DESIGN OF MM-WAVE HAIRPIN FILTER

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ELECTRICAL AND ELECTRONICS ENGINEERING

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CERTIFICATION OF APPROVAL

Design of Mm-wave Hairpin Filter

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____

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CERTIFICATION OF ORIGINALITY

This is to guarantee that I am in charge of the work submitted in this extend, that the first work is my own particular aside from as indicated in the references and acknowledgements, and that the first work held thus have not been attempted or done by unspecified sources or persons.

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ABSTRACT

The scope of this project presented analyze, simulation, fabricate for the MM-wave hairpin filter. Hairpin filter is one of the most popular microwave frequency filter because it is compact and does not required grounding. The design of the filter is to operate at 60 GHz of center frequency with 5% of the bandwidth which is at 58.5 GHz and 61.5 GHz frequency band respectively. This frequency band fall under the MM-wave which is ranging from 30 to 300 GHz. To design hairpin filter, a few steps are considered which including determine the order of the filter, transformation from low pass filter to band pass filter and calculation of the width, length and the spacing between the resonators. All the simulation were doing with Advance Design System (ADS) software. The Rogers RO5880 substrate with dielectric constant 2.2 and 787 um thickness of the substrate will be used to fabricate by using etching technique.

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Bandpass filter are used as frequency selective devices in many radio frequency and microwave applications. Filters are typically utilize lumped and distribution circuit components. However with the progressed materials and new manufacture strategies, a channel named microstrip channels have ended up exceptionally well known to be used in microwave filter because of smaller in size where reduce the cost to design and excellent in performance. The implementation on how to design the bandpass filter have many topology to implement such as parallel coupled, end-coupled, interdigital and combined filter. A few parameter identified to design the bandpass filter that crucial such as center frequency and bandwidth. With all the parameter available, this parameter then will be simulate using simulation software such as Advance Design System (ADS).

1.2 Problem statement

Nowadays filter in the market are more complex to develop. A hairpin filter capable to handle a wide range of frequencies, also a better and excellent in term of designing these filter because it is compact filter which will reduce the cost and also grounding doesn’t needed for these type of filter.

1.3 Objectives

The objectives of this project are:-

1. To calculate parameter and simulation hairpin filter at center frequency 60 GHz with 5% of the bandwidth.
2. To fabricate and measurement the microstrip filter
3. To compare the result of measurement with the simulation

1.4 Scope of Work

A several scope of work has been determined are:-

4.1 To calculate hairpin filter using software.

4.2 To design and simulation hairpin filter using simulation software Advance Design System 2011.

4.3 To fabricate, measure and observe the hairpin filter.

CHAPTER 2: LITERATURE REVIEW

2.1 Background study

Millimetre-wave (MM-wave) or Extreme High Frequency (EHF) [1] is the highest frequency band in the practical use today. This EHF includes the frequency from 30 to 300 GHz. MM-wave is the next band, above "Microwave".

It is because this band has a wavelength of between 1 and 10 mm that is has given rise to the name "Millimetre Band" or "Millimetre-wave". The frequencies in this band are very susceptible to attenuation due to rain or fog (depending on which part of the band). Because of this, they are not used for the long distances, but they are excellent in the some short distance applications, and this millimetre-wave allows for smaller frequency re-use distances than lower frequency. A small antenna will be used for the mm-wave because of the small wavelength which will further increase the frequency re-uses potential.

Designing a microwave filter, microstrip is the most well-known because of it capability to handle a wide range of frequencies. Microstrip is also a lightweight design whereby it will reduce the cost to fabricate. Many equations to analysis and synthesis have been presented by the researcher for the microstrip design. Even in the simulation software have numerous example on the fabrication of this microstrip filters since this type of filter is quite well known in designing the microwave filter. There various type and classification of filter, these also verified which equation and each classification and type will gives different result. The hairpin filter is a bandpass filter which will only allowed every frequency within the bandwidth.

The Hairpin filter is a standout amongst the most acclaimed low microwave frequency filters in view of it is a smaller segment and does not require grounding. Its structure is determined from the edge-couple resonator filter by collapsing back the finishes of the resonators into a "U" shape. This has surprisingly lessens the length and enhances the angle degree of the micro strip altogether contrasted with edge-coupled setup. There are numerous substrates with different dielectric constants that are utilized as a part of the remote applications. Those with high dielectric steady are more suitable for the lower frequency applications so as to help minimize the size [2]. Parallel Coupled microstrip bandpass channel (PCM-BPF) is to be considered, where the resonators arranged so that coterminous resonators are shunt to each other and along half of their length. This parallel blueprint given by and large broad coupling for a given scattering between the resonators [3].

2.2 Filter

A microwave filter is a two-port system utilized to control the recurrence reaction at certain point in a microwave framework by giving transmission at frequencies inside the passband of the filter and weakening in the stopband of the filter [4].number of ways might be arranged when decided the channel. An illustration of one such classification is reflective versus dissipative. With respect to reflective filter, sign dismissal is accomplished by reflection the episode force, while in a dissipative filters are utilized within generally applications. The most ordinary depiction of a filter is by its frequency characteristic, for example low-pass, highpass, and band-reject.

