Guiding electromagnetic systems

Project 1

Stepped-impedance low-pass filter with 0.5 dB ripple, equal electric length transmission line segments (45°)

Subgroup 1

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Abstract- This paper introduces a microstrip stepped impedance low pass filter with low insertion. Microstrip filters are largely used to fulfill demands for microwave systems and to contribute to solve the telecommunication challenges in terms of performance, size and cost. Here, a stepped impedance filter is expected to be designed and optimized at a center frequency of 2.4 GHz and to operate between 0 GHz and 5 GHz as range of frequencies. This paper outlines a common design method foe microstrip low pass filters which are used to attenuate microwave frequency signals beyond the cut-off frequency.

INTRODUCTION

A low pass filter is a filter that passes low frequency signals and attenuates the amplitude of signals with frequencies higher than the cut-off frequency. Low pass filters can be found in many different forms, including electronic circuits such as a hiss filter used in audio, anti-aliasing filters for conditioning signals, digital filters for smoothing sets of data, acoustic barriers, blurring of images…

Project specifications

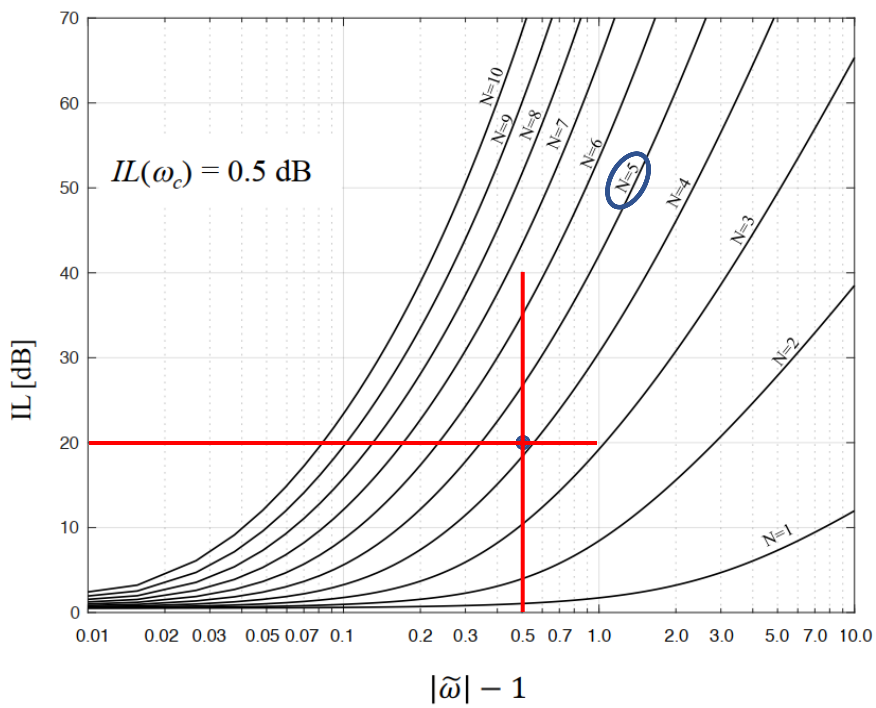
- microstrip filter
- dielectric material : $\varepsilon r = 4.4$, $h = 1.6$ mm
- Filter type : Low-pass
- Response type : Equal-ripple (0.5 dB)
- $f1$ [GHz] : 2.4
- $R0$ [Ω] : 50
- Insertion loss [dB] @ f = 3.6 [GHz] > 20 dB

Design of the prototype filter

First we have to determine the order of the filter using specifications.

$$\tilde{\omega} = \frac{\omega}{\omega_c} = \frac{f}{f_c} = \frac{3.6}{2.4} = 1.5$$

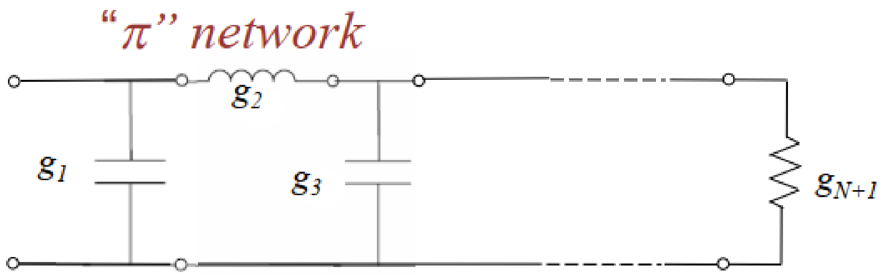
$$\Rightarrow \tilde{\omega} - 1 = 0.5$$



