Microwave Filters

Microwave Design and Measurements (EERF 6396)
Prof. Dr. Randall E. Lehmann
The University of Texas at Dallas

Submitted By

Niyati Sanandiya
(2021317640)

Lab partner: Megha Sarvagnappa

1. Introduction

Objectives:

- Design, simulate and build **0.5 dB ripple Chebyshev low pass micro strip filter** with cut off frequency 3 GHz on FR-4 material using AWR MWO (Axiem). Compare the measurement results and Axiem simulation results.
- Design, simulate and build **Butterworth (Maximally flat) low-pass micro strip filter** with cut off frequency 3 GHz on FR-4 material using AWR MWO (Axiem). Compare the measurement results and Axiem simulation results.

2. Design

A. Design Process

Design A: Chebyshev 0.5 dB ripple low-pass microstrip filter

- Chebyshev filter has better rejection in the reject band compared to Butterworth filter for same number of elements.
- Design goal is to achieve minimum 40 dB attenuation at 2Fc , n =5 is taken for fulfilling requirement.(As in this experiment, we are taking ideal minimum values and observing the practical results)
- The value of inductances and capacitances were calculated from the below equations:

$$L = \frac{Gn * R}{2 * pi * Fc} \qquad C = \frac{Gn}{2 * pi * Fc * R}$$

where Gn is equal to polynomial value of this 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

- Lumped Element schematic was built using iFilter Synthesis Wizard to verify the calculations.
- For each element, the reactance value was calculated from the above values.
- For inductors, reactance was normalized with Z0 = 115 ohm and open circuit stub length was calculated from the smith chart.
- For capacitors, reactance was normalized with Z0 = 45 ohm and open circuit stub length was calculated from the smith chart.
- Using TX Line tool in AWR MWO, physical length and width of each MLIN was calculated by entering electrical length from the smith chart and cut off frequency 3 GHz.

Design B: Butterworth (Maximally flat) low-pass micro strip filter

- Butterworth filter has flat response both in pass band and reject band at cost of gradual roll of than Chebyshev filter of the same order.
- Design goal is to achieve minimum 40 dB attenuation at 2Fc , n =7 is taken for fulfilling requirement. (As in this experiment, we are taking ideal minimum values and observing the practical results)
- The value of inductances and capacitances were calculated from the below equations:

$$L = \frac{Gn * R}{2 * pi * Fc} \qquad C = \frac{Gn}{2 * pi * Fc * R}$$

where Gn is equal to polynomial value of this table:

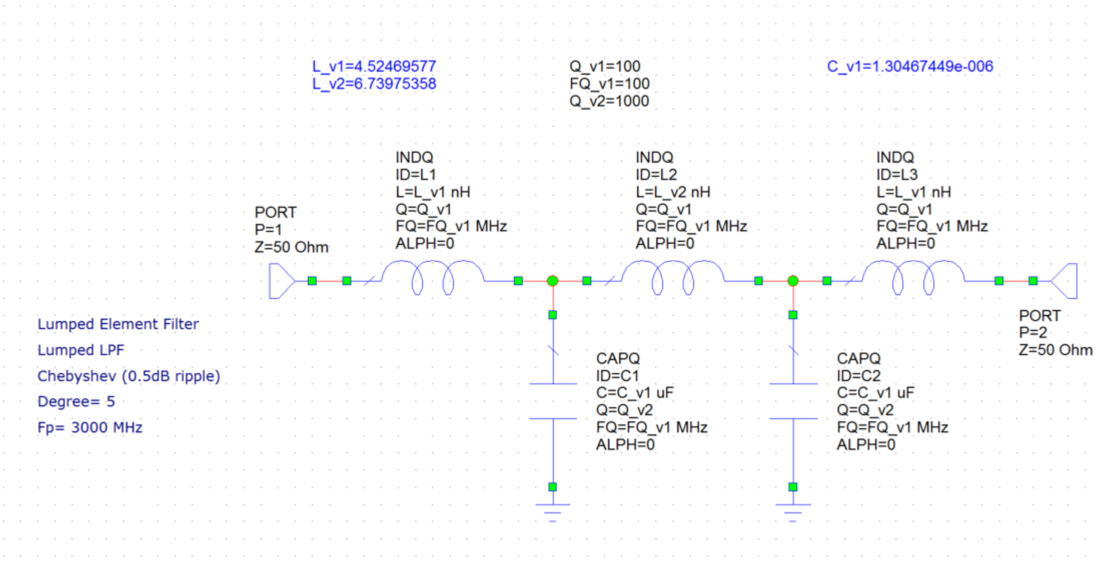
Order	R_S	C_1 a_1	L_2 a_2	C_3 a_3	L_4 a_4	C_5 a_5	L_6 a_6	C_7 a_7
1	1.0	2.0000						
2	1.0	1.4142	1.4142					
3	1.0	1.0000	2.0000	1.0000				
4	1.0	0.7654	1.8478	1.8478	0.7654			
5	1.0	0.6180	1.6180	2.0000	1.6180	0.6180		
6	1.0	0.5176	1.4142	1.9319	1.9319	1.4142	0.5176	
7	1.0	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450

- Lumped Element schematic was built using iFilter Synthesis Wizard to verify the calculations done for 7 elements.
- For each element, the reactance value was calculated from the above values.
- For inductors, reactance was normalized with Z0 = 115 ohm and open circuit stub length was calculated from the smith chart.
- For capacitors, reactance was normalized with Z0 = 25 ohm and open circuit stub length was calculated from the smith chart.
- Using TX Line, the physical length and width of each MLIN was calculated by entering the electrical length from the smith chart and cut off frequency 3 GHz.

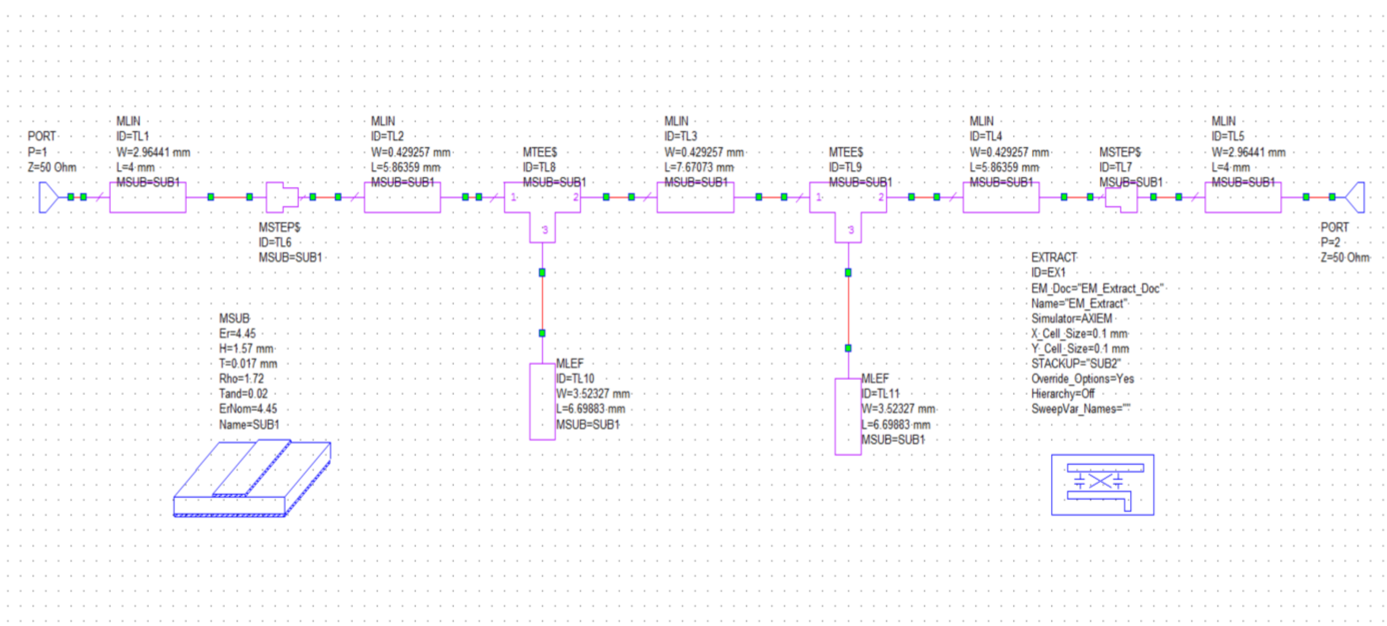
B. Figures related to design:

Design A: Chebyshev 0.5 dB ripple low-pass microstrip filter (my design)

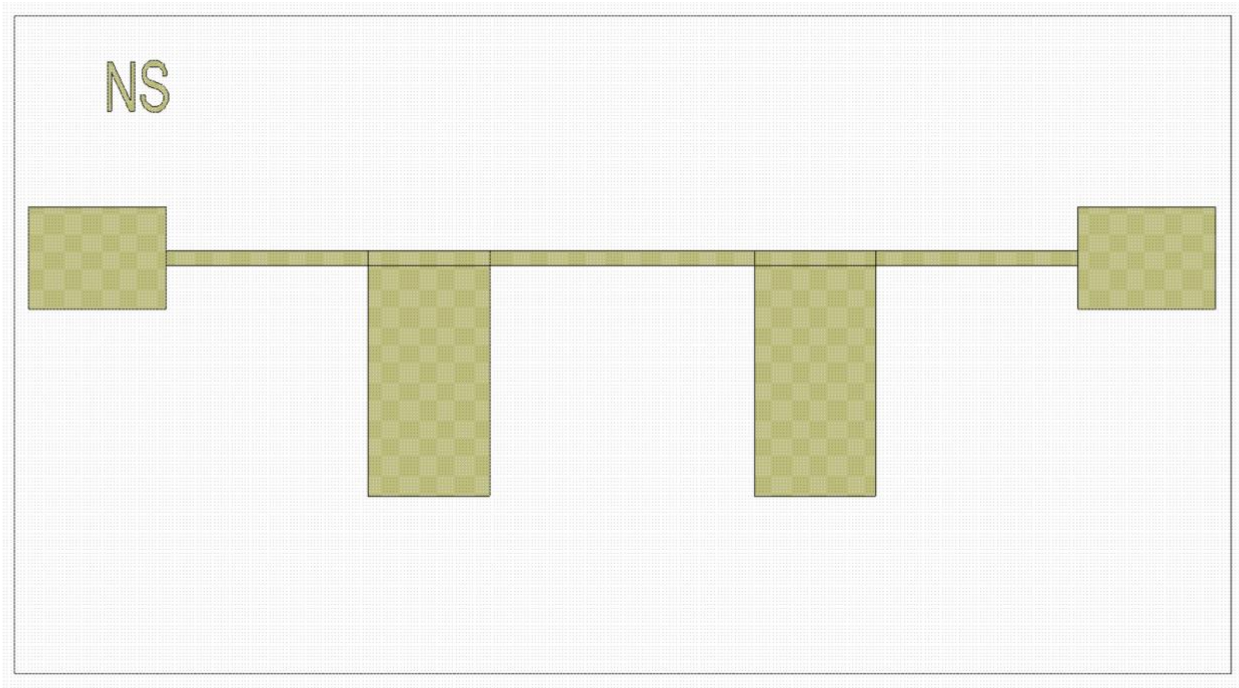
Lumped Element Schematic:



