

# Lab8 Microstrip Filters

---

EERF – 6396

Prof. Dr. Randall E. Lehmann  
Dept. of Electrical Engineering  
The University of Texas at Dallas

**Submitted by: Omkar Kulkarni**

**Lab partner: Behnam Pouya**

**11/4/2017**

## 1. Introduction

### Objectives:

- Design a Chebyshev low pass filter for  $f_c = 3\text{GHz}$
- Design a Butterworth low pass filter for  $f_c = 3\text{GHz}$

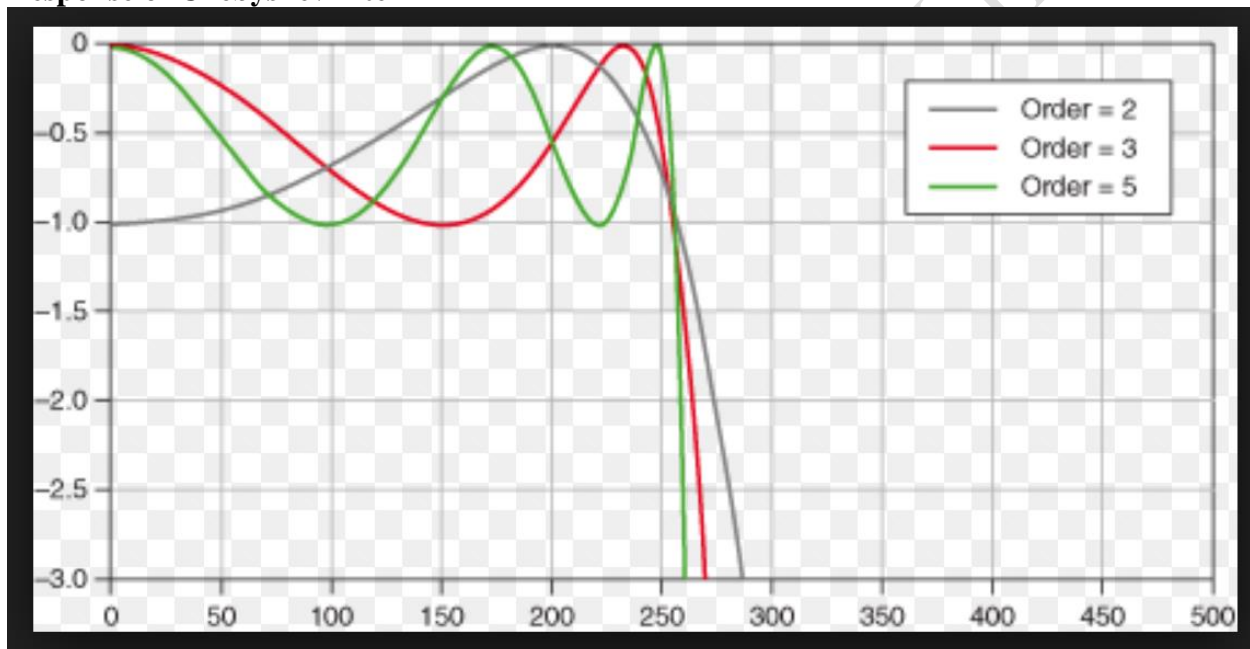
## 2. Significance

Microstrip filters are widely used to restrict certain frequencies and pass certain frequencies. They find application in broadcast radio, mobile communication. Filters are building blocks of various RF systems.

## 3. Design

### A. Chebyshev filter – Behnam Pouya

#### Response of Chebyshev filter



**Source:** National instruments

The Chebyshev filter response is characterized with ripples in the pass and stop band. The number of ripples is equal to the order of the prototype design. However, the Chebyshev filter has an advantage of faster roll off as compared to Butterworth filter prototypes of the same order.

Butterworth filters have flat curves both in pass and reject bands at the cost of gradual roll off than the Chebyshev design of same order. Usually a higher order design is required for achieving the required attenuation.

According to the design goal an attenuation of 40dB is expected at  $2f_c$  accordingly the order of filter  $n=5$  is chosen to meet the specifications

The design values are found by using equations:

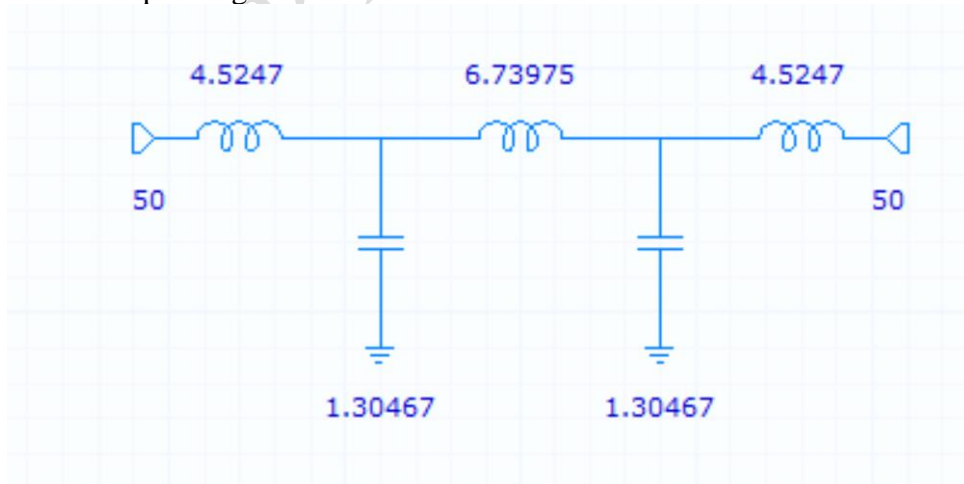
$$L_n = \frac{gn \times R}{2\pi \times fc} \quad C_n = \frac{gn}{2\pi \times fc \times R}$$

Where  $g_n$  is the value of the Chebyshev polynomial given in the table:

N	$g_1$	$g_2$	$g_3$	$g_4$	$g_5$	$g_6$	$g_7$	$g_8$	$g_9$	$g_{10}$	$g_{11}$
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	1.2583	2.6381	1.3444	2.6381	1.2583	1.7372	1.0000			
8	1.7451	1.2647	2.6564	1.3590	2.6964	1.3389	2.5093	0.8796	1.9841		
9	1.7504	1.2690	2.6678	1.3673	2.7939	1.3673	2.6678	1.2690	1.7504	1.0000	
10	1.7543	1.2721	2.6754	1.3725	2.7392	1.3806	2.7231	1.3485	2.5239	0.8842	1.9841

R for inductor is chosen as  $120\Omega$  and for capacitor is  $20\Omega$ . Fixing the R values the width of the microstrip elements were obtained from the transmission line tool in AWR. For calculating the lengths of the elements, the individual elements were tuned to get the desired reactance at the specified frequency. These lengths were used to construct the overall structure.

The corresponding values are:



Stackup Diagram:

Layer	Material	Thickness (mm)	Properties
1	FR4	0.127	FR4
2	FR4	0.127	FR4
3	FR4	0.127	FR4
4	FR4	0.127	FR4
5	FR4	0.127	FR4
6	FR4	0.127	FR4
7	FR4	0.127	FR4
8	FR4	0.127	FR4
9	FR4	0.127	FR4
10	FR4	0.127	FR4
11	FR4	0.127	FR4
12	FR4	0.127	FR4
13	FR4	0.127	FR4
14	FR4	0.127	FR4
15	FR4	0.127	FR4
16	FR4	0.127	FR4

3D Model Dimensions:

- Overall Length: 100.0 mm
- Overall Width: 100.0 mm
- Overall Thickness: 1.6 mm
- Internal Layer Thickness: 0.127 mm

Component Placement:

- PORT P1: 2x50 Ohm
- PORT P2: 2x50 Ohm
- Component 1: 100.0 mm x 100.0 mm
- Component 2: 100.0 mm x 100.0 mm
- Component 3: 100.0 mm x 100.0 mm
- Component 4: 100.0 mm x 100.0 mm
- Component 5: 100.0 mm x 100.0 mm
- Component 6: 100.0 mm x 100.0 mm
- Component 7: 100.0 mm x 100.0 mm
- Component 8: 100.0 mm x 100.0 mm
- Component 9: 100.0 mm x 100.0 mm
- Component 10: 100.0 mm x 100.0 mm
- Component 11: 100.0 mm x 100.0 mm
- Component 12: 100.0 mm x 100.0 mm
- Component 13: 100.0 mm x 100.0 mm
- Component 14: 100.0 mm x 100.0 mm
- Component 15: 100.0 mm x 100.0 mm
- Component 16: 100.0 mm x 100.0 mm
- Component 17: 100.0 mm x 100.0 mm
- Component 18: 100.0 mm x 100.0 mm
- Component 19: 100.0 mm x 100.0 mm
- Component 20: 100.0 mm x 100.0 mm
- Component 21: 100.0 mm x 100.0 mm
- Component 22: 100.0 mm x 100.0 mm
- Component 23: 100.0 mm x 100.0 mm
- Component 24: 100.0 mm x 100.0 mm
- Component 25: 100.0 mm x 100.0 mm
- Component 26: 100.0 mm x 100.0 mm
- Component 27: 100.0 mm x 100.0 mm
- Component 28: 100.0 mm x 100.0 mm
- Component 29: 100.0 mm x 100.0 mm
- Component 30: 100.0 mm x 100.0 mm
- Component 31: 100.0 mm x 100.0 mm
- Component 32: 100.0 mm x 100.0 mm
- Component 33: 100.0 mm x 100.0 mm
- Component 34: 100.0 mm x 100.0 mm
- Component 35: 100.0 mm x 100.0 mm
- Component 36: 100.0 mm x 100.0 mm
- Component 37: 100.0 mm x 100.0 mm
- Component 38: 100.0 mm x 100.0 mm
- Component 39: 100.0 mm x 100.0 mm
- Component 40: 100.0 mm x 100.0 mm
- Component 41: 100.0 mm x 100.0 mm
- Component 42: 100.0 mm x 100.0 mm
- Component 43: 100.0 mm x 100.0 mm
- Component 44: 100.0 mm x 100.0 mm
- Component 45: 100.0 mm x 100.0 mm
- Component 46: 100.0 mm x 100.0 mm
- Component 47: 100.0 mm x 100.0 mm
- Component 48: 100.0 mm x 100.0 mm
- Component 49: 100.0 mm x 100.0 mm
- Component 50: 100.0 mm x 100.0 mm
- Component 51: 100.0 mm x 100.0 mm
- Component 52: 100.0 mm x 100.0 mm
- Component 53: 100.0 mm x 100.0 mm
- Component 54: 100.0 mm x 100.0 mm
- Component 55: 100.0 mm x 100.0 mm
- Component 56: 100.0 mm x 100.0 mm
- Component 57: 100.0 mm x 100.0 mm
- Component 58: 100.0 mm x 100.0 mm
- Component 59: 100.0 mm x 100.0 mm
- Component 60: 100.0 mm x 100.0 mm
- Component 61: 100.0 mm x 100.0 mm
- Component 62: 100.0 mm x 100.0 mm
- Component 63: 100.0 mm x 100.0 mm
- Component 64: 100.0 mm x 100.0 mm
- Component 65: 100.0 mm x 100.0 mm
- Component 66: 100.0 mm x 100.0 mm
- Component 67: 100.0 mm x 100.0 mm
- Component 68: 100.0 mm x 100.0 mm
- Component 69: 100.0 mm x 100.0 mm
- Component 70: 100.0 mm x 100.0 mm
- Component 71: 100.0 mm x 100.0 mm
- Component 72: 100.0 mm x 100.0 mm
- Component 73: 100.0 mm x 100.0 mm
- Component 74: 100.0 mm x 100.0 mm
- Component 75: 100.0 mm x 100.0 mm
- Component 76: 100.0 mm x 100.0 mm
- Component 77: 100.0 mm x 100.0 mm
- Component 78: 100.0 mm x 100.0 mm
- Component 79: 100.0 mm x 100.0 mm
- Component 80: 100.0 mm x 100.0 mm
- Component 81: 100.0 mm x 100.0 mm
- Component 82: 100.0 mm x 100.0 mm
- Component 83: 100.0 mm x 100.0 mm
- Component 84: 100.0 mm x 100.0 mm
- Component 85: 100.0 mm x 100.0 mm
- Component 86: 100.0 mm x 100.0 mm
- Component 87: 100.0 mm x 100.0 mm
- Component 88: 100.0 mm x 100.0 mm
- Component 89: 100.0 mm x 100.0 mm
- Component 90: 100.0 mm x 100.0 mm
- Component 91: 100.0 mm x 100.0 mm
- Component 92: 100.0 mm x 100.0 mm
- Component 93: 100.0 mm x 100.0 mm
- Component 94: 100.0 mm x 100.0 mm
- Component 95: 100.0 mm x 100.0 mm
- Component 96: 100.0 mm x 100.0 mm
- Component 97: 100.0 mm x 100.0 mm
- Component 98: 100.0 mm x 100.0 mm
- Component 99: 100.0 mm x 100.0 mm
- Component 100: 100.0 mm x 100.0 mm

closed form

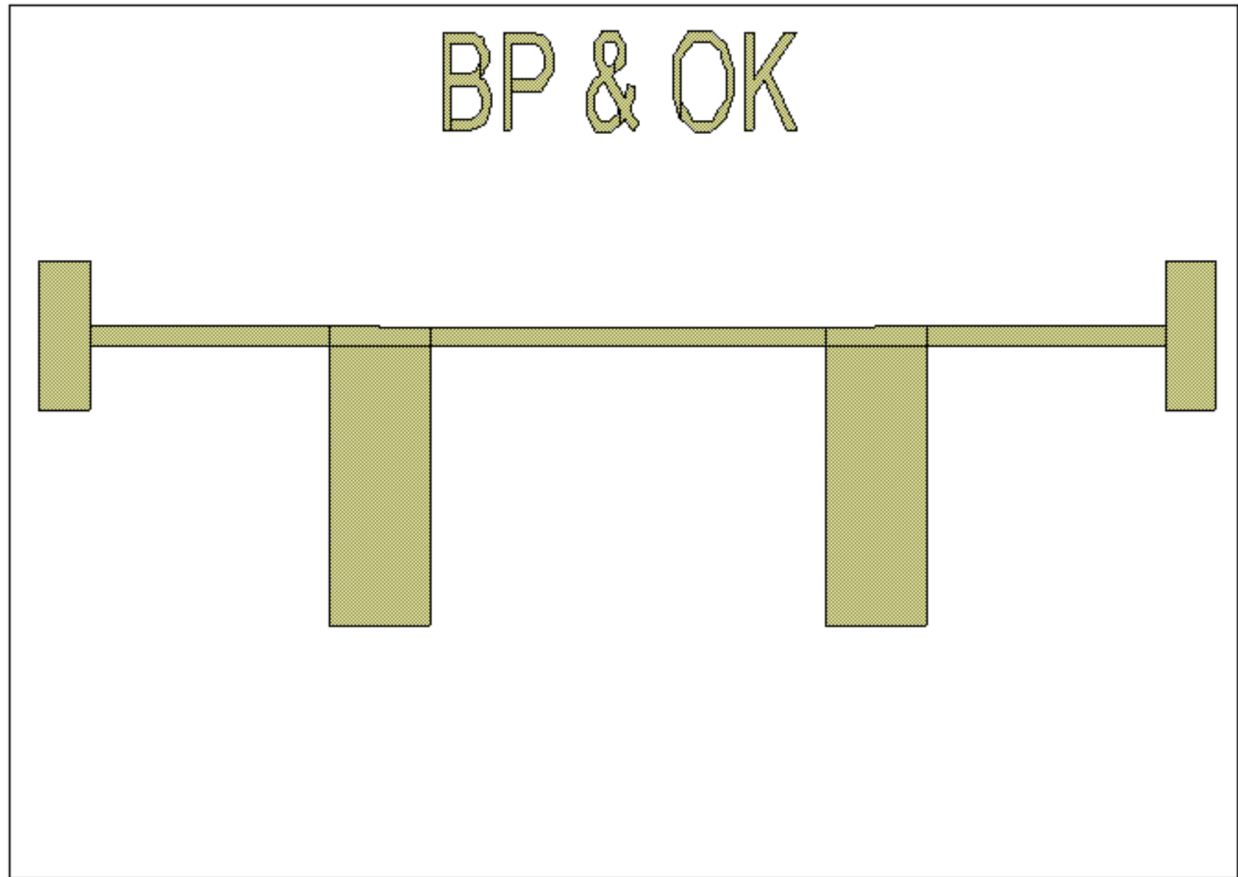
Legend:

- $\Delta$  DB(|S(1,1)|) chebychev
- $\square$  DB(|S(2,1)|) chebychev
- $\diamond$  DB(|S(2,2)|) chebychev

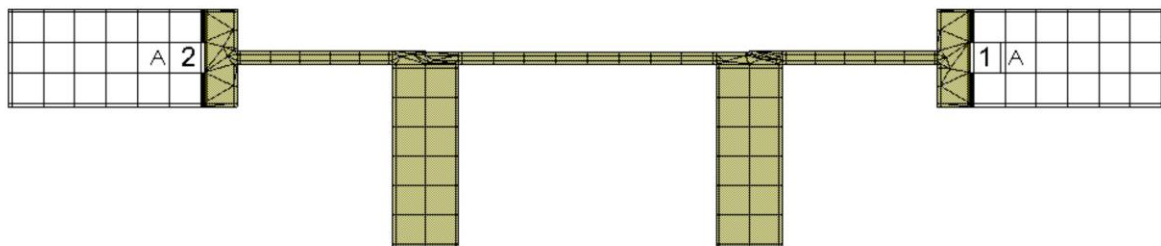
Annotations:

- m2: 3000 MHz -0.3916 dB
- m1: 6000 MHz -23 dB

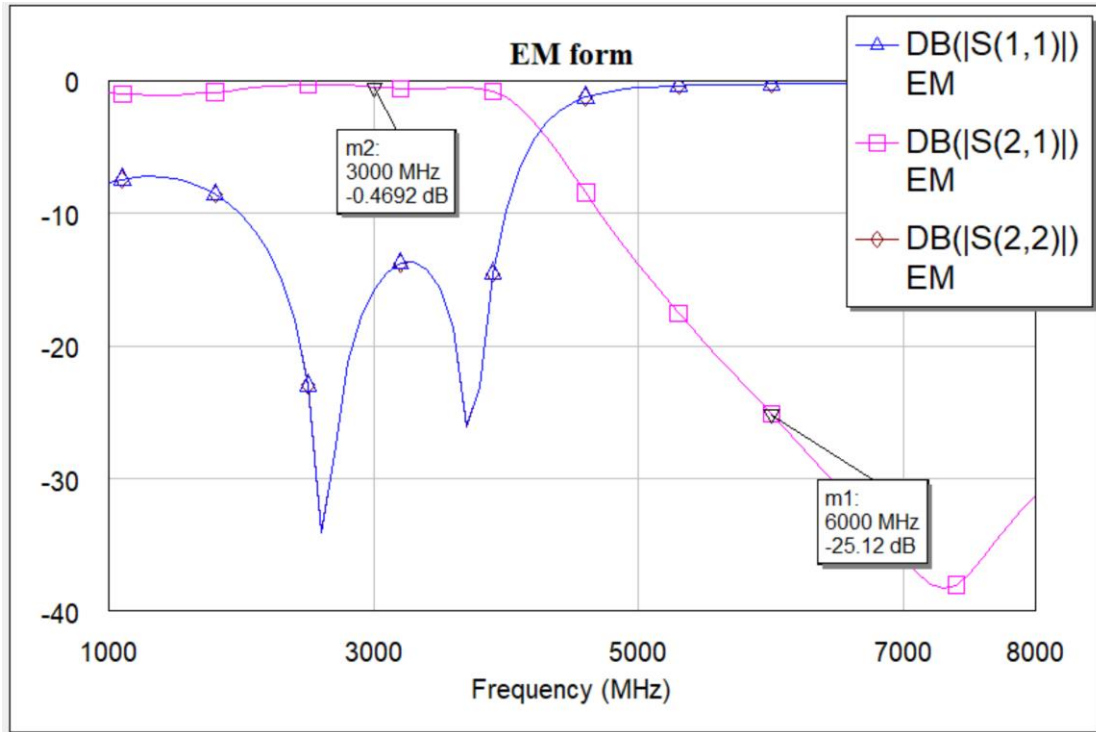
## Page 3



**Axiem Mesh:**

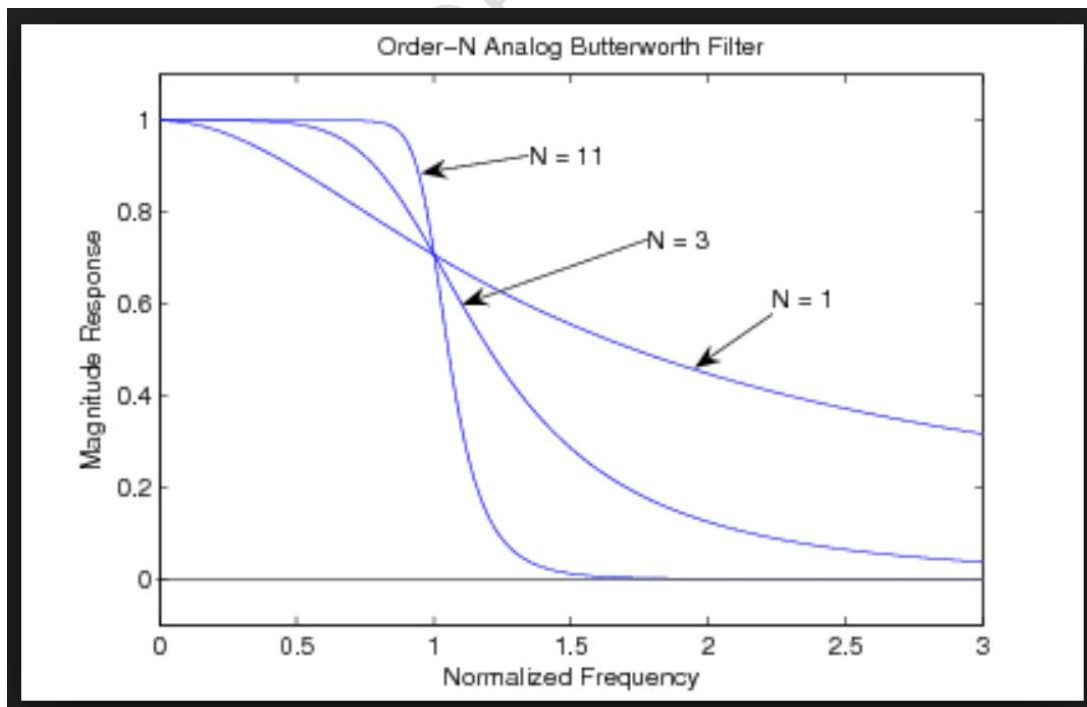


## Axiem Simulation results:



## B. Butterworth filter – Omkar Kulkarni

### Response of Butterworth filter



**Source:** archive.cnx.org

Butterworth filters have flat curves both in pass and reject bands at the cost of gradual roll off than the Chebyshev design of same order. Usually a higher order design is required for achieving the required attenuation.

According to the design goal an attenuation of 40dB is expected at  $2f_c$  accordingly the order of filter  $n=9$  is chosen to meet the specifications

The design values are found by using equations:

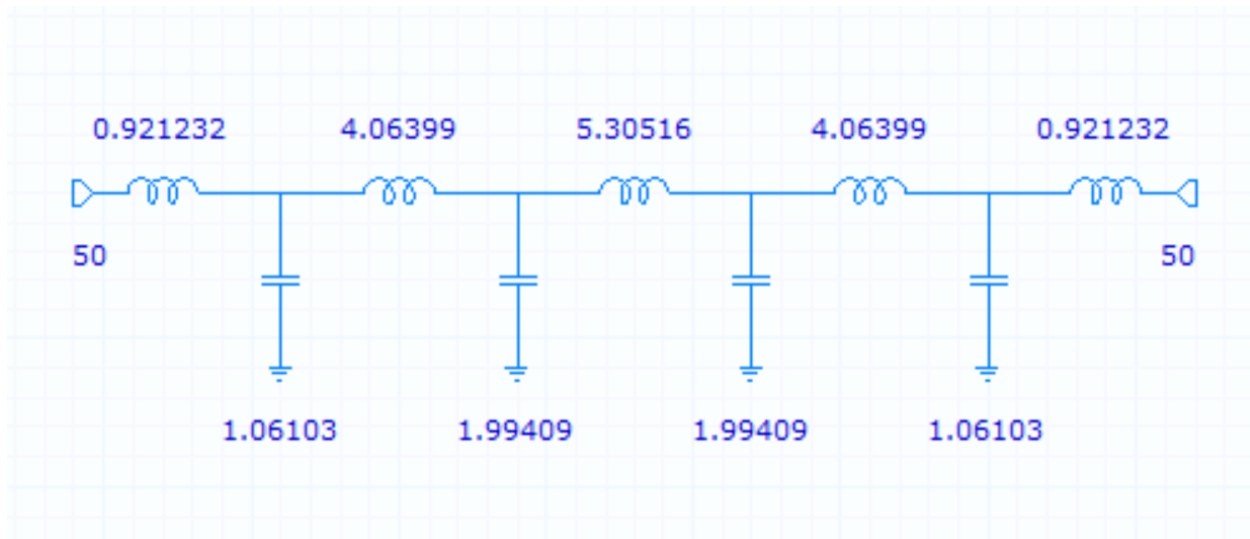
$$L_n = \frac{gn \times R}{2\pi \times f_c} \quad C_n = \frac{gn}{2\pi \times f_c \times R}$$

Where  $g_n$  is the value of the Butterworth polynomial given in the table:

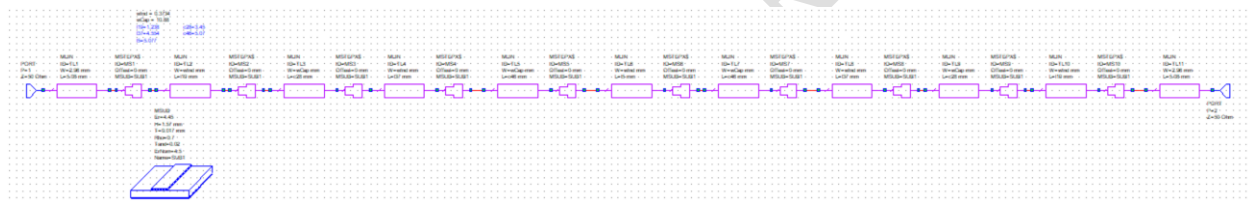
$N$	$g_1$	$g_2$	$g_3$	$g_4$	$g_5$	$g_6$	$g_7$	$g_8$	$g_9$	$g_{10}$	$g_{11}$
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000			
8	0.3902	1.1111	1.6629	1.9615	1.9615	1.6629	1.1111	0.3902	1.0000		
9	0.3473	1.0000	1.5321	1.8794	2.0000	1.8794	1.5321	1.0000	0.3473	1.0000	
10	0.3129	0.9080	1.4142	1.7820	1.9754	1.9754	1.7820	1.4142	0.9080	0.3129	1.0000

R for inductor is chosen as  $120\Omega$  and for capacitor is  $20\Omega$ . Fixing the R values the width of the microstrip elements were obtained from the transmission line tool in AWR. For calculating the lengths of the elements, the individual elements were tuned to get the desired reactance at the specified frequency. These lengths were used to construct the overall structure.

