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EEE Department of Electrical and Electronic Engineering

Low-Pass Microstrip Filter Design Coursework

EEEE3096: Analogue Electronics

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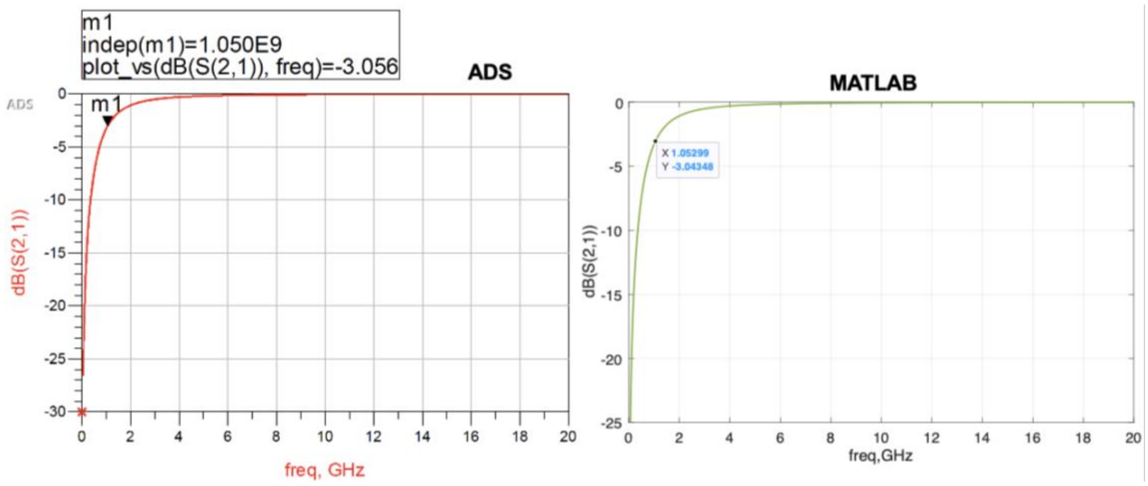
1. A 1.5pF capacitor is connected between two transmission lines of characteristic impedance Zo=50Ω in a shunt (parallel) and a series connection. For each connection, derive S(2,1) analytically, plot using MATLAB (or equivalent) and compare the results with an S(2,1) plot using ADS – use a frequency range of 0-20GHz. Comment on the results including a comparison of the ADS and analytical plots, the nature of the capacitor when placed in the series and shunt connection and any other observations.

a) S21 Plots for the Capacitor in a Series Connection



b) S21 Plots for the Capacitor in a Parallel Connection

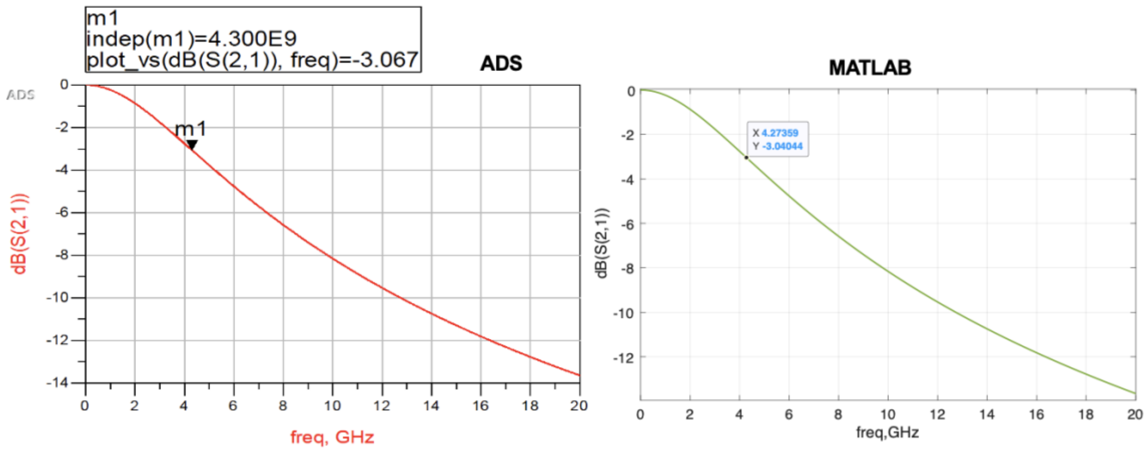


Figure A1. S21 Plots for the Capacitor in the a) Series Connection b) Parallel Connection