$$\Rightarrow N = 5$$

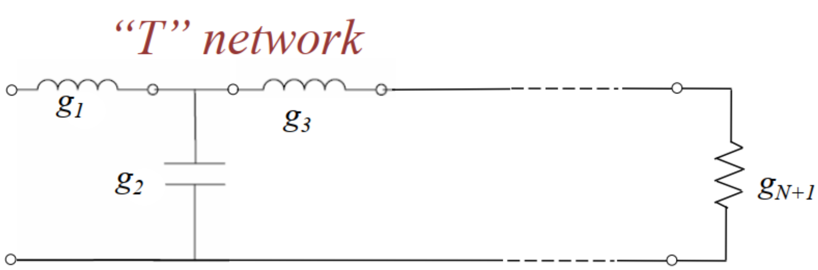
N	g1	g2	g3	g4	g5	g6	g7	g8	g9	g10	g11
1	0.6986	1.0000									
2	1.4029	0.7071	1.9841								
3	1.5963	1.0967	1.5963	1.0000							
4	1.6703	1.1926	2.3661	0.8419	1.9841						
5	1.7058	1.2296	2.5408	1.2296	1.7058	1.0000					
6	1.7254	1.2479	2.6064	1.3137	2.4758	0.8696	1.9841				
7	1.7373	1.2582	2.6383	1.3443	2.6383	1.2582	1.7373	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

● π network :



- Pi filters are basically one inductor surrounded by two capacitors and arranged like the Greek letter Pi. The input capacitor is selected to offer low reactance and repel the majority of the nuisance frequencies or bands to block.
- Pi filters present very-low impedances at high frequencies at both ends due to the capacitive shunting.

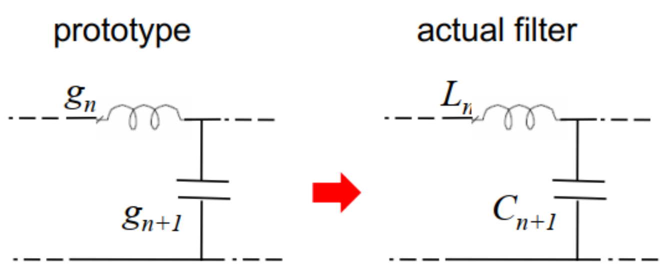
● T network :



- The T filter uses two shunt inductors and a coupling capacitor.
- T filters conversely have very-high impedances at high frequencies because of the inductive coupling.

Design of the LPP

We have designed the filter using T network prototype.



$$R = rR_0$$

$$\text{with } r = \begin{cases} g_{N+1} & \text{if } g_N \text{ is a shunt capacitor} \\ 1/g_{N+1} & \text{if } g_N \text{ is a series inductor} \end{cases}$$

$$L_n = \frac{g_n}{\omega_c} R_0$$

$$C_{n+1} = \frac{g_{n+1}}{\omega_c R_0}$$

⇨ $L_1 = L_5 = 5.656$ nH , $L_3 = 8.425$ nH , $C_2 = C_4 = 0.927$ uF

$\theta = kl = 45°$

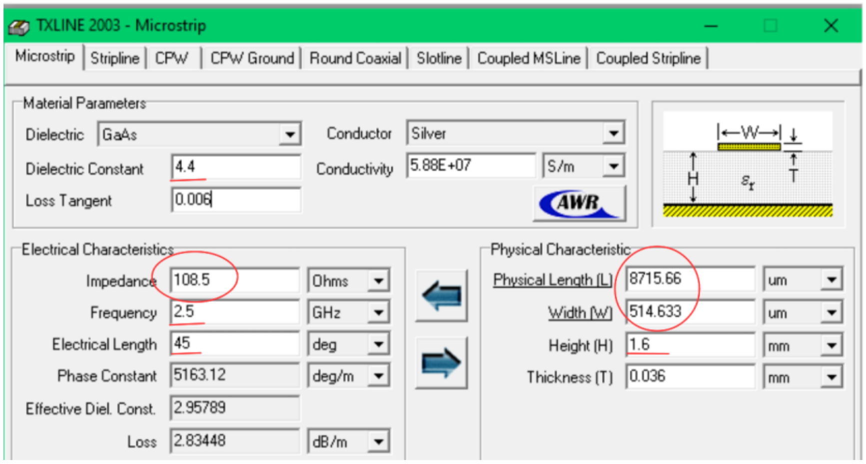
section 1 $\longrightarrow$ $Z_{h_1} = \frac{g_1 R_0}{\theta} = \frac{g_1 \times 50}{0.785} = 108.5\ \Omega$

