DESIGN OF A MICROSTRIP FILTER
FOR MICROWAVE POINT-TO-POINT LINK

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

____

Dr. Wong Peng Wen

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2012

CERTIFICATION OF ORIGINALITY

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

Tahyr Orazov

ABSTRACT

The goal of the project is to design a Microstrip Bandpass filter for a point-to-point exchange of information over the microwave-frequency signals. Thus, the main idea of this project is to design a bandpass Chebyshev-type 1 filter using a Microstrip as a transmission line. The biggest obstacle for the project is to have a high performance or in other words a high quality response using a Microstrip transmission line. The scope of the project embraces the understanding and application of techniques for designs of microwave filters, which takes us back to the two-port networks, transmission lines, bandpass filters and microwave communications with enabling us to make more research on the mentioned areas. The design was simulated on MATLAB and a 7th order Chebyshev type 1 filter response was generated. After the design calculations were done, it was simulated, tuned and optimized on AWR Microwave Office, simulation software for better approximations, where we could analyze the response of the filter. The AWR simulation software showed an almost equiripple response with 7 ripples, which concludes that the design was successful.

ACKNOWLEDGEMENTS

First of all, I would like to express my utmost appreciation to my supervisor, Dr. Wong Peng Wen for his patience and guidance throughout the Final Year Project, which lasted for the past 8 months; for his attention and kindness in helping me whenever I needed help to complete my research and work for my project and proposing more and more ideas throughout my research.

I would also like to thank the FYP I and FYP II coordinators, lecturers, technicians and also the examiners for their valuable time in assisting and making this project come to a success. I would also like to thank the Microwave Research Lab members for the assistance and information they have given in the making of this project.

I would like to express special appreciation to Mr. Sovuthy Cheab and Mr. Sohail Khalid from the Communication cluster of Postgraduate Research team for giving extra helpful information and assistance to me. For providing me with lots of possibilities to overcome the problems I have encountered over the duration of this project.

Thanks to my colleagues and course mates doing their project on the similar subject, without assistance and guidance to each other, we might not have come to this conclusion. It has been a very educating experience since it was harder than usual for working on an individual project that takes such a long time to perform it and I am very grateful to have such a good experience in my life. Thanks to everybody making this course a success.

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LIST OF ABBREVIATIONS

FYP – Final Year Project

AWR – Applied Wave Research

HFSS – High Frequency Structural Simulator

2D- two-dimensional structure

3D- three-dimensional structure

TEM - Transverse Electromagnetic Wave

GHz- Gigahertz (unit of measure of frequency)

MHz- Megahertz (unit of measure of frequency)

AC- Alternating Current

BPF- Bandpass Filter

LPF – Low-pass Filter

HPF – High-pass filter

dB- decibels (unit of measure of sound strength)

MATLAB – Matrix Laboratory

TL – Transmission Line

CHAPTER 1

INTRODUCTION

1.1 Background

The objectives that needed to be achieved for this project were:

- To use network synthesis techniques to design a Chebyshev type-1 bandpass filter
- To use the Chebyshev filter and approximate the design with its Microstrip equivalences
- To build the design on AWR to predict the output response for the desired filter.

1.1.1 Scope of Studies

There are four main elements in this scope of studies which are:

1. Network synthesis for design of Chebyshev type-1 bandpass filter

The use of the Network synthesis techniques are quite easy with all the available mathematical formulas that can be used to estimate, firstly, the order of the filter and then using that and other parameters to build a circuit that describes Chebyshev type-1 bandpass filter.

2. Microstrip transmission lines

To transmit those high frequencies, a traditional type of transmission line will not be enough, and therefore Microstrip transmission lines are to be used. The design obtained by network synthesis is to be approximated to its Microstrip equivalences by using the available transformations.

3. AWR- Microwave office software

A simulation software that gives a possibility to design and analyze Microwave circuit designs. As it is a bandpass filter that is going to be used among two points, this design will be able to be used where there to be two peers to communicate.

1.1.2 The Relevancy of the Project

After taking few courses on Communication systems and Electromagnetic theory, the student who has received some knowledge on the matter can now expand his knowledge in the above mentioned areas by working on this project, which in turn is relevant to his studies in this University as an Electrical & Electronics Engineering student.

Once the project is successful, it has a big change to be implemented on various applications, which will act as a great experience to the student.

1.1.3 Feasibility of the Project

The project is expected to be fully performed within 2 semesters during the Final Year Project 1 (FYP 1) and Final Year Project 2 (FYP 2) courses. The time of FYP 1 Course was taken to be spent for research and applications on the theory part, or gathering information before starting to implement the design into a real prototype. The expected results that were to be achieved during the FYP 1 are already achieved and thus we can conclude that for FYP 1, the objectives are already met and the project went on well within the desired time frame.

During FYP 2 course, the gathered information on the filter response and the transmission line impedance were taken and calculations were done in order to estimate the required parameter values. Once the necessary parameters were estimated, the simulation of the design on the simulation software was done and the response of the filter was obtained.

1.2 Introduction to Microstrip Transmission Lines

In today’s world, the communication technologies have vastly evolved, by constantly making and applying new discoveries to the communication systems. With the advancing technologies, there are arising problems as well: more and more ways for a quality communication are in demands with the noise or undesired signals affecting the source signal. Nowadays, people come up with special filters to keep the information transmitted with a better quality. Microstrip devices are widely used in different applications: cellular radio, satellites, radar, navigation, wireless communications, etc. Microstrip is a very useful transmission line medium for implementation in distributed circuit designs at frequencies from below 1 GHz to some tens of GHz.

The main reason for the popularity of the Microstrip is that it is:

- cheaper
- light-weight, and
- easy to integrate with microwave integration circuits

compared to the traditional transmission lines.

The coupled Microstrip bandpass filter has been widely used in many microwave systems in order to achieve high performance, low cost, and small size while summing it up for the desired transmission specifications. There are many types of bandpass filter design techniques to meet the above requirements, where Microstrip acts as a transmission line to the electrical circuit. Microstrip is basically a transmission line which is used to carry microwave signals.

THE GEOMETRY OF MICROSTRIP

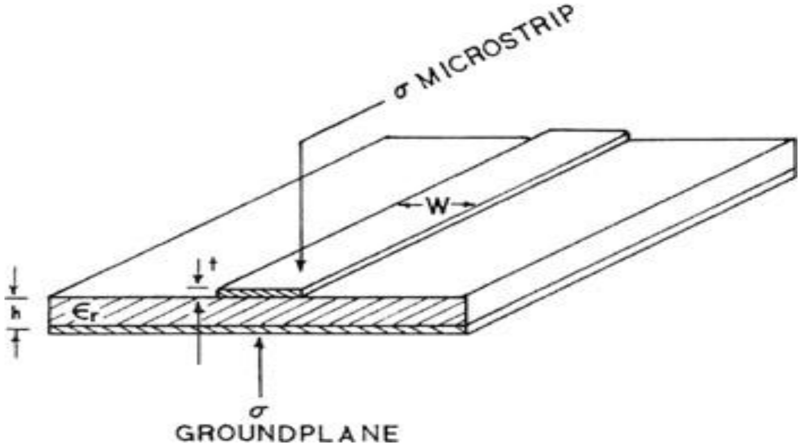


Figure 1. Microstrip transmission line architecture

It consists of:

1. A conducting strip, and
2. A substrate

The conducting strip of a width “W” and thickness “t” is separated from the ground plane by the substrate, which acts as a dielectric layer with a thickness “H”. Microstrip is known as the most popular microwave transmission line, especially for the microwave circuits. Its components can act as antennas, filters or other devices. By the use of the mentioned property of the Microstrip, we are going to use it for our project.

1.3 Problem Statement

The project that is going to be performed is however not a breakthrough to today’s technology, but the quality of Microstrip is clearly not good enough to as for example, the waveguide technology. In this project, we will be trying to improve the quality factor, in order to have a stronger signal at the passband.

1.3.1 Problem identification

As stated above, the quality is the main issue of the Microstrip filter. As in the design of Microstrip, the factors affecting the quality are the impedance, width, physical and electrical parameters. In this project, we will be evaluating the parameters affecting the quality to achieve the best results.

As the project is implemented and achieved successful results, it is going to make a breakthrough in the industry. A Microstrip filter with an improved quality is what is wanted in the industry, and with the improved response of a Microstrip filter, it is going to help the industry to have a cheap, compact and at the same time a high quality filter.

2

THEORY

There are various applications for Microwave filters in the communication systems industry that is in a need of different design approaches. The main goal will be to find a way to have the output amplitude to be of a good quality, which means that the unwanted signals will be rejected while the desired frequencies will be passed through the filter. Microstrip design parameters are to be considered, which will take us back to the study of transmission lines, thus to two-port networks as the transmission lines are implemented as two-port networks.

