UNIVERSITY OF OULU

FACULTY OF INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING - ITEE

521225S RF COMPONENTS AND MEASUREMENTS

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DESIGN EXERCISE #4

FILTER

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Introduction

Designing and implementing high-performance filters is a meticulous task in the world of electronics. Different components and techniques can be used to implement filters, each with its own benefits and challenges.

While an ideal filter is a theoretical concept with perfect response characteristics, it serves as the benchmark against which other filter implementations are measured. Using ideal inductors, capacitors, and resistors is required to implement an ideal filter, but these components are not practical in the physical world.

Real components, such as capacitors, inductors, and resistors, have non-ideal properties that affect the filter's performance. Implementing filters using these components requires careful consideration of their parasitic properties to achieve the desired filter response.

Microstrip transmission lines offer a suitable platform for implementing filters due to their low losses and ease of integration into a PCB layout. However, implementing filters using microstrip transmission lines requires careful consideration of wave nature and substrate properties, which can significantly impact the filter's performance. Simulation tools are therefore necessary to simulate the design and optimize the layout for achieving the desired filter response.

In this exercise, the seventh order Butterworth is simulated with ideal components. Then, reconstructed with real components from the vendor based library of AWRDE. Finally, the ideal components are replaced with microstrip transmission lines and the performance of each filter implementation is analyzed.

1. TASK 4-1: Ideal filter and real components

In this task, a Low-Pass Butterworth filter is simulated with ideal components and then resimulated with real parts from components vendors. Using the provided ideal components values, the filter has a 3dB bandwidth of 2GHz.

The schematic of the ideal filter is shown in Figure 1 and the schematic for the real filter is shown in Figure 2. The selected real inductors are from muRata's Thick Film chip coil series which are well suited for the operating frequency range and they have a 01005 (0402 Metric) footprint. The selected capacitors are from muRata's EIA High-Frequency category and they have a 0402 (metric 1005) footprint. It's worth noting that the capacitor C2 has been replaced with a 2.2 pF real capacitor in order to resemble the same performance of the ideal filter in the pass band.

