University of Oulu

Faculty of Information Technology and Electrical Engineering - ITEE

521225S RF Components and Measurements

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Design Exercise #2

Modelling of passive component

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Contents

Introduction

Modeling lumped components involves creating a mathematical model that describes the behavior of a physical system made up of discrete or "lumped" components.

The goal of modeling lumped components is to gain a better understanding of how the system behaves under different conditions and to predict its behavior in response to different signals. This can be used for a variety of purposes, such as designing and optimizing systems, troubleshooting problems, and making predictions about future behavior.

In this exercise, different models are tunned and optimized to mimic the operation of different lumped components using their measured S-parameters responses. Also, the different parasitics contributions will analyzed and discussed.

1. Task 2-1: Define equivalent circuit for open and closed SMA-connector

In this task, an SMA connector, Figure 1 will be modeled in the open and shorted cases.

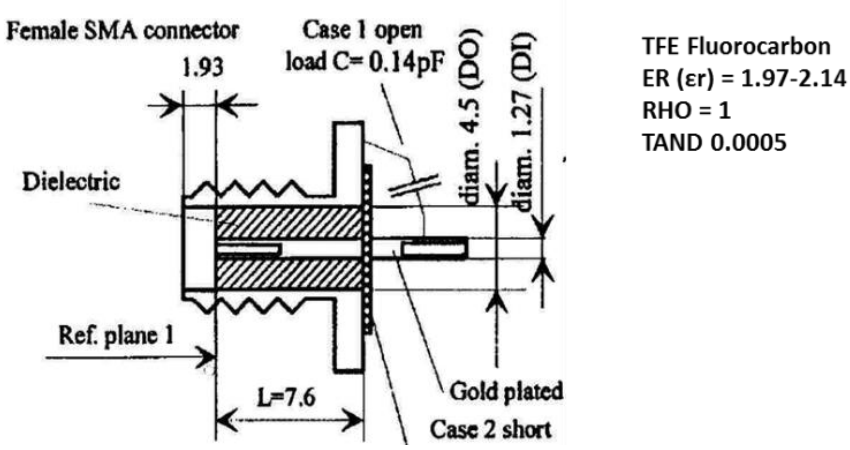


Figure 1: SMA connector structure

1.1 Open SMA connector

In the open case, the SMA connector could be modeled as shown in Figure 2. The results of tunning the different parameters are shown in Figure 3.

The tunning was done to match the S11 phase responses. "sma_open" is the response loaded from the measurement data file whereas the "SMA open" is the result of simulating the model. The S11 phase responses match very well over the whole frequency range whereas the S11 magnitude response don't and there is a small mismatch (less than 0.001 dB).

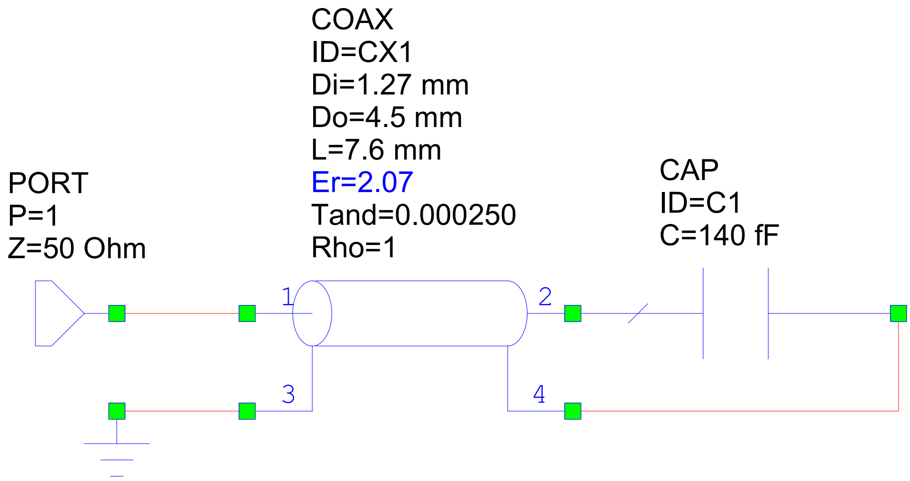
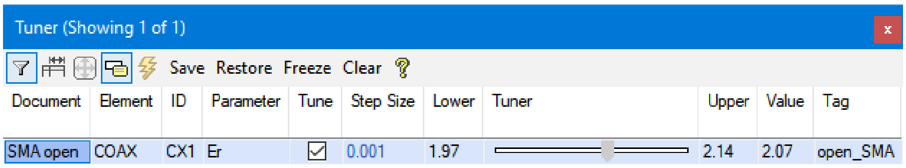
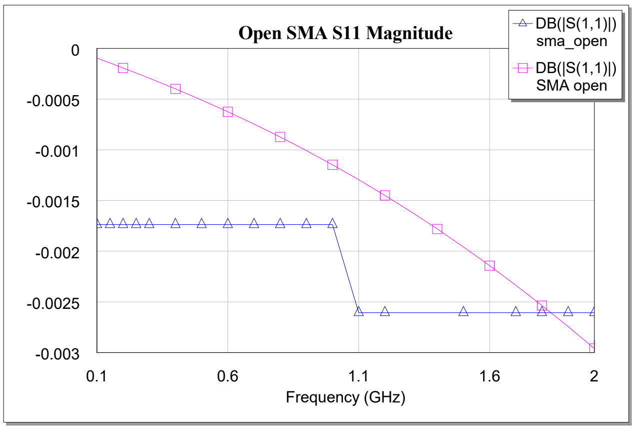