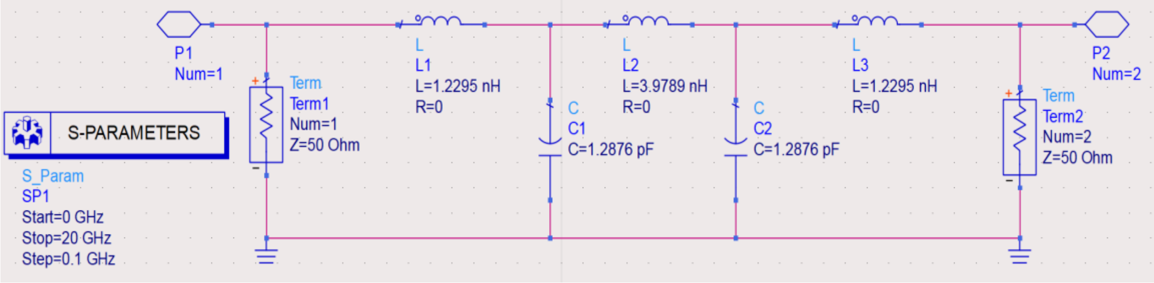
Comments:

In a series connection, the characteristic of a capacitor approximates a high-pass filter. Its attenuation is large in the low frequency region and decreases rapidly in the 0-4 GHz interval. The attenuation then increases to 0 dB as the frequency increases, which is reflected by similar results in both ADS and MATLAB results. However, the exact point at which the two plots change may differ, possibly due to differences in the model and simulation setup. At 1.05 GHz, the response of both plots is roughly -3 dB, with only minor differences. The difference may result from parasitic effects in the actual circuit or different algorithmic ways in the simulation tool.

In the parallel connection case, the capacitor behaves like a low-pass filter, and a smooth decrease from 0 in the attenuation value with increasing frequency can be seen in both plot results, suggesting that the capacitor passes the signal efficiently at low frequencies, and gradually stops the signal at high frequencies. This smooth attenuation curve reflects the stability of the capacitor when connected in parallel. At 4.3 GHz, the response of both plots is roughly -3 dB, with only minor differences. Similarly, the plots produced by the two methods may have slight differences in accuracy depending on model and simulation setup.

2. Give a schematic of the lowest order microwave LC filter (indicating all the L and C values) that satisfies the filter design requirements. Plot S11 and S21 of the microwave LC filter and comment on how this response compares with the desired filter characteristics.

