Lab8 Microstrip Filters

EERF – 6396

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Lab partner: Behnam Pouya

11/4/2017

1. Introduction

Objectives:

a. Design a Chebyshev low pass filter for $f_c = 3GHz$
b. Design a Butterworth low pass filter for $f_c = 3GHz$

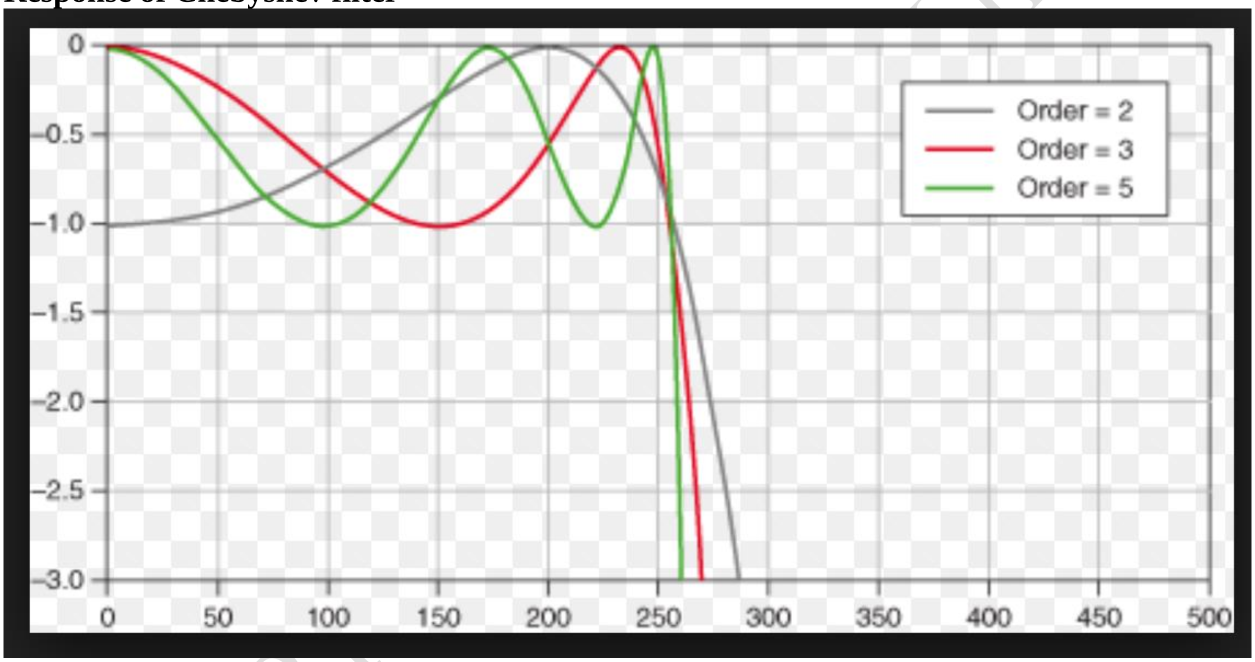
2. Significance

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:

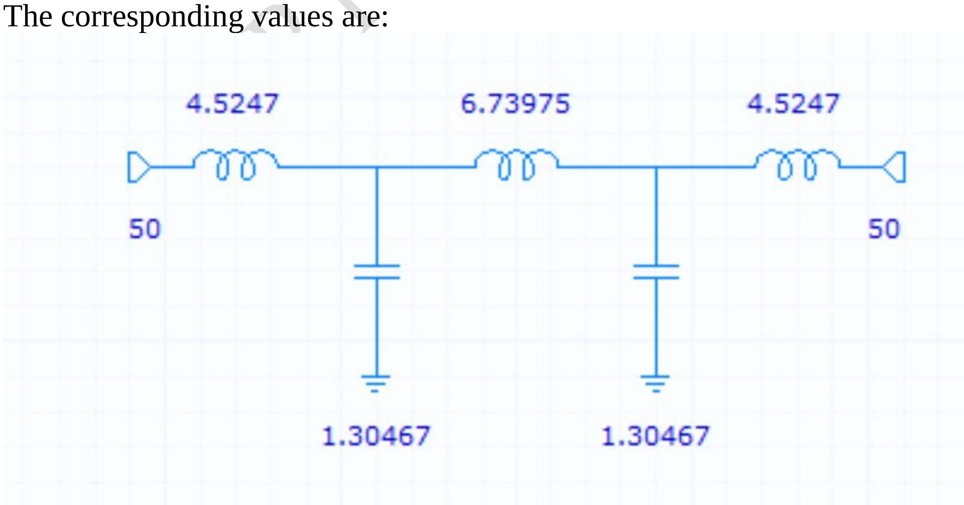
$L_n = \frac{gn \times R}{2\pi \times fc}$ $C_n = \frac{gn}{2\pi \times fc \times R}$

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

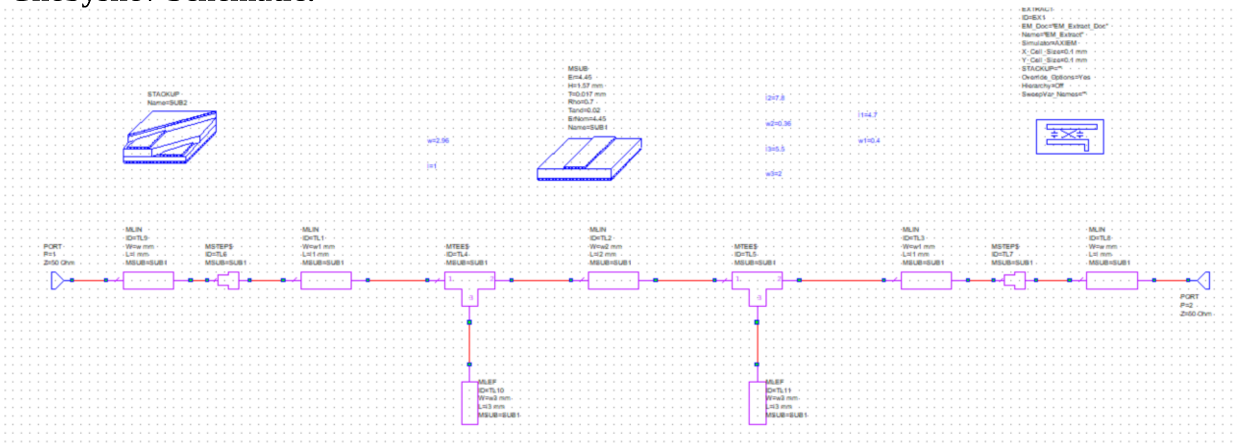
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7372	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 120Ω and for capacitor is 20Ω. 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.

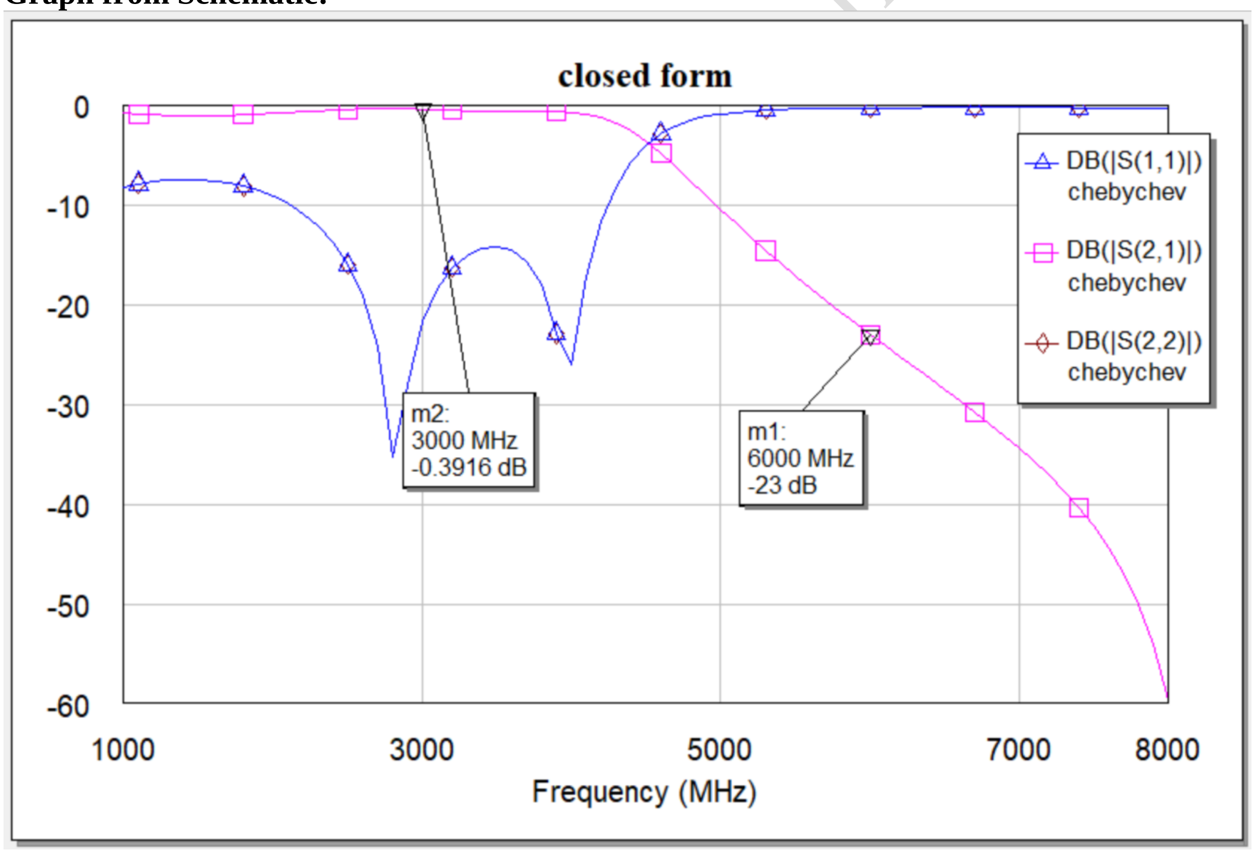
The corresponding values are:



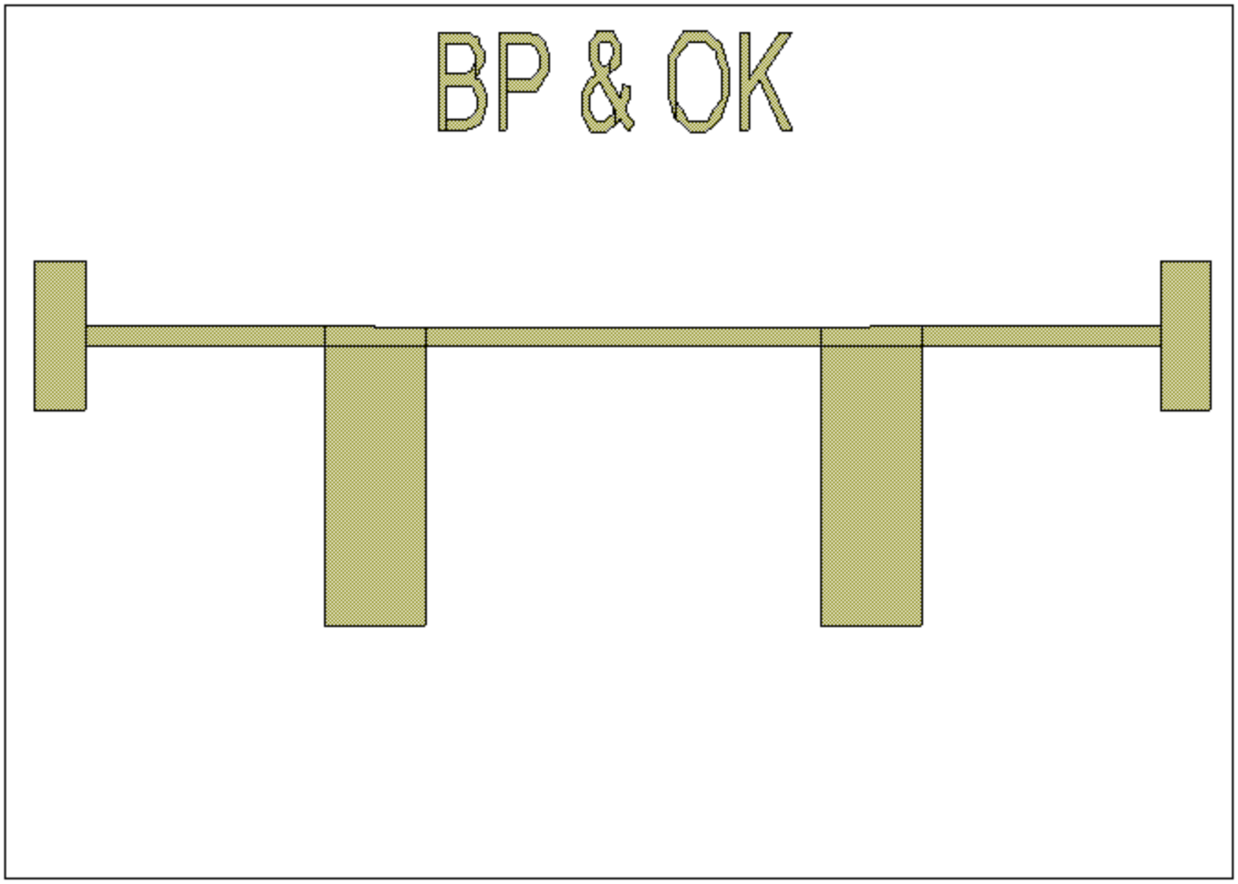
Chebyshev Schematic:



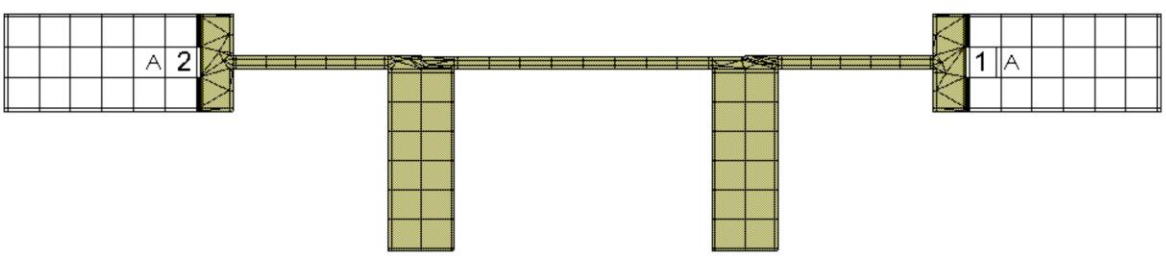
Graph from Schematic:



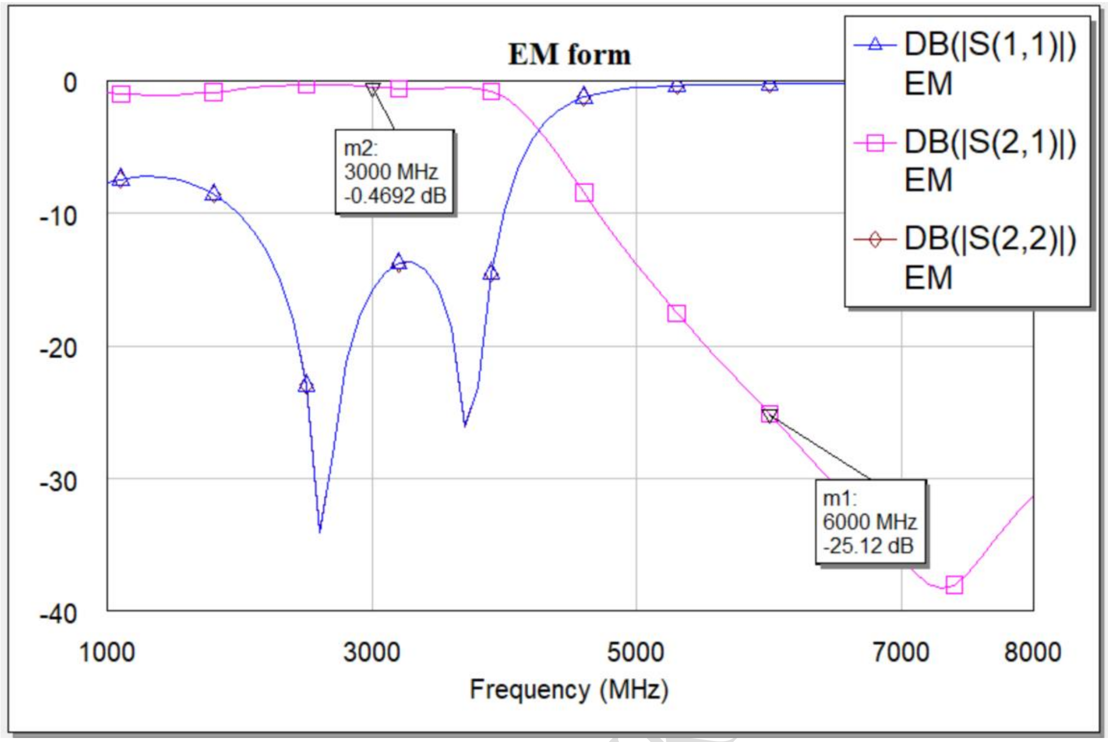
Layout:



Axiem Mesh:

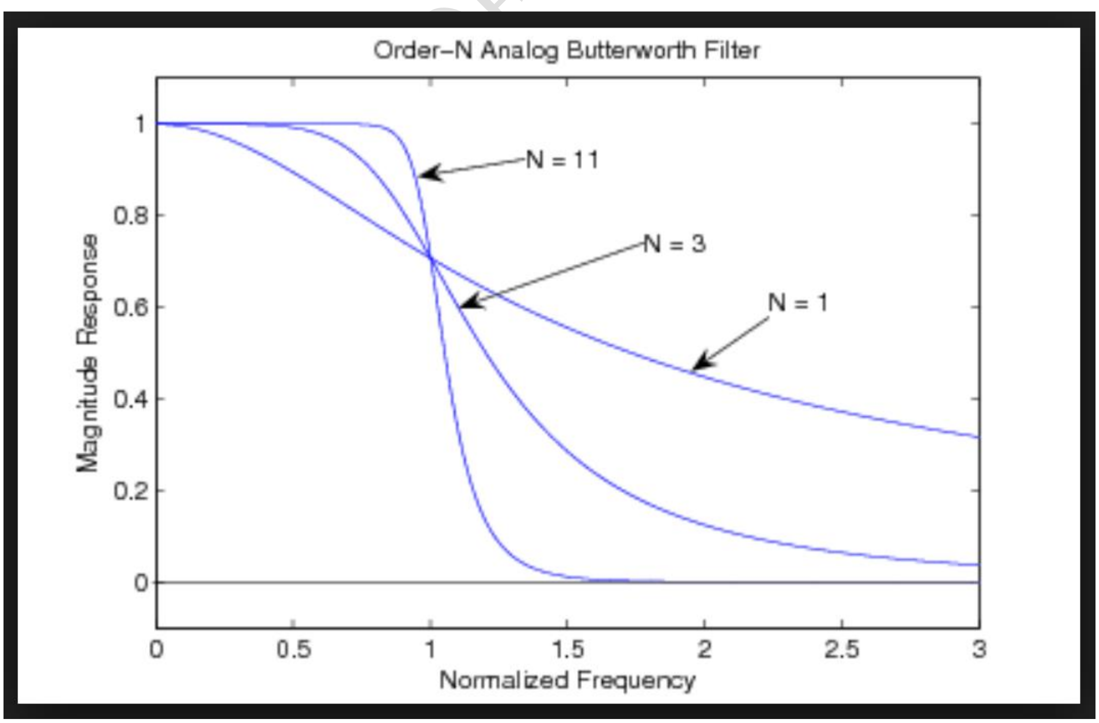


Axiem Simulation results:



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:

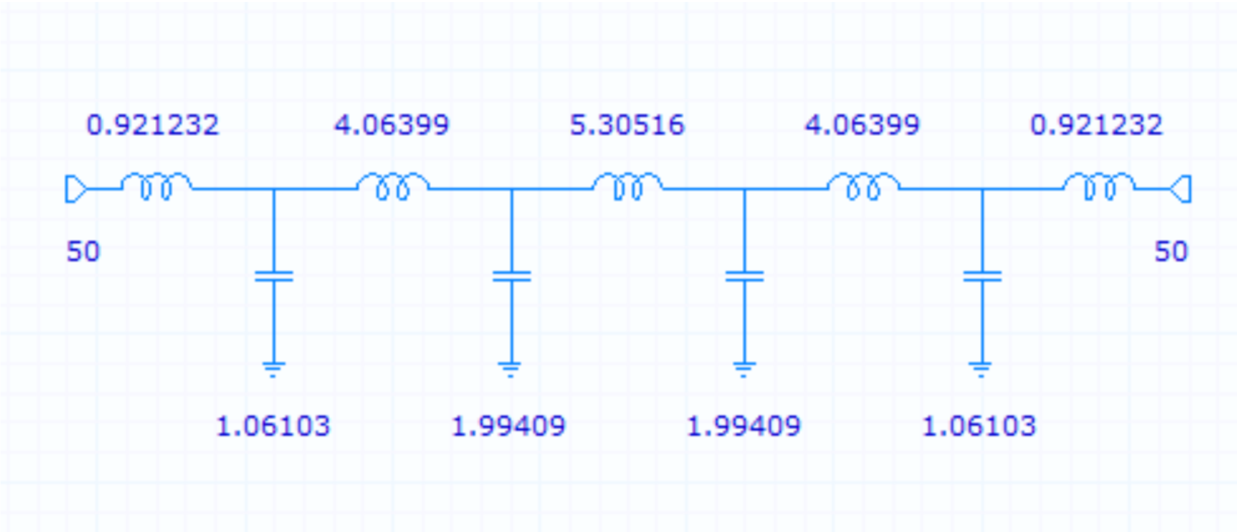
$L_n = \frac{gn \times R}{2\pi \times fc}$ $\qquad\qquad$ $C_n = \frac{gn}{2\pi \times fc \times R}$

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

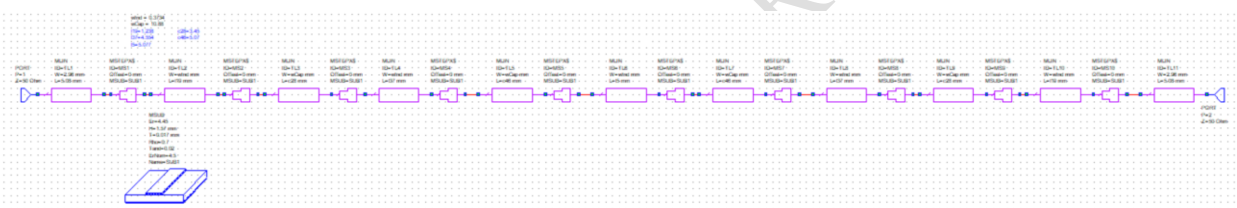
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	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 120Ω and for capacitor is 20Ω. 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.

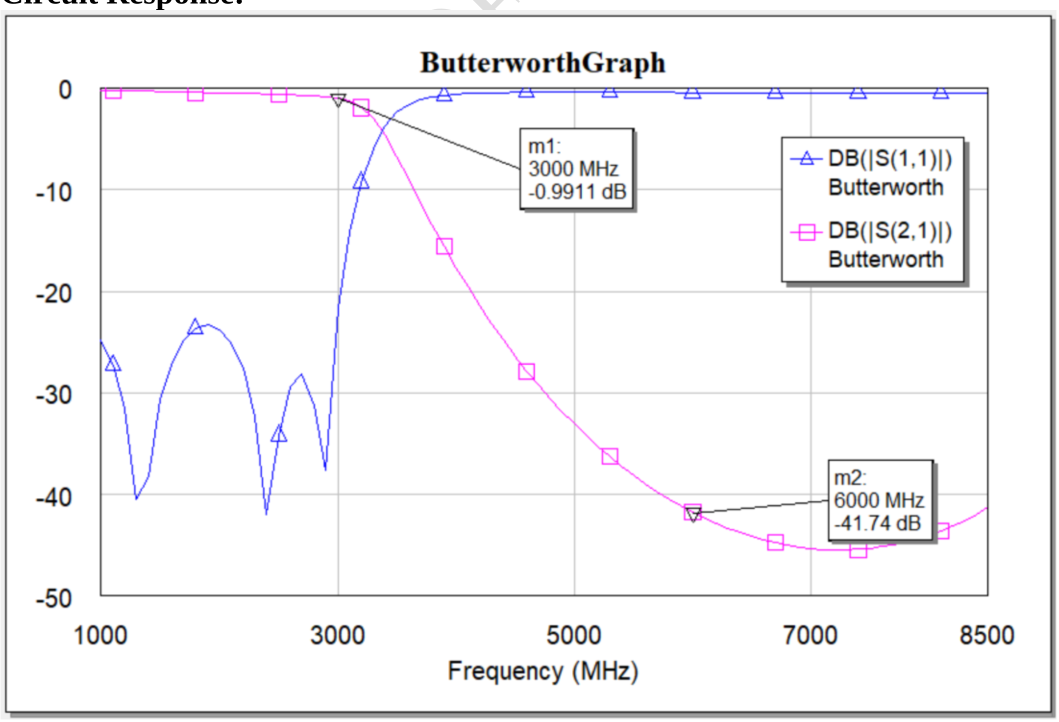
The corresponding values are:



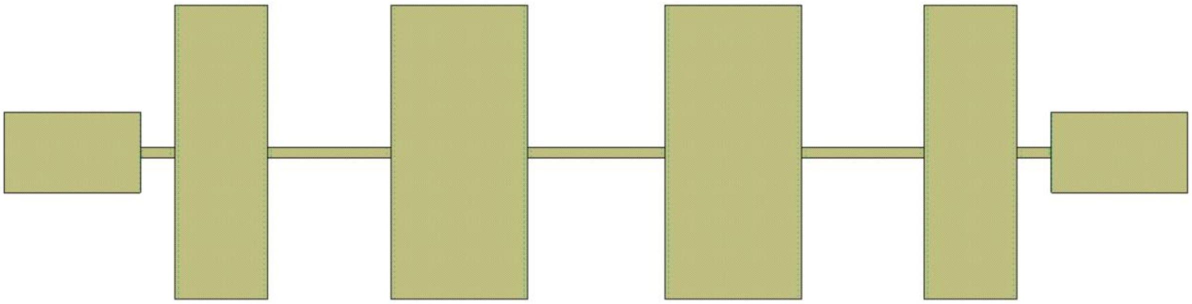
Schematic:



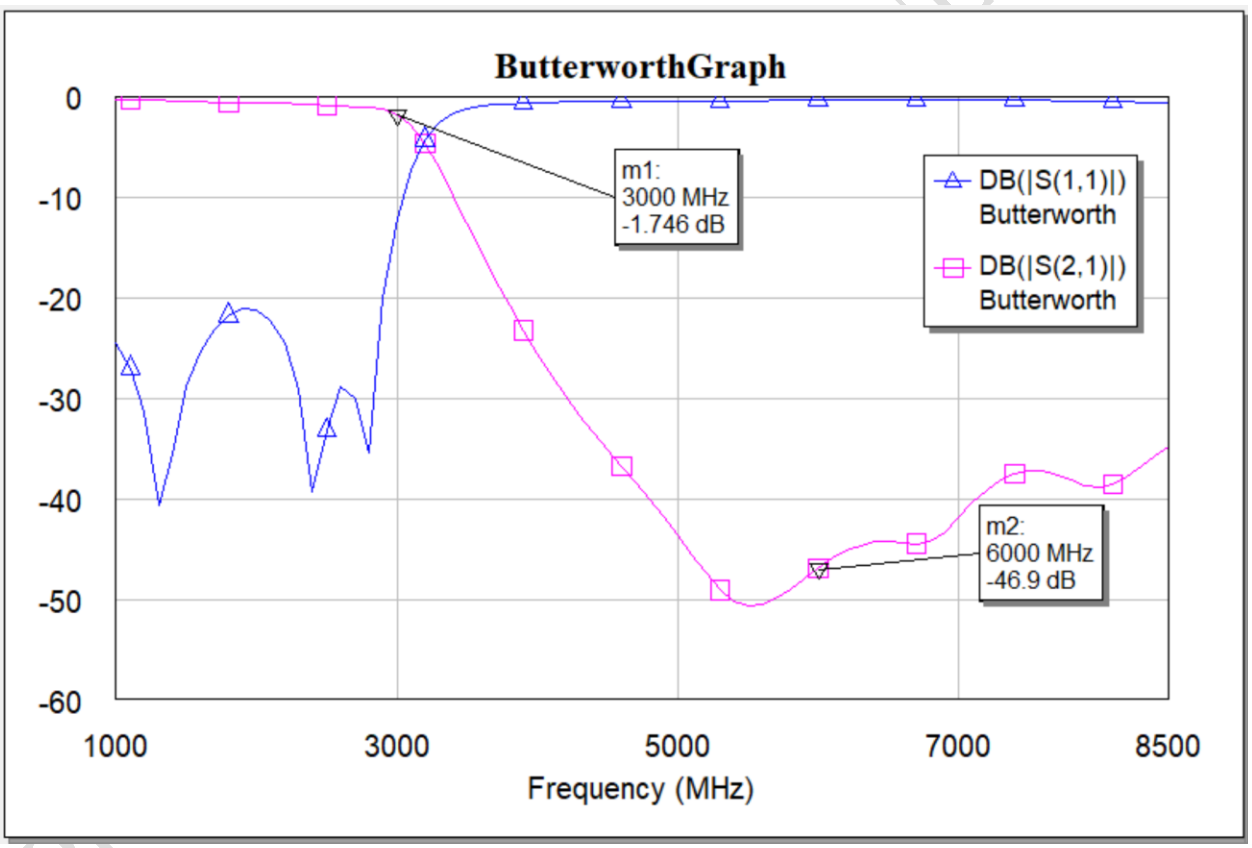
Circuit Response:



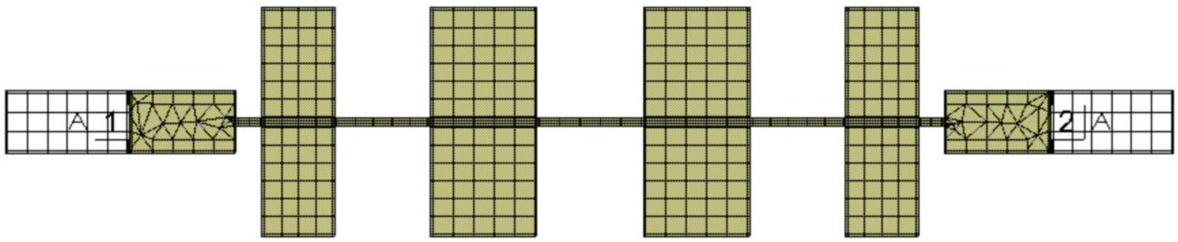
Board layout:



Axiem Response:



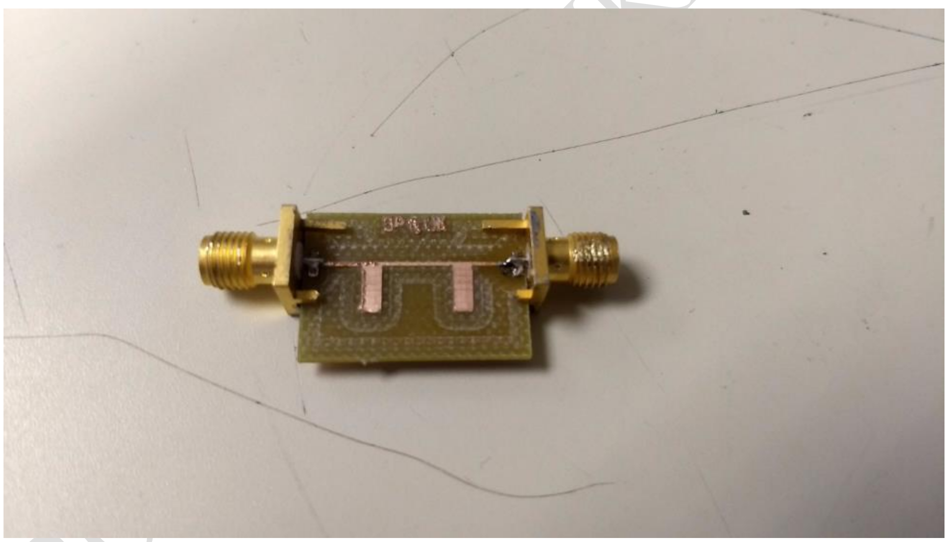
Axiem mesh:



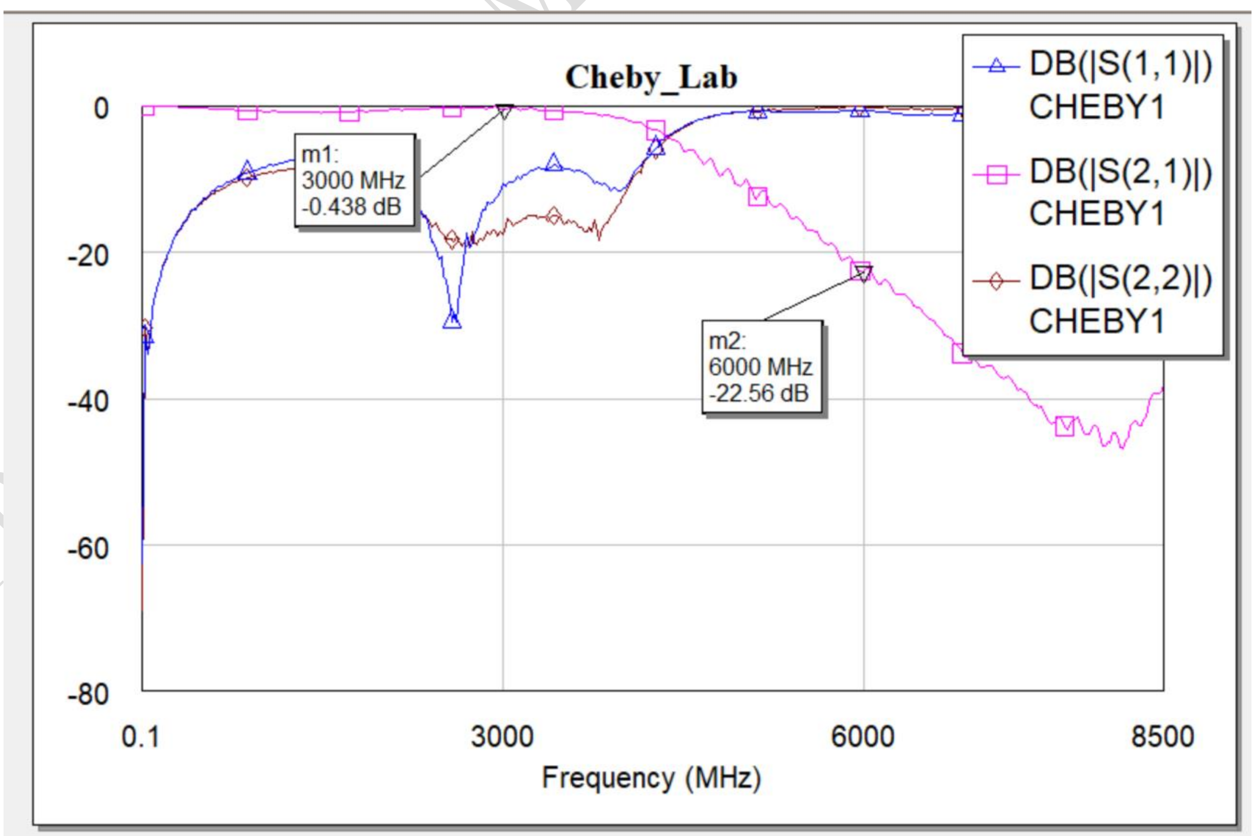
- **Summary:**
  The results obtained from the circuit simulation and Axiem simulation are close to each other. Initially the design values didn't lie near the objectives. After tuning the design goals were achieved.