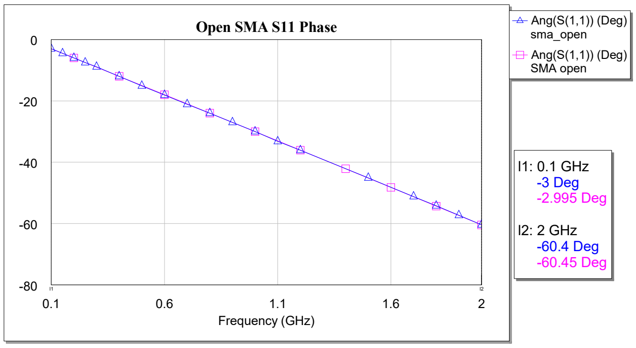
Figure 2: SMA connector model the open case



(a) Tunning



(b) Magnitude of S11



(c) Phase of S11

Figure 3: Open SMA connector model tunning results

1.2 Closed SMA connector

In the closed/shorted case, the SMA connector could be modeled as shown in Figure 4. The results of tunning the different parameters are shown in Figure 5.

The tunning was done to match the S11 magnitude and phase responses. "sma_closed" is the response loaded from the measurement data file whereas the "SMA closed" is the result of simulating the model. The S11 phase responses match very well over the whole frequency range. The S11 magnitude responses match better than the open case but still, there some mismatch (less than 0.001 dB over the frequency range).

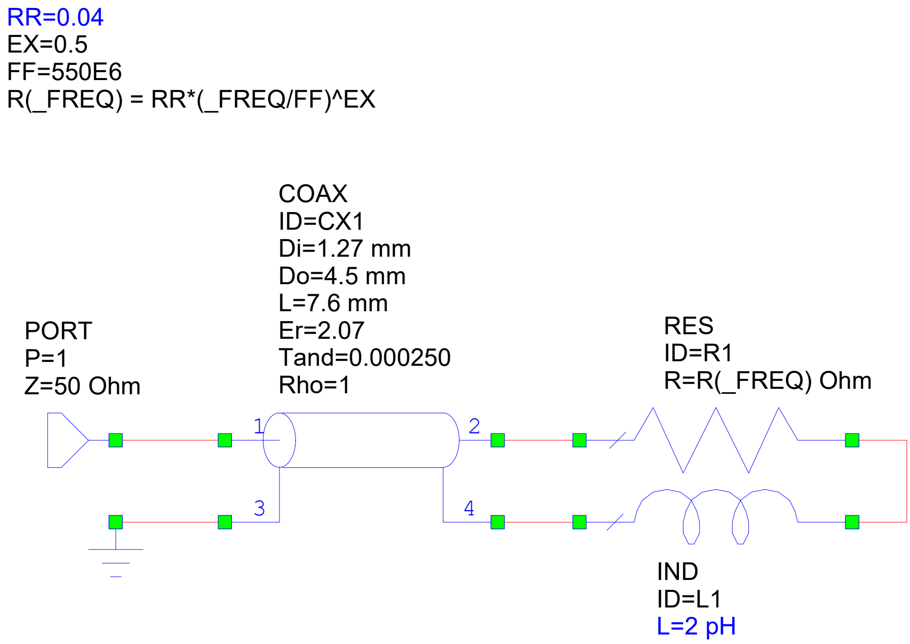
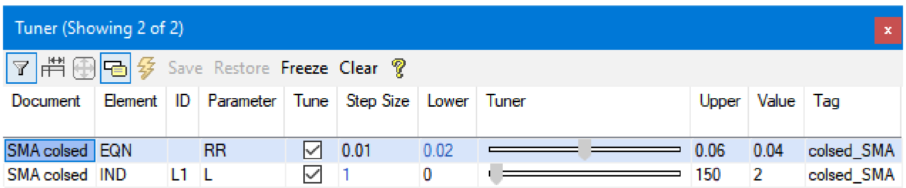
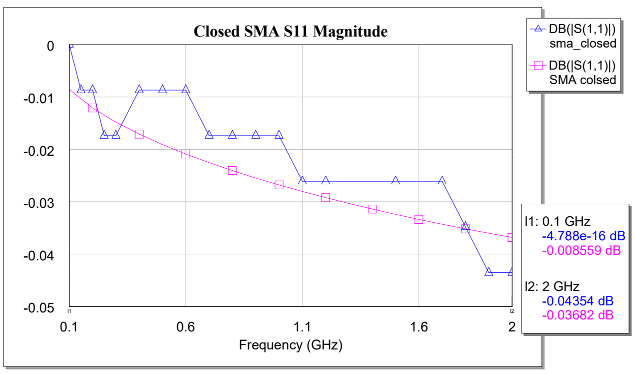