a) LC Microwave Schematic



b) S11 & S21 Response of the LC Microwave Filter

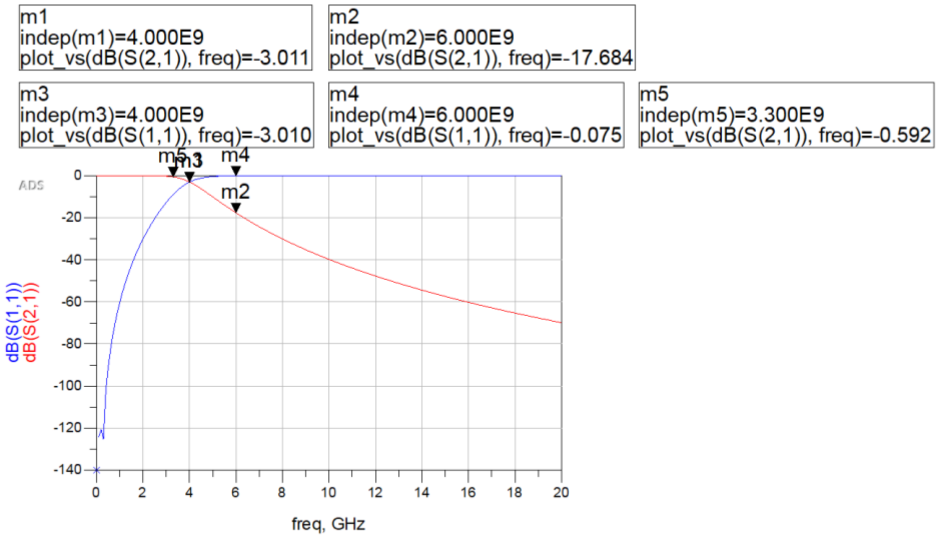


Figure A2. a) Schematic of the LC Microwave Filter b) S11 & S21 Response of the Microwave LC Filter

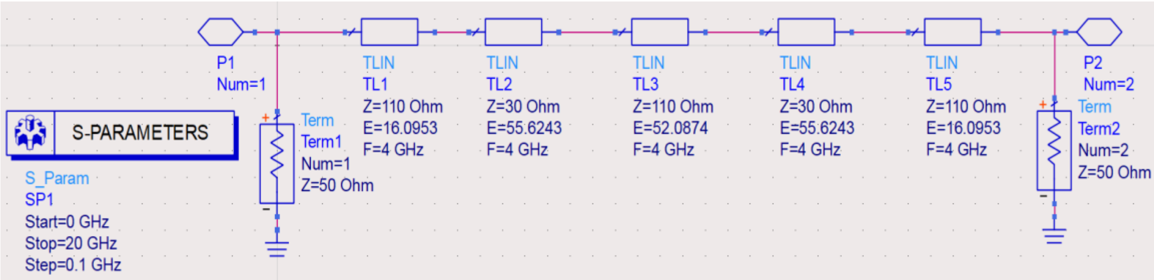
Comments:

Based on the ADS results, S21 represents the efficiency of signal transmission from port 1 to port 2. The response of this low-pass filter is approximately -3 dB at 4 GHz, which meets the expectations for a cut-off frequency design. It shows very little attenuation below 4 GHz and significant attenuation after 4 GHz. The response is -17.684 dB at 6 GHz, which also meets the design requirement of at least 14 dB attenuation at 6 GHz. However, the absolute value of S21 is 0.592dB at 3.3GHz, which is already greater than the maximum insertion loss of 0.5dB expected by the design. S11 represents the return loss, indicating how much power is reflected to the source. For low-pass filters, this value should be as low as possible (with a large negative value) below the cut-off frequency to ensure that most of the energy is transmitted by the filter rather than reflected. In this plot, the value of S11 increases gradually with frequency, being -3.011 dB at 4 GHz and already -0.075 dB at 6 GHz. It is not exactly 0 at frequencies greater than the cut-off frequency, indicating some degree of transmission, but this is acceptable.

Overall, these two curves reflect that the low-pass filter is generally as expected. The insertion loss in the passband slightly exceeds the design target, while the attenuation performance in the stopband is better than the specified requirements, and the reflection loss is controlled within acceptable limits. Although the simulation results reveal minor deviations from the theoretical calculations, the design can be considered successful overall.

3. Give a schematic of a transmission line microwave filter (indicating all the parameters of the transmission lines). Plot the S21 and S11 of the transmission line filter and the microwave LC filter and comment on how they compare.

a) Transmission Line Filter Schematic



b) Comparison of the S11 & S21 Response of the Microwave LC & Transmission Line Filter