The transmission characteristics that we will need to be looking for are: bandwidth, insertion loss, return loss, centre frequency, the cutoff frequencies, roll-off and selectivity. It is very important to understand any changes in the above-mentioned parameters. For instance, by increasing the bandwidth, we can get less loss in the passband, but that will cost us a reduce in selectivity. Increasing the number of ripples in the passband for Chebyshev type-1 filter will increase the selectivity, but that will reduce the return loss.

Going back to what have been studied and analyzed during the network analysis, a transmission line is a special cable designed to carry an AC current of radio frequency, or in other words, currents of such a high frequency that their wave characteristics must also be considered. Transmission lines are very popularly used for connecting radio transmitters and receivers with their antennas.

The traditional, or ordinary electrical cables are good enough to carry low frequency signals, however, they are not reliable to carry signals in the radio frequency range or higher. Also, radio frequency signals tend to reflect from discontinuities in the cable such as connectors, and get transmitted down the cable toward the source. But transmission lines use a specialized construction that offer a more accurate conductor dimensions and spacing, which in turn carries the electromagnetic signals with minimal reflections and thus, power losses. The higher the frequency, the shorter are the waves in a transmission medium as it has been discussed throughout the study in Universiti Teknologi Petronas for several subjects.

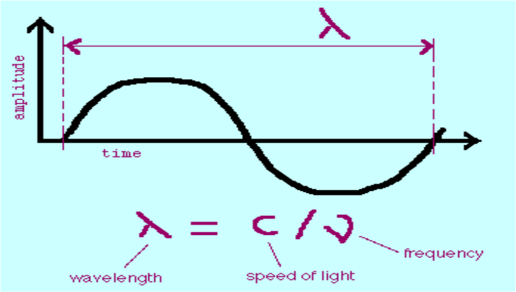


Figure 2. Wavelength vs. Frequency relationship

However, it is not the same for Microstrip transmission lines. When *w (angle in degrees)*=0, Microstrip tends to be a function of the relative permittivity, while when *w* approaches infinity, it will be a function of effective relative permittivity. These parameters and the relations are to be discussed later.

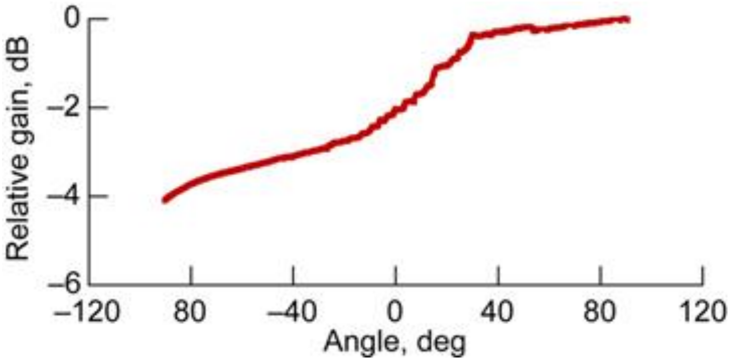


Figure 3. Frequency variation of Microstrip lines

Transmission lines are ought to be used when the frequency is so high that wavelength of the waves begins to approach the length of the cable used as cited from the “Theory and Design of Microwave filters” book by Ian Hunter. From the study of Network analysis, for the analysis purposes, an electrical transmission line is modeled as a two-port network:

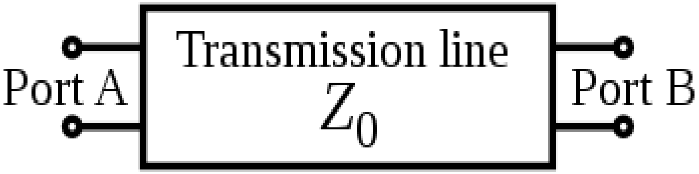


Figure 4. Two-port network

It is desired that as more power as possible is absorbed by the load for a less power to be reflected back to the source. This can be performed by making the load impedance equal to Z_0, which will have zero reflections, or its impedances matched. But of course, the ideal case cannot be met in the real world applications, some of the power that is fed into a transmission line will still be lost because of the resistance of the transmission line. This effect is known as the Ohmic Loss. As the frequency gets higher, there will be another loss appearing, known as the dielectric loss. This means that at high frequencies we have more troubles to face. Dielectric loss happens when the insulator of the transmission line absorbs energy from the alternating electric field and converts it to heat.

Microwave filters represent a class of electronic filters, designed to operate on signals in the range of 1-40 GHz, as studied during the Communication Systems 1 course at UTP. This frequency used by microwave is the range used by most of broadcast radio, television and wireless communication.

There are 4 types of filters in the market:

1. Band-pass filter (BPF): selects only a desired band of frequencies
2. Band-stop (Notch) filter: stops or eliminates an unwanted band of frequencies
3. Low-pass filter (LPF): transmits frequencies below a cutoff frequency
4. High-pass filter (HPF): transmits frequencies above a cutoff frequency

For our case, a band-pass filter is to be designed. An ideal bandpass filter has a flat passband and filters out all frequencies outside the passband with a perfect parallel slope. In real case, bandpass filters are never ideal. The filter does not filter out all frequencies outside the wanted frequency range, but there is a region just outside the desired passband where frequencies are attenuated rather than stopped. This phenomenon is called the filter roll-off. The design of a filter seeks to make the roll-off as steep as possible.

The bandwidth of a filter is simply the difference between the upper and lower cutoff frequencies.

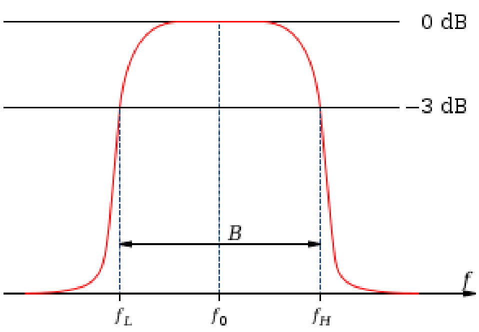


Figure 5. Band-Pass Filter

Thus, for a better selectivity, we will be designing our filter to have a steeper roll-off, which means that the transition between the stopband and the passband is going to be much faster for the desired filter.

Next, for designing filters, we need to use special techniques. Filters can be divided into two categories:

1. Analogue filters
2. Digital filters

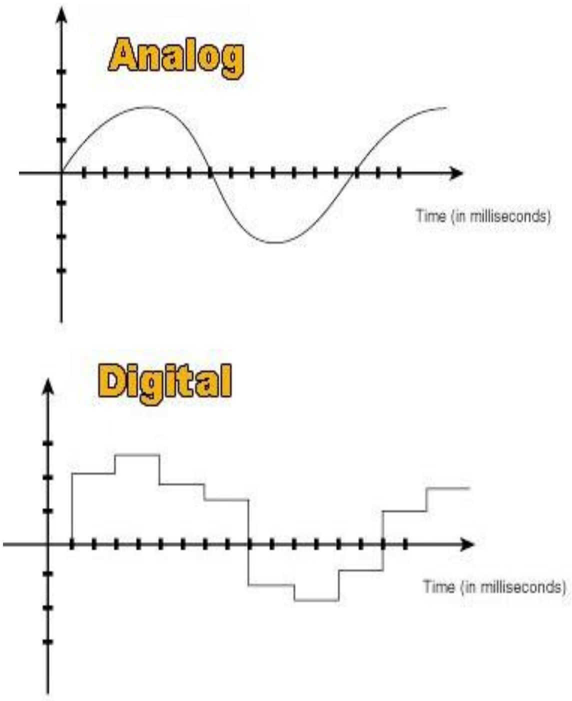


Figure 6. Analogue vs. Digital signal

As it can be clearly understood, we are required to design an analogue filter. Analogue (continuous-time) filters are the foundational block of signal processing, which are vastly used in electronics and filter design. Among the many various applications is the separation of audio signals from the original signal for better communication without noise. The audio signal is then applied to the speakers.

Apart from separation, another possible action is merging different audio signals which are used in many audio software, telephone or video conversations. One of the greatest examples to relate to nowadays technology is by using the Skype video conferencing software. If we take a closer attention, we will notice that when we are in a conversation using the Skype software, almost the only audio signal that we can hear is the loudest signal, which in most cases is the voice of the either party. In case there is a stronger (a higher amplitude) noise than the person speaking, we are not able to hear the speaker. This is basically done by the use of the techniques of separating different amplitudes of noise from each other and eliminating the unwanted noise. This can be done by the use of Analogue filter design techniques.

Passive electronic filters are filters which are composed of passive elements (resistors, capacitors, inductors) and they can be derived through linear differential equation. Analogue filters are very widely used in wave filtering applications; where just like in our case some of the components of the signal are to be rejected (noise) and only some are to be accepted (signal).