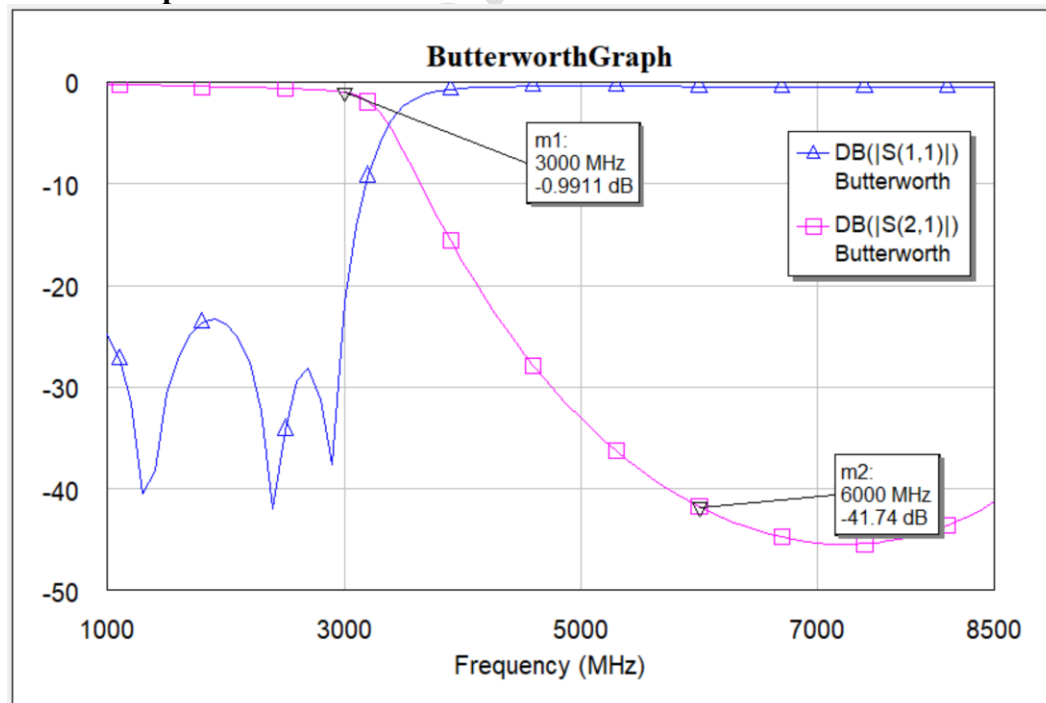
The corresponding values are:



**Schematic:**

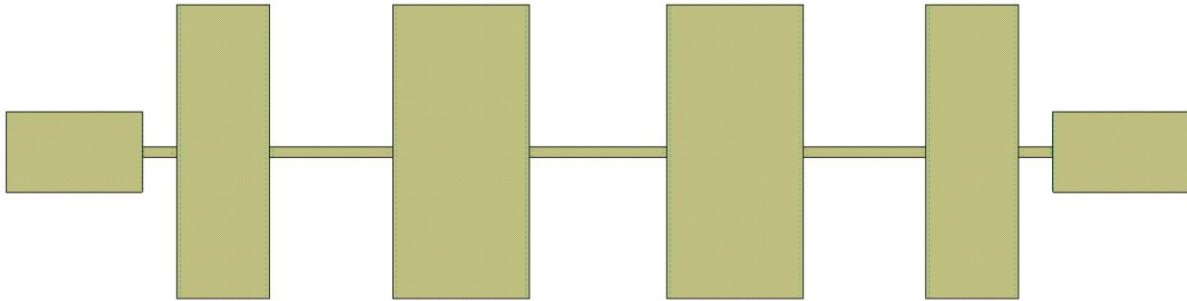


**Circuit Response:**

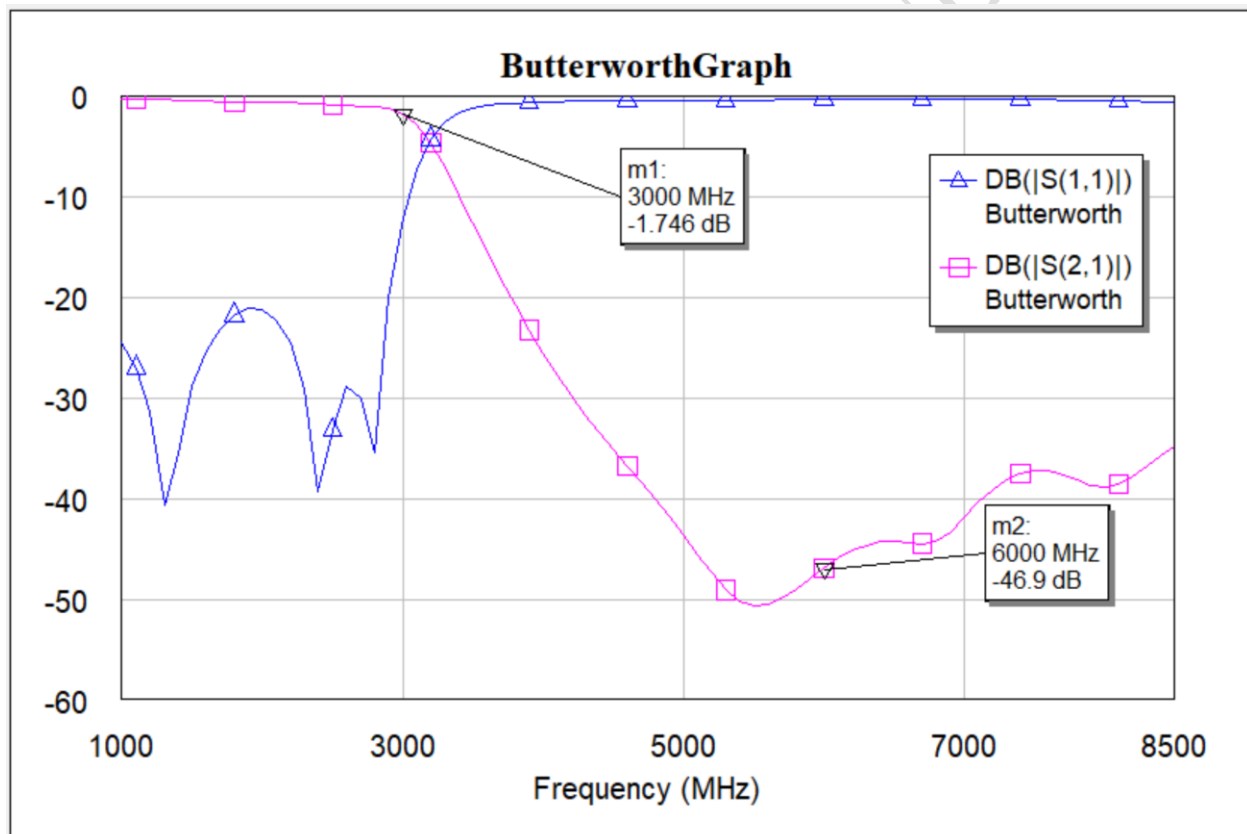




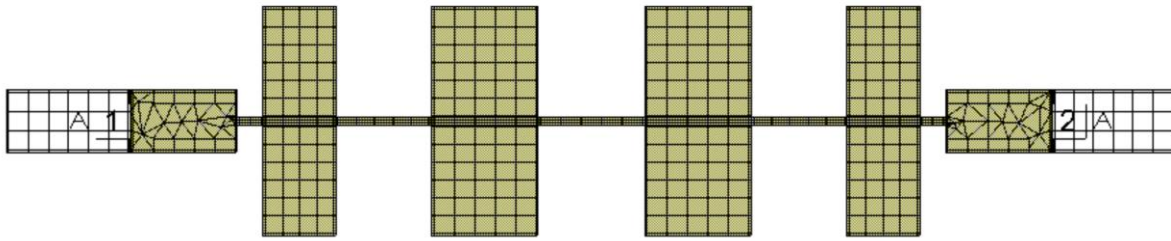
**Board layout:**



**Axiem Response:**



**Axiem mesh:**

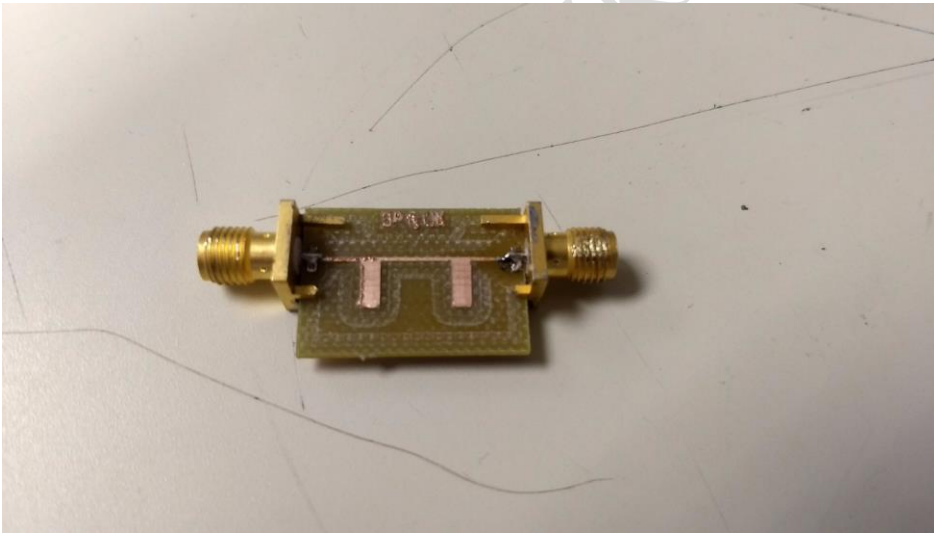


- **Summary:**

The results obtained from the circuit simulation and Axiem simulation are close to each other. Initially the design values didn't lie near the objectives. After tuning the design goals were achieved.

