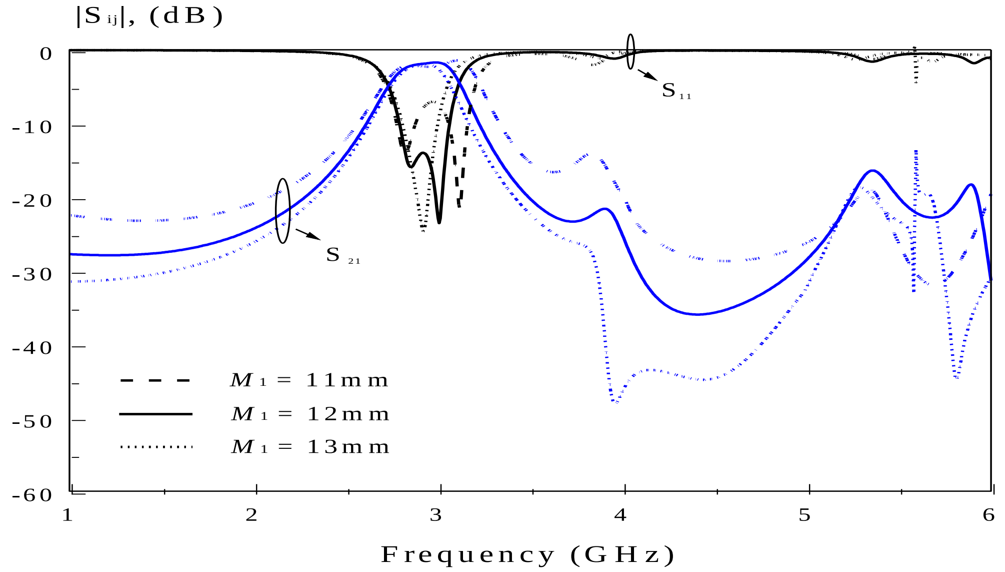

Figure 3.10: Effect of metal position m_1 on the rectangular block filter.

Description:

Parameter analysis is carried out by shifting the metal position along x-axis. By shifting the metal position, it has no significant effect on the result. It shifts the whole graph up by few dB when the metal is shifted to right and vice versa. However, the 2nd harmonic is affected when the metal is shift to the left along x-axis.

Analysis 7

- Parameter : m_2
- Optimum value : -12 mm
- Step-down value : -11 mm
- Step-up value : -13 mm
-

Results:

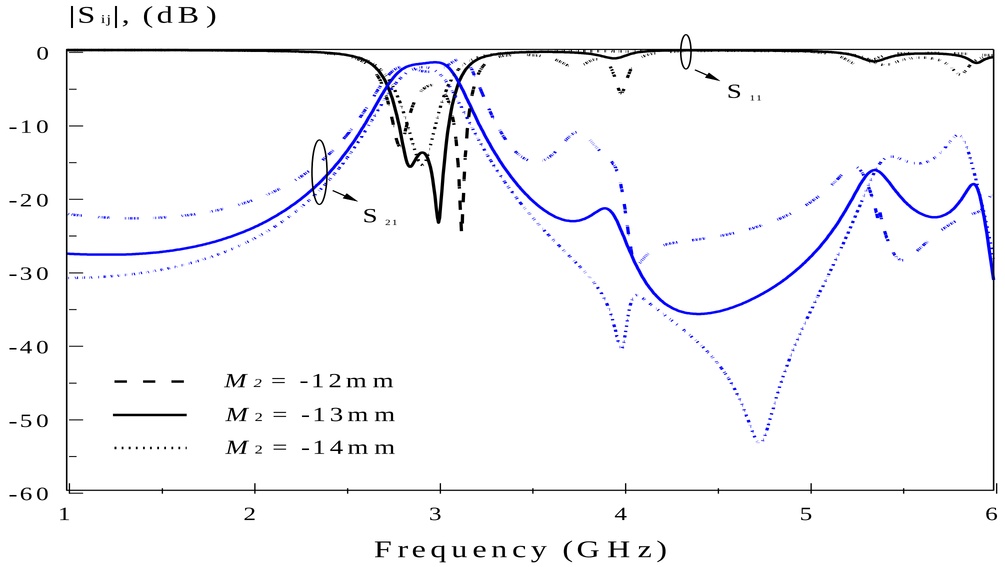

Figure 3.11: Effect of metal position *m*₂ on the rectangular block filter.

Description:

Parameter analysis is carried out by shifting the metal position along y-axis. The result is slightly affected when shifting along y-axis. When the metal is shifted upward, the operating frequency of the filter moves away to 3.25 GHz and eventually affected the 2nd harmonic. According to Figure 3.11, the optimal position gives the best result as it shows the two-mode bandpass effect and a matching level below -20dB as compare to -15dB when shifted downward.

Analysis 8

- Parameter : w_1
- Optimum value : 25 mm
- Step-down value : 20 mm
- Step-up value : 30 mm

Results:

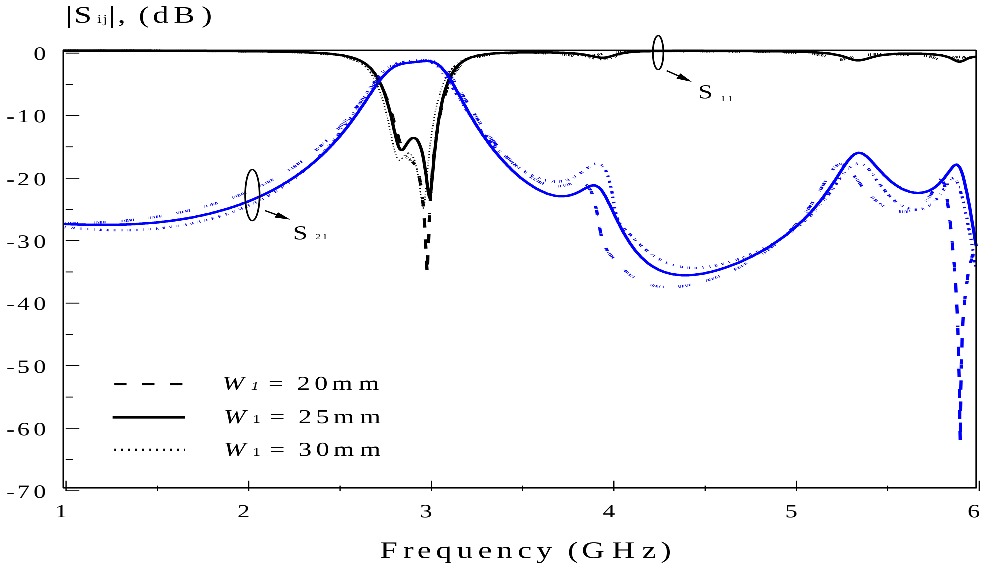

Figure 3.12: Effect of width w_1 on the rectangular block filter.

Description:

In analysis 8, width of the substrate at x-axis is modified by stepping up and stepping down. However, all those parameters do not affect the result at operating frequency. It affected the result at higher frequency which is between 3.5 GHz to 6 GHz.

Analysis 9

- Parameter : w_2
- Optimum value : 20 mm
- Step-down value : 15 mm
- Step-up value : 25 mm

Results:

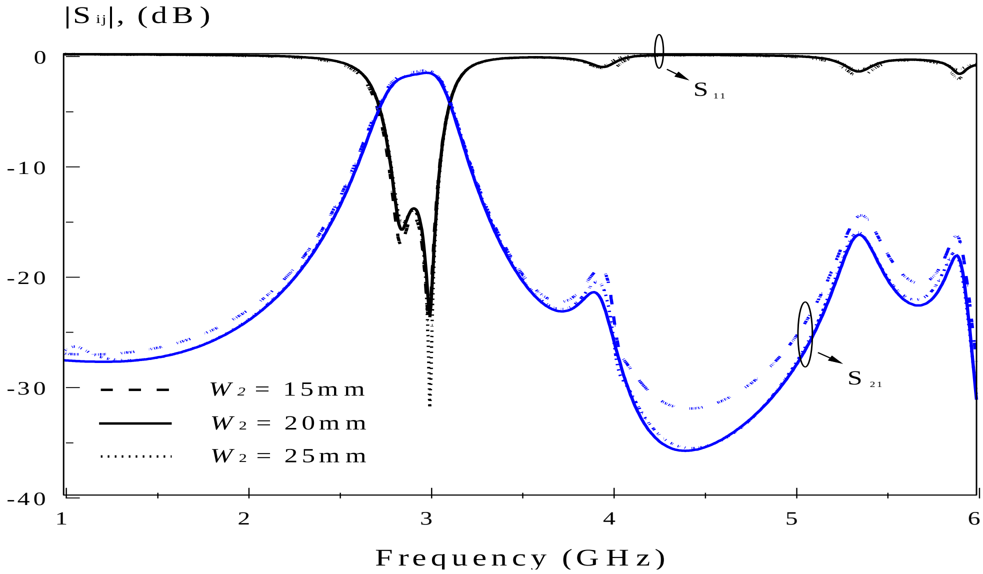

Figure 3.13: Effect of width w_2 on the rectangular block filter.

Description:

In analysis 9, width of the substrate at y-axis is modified by stepping up and stepping down. All those parameters do not affect much the result at operating frequency. When the width of substrate is stepped up, it obviously increase the sharpness of signal at 3GHz operating frequency. However, it affected the result at higher frequency which is between 4 GHz to 6 GHz.

Analysis 10

- Parameter : w_3
- Optimum value : 6.45 mm
- Step-down value : 4.5 mm
- Step-up value : 9 mm

Results:

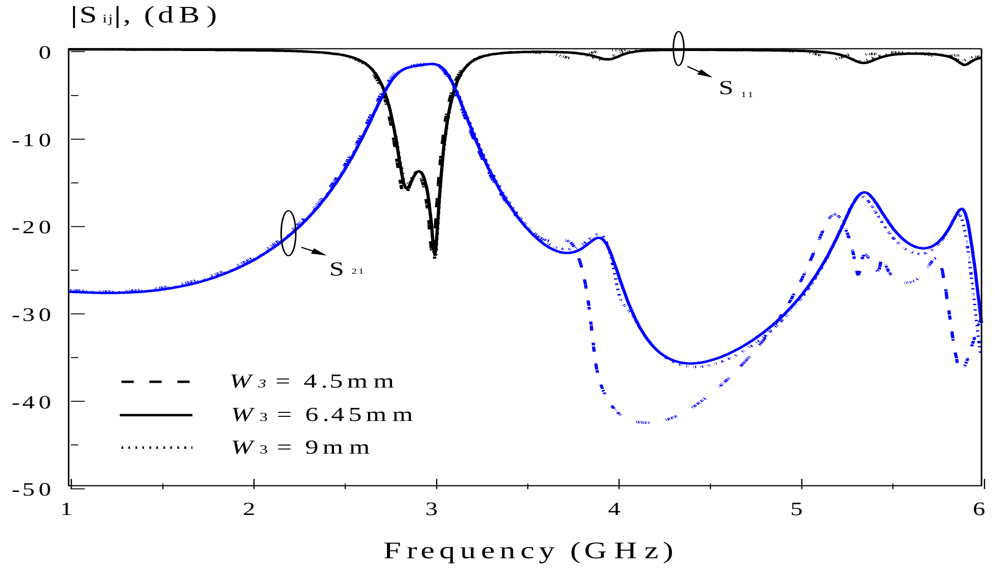

Figure 3.14: Effect of width w_3 on the rectangular block filter.

Description:

In analysis 10, the port of the design is being stepped up and stepped down to simulate the mismatch of characteristic impedance. Increasing the width of port does not affect much on the result. It shows exactly the same result as optimal value. However, the result at higher frequency above 4 GHz is greatly affected when the port width is reduced.