Analogue filters have been a real breakthrough to today's technology and has made an extremely large profits for communication companies. The development of the analogue filters was solely dependent on the transmission lines, when after that the network synthesis was introduced to the technology, which greatly improved the quality of the control of the filters. Nowadays, most of the filtering applications are tried out in the digital domain where complex mathematical calculations are easier, but anyhow, analogue filters are still a strong force in the communication technology, especially for simple low-order tasks and are still more preferred when dealing with higher frequencies, where digital technology is still not well developed.

As mentioned earlier, network synthesis is a newer method of designing analogue filters. Network synthesis has introduced several important classes of filters, such as the Butterworth filter, the Chebyshev filter and the Elliptic filter. Originally, the network synthesis was planned to be applied for passive linear analog filters, but later on it was figured out that the results from the network synthesis can also be applied to implementations of active and digital filters. The purpose of these filters is to pass wavelengths of the specific filter and block any other wavelengths. The technique behind it is to obtain the component values of the filter through a polynomial ratio that represents the desired function.

Network synthesis can be approached as the inverse of the network analysis: network analysis starts with a network and by performing the analysis ends up with the response of the network. Whereas, network synthesis starts with the desired response, performs its analysis techniques and ends up with a network that describes the desired response.

Since there are different classes of the analogue network synthesis filters, each class of a filter can be classified according to the class of polynomials from which the filter is algebraically derived. The order of the filter can be known by knowing the number of filter elements existing in the filter's implementation, which implies that, the higher the order of the filter, the steeper the roll-off (cut-off transition from passband to stopband). This in turn means that the higher the order of the filter, the higher the selectivity of the filter.

The most popular filter classes for network synthesis are discussed below.

1. Butterworth filter

Butterworth filters are the filters with the maximum possible flat response, which means that the output curve is the smoothest, with no ripples in the frequency domain, but this comes in an expense of having a large roll-off. Thus, the disadvantage of this filter is that it might accept some of the frequencies outside the desired band.

2. Chebyshev filter

Chebyshev filter has 2 types:

- Chebyshev filter has a smaller roll-off (faster cutoff transition) compared to Butterworth, but this is at the expense of having ripples in the passband in the frequency response (Chebyshev type 1).
- The other type (Chebyshev type 2) is a filter with no ripple in the passband, but in expense of having ripples in the stopband.

3. Eliptic/Cauer filter

Cauer filters are filters with equal ripple in the passband and stopband with the fastest roll-off compared to any other class of filter. The small difference between Cauer and Elliptical filters is that elliptical filters sometimes have unequal ripples.

Precise transmission characteristics are required by bandpass filters to allow a desired signal band to pass through with a minimum loss when passing through a two-port network and block undesired signals out of the passband.

An easy way to understand the structure and the filter itself for microwave band pass filters is to look at it as a number of resonant elements, connected with admittance or impedance inverters (K-inverters), which are usually referred to as the filter couplings. The resonant elements may be series or parallel and may be of any number N, which defines the order of the filter. Increasing N increases the ripple number, which in turn as we discussed just earlier, increases selectivity and reduces the return loss. For an N section two port filter, with no cross couplings, we need to define N resonant elements, N-1 internal couplings and two external couplings. Using symmetry we can reduce this by a factor of two or nearly two if the number of resonators is odd. This is a very important concept, and is extremely useful and time-saving during the mathematical calculations and also when optimizing filter structures using the simulator software. Couplings can be realized using the electromagnetic interaction between adjacent transmission lines.

Last, but not least, the introduction with the Microwave Office has to be done: to get introduced with the software and how to use it and apply for our design. Once the design is final, the simulations have to be performed until the software can get the desired result.

Two different software are available for use for the design of the Microstrip:

1. AWR
2. HFSS

The difference between the two is that, the latter one, HFSS allows us to have three-dimensional designs considering the enclosure around the filter built, while the first one is only for 2D designs. Since Microstrip does not require a 3D design, it was decided that the project will be continued using the AWR software.

AWR (Applied Wave Research) - Microwave design software is today’s fastest growing microwave design platform. Microwave Office design includes the following tools, which are essential for our design:

- Linear and non-linear circuit simulators
- Integrated schematic and layout
- Statistical design capabilities
- Electromagnetic analysis tools

A very popular type of Microstrip filter configuration is the Hairpin configuration which has its resonators folded into a ‘hairpin’ structure to save some board space. This type of structure is pre-defined and is available at the AWR software.

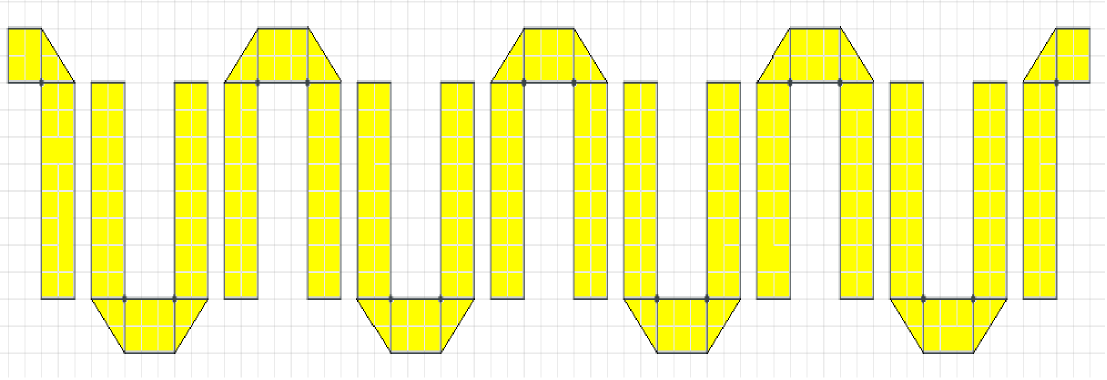


Figure 7. Coupled line input Microstrip Hairpin configuration of 7th order

CHAPTER 3

IMPLEMENTATION OF THE PROJECT

3.1 Choosing of the Network Synthesis type

Now that we know we are familiar with some of the popular classes of filters for network synthesis, we need to choose which one of the classes is the most suitable for our case. For that, let us discuss some of the important differences between those filters to choose the best class for our filter.

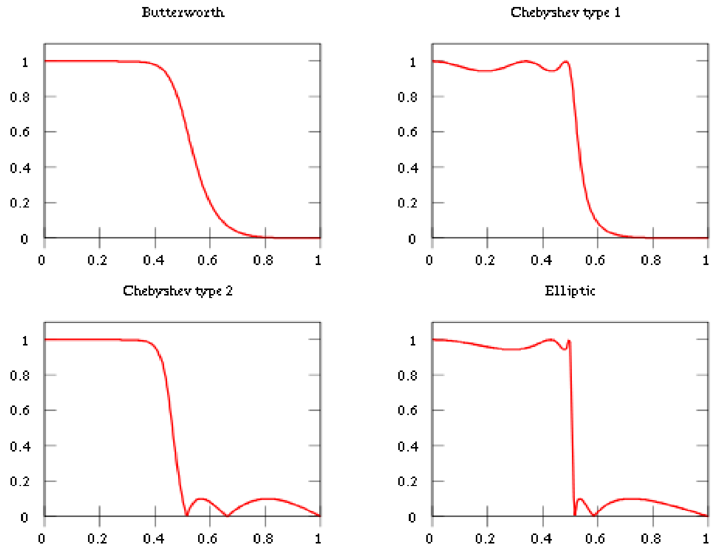


Figure 8. Frequency responses for different filter classes

Below are the frequency responses for the different classes of filters merged together for an easier comparison.

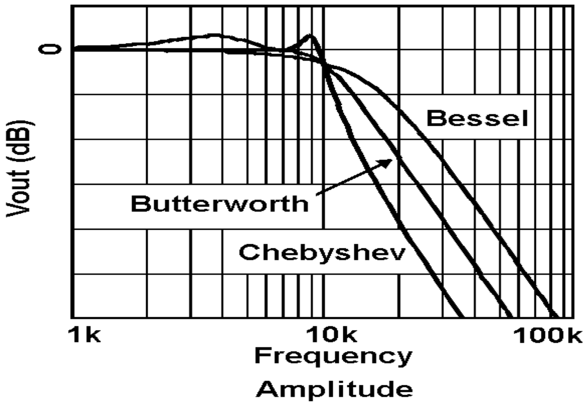


Figure 9. The Frequency response of different filters classes (merged)

From the above figure, it is obvious that there is a ripple in the passband of the Chebyshev filter with the position and the number of ripples being determined through the order of the filter. Filters of even orders have ripples above, whereas the filters with odd orders generate ripples below the 0 dB intercept.