4. Lab Measurements

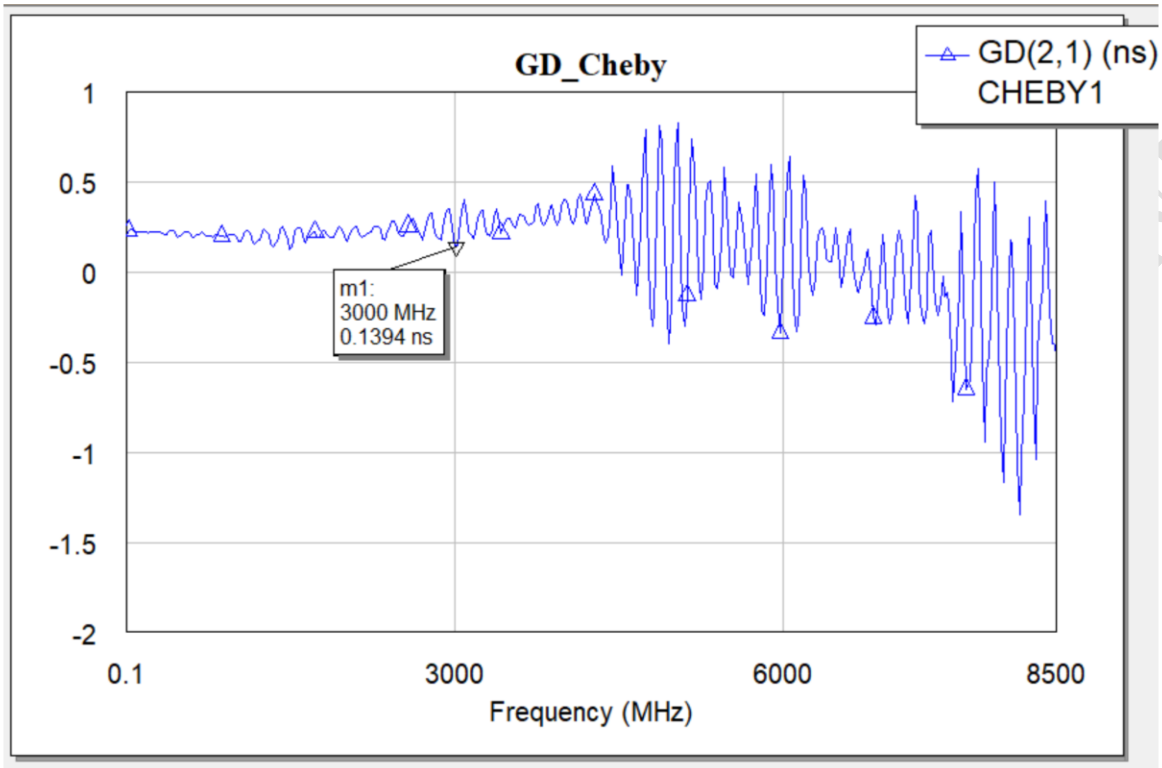
- **Lab setup photographs**



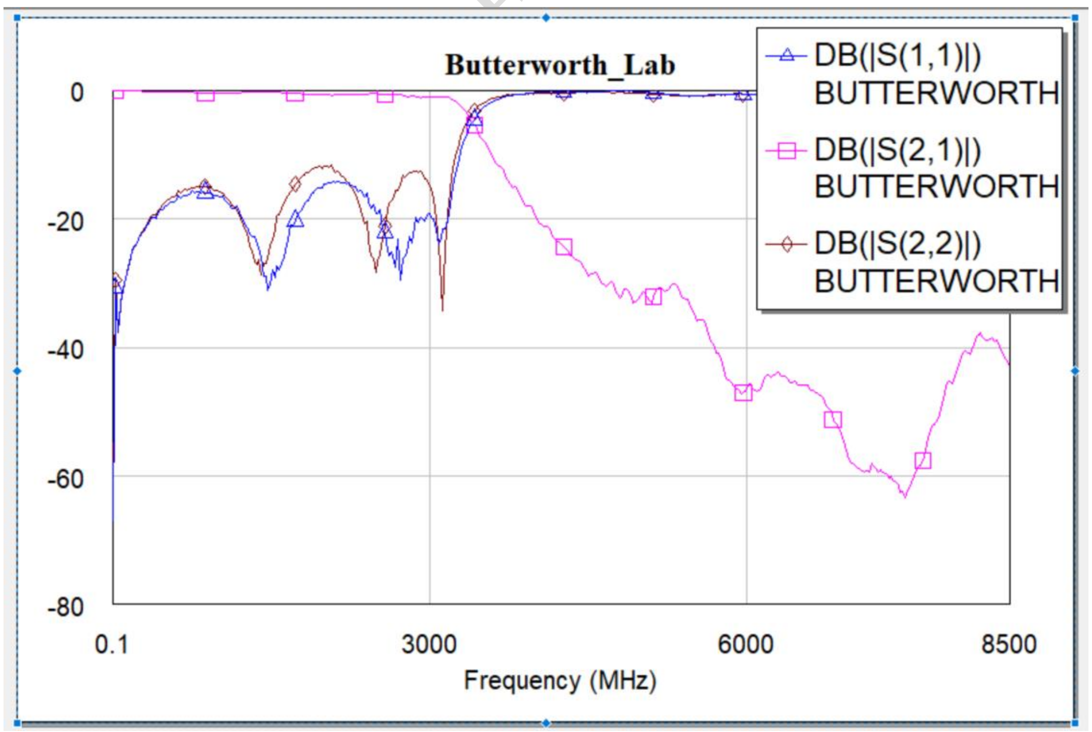
Chebyshev Graph for Lab measurements:



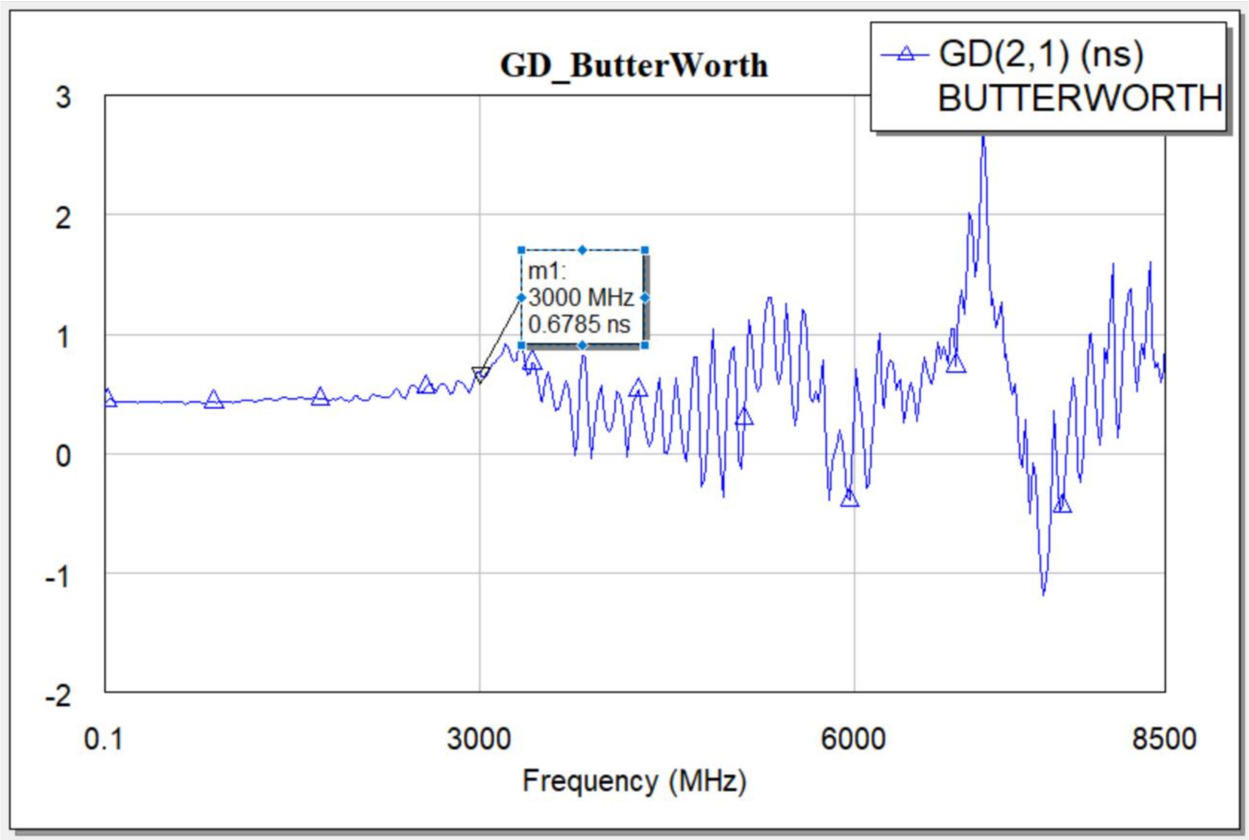
Measured Group delay in lab:



Chebyshev Graph for Lab measurements:



ButterWorth Group Delay:

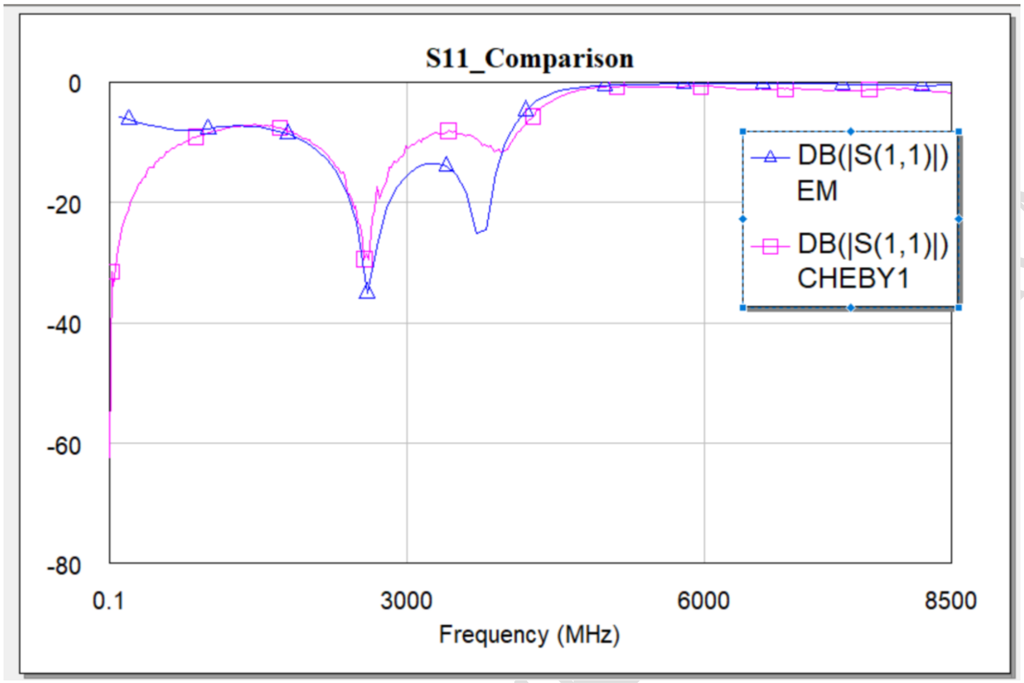


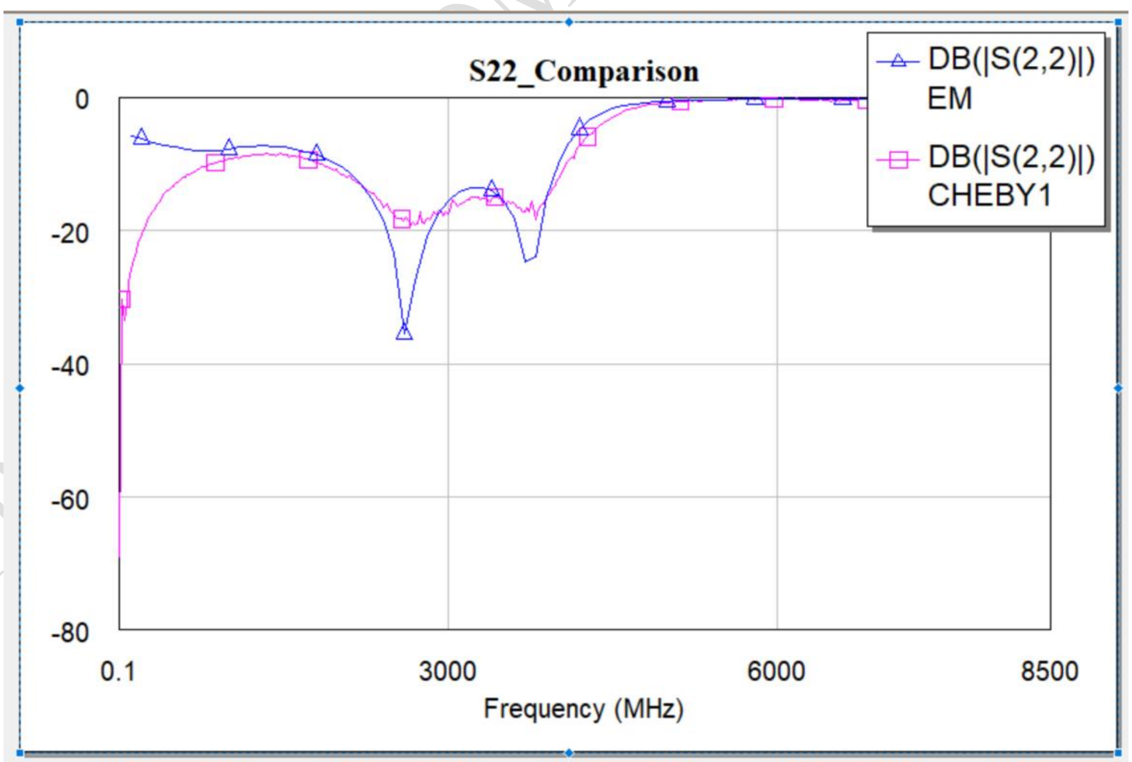
Summary:

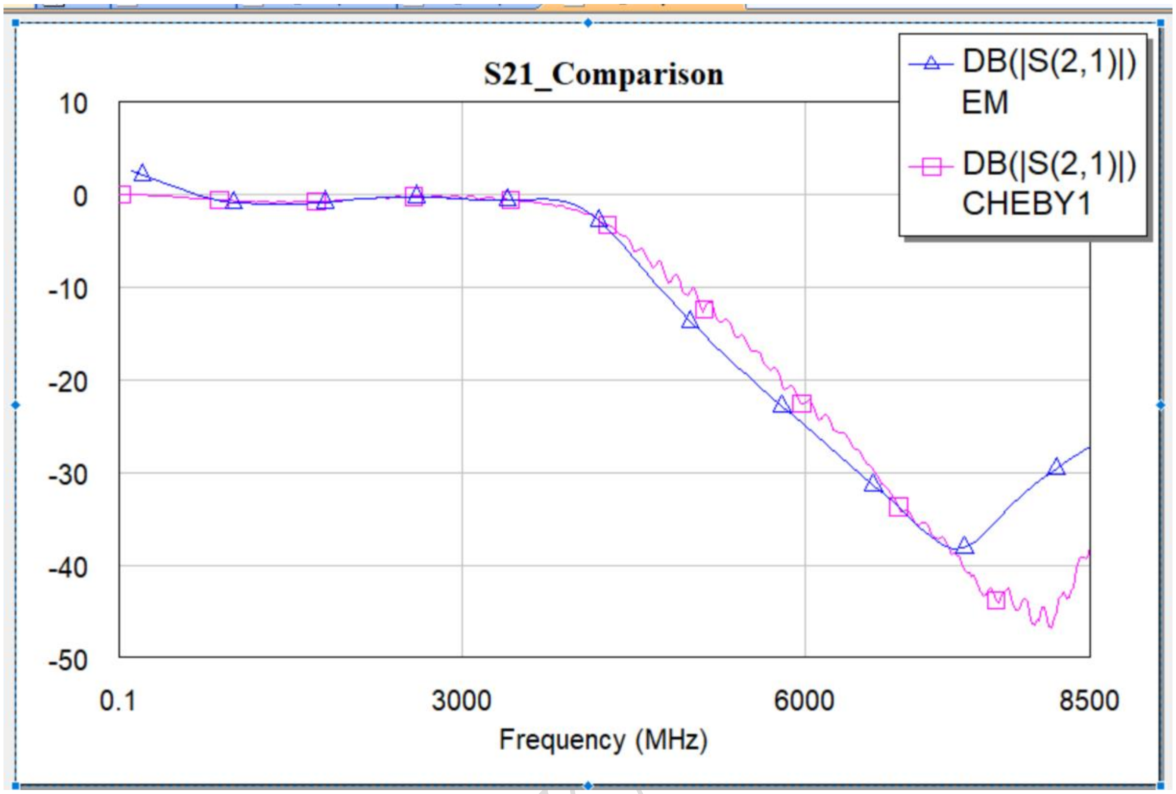
The 0.5 dB ripple of Chebyshev is hard to see. The cut off frequency of Chebyshev is off the mark.