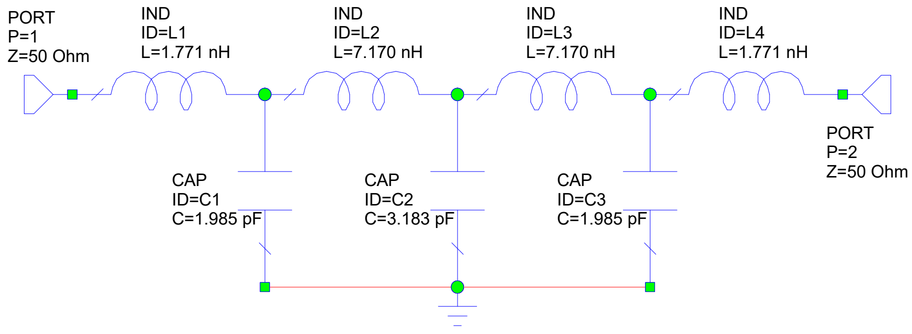


Figure 1: Ideal filter schematic

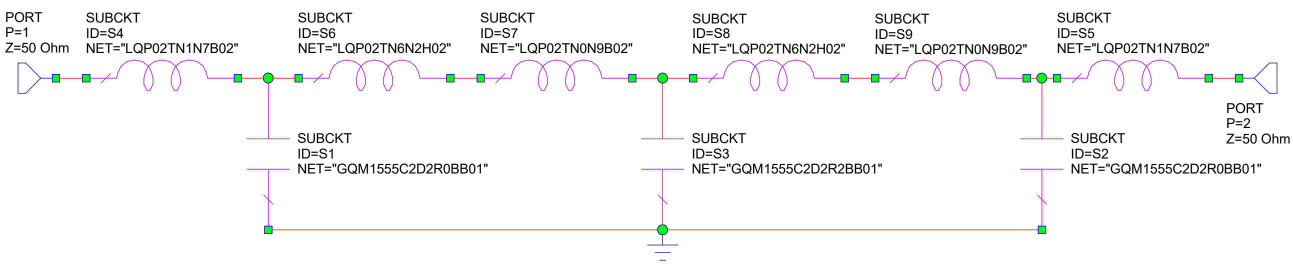


Figure 2: Real filter schematic

The S21 and S11 of both filter realizations is shown in Figures 3 and 4, respectively. From the S21 traces and markers, the -3dB attenuation frequency for the ideal and real component filters is 1.999 GHz and 2.052 GHz, respectively. The attenuation on the pass band of the filter with ideal and real components is -4.032e-11 dB and -0.2295 dB, respectively. The response of the real filter matches the ideal filter's response in the pass band but with slightly higher attenuation and about 52 MHz of excess bandwidth. In the stop band, the real filter performs better than the ideal one with higher attenuation.

