

RF Laboratory Manual - Passive Filter Design.

H. Matzner, S. Levy, H. Moalem and D. Ackerman.

December 2008.

CONTENTS

1	Background Theory	7
1.1	Group Delay	7
1.2	Passive Filters	7
1.3	Insertion Loss Method	7
1.4	Butterworth Filter Theory	8
1.5	Chebyshev Filter Theory	10
1.5.1	Chebyshev LPF Implementation	12
1.6	Elliptic Filter Theory	14
1.7	Low Pass Filter Design	16
1.7.1	Impedance and Frequency Scaling	16
1.8	High Pass Filter Transformation	16
1.8.1	Example	16
1.8.2	Solution	17
1.9	Band Pass Filter Transformation	18
1.9.1	Impedance and Frequency Scaling	18
2	Experiment Procedure	21
2.1	Required Equipment	21
2.2	Chebyshev 3dB equal ripple LPF Design	21
2.2.1	Simulation	21
2.2.2	Measurement	22
2.3	Butterworth BPF Design	22
2.3.1	Simulation	23
2.3.2	Measurement	25
2.4	Elliptic LPF Design	25
2.4.1	Simulation	25
2.4.2	Measurement	27
2.5	Final Report	27

PRELAB EXERCISE

1. Using Matlab, draw a graph of PLR as a function of the normalized frequency of a Chebyshev LPF, $3dB$ equal ripple, $N = 1, 3, 5, 7$ (see Figure 3).
2. Compare Butterworth and Chebyshev LPF with $1dB$ equal ripple, $N = 3$, $f_c = 1GHz$, $Z_{in} = Z_{out} = 50\Omega$:
 1. Calculate the elements values.
 2. Calculate the transfer function of each filter.
 3. Draw the graph of the transfer function of each filter (only magnitude) up to $2GHz$.
 4. Calculate the stopband attenuation (dB/octave) of each filter.

1. BACKGROUND THEORY

A filter is a two port network used to control the frequency response at a certain point in a system by providing transmission within the passband of the filter and attenuation in the stopband of the filter. The basic filter types are low-pass, high-pass, bandpass and band-reject (notch) filters.

1.1 Group Delay

The group delay is the derivative of the transmission phase with respect to the angular frequency and it is a measure of the distortion in the signal introduced by phase differences for different frequencies. It is defined as:

$$\tau_g(\omega) = -\frac{d\phi}{d\omega}$$

Where ϕ is the transmission phase in radians and ω is the angular frequency in radians per second. From this definition, we can conclude that a linear phase (in respect to frequency) is represented by a constant group delay. The group delay is the slope of the graph of S_{21} (phase) as a function of frequency.

1.2 Passive Filters

A passive filter is one which can be made of inductors and capacitors. In the Butterworth and Chebyshev cases, the total number of capacitors and inductors is equal to the highest power of frequency in the frequency polynomial, and gives us the order of the filter. In the Elliptic filter case, the number of capacitors indicates the order of the filter. The lumped elements values have been computed and tabulated for each filter type for the normalized frequency $\omega_c = 1 \frac{\text{rad}}{\text{sec}}$ and source and load impedances of $Z_{in} = Z_{Load} = 1\Omega$.

1.3 Insertion Loss Method

Ideal filter would have no insertion loss and a linear phase response in the passband, an infinite attenuation in the stopband and matched at the input and

output. It is impossible to practically built such a filter, therefore compromises must be made. Design by insertion loss method, allows a high degree of control over the filter width, stopband slope and phase characteristic. Depend on the application, the necessary trade off design can be evaluated.

The filter response is defined by the Power Loss Ratio (PLR) method:

$$PLR(\omega) = \frac{\text{Power available from source}}{\text{Power delivered to load}} = \frac{P_{inc}}{P_{Trns.}} = \frac{1}{1 - |\Gamma(\omega)|^2} \quad (1.1)$$

Where $\Gamma(\omega)$ is the reflection coefficient looking into the input of the filter network. Pay attention that the PLR can be described as $1/|S_{12}|^2$, under the assumption that the filter input and output are matched. If $|\Gamma(\omega)|^2$ is an even function of ω , it can be expressed as:

$$|\Gamma(\omega)|^2 = \frac{M(\omega^2)}{M(\omega^2) + N(\omega^2)} \quad (1.2)$$

Where M and N are real polynomials of the order 2. Substituted equation (1.2) in equation (1.1) yields:

$$PLR = 1 + \frac{M(\omega^2)}{N(\omega^2)} \quad (1.3)$$

1.4 Butterworth Filter Theory

Another name of the Butterworth Filter is 'maximally flat magnitude' filter. Butterworth has a maximally flat (has no ripples) filter response. Butterworth filter transfer function contains only poles. The Butterworth filter has a more linear phase response in the passband than the Chebyshev and Elliptic filters.

The PLR of the low pass filter is specified by:

$$PLR = 1 + k^2 \left(\frac{\omega}{\omega_c} \right)^{2N} \quad (1.4)$$

Where N is the order of the filter.

ω_c - The cutoff frequency of the filter.

At frequency $\omega = \omega_c$, which is at the edge of the passband, the PLR is equal to $1 + k^2$. If $k = 1$, this point is the '-3dB point'. Figure 1 shows the PLR of a Butterworth LPF as a function of the normalized frequency for different orders.

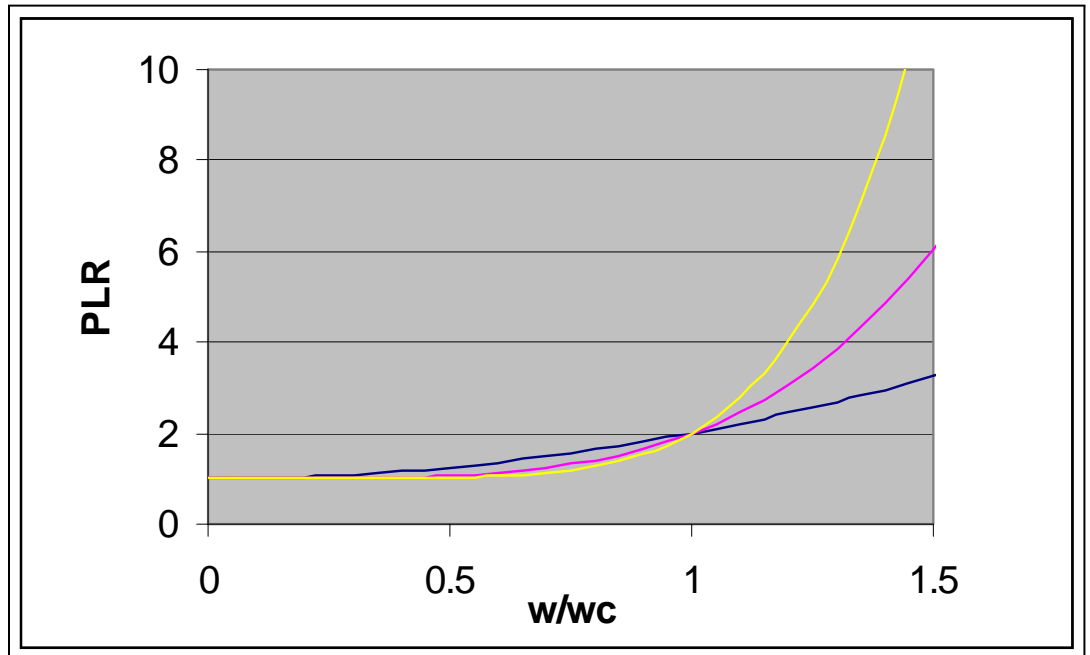


Figure 1 - Butterworth PLR. Blue line - Order N=1. Pink line - Order N=2. Yellow line - Order N=3.