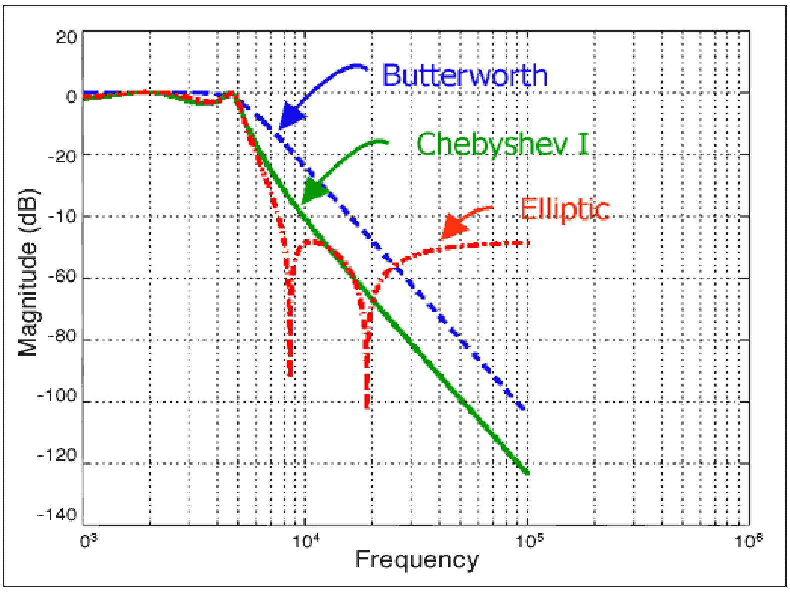


Figure 10. Phase responses of different classes of filters

It can be seen from the graph that the Chebyshev class filter's rate of phase change is the fastest. Also, The Chebyshev response has the longest group delay.

Thus, from the comparing and finding of the different classes of filters, we can conclude that the most suitable response for our case is the Chebyshev type filter.

The Gantt charts for FYP 1 and FYP 2 are as below:

FYP 1															
		Week No.													
No	**Activity**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Title Selection	▨	▨												
2	Title Proposal		▨												
3	Literature Review		▨	▨	▨	▨	▨								
5	FYP Sharing Session		▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
4	Submission of Extended Proposal						🟨								
6	Proposal Defense									🟥					
7	Calculation of Parameters for the Filter											▨	▨	▨	▨
8	Submission of Draft Report to SV													🟨	
9	Submission of Final (Interim) Report														🟥

Table 1. Gantt Chart for FYP 1

FYP 2																
No	**Activity**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Calculation of Parameters for the Filter	▨	▨	▨	▨	▨	▨									
2	Literature Review		▨	▨	▨	▨	▨	▨								
3	Submission of Progress Report								🟨							
4	Simulation of the design on AWR								▨	▨	▨	▨	▨			
5	Pre-EDX											🟨				
6	Sending for fabrication													🟨		
7	Draft Report													🟨		
8	Final Report														🟥	
9	Viva															🟥

Table 2. Gantt Chart for FYP 2

3.2 Calculations

The parameters given:

f_1 = 5150 MHz BW = $f_2 - f_1$ = 100 MHz

f_2 = 5250 MHz $L_A = L_{As}$ = - 60 dB | 5080 MHz

5320 MHz

f_0 = 5200 MHz Z_0 = 50 Ω

IL (Insertion Loss) = 1 dB L_R = -15 dB

Step 1. Calculation of the order of the filter using the Chebyshev type-1 response

$$N \geq \frac{\cosh^{-1}\sqrt{\frac{10^{0.1L_{As}}-1}{10^{0.1L_{Ar}}-1}}}{\cosh^{-1}\Omega_S}$$

With Ω_S being the ratio of stopband to passband frequencies and L_{Ar} is passband ripple. Let's start evaluating the unknowns:

$$\Omega_S = \frac{5320-5080\ MHz}{5250-5150} = \frac{240\ M}{100\ M} = 2.4$$

$$L_{Ar} = -10\log\left(1-10^{0.1L_R}\right)\ dB$$

$$L_{Ar} = -10\log\left(1-10^{0.1\times(-15)}\right)\ dB = 0.1396 \approx 0.14$$

Now, entering the derived values to the previous equation:

$$N \geq \frac{\cosh^{-1}\sqrt{\frac{10^{0.1\times 60}-1}{10^{0.1\times 0.14}-1}}}{\cosh^{-1} 2.4} = 6.1167 \approx 6.12$$

Thus, our filter is of 7th order.

To ensure the order of our filter, we can use MATLAB simulations. MATLAB Code for the above parameters for a Chebyshev type-1 response. The MATLAB Code is available on the Appendix A.

The result of the MATLAB coding response is as below:

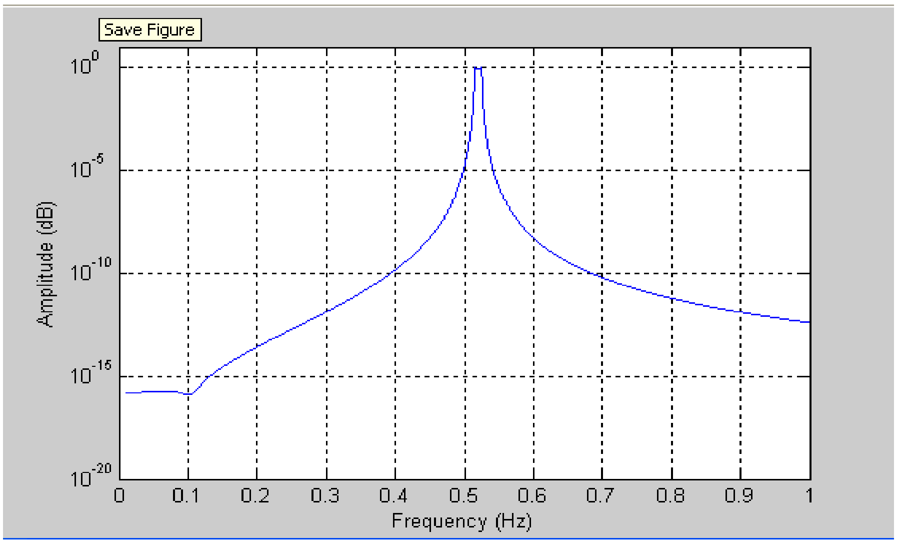


Figure 11. Response for the desired Chebyshev bandpass filter

From the figure above, we can see that the desired passband filter has been achieved, but unfortunately the filter characteristics cannot be seen. To compensate for that, the use of MATLAB scaling techniques were used to have a better glance at the frequency response of our filter:

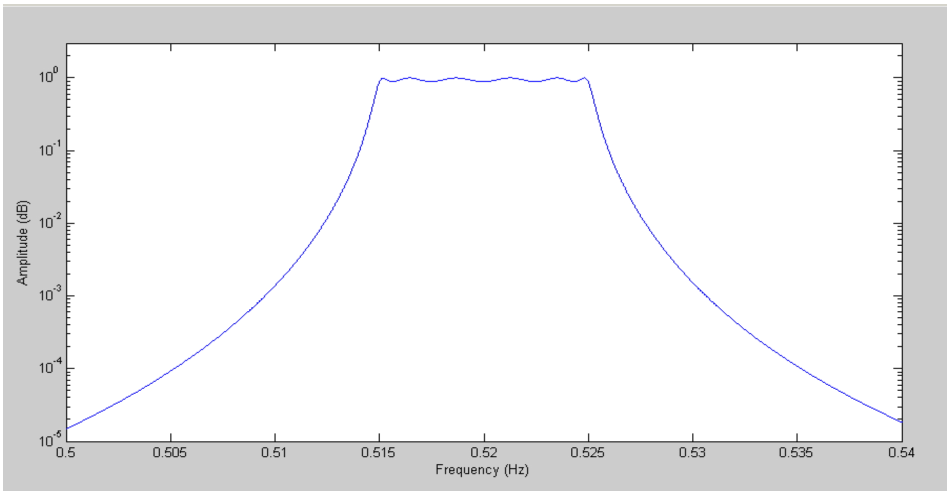


Figure 12. 6th order Chebyshev bandpass filter frequency response

Now, we can clearly see an almost smooth frequency response of our passband filter with some ripples in the passband (Chebyshev type 1 filter). And from the number of ripples in the passband: the filter is of 7th order. Now, we are sure that we can proceed with the 7th order bandpass filter.

Step 2. Design of Low pass Chebyshev prototype network.