Section 3,5 $\longrightarrow$ $Z_{h_3} = 161.8\ \Omega$, $Z_{h_5} = 108.5\ \Omega$

Section 2,4 $\longrightarrow$ $Z_{l_2} = \frac{R_0 \theta}{g_2} = 31.9\ \Omega$, $Z_{l_4} = 31.9\ \Omega$

To calculate width and length we used TXLINE tool of AWR software.

(We could also use the normal formulas in the slides)



$$\begin{cases} l_1 = 8.71566 \text{ mm} \\ W_1 = 514.633 \ \mu m \end{cases} \qquad \begin{cases} l_2 = 7.89692 \text{ mm} \\ W_2 = 6008.73 \ \mu m \end{cases}$$

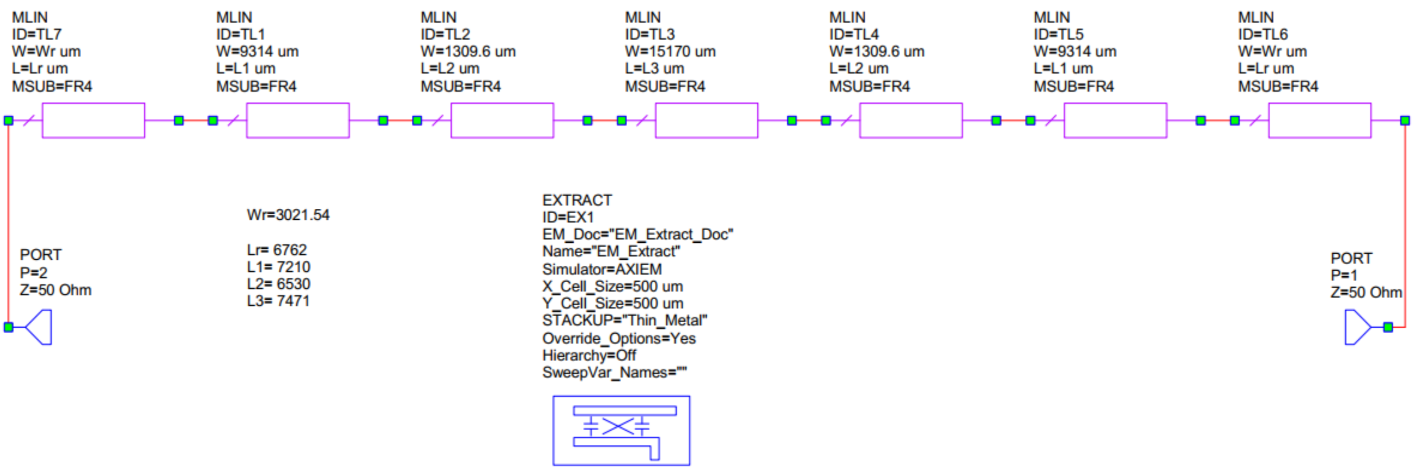
$$\begin{cases} l_3 = 9.03204 \text{ mm} \\ W_3 = 93.7083 \ \mu m \end{cases} \qquad \begin{cases} l_4 = 7.89692 \text{ mm} \\ W_4 = 6008.73 \ \mu m \end{cases}$$

$$\begin{cases} l_5 = 8.71566 \text{ mm} \\ W_5 = 514.633 \ \mu m \end{cases} \qquad \begin{cases} l_6 = 8.17788 \text{ mm} \\ W_6 = 3021.54 \ \mu m \end{cases}$$