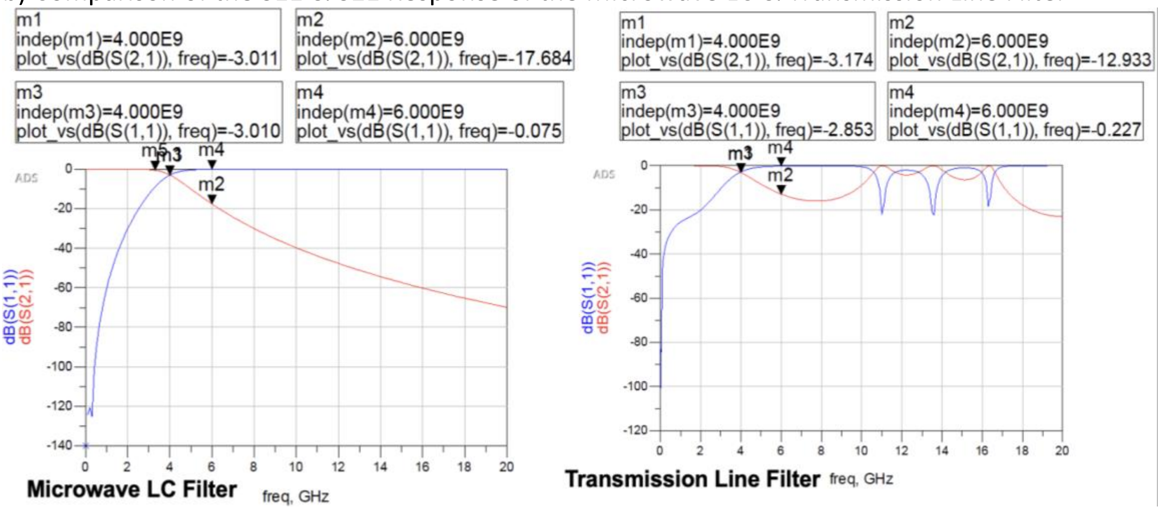


Figure A3. a) Schematic of the Transmission Line Filter b) Comparison of the S11 & S21 Parameters of the Microwave LC Filter & Transmission Line Filter

Comments:

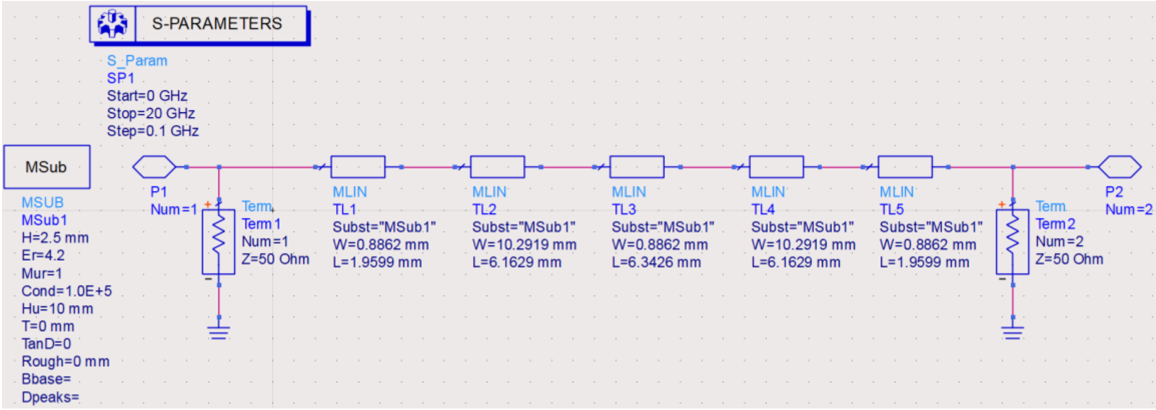
For S21 (transmission loss): both filters exhibit the typical behaviour of low-pass filters, with a small loss in the passband and a significant increase in the stopband after the cut-off frequency (4 GHz). The magnitude of S21 is similar for both filters at 4 GHz, being about -3 dB. However, in the stopband (6 GHz), the LC filter (-17.684 dB) shows a higher loss than the Transmission line filter (-12.933 dB), suggesting a better attenuation of unwanted frequencies. Another difference is that the response of the transmission line filter has a significant peak-to-valley structure after 8 GHz suggesting selective frequency transmission behaviour, which is not present in the LC filter. This reflects the more consistent transmission behaviour of the LC filter over a wide frequency range.

For S11 (return loss): both filters present a very low return loss at the beginning of the passband, indicating good impedance matching and minimal signal reflection. After the frequency exceeds the cut-off point, the S11 value rises, means that more signal is reflected to the source. At 4 GHz, the LC filter (-3.011 dB) is slightly smaller than the transmission filter (-2.853 dB), it reflects less signal at this frequency. At 6 GHz, the LC filter (-0.075 dB) is closer to 0 than the transmission filter (-0.227 dB), it reflects more signal at this frequency. The response of the transmission line filter still has valley structure after 8 GHz, unlike the LC filter which is flat.