Analysis 11

- Parameter : w_4
- Optimum value : 2.15 mm
- Step-down value : 2 mm
- Step-up value : 2.3 mm

Results:

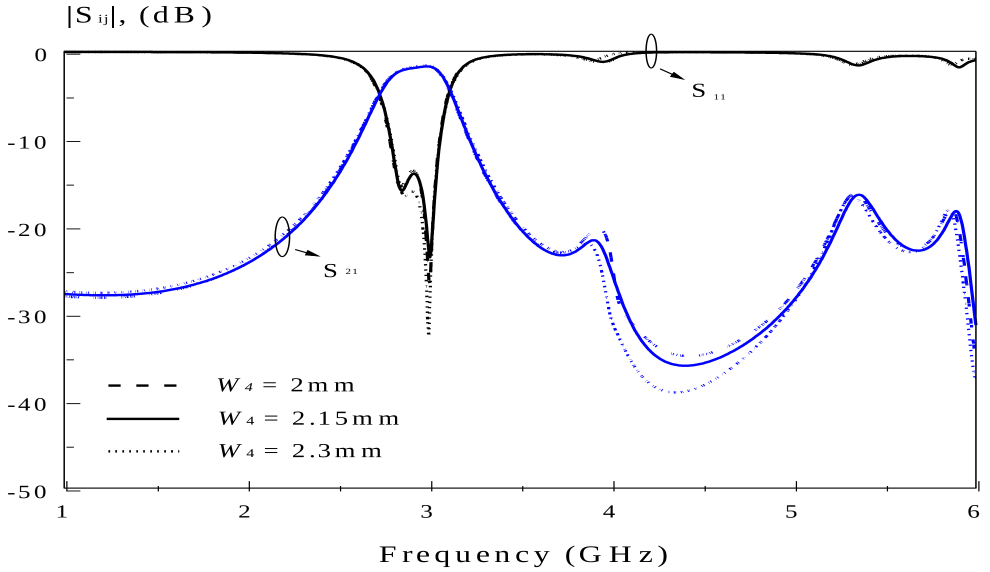

Figure 3.15: Effect of width w_4 on the rectangular block filter.

Description:

Width of the transmission line is being modified in analysis 11. It shows that the impedance mismatch does not contribute to big changes to the signal at frequency below 3 GHz. At frequency 4 GHz and above, signal mismatch is being observed. It also shows sharp selectivity at 3 GHz operating frequency when the width of transmission line has increased to 2.3mm.

Analysis 12

- Parameter : w_5
- Optimum value : 1 mm
- Step-down value : 0.5 mm
- Step-up value : 2 mm

Results:

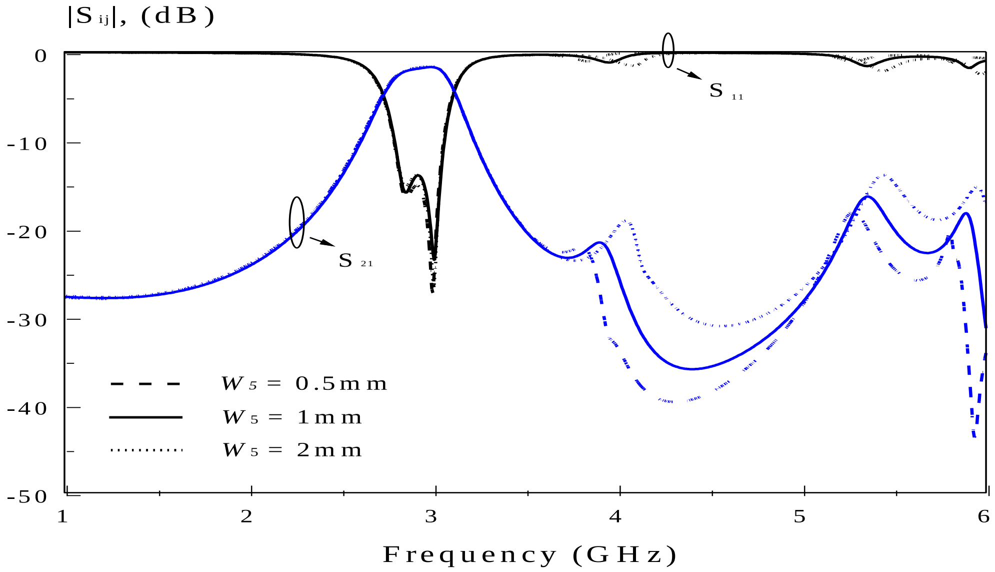

Figure 3.16: Effect of width w_5 on the rectangular block filter.

Description:

Curve at the metal is being introduced in the design to create some disturbance on how the signal coupled. The curve obviously do not interfere the signal at 3 GHz center frequency. It only affects the signal at higher frequency from 4 GHz onwards.

Analysis 13

- Parameter : w_5
- Optimum value : Curved
- Analysis value : No Curve

Results:

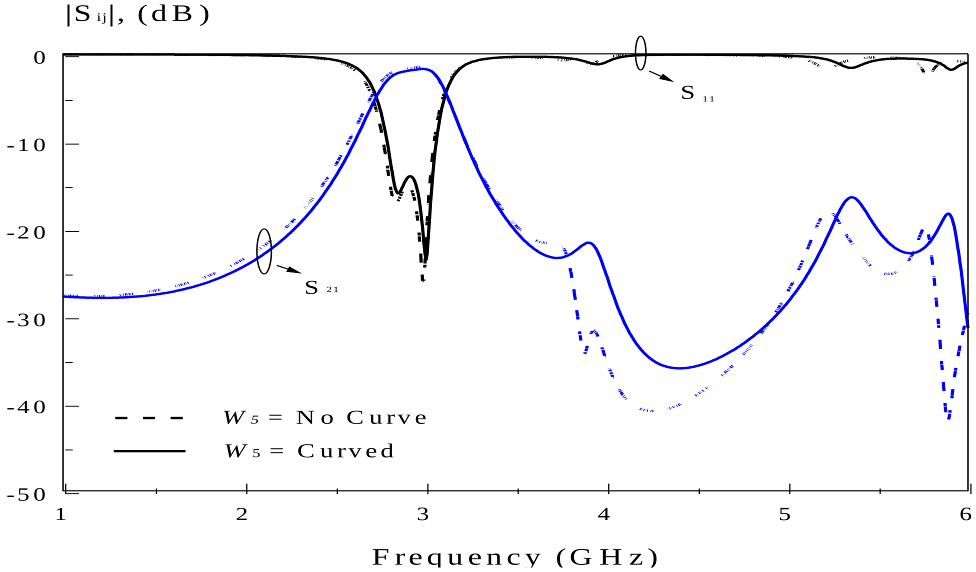

Figure 3.17: Effect of width w_5 on the rectangular block filter.

Description:

In analysis 13, curve and no curve design is introduced to the rectangular block filter. Obviously, the curve does not affect the result too much at operating frequency. It only sharpens the signal at 3.75 GHz with a sharp edge.

Analysis 14

- Parameter : w_6
- Optimum value : 24 mm
- Step-down value : 20 mm
- Step-up value : 28 mm

Results:

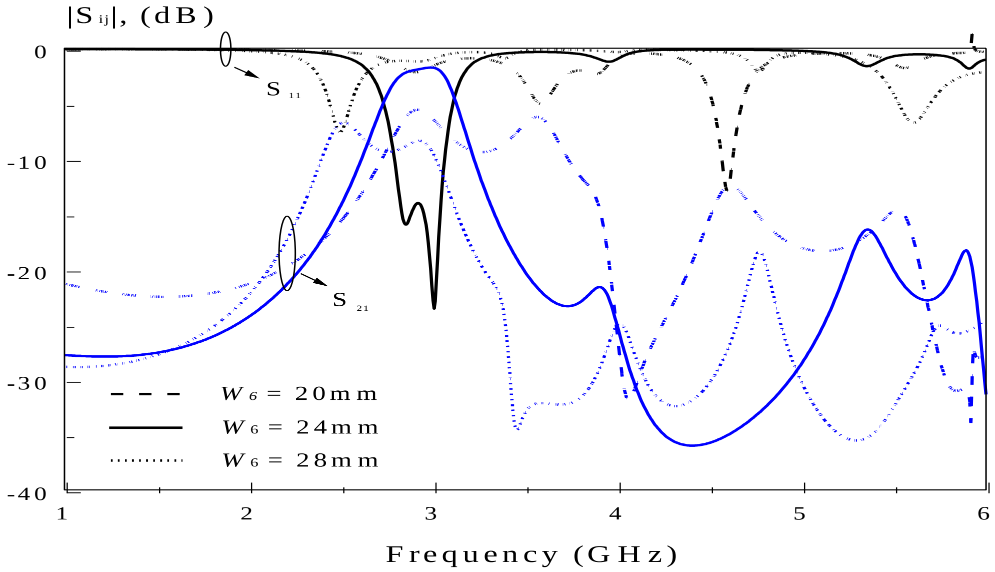

Figure 3.18: Effect of width w_6 on the rectangular block filter.

Description:

The width of the metal which couple signal is being stepped up and down. It shows that the area of couple path should stay the same as the receiving area. If mismatch of area by ±4mm, it will malfunction the purpose of rectangular block filter. Most of the signal will be not able to couple from one metal to another and we do not observe the bandpass filtering effect.

Analysis 15

- Parameter : w_7
- Optimum value : 24 mm
- Step-down value : 20 mm
- Step-up value : 28 mm

Results:

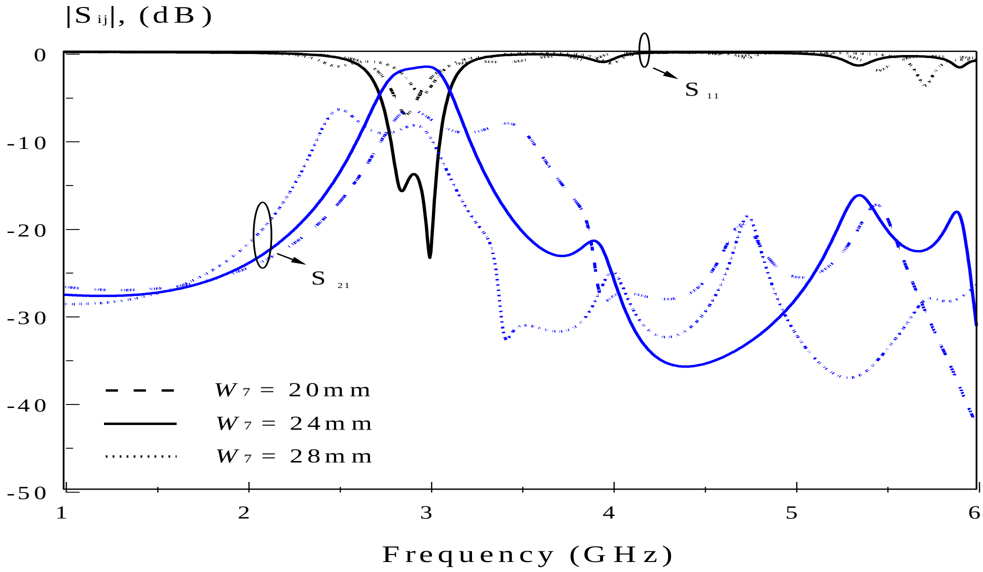

Figure 3.19: Effect of width w_7 on the rectangular block filter.

Description:

In analysis 15, coupling path of the metal is tested. It shows that coupling area of both metals have to be same so that the signal can be coupled. By adjusting the width to ±4mm, it shows the bandpass behaviours. However, the signal is not able to couple from one metal to another as well like what is shown in analysis 14.

3.5 Result

The configuration of the rectangular block filter was simulated by using Ansoft HFSS. A series of measurement were carried out using the Rohde & Schwarz ZVB8 Vector Network Analyser in order to examine the performances of the rectangular block filter. Amplitude of the HFSS simulation and measurement by VNA were compared as below.

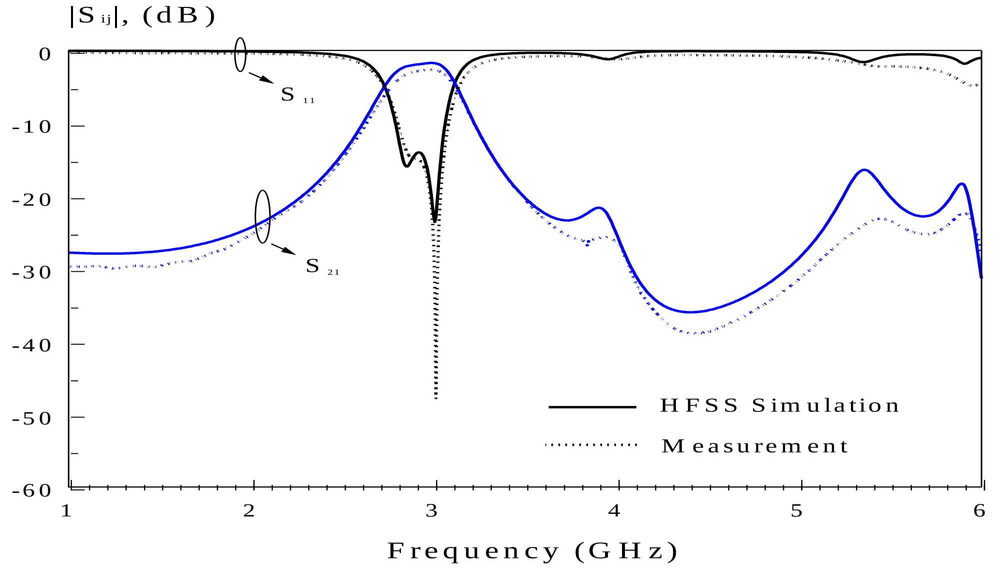

Figure 3.20: Simulated and measured amplitude responses of the rectangular block filter.