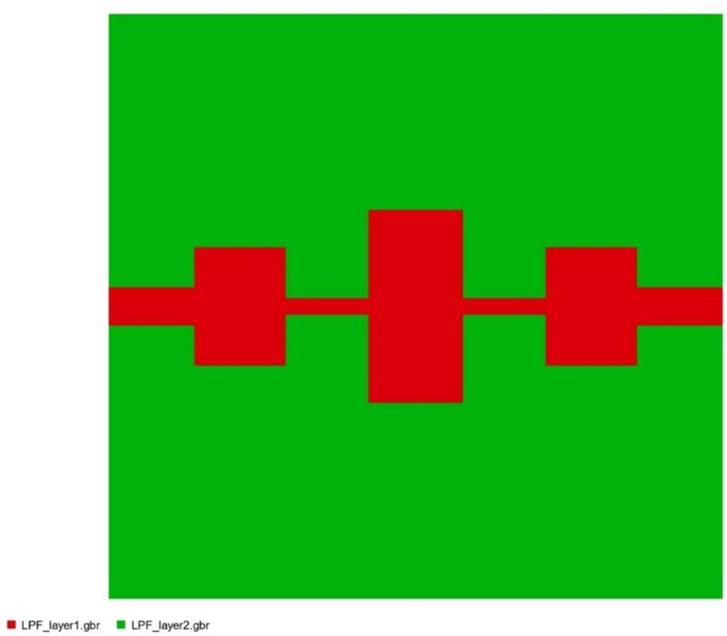
Now we have all characteristics of the filter, and we can start simulation using AWR.

Simulation with AWR

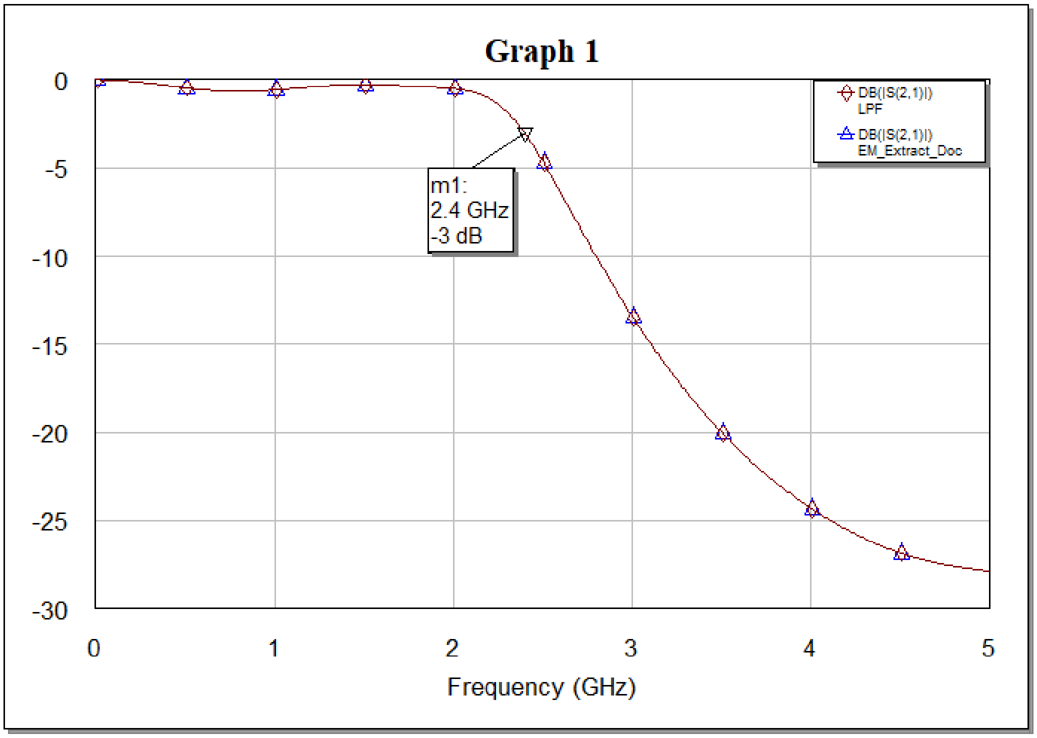
- In simulation phase we got a lower cut-off frequency. To increase this frequency we made each length shorter (about 10%).
- After adding electromagnetic effects, the same frequency change happened again. So we did the same solution as before by decreasing the length (about 9%).
- For the electromagnetic simulation we have used the "Extract" element which automatically creates an electromagnetic model starting from our schematic.



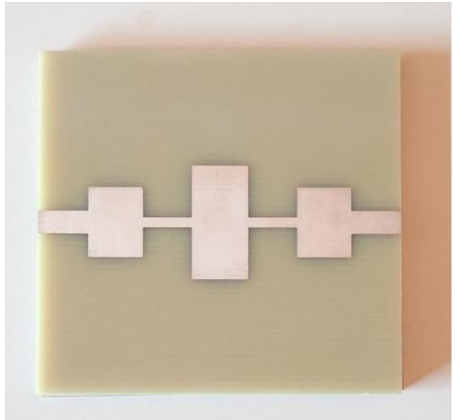
- Here we have the GERBER output image that shows 2 layers of substrate and microstrip.