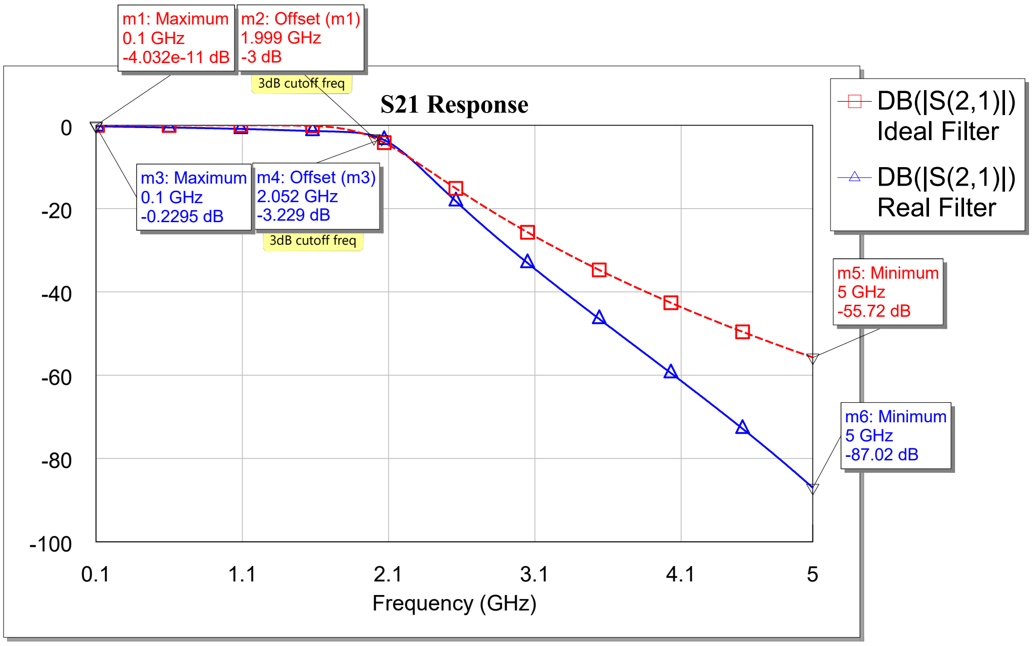


Figure 3: Ideal and real filters S21 response

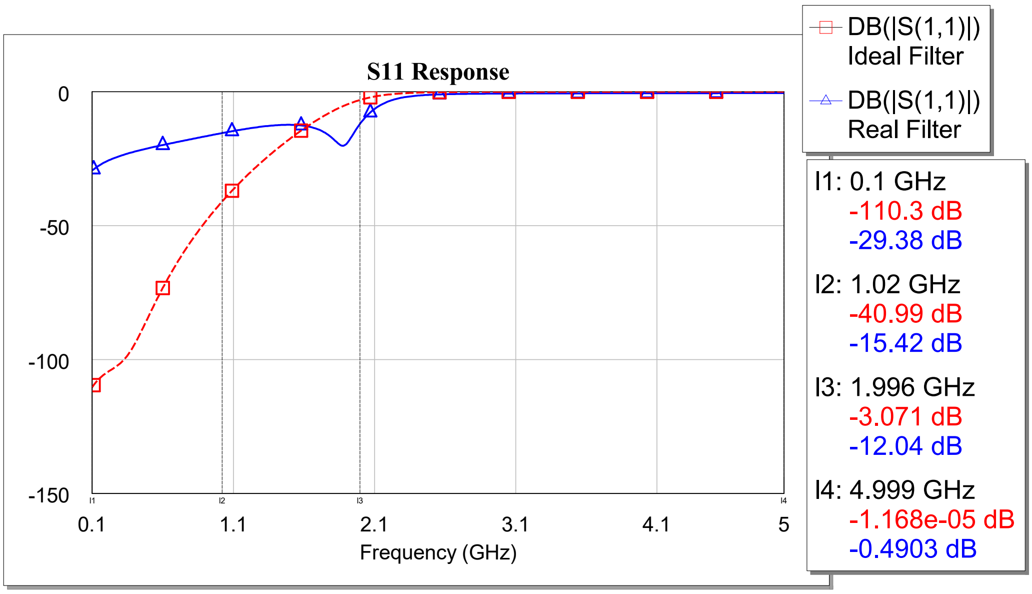


Figure 4: Ideal and real filters S11 response

2. TASK 4-2: Filter with transmission lines

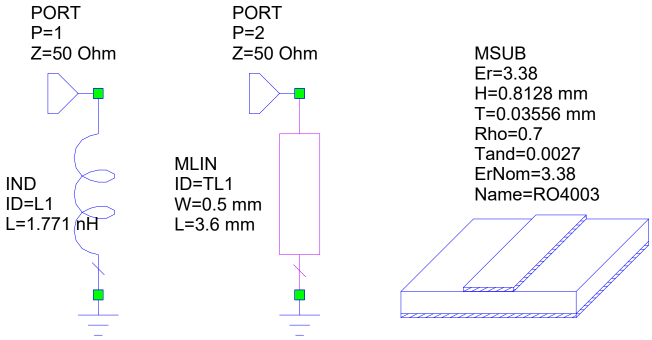
In this task, the previous Butterworth filter is reconstructed with distributed elements replacing the used inductors and capacitors.

First, the used microstrip transmission lines should be verified to resemble the operation of the lumber components on