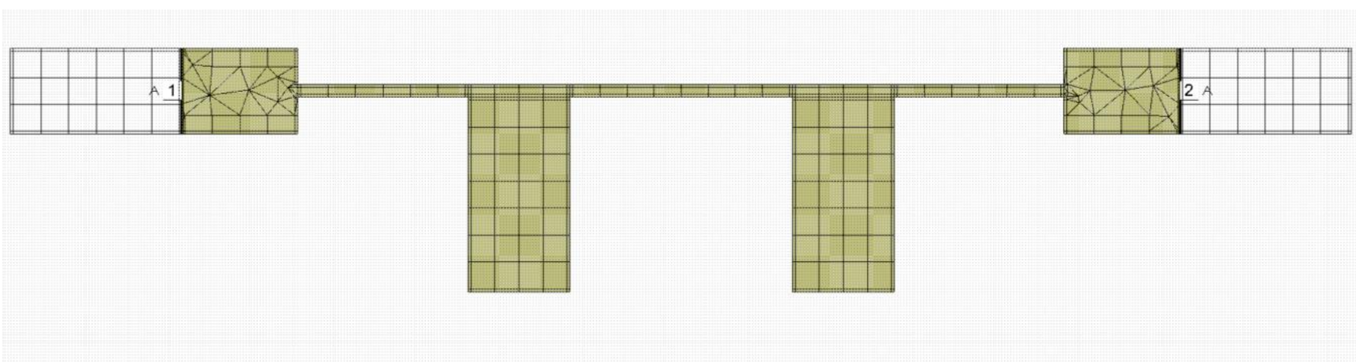
Circuit Schematic(Microstrip):



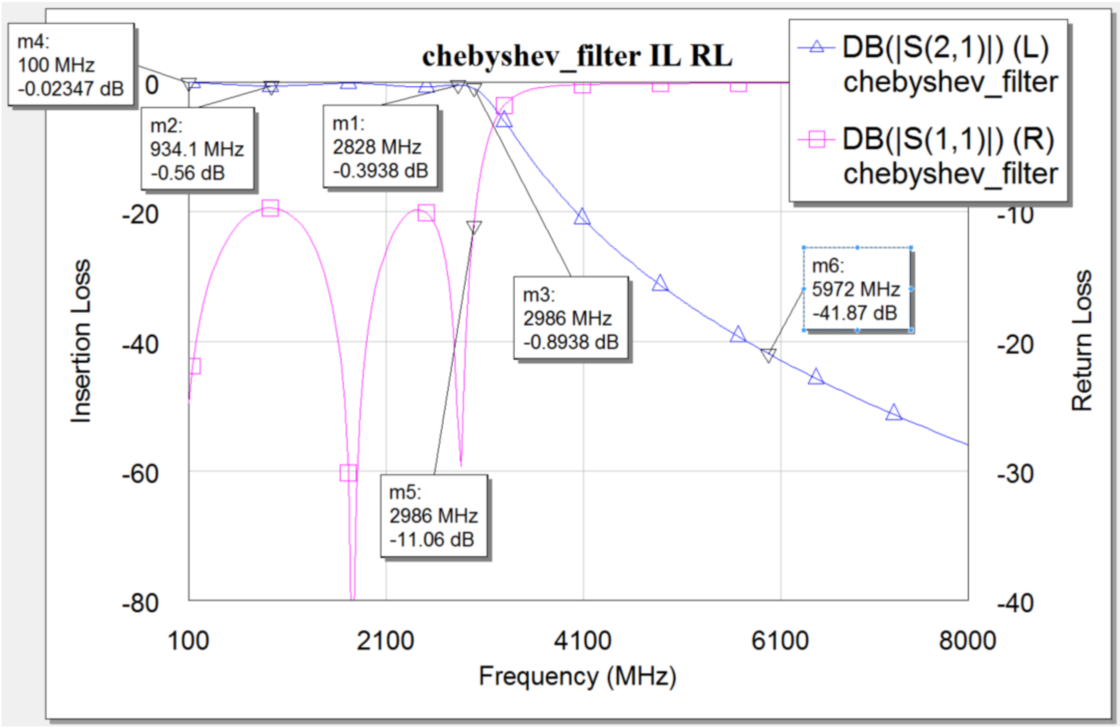
Layout:



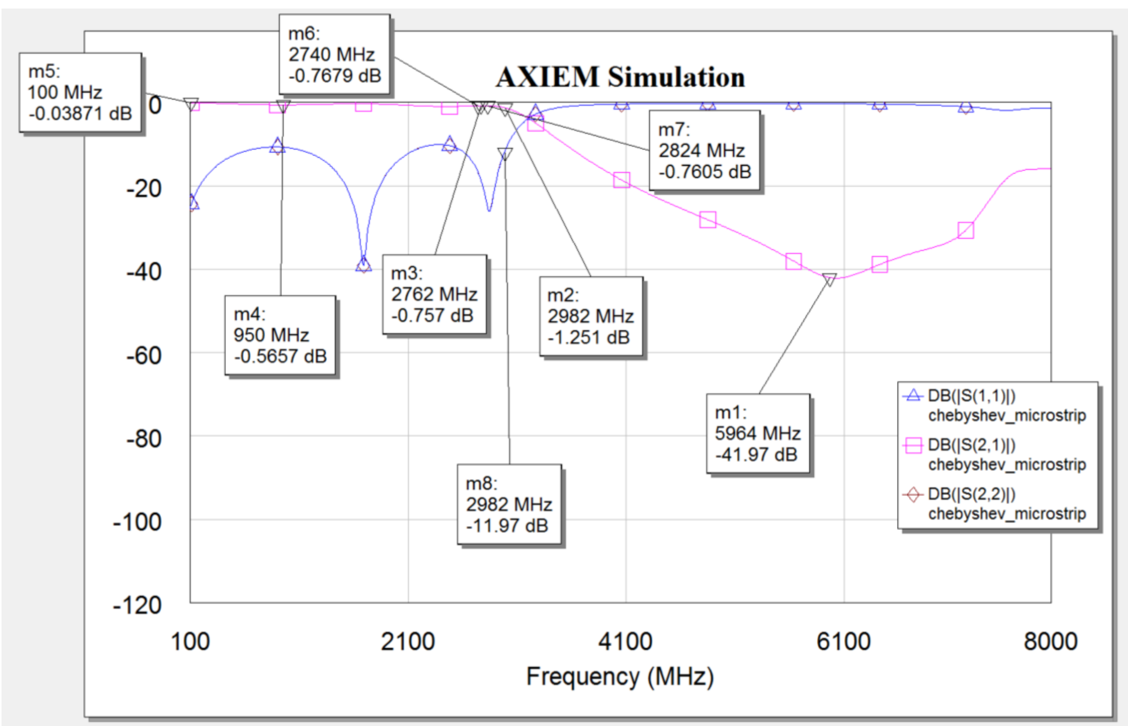
AXIEM Layout:



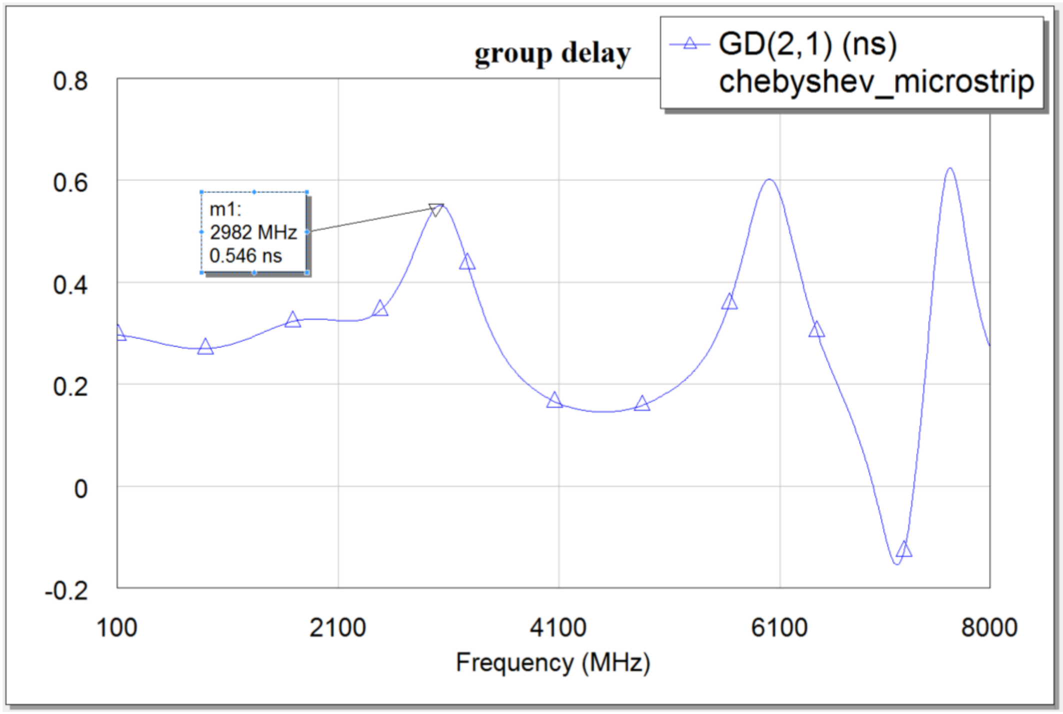
Lumped Element Circuit Simulation:



AXIEM Simulation:

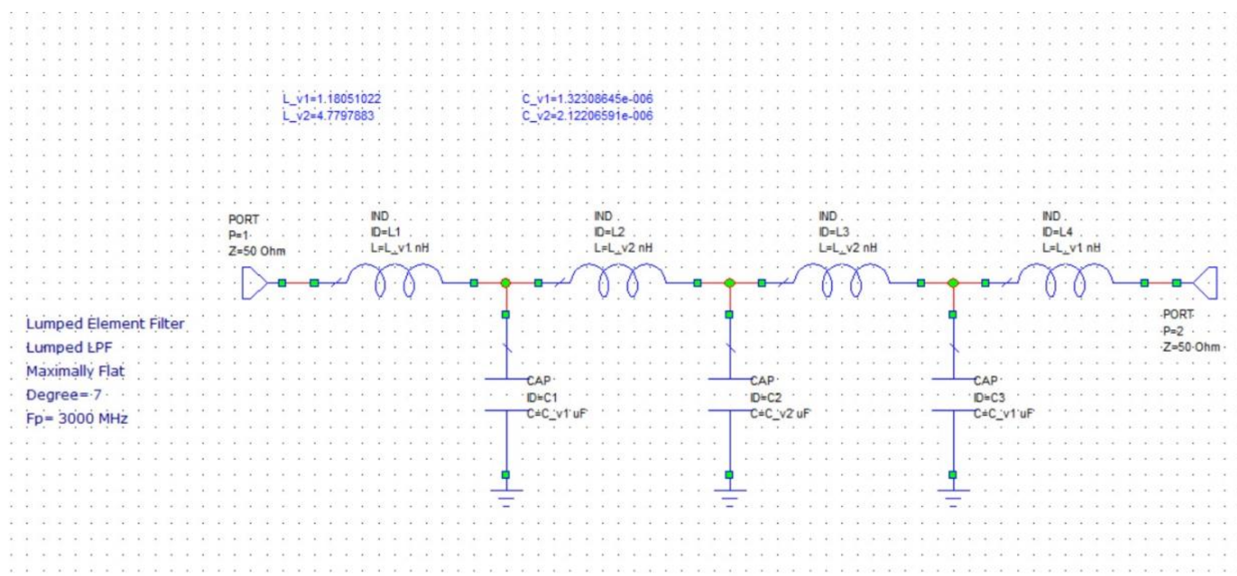


From the above graph, it is seen that the last peak is at 2.762 GHz (S21 = -757 dB). So, by adding 0.5 dB to IL at that point gives **cut off frequency at 2.982 GHz** (S21 = -1.251 dB).

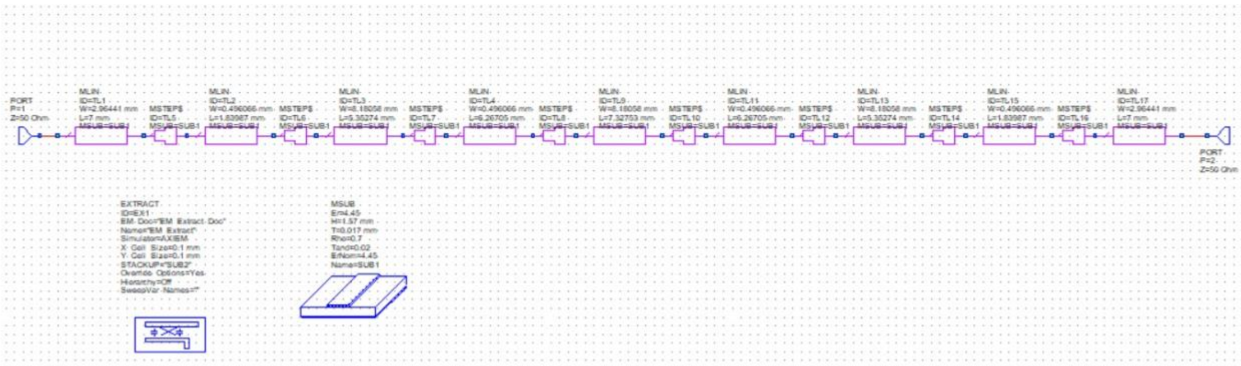


Design B: Butterworth (Maximally flat) low-pass micro strip filter (Megha Sarvagnappa)

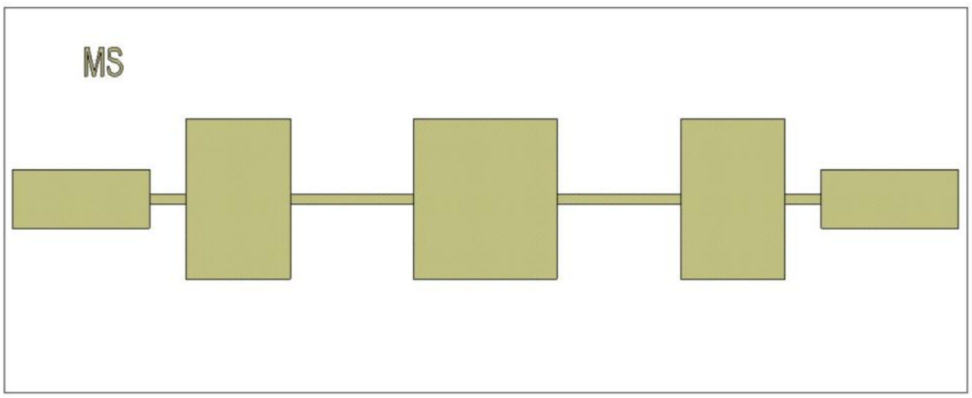
Lumped Element Schematic:



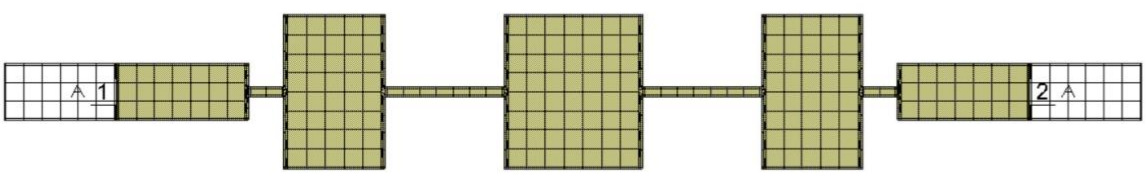
Circuit Schematic (Micro strip):



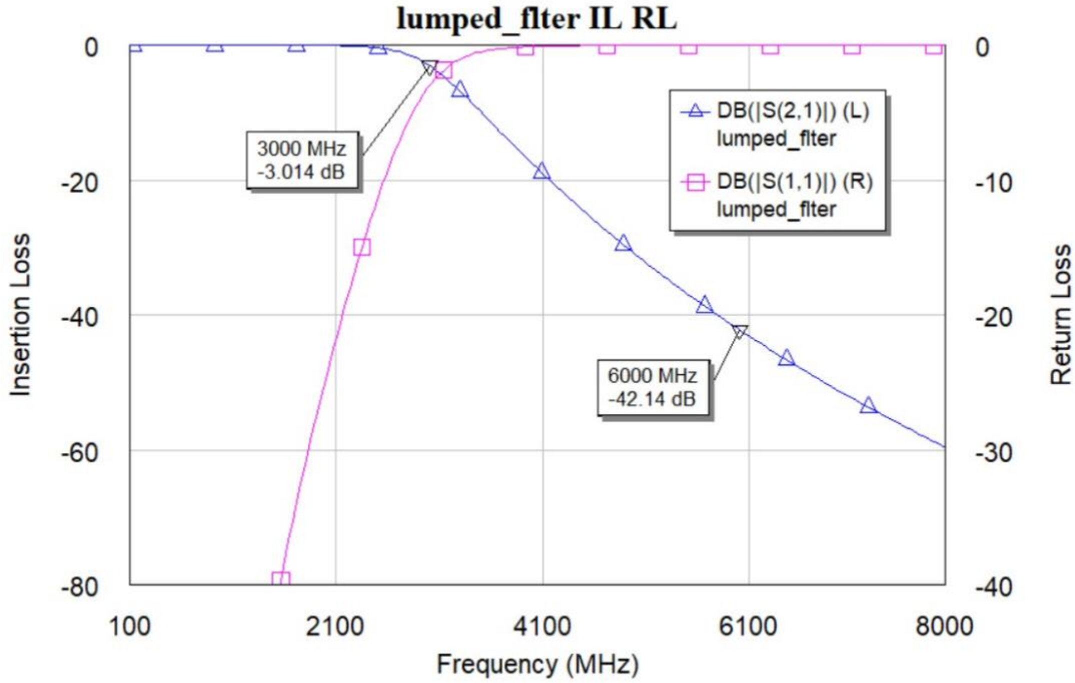
Layout:



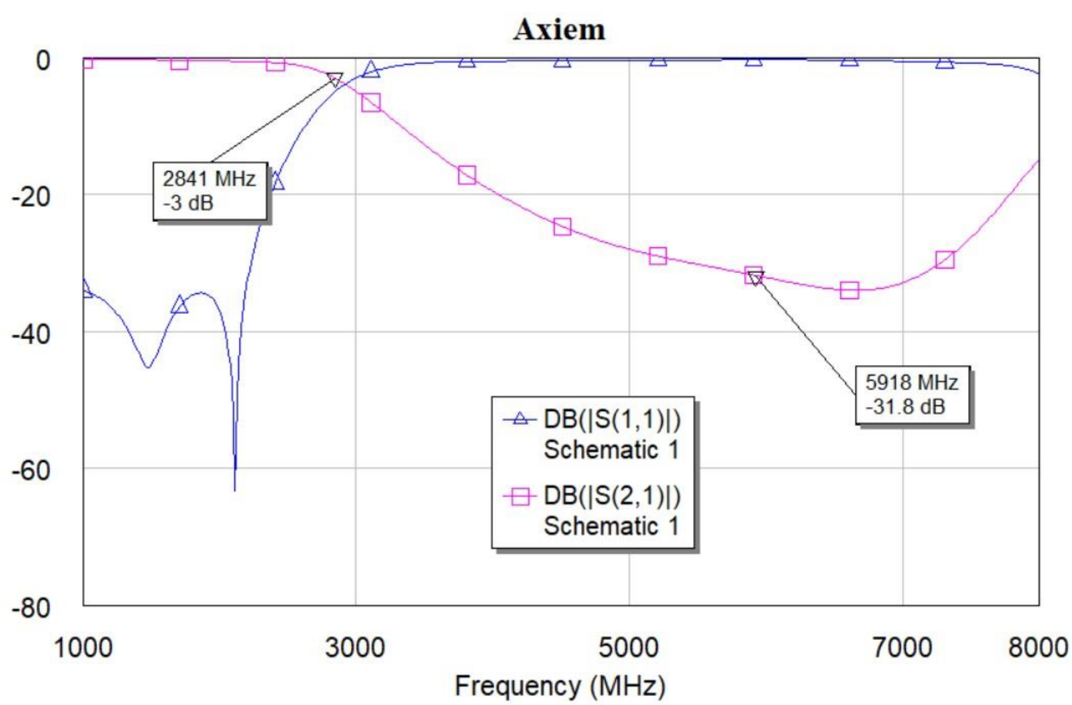
AXIEM Layout:

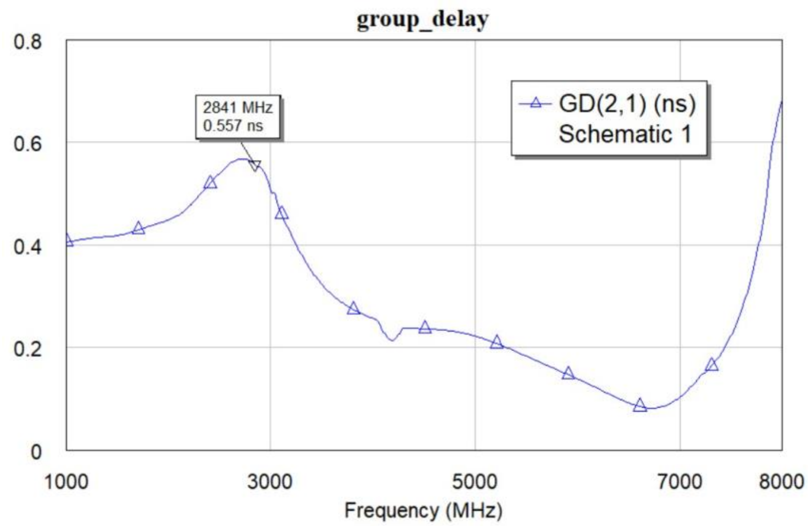


Lumped Element Circuit Simulation:



AXIEM Simulation:

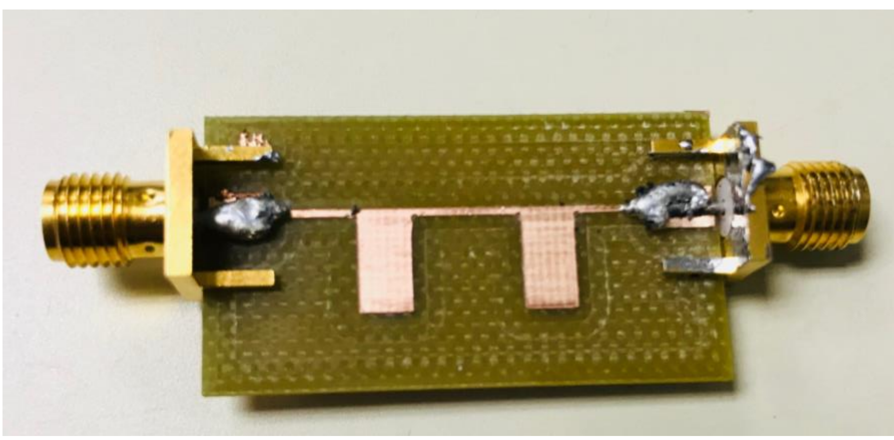


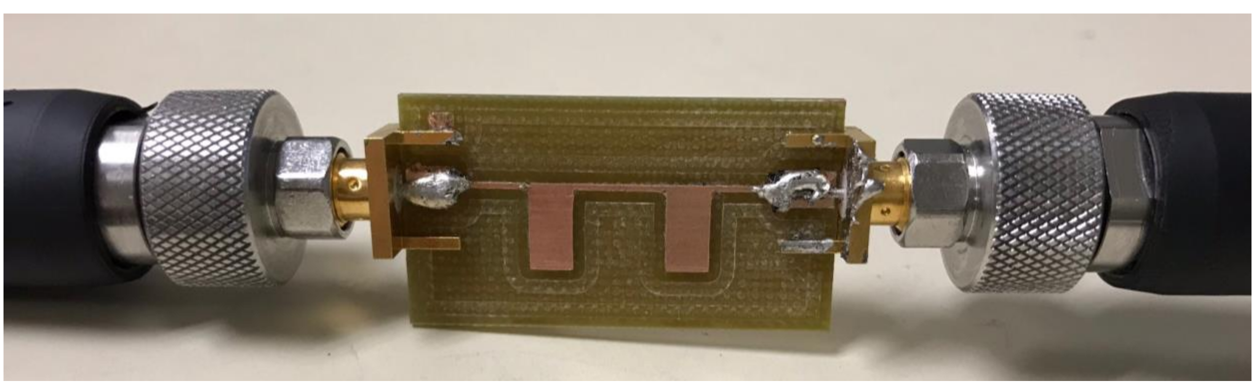


3. Measurement

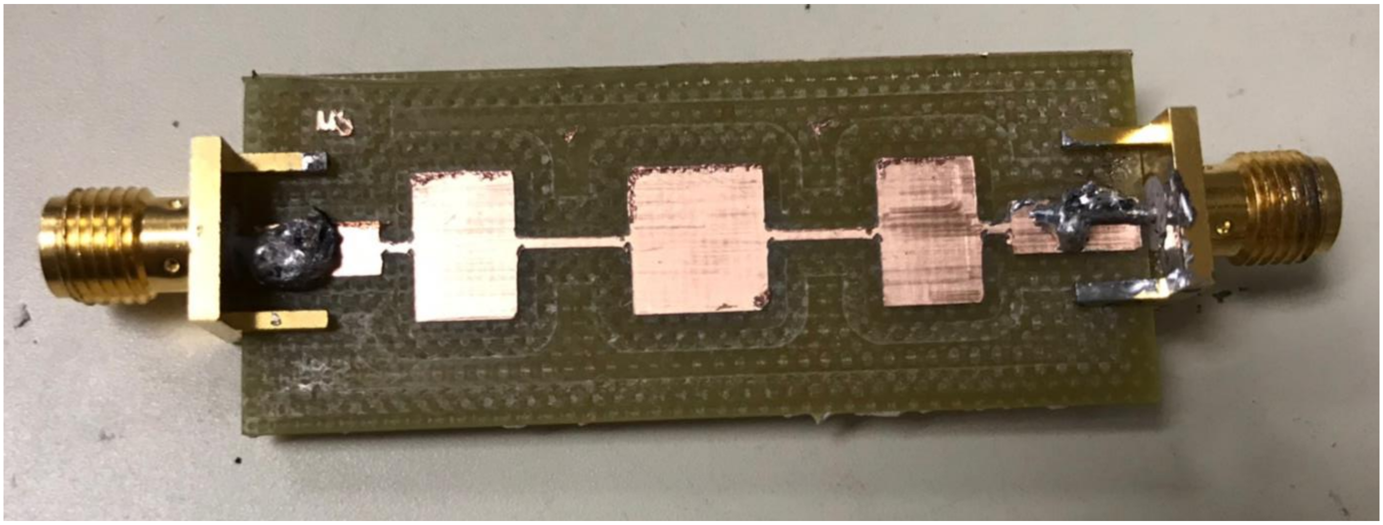
A. Photographs of measured circuit:

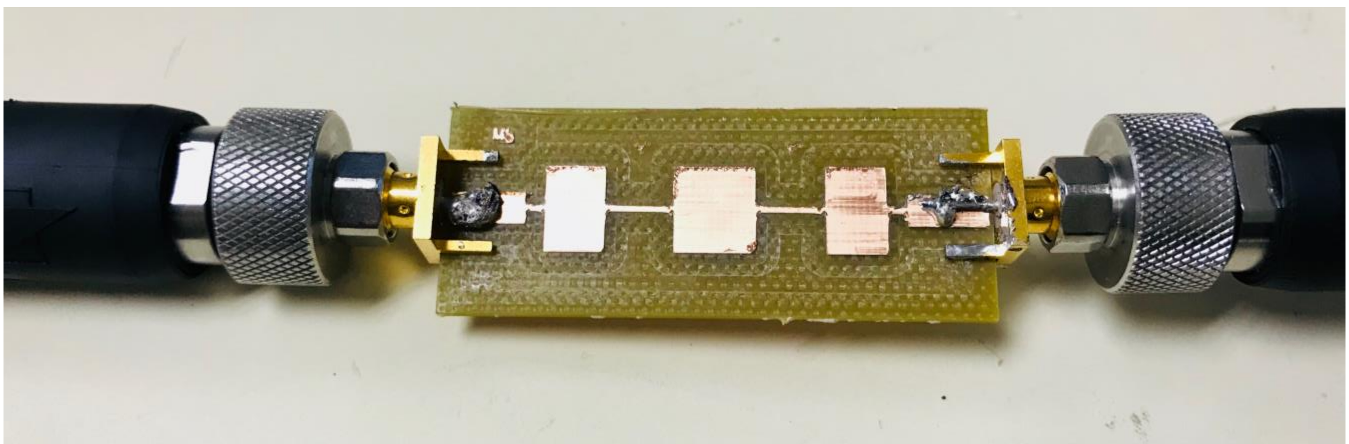
Design A: Chebyshev 0.5 dB ripple low-pass microstrip filter