Overall, both filters have similar curves in the low frequency region and differ in the high frequency region. However, the LC filter performs relatively better because it accepts low frequencies and suppresses high frequencies more efficiently.

4. Give a schematic of a microstrip microwave filter (indicating all the parameters of the microstrip lines i.e. widths and lengths). Plot the S21 and S11 parameters of the microstrip filter and the transmission line filter and comment on how they compare.

a) Microstrip Line Filter Schematic



b) Comparison of the S11 & S21 Response of the Transmission Line & Microstrip Filter

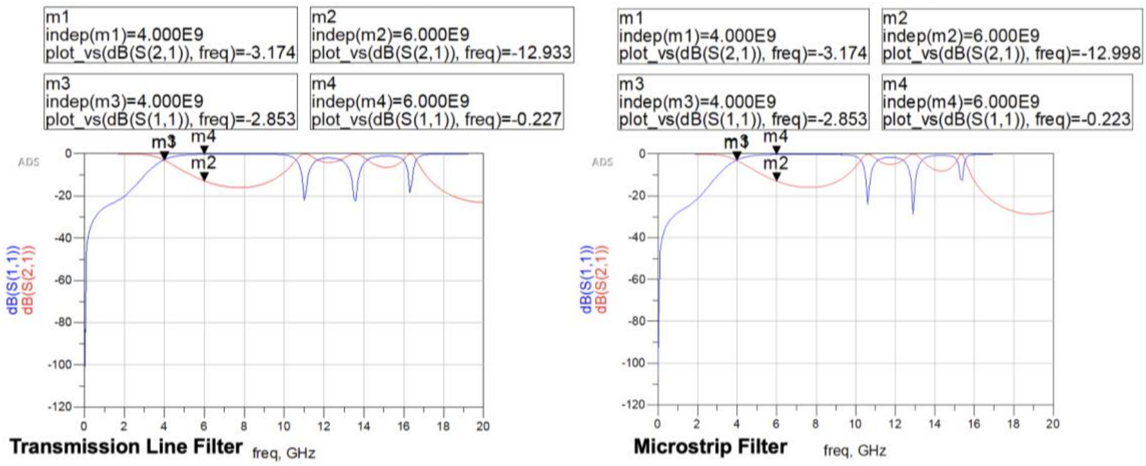


Figure A4. a) Schematic of the Microstrip Filter b) Comparison of the S11 & S21 Parameters of the Transmission Line & Microstrip Filter

Comments:

For S21 (Transmission Loss) analysis: Both filters show typical low-pass filter characteristics, with minimal loss in the passband and increasing loss above the cut-off frequency (4 GHz). At 4 GHz, both filters have the same response value of -3.174 dB, indicating a comparable signal transmission level at this frequency. At the stopband of 6 GHz, the absolute attenuation of the microstrip filter is higher (-12.998 dB) than that of the transmission line filter (-12.933 dB), or even almost the same, which indicates that it is relatively more effective in suppressing unwanted frequencies. After 8 GHz both filters show similar levels of peaks and valleys. The transmission loss curve of the microstrip filter is slightly more dramatic than that of the transmission line filter, which is probably due to the design and operation principle of the microstrip filter. The exact location and depth of each peak and valley is related to the design parameters of the filter.

For S11 (return loss): At 4 GHz, both filters have the same response value at -2.853 dB. At 6 GHz the absolute value of the attenuation of the microstrip filter (-0.223 dB) is slightly smaller than that of the transmission line filter (-0.227 dB), or even almost the same. This indicates that the two filters have almost the same degree of ability to reflect signals.

Overall, the two filters have almost the same ability to transmit and reflect signals and only small differences in the high frequencies.