the filter operation band (0-2 GHz). Figure 5 shows the schematic and response resulting from verifying the operation of the inductor L1 and its equivalent microstrip transmission line. The microstrip resembles the operation of the inductor well below 4 GHz, and after that the different self resonance modes kick in and it becomes unusable as a regular inductor.

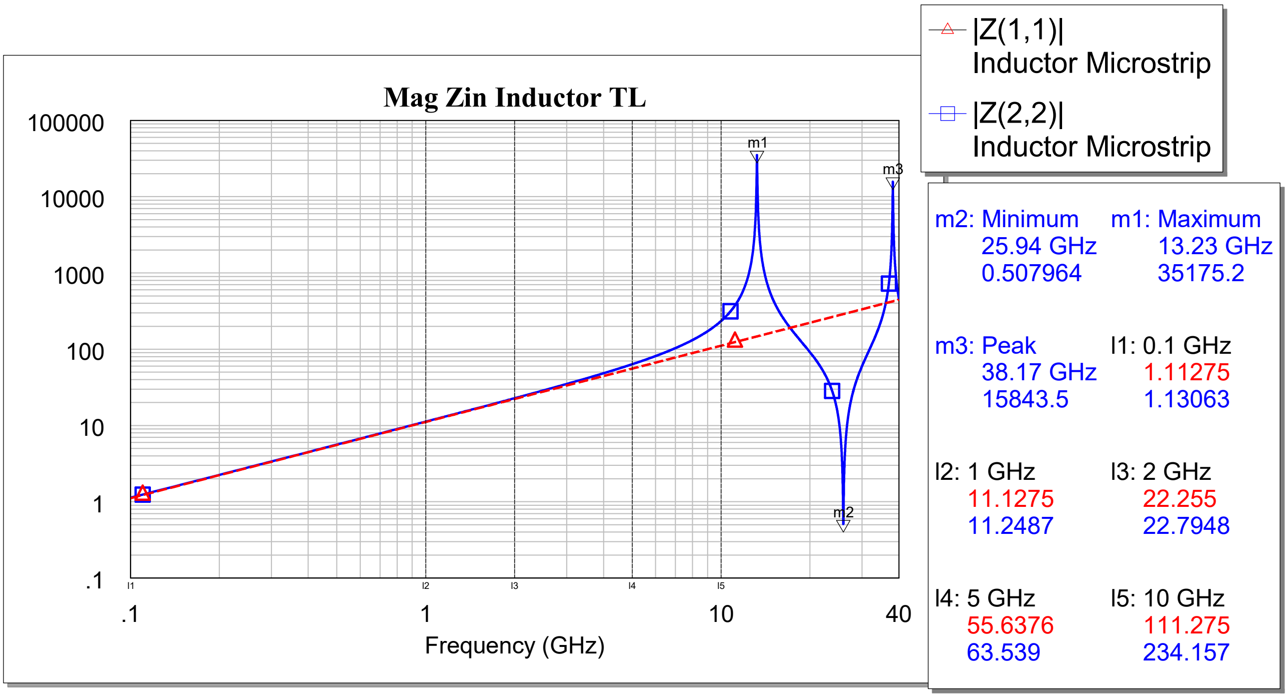
The cutoff frequency of a microstrip transmission line [1, Eq 14.27] [2] can be calculated using Equation 1 below.