2.3 Basic Filter Types

There are primarily five sorts of filter are utilized as a part of microwave correspondences which are briefly described in the following:

2.3.1 Low-Pass Filter

Low-pass filter systems transmit all signs in the middle of DC and some upper point of confinement ω_c, and it will attenuate all signal with the frequencies above ω_c. They utilizing a course of arrangement inductors and shunt capacitors. The frequency scope of the filter specification has been isolated into 3 ranges. The passband reaches out from zero frequency (dc) to the passband edge frequency f_{pass}, and stopband stretches out from the stopband edge frequency f_{stop} to infinity. The transition band that stretches out from f_{pass} to f_{stop} will separate that two band.

2.3.2 Highpass Filter

Highpass filter will pass all signs with frequencies over the cut-off value ωc to the load with the minimum loss and will reject signal with frequencies underneath ωc. Highpass filter systems are utilizing a course of arrangement capacitors and shunt inductors. For this situation the passband reaches out from f_{pass} to infinity and is placed at a higher frequency than the stopband which stretches out from zero to f_{stop}. Highpass filters are utilized when it is imperative to wipe out low frequencies.

2.3.3 Bandpass Filter

The bandpass filter demonstrates the signal is exchanged to the load in a band of frequencies between the lower cut-off frequency ω_{c1}, and the upper cut-off frequency ω_{c2}. Between the lower and upper cut-off frequency is the middle frequency ω_0, defined by the geometric mean of ω_{c1} and ω_{c2} **[4]**. Bandpass filter will limit all the frequency except for the signal within it bandwidth.

2.3.4 Bandstop Filter

The bandstop filter is a supplement to the bandpass filter. The indicator encounters high losses between ωc_1 to ωc_2. Consequently the name bandstop. For this situation, the band of frequency being rejected is spotted between the two passband. The stopband exist in the middle of the lower stopband edge frequency f_{stop1} and the upper stopband edge frequency f_{stop2}. The bandstop channel has two passband, the lower passband stretch out from 0 to f_{pass1}, while the upper passband reach out from f_{pass2} to the infinity.

2.3.5 Allpass Filter

The allpass channel permits the signal amplitude for all frequencies to pass through the system without any critical loss. This system has no frequency specific passband or stop band. Ordinarily frequency and amplitude reactions for these contrasts sorts are demonstrated in Figure 1. In extra, a perfect filter presentation zero insertion loss, steady gathering defer over the longing passband and unending rejection somewhere else. Notwithstanding, in reasonable filter digress from these aspects and the parameters in the presentation above are a decent measured of execution. The cutoff frequency is regularly characterized as the frequency at which the force transmitted by the channel drops to one-half (-3dB) of the greatest force transmitted in the passband.

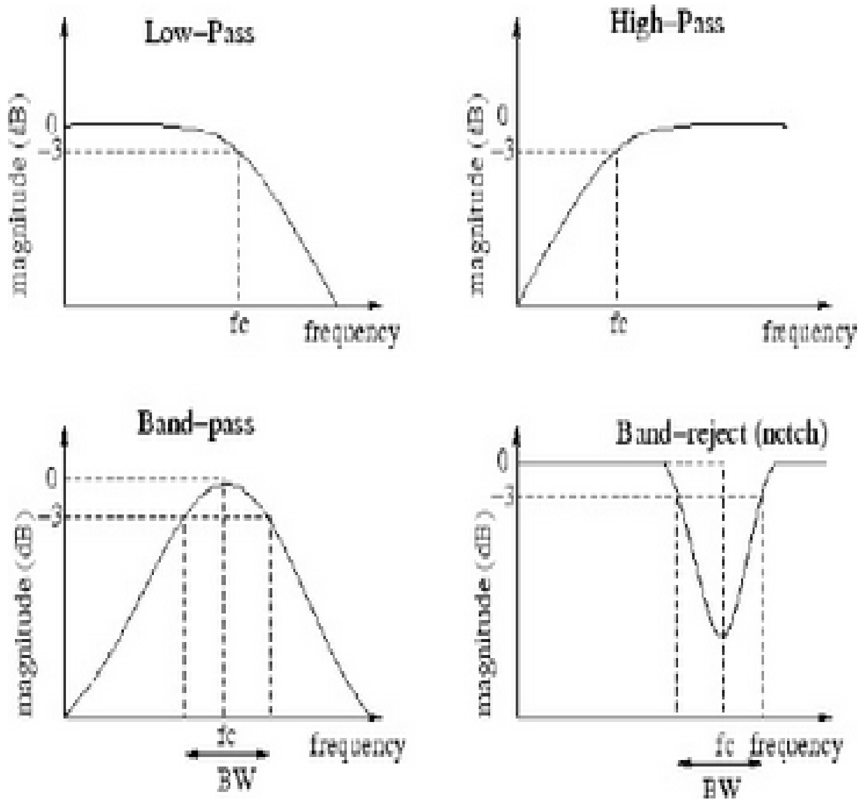


Figure 1 Characteristic of Filter

2.4 Response Type Filter Categories

In view of planning sign transforming channel, there are a few essential classes of filter, for example, Butterworth, Chebyshev, Elliptic, and Bessel channel. It was initially planned to be connected to the configuration of passive linear filter however its result might be additionally be connected to the execution in dynamic filter and digital filter. The class of the channel alludes to the class of polynomial from which the channel is scientifically derived [2]. The order of the filter components introduce in the filter's ladder usage. As a rule, the filter with higher number of order, the stepper the cutoff move between passband and stop band as represented in Figure 2. In the accompanying a portion of the filter are described.