Based on the results above, it is obvious that a two-mode filtering effect can be realised by the proposed design. The experimental results agree well and very similar with the simulated data. Figure 3.20 shows the amplitude responses of proposed rectangular block filter. As can be seen from the experimental result, a flat passband at around -2.6 dB is shown and achieved at operating frequency range of 2.75 GHz to 3.25 GHz which give a total bandwidth of 0.5 GHz. As compared with the measurement, it is 90% alike to the HFSS simulation and hence proved the wall coupling theory. From the result, we can see that there are two poles which contribute to the wideband filtering effect for rectangular block filter. The first pole located at 2.85 GHz whereas the second pole is at exactly 3 GHz which is the center frequency of the filter. In addition, we also observe a high signal which transmitted at s-parameter of S_{11}. It happens exactly at 3 GHz operating frequency with more than -45dB in measurement which is higher than the HFSS simulation.

Table 3.1: Comparison of the experiment, and HFSS simulation results.

	Experiment	HFSS Simulation
f_L (GHz) / f_H (GHz)	2.75 / 3.13	2/7375 / 3.1188
f_c(GHz)	2.94	2.928
Fractional Bandwidth (%)	12.9	13

3.6 Discussion

In general, a two mode bandpass filter has wider bandwidth. It has to be sharp roll off for higher selectivity. This helps to filter out the undesired signals. In the past, we often create microstrip filter with around 0.1mm of strip height. However, a rectangular block filter has been purposed in this experiment to test the height which affects the amount of signal which coupled. The increase of height in rectangular block filter helps to reduce the fabrication problem. That fabrication problem that usually happens is the imperfection of the gap since the gap is too small and very hard to fabricate. By using the block design, larger gap is allowed since the increased of height simulate more signal to be coupled from one side to another. In this experiment, the HFSS simulation is exactly same as the measurement result and hence proves that the rectangular block filter is working perfectly in practical case.

Figure 3.21 shows the conventional design of microstrip bandpass filter where the conductor height is 0.1mm. When the height is 0.1mm, the gap eventually will be as small as 0.1mm as well. Figure 3.22 shows the rectangular block filter where the conductor height is increased to 2mm. When the height increased, area that coupled the signal also increased. So the gap of the metal can be increased to 2.8mm which shown in this experiment.

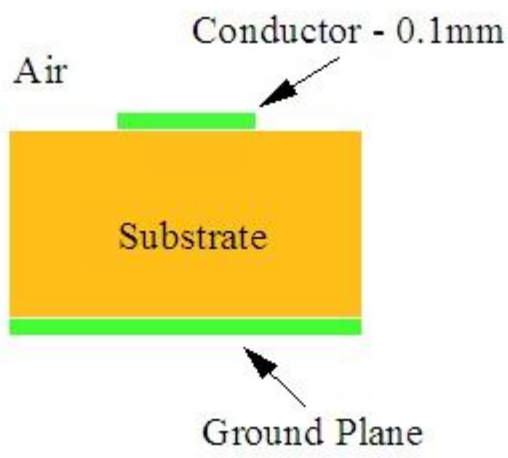

Figure 3.21: Conventional Microstrip Bandpass Filter.

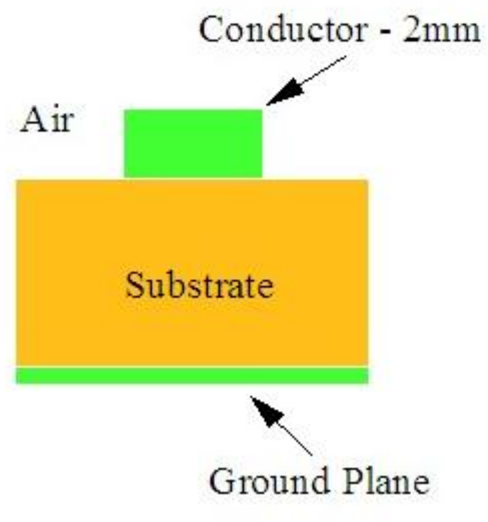

Figure 3.22: Rectangular Block Filter.

Based on the parametric analysis in Section 3.4, several parameters are proven to be important for the performance of the rectangular block filter. Parameters such as g_1, h_1, and l_1 are found to be crucial which will determine the performance and operating frequency of the rectangular block filter. The coupling level is mainly affected by g_1, and h_1. As a rule of thumb, the higher the conductor's height, the more signal couples through the metal. By knowing the characteristic and effect of all design parameters, the rectangular block filter can be easily optimized.

CHAPTER 4

SIDE-COUPLED BLOCK FILTER

4.1 Background

In this chapter, a side-coupled block filter with two-port is simulated and analysed. The side-coupled block filter will preserve the block coupling theory that was investigated in previous chapter. However, in this chapter, the side-coupled block filter will perform in wider bandwidth since it is a three-mode bandpass filter. This chapter will also prove that the signal can couple at both side of the metal block. To prove the performance of the side-coupled block filter, a series of experiment which include HFSS simulation, real time measurement and TLM modelling will be carried out.

4.2 Configuration

Side-coupled block filter will preserve the characteristic of conventional bandpass filter. In this experiment, a side-coupled block filter that operates across 2 GHz to 5 GHz with a centre frequency of 3 GHz was designed. It consists of port 1 which functions as an input port, and port 2 defined as an output port. Substrate FR-4 with dielectric constants of ε_r = 4.4 and thickness of 1.57mm was used in this HFSS simulation. Three metal blocks are placed side by side to allow the signal to couple thru. Besides that, all the two ports of the side-coupled block filter are designed with the characteristic impedance of 50Ω for ease of interconnection with other microwave systems. To further improve the bandwidth of the bandpass filter, three-mode is being used for creating wider bandwidth at -3dB.

With the design requirements stated above, a side-coupled block filter was drawn using the Ansoft HFSS. The top-down view of the side-coupled block filter is shown in the figure below. The detailed design parameters are given by: $g_1 = 2.0$ mm, $g_2 = 2.0$ mm, $g_3 = 2.0$ mm, $h_1 = 2.0$ mm, $l_1 = 27.0$ mm, $l_2 = 25.5$ mm, $l_3 = 27.0$ mm, $l_4 = 27.0$ mm, $l_5 = 27.0$ mm, $l_6 = 31.0$ mm, $l_7 = 31.0$ mm, $l_8 = 31.0$ mm, $w_1 = 2.0$ mm, $w_2 = 2.0$ mm, $w_3 = 2.0$ mm, and $w_4 = 2.0$ mm.

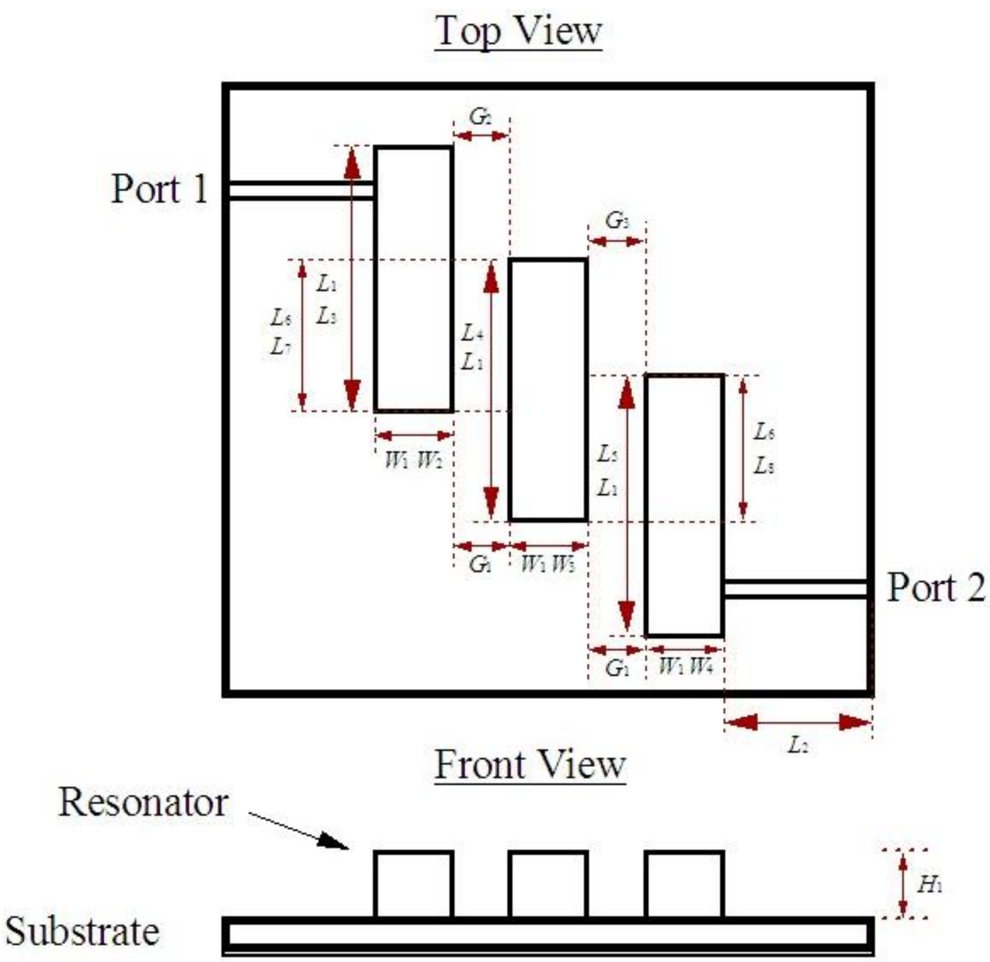

Figure 4.1: Top-down view of the side-coupled block filter.

The top-down view and side view of the proposed side-coupled block filter is shown in Figure 4.2 and Figure 4.3.

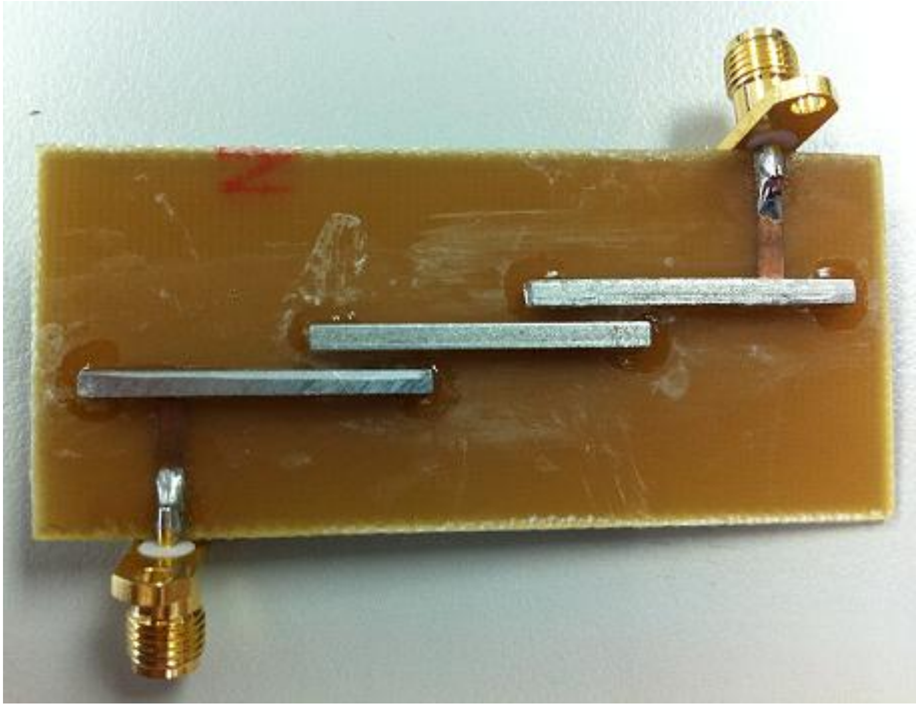

Figure 4.2: Top-down view of the proposed side-coupled block filter.