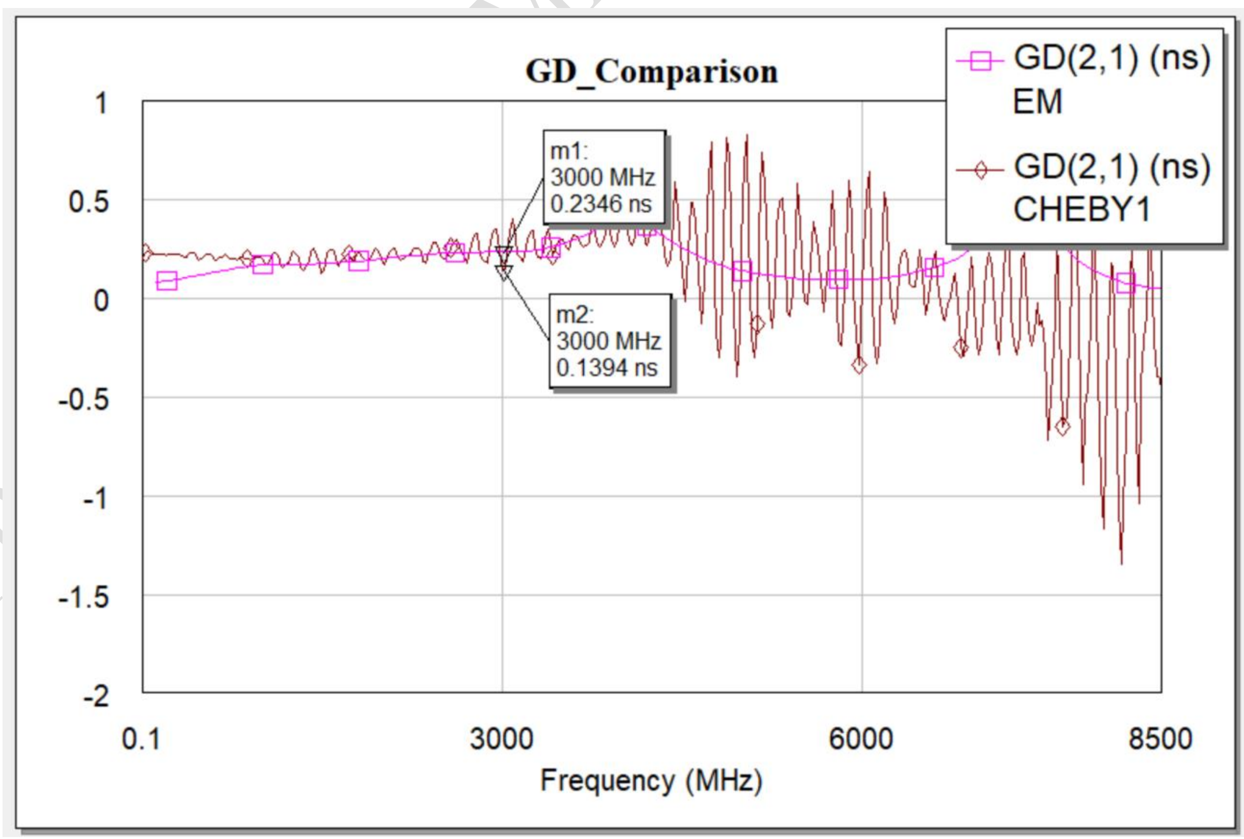
Analysis:

A. Chebyshev Filter






S21_Comparison
DB(|S(2,1)|)
EM
DB(|S(2,1)|)
CHEBY1
10
0
-10
-20
-30
-40
-50
0.1
3000
6000
8500
Frequency (MHz)


GD_Comparison
GD(2,1) (ns)
EM
GD(2,1) (ns)
CHEBY1
m1:
3000 MHz
0.2346 ns
m2:
3000 MHz
0.1394 ns
1
0.5
0
-0.5
-1
-1.5
-2
0.1
3000
6000
8500
Frequency (MHz)

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

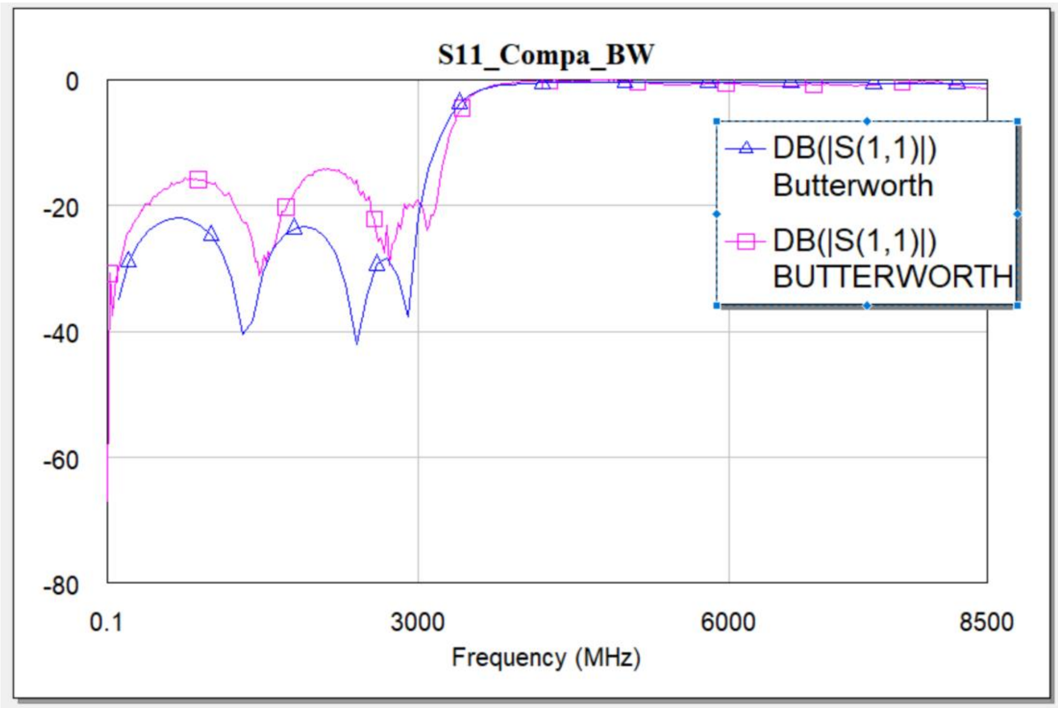
Predicted difference = 3038 – 3000 = 38 MHz
Measured difference = 3281 – 3000 = 281 MHz