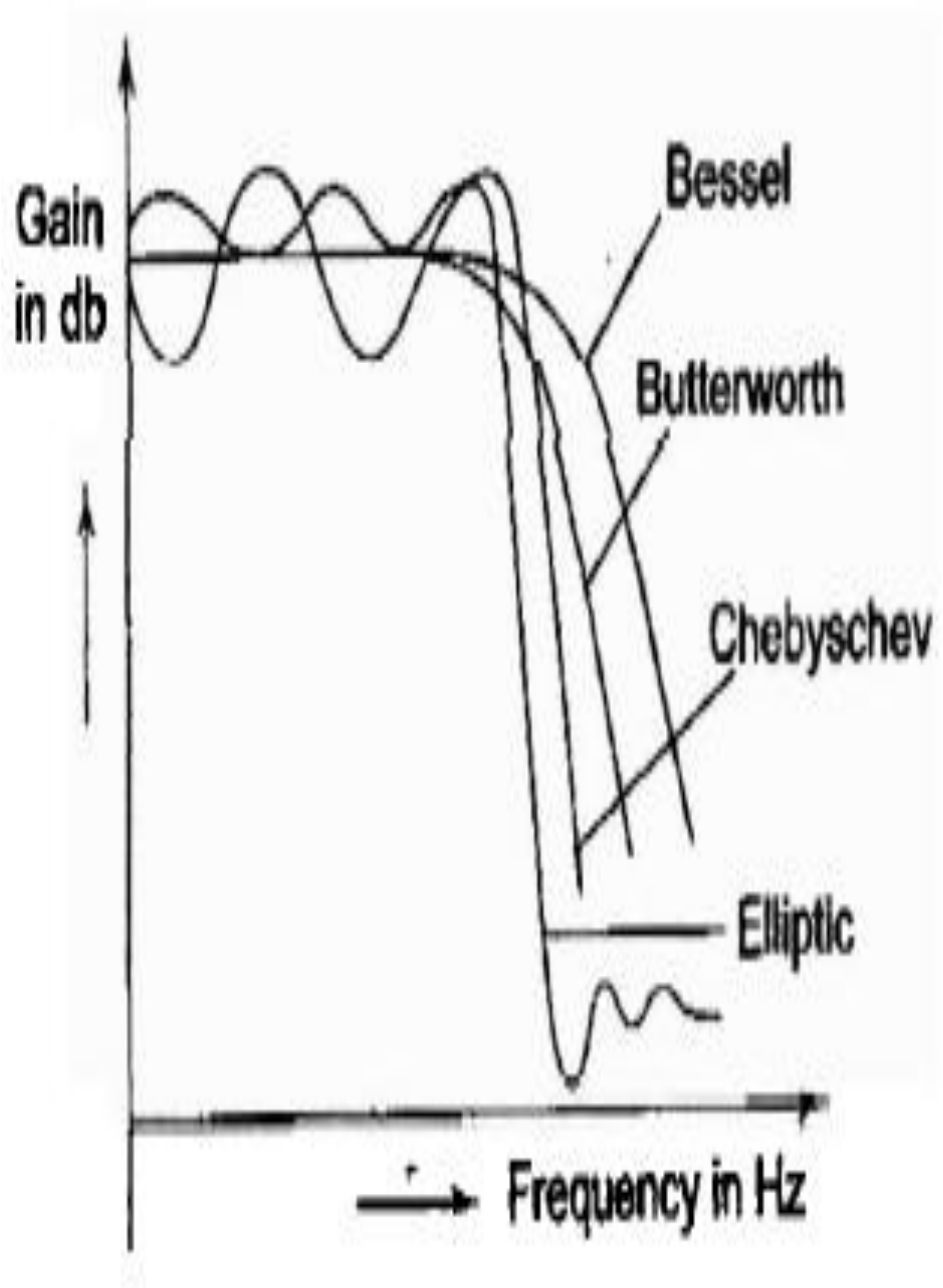


Figure 2 Type of Filter Characteristic

2.4.1 Butterworth Filter

The Butterworth filter has basically flat passband amplitude versus frequency. The Butterworth filter is the best compromise between attenuation and phase response. Butterworth filter sometimes called as a maximally flat response filter because it has no ripple in the pass band or the stop band. Since Butterworth filter has wide transition which is the gap between stop band and the Passband, this filter able to achieve the flatness. Response up to the cut-off frequency. Butterworth filters are otherwise called maximally flat sort filters and have the flattest conceivable Passband extent reaction. This class of filters approximates the perfect filter in the pass band. It has a monotonic lessening in gain with frequency in the cut-off area and a maximally flat response underneath cut-off. Attenuation is -3 dB at the outline cut-off frequency. Attenuation past the cut-off frequency is a modestly steep -20 dB/decade/shaft. The pulse reaction of the Butterworth filter has moderate overshoot and ringing. The Butterworth filter is said to have maximally flat response in the Passband which will give better performance. The pulse response of the Butterworth filter is much better than the Chebyshev and also better than Bessel filter in term of the rate of the attenuation and the downside of the filter is to have few overshoot and some ringing in the step response.

2.4.2 Bessel Filter

The Bessel chosen for application where the phase is critical, which is negligible phase shift filter, is utilized despite the fact that its cut off characteristic is not sharp. The Bessel filter gives ideal phase characteristic with more or less linear phase response up to about cut-off frequency. The Bessel filter has an exceptionally liner phase response however a reasonably gently skirt slope. Because of its linear phase response, this filter has phenomenal beat response which is negligible overshoot and ringing. This type of the filter has small overshoot and ringing which will provide the best step of response. Although it has small overshoot and ringing, this filter has slower initial rate of attenuation in the Passband than the Butterworth filter.