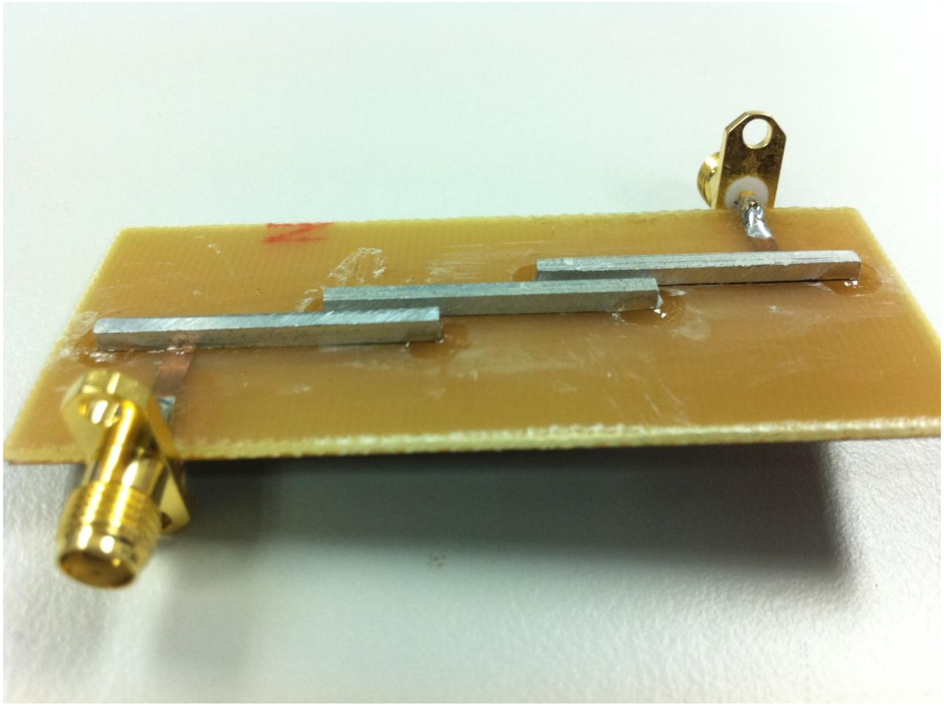

Figure 4.3: Side view of proposed side-coupled block filter.

4.3 Simulation

Simulation has been carried out using Ansoft HFSS with all the parameters shown above. Figure 4.4 shows the simulation performance of the proposed side-coupled block filter. As we can observe from the graph, the operating frequency of the side-coupled block filter is ranging from 2.5 GHz to 3.5 GHz with a total operating bandwidth of 1 GHz. It is a three-mode bandpass filter with a wide and flat passband ranging from 2.795 GHz to 3.385 GHz. In addition, the fractional bandwidth of the bandpass filter can be calculated as the following:

Centre Frequency

$$= \frac{Lower\ Frequency\ +\ High\ Frequency}{2}$$

$$= \frac{2.795\ GHz + 3.385\ GHz}{2}$$

$$= 3.085\ GHz$$

Fractional Bandwidth

$$= \frac{High\ Frequency - Lower\ Frequency}{Center\ Frequency} \times 100\%$$

$$= \frac{3.385\ GHz - 2.795\ GHz}{3.085\ GHz} \times 100\%$$

$$= 18.8\%$$

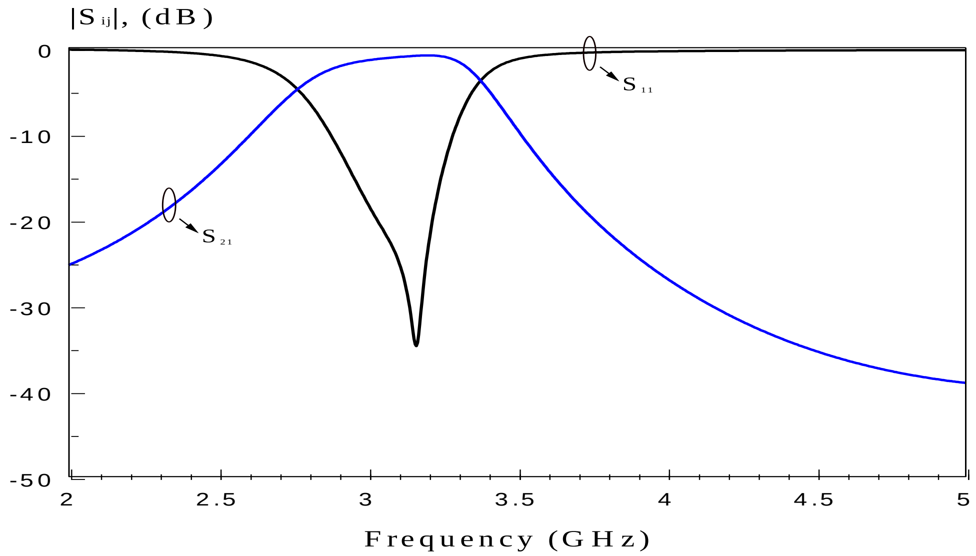

Figure 4.4: S-parameter of the proposed side-coupled block filter.

4.4 Transmission Line Model

In this section, a transmission line model is derived to simulate the wall coupling effect of the side-coupled block filter. An equivalent circuit is being designed by combining the coupled line and transmission line into the design and being simulated using Microwave Office. Figure 4.5 shows the equivalent circuit of side-coupled block filter.

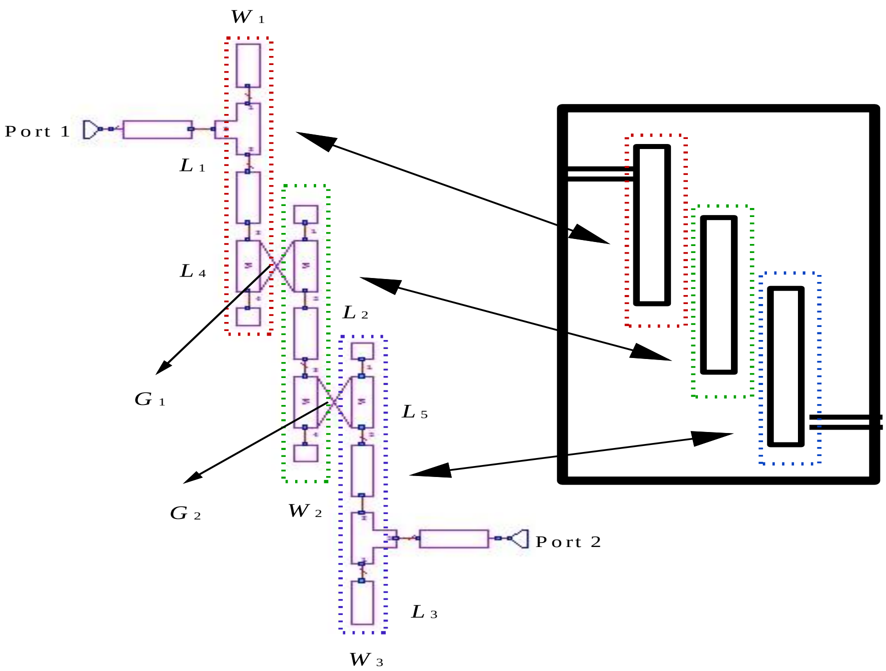

Figure 4.5: Transmission line model of side-coupled block filter.

The detailed design parameter of the transmission line model is given by: w_1 - = 2 mm, w_2 = 2 mm, w_3 = 2 mm, l_1 = 17.5 mm, l_2 = 17.5 mm, l_3 = 17.5 mm, l_4 = 9.5 mm, l_5 = 9.5 mm, g_1 = 0.20 mm and g_2 = 0.20 mm.

As can be seen from the model, the l_4 and l_5 represent the length where the signal couple along the metal block passing through the gap g_1 and g_2. The length l_4 and l_5 has been set to 9.5mm which is similar to the HFSS simulation. In designing the equivalent circuit, MTEE (Microstrip Tee-Junction) is used to connect the 50Ω transmission line to the metal block. Besides that, the MCLIN (Symmetric Edge Coupled Microstrip Line) is used to simulate the length and gap between the metal blocks. The gap g_1 and g_2 is set to 0.2mm instead of 1.5mm since we cannot simulate the height of metal block in Microwave Office. In this analysis, we are using this equivalent circuit to examine the effect of height and gap which will affect the return loss of S_{11}. Below shows the amplitude response and phase response of the HFSS simulation and TLM model for the proposed side-coupled block filter.

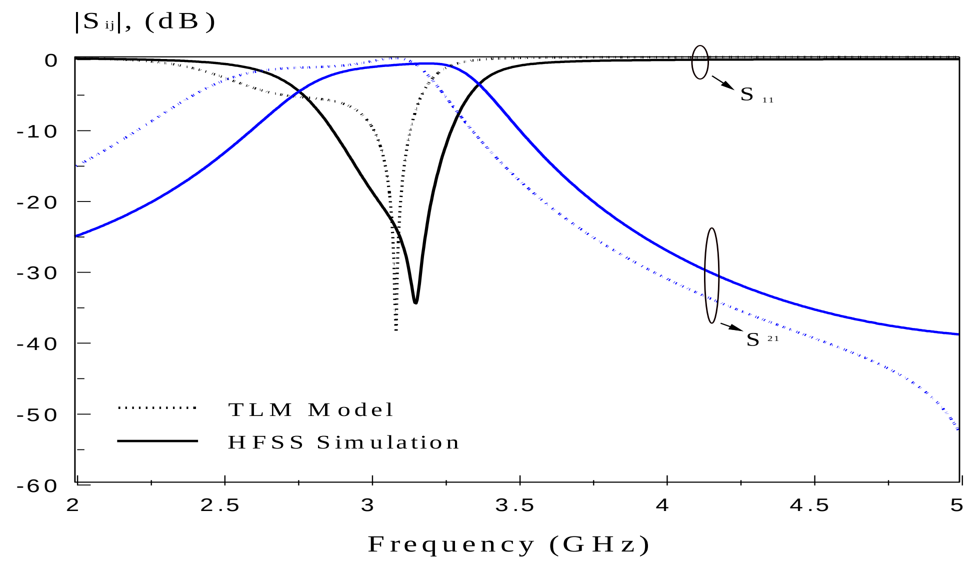

Figure 4.6: Amplitude Response of the HFSS simulation and TLM modelling for side-coupled block filter.

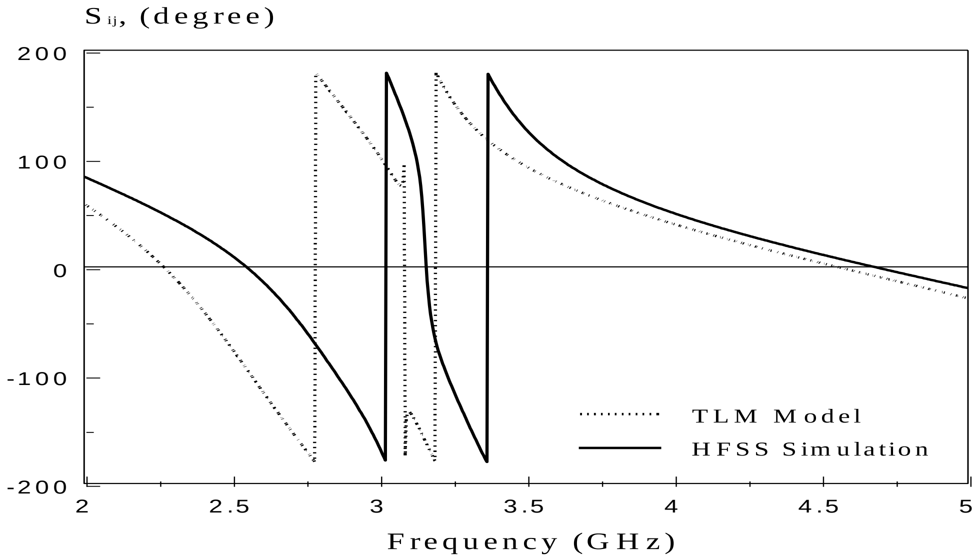

Figure 4.7: Phase response of the HFSS simulation and TLM modelling for side-coupled block filter.

According to figure 4.6, we can see that the transmission line model show the three-mode passband but the first and second passband do not transmit so well with only -8dB. We can also see that the centre operating frequency of the TLM model has shifted to 3 GHz because this TLM model cannot fully simulate the height of the metal blocks. In figure 4.7, we can observe that the phase response of transmission line modelling has shifted to 2.75 GHz at the first mode. However, the fractional bandwidth that we can obtain from the transmission line modelling is 24.2% which is very close to the fractional bandwidth of HFSS simulation and measurement by 5% to 7%.

4.5 Parameter Analysis

Parameter analysis is performed using HFSS to study all the changes. All the parameters are stepped up and stepped down within a range to obtain the optimal result. Overall, the key parameters to analyse for the proposed side-coupled block filter is the height and gap between each metal block. Other parameters will be analysed since it may cause some effect to the result as well. The design considerations and issues of each parameter will be discussed here.