$$f_c = \frac{c_0}{\sqrt{\epsilon_r}(2W + 0.8h)} \tag{1}$$

For the microstrip equivalent to the inductor L1, the cutoff frequency is 98.88 GHz. From the simulation, the first self resonance happens at 13.23 GHz which is well above the filter cutoff frequency of the filter so this microstrip could be used to replace the inductor L1.



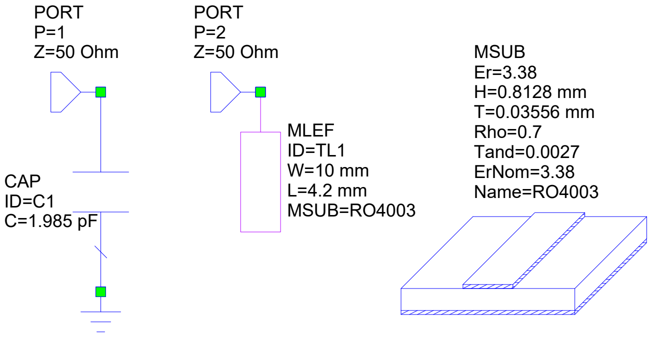
(a) Schematic



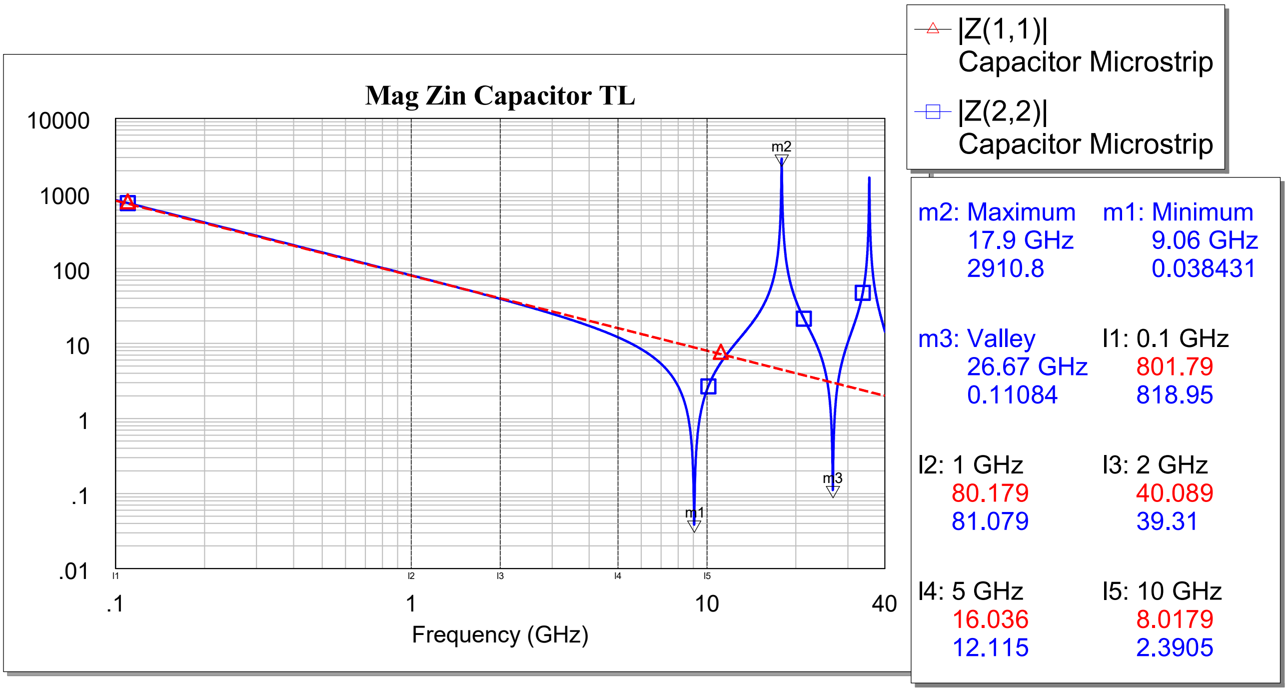
(b) Magnitude of Z11

Figure 5: Microstrip equivalent L1 inductor

Similarly for the capacitor C1, Figure 6 shows the schematic and response resulting from verifying the operation of the capacitor C1 and its equivalent microstrip transmission line. The microstrip resembles the operation of the capacitor C1 well under 3.5 GHz, and after that it becomes unusable as a regular capacitor. The calculated cutoff frequency of the microstrip equivalent to the capacitor C1 is 7.902 GHz. The first resonance happens at 4.56 GHz which is also above the cutoff frequency of the filter and hence this microstrip could be used to replace the capacitor C1.



(a) Schematic



(b) Magnitude of Z11

Figure 6: Microstrip equivalent C1 capacitor

The schematic of the microstrip based filter is shown in Figure 7 and its layout is shown in Figure 8. Input and output microstrip transmission lines were added to match the filter to the 50 Ω ports impedance.

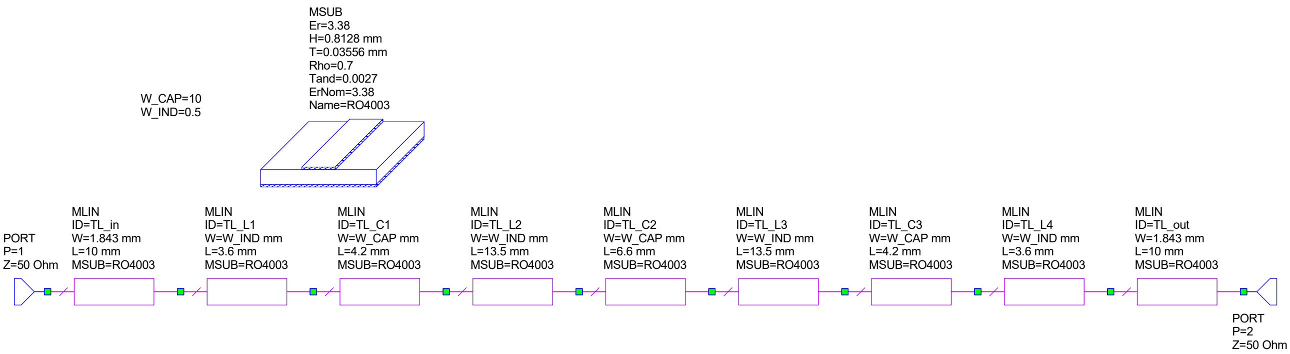


Figure 7: Microstrip filter schematic

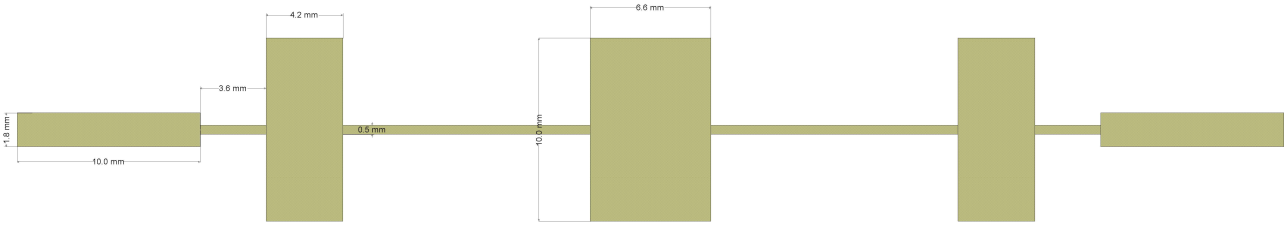


Figure 8: Microstrip filter layout

The added output equation[3], shown in Figure 9, is used instead of the ideal filter schematic to have the measurement of the ideal Butterworth filter response as a reference.