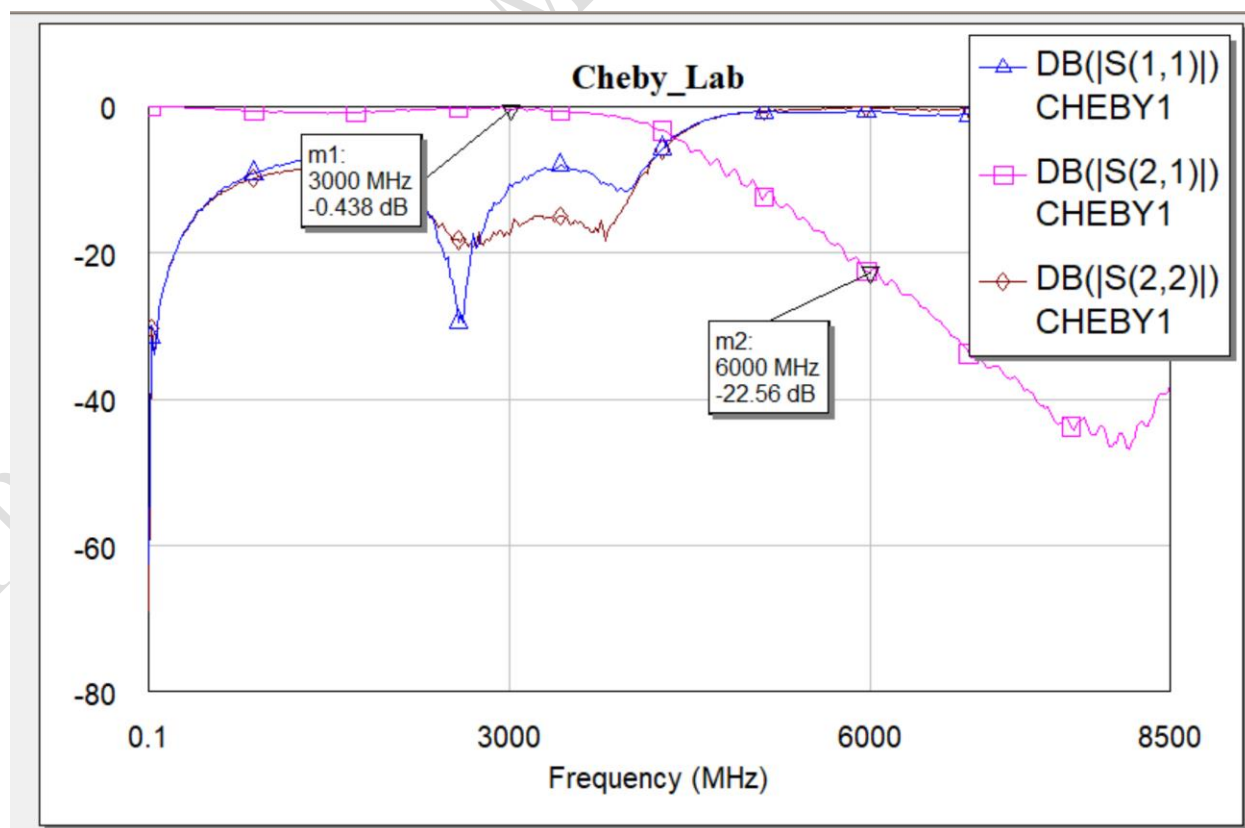
#### 4. Lab Measurements

- **Lab setup photographs**

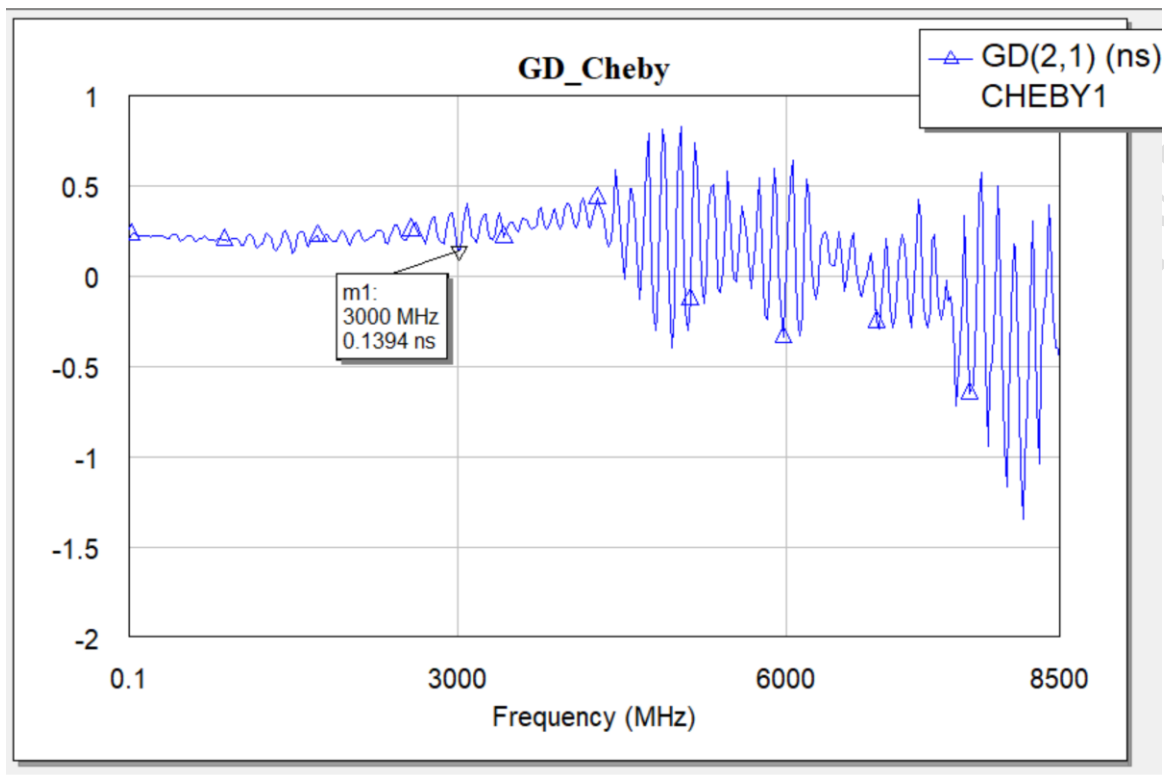




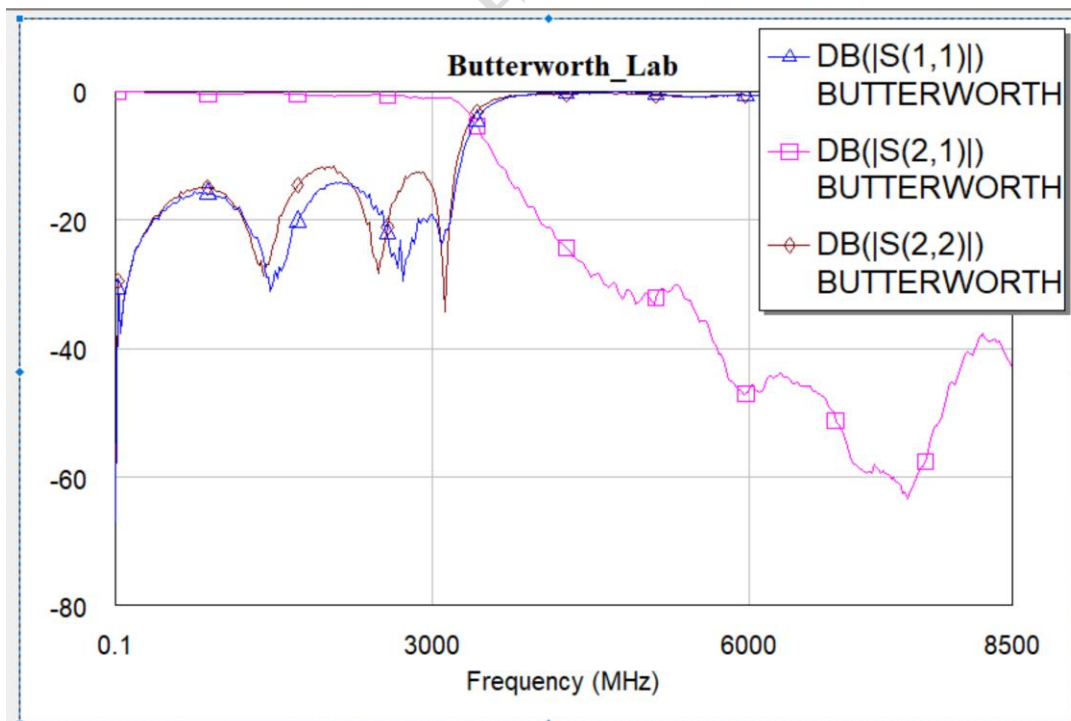
**Chebyshev Graph for Lab measurements:**