Analysis 1

- Parameter : g_1
- Optimum value : 2.0 mm
- Step-down value : 0.5 mm
- Step-up value : 2.5 mm

Results:

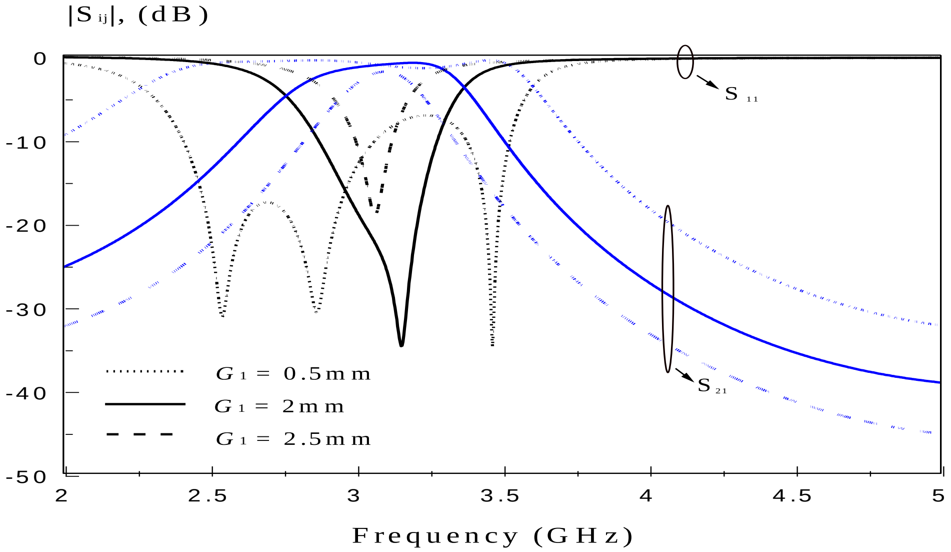

Figure 4.8: Effects of gap g_1 on the side-coupled block filter.

Description:

The parameter g_1 shows the gap between three metal blocks. It caused significant change on the side-coupled block filter. We can clearly see that the operating frequency of the side-coupled block filter is greatly affected. When the gap is stepped down to 0.5mm, we can see the three-mode passband are separated at 2.5 GHz, 2.75 GHz and 3.5 GHz. The result is not so good if stepped up to 2.5mm because the amplitude response is obviously lower at -20dB. From Figure 4.8, the optimal value of g_1 at 2mm gives the best three-mode bandpass effect with matching level below -35dB.

Analysis 2

- Parameter : g_2
- Optimum value : 2 mm
- Step-down value : 1 mm
- Step-up value : 3 mm

Results:

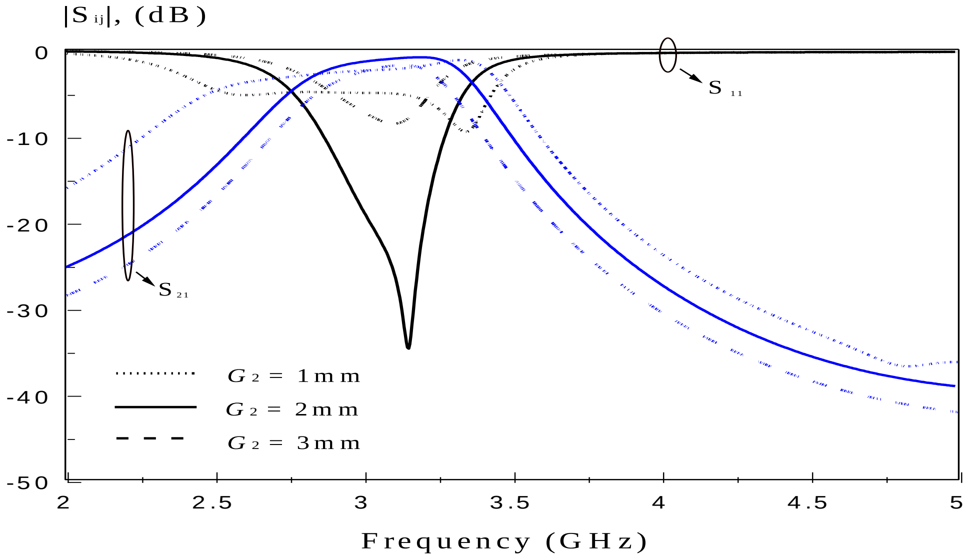

Figure 4.9: Effect of gap, g_2 on the rectangular block filter.

Description:

In analysis 2, the effect of gap change does not contribute too much change. It causes the amplitude response to stay around -10dB when stepped up or down. High amplitude response means fewer signals are coupled from one to another. With the optimal gap, it gives the best amplitude response at -35dB.

Analysis 3

- Parameter : g_3
- Optimum value : 2 mm
- Step-down value : 1 mm
- Step-up value : 3 mm
-

Results:

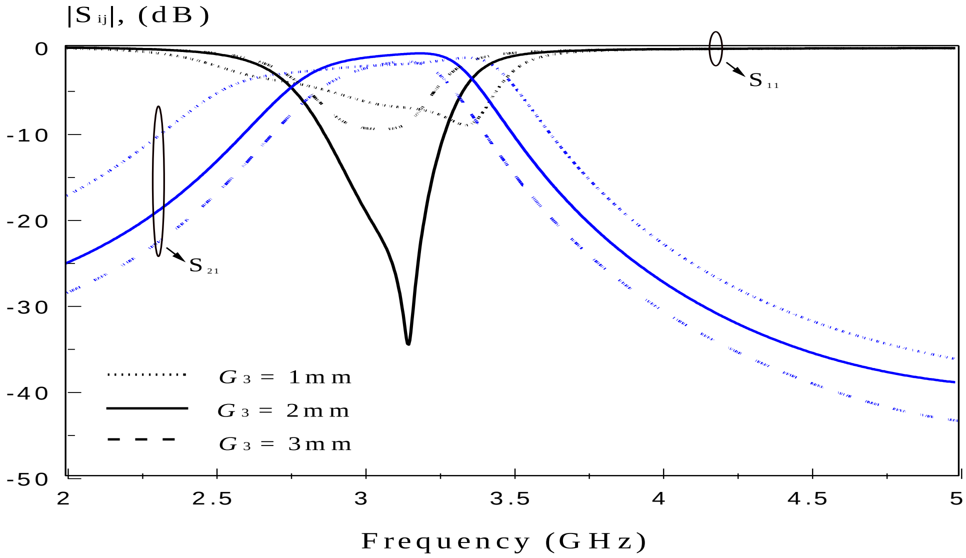

Figure 4.10: Effect of gap g_3 on the side-coupled block filter.

Description:

In analysis 3, it shows the similar result in analysis 2 because the design of the side-coupled block filter is symmetrical. So, by changing the other gap, it is the same as changing the first gap. It does shows that the response amplitude of S_{11} at 3 GHz is -10dB. The optimal gap is giving the best amplitude response to the overall result.

Analysis 4

- Parameter : h_1
- Optimum value : 2.0 mm
- Step-down value : 0.5 mm
- Step-up value : 4.0 mm
-

Results:

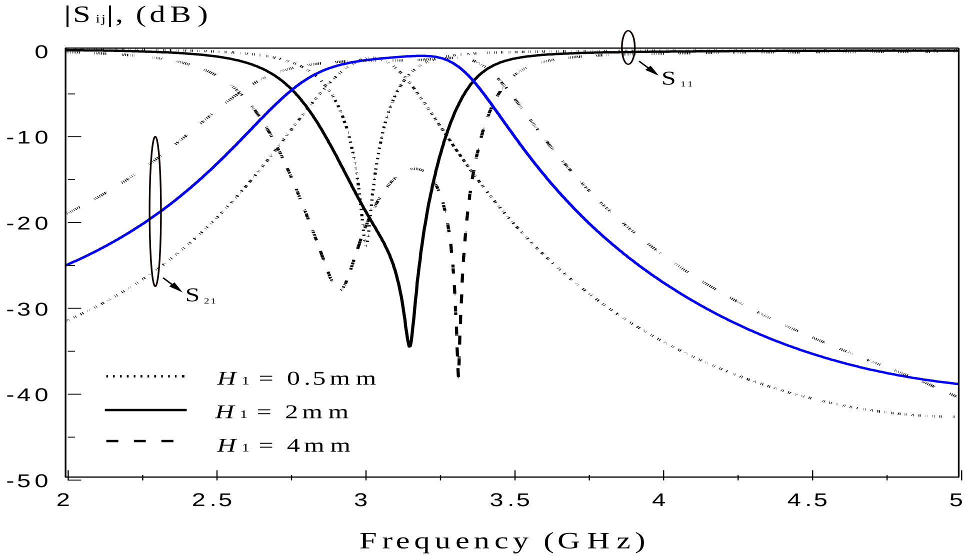

Figure 4.11: Effect of height h_1 on the side-coupled block filter.

Description:

Parameter analysis is carried out by changing the height of the metal block. Height is the crucial parameter that we are going to analyse in this experiment. As we increase the height, it obviously shows the three-mode passband separating at 2.75 GHz and 3.3 GHz. The result does not improve as we decreased the height of metal block, showing only -25dB. The optimal height of 2mm is giving the best result among other parameters.

Analysis 5

- Parameter : l_1
- Optimum value : 27 mm
- Step-down value : 24 mm
- Step-up value : 30 mm
-

Results:

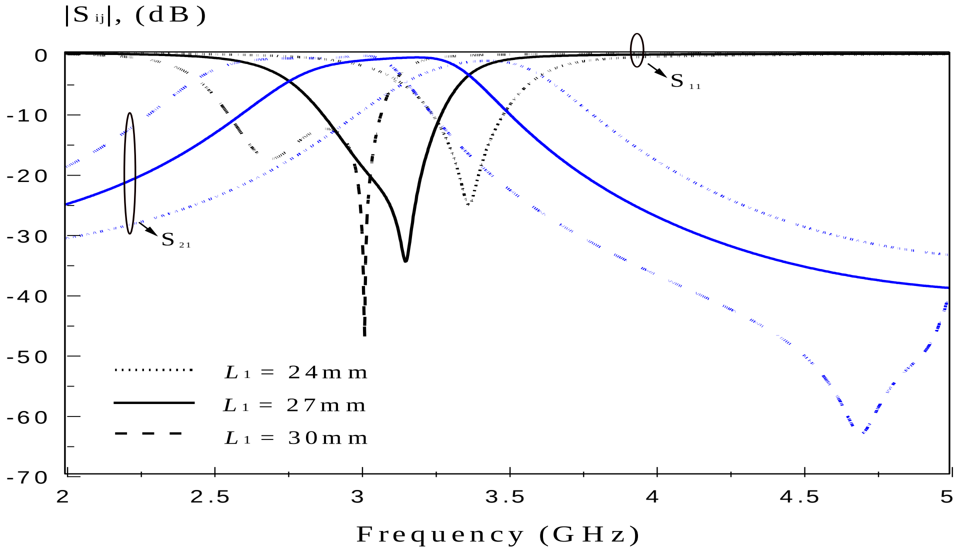

Figure 4.12: Effect of length l_1 on the side-coupled block filter.

Description:

In analysis 5, all the length of the metal blocks is changed according to the specific parameter to examine the changes. When the length of the metal block is stepped up, three mode passband are separated and it achieve as low as -45dB. However, by shorten the length of the metal block, the operating frequency of the filter shifted to 3.5 GHz which is 0.5 GHz away from the original operating frequency.

<u>Analysis 6</u>

- Parameter : l_2
- Optimum value : 25.5 mm
- Step-down value : 22.5 mm
- Step-up value : 28.5 mm
-

Results:

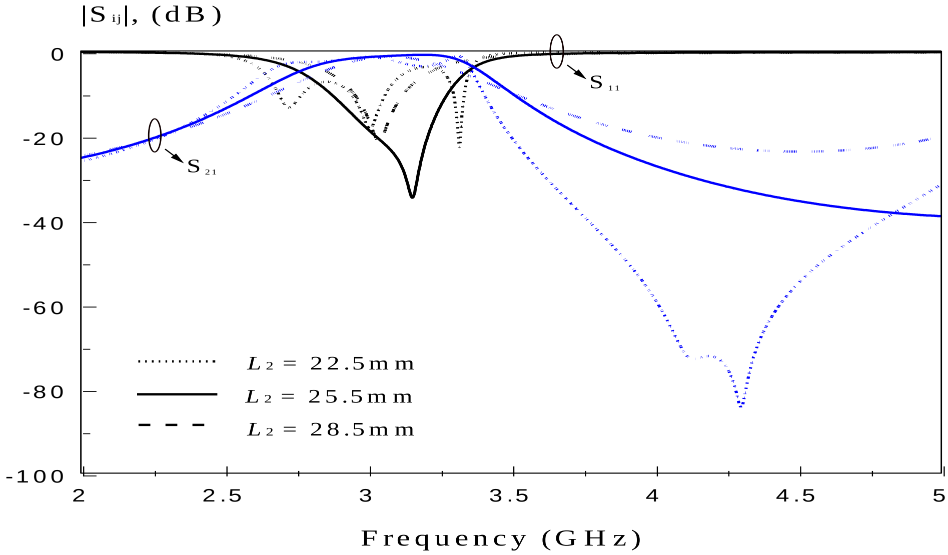

Figure 4.13: Effect of length l_2 on the side-coupled block filter.