5. Plot the layout of the microstrip filter indicating its overall dimensions (the total length and width).

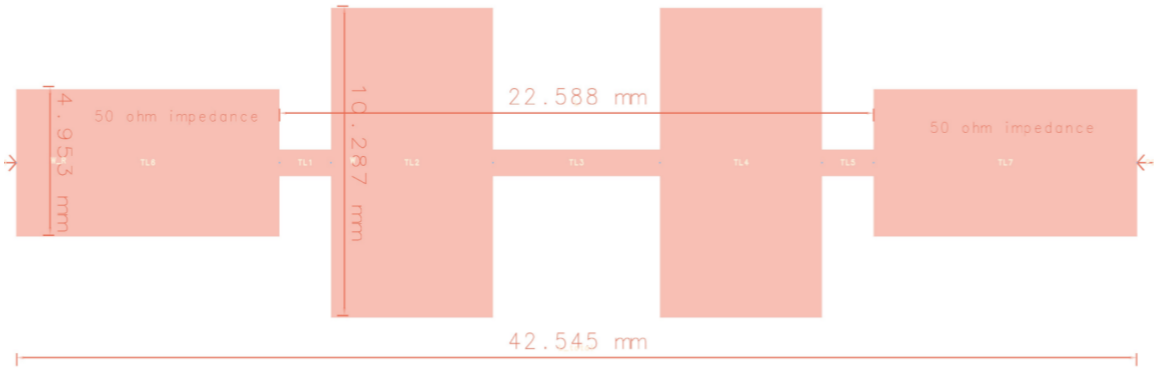
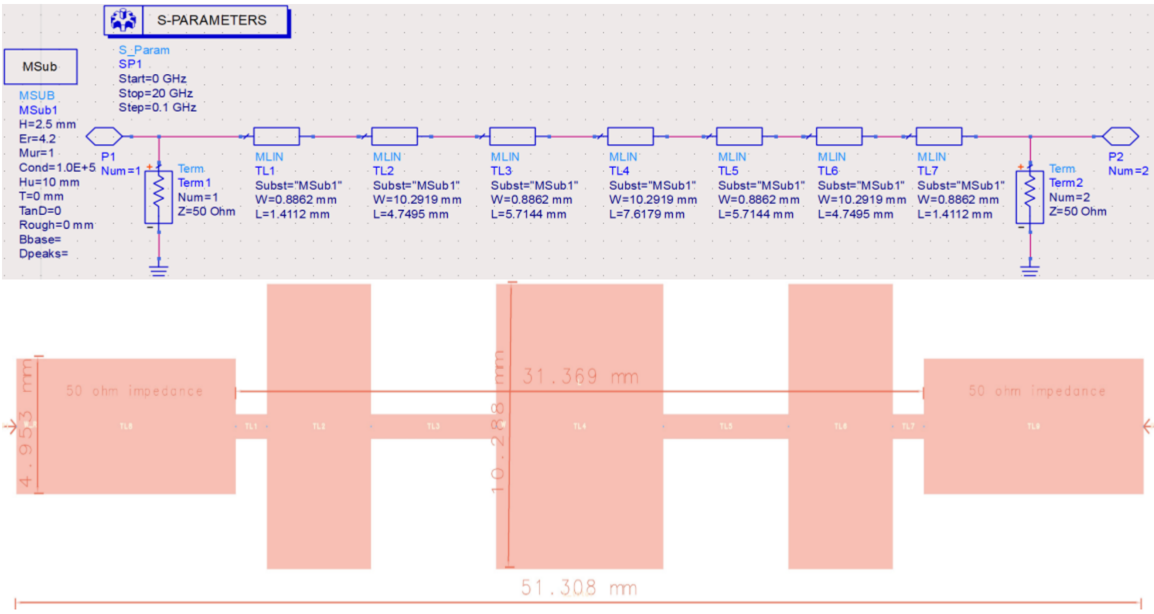


Figure A5. Layout of the Microstrip Filter

6. Increase the order of the filter by 2 orders. Compare the final design of the microstrip filters in terms of parameters S21 and S11 and comment on their performance, size and relative costs.

a) (N=7) 7th Order Microstrip Schematic & Layout



b) Comparison of the S11 & S21 Response of the N=5 & N=7 Order Microstrip Filters