Before we proceed to the design of the bandpass filter for Chebyshev filters, first we need to design a prototype for the low-pass filter and only then transform it to the band-pass. To evaluate the inductance and K-inverter values of the components of the Chebyshev type-1 prototype network, we use the following formulas:

$$K_{R,R+1} = \frac{\sqrt{\eta^2 + sin^2({}^{r\pi}/_{N})}}{\eta}$$

$$L_R = \frac{2}{\eta} \sin\left[\frac{(2r-1)\pi}{2N}\right]$$

Where $\eta = \sinh\left[{}^{1}/_{N} \sinh^{-1}({}^{1}/_{\varepsilon})\right] = 0.35$ and ε= $\left[10^{{}^{L_R}/_{10}} - 1\right]^{-{}^{1}/_{2}} = 0.18$

Using the above parameters and formulas, we can estimate the values for the components:

$$K_{1,2} = K_{6,7} = \frac{\sqrt{0.35^2 + sin^2({}^{\pi}/_{7})}}{0.35} = 0.94\Omega$$

$$K_{2,3} = K_{5,6} = \frac{\sqrt{0.35^2 + sin^2({}^{2\pi}/_{7})}}{0.35} = 1.45\Omega$$

$$K_{3,4} = K_{4,5} = \frac{\sqrt{0.35^2 + sin^2(3\,{}^{\pi}/_{7})}}{0.35} = 1.75\Omega$$

$$L_1 = L_7 = \frac{2}{0.35} \sin\left(\frac{\pi}{14}\right) = 1.27$$

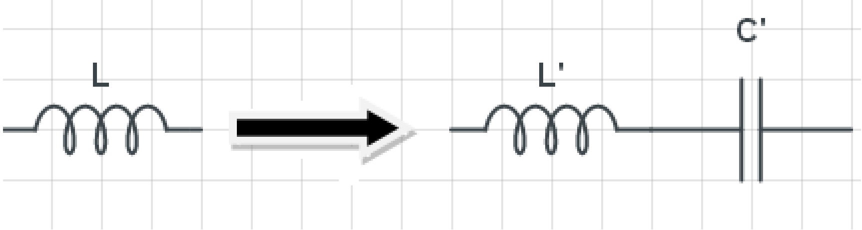
$$L_2 = L_6 = \frac{2}{0.35} \sin\left(\frac{3\pi}{14}\right) = 3.56$$

$$L_3 = L_5 = \frac{2}{0.35} \sin\left(\frac{5\pi}{14}\right) = 5.15$$

$$L_4 = \frac{2}{0.35} \sin\left(\frac{7\pi}{14}\right) = 5.71$$

Step 3. Transformation from lowpass to bandpass prototype network.

Next, we have to transform our lowpass filter to bandpass filter. To evaluate the new components, we would need the following transformation:



with,

$$L' = \frac{\alpha L}{w_0} \quad \& \quad C' = \frac{1}{\alpha L w_o}$$

where,

$w_o = \sqrt{w_1 w_2}$ and $\boldsymbol{\alpha} = \frac{w_o}{w_2 - w_1}$

By evaluating the above equations, we get:

$L_1 = L_7 = 1.27\mu H$

$L_2 = L_6 = 3.56\ \mu H$

$L_3 = L_5 = 5.15\mu H$

$L_4 = 5.71\mu H$

$C_1 = C_7 = 7.36pH$

$C_2 = C_6 = 2.63pH$

$C_3 = C_5 = 1.81pH$

$C_4 = 1.64\,pH$

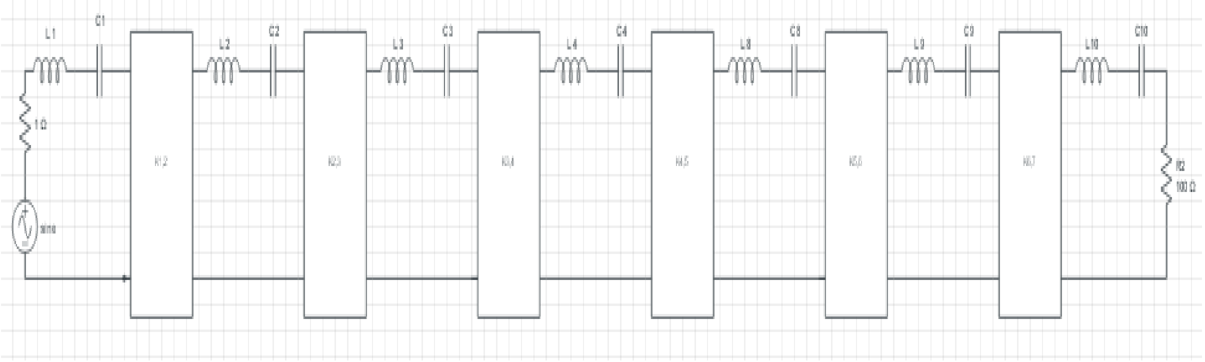
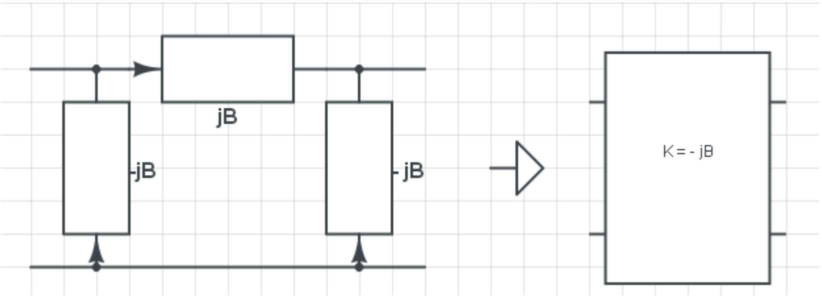


Figure 13. 7th- order Chebyshev Prototype network for bandpass filter using K-inverters

Next, we need to evaluate the values for the K-inverters:



By using the above transformation for K-inverters, we get:

L1’=L6’=28.8pH
L2’=L5’=44.4pH
L3=L4’=53.6pH

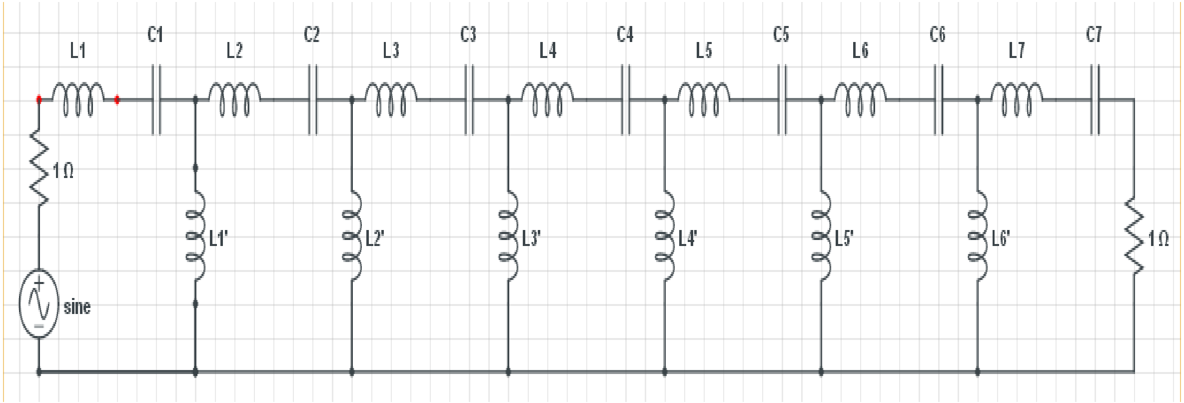
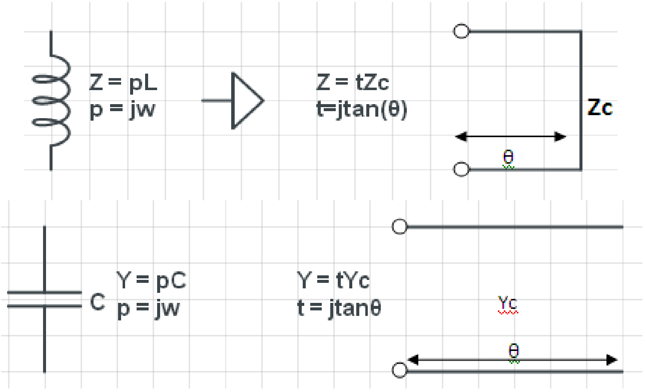


Figure 14. Final design of the Chebyshev type-1 7th order Bandpass filter

Step 4. Transforming into Microstrip equivalence circuit

After getting the previous circuit, we next need to transform the circuit into its Microstrip equivalence by finding the characteristic impedance of each component.



by using the above transformation, we get the following design:

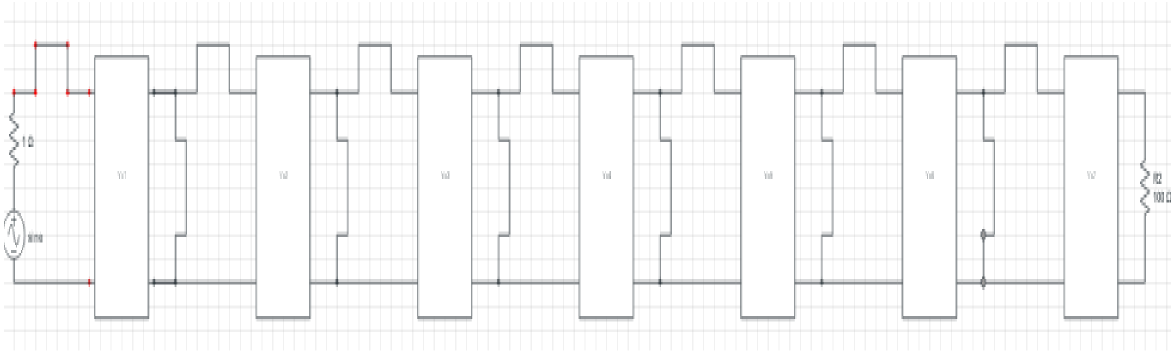


Figure 15. Microstrip equivalences for the Chebyshev type-1 design

After transforming the admittances, we get the following impedances of the transmission lines for the Microstrip design:

TL1 = TL32 = 92.3 Ω	TL7E = TL27E = 191.5 Ω	TL11O= TL23O=105.1 Ω	TL16E = 181.6 Ω
TL2 = TL5 = TL6 = 50 Ω	TL7O = TL27O = 90 Ω	TL12E = TL20O= 165.9 Ω	TL16O = 99.8 Ω
TL3E = TL31E= 172.1 Ω	TL8E = TL24E= 122.4 Ω	TL12O =TL20O 97 Ω	TL17=TL18= 50 Ω
TL3O = TL31O= 80.2 Ω	TL8O= TL24O = 108.7 Ω	TL13 =TL14 = 50 Ω	TL21= TL22 = 50 Ω
TL4E = TL28E = 190.2 Ω	TL9 = TL10 = 50 Ω	TL15E = TL19E= 117 Ω	TL25 = TL26 = 50 Ω
TL4O = TL28O = 89.7 Ω	TL11E = TL23E= 121.2 Ω	TL15O = TL19O=109.4 Ω	TL29 = TL30 = 50 Ω

Table 3. Admittance values of all transmission lines

Step 5. Static-TEM Design Calculations

For narrow strips (i.e. when $Z_0 > (44 - \varepsilon_r)\Omega$)

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2}\left(1 + \frac{29.98}{Z_0}\left[\frac{2}{\varepsilon_r + 1}\right]\left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)\left[ln\frac{\pi}{2} + \frac{1}{\varepsilon_r}ln\frac{4}{\pi}\right]\right)^{-2}$$

Where ε_{eff} is the effective Microstrip permittivity. Next, $Z_0 = 50 > (44 - 2.2)$. Thus, transmission line for 50 Ω is considered as a narrow strip. Using the above equation:

$$\varepsilon_{eff} = \frac{3.2}{2}\left(1 + \frac{29.98}{50}\left[\frac{2}{2.2 + 1}\right]\left(\frac{2.2 - 1}{2.2 + 1}\right)\left[ln\frac{\pi}{2} + \frac{1}{2.2}ln\frac{4}{\pi}\right]\right)^{-2} = 1.37$$

Next, we are going to evaluate the width of our Microstrip:

$$\frac{w}{h} = \left(\frac{expH'}{8} - \frac{1}{4expH'}\right)^{-1}$$

where

$$H' = \frac{50\sqrt{2\times(\varepsilon_r+1)}}{119.9} + \frac{1}{2}\left(\frac{\varepsilon_r-1}{\varepsilon_r+1}\right)\left[ln\frac{\pi}{2} + \frac{1}{\varepsilon_r}ln\frac{4}{\pi}\right] = \frac{50\sqrt{2\times(2.2+1)}}{119.9} + \frac{1}{2}\left(\frac{2.2-1}{2.2+1}\right)\left[ln\frac{\pi}{2} + \frac{1}{2.2}ln\frac{4}{\pi}\right] = 1.16$$

$$\frac{w}{h} = \left(\frac{\exp(1.16)}{8} - \frac{1}{4\exp(1.16)}\right)^{-1} = 3.12$$

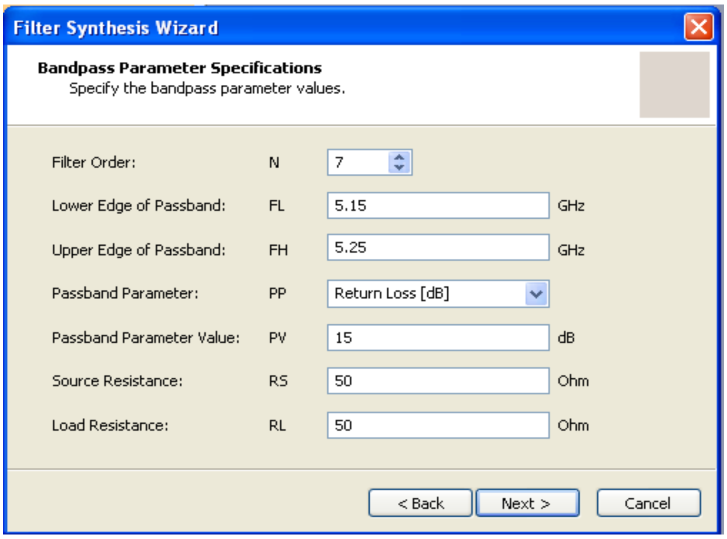
w =h ×3.12 = 17.5µ ×3.12

w=54.62µ

The results for the calculation of the width and length of the rest of the transmission lines is available in Appendix B

3.3 Discussion and Results

On the AWR software, there is a special tool called the Filter Synthesis Wizard that allows us to build a Microstrip structure filter by saving a lot of time and hassle. Upon the usage of the filter Synthesis Wizard, it is needed to enter the parameters of the filter:



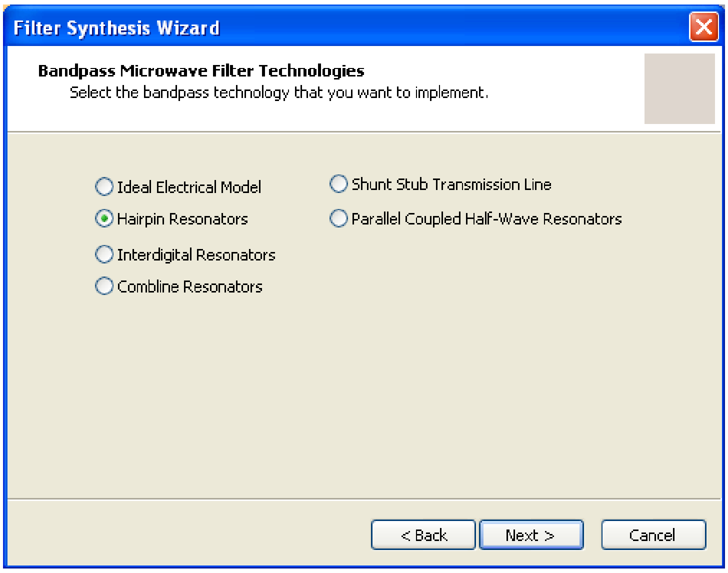
Bandpass Parameter Specifications
Specify the bandpass parameter values.

Filter Order:	N	7	
Lower Edge of Passband:	FL	5.15	GHz
Upper Edge of Passband:	FH	5.25	GHz
Passband Parameter:	PP	Return Loss [dB]	
Passband Parameter Value:	PV	15	dB
Source Resistance:	RS	50	Ohm
Load Resistance:	RL	50	Ohm

Figure 16. Filter Parameters being entered

Next, we need to choose the type of configuration we would like to use for our filter.

As we can see in the picture below, AWR has a pre-defined and ready-for-use Hairpin structure for the Microstrip transmission lines.



Bandpass Microwave Filter Technologies
Select the bandpass technology that you want to implement.

○ Ideal Electrical Model
● Hairpin Resonators
○ Interdigital Resonators
○ Combline Resonators
○ Shunt Stub Transmission Line
○ Parallel Coupled Half-Wave Resonators

Figure 17. Choosing the Hairpin Resonators structure.

After going through few more steps using the Filter Synthesis Wizard, at the end of it will give us a ready-for-use circuit as below. If we look closely at the structure, we can see that there are exactly 7 ‘hairpins’ which represent 7 resonators used for the 7th order Bandpass filter.