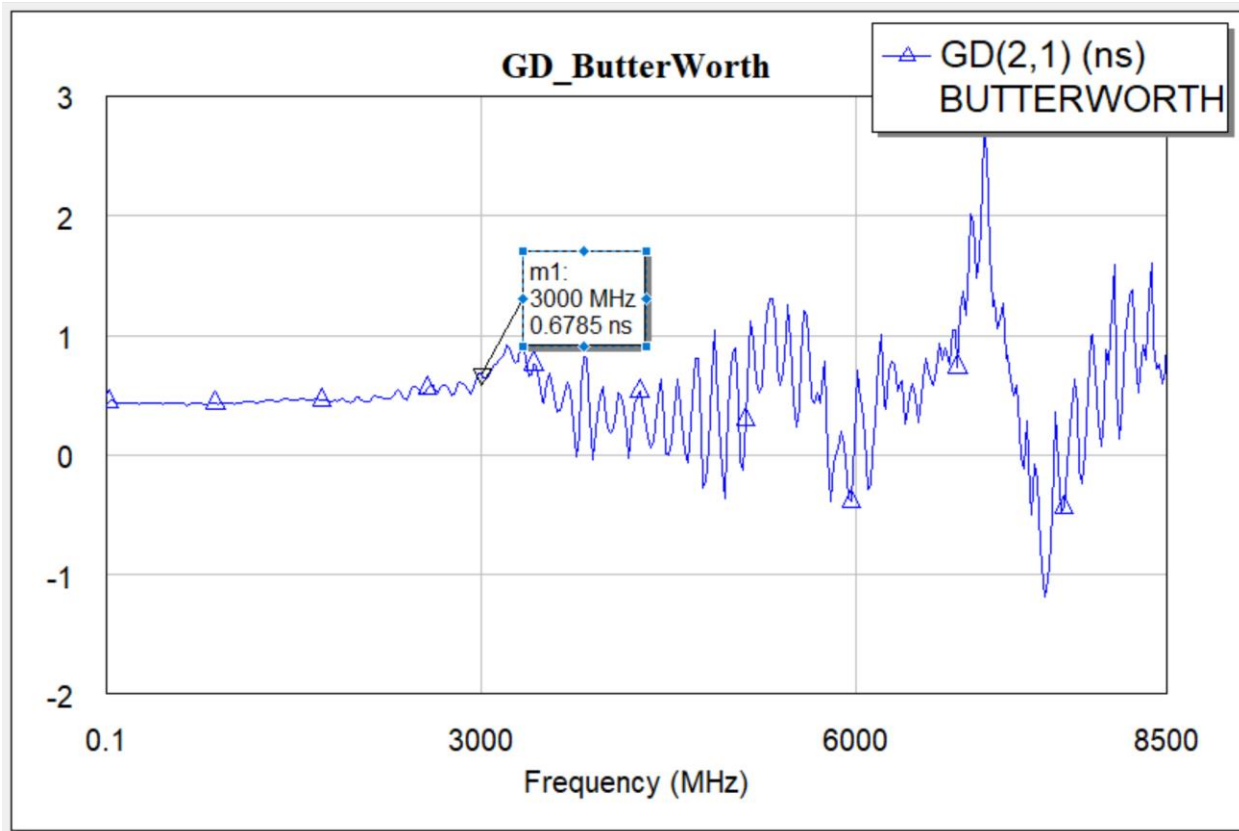
Measured Group delay in lab:



Chebyshev Graph for Lab measurements:



### ButterWorth Group Delay:

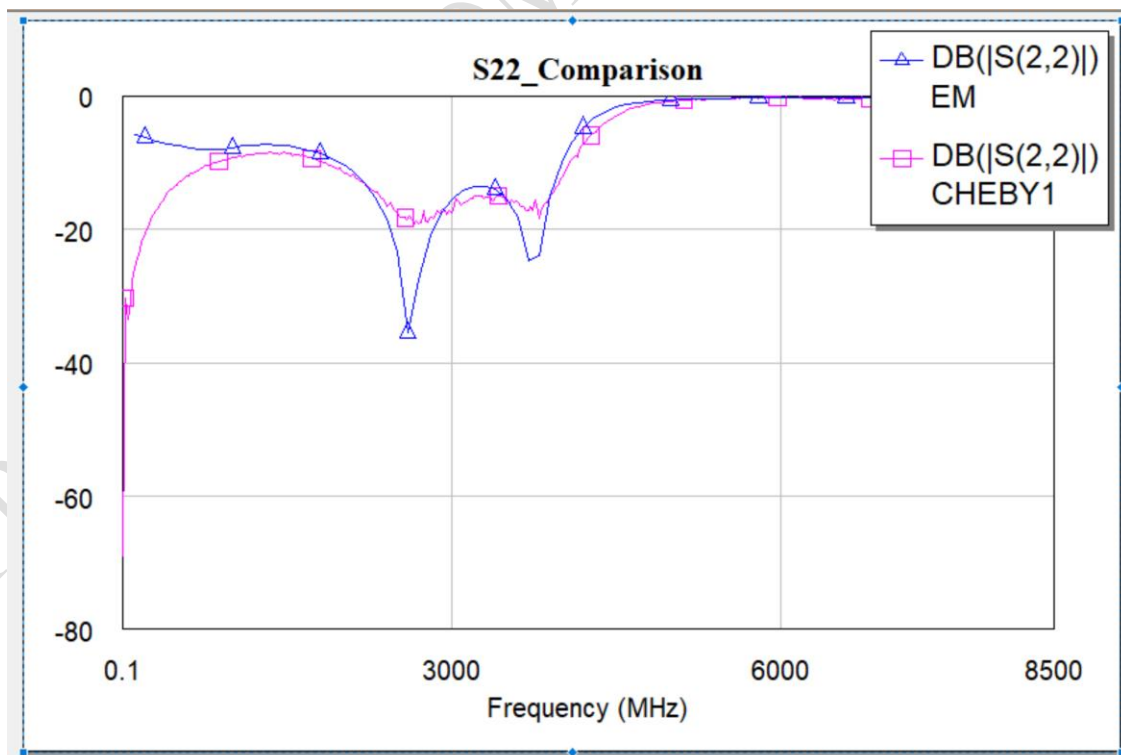
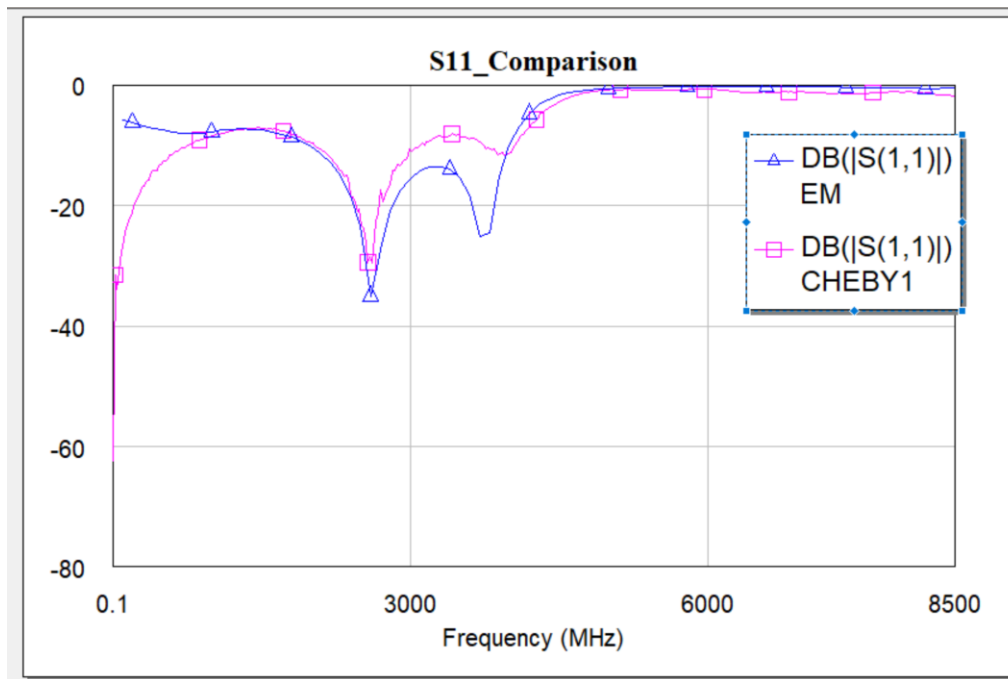