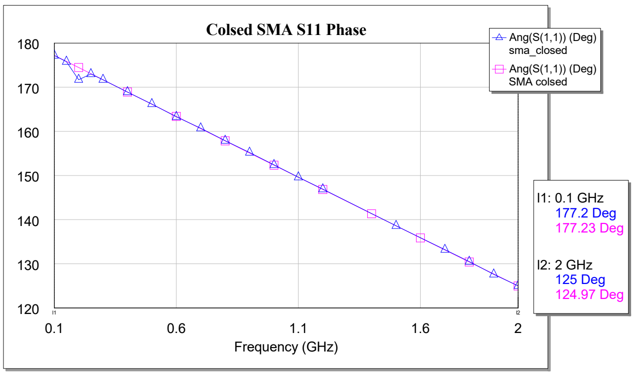
Figure 4: SMA connector model the closed (shorted) case



(a) Tunning



(b) Magnitude of S11



(c) Phase of S11

Figure 5: Closed (shorted) SMA connector model tunning results

The values that resulted in the different tuned responses are $ER = 2.07$, $L = 2\ pH$, and $RR = 0.04\ \Omega$.

The resistance of a copper wire on a closed connection depends on the frequency of the current passing through it due to the skin effect [1]. The skin effect is a phenomenon in which high-frequency alternating current tends to flow on the surface of a conductor rather than through its entire cross-section. As the frequency of the current increases, the skin depth decreases, meaning that the current encounters a narrower cross-section of the conductor, resulting in an effective increase in resistance. The skin effect is determined by the physics of electromagnetic waves and their interaction with conductive materials, and has practical implications for the design and operation of electrical systems, particularly at high frequencies.

2. Task 2-2: Define equivalent circuit for resistor connected to SMA-connector

In this task, a surface mount chip resistor with a $50\ \Omega$ resistance that has been soldered onto the ground plane of a female SMA connector will be modeled. The resistor is placed between the ground plane and the middle pin of the SMA connector as shown in Figure 6. The simulation is conducted over a frequency range of 20 MHz to 2 GHz and the previously tunned permittivity value (ER=2.07) was used to parameterize the COAX element.