2.4.3 Chebyshev Filter

The Chebyshev filter, likewise called as the equal ripple filter, this type of filter difference compared to the Butterworth filter with the same number of order is it has smaller transition region between stopband and passband. This filter get its name because the Chebyshev filter minimizes the height of the maximum ripple, which is the Chebyshev criterion. Chebyshev filters have 0 dB relative attenuation at dc. Odd order filter have an attenuation band that extends from 0 dB to the ripple value. While the even order filters have a gain equal to the passband ripple. The number of cycles of ripples in the passband is equal to the order of the filter. Thus, the Chebyshev filter is better than the Butterworth at the rate of the attenuation beyond the passband, a few drawback in the

Chebyshev filter which is the Chebyshev filter have ripple in the passband region and also it has more ringing in the step response.

2.5 Microstrip Line

As circuits have been lessened in size with incorporated semiconductor electron devices, a transmission structure was obliged that was perfect with circuit development techniques to provide guided wave over limited distances. This was acknowledged with a planar manifestation of single wire transmission line over a ground plane, called microstrip. Microstrip utilizes a flat strip conductor suspended over a ground plane by a low-loss dielectric material. The measure of the circuit might be lessened through judicious use of a dielectric constant at 2-10 times that of free space (or air), with a penalty that the presence of two different dielectric constants (underneath or above the strip) makes the circuit difficult to investigate in closed structure and furthermore will presents a variability of propagation speed with frequency that could be a restriction on some application.

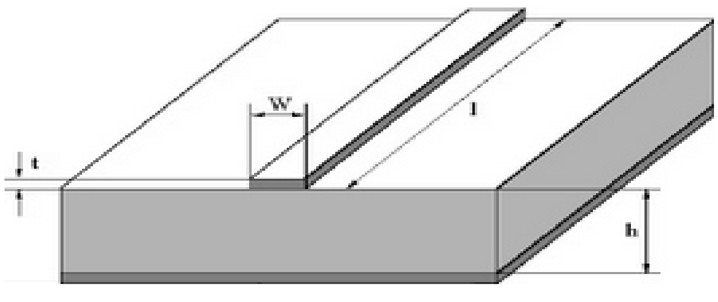


Figure 3 Microstrip

Where:

l = Length of the element.

w =Width of the element.

h = Height of the dielectric element.

t = Thickness of the element.

The microstrip has their focal points contrast with other microwave transmission like wave guide, coaxial cable, and strip line and so on and it has likewise a few disadvantages as well.

Advantages:

- To make less demanding manufacture of circuit complex.
- Smaller in size.
- Wide of bandwidth.
- Good reliability.
- Good reproducibility.

Disadvantages:

- Low power.
- High of signal attenuation.

2.6 Coupled Microstrip Line

At the point when two transmission lines are near one another, on account of the association of the electromagnetic fields of each one line, force could be coupled between the lines. Those coupled lines are utilized to develop directional couplers. By and large, in configuration of directional couplers microstrip and strip line structures are utilized. Despite the fact that microstrip transmission lines don't help TEM and named as quasi-TEM, typically they are assumed to work in TEM mode. Z_{oe} and Z_{oo} which are the even and odd impedance, this is result from the parallel line coupler have odd and even mode.

The equation will be used in this project to find the odd and even impedance:

$$\boldsymbol{ZoJ1} = \sqrt{\frac{\pi.\Delta}{2.g1}}\ ; \qquad (1.1)$$

$$\boldsymbol{ZoJn} = \frac{\pi.\Delta}{2\sqrt{g_{n-1}.g_n}}\ ; \qquad (1.2)$$

$$\boldsymbol{ZoJn+1} = \sqrt{\frac{\pi.\Delta}{2.g_n.g_{n+1}}}; \qquad (1.3)$$

From the above equation, the even and odd impedance characteristic can be obtained:

$$\mathbf{Zoe} = \mathbf{Zo}(\mathbf{1} + \mathbf{JZo} + (\boldsymbol{JZo})^{\mathbf{2}}) \quad ; \qquad (1.4)$$

$$\mathbf{Zod} = \mathbf{Zo}(\mathbf{1} - \mathbf{JZo} + (\boldsymbol{JZo})^{\mathbf{2}}) \quad ; \qquad (1.5)$$

Where:

Zo = Characteristic Impedance of the line

J = Admittance inverter

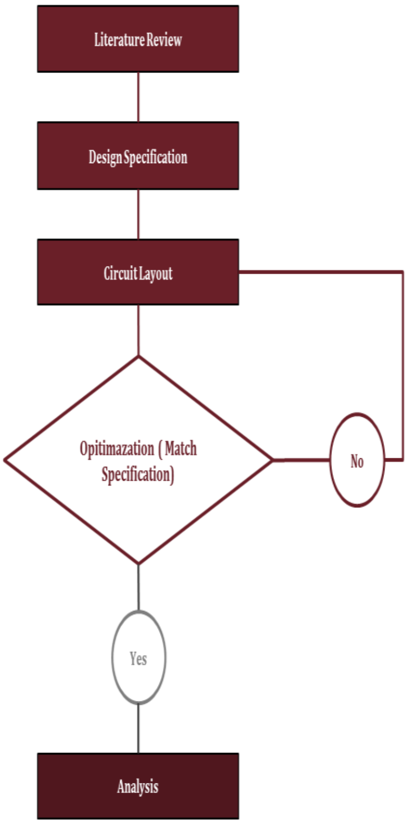
Δ = Relative bandwidth

g = Filter prototype

n = 2, 3, 4… N.