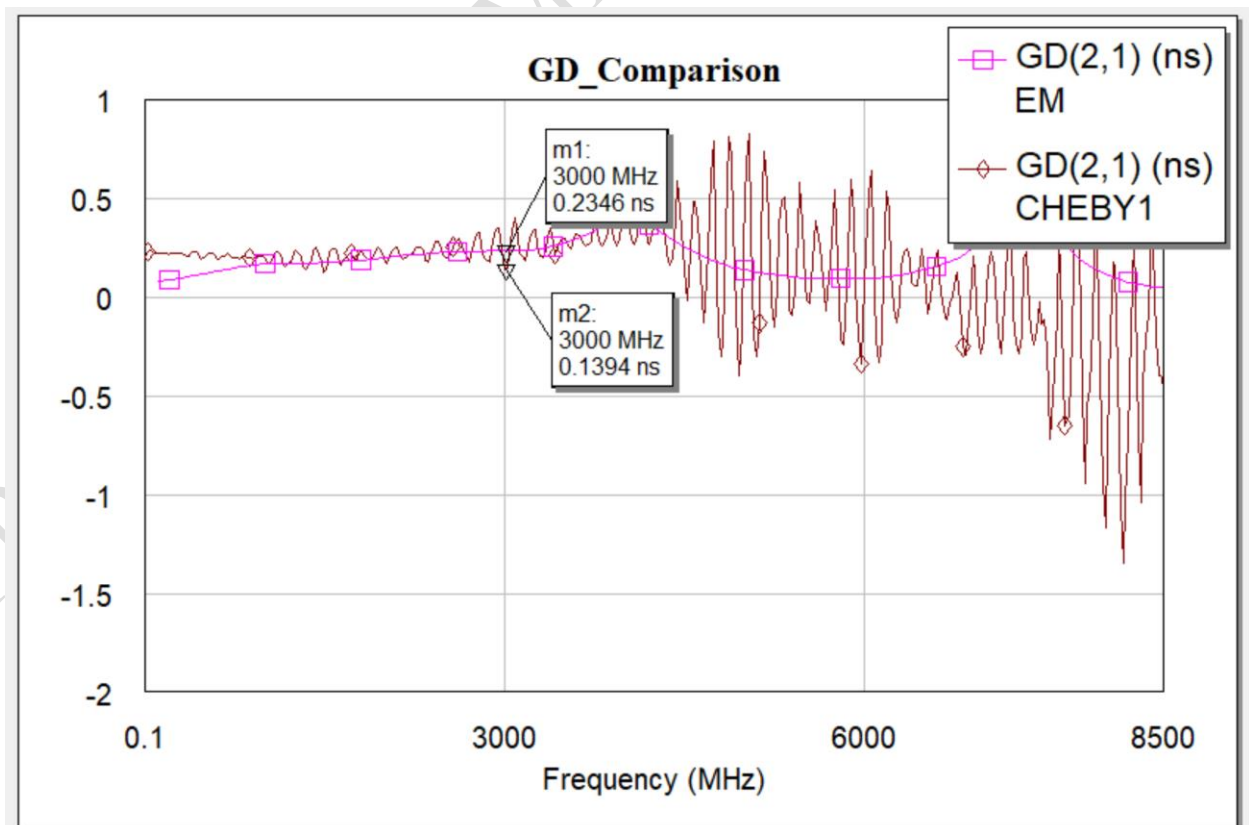
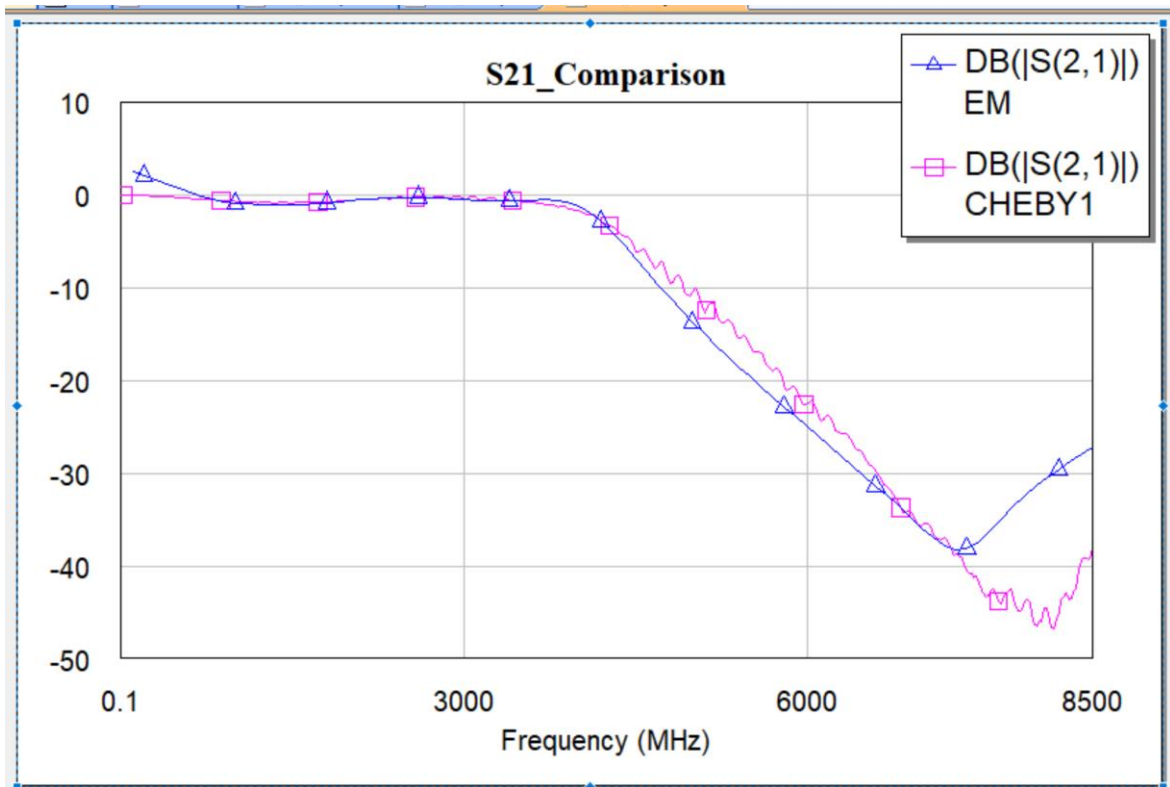
### Summary:

The 0.5 dB ripple of Chebyshev is hard to see. The cut off frequency of Chebyshev is off the mark.

## Analysis:

### A. Chebyshev Filter





### Calculations:

#### Cutoff Frequencies

Predicted = 3.038 GHz

Measured = 3.281 GHz

#### Group Delay

Predicted GD = 0.2346 ns

Measured GD = 0.1394 ns

#### Ripples

Predicted (dB) =  $1.06 - 0.3069 = 0.7531$

Measured (dB) =  $0.8534 - 0 = 0.8534$  dB

#### Attenuation at $2f_c$

Predicted (dB) = 24.98

Measured (dB) = 22.56

#### Difference between cutoff frequencies compared to ideal

Predicted difference =  $3038 - 3000 = 38$  MHz

Measured difference =  $3281 - 3000 = 281$  MHz

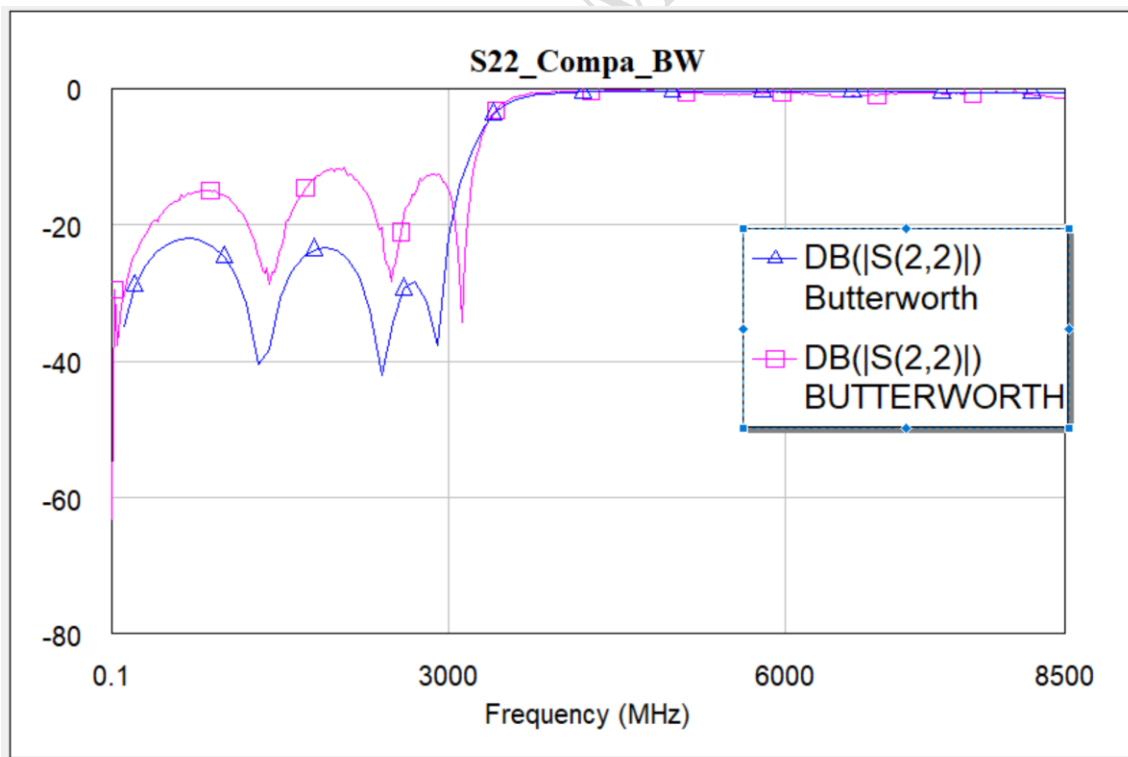
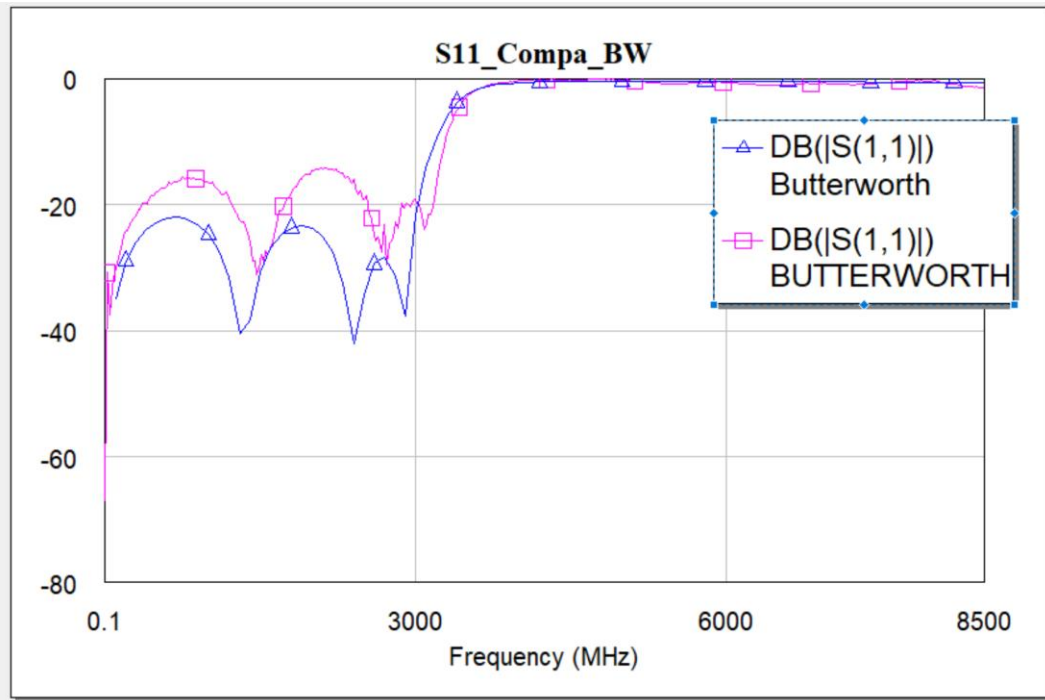
#### COMPLIANCE MATRIX