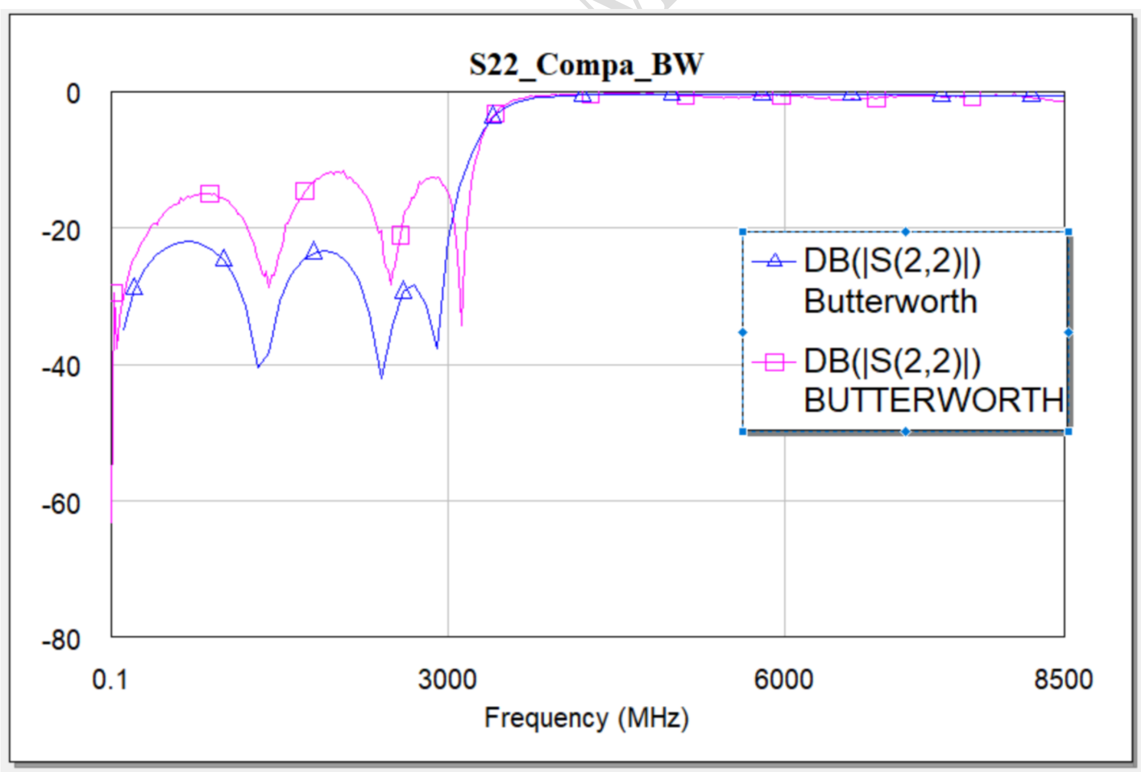
COMPLIANCE MATRIX

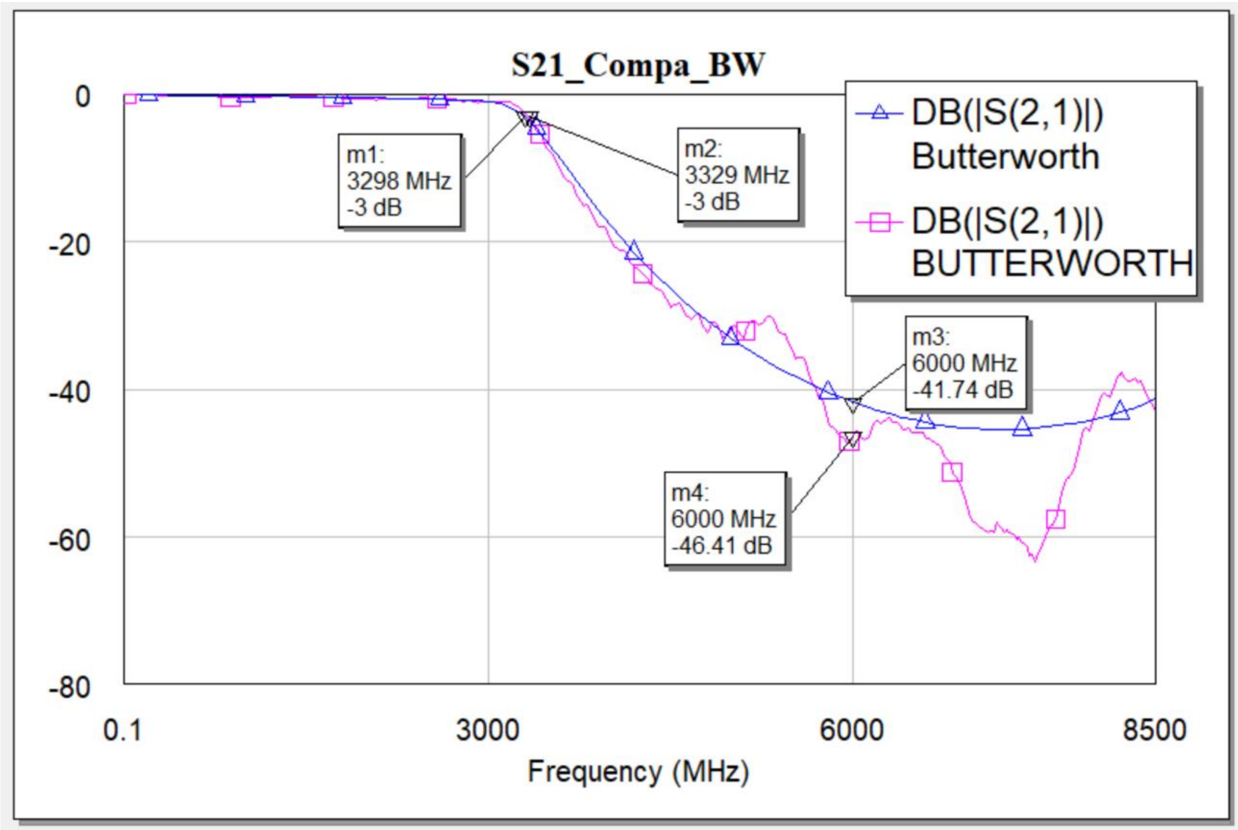
	Ideal	**Predicted**	**Measured**	**Compliance**
Frequency (GHz)	**3**	**3.038**	**3.281**	**YES**
Ripple (dB)	**0.5**	**0.7531**	**0.8534**	**NO**
Attenuation at 6GHz (dB)	**40**	**24.98**	**22.56**	**NO**

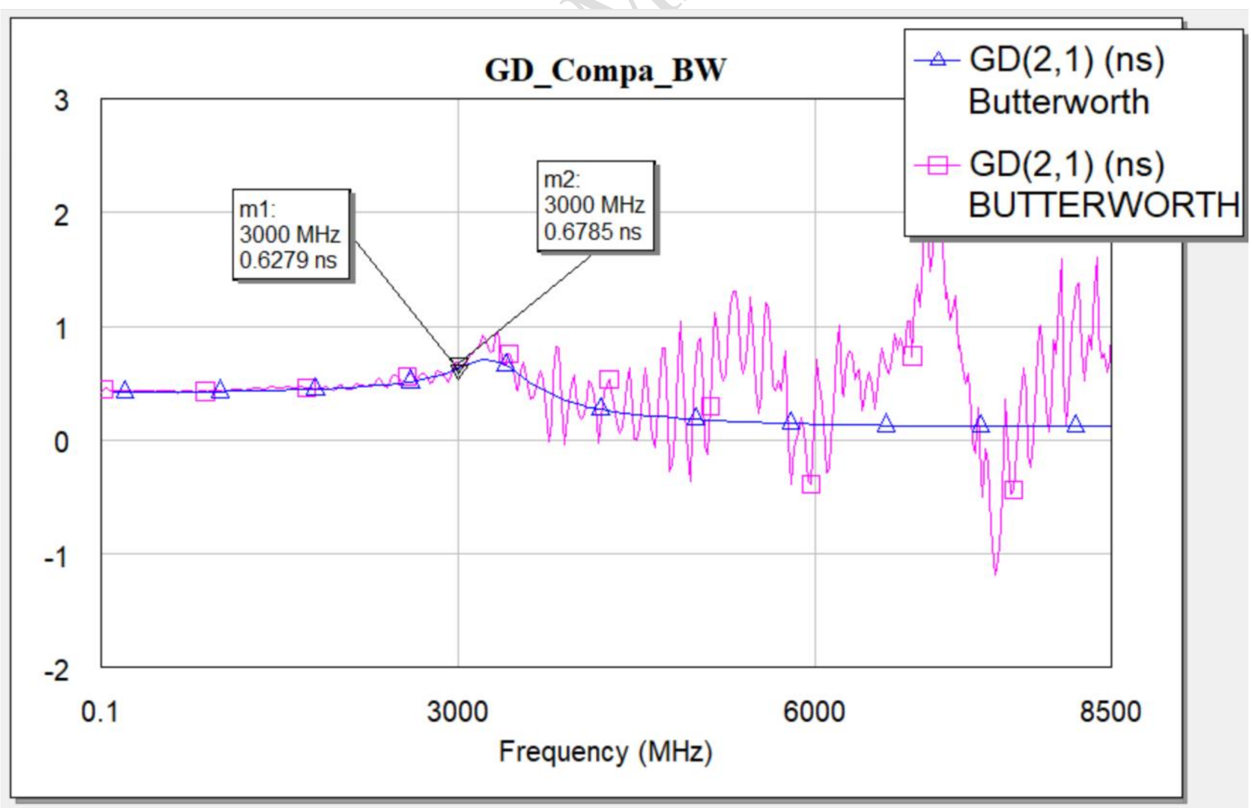
Summary: Some of the goals are not within the compliant range. Overall the design was not successful.

B. Butterworth Filter






S21_Compa_BW
DB(|S(2,1)|)
Butterworth
DB(|S(2,1)|)
BUTTERWORTH
m1:
3298 MHz
-3 dB
m2:
3329 MHz
-3 dB
m3:
6000 MHz
-41.74 dB
m4:
6000 MHz
-46.41 dB
0
-20
-40
-60
-80
0.1
3000
6000
8500
Frequency (MHz)


GD_Compa_BW
GD(2,1) (ns)
Butterworth
GD(2,1) (ns)
BUTTERWORTH
m1:
3000 MHz
0.6279 ns
m2:
3000 MHz
0.6785 ns
3
2
1
0
-1
-2
0.1
3000
6000
8500
Frequency (MHz)

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 Δf = 3 – 3.29 = 0.29 GHz
Measured Δf = 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 = -6.41dB

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.