It can be seen from Figure 1 that for higher orders, the attenuation outside the passband is higher, which means that the filter frequency response is sharper.

The attenuation outside of the passband is increasing monotonically with frequency for $\omega > \omega_c$. The rate of the increasing of the insertion loss outside the passband is $20N \text{ dB/decade}$.

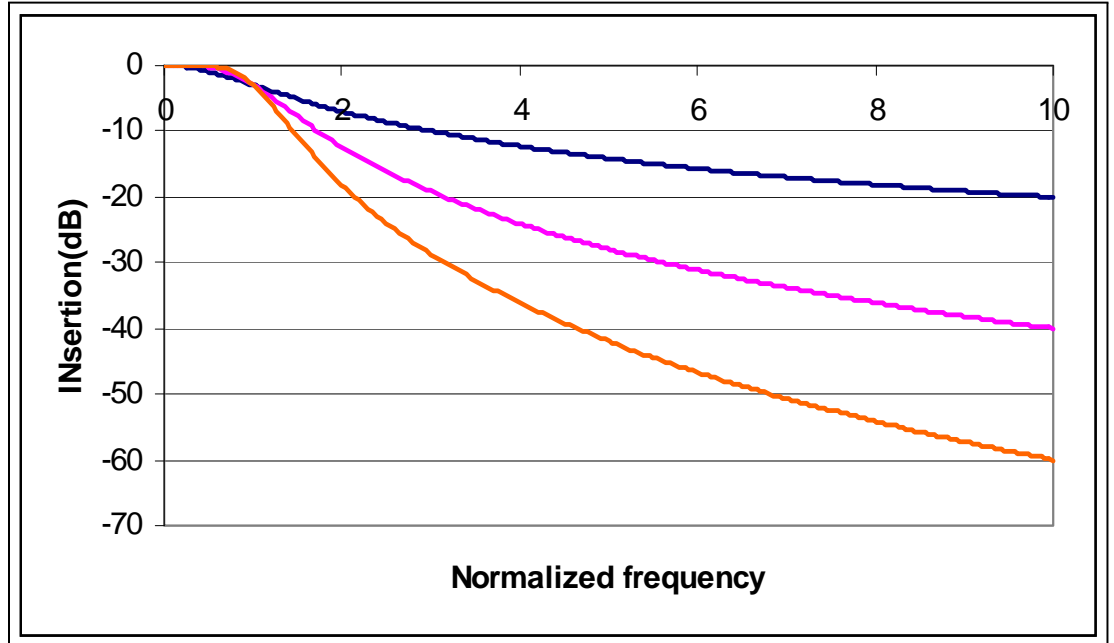


Figure 2 - Butterworth low pass filter, theoretical response for N=1 (upper blue line), N=2 (middle pink line), N=3 (lower red line).

Table 1 contains the elements values for Butterworth LPF for different

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8
1	2.0000	1.0000						
2	1.4142	1.4142	1.0000					
3	1.0000	2.0000	1.0000	1.0000				
4	0.7654	1.8478	1.8478	0.7654	1.0000			
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000		
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000	
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000

orders:

Table-1: Elements values for Butterworth LPF.

1.5 Chebyshev Filter Theory

Chebyshev filters have a narrower transition region between the passband and the stopband and more passband ripple (type I) or stopband ripple (type II) than the Butterworth filters.

Chebyshev poles can be derived by moving the poles of the normalized Butterworth low-pass transfer function to the right, by multiplying the real parts of the poles positions by a constant Kr and the imaginary parts by a constant Kj , where both K 's are smaller than 1. The poles would lie on an

ellipse of the unit circle. That means that like Butterworth filters, Chebyshev filters contain only poles. However, while the poles of the Butterworth filter lie on a circle in the s-plane, those of the Chebyshev filter lie on an ellipse. The Chebyshev phase response exhibits more linearity than the Elliptic one and less linearity than the Butterworth one. The insertion loss of an N order Chebyshev LPF is:

$$PLR = 1 + k^2 T_N^2 \left(\frac{\omega}{\omega_c} \right) \quad (1.5)$$

Where

$$T_N(x) = x^N - \left(\frac{N}{2} \right) x^{N-2} (1 - x^2) + \left(\frac{N}{4} \right) x^{N-4} (1 - x^2)^2 - \dots \quad (1.6)$$

$T_N(x)$ is the N^{th} order Chebyshev polynomial where $x = \omega/\omega_c$. Chebyshev polynomials result in a sharp slope of the filter response outside of the passband and a ripple of $1+k^2$ of the amplitude. The polynomial $T_N(x)$ is oscillating between ± 1 for $|x| \leq 1$ (the passband region). The amplitude of the ripple is determined by k^2 . Like in the case of the Butterworth filter, the response for the PLR is increasing by at least 20NdB/decade. Figure 3 shows the insertion loss of a Chebyshev 3dB ripple LPF for different orders:

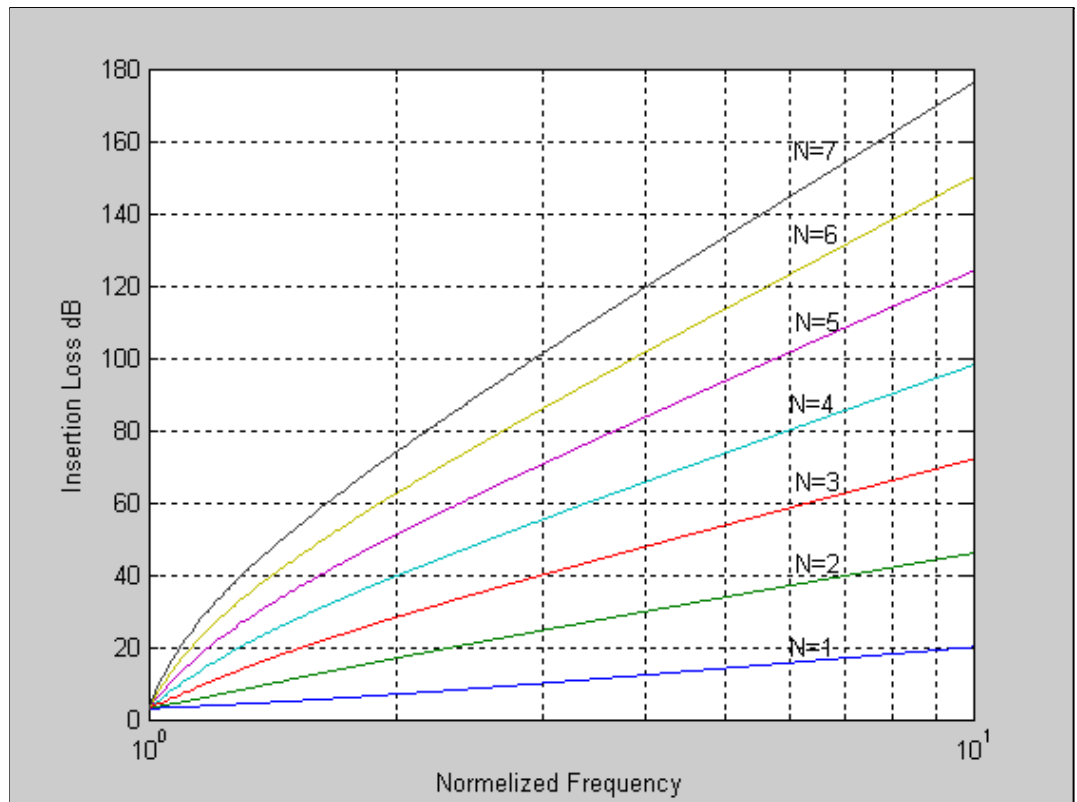


Figure 3 - Chebyshev Low Pass Filter response for 3 dB ripple, orders 1 to 7.