CHAPTER 3: METHODOLOGY

3.1 Project Methodology



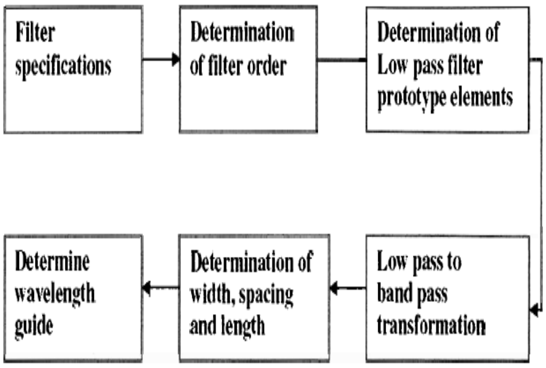


Figure 4 Steps of calculation

Figure 5 Project Flow Chart

In order to design, built and measure the hairpin filter configuration, following steps are to be considered.

Three major steps contributed in this project:-

3.1.1 Background Studies

- Information regard to the Hairpin filter obtained by published books, internet and journals.
- The uses of the simulation software.
- Do a research to know more about how to design the hairpin filter through forum and articles with the identified parameters.

3.1.2 Calculation, Analysis and Simulation

- Analysed and ascertain all the parameter that identified with configuration the step impedance hairpin resonance.
- Simulation using software to observe the frequency and response.

3.1.3 Hardware Development and Implementation

- Proceed to designing the microstrip filter prototype using etching technique and measured the hardware.
- Compared the simulation and measured result.

3.2 Filter Prototype and Transformations

3.2.1 Low-Pass to Bandpass Transformation

So as to change over low-pass filter to bandpass filter amounts of two conditions are maintained.

1. All capacitors become parallel resonators

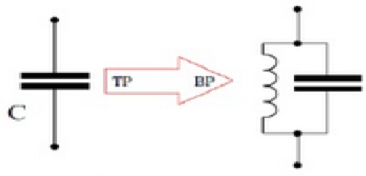


Figure 6 Parallel Resonators

2. All inductors become series resonators.

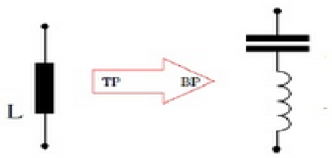


Figure 7 Series Resonators

Two equation are to be considered:

For inductors (L):

$$\boldsymbol{L'} = \frac{\boldsymbol{R_0 L}}{\boldsymbol{\omega_c BW}}; \tag{1.6}$$

$$\boldsymbol{C'} = \frac{\boldsymbol{BW}}{\boldsymbol{\omega_c R_0 L}}; \tag{1.7}$$

For Capacitors (C):

$$\boldsymbol{L'} = \frac{\boldsymbol{R_0 BW}}{\boldsymbol{\omega_c C}}; \tag{1.8}$$

$$C' = \frac{C}{\omega_c R_0 BW};\tag{1.9}$$

3.3 Calculation of the Lumped to Coupled-line Parameters.

With all the Formula given, a simple programme based on the Matlab code written to simplify of findings the Impedance for Odd and Even mode for the coupled-edge. See **Appendix 1** for Matlab code and Odd and Even Impedances.

3.4 Hairpin Filter Designing and Simulation.

The result of Odd and Even parameters obtained from the Matlab will be used in the simulation program to calculate the length, wide and spacing between the resonators. LineCalc in the Advanced Design System will be used to provide applicable parameters for microstrip line. In this design, substrate of ROGERS 5880 will be used to produce prototype.

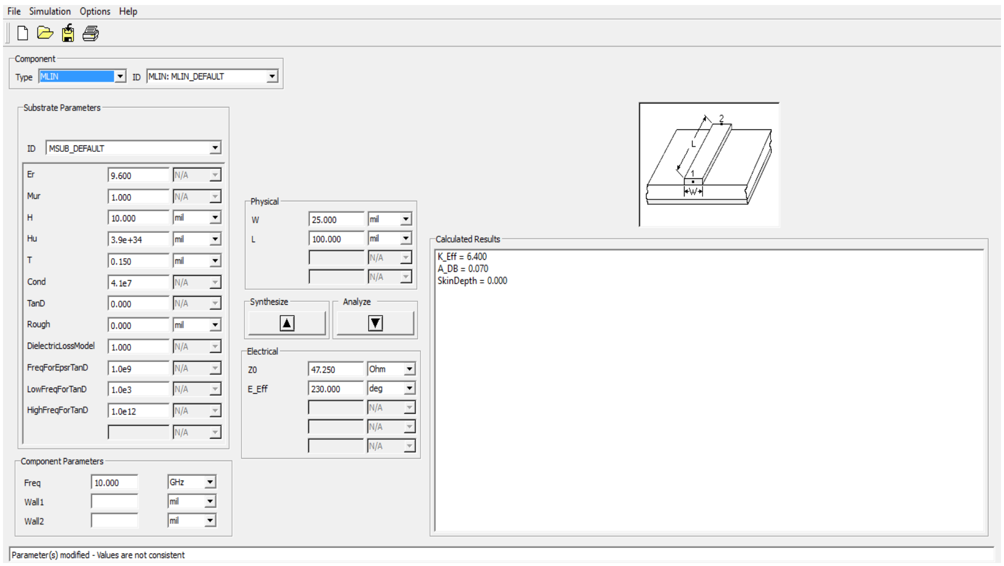


Figure 8 ADS LineCalc

With all the length, wide and spacing between spacing were obtained by LineCalc. All the parameter then convert into the Hairpin filter configuration as **Appendix 2** and **Appendix 3** for 5th order and 7th Order. S-parameter simulation in the ADS will provide the insertion loss and the return loss of the configure Hairpin filter. These Insertion loss and Return loss is the most crucial parameter as per require in this project. The S-parameter trend will be show after running the simulation as shown in the Figure 9.