Description:

Length, l_2 shows the feeding position of the transmission lines. When we change the position of the feeding line, it will eventually affect the signal as the signal may couple along different path on the metal block. When we move both of the feeding line closer, it clearly shows the three mode passband across 2.5 GHz to 3.25 GHz. When the feeding line is separated away, the amplitude response of the side-coupled block filter is -20dB because fewer signals are coupled through the gap.

Analysis 7

- Parameter : l_3
- Optimum value : 27 mm
- Step-down value : 24 mm
- Step-up value : 30 mm

Results:

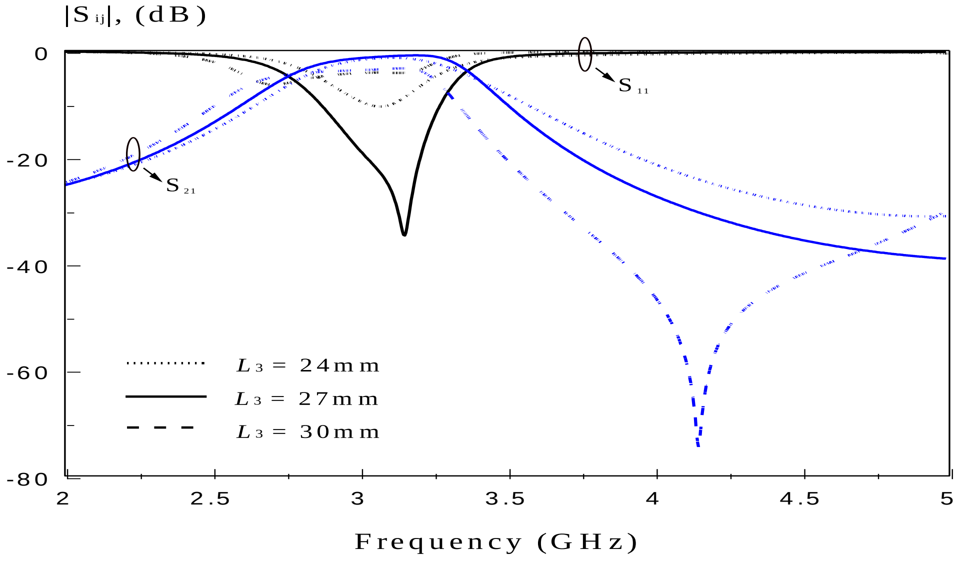

Figure 4.14: Effect of length l_3 on the side-coupled block filter.

Description:

Length, l_3 shows the different parameter of metal block most left. Length of the metal block is important since it can affect the way and amount of signal that coupled along the conductor. Ideal length for the design is 27mm, adding or subtracting the length only caused the result to be worsened.

Analysis 8

- Parameter : l_4
- Optimum value : 27 mm
- Step-down value : 24 mm
- Step-up value : 30 mm

Results:

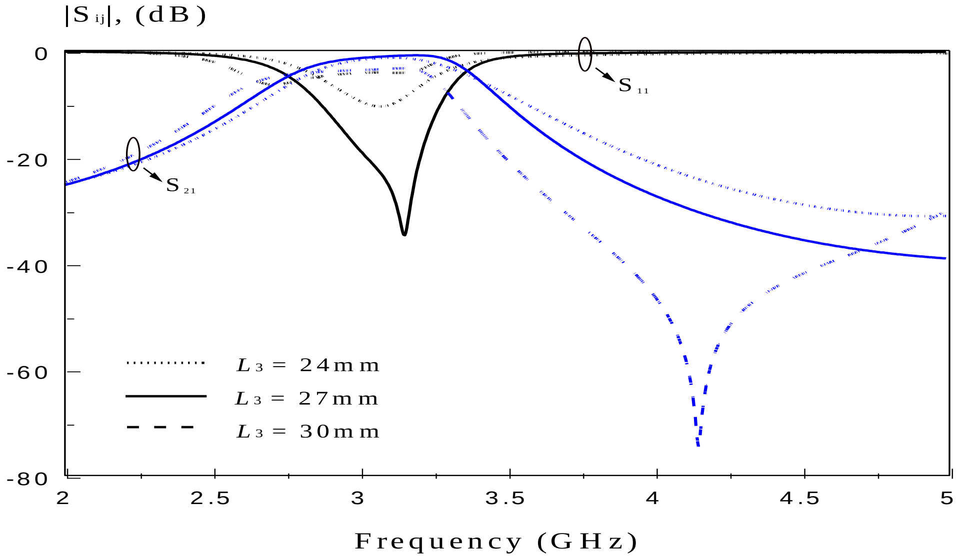

Figure 4.15: Effect of length l_4 on the side-coupled block filter.

Description:

Length, l_4 shows the different parameter of metal block at middle. This parameter analysis has proved that the length has great importance because it affects the coupling signal. When the length increased by 3mm, the operating frequency shifted to 2.6 GHz which is far from the ideal operating frequency. Decreasing the length does not improve the result as well. The length of 27mm is the most suitable as it gave the nearest result to 3GHz of frequency.

Analysis 9

- Parameter : l_5
- Optimum value : 27 mm
- Step-down value : 24 mm
- Step-up value : 30 mm

Results:

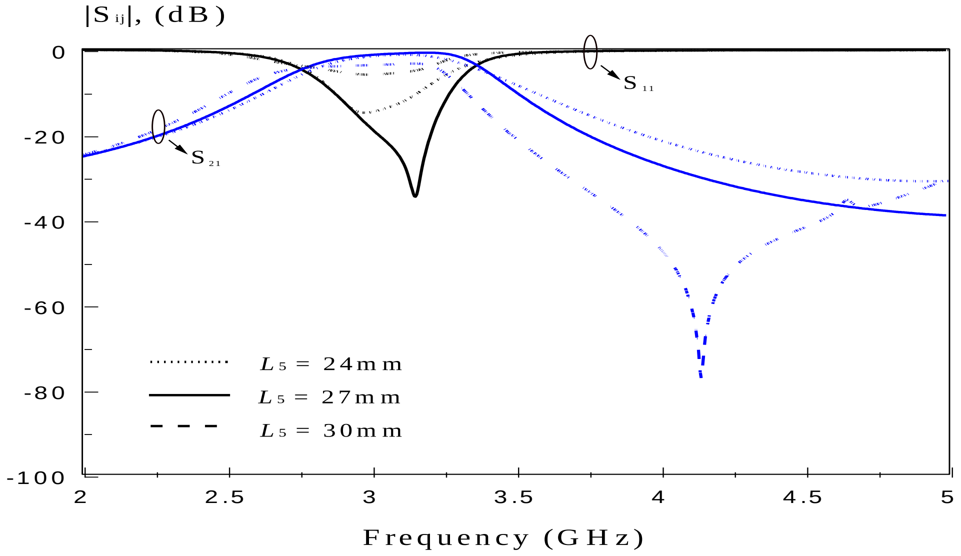

Figure 4.16: Effect of length l_5 on the side-coupled block filter.

Description:

In analysis 9, length, l_5 shows the different length of metal block at most right. By changing the length of the metal block, we can observed that both of the parameter also caused the amplitude response to fall above -15dB. As an alternative, we have to select length 27mm which give the best result which contribute to amplitude response of -35dB.

Analysis 10

- Parameter : l_6
- Optimum value : 31 mm
- Step-down value : 29 mm
- Step-up value : 33 mm

Results:

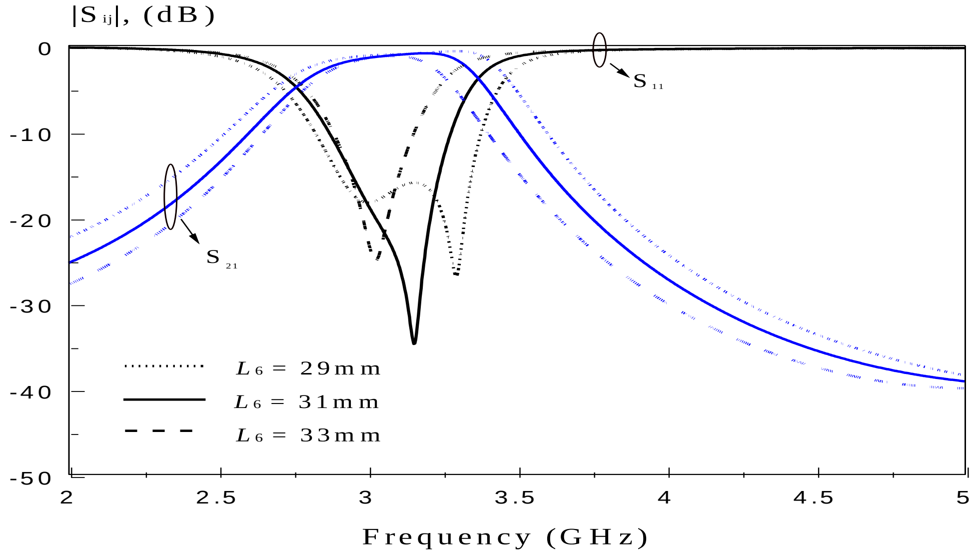

Figure 4.17: Effect of length l_6 on the side-coupled block filter.

Description:

In analysis 10, the area for both metal blocks that couple signal is being stepped up and down for parameter analysis. From Figure 4.17, we can see that the size of coupling area does not contribute too many changes to the result. It only shifts the result slightly to 3GHz and 3.25 GHz by varying the size of coupling area.

Analysis 11

- Parameter : l_7
- Optimum value : 28 mm
- Step-down value : 31 mm
- Step-up value : 34 mm

Results:

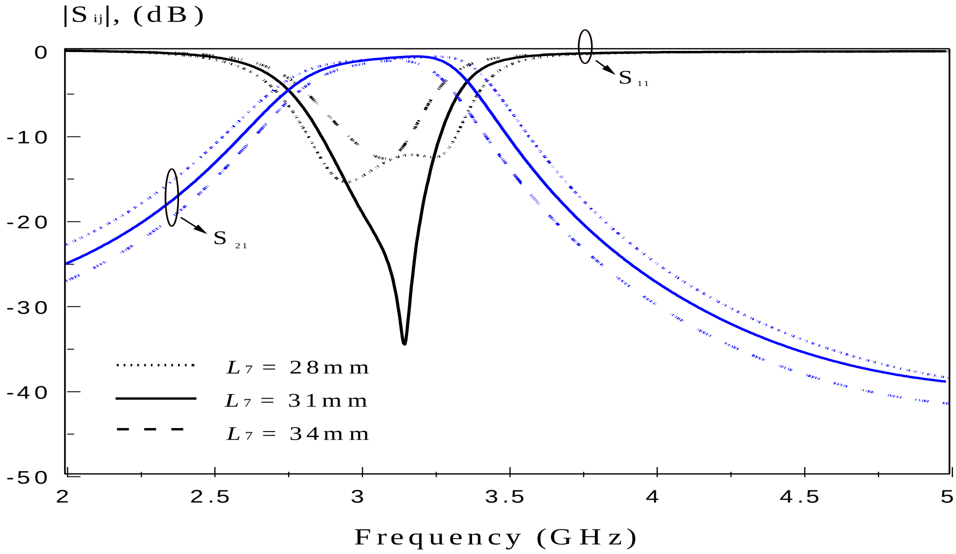

Figure 4.18: Effect of length l_7 on the side-coupled block filter.

Description:

The amplitude response of the signal is affected when the length l_7 changes. However, the changes that occur are just minor changes. It shifts the operating frequency to 3 GHz and 3.25 GHz with reducing the amplitude response to -15dB. From Figure 4.18, optimal value of length l_7 gives the best result among others with higher amplitude response at -35dB.