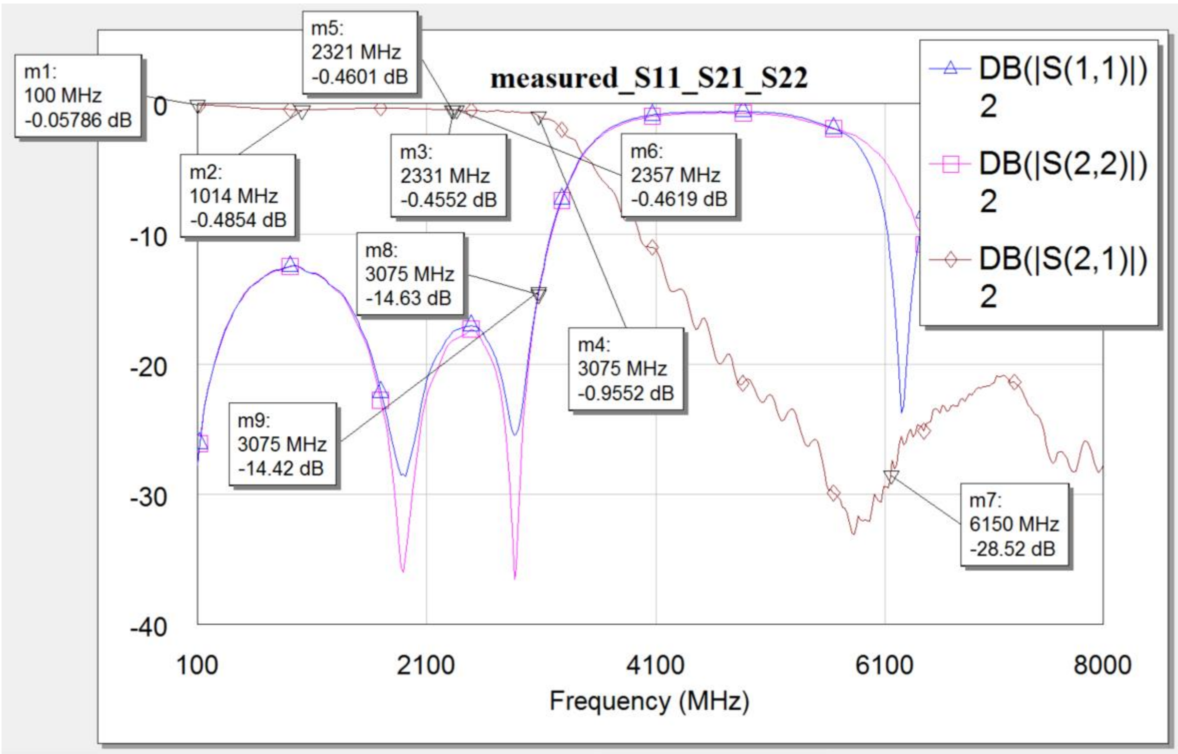
Design B: Maximally flat low-pass micro strip filter



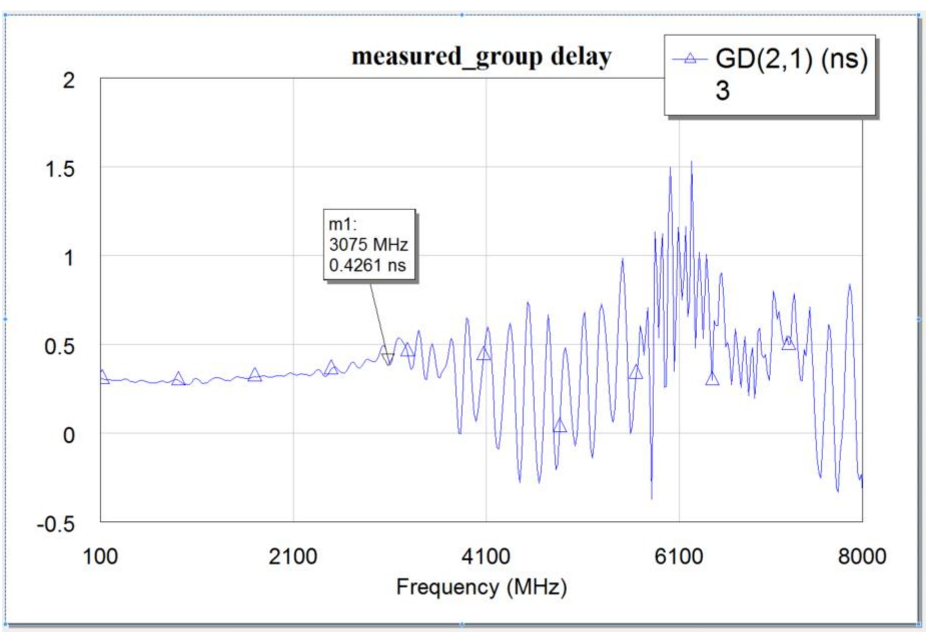


B. Plots of Measured Data

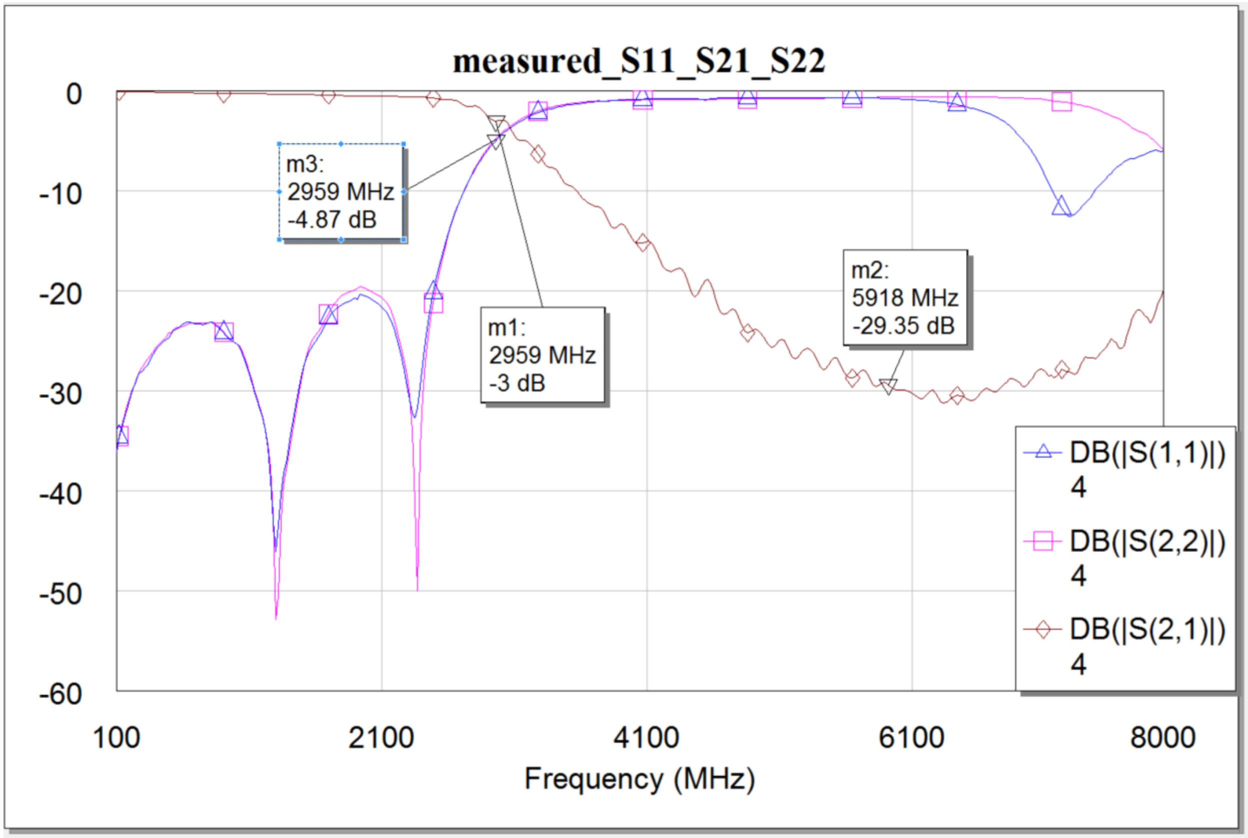
Design A: Chebyshev 0.5 dB ripple low-pass microstrip filter

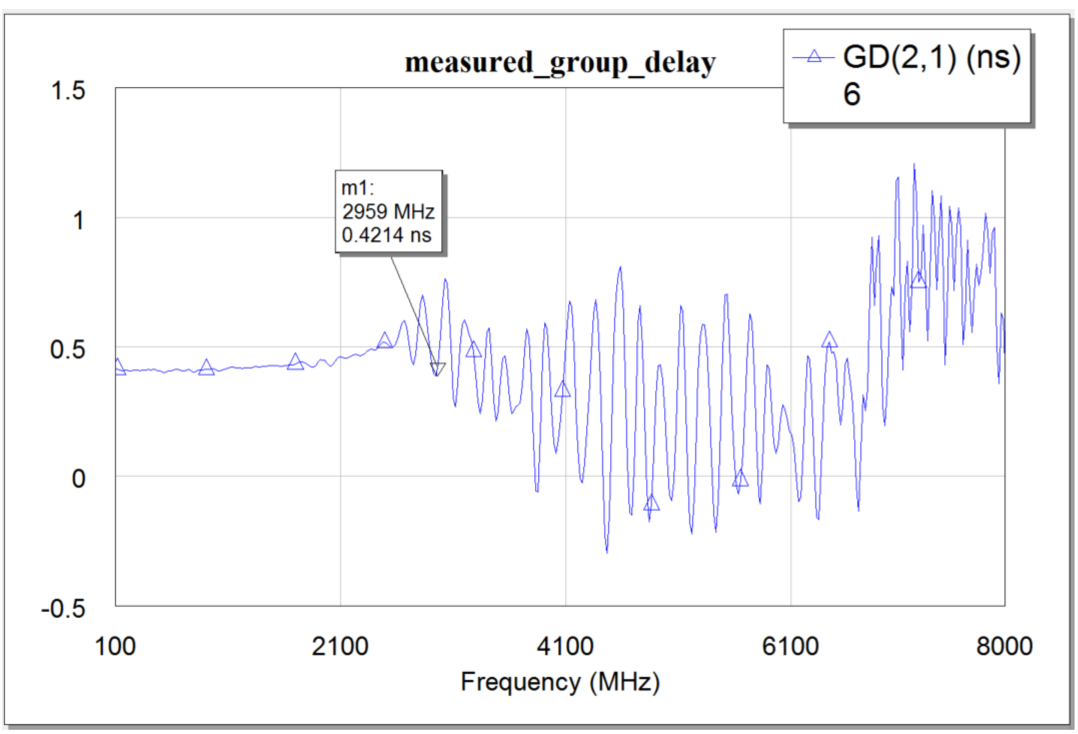


From the above graph, it is seen that the last peak is at 2.331GHz (S21=-0.4553). So, by adding 0.5 dB to IL at that point gives **cut off frequency at 3.075** GHz (S21 = -0.9552 dB).
S22 = -14.63 dB, S11 = -14.42 dB.