Figure 4 shows the PLR of Chebyshev and Butterworth filters for N=3:

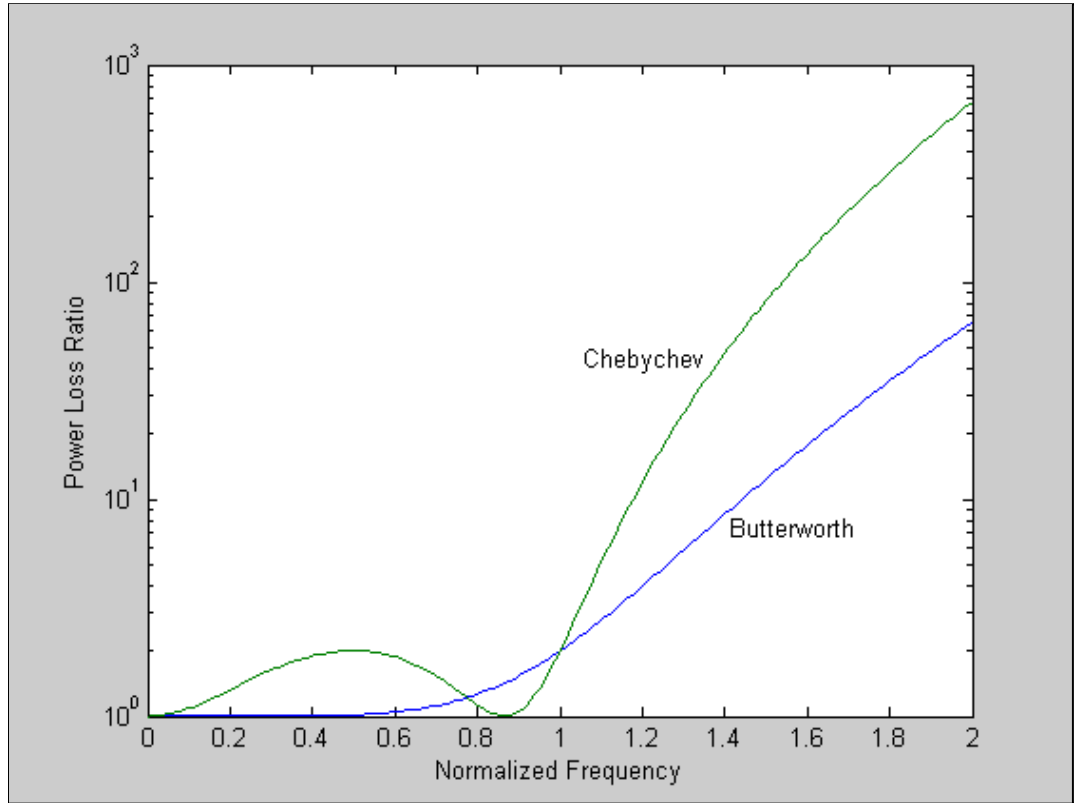


Figure 4 - Butterworth and Chebyshev PLR for $N=3$.

1.5.1 Chebyshev LPF Implementation

For a Chebyshev LPF with a normalized cutoff frequency $\omega_c = 1$ and a normalized unity source impedance, we will derive the normalized elements values of the inductor, L , and capacitor, C . Figure 4 shows the structure of a second order ($N = 2$) Chebyshev LPF.

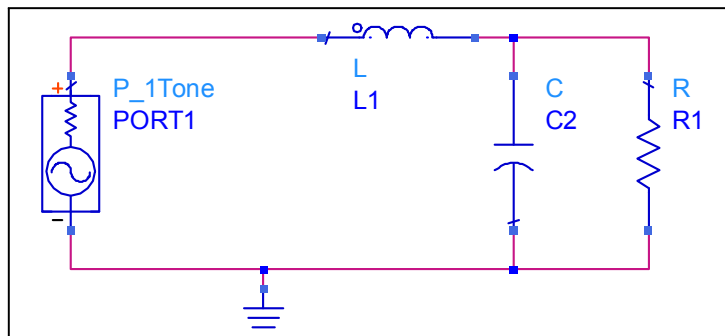


Figure 4 - Low pass filter structure for $N=2$.

The PLR is:

$$PLR = 1 + k^2 T_N^2(\omega) = \frac{1}{1 - |\Gamma(\omega)|^2} \quad (1.7)$$

In order to find $\Gamma(\omega)$, we have to calculate Z_{in} (see Figure 4):

$$Z_{in} = R \parallel \frac{1}{j\omega C} + j\omega L = \frac{R \frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} + j\omega L = j\omega L + \frac{R(1 - jR\omega C)}{1 + \omega^2 R^2 C^2}$$

Where

$$\Gamma(\omega) = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (1.8)$$

By inserting equation (1.8) in equation (1.7), the PLR becomes:

$$PLR = \frac{1}{1 - \left| \frac{Z_{in}-1}{Z_{in}+1} \right|^2} = \frac{1}{1 - \left(\frac{Z_{in}-1}{Z_{in}+1} \right) \left(\frac{Z_{in}^*-1}{Z_{in}^*+1} \right)} = \frac{|Z_{in} + 1|^2}{2(Z_{in} + Z_{in}^*)} \quad (1.9)$$

Taking the real and imaginary parts of equation (1.9), we get:

$$\begin{aligned} Z_{in} + Z_{in}^* &= \frac{2R}{1 + \omega^2 R^2 C^2} \\ |Z_{in} + 1|^2 &= \left(\frac{R}{1 + \omega^2 R^2 C^2} + 1 \right)^2 + \left(\omega L - \frac{\omega R^2 C}{1 + \omega^2 R^2 C^2} \right)^2 \end{aligned} \quad (1.10)$$

Therefore:

$$PLR = 1 + \frac{1}{4R} [(1 - R)^2 + \omega^2 (R^2 C^2 + L^2 - 2LCR^2) + L^2 R^2 C^2 \omega^4] \quad (1.11)$$

By recalling that the second order of a chebyshev polynom is $T_2(x) = 2x^2 - 1$, we get:

$$PLR = 1 + k^2 T_2^2(\omega) = 1 + k^2 (4\omega^4 - 4\omega^2 + 1) \quad (1.12)$$

By equating (1.11) and (1.12) we get:

$$1 + k^2 (4\omega^4 - 4\omega^2 + 1) = 1 + \frac{1}{4R} [(1 - R)^2 + \omega^2 (R^2 C^2 + L^2 - 2LCR^2) + L^2 R^2 C^2 \omega^4] \quad (1.13)$$

If the ripple is known, one can solve the equation at $\omega = 0$ for R and get:

$$R = 2k^2 + 1 + 2k\sqrt{(k^2 + k)} \quad (1.14)$$

Equating the coefficients of ω^4 and ω^2 yield:

$$\begin{aligned}
4k^2 &= \frac{1}{4R}L^2C^2R^2 \\
-4k^2 &= \frac{1}{4R}(C^2R^2 + L^2 - 2LCR^2)
\end{aligned}
\tag{1.15}$$

One can use the equations to obtain the values of the capacitor and inductor of the second order Chebyshev LPF. Thus constructing the famous table of Matthaei, Young and Jones for Chebychev 3dB ripple in the passband. The normalized elements values are given in Table-2:

N	g ₁	g ₂	g ₃	g ₄	g ₅	g ₆	g ₇	g ₈
1	1.9953	1.00						
2	3.1013	0.5339	5.8095					
3	3.3487	0.7117	3.3487	1				
4	3.4389	0.7483	4.3471	0.5920	5.8095			
5	3.4817	0.7618	4.5381	0.7618	3.4817	1		
6	3.5045	0.7685	4.6061	0.7929	4.4641	0.6033	5.8095	
7	3.5182	0.7723	4.6386	0.8039	4.6386	0.7723	3.5182	1

Table-2: Elements values for 3dB equal ripple Chebychev LPF.