Analysis 12

- Parameter : l_8
- Optimum value : 31 mm
- Step-down value : 31 mm
- Step-up value : 34 mm

Results:

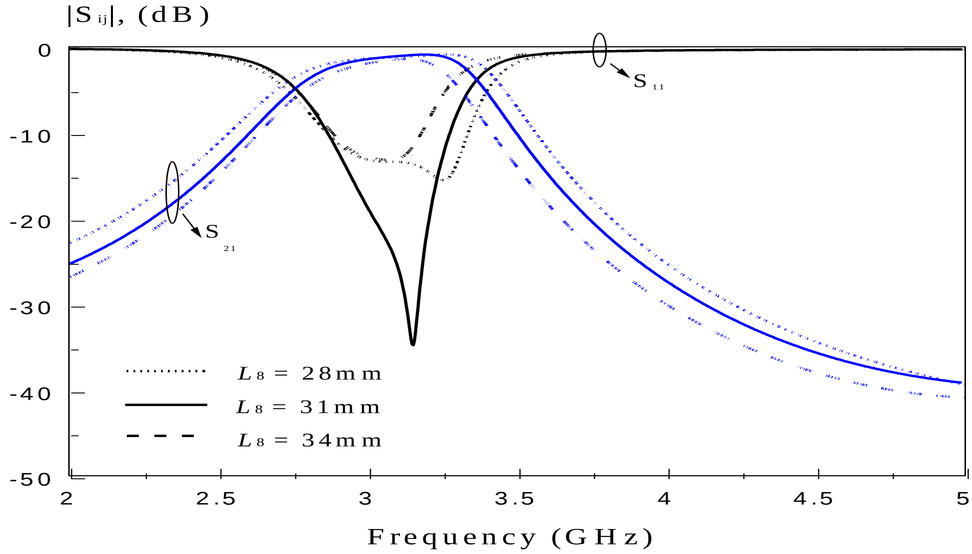

Figure 4.19: Effect of length l_8 on the side-coupled block filter.

Description:

The amplitude response of the signal is affected when the length l_8 changes. However, the changes that occur are not so crucial to the result. It shifts the operating frequency to 3 GHz and 3.25 GHz with reducing the amplitude response to -15dB. Besides that, it also reduces the sharpness of the amplitude response at S_{11}. From Figure 4.19, optimal value of length l_7 gives the best result among others with higher amplitude response at -35dB.

Analysis 13

- Parameter : w_1
- Optimum value : 2 mm
- Step-down value : 1 mm
- Step-up value : 3 mm

Results:

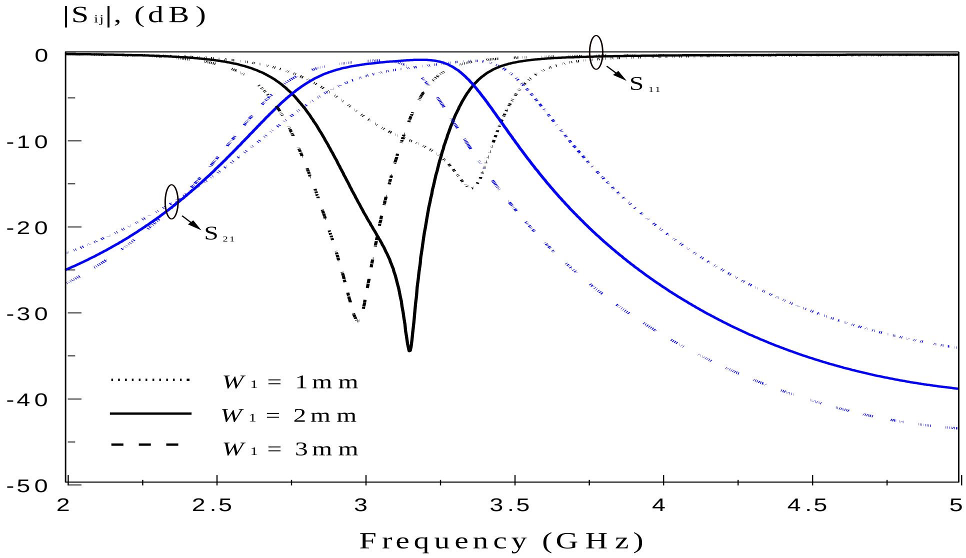

Figure 4.20: Effect of width w_1 on the side-coupled block filter.

Description:

The parameter analysis is carried out by changing all the width of metal blocks. When we reduce the metal block, few signal will be coupled among each other and hence causing the amplitude response to drop at -15dB. It also shifted the operating frequency to 3.5 GHz. However, the changes is not much as we increase the width of the metal block because it couples the same amount of signal as compare to 2mm width of metal block. It only shifts the operating frequency to 3GHz.

Analysis 14

- Parameter : w_2
- Optimum value : 2 mm
- Step-down value : 1 mm
- Step-up value : 3 mm

Results:

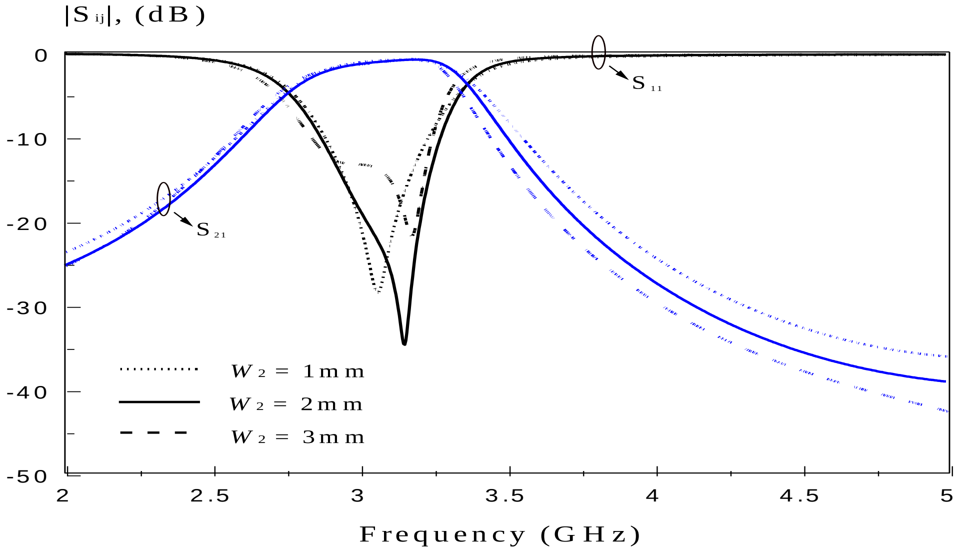

Figure 4.21: Effect of width w_2 on the side-coupled block filter.

Description:

In analysis 14, width of the metal block at most left is being varied for parameter analysis. From Figure 4.21, we can observe that not much change has happened to the result. It shifts the operating frequency away from 3.1 GHz. It also slightly reduces the amplitude response to ranging from -20dB to -30dB.

Analysis 15

- Parameter : w_3
- Optimum value : 2 mm
- Step-down value : 1 mm
- Step-up value : 3 mm

Results:

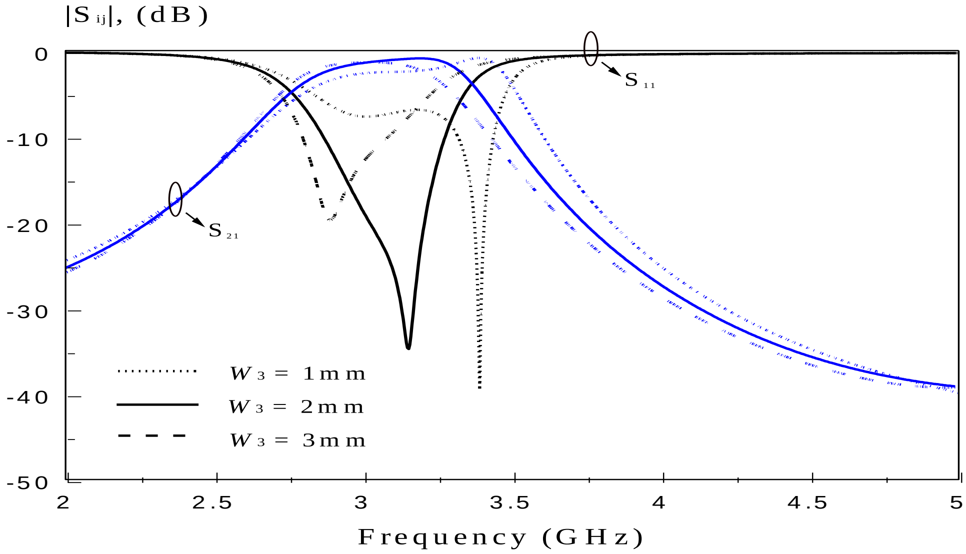

Figure 4.22: Effect of width *w*$_3$ on the side-coupled block filter.

Description:

The width of metal block at middle is being stepped up and stepped down for parameter analysis. It does affect the operating frequency of the result. It shifts the operating frequency to 2.7 GHz when the width is being increased. When we decrease the width to 1mm, it shifts to 3.4 GHz of operating frequency. It also distorts the flat passband at S_{21} eventually. The optimal width is discussable because it gives a wider bandwidth with a flatter response.

Analysis 16

- Parameter : w_4
- Optimum value : 2 mm
- Step-down value : 1 mm
- Step-up value : 3 mm

Results:

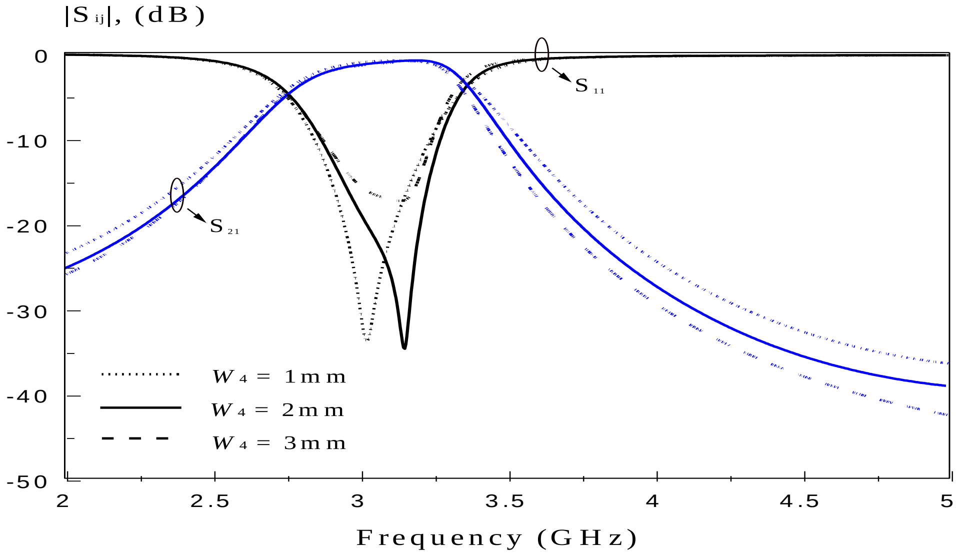

Figure 4.23: Effect of width w_4 on the side-coupled block filter.

Description:

In analysis 16, we have varied the width of metal block at most right for further analysis. The width of the metal at most right does not contribute many changes to the result. However, it shifts the operating frequency away from 3.1 GHz. It also slightly reduces the amplitude response to -15dB when the width is increased.

4.6 Results

Based on the design in chapter 3, we have proposed another idea which is side-couple block filter. Simulation has been done by using Ansoft HFSS and Vector Network Analyzer was used to measure the real time performance of the proposed side-coupled block filter. The criteria that being measured in this assignment is the amplitude response of the side-couple block filter. The amplitude response of the HFSS simulation and measurement by VNA were compared as in Figure 4.24.

The objective of this project is to achieve the three-mode passband at -3dB of the amplitude response. It is also to prove the side coupling effect of the aluminium blocks across microwave frequencies. The gap and height can be the most significant factors which affect the coupling effect of aluminium.

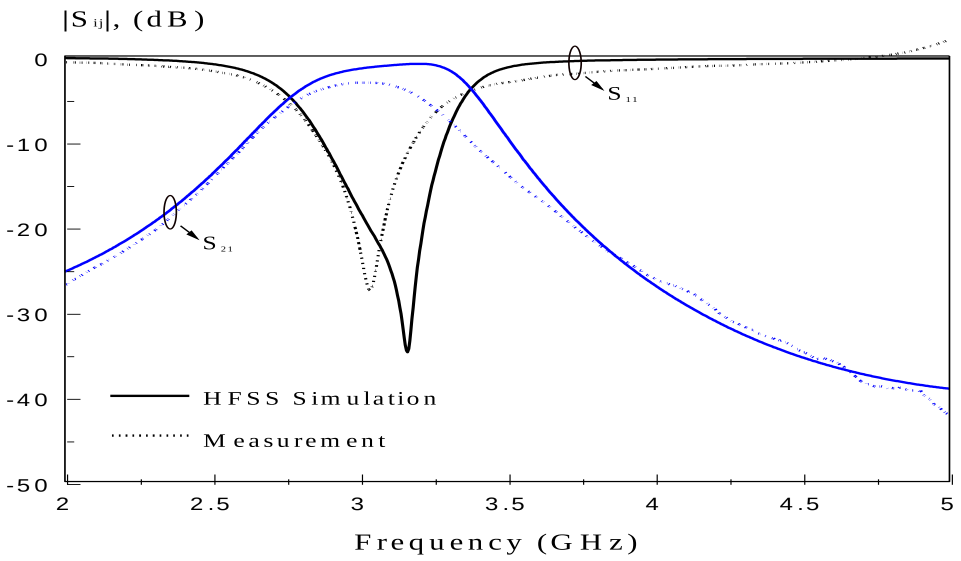

Figure 4.24: Amplitude responses of the HFSS simulation and experiment for the proposed side-coupled block filter.