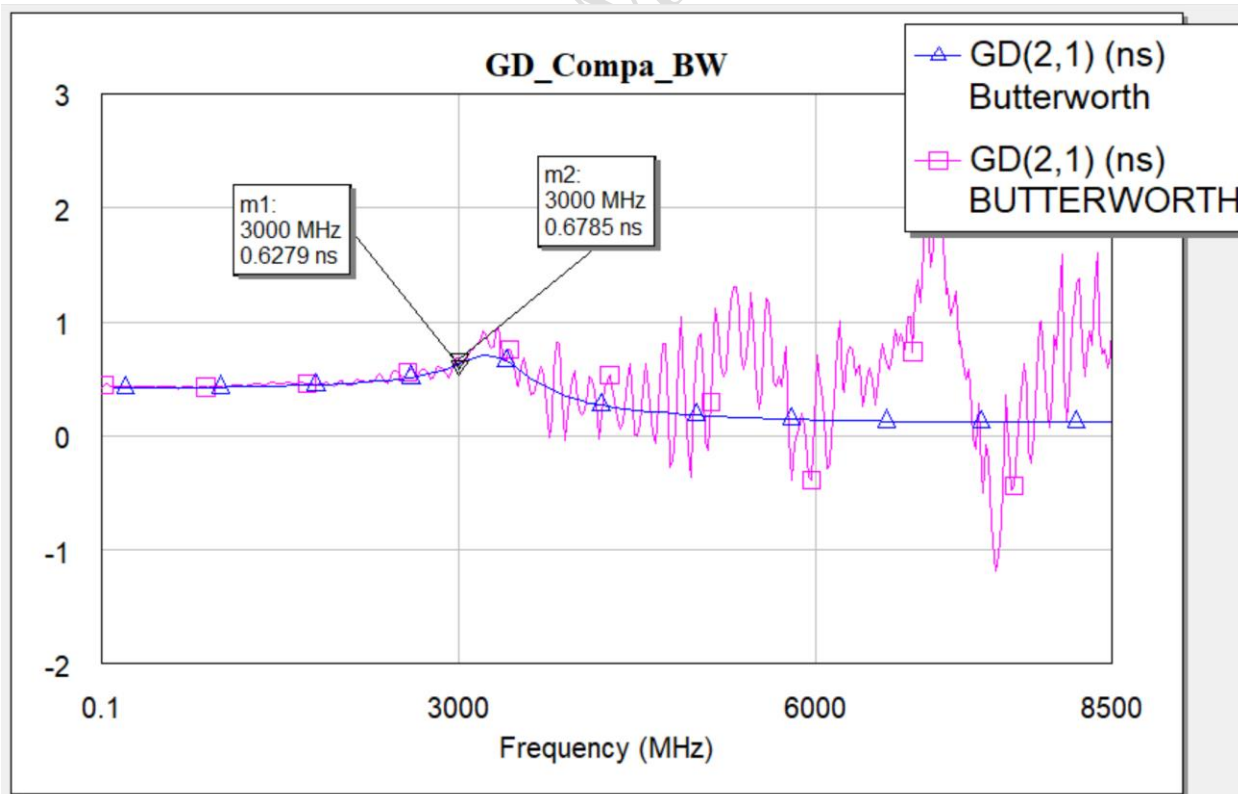
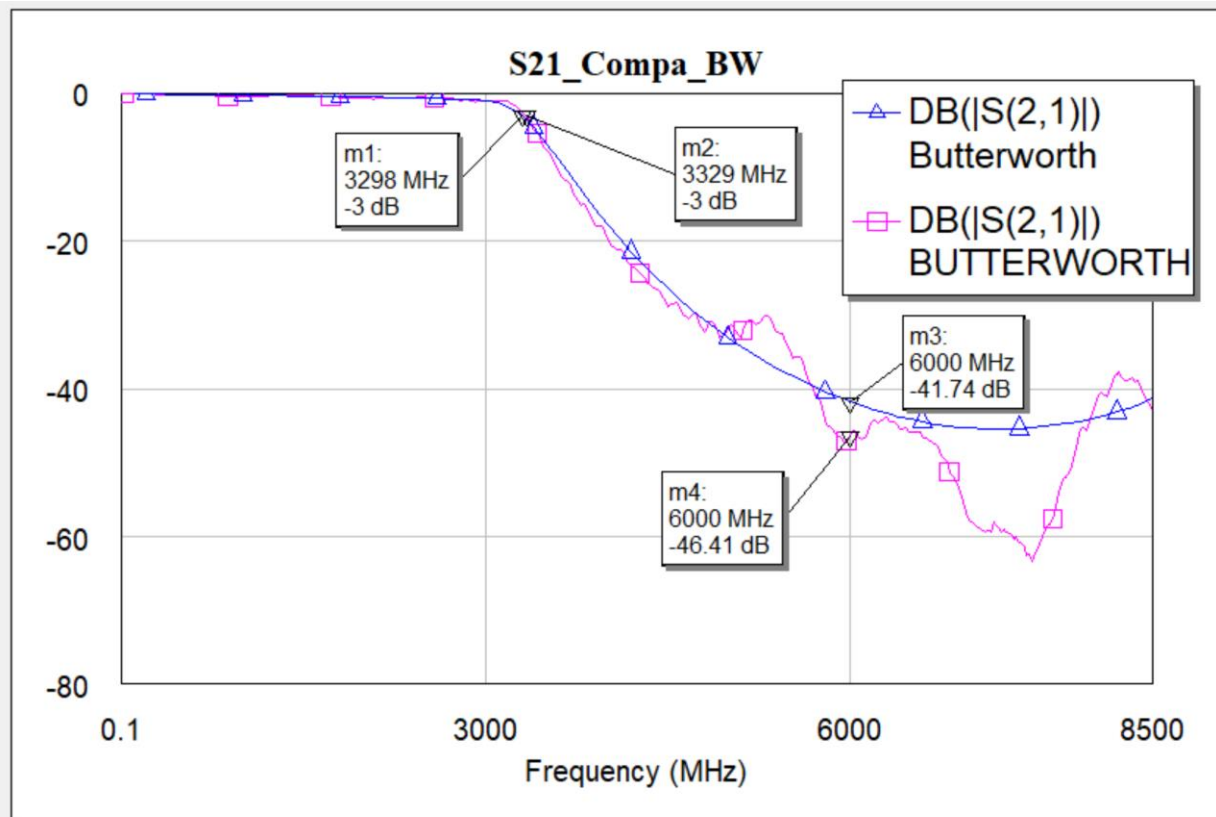
	Ideal	Predicted	Measured	Compliance
Frequency (GHz)	3	3.038	3.281	YES
Ripple (dB)	0.5	0.7531	0.8534	NO
Attenuation at 6GHz (dB)	40	24.98	22.56	NO

**Summary:** Some of the goals are not within the compliant range. Overall the design was not successful.



## B. Butterworth Filter





### Cut-off frequencies

Predicted cutoff frequency = 3.298 GHz

Measured cutoff frequency = 3.329 GHz

### Group Delays

Predicted group delay is = 0.6279 nses

Measured group delay is = 0.6785 nsec

### Difference of cutoff frequencies compared to ideal

Predicted  $\Delta f = 3 - 3.29 = 0.29$  GHz

Measured  $\Delta f = 3 - 3.329 = 0.329$  GHz

### Difference of attenuation at 6dB compared to ideal

Predicted =  $40 - 41.74 = -1.74$  dB

Measured =  $40 - 46.41 = -6.41$  dB

### COMPLIANCE MATRIX

	Ideal	Predicted	Measured	Compliant
Frequency (GHz)	3	3.298	3.329	YES
Attenuation at 6GHz (dB)	40	41.74	46.41	YES

### Analysis:

#### 1. Which filter has better (lower) group delay?

From the observed results Chebyshev filter has better group delay.

#### 2. Was your design successful?

The design for Butterworth filter was successful while the Chebyshev design was not successful.

#### 3. How could you have improved your filter(s)?

Using radial stubs would have yielded better results. Varying the widths of elements would have helped to tune the elements better.

### Summary:

The design for Butterworth filter was successful while the Chebyshev design was not successful.

The practical performance was not the same as the simulated one due to the complexities involved in practical implementation like junction capacitances, non-ideal bends and fringing effects.

**Conclusion:****I. Was your design successful? Why or why not?**

The design for Butterworth filter was successful while the Chebyshev design was not successful.

**II. What lessons did you learn from the lab?**

The lossy nature, the inhomogeneities in the material, the oxide film on the copper, inherent inaccuracies in the milling process all cause deviation in the practical performance. Having knowledge of effective dielectric constant will be helpful to attain desired results.