1.6 Elliptic Filter Theory

Another name for the Elliptic Filter is 'Cauer' filter. Compared with Butterworth and Chebyshev filters, Elliptic filters have the most rapid transition (narrow transition band). However, this does not come without a price. Elliptic filters have a ripple in both the passband and stopband. This is the result of a pole-zero configuration which consists of both poles and zeros. An Elliptic filter is notorious for introducing large phase distortions, especially near the edge of the pass-band where the sharp amplitude characteristic implies a strongly non-linear phase characteristic.

The PLR of the low pass filter is specified by:

$$PLR = 1 + k^2 Z_n^2 \left(\frac{\omega}{\omega_c} \right)^{2N}
\tag{1.16}$$

Where $Z_n(x)$ is the N^{th} order Elliptic function.

For an odd order, $m = (N - 1)/2$ and $Z_n(x)$ is:

$$Z_n(x) = \frac{x(a_2^2 - x^2)(a_4^2 - x^2) \cdots (a_m^2 - x^2)}{(1 - a_2^2 x^2)(1 - a_4^2 x^2) \cdots (1 - a_m^2 x^2)}$$

For an even order, $m = N/2$ and $Z_n(x)$ is:

$$Z_n(x) = \frac{(a_2^2 - x^2)(a_4^2 - x^2) \cdots (a_m^2 - x^2)}{(1 - a_2^2 x^2)(1 - a_4^2 x^2) \cdots (1 - a_m^2 x^2)}$$

The zeros of Z_n are a_2, a_4, \dots, a_m whereas the poles are $\frac{1}{a_2}, \frac{1}{a_4}, \dots, \frac{1}{a_m}$. The reciprocal relationship between poles and zeros of Z_n results in equiripple behavior in both the stopband and the passband.

Elliptic function filters have been extensively tabulated by Saal and Zverev. A sample section table is presented in Table 3.

θ	A_{\min}	$C_1 = C_3$	C_2	L_2
25	31.47	1.0933	0.1345	1.0199
26	30.41	1.0855	0.1466	1.009
27	29.39	1.0773	0.1593	0.9976
28	28.41	1.0689	0.1728	0.9859
29	27.45	1.0602	0.1869	0.9738
30	26.53	1.0512	0.2019	0.9612

Table-3: Section table for elements values for an Elliptic LPF.

Where θ is calculated by:

$$\theta = \sin^{-1} \left(\frac{\omega_c}{\omega} \right)$$

and A_{\min} is the minimum stopband attenuation (see Figure 5).

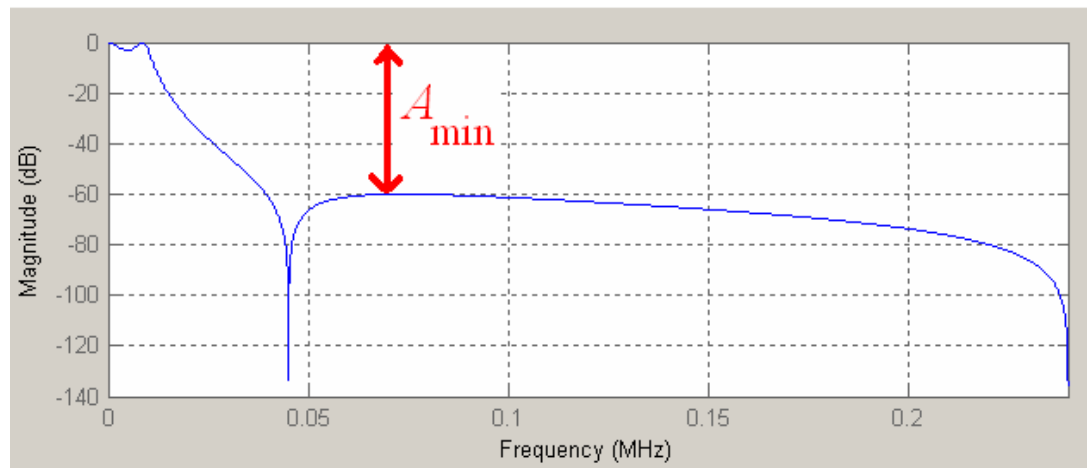


Figure 5 - Magnitude response of a third order Elliptic LPF.

A prototype of a third order Elliptic LPF is shown in Figure 6.

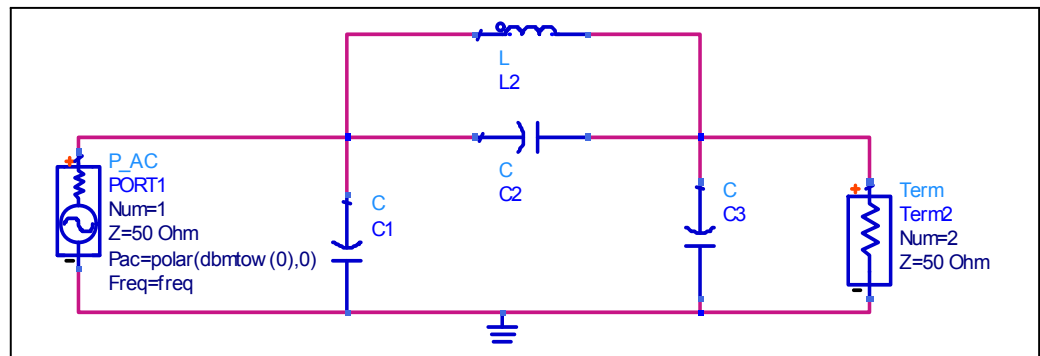


Figure 6 - A prototype of a third order Elliptic LPF.

1.7 Low Pass Filter Design

We will begin with a design of a low pass filter and then transform the design to another type of filter. We will use the elements from the table of each filter type.

1.7.1 Impedance and Frequency Scaling

As indicated before, the elements from the tables of the LPF are normalized by frequency and impedance. For different frequency and impedance, elements can be obtained by impedance and frequency transformation:

$$\begin{aligned} L'_k &= \frac{L_k Z_0}{\omega_c} \\ C'_k &= \frac{C_k}{Z_0 \omega_c} \end{aligned} \quad (1.17)$$

Where L_k and C_k are the relevant normalized elements values from the tables.

1.8 High Pass Filter Transformation

We can design a HPF by first designing a LPF (see Figure 7) then replacing the capacitors by inductors and the inductors by capacitors (see Figure 8).

By scaling the elements from the tables by equation (1.17), we can find the capacitor and inductor values.

1.8.1 Example

Design a HPF, type Chebychev 3 dB equal ripple, with a cutoff frequency of 100 MHz, input and output impedance of 50Ω , and at least 25 dB insertion loss at 50MHz. Calculate the values of the elements and plot the frequency response of the filter at 300 MHz.

1.8.2 Solution

According to Figure 5, we have to choose $N=3$. The structure of a LPF Chebychev 3 dB equal ripple is shown in Figure 7.