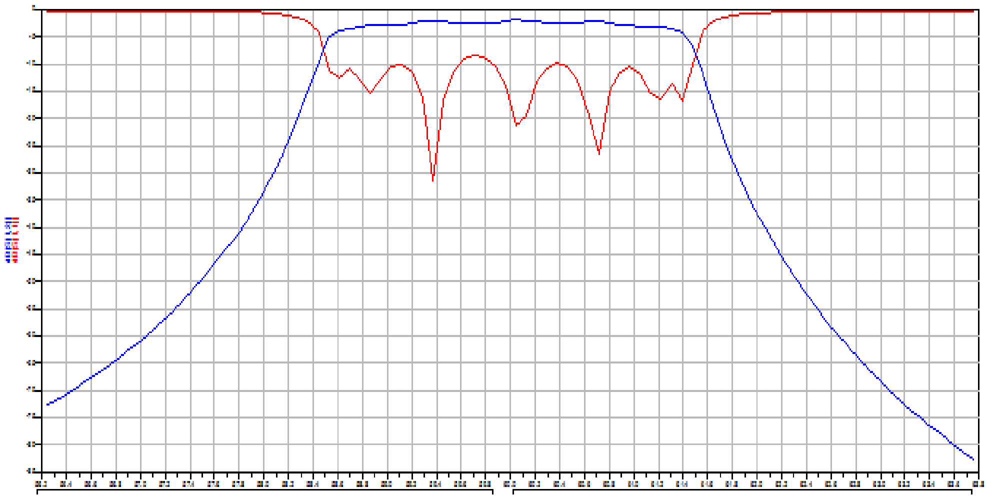


Figure 9 Insertion Loss and Return Loss

To obtained the require Insertion Loss which is below 3dB and the return loss at 15dB. These hairpin filter can be optimized in the ADS to meet the requirements. The length and sliding factor of the hairpin filter can be optimized in order to achieve the goals. The optimization goals set in the ADS as follow in figure 10.