7th order ideal Butterworth filter

TwoN=2*7 ► TwoN: 14

Fn=_FREQ/2e9

Pat=-10*Log10(1+pow(Fn,TwoN))

Figure 9: Ideal Butterwoth output equations

The S21 of the ideal and transmission lines based filter is shown in Figure 10. From the S21 traces and markers, the -3dB attenuation frequency for the microstrip filter is 1.9661 GHz which almost matches the ideal filter with 1.9993 GHz cut off frequency. The attenuation on the pass band of the microstrip filter is minimal and very close to the ideal one, however its stop band response doesn't have enough attenuation especially at 7 GHz where it has only 3 dB of rejection.

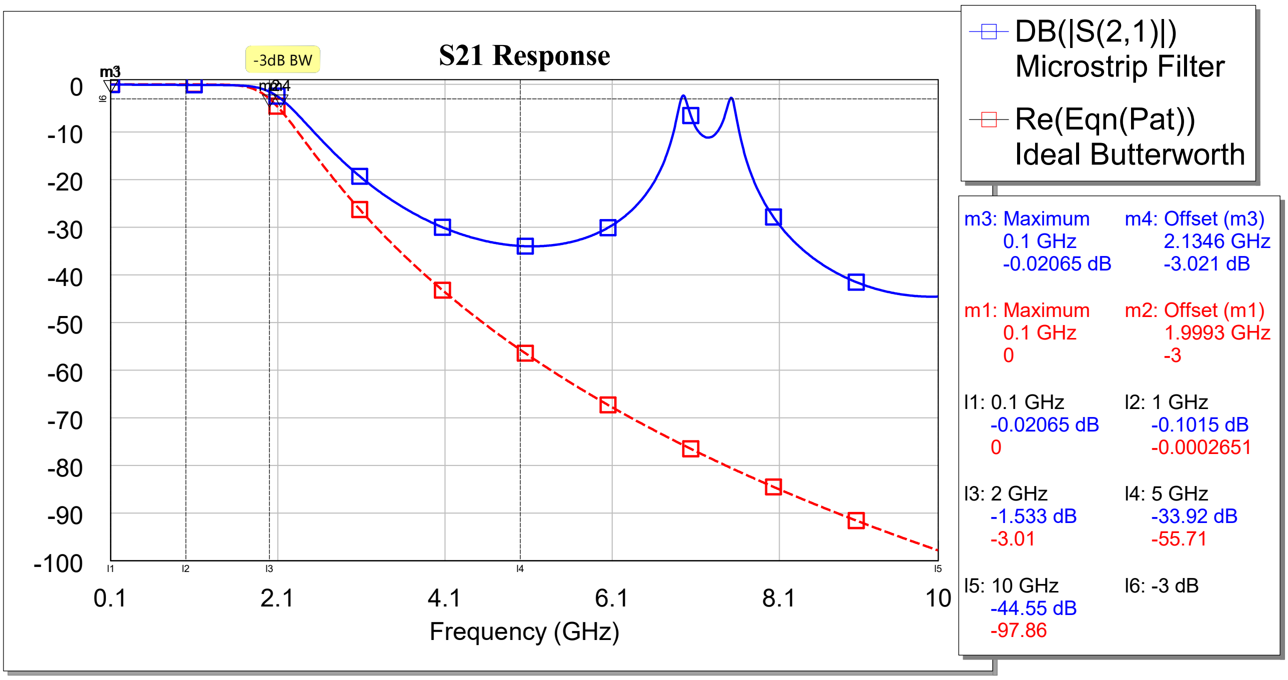


Figure 10: Ideal and microstrip filters S21 responses

To compare the response to the real components and transmission lines based filters, Figure 11 shows their response in comparison to the ideal case. The real components filter has a slightly higher attenuation in the pass band (around 0.22dB) however it is much better then the microstrip based one in rejecting signals in the stop band. Since, the attenuation of 0.22dB is tolerable and the microstrip filter doesn't have enough rejection at higher frequencies, the real components based filter would be better to use.