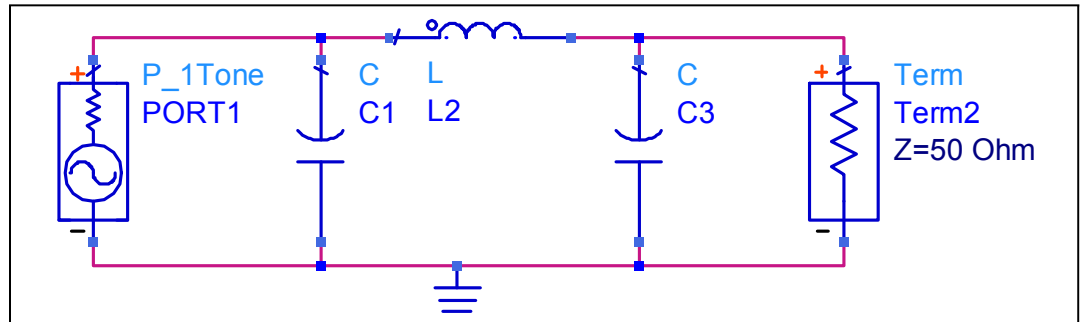


Figure 7 - A prototype of a Chebychev LPF 3 dB equal ripple response with $N=3$.

By replacing the capacitors by inductors and the inductors by capacitors we can get the structure of a HPF, as shown in Figure 8.

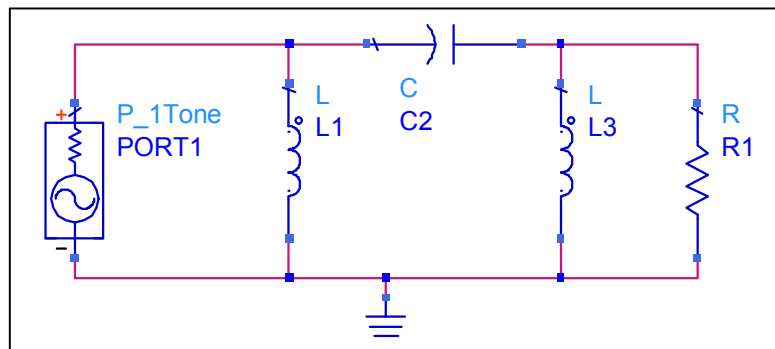


Figure 8 - High Pass Filter prototype.

Table-2 gives the prototype elements values as:

- $g_1 = 3.3487$
- $g_2 = 0.7117$
- $g_3 = 3.3487$
- $g_4 = 1$

Using equation (1.16), the elements values of the prototype are:

$$\begin{aligned}
 C'_1 &= C'_3 = \frac{g_1}{Z_0 \omega_c} = \frac{3.3487}{50 * 2\pi * 10^8} = 1.066 \times 10^{-10} & (1.18) \\
 L'_2 &= \frac{g_2 Z_0}{\omega_c} = \frac{0.7117 * 50}{2\pi * 10^8} = 5.664 \times 10^{-8} \\
 R_{out} &= R_4 = g_4 Z_0 = 1 * 50 = 50\Omega
 \end{aligned}$$

The frequency response of the filter using ADS is shown on Figure 9.

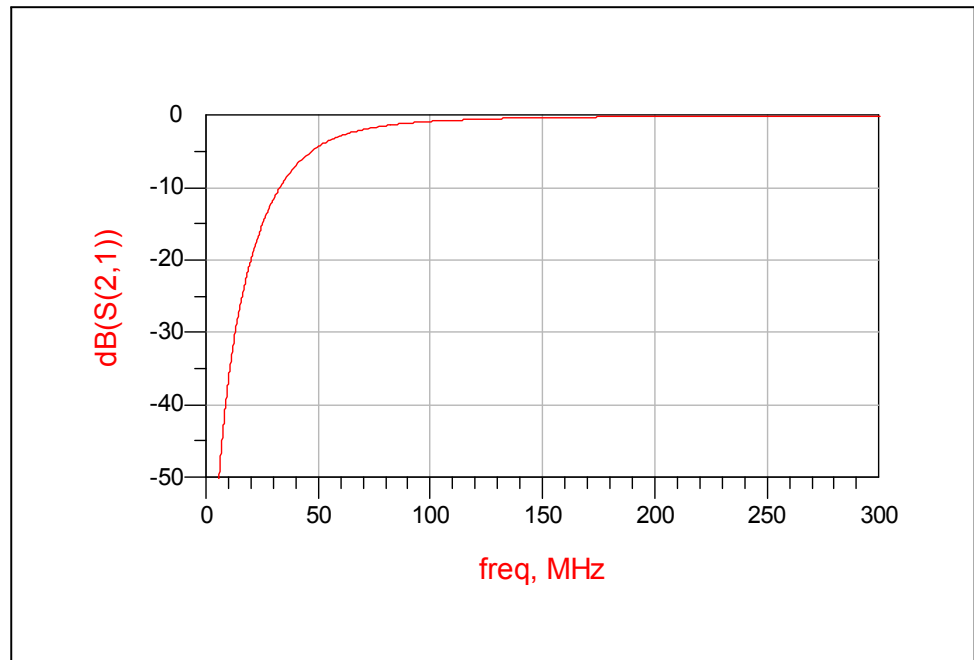


Figure 9 - HPF Chebyshev 3 dB equal ripple response.

1.9 Band Pass Filter Transformation

In similar of designing a LPF, we can design a Band Pass Filter.

1.9.1 Impedance and Frequency Scaling

The parallel components values are:

$$\begin{aligned} L'_k &= \frac{\Delta Z_0}{\omega_0 C_k} \\ C'_k &= \frac{C_k}{\omega_0 \Delta Z_0} \end{aligned} \quad (1.19)$$

The series components values are:

$$\begin{aligned} L'_k &= \frac{L_k Z_0}{\omega_0 \Delta} \\ C'_k &= \frac{\Delta}{\omega_0 L_k Z_0} \end{aligned} \quad (1.20)$$

Where C_k and L_k are the elements values taken from Table-1.

Δ is the desired bandwidth of the filter, it is measured in % and it is calculated by:

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_0} \quad (1.21)$$

Where ω_2 and ω_1 are the '-3dB points' of the filter. The prototype of a BPF for N=3 is shown in Figure 10.

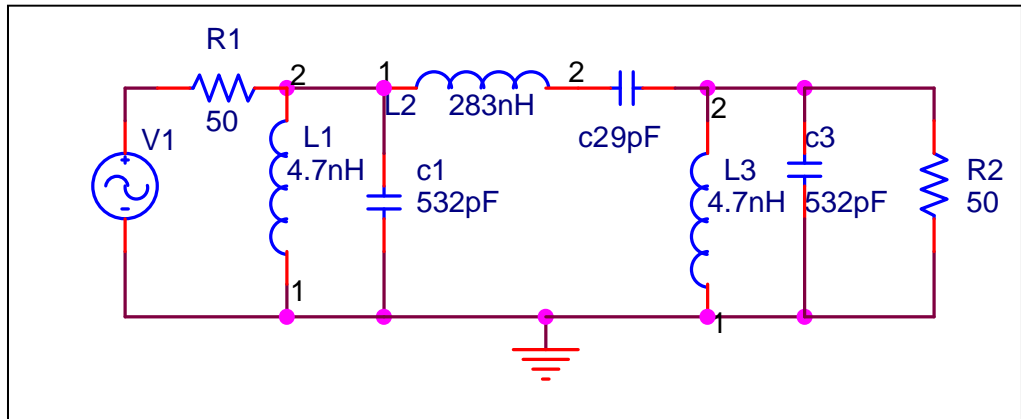


Figure 10 - Band Pass Filter prototype for N=3. $\omega_0 = 100MHz$, $\Delta = 20\%$.

The frequency response using a simulation software is shown in Figure 11.