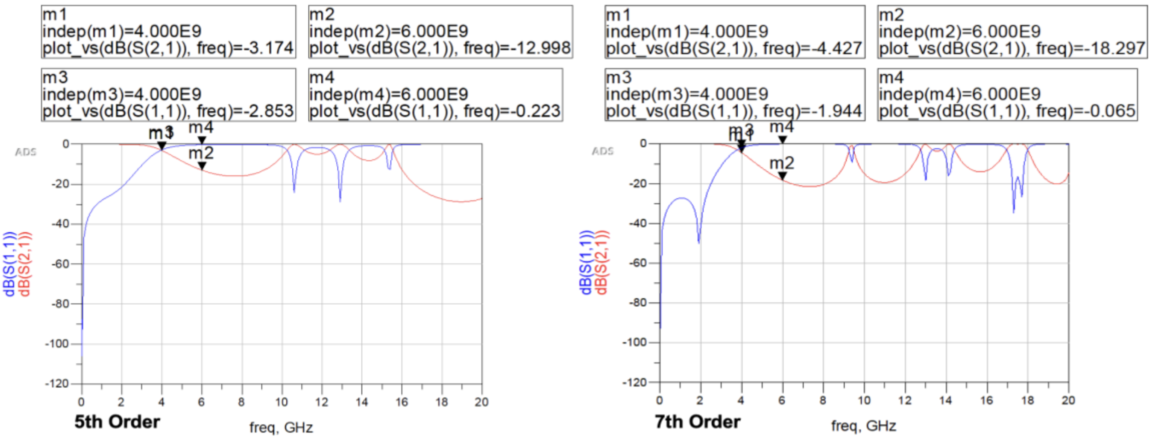


Figure A6. a) 7th Order Microstrip Filter Schematic & Layout b) Comparison of S11 & S21 Parameters of the Microstrip Filters of the Two Different Orders

Comments:

Performance: Overall, Higher order filters show steeper roll-off and better selectivity. For the S21 (transmission loss): At the cut-off frequency of 4 GHz, the absolute value of 5thorder (-3.174 dB) is lower than 7thorder (-4.427 dB). This indicates that the lower order filter is closer to the ideal cut-off (-3 dB), while the higher filter has steeper transition slopes and more clearly differentiates between passband and stopband. At 6 GHz in the stopband, the absolute value of 5th order (-12.998 dB) is lower than 7th order (-18.297 dB). This indicates that higher order filters are more effective in suppressing interfering signals beyond the cut-off frequency. For the S11 (return loss): At 4GHz, the absolute value of 5thorder (-2.853 dB) is higher than 7thorder (-1.944 dB). It shows that fewer order filters have less signal reflection at the passband edge. At the stopband 6GHz, the absolute value of 5thorder (-0.223 dB) is higher than 7thorder (-0.065 dB). It shows that less order filter can block the signal of unwanted frequency better.

Size and relative costs: Increase the order of the microstrip filter results in an increase in physical size because more resonators are required. More components mean a longer filter on the PCB layout. This means the cost of higher order filters increases, because the increased size requires the use of more material and more complex manufacturing process.

7. Explore how the conductor thickness affects the response of the microstrip filter. Plot the S21 parameter of the microstrip filter for different conductor thicknesses. Assume no more than 3 different cases: zero thickness, thickness of 0.1mm and thickness of 0.5mm.