Design B: Maximally flat low-pass micro strip filter

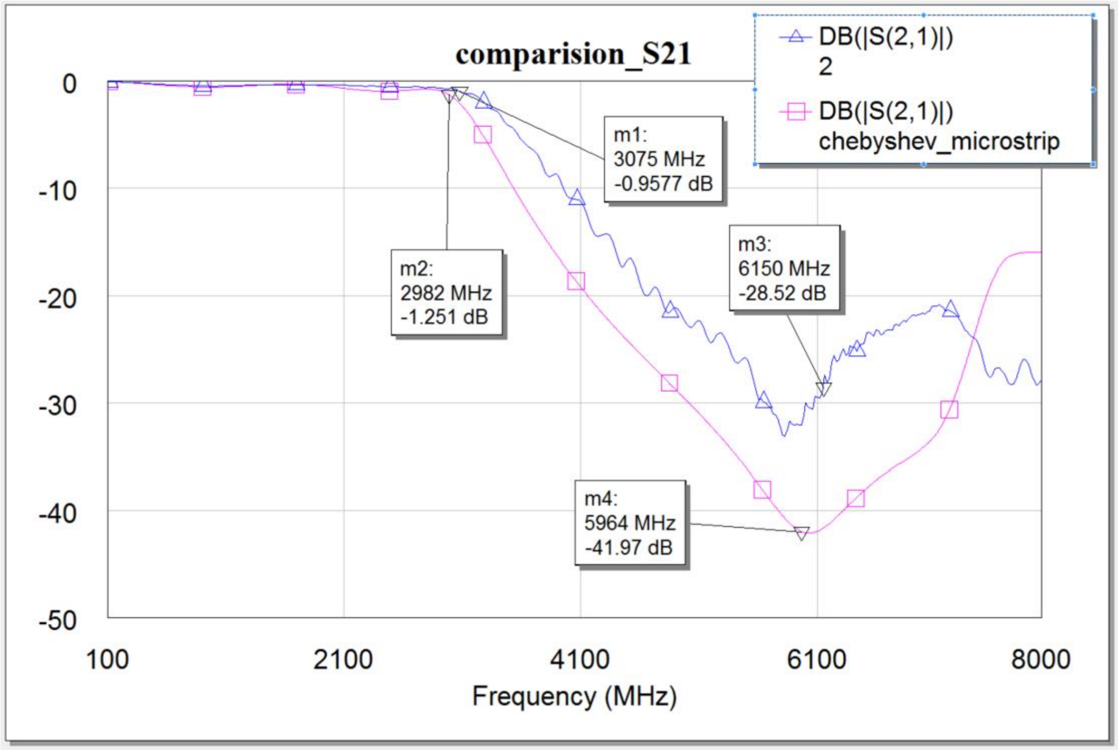


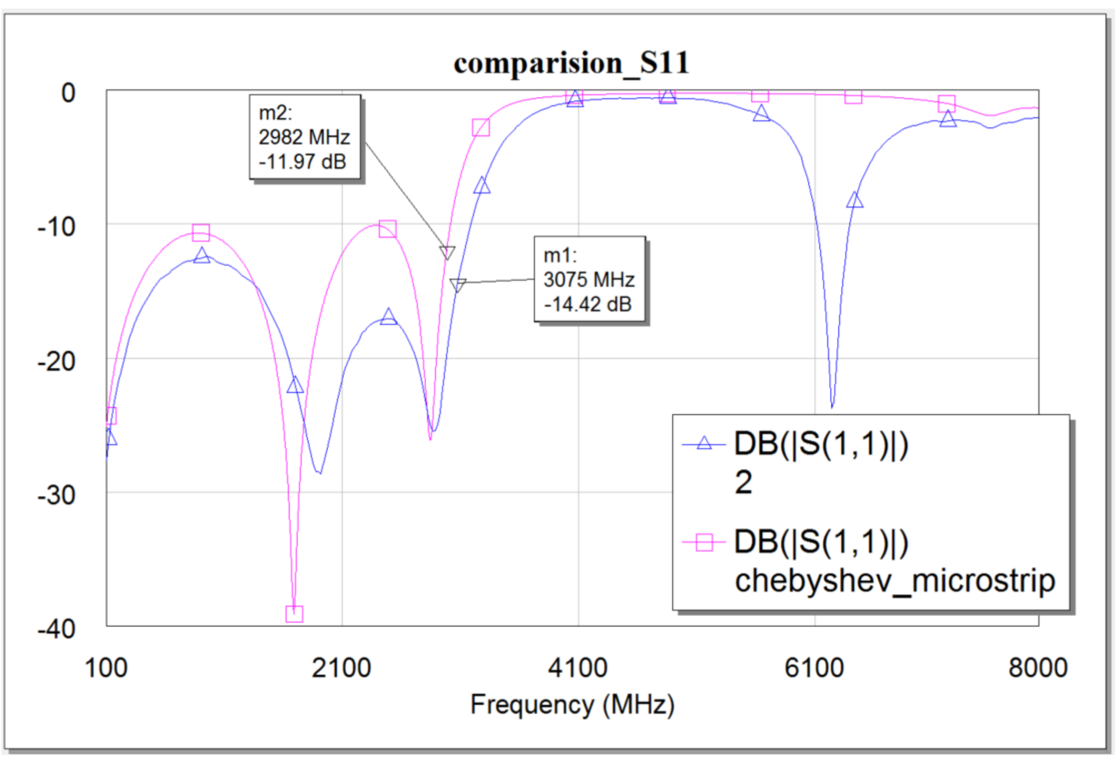


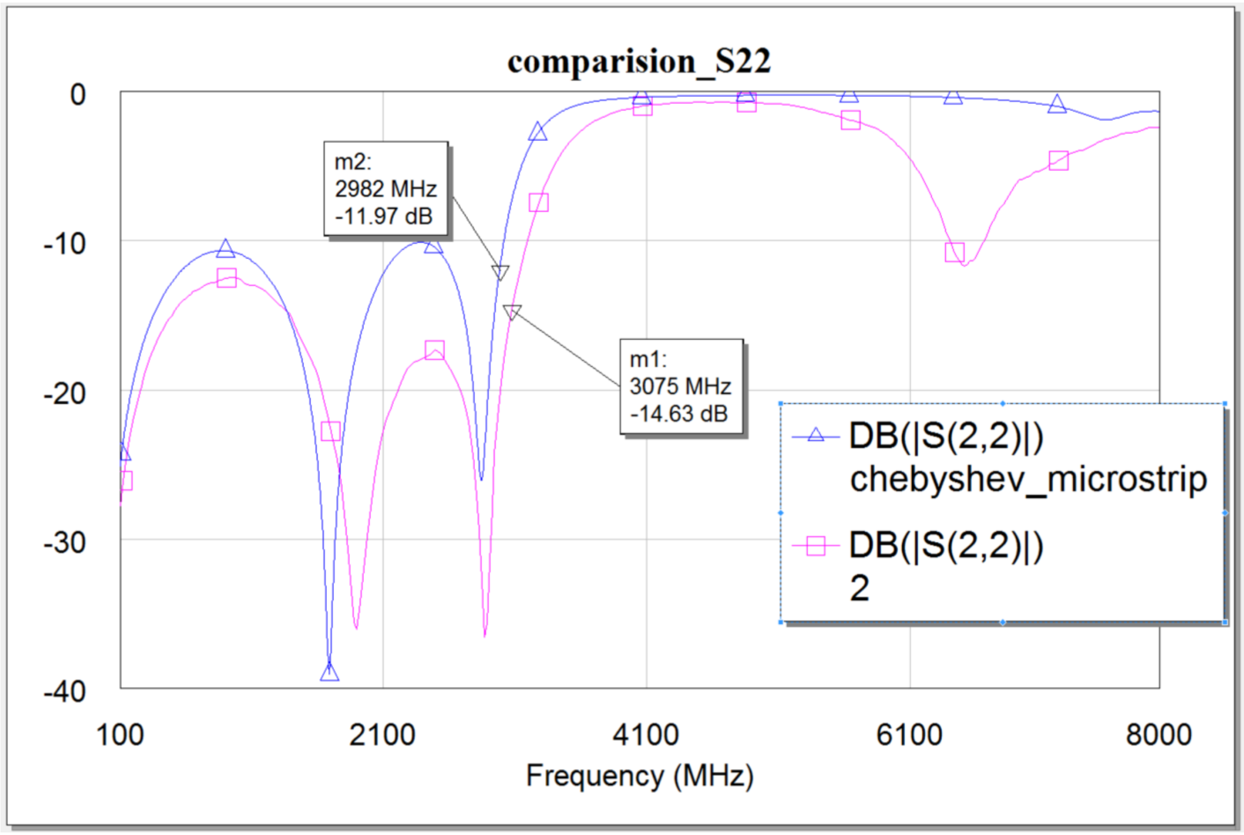
4. Analysis

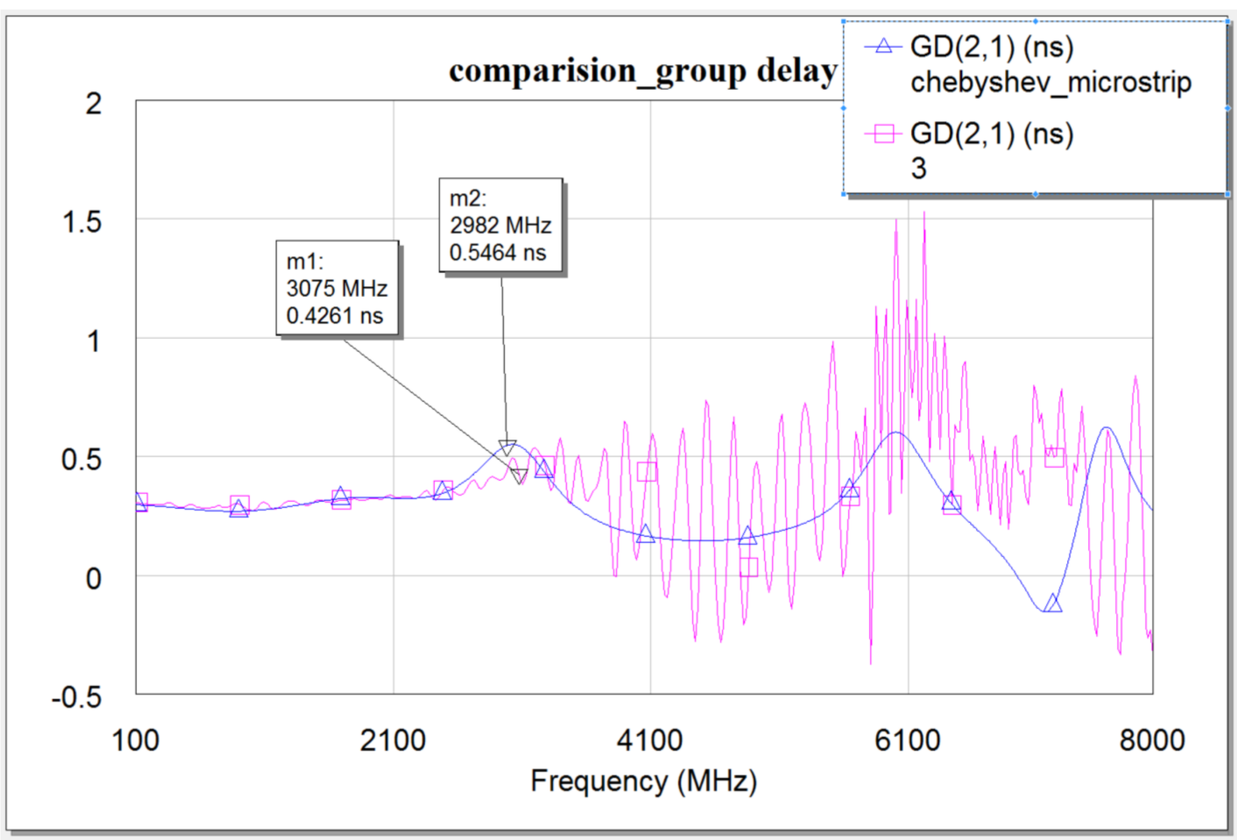
A. Comparison graph of predicted and measured graph

Design A: Chebyshev 0.5 dB ripple low-pass microstrip filter (my design was milled)