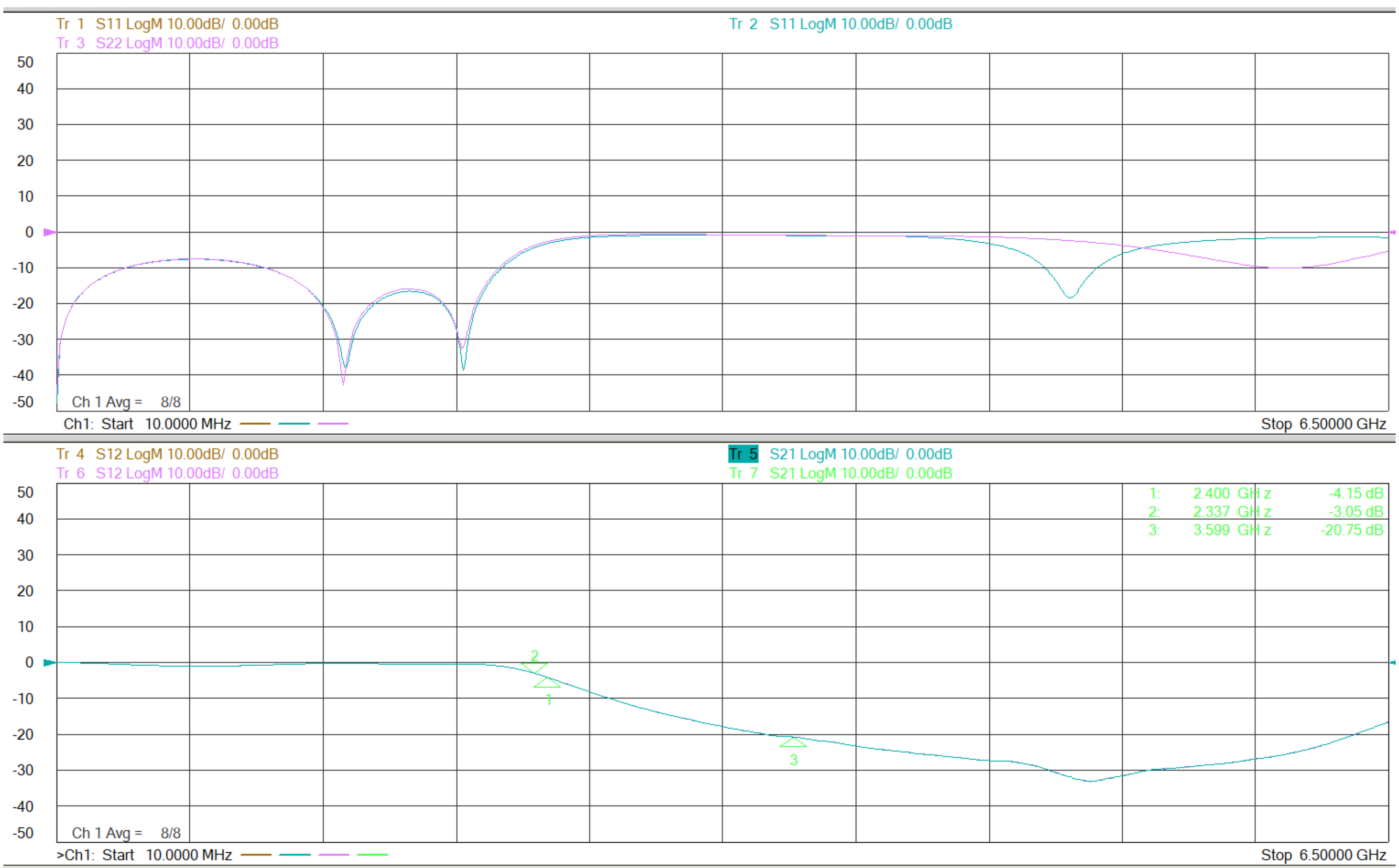


This is the graph of the filter in simulation:



Measurements with VNA





As it can be seen on the plot, the center frequency of the filter is 2.337 GHz (instead of 2.4 that we had in simulation), and this is reasonable due to the fabrication and the interconnections (maybe not ideal ports).

We can also see that at frequency of 3.6 GHz, the insertion loss is more than 20 dB. So it works properly.