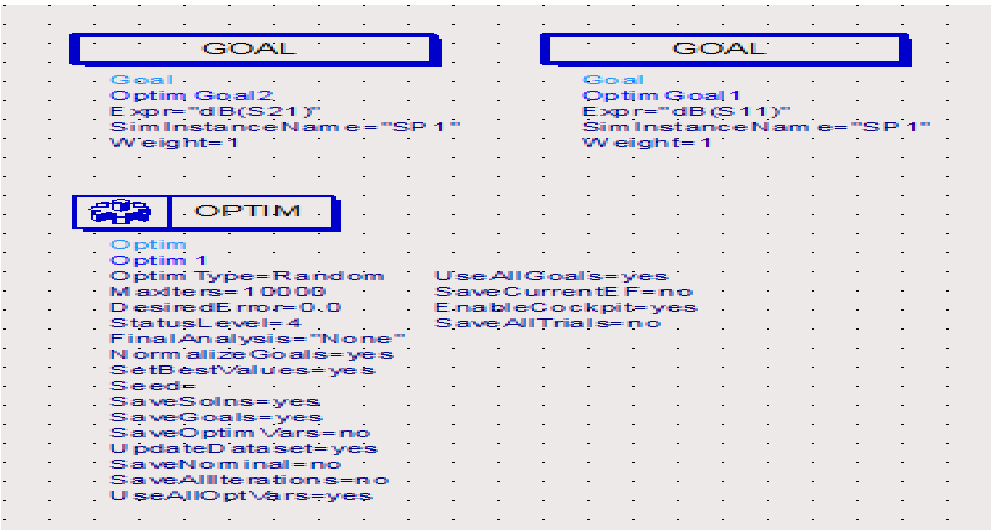


Figure 10 Hairpin Optimization

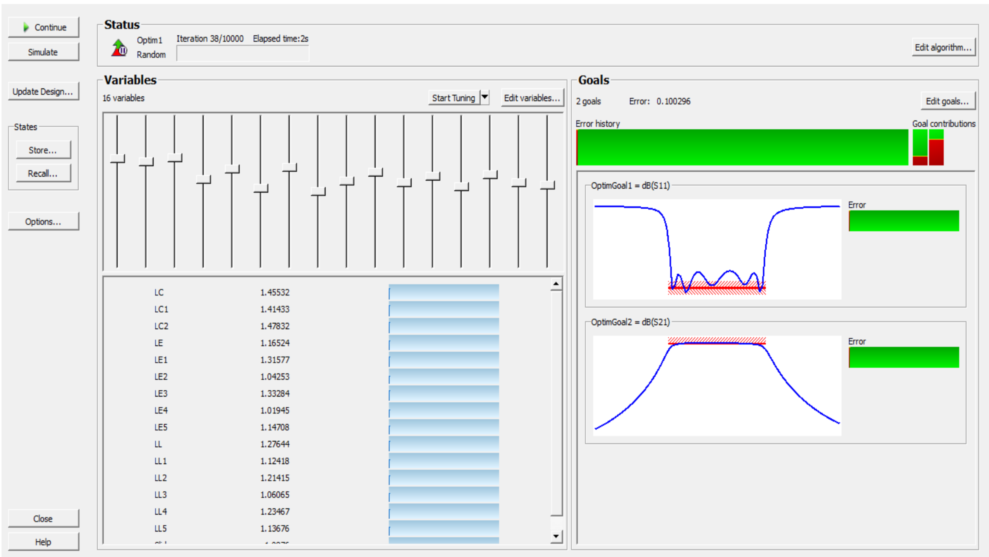


Figure 11 Optimization Simulation

After a few iterations of optimizations carried out by the ADS until it satisfy the goals set by the user. A new trend of the hairpin filter will be show, as expected it will optimize the hairpin filter to meet the requirement as shown in the figure 12. A new length and sliding factor will be updated automatically by the ADS after achieving the goals.

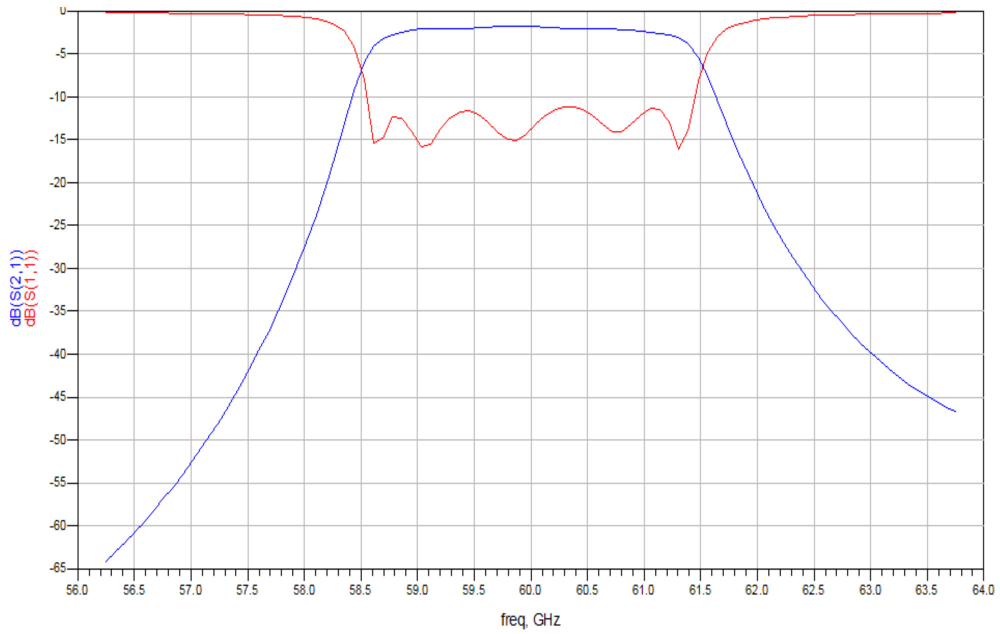


Figure 12 Optimized Insertion Loss and Return Loss

Figure 13 Fabricated Hairpin Filter

Figure 13 is the fabricated hairpin filter with the Rogers RO5880. At the end of the filter should be solder with the SMA connector in order to test the performance of the filter by using Network Analyzer.

CHAPTER 4: CONCLUSION

4.1 Conclusion

In this project, a Chebyshev microwave hairpin filter with the cutoff frequency 60 GHz were designed and fabricated. All the given parameters will be used to determine the hairpin configuration. After the calculation, a simulation software will be used to determine and observe the characteristic of the design hairpin filter meets with the parameters. All the process are recorded and included in the research papers. The parameter of this hairpin filter are as followed:

Table 1 Parameter of Hairpin Filter

Parameter	Symbol	Value	Unit
Center Frequency	f_c	60	GHz
Bandwidth	BW	5%	GHz
Insertion Loss	IL	<3	dB
Return Loss	RL	15	dB

5th order and 7th order of the Hairpin filter were produced by using the software and has been optimized to meet the requirement. Complications arise when the 7th order of the Hairpin filter cannot be fabricate by the Laboratory Technologist due to the complexity in term of size which is too small to fabricate although the 7th order of the Hairpin filter offer smaller in the transition region. The 5th order filter width of the resonator were also adjusted to 1 mm for easier to fabricate.

4.2 Project Gantt Chart

Table 2 Project Gantt chart

Month	May				June				July				August				September				October				November				Disember			
	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
Choosing Project Title			■	■																												
Project Title Review					■	■																										
Project Execution																																
Literature Review																																
Informations & References gathering							■	■	■																							
Simulation Software Introduction										■	■	■																				
Research detail on Hairpin Filter													■	■	■	■																
Analysis																																
Analyze and Calculate Parameter																	■	■	■													
Run on simulation to observe frequency and response																				■	■	■										
Hardware Development																																
Designing the hairpin filter																							■	■	■	■						
Testing and Result																																
Testing and result comparison																									■	■	■	■				
Conclusion and Full Report																													■	■	■	■

Table 2 is Gantt chart for the whole project, for the first part of the project which is from May 2014 until August 2014, all the literature review has been made. All the parameter acquires in order to proceed for the calculation and simulation of the hairpin filter which is will be made by September 2014.