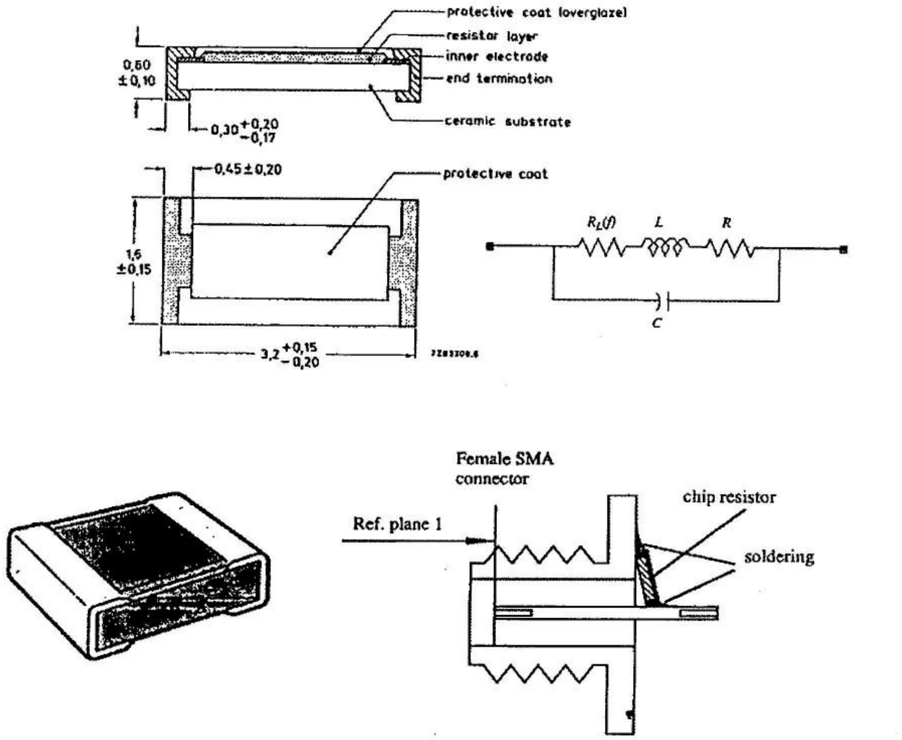


Figure 6: SMA connector with soldered $50\ \Omega$ chip resistor structure

The developed model is shown in Figure 7 and the tunning and simulation results are shown in Figure 8. "sma_resistor" is the response loaded from the measurement data file whereas the "SMA Resistor model" is the result of simulating the circuit. The real part of the simulated input impedance matches the imported data well over the frequency range. However, the imaginary part resulting from simulation differs a bit from the imported data over the middle frequency range (0.4 GHz - 1.7 GHz) but the difference is insignificant.

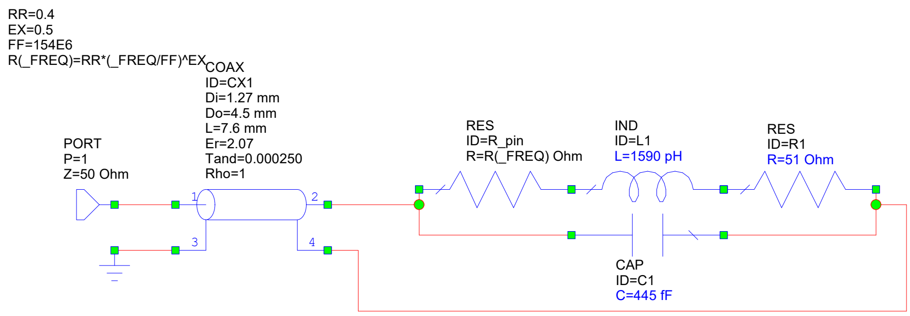
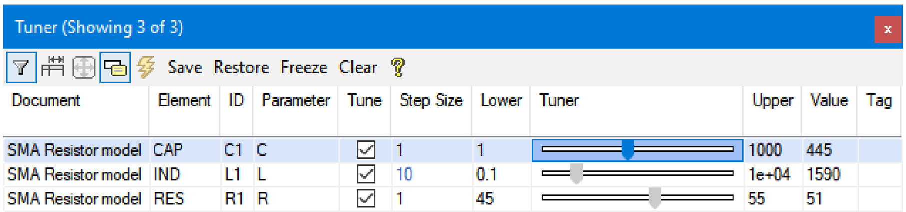
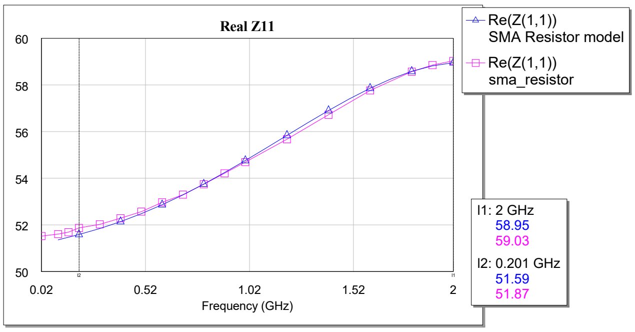