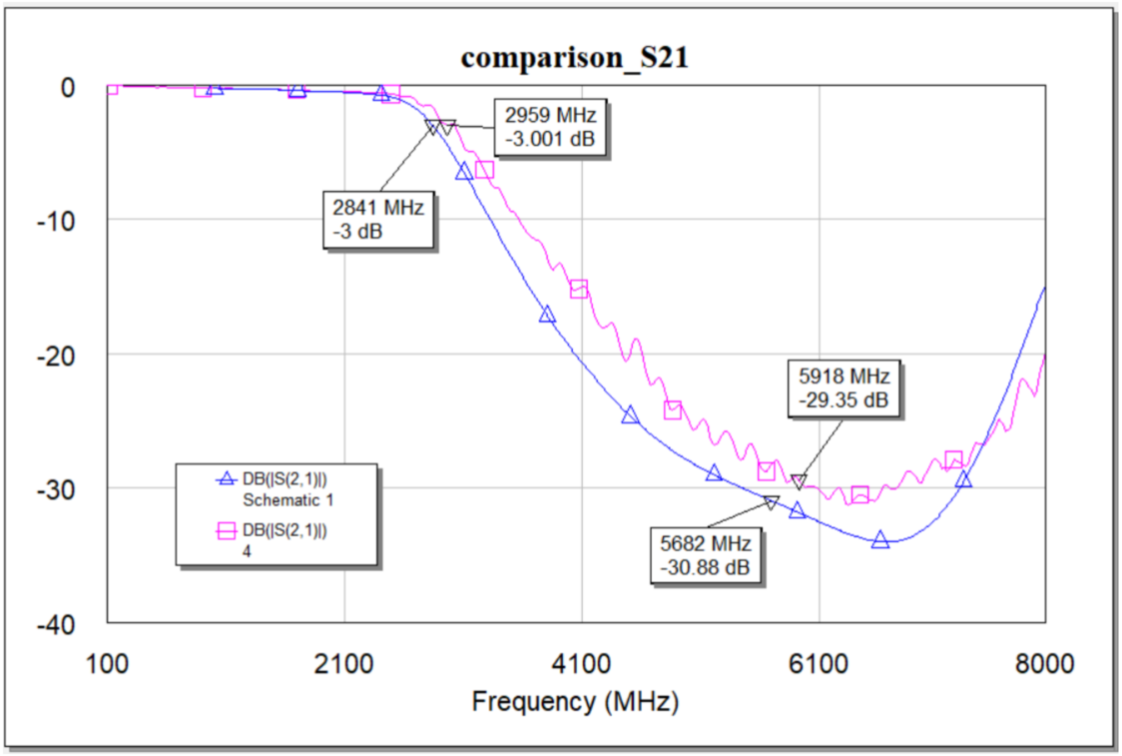


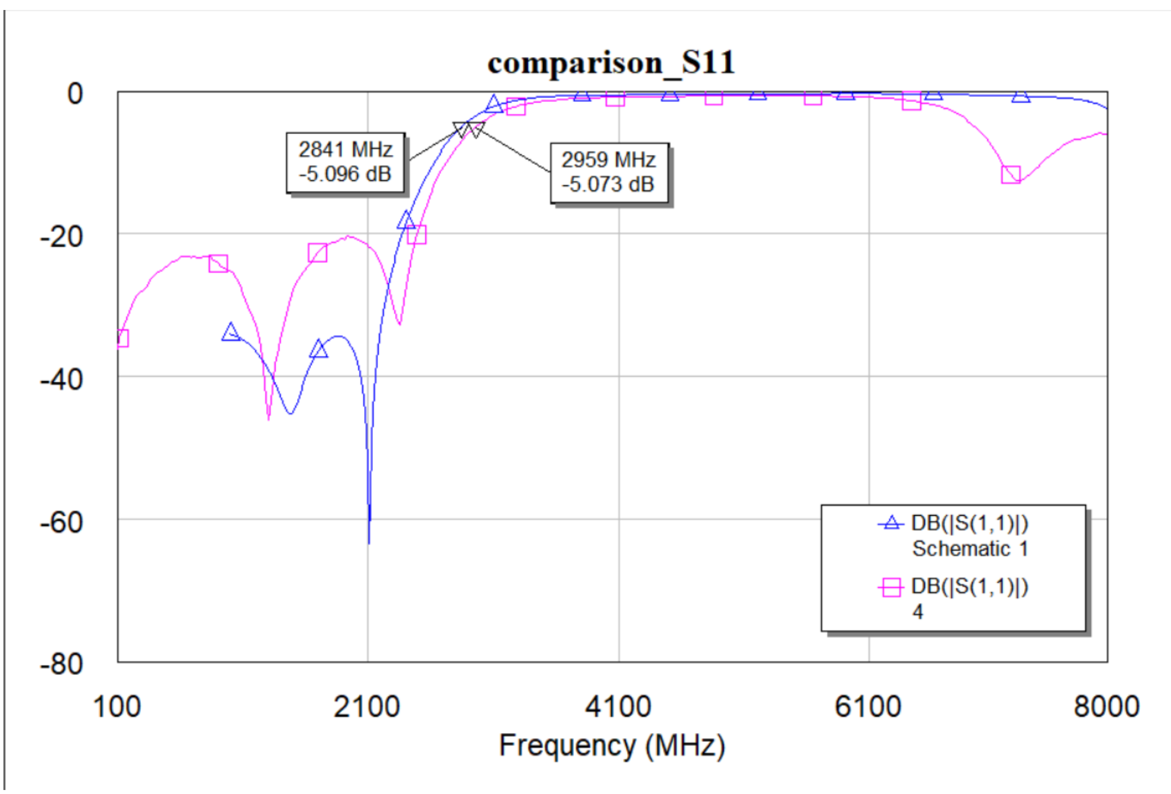


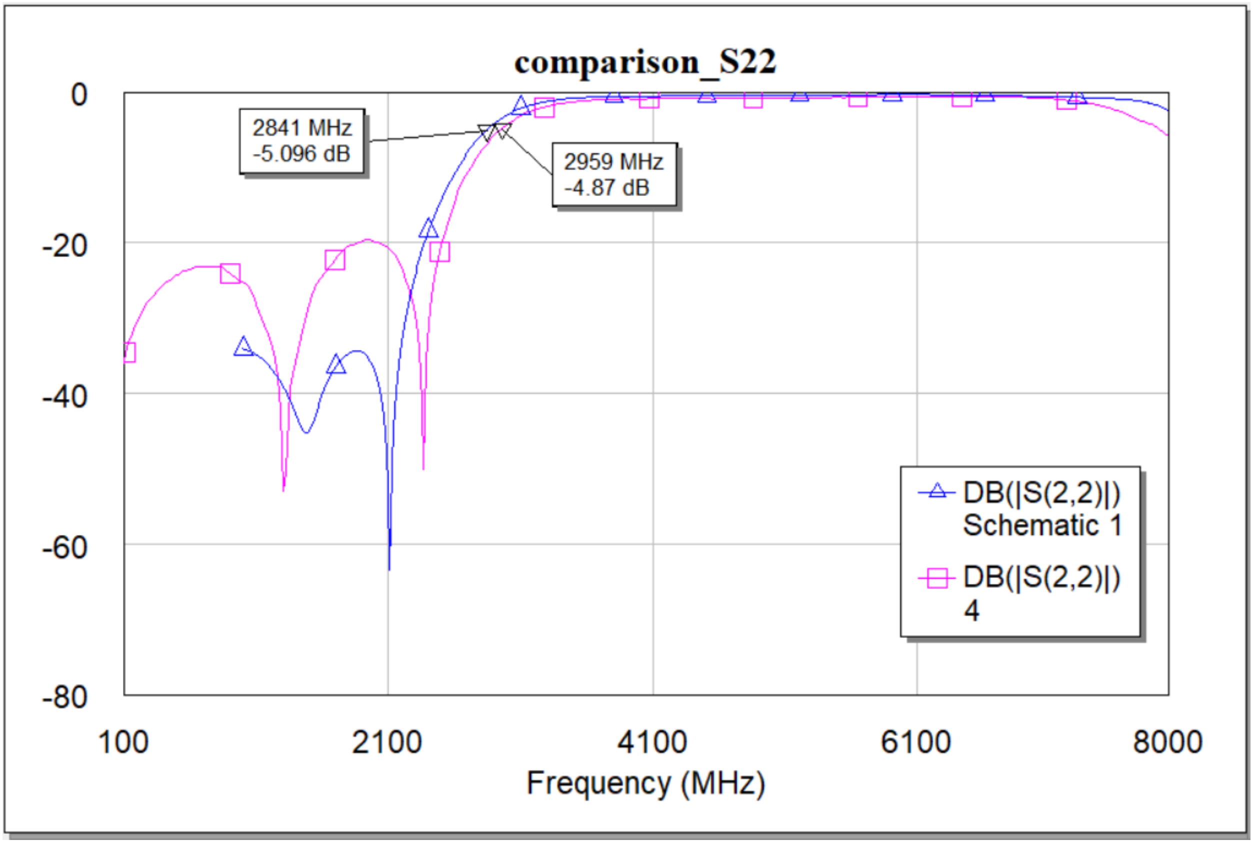

comparision_S22
0
-10
-20
-30
-40
100
2100
4100
6100
8000
Frequency (MHz)
m2:
2982 MHz
-11.97 dB
m1:
3075 MHz
-14.63 dB
DB(|S(2,2)|)
chebyshev_microstrip
DB(|S(2,2)|)
2

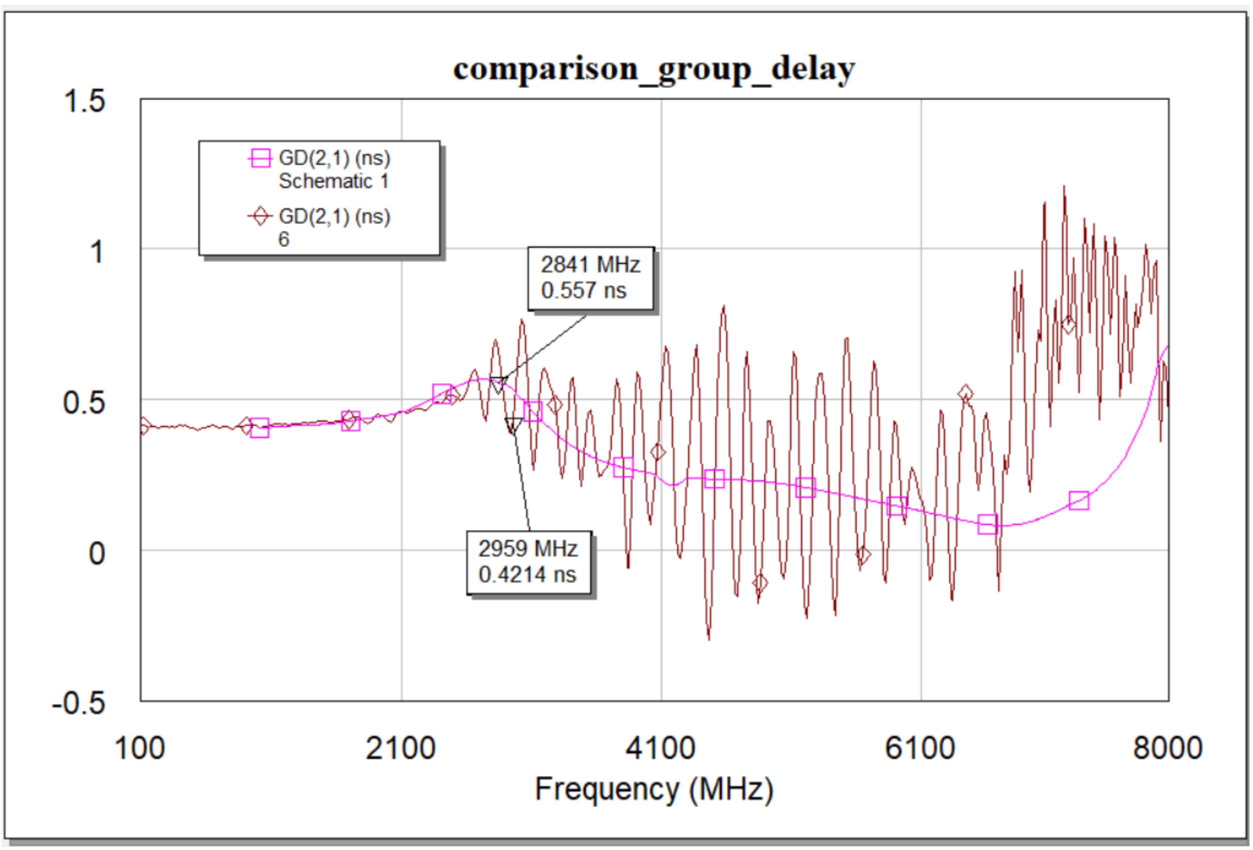

comparision_group delay
2
1.5
1
0.5
0
-0.5
100
2100
4100
6100
8000
Frequency (MHz)
m1:
3075 MHz
0.4261 ns
m2:
2982 MHz
0.5464 ns
GD(2,1) (ns)
chebyshev_microstrip
GD(2,1) (ns)
3

Design B: Maximally flat low-pass micro strip filter (Megha's Design was milled)






comparison_S22
2841 MHz
-5.096 dB
2959 MHz
-4.87 dB
DB(|S(2,2)|)
Schematic 1
DB(|S(2,2)|)
4
0
-20
-40
-60
-80
100
2100
4100
6100
8000
Frequency (MHz)


comparison_group_delay
GD(2,1) (ns)
Schematic 1
GD(2,1) (ns)
6
2841 MHz
0.557 ns
2959 MHz
0.4214 ns
1.5
1
0.5
0
-0.5
100
2100
4100
6100
8000
Frequency (MHz)

B. Compliance matrix

Design A: Chebyshev 0.5 dB ripple low-pass microstrip filter

Parameter	Design Goal	Predicted Performance	Measured Performance	Compliant (Yes/No)
Cut-off frequency (f_c)(GHz)	3 GHz	2.982 GHz	3.075 GHz	Yes
Ripple (dB)	0.5 dB	0.5316 dB	0.495 dB	Yes
Insertion Loss @ 2f_c GHz (dB) Ideal	> 40 dB	41.97 dB @ 5.964 GHz	28.52 dB @ 6.150 GHz	No

Design B: Maximally flat low-pass micro strip filter

Parameter	Design Goal	Predicted Performance	Measured Performance	Compliant (Yes/No)
Cut-off frequency (f_c)(GHz)	3 GHz	2.841 GHz	2.959 GHz	Yes
Insertion Loss @ 2f_c GHz (dB) Ideal	> 40 dB	30.88 dB @ 5.682 GHz	29.35 dB @ 5.918 GHz	No

C. Summary

Design A: Chebyshev 0.5 dB ripple low-pass microstrip filter

Design B: Maximally flat low-pass micro strip filter

1. How does your measured cutoff frequency compare to :
   a. theory (ideal) (in +/- Δf from f_c)?
   b. your predicted response (in +/- Δf from f_c)?

A1:
Δf (measured – ideal) = 3.075 - 3 = 0.075 GHz (within +/- 5% tolerance)
Δf (measured – predicted) = 3.075 – 2.982 = 0.093 GHz (within +/- 5% tolerance)

B1:
Δf (measured – ideal) = |2.959 – 3| = 0.041 GHz (within +/- 5% tolerance)