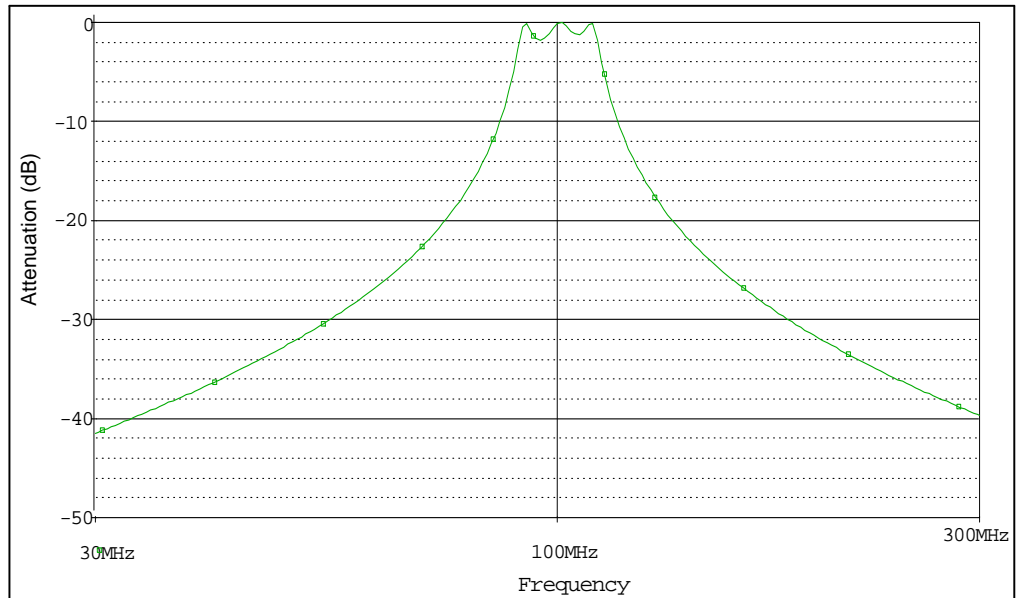


Figure 11 - The frequency response of the BPF prototype for N=3, $\omega_0 = 100MHz$, $\Delta = 20\%$.

2. EXPERIMENT PROCEDURE

2.1 Required Equipment

1. Network analyzer *HP – 8714B*.
2. High quality 50Ω coaxial cable.
3. Microstrip Chebyshev 3dB equal ripple LPF, $f_c = 100MHz$, order $N=3$.
4. Microstrip Butterworth BPF, $f_0 = 10MHz$, order $N=3$.
5. Microstrip Elliptic LPF, $f_c = 1.9MHz$, order $N=3$.
6. Mini-Circuits Elliptic LPF, $f_c = 1.9MHz$, order $N=3$.
7. Simulation software ADS.

2.2 Chebyshev 3dB equal ripple LPF Design

1. Design a Chebyshev 3dB equal ripple LPF, $f_c = 5.66 MHz$ and $N = 3$. Calculate the values of the capacitors and inductors using the proper table, assume that $Z_{in} = Z_{Load} = 50\Omega$.

2.2.1 Simulation

2. Verify your design by simulation using ADS software, as shown in Figure 1.

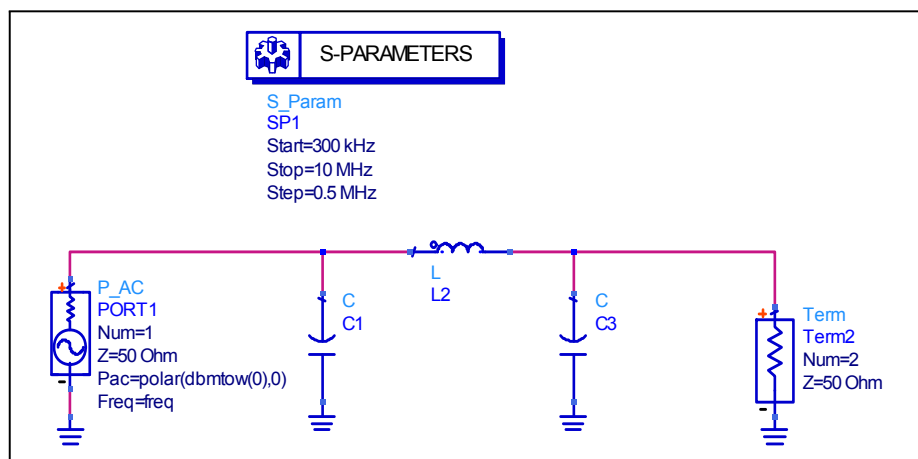


Figure 1 - Chebyshev 3dB equal ripple LPF for $N=3$ simulation.

Drew the graphs of S_{21} (Magnitude and phase), S_{11} (Magnitude only), S_{22} (Magnitude only) of the filter in the frequency range of 300 kHz - 10 MHz. **Save the data on magnetic media.**

3. Examine the effects of a real microstrip filter by adding microstrip transmission lines between the elements, add impedance to the inductors and use the nominal values of the capacitors and inductors, as shown in Figure 2.

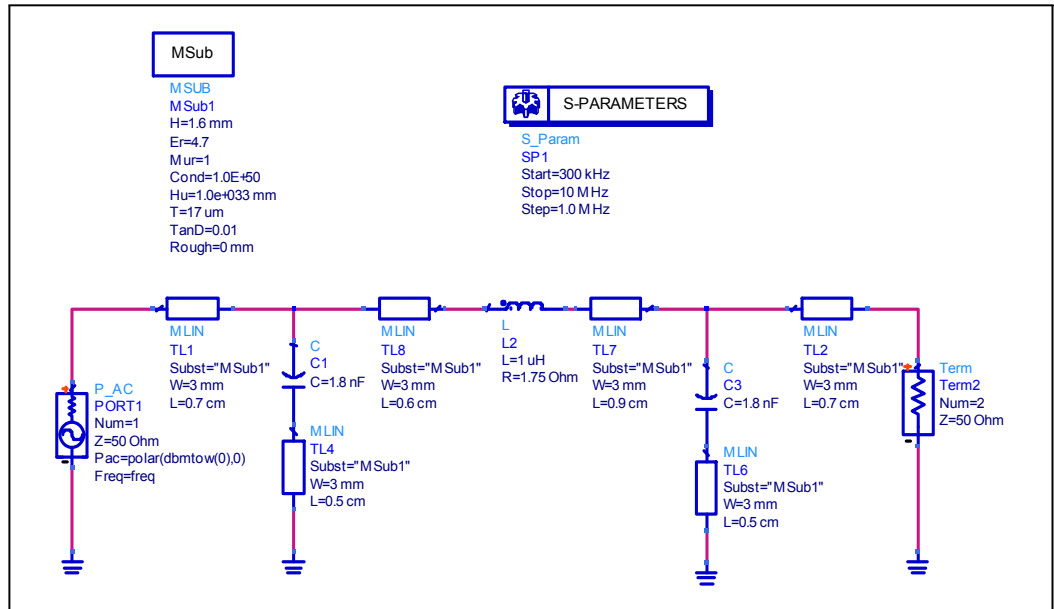


Figure 2 - A more realistic Chebyshev 3dB equal ripple LPF for N=3 simulation.

Drew the graphs of S_{21} (Magnitude and phase), S_{11} (Magnitude only), S_{22} (Magnitude only) of each element. **Save the data on magnetic media.**

2.2.2 Measurement

4. Set the network analyzer to transmission measurement, set the frequency range to 300kHz - 10MHz, connect a coaxial cable between port 1 and port 2 of the network analyzer and implement a transmission calibration.

5. Connect the microstrip Chebyshev LPF to the network analyzer with the coaxial cable and measure S_{21} (Magnitude and phase), S_{11} (Magnitude only), S_{22} (Magnitude only) of the filter. **Save the data on magnetic media.**

2.3 Butterworth BPF Design

1. Design a Butterworth (maximally flat) BPF, $f_0 = 24MHz$ and $N = 3$.

The bandwidth is 20%. Calculate the values of the capacitors and inductors, assume that $Z_{in} = Z_{Load} = 50\Omega$.