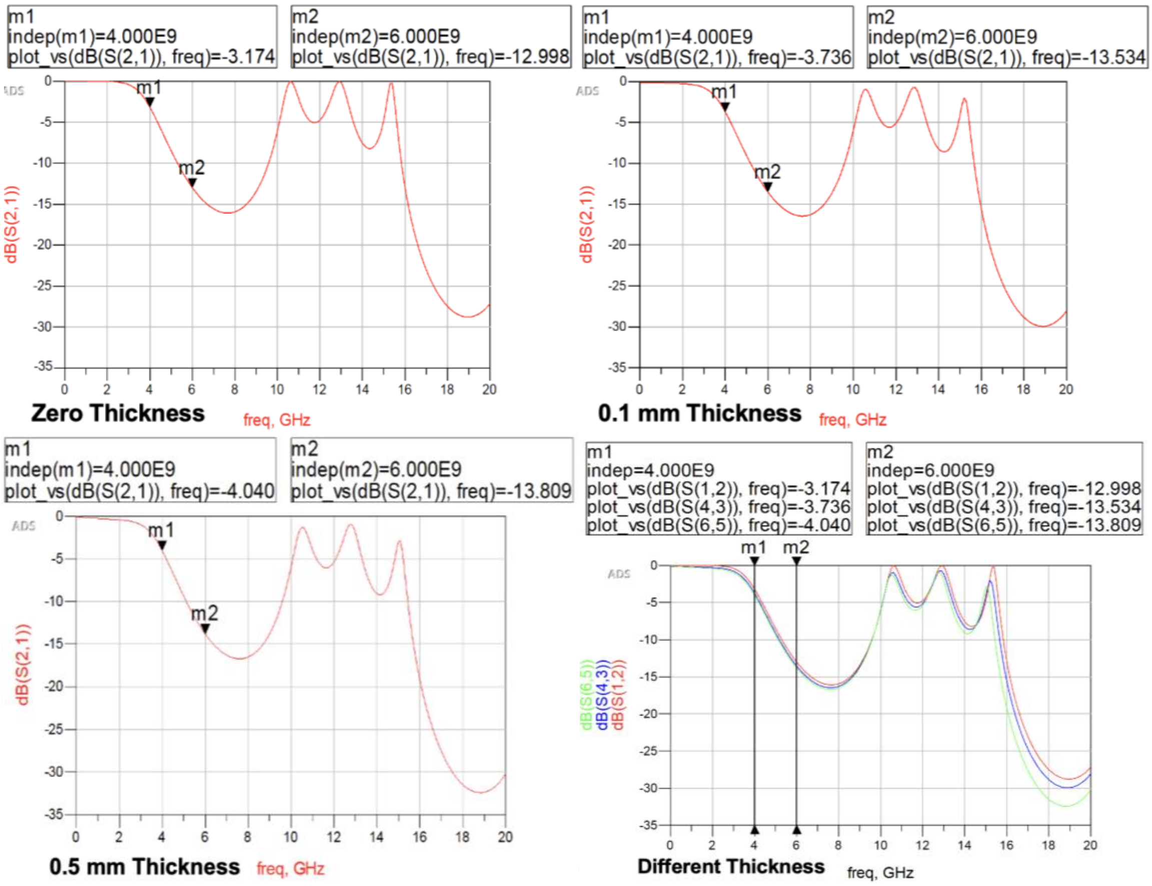


Figure A7. S21 Response to a Thickness of a) 0mm b) 0.1mm c) 0.5mm

Comments:

The figures above show a comparison of S21 for conductor thicknesses of 0, 0.1 mm, 0.5 mm, and different thicknesses integrated together. The three curves have a similar trend, but the loss in each band slightly increases as the thickness increases, and some points are analysed below:

With zero conductor thickness, the filter response is -3.174 dB at the cut-off frequency of 4 GHz and -12.998 dB at the stopband of 6 GHz. With 0.1 mm thickness, it is -3.736 dB at 4 GHz and -13.534 dB at 6 GHz. With 0.5 mm thickness, it is -4.040 dB at 4 GHz and -13.809 dB at 6 GHz.

Overall, as the conductor thickness increases, the transmission loss of the filter increases slightly in the low frequency range (especially below 6 GHz), which is detrimental to the performance of the low-frequency filter in its primary operating frequency range. However, in the high frequency range, especially at 0.5 mm thickness, the filter shows better attenuation, which is a positive characteristic for low pass filters as it means that high frequency signals are blocked more effectively. Thus, the increase in conductor thickness, while inducing some additional losses in low frequency range, may compensate for this by providing better filtering in high frequency range. The reason for this phenomenon is that an increase in conductor thickness can provide lower losses at high frequencies because it can help reduce the current density per unit area and improve the distribution of the electromagnetic field. However, at low frequencies, the increased surface resistance may result in higher transmission losses.