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APPENDIX 1

EVEN AND ODD IMPEDANCE MATLAB SIMULATION

```
clc;
clear all;
fo=input('\n Enter the center frequency fo in GHz : '); % center
frequency
f1=input('\n Enter the pass band frequency fp1 GHz  : ');
f2=input('\n Enter the pass band frequency fp2 GHz  : ');

Lr=input('\n Enter the pass-Band ripple in dB : '); % passband
ripple
Zo=input('\n Enter the chractarestic Impedance Zo : ');
n=input('\n Enter the number of order : ');
wp=1; % wprime
Yo=1/Zo;
Lro=10^(Lr/10);

delta=((f2-f1)/fo);%fractional B.W

x=log(coth(Lr/17.37)); %17.37 is a constant
y=sinh(x/(2*n));
for k=1:n
a(k)=sin(((2*k)-1)*pi/(2*n));
b(k)=y^2+(sin((k*pi)/n))^2;
end
fprintf('\n The quantities (g) refer to the prototype element
values:')
g0=1
g(1)=2*a(1)/y; % g0=1
for k=2:n
g(k)=4*a(k-1)*a(k)/(b(k-1)*g(k-1)); % provides g2 to gn
end
if ((fix(n/2)*2)==n)
%r=(tanh(beta/4))^2; % for n even
g(n+1)=(coth(x/4))^2; % for n even Konishi Yoshiro, page 203;
else
g(n+1)=1; % for n odd
end
g=g'
% J(j,j+1) Determination
fprintf('\n The admittance inverter parameters (J) normalized to Yo
are:')
J(1)=sqrt(pi*delta/(2*g0*g(1))); % corresponds to J01 first coupling
for k=1:(n-1)
J(k+1)=pi*delta/(2*sqrt(g(k)*g(k+1)));%intermidate coupling
end
J(n+1)=sqrt(pi*delta/(2*g(n)*g(n+1))); %corresponds to J(n,n+1)
final
J=J'
% Z0e and Z0o Determination
fprintf('\n The even and odd mode coupled-line impedances (Z0e,Z0o)
are:')
for k=1:(n+1)
Z0e(k)=Zo*(1+J(k)+(J(k))^2);
Z0o(k)=Zo*(1-J(k)+(J(k))^2);
end
Z0e
Z0o
```

Enter the center frequency fo in GHz : 60

Enter the pass band frequency fp1 GHz : 58.5

Enter the pass band frequency fp2 GHz : 61.5

Enter the pass-Band ripple in dB : 0.1

Enter the chractarestic Impedance Zo : 60

Enter the number of order : 7

The quantities (g) refer to the prototype element values:

g0 =

1

g =

1.1812

1.4228

2.0967

1.5734

2.0967

1.4228

1.1812

1.0000

The admittance inverter parameters (J) normalized to Yo are:

J =

0.2579

0.0606

0.0455

0.0432

0.0432

0.0455

0.0606

0.2579

The even and odd mode coupled-line impedances (Z0e,Z0o) are:

Z0e =

79.4610 63.8552 62.8524 62.7067 62.7067 62.8524 63.8552 79.4610

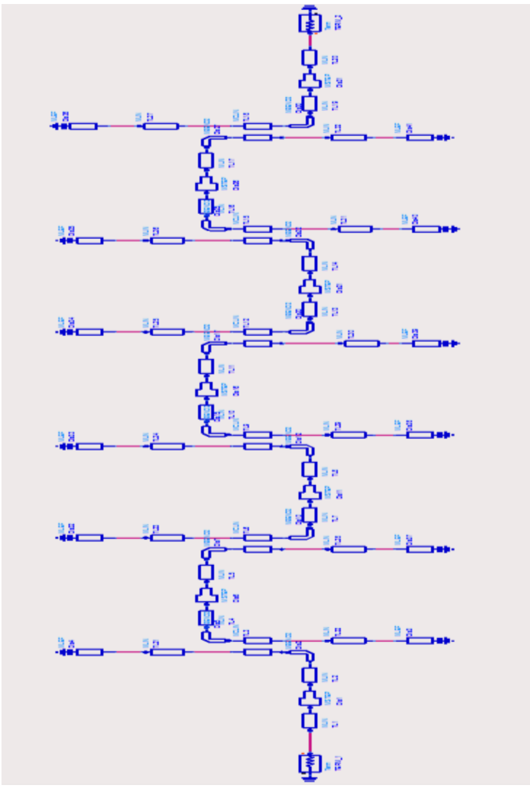
Z0o =

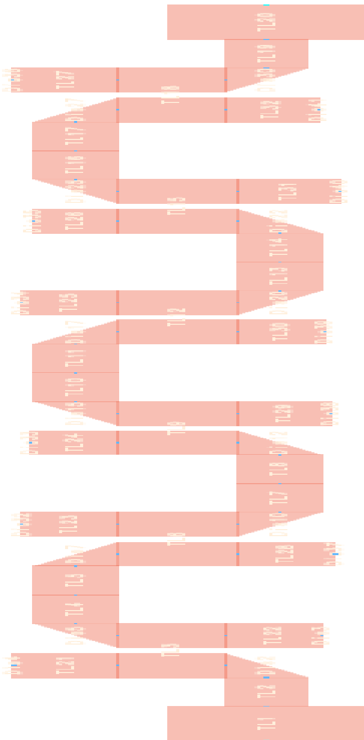
48.5179 56.5852 57.3957 57.5177 57.5177 57.3957 56.5852 48.5179

>>

APPENDIX 2

5TH ORDER HAIRPIN FILTER CIRCUIT AND LAYOUT





APPENDIX 3

7^{TH} ORDER HAIRPIN FILTER CIRCUIT AND LAYOUT