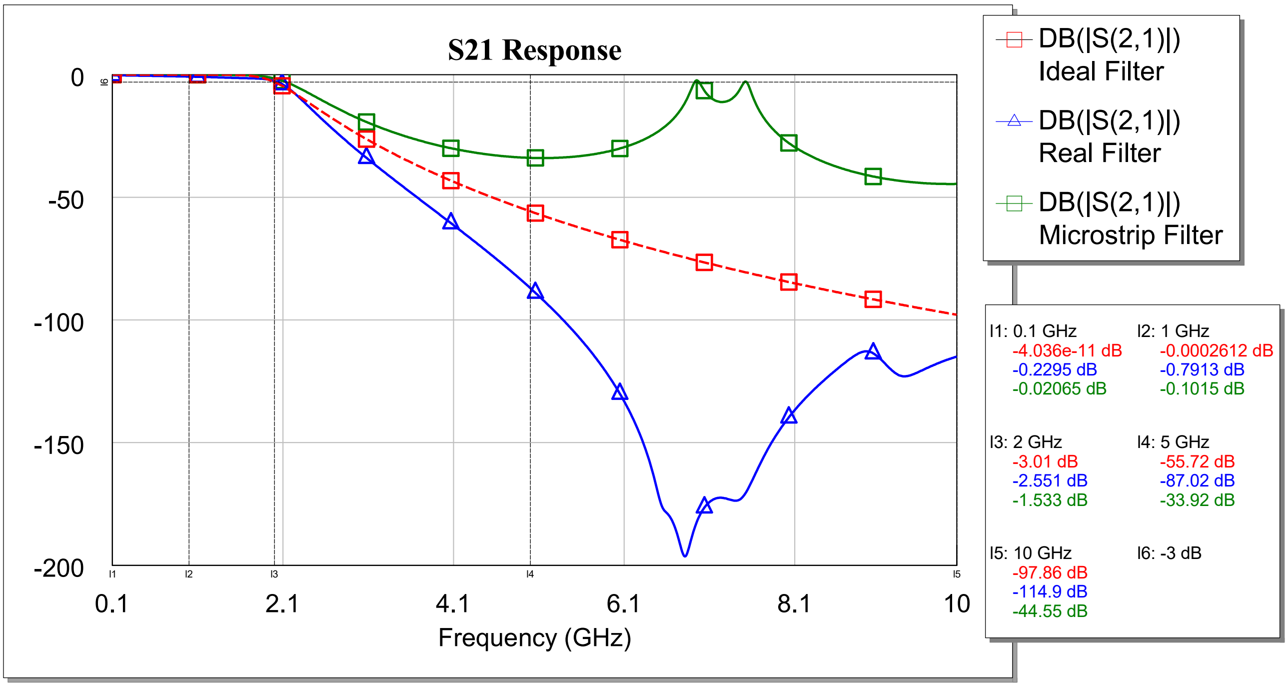


Figure 11: Ideal, real, and microstrip filters S21 responses

Feedback

- The exercise took about one day.
- The exercise was easy.
- The questions were easy. There is a small mistake in the provided cutoff frequency equation which needed some research and reading.
- From this exercise, I managed to better understand resonance modes in microstrips and how to verify the use of distributed elements instead of lumped ones.

References

[1] I. Bahl, *Lumped Elements for RF and Microwave Circuits* (Artech House microwave library). Artech House, 2003, ISBN: 9781580536615.

[2] *Microstrip Operating Frequency Limitations*, https://bit.ly/libretexts_Mictrostrip_Limitations, [Online; accessed 2023-04-26], May 2022.

[3] Wikipedia contributors, *Butterworth filter — Wikipedia, The Free Encyclopedia*, https://en.wikipedia.org/w/index.php?title=Butterworth_filter&oldid=1151306238, [Online; accessed 25-April-2023], 2023.