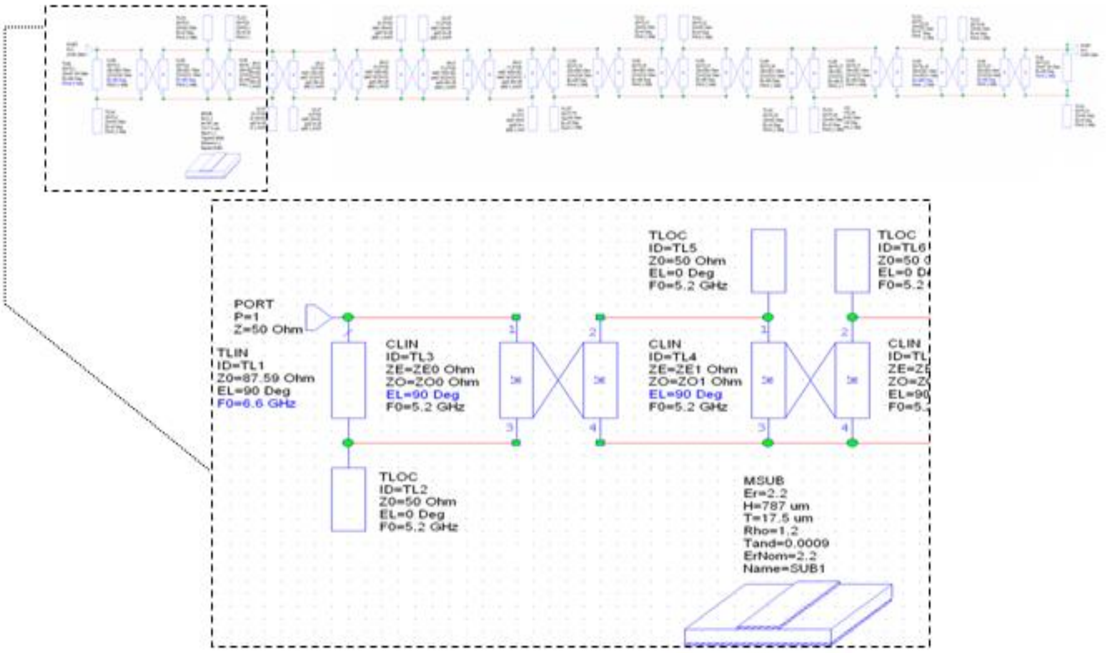


Figure 18. The design built on the AWR using the filter synthesis wizard

If we run the available design on the simulator, we will get the following response:

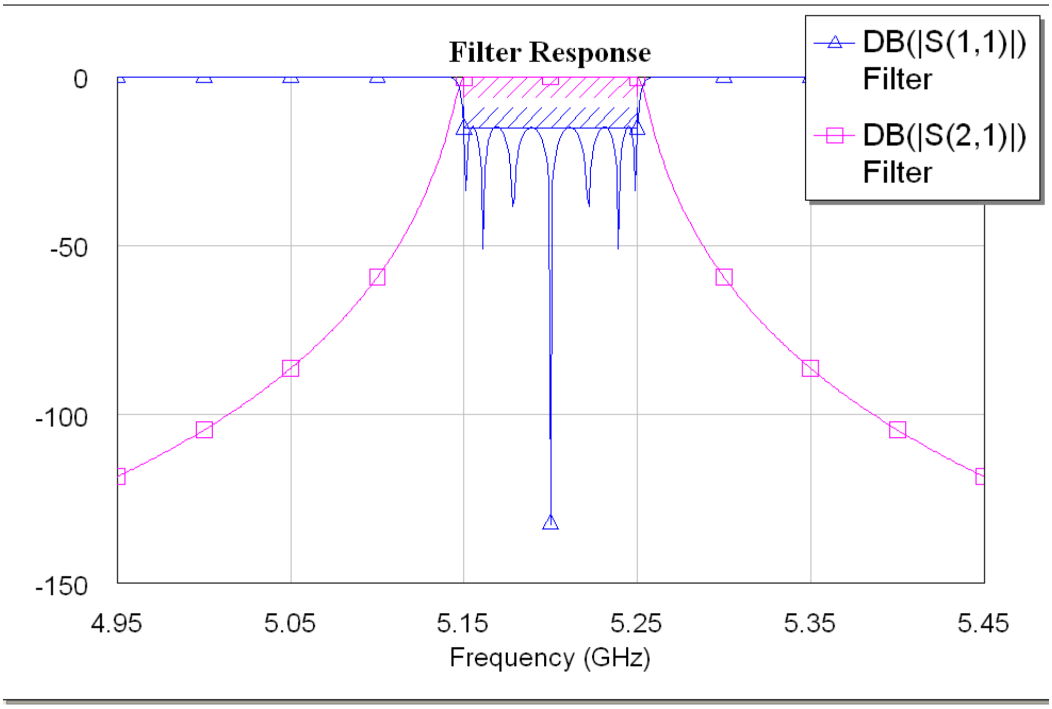
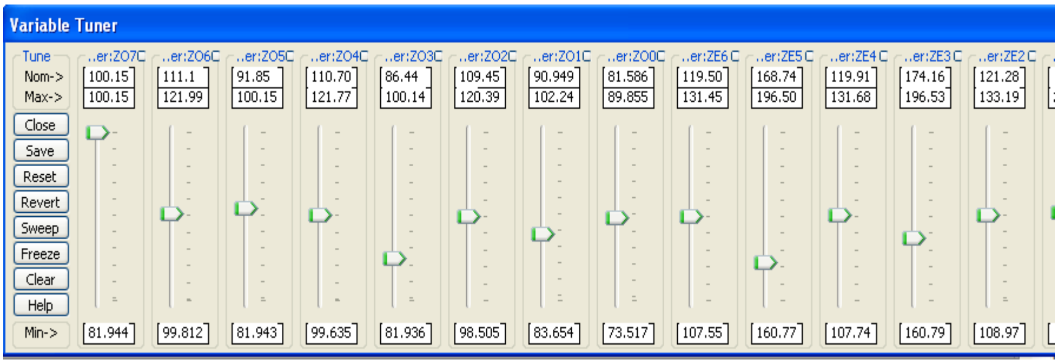


Figure 19. The Filter response before tuning or optimization

It can be clearly noticed that the response is not ideal because of the center ripple falling far below the maximum allowed attenuation loss. This type of response will give us an undesired output resulting in the loss of the information sent through the filter. To improve the response of our filter, AWR has few more available tools that are very easy to use and only need a little time and focus.

The first tool that was used is known as the Tuner tool, which allows tuning any desired parameters from our design, while observing the filter response come to a better acceptable response.



Tune	..er:ZO7C	..er:ZO6C	..er:ZO5C	..er:ZO4C	..er:ZO3C	..er:ZO2C	..er:ZO1C	..er:ZO0C	..er:ZE6C	..er:ZE5C	..er:ZE4C	..er:ZE3C	..er:ZE2C
Nom->	100.15	111.1	91.85	110.70	86.44	109.45	90.949	81.586	119.50	168.74	119.91	174.16	121.28
Max->	100.15	121.99	100.15	121.77	100.14	120.39	102.24	89.855	131.45	196.50	131.68	196.53	133.19
Min->	81.944	99.812	81.943	99.635	81.936	98.505	83.654	73.517	107.55	160.77	107.74	160.79	108.97

Figure 20. Tuning of the parameters.

After using the tuning tool illustrated in the above picture, we got the following response:

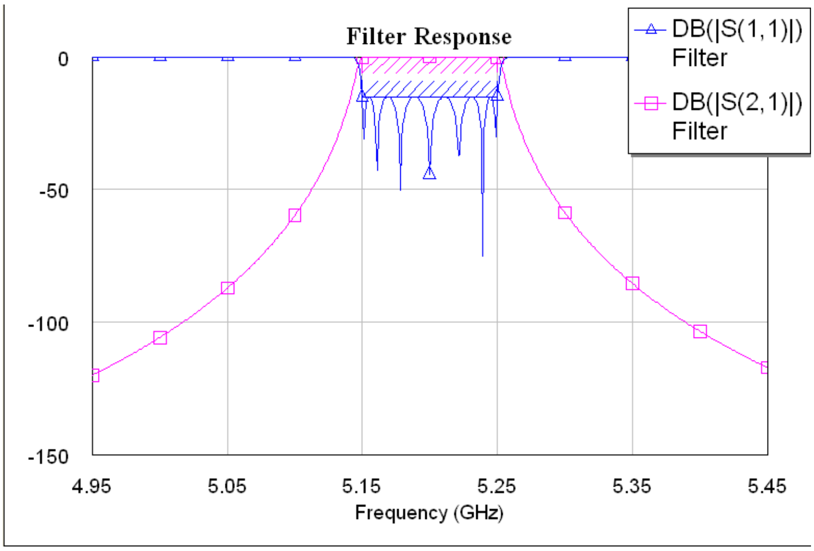
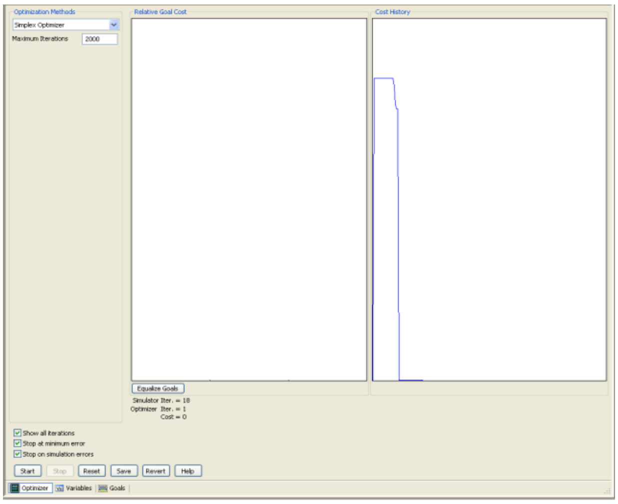


Figure 21. The Filter response after tuning and before the optimization.