From the Figure 4.24, we can determine that a three-mode passband was realised from the proposed side-coupled block filter. It has an operating frequency ranging from 2.75 GHz to 3.5 GHz with a total bandwidth of 750 MHz. As we can see for the measurement, the operating frequency is ranging from 2.75 GHz to 3.25 GHz which is 500 MHz in total bandwidth. There is 66.67% of the measurement to the HFSS simulation. However, we can still observe the three-mode filtering effect on the measurement without many differences as compared to the HFSS simulation. This has also proved the wall coupling theory which we hope to examine in this experiment.

For fabrication, an important point needs to be taken care of since it will determine the success or failure of the experiment. The copper must be made exactly same size as the copper strip on FR-4 substrate. With the existence of the copper on FR-4, it allows more perfect signal to couple into the aluminium metal blocks.

Below is showing the comparison of fractional bandwidth for the experiment, HFSS simulation and TLM modelling.

Table 4.1: Comparison of the experiment, HFSS simulation, and TLM modelling.

	Experiment	HFSS Simulation	TLM Modeling
f_L (GHz) / f_H (GHz)	2.75 / 3.25	2.795 / 3.375	2.516/3.209
f_c(GHz)	3	3.085	2.863
Fractional Bandwidth (%)	16.6	18.8	24.2

4.7 Discussion

For creating a microstrip bandpass filter, the most basic method has been used in microstrip filter design. A simple bandpass filter may consist of resistor and capacitors. In microstrip design, gap is used as it represents the capacitance and the transmission line will introduce 50Ω of characteristic impedance to the filter. A side-coupled block filter with gap on microstrip is designed to function as bandpass filter. From Figure 4.25, we can see that the conventional method for creating inductance and capacitance in microstrip design.

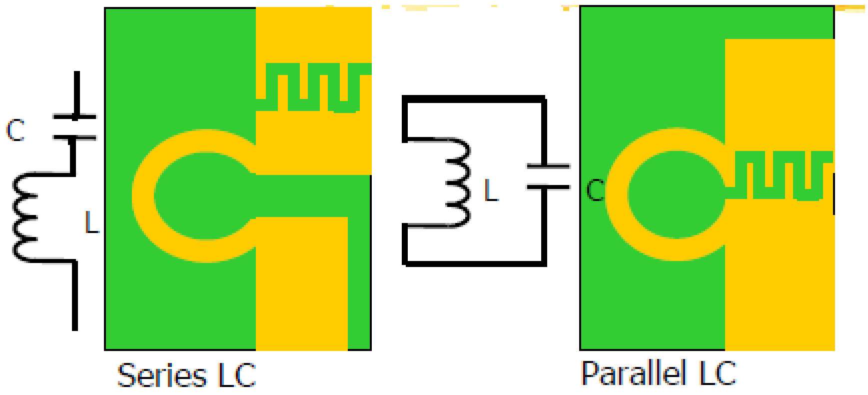

Figure 4.25: Series LC and Parallel LC in Microstrip.

From this experiment, the three-mode bandpass filter has even wider bandwidth as compared to the rectangular block filter. The mode of the side couple filter is generally affected by the number of the gap as it represents the number of capacitor used. From Table 4.1, the fractional bandwidth of the measurement is very close to HFSS simulation and hence it again, proved the wall coupling theory that we are going to examine in this experiment. The signal may couple from each of the metal when the gap and height of the metal block is in optimal value.

Based on the parametric analysis on section 4.5, we can identify several parameters which are crucial to the performance of the side-coupled block filter. Parameters such as g_1, g_2, g_3, h_1, and l_1 are found to be important in parameter analysis. The gap may affect the amplitude response of the result as it may affect the amount of signal which coupled along the metal block. The larger the gap, the lower of amplitude response that we have observed. Besides that, the height of the metal block must also be set to optimal value. The height of the metal block generally will affect the mode and amplitude response of the result. It may separate the three-mode and clearly visible as we can see in Figure 4.11. It may also cause the amplitude response to be around -22dB since fewer signals is passing thru in S_{11}. For the length of the metal block, it will affect the center frequency of the filter. It shifts to higher center frequency when the length is decreased; it shifts to lower center frequency when the length increased.

In Chapter 4, we have successfully design a side-coupled block filter with more than 80% of similarity of HFSS simulation and measurement. It proved that the block filter is performing in real practice.

CHAPTER 5

FUTURE WORK AND RECOMMENDATIONS

5.1 Achievements

During this project, the rectangular block filter has been proposed and examined as shown in Chapter 3. From Figure 3.1, a proposed rectangular block filter has been designed. All the simulation and parameter analysis has been done on the rectangular block filter to observe its results. The proposed design is fabricated on the FR-4 substrate with substrate thickness of 1.57mm. The measured result is then compared with the HFSS simulation result. All the parameters are plotted in Freelance Graphics for analysis. This rectangular block filter has two-mode bandpass effect. As seen in Figure 3.20, the result of HFSS simulation and measurement are about 90% similar. The fractional bandwidth of HFSS simulation and measurement are 12.9% and 13% respectively. Hence we can prove that the experiment is successfully done.

In Chapter 4, a side-coupled block filter with three-mode passband has been introduced and designed. The side-coupled block filter was demonstrated on FR-4 substrate with relative permittivity of 4.4 and substrate thickness of 1.57mm. In this chapter, a series of parameter analysis has been done to analysis to effect of each parameter to the result. HFSS simulation and measurement result has been compared. The fractional bandwidth of HFSS simulation, measurement and TLM modelling have been obtained, they are 16.6%, 18.8% and 24.2% respectively. As final, is has been confirmed that the theory of wall coupling effect. By increasing the height of the metal, we can fabricate a design with larger gap with same amount of coupling signal.

5.2 Future Work

For the proposed rectangular block filter and side-coupled block filter, the problem that occurs is the imperfection of the metal block. The imperfections and rough surface of the metal block can caused the result to become jittered and interfered since the signal cannot couple through the surface. Therefore, for the future improvement, the metal block needs to be fabricated by highly skilled staff in University. Besides that, more capacitors which is representing by the gap can be added to the design to achieve higher mode for obtaining wider bandwidth. Wider bandwidth is always realizable because it allows more components to share the same spectrum simultaneously.

5.3 Conclusion

In this project, the rectangular block filter and side-coupled block filter have been designed and demonstrated successfully. The measured result on Vector Network Analyzer has agreed well with those of the HFSS simulation and TLM modelling on both of the proposed designs in Chapter 3 and Chapter 4. Author also mentioned the design considerations and issues of microstrip bandpass filter in Chapter 2 which allows the author to understand well the design and performance of the bandpass filter. The objectives of this project have been successfully met. From the result generated on this project, it is sufficient to be submitted to *IEEE Transaction on Microwave Theory and Techniques* and *IEEE Microwave and Wireless Components Letters*.

REFERENCES

Chang, K. *RF and Microwave Wireless System.* New York/ Chichester/ Weinheim/ Brisbane/ Singapore/ Toronto: John Wiley & Sons, Inc.

Hong J. S. & M.J. Lancaster. . (2001). *Microstrip Filtter for RF/Microwave Applications.* New York/ Chichestor/ Weinheim/ Brisbane/ Singapore/ Toronto: John Wiley & Sons, Inc.

Hyde, G. (Dec 1998). Historical Perspectives on Commercial and Nonmilitary Government Space Applications of Microwave System in the Baltimore/ Washington Area. *IEEE Transaction on Microwave Theory and Techniques* , Vol. 46, No. 12.

J. Y. Shao, S. C. Huang and Y. H. Pang. (November 2011). Wilkinson power divider incorporating quasi-elliptic filters for improved out of band rejection. *Electronics Letters* , Vol.47 , No. 23.

Juan Enrique Page, Jaime Esteban and Carlos Camacho-Penalosa. (n.d.). Lattice Equivalent Circuits of Transmission-Line and Coupled-Line Section. *IEEE Transaction on Microwave Theory and Techniques* .

Kaixue Ma, Keith Chock Boon Liang, Rajanik Mark Jayasuriya, Kiat Seng Yeo. (Jan 2009). A wideband and high rejection multimode bandpass filter using stub pertubation. *IEEE on Microwave and Wireless Components Letter* , vol 19, no.1, pages 24-26.

Leo Young, M.A., Dr. Eng. (1963). The analytical equivalence of TEM-mode directional couplers and transmission-line stepped-impedance filters. *Proceeding I.E.E.* , vol 110, No.2.

Pozar, D. M. (Jan 1985). Microstrip antenna aperture-coupled to a microstripline. *Electronic Letter* , vol. 21, no. 2, pp. 49 - 50.

Pozar, D. M. (1998). *Microwave Engineering* . Canada: John Wiley & Sons, Inc.

Pu-Hua Deng and Li-Chi Dai. (2011). Unequal Wilkinson power dividers with favourable selectivity and high isolation using coupled-line filter transformer. *IEEE transaction of Microwave Theory and Techniques* .

Ravee Phromloungsri, Mitchai Chongcheawchamnan, Ian D. Robertson. (2006). Inductively compensated parallel coupled microstrip lines and their applications. *IEEE transaction on Microwave Theory and Techniques* , Vol. 54, No.9.

T. Jensen, V. Zhurbenko, V. Krozer, and P. Meincke. (Dec. 2007). Coupled transmission lines as impedance transformer. *IEEE transaction on Microwave Theory and Techniques* , vol 55, no. 12, pages 2957-2965.

Goh Chin Hock and Chandan Kumar Chakrabarty. (2006). Parallel Coupled Microstrip Line Bandpass Filter on theRO4003C Substrate. *IEEE transaction on Microwave Theory and Techniques*.

K. Srisathit and W. Surakumpontorn. (2010). Wideband Microstrip Bandpass Filter Based on Modified Parallel-Coupled Line Topology. *IEEE transaction on Microwave Theory and Techniques*.

Thirumalaivasan K and Nakkeeran R. (2011). Ultra-Wideband Parallel Coupled Line Microstrip Bandpass Filter. *IEEE transaction on Microwave Theory and Techniques.*

Yue Ping Zhang and Mei Sun (Oct. 2006). Dual-Band Microstrip Bandpass Filter Using Stepped-Impedance Resonators with New Coupling Schemes. *IEEE transaction on Microwave Theory and Techniques*, vol. 54, no. 10.

Po-Ying Chang and Yo-Shen Lin (2011). Electronically Switchable Microstrip Bandpass Filter with Good Selectivity. *IEEE transaction on Microwave Theory and Techniques*.

A. Thabet, Adel Z. El Dein and A. Hassan. (n. d.). Compact Microstrip Bandpass Filter by using New Nano-Composite Materials. *IEEE transaction on Microwave Theory and Techniques*.

C. P. Chiang and K. W. Tam. (2009). Compact Quasi-Elliptic Microstrip Bandpass Filter using Terminated Anti-Parallel Coupled-Line. *IEEE transaction on Microwave Theory and Techniques*, vol. 3, no. 8, pages 1206-1210.

Shih-Cheng Lin, Yo-Shen Lin, and Chun Hsiung Chen (n. d.). Compact Microstrip Bandpass Filters with Quarter-Wavelength Stepped-Impedance Resonators. *IEEE transaction on Microwave Theory and Techniques*.

CHENG Kunlun, LI Pinghui, ZHAO Zhiyuan, FENG Lin (2011). Compact Microstrip Bandpass Filter Based on Open Stub-Loaded Triple-Mode Resonator. *IEEE transaction on Microwave Theory and Techniques*.

Ahmed Boutejdar, Galal Nadim, A. S. Omar. (n. d.). Compact Bandpass Filter Structure Using an Open Stub Quarter-Wavelength Microstrip Line Corrections. *IEEE transaction on Microwave Theory and Techniques.*

Lung-Hwa Hsieh, Kai Chang (Feb. 2003). Tuneable Microstrip Bandpass Filters with Two Transmission Zeros. *IEEE transaction on Microwave Theory and Techniques,* vol. 51, no. 2.

L. Zhu, H. Bu and K. Wu. (Feb. 2002). Broadband and Compact Multi-Pole Microstrip Bandpass Filters using Ground Plane Aperture Technique. *IEEE transaction on Microwave Theory and Techniques*, vol. 149, no. 1.

Kamol Boonlom, Teerapan Pratumvinit and Prayoot Akkaraekthalin (2009). Compact Microstrip Two-Layers Bandpass Filter using Improved Interdigital-Loop Resonators. *IEEE transaction on Microwave Theory and Techniques*.