Δf (measured – predicted) = 2.959 – 2.841 = 0.118 GHz (within +/- 5% tolerance)

2. How does your measured rejection (|S21|) at $2f_c$ compare to:
    a. theory (ideal) (in +/- dB)?
    b. your predicted response (in +/- dB)?

A2:
ΔRejection (measured – ideal) = |28.52 - 41.87| dB = 13.35 dB
ΔRejection (measured – predicted) = |28.52 - 41.97 | dB = 13.45 dB

B2:
ΔRejection (measured – ideal) = |29.35 – 42.14| dB = 12.79 dB
ΔRejection (measured – predicted) = |29.35 – 30.88 | dB = 1.53 dB

3. Which filter has better (lower) group delay?

- Chebyshev 0.5 dB ripple low-pass microstrip filter has group delay 0.4261 ns.
- Maximally flat low-pass micro strip filter has group delay 0.4214 ns.
- Group delay of Maximally flat filter is lower than Chebyshev 0.5 dB ripple filter.

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

- Insertion loss could be made better by adding more number of lumped elements in the circuit. (As in this experiment, we had taken ideal minimum values for observing the practical results)

5. Conclusion

A. Was the design successful? Why or why not?

- Cut-off frequency of both filters were met as lossy nature of FR-4 substrate was taken into consideration while designing the circuits. Insertion loss could be made better by adding more number of lumped elements in the circuit. (As in this experiment, we had taken ideal minimum values for observing the practical results)

B. What lessons did you learn from the lab?

- From this lab, I learned how to take dielectric constant value into consideration while designing the circuit to obtain desired cut-off frequency in practical results.
- The goal of the experiment was to take ideal minimum number of lumped elements and observe the practical results. As we can conclude from the measurements, required insertion loss is not achieved by using ideal number of lumped elements due to the lossy nature of substrate and inaccuracy in milling process. We need to add more number of lumped elements in the circuit to get desired insertion loss.