It is very easy to notice that the response of the filter has now vastly improved, but unfortunately is still not acceptable for a good quality bandpass filter. As the next and last step for improving the filter response, we used the Optimization tool, which is available at AWR and is even easier to use than the tuning tool.

What the optimization tool does is, it runs the filter response through a number iterations while changing its parameters and automatically improves the filter response. After several iterations done on the Optimizer tool, we finally got an acceptable response.



Simplex Optimizer

Maximum Iterations 2000

Simulator Iter. = 18
Optimizer Iter. = 1
Cost = 0

☑ Show all iterations
☑ Stop at minimum error
☑ Stop on simulation errors

Figure 22. Running the Optimizer tool.

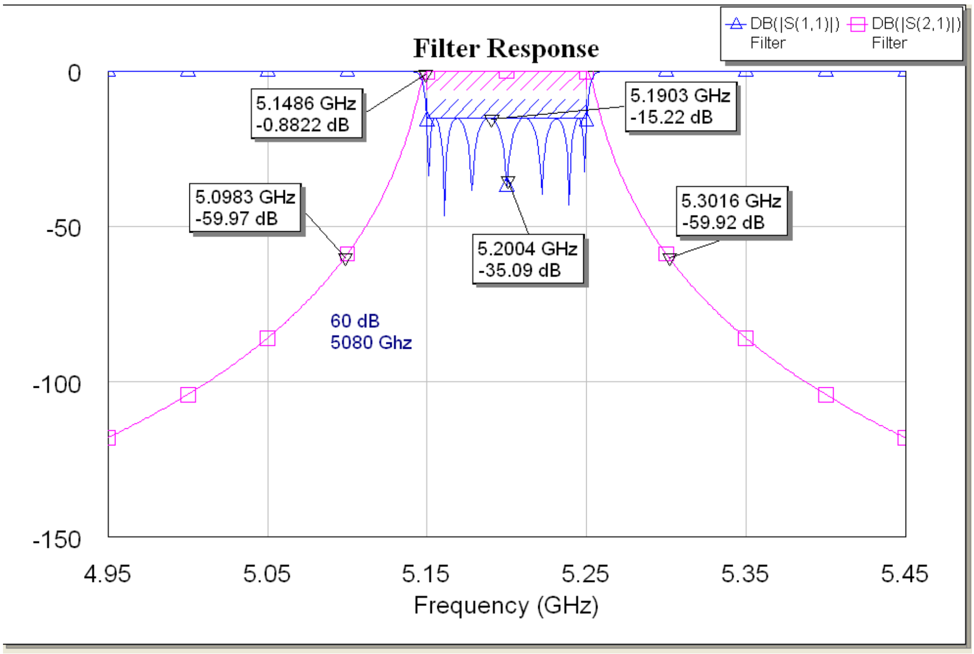


Figure 23. The final response after the optimization technique used.

The final response of the filter is illustrated in the figure above. It is noticeable that all the parameters that were pre-specified are met: the insertion loss is less than 1 dB, the return loss is less than 15 dB and the attenuation loss is even better with a roll-off steeper than expected. We can see that 60dB attenuation limit is met at the bandwidth specified (5080-5320MHz) being in the range of approximately 5098-5316 MHz. Thus, all the parameters expected are met and the filter response is acceptable.

CHAPTER 4
CONCLUSION AND RECOMMENDATIONS

As through the FYP, the expected objectives are fulfilled and the time frame was acceptable to fully finish the project.

- A design of a filter order using the mathematical expressions and MATLAB was achieved, which now allows us to predict the output response for our filter.
- Network synthesis techniques to design a Chebyshev type-1 bandpass filter were used and a design was achieved
- The Chebyshev filter design was achieved and approximated to its Microstrip equivalences
- The design was built on AWR and the output response for the desired filter was predicted.

However, the project still has more room for improvement as there are some factors not considered throughout this project. By taking this additional factors into consideration, we can improve the design of the filter to even a better extent. The factors that could be improved are:

- One of the main factors that considered is a 3D design instead of the 2D design, as 2D designs do not cover up for the enclosure around the Microstrip circuit. Thus, by using a 3-D design, we can estimate for the extra losses. This can be done by using a different software than AWR. For instance, usage of HFSS would compensate for this defect. As discussed earlier, HFSS allows 3D designs, which means that it can also compensate for the enclosure around the transmission line circuit.

- Another factor that should be considered is that the values of the components used are not the common values for the fabrications. This in turn will make it not very possible to fabricate the real prototype of the filter. Or in other case, the design might need a special order for those components, which would make the design extra expensive. To make sure that there are no unnecessary spending made, the values of the components should be taken into more consideration by making them as close as possible to the factory values.
- However, the hairpin structure should be kept the same, as this structure allows us to save board space and it is very recommended that we fabricate designs that take less space as it would be handy for those utilizing the filter. If for example the filter is used as a feature in some larger equipment, it is going to save up some space, in turn making it more desirable for customers to want to use this filter.
- To further improve the functionality of the filter, we can also turn our filter from bandpass filter to an adaptive filter. It will allow the user of the filter to choose his own desired frequencies in case he needs to operate on more than one frequency.
- Last, but not least, using of a different Network Synthesis that promises a better result could be very useful. For instance, Cauer or Elliptical filters could be used to improve the filter response even more than it is.

As a conclusion, we can state that the project was successfully implemented as all the objectives of the project were met and with the roll-off being even steeper than expected, we can surely conclude that the implementation of this project was a success.

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APPENDICES

APPENDIX A

MATLAB CODE FOR ORDER OF THE FILTER

```
wp = [2*pi*5150e6 2*pi*5250e6];        % the frequency range of -3 dB
ws = [2*pi*5080e6 2*pi*5320e6];         % frequencies for attenuation maximum of -
60 dB
rp = 1;                                   % low cutoff passband ripple
rs = 60;                                  % attenuation maximum ripple

[n,Wl] = cheb1ord(wp,ws,rp,rs,'s');      % Chebyshev Type-1 order calculator for a
filter of order n
[z,p,k] = cheb1ap(n,rp);                          % predetermined MATLAB tool for
designing Chebyshev type-1 filter
[a,b,c,d] = zp2ss(z,p,k);                 % converting the system to state-space form
y1 = 2*5150e6*pi/10000e6;              % normalizing the passband frequencies
y2 = 2*5250e6*pi/10000e6;



bw = y2-y1;                               % bandwidth of the filter
fc = sqrt(y1*y2);                        % center frequency of the filter
[at,bt,ct,dt] = lp2bp(a,b,c,d,fc,bw);   % transforming the system from low pass to
bandpass
[b,a] = ss2tf(at,bt,ct,dt);             % converting the system to a transfer function
form.

w = linspace(0.01,1,50000)*2*pi;       % generating a frequency vector.
h = freqs(b,a,w);                       % computing the frequency response.
semilogy(w/2/pi,abs(h));               % plotting the response
grid;
xlabel('Frequency (Hz)');
ylabel ('Amplitude (dB)');
```

APPENDIX B

TRANSMISSION LINE PARAMETER CALCULATION RESULTS

Impedance of TL	**Width and Length of TL (in µm)**	**Impedance of TL**	**Width and Length of TL**
TL1 = TL32 = 92.3 Ω	W=62.55 L= 4537.95	TL11E = TL23E= 121.2 Ω	W= 4606.71 L= 4606.71
TL3E = TL31E= 172.1 Ω	W=15.46 L=4554.95	TL11O = TL23O=105.1 Ω	W=44.13 L= 4574.21
TL3O = TL31O= 80.2 Ω	W= 79.43 L= 4412.13	TL12E = TL20O= 165.9 Ω	W=15.46 L=4554.95
TL4E = TL28E = 190.2 Ω	W=15.46 L=4554.95	TL12O =TL20O= 97 Ω	W=53.11 L= 4555.65
TL4O = TL28O = 89.7 Ω	W=59.68 L= 4444.38	TL15E = TL19E= 117 Ω	W=33.47 L= 4599.08
TL7E = TL27E = 191.5 Ω	W=15.46 L=4554.95	TL15O = TL19O=109.4 Ω	W=40.24 L= 4582.87
TL7O = TL27O = 90 Ω	W=59.68 L= 4444.38	TL16E = 181.6 Ω	W=15.46 L=4554.95
TL8E = TL24E= 122.4 Ω	W=29.83 L= 4608.58	TL16O = 99.8 Ω	W=49.54 L= 4562.81
TL8O= TL24O = 108.7 Ω	W=40.24 4582.87		