2.3.1 Simulation

2. Verify your design by simulation using ADS software, as shown in Figure 3.

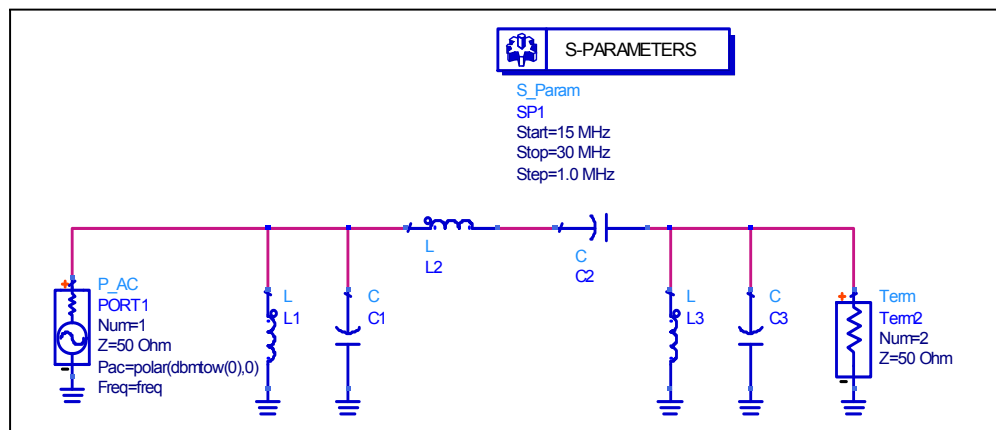


Figure 3 - Butterworth BPF for N=3 simulation.

Draw the graphs of S_{21} (Magnitude and phase), S_{11} (Magnitude only), S_{22} (Magnitude only) of the filter in the frequency range of 15 MHz - 30MHz. **Save the data on magnetic media.**

3. Examine the effects of a real microstrip filter by adding microstrip transmission lines between the elements, add impedance to the inductors and use the nominal values of the capacitors and inductors, as shown in Figure 4.

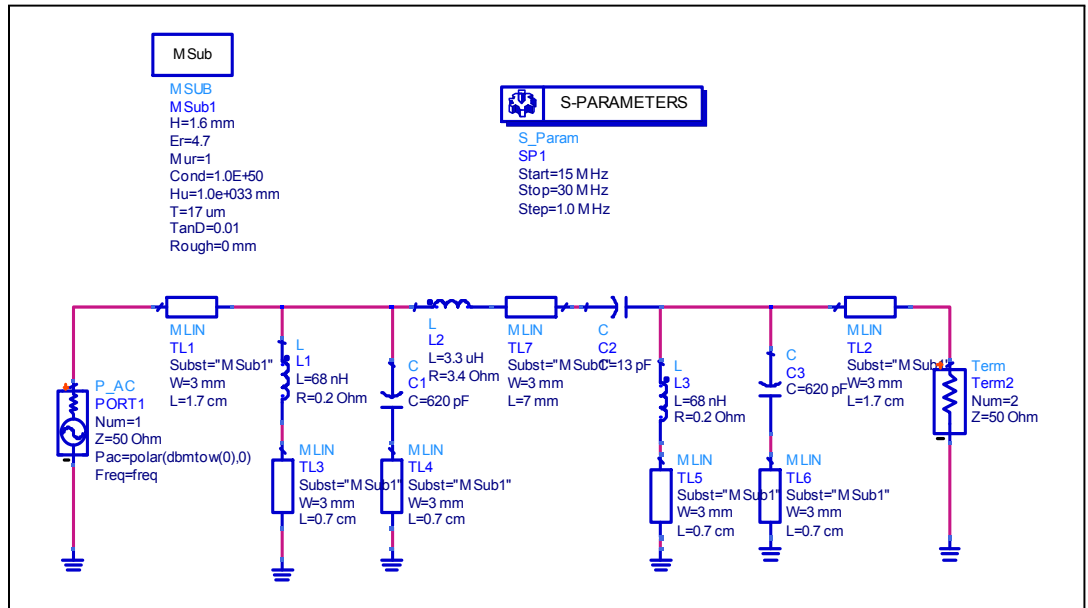


Figure 4 - A more realistic Butterworth BPF for N=3 simulation.

4. Draw the graph of the amplitude response (S_{21} magnitude) of the series LC and parallel LC separately and compare it to the amplitude response of all the elements connected together.

5. Simulate the system as indicated in Figure 5.

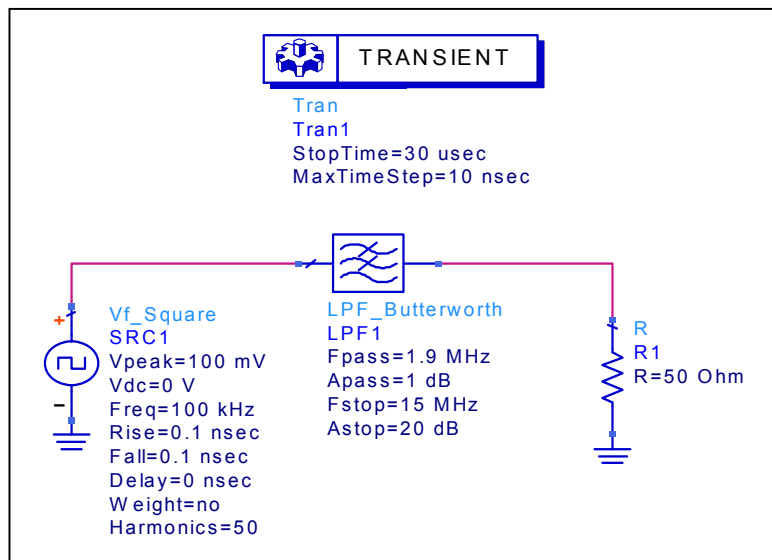


Figure 5 - Simulation of a square wave through a Butterworth LPF in the time domain.

Draw the graph of the current as a function of time.

2.3.2 Measurement

5. Connect the microstrip Butterworth BPF to the network analyzer with a coaxial cable and measure S_{21} (Magnitude and phase), S_{11} (Magnitude only), S_{22} (Magnitude only) of the filter in the frequency range to 15 MHz - 30 MHz. **Save the data on magnetic media.**

2.4 Elliptic LPF Design

1. Design an elliptic LPF, $f_0 = 1.9\text{MHz}$, $N = 3$ and at least 28 dB stopband attenuation at 4.5 MHz. Calculate the values of the capacitors and inductors, assume that $Z_{in} = Z_{Load} = 50\Omega$.

2.4.1 Simulation

2. Verify your design by simulation using ADS software, as shown in Figure 6.

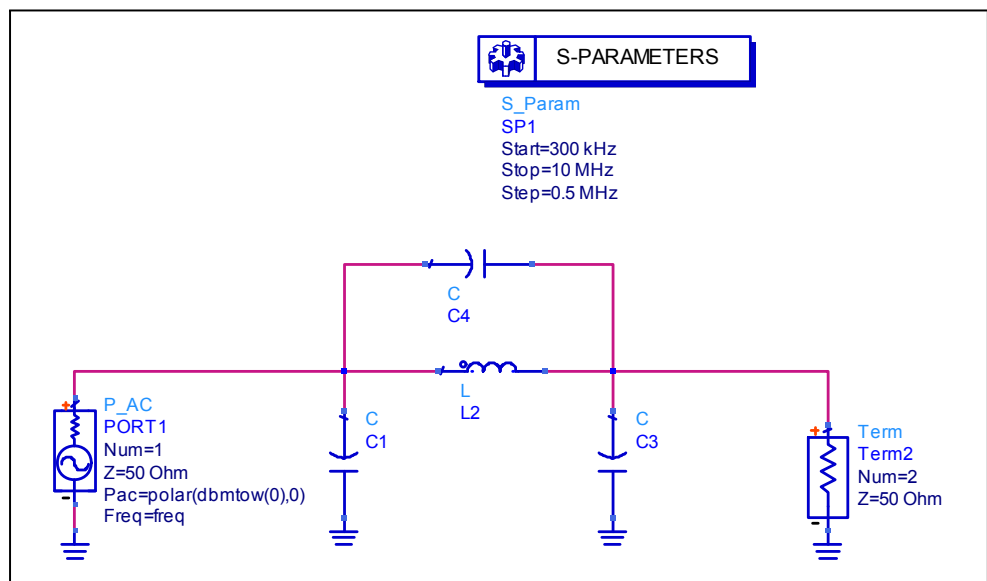


Figure 6 - Elliptic LPF for N=3 simulation.

Draw the graphs of S_{21} (Magnitude, and phase), S_{11} (Magnitude only), S_{22} (Magnitude only) of the filter in the frequency range of 300 kHz - 10 MHz. **Save the data on magnetic media.**

3. Examine the effects of a real microstrip filter by adding microstrip transmission lines between the elements, add impedance to the inductors and use

the nominal values of the capacitors and inductors, as shown in Figure 7.

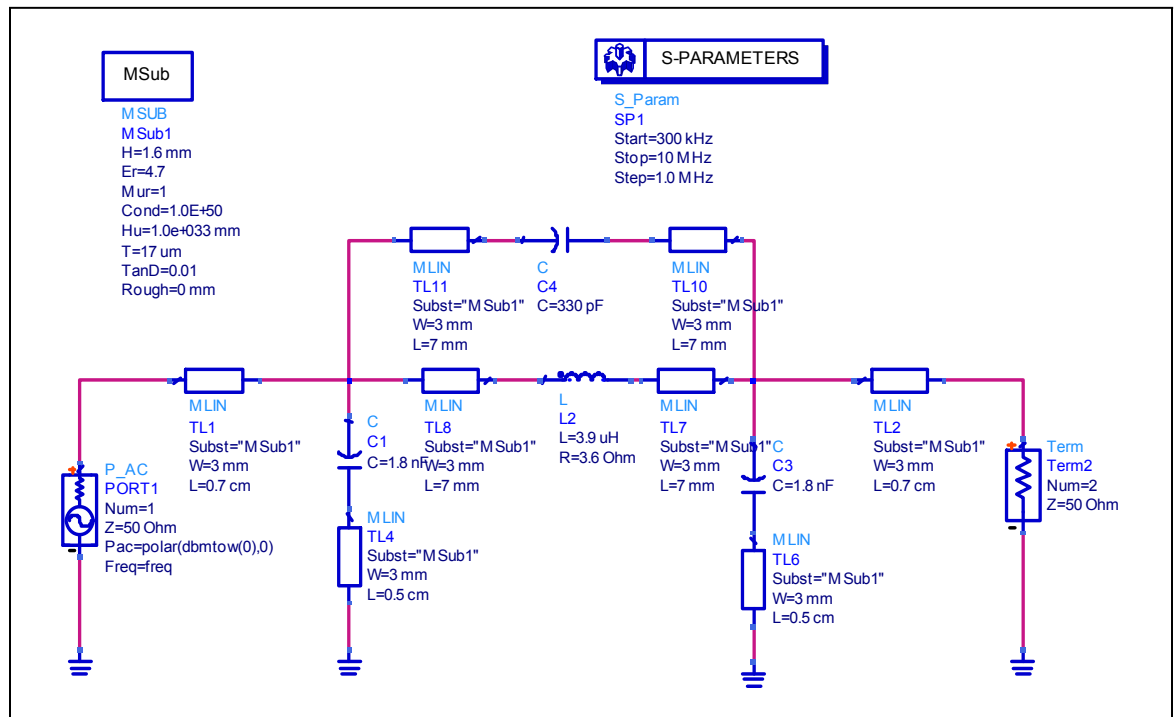


Figure 7 - A more realistic Elliptic LPF for N=3 simulation.

4. Simulate the system as indicated in Figure 8.

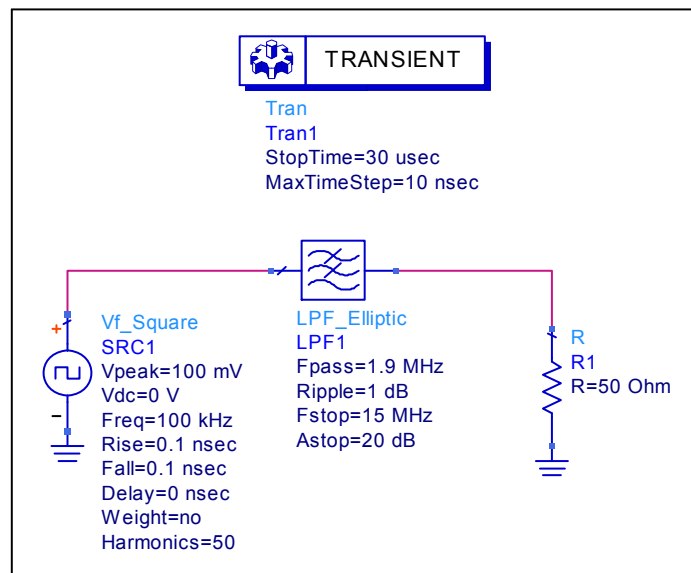


Figure 8 - Simulation of a square wave through an Elliptic LPF in the time domain.

Drew the graph of the current as a function of time. Compare this graph to the graph you received in paragraph 4 from the 'Butterworth BPF Design' section and explain why the wave is distorted.

2.4.2 Measurement

4. Connect the microstrip LPF-1.9MHz to the network analyzer with a coaxial cable and measure S_{21} (Magnitude and phase), S_{11} (Magnitude only), S_{22} (Magnitude only) of the filter in the frequency range to 300 kHz - 10 MHz.

Save the data on magnetic media.

5. Exchange the microstrip LPF with the coaxial LPF (Mini-Circuits BLP-1.9) and measure S_{21} (Magnitude and phase), S_{11} (Magnitude only), S_{22} (Magnitude only) of the filter. **Save the data on magnetic media.**

6. Compare the graphs from paragraph 5 to the graphs from paragraph 4.

2.5 Final Report

1. Compare your simulation results to your measurement results.

2. Using ADS, compare S_{21} (magnitude and phase), S_{11} and S_{22} (magnitude only) of a LPF Chebyshev 3dB equal ripple to a Butterworth and an Elliptic LPFs, order $N = 3$ and $f_0 = 100MHz$ (you can use the LPF_Elliptic, LPF_Butterworth and LPF_Chebyshev components) in the frequency range of 300KHz-300MHz.

3. Design a network which consists of three cascades RC LPF, f_0 is equal to 100MHz.

Draw the graphs of S_{21} , S_{11} and S_{22} (magnitude only).

Compare the graphs from this exercise to the graphs from paragraph 2 of 'Final Report'.

4. Using ADS, Draw the graphs of S_{21} (magnitude only) of a Butterworth LPF and HPF, $N = 3$ and $f_0 = 10MHz$ (you can use the LPF_Butterworth and HPF_Butterworth components).

What is the relationship between these graphs and the graph of S_{21} (Magnitude only) from the 'Butterworth BPF Design' section of 'Experiment Procedure'?

5. Draw conclusions from the 'Experiment Procedure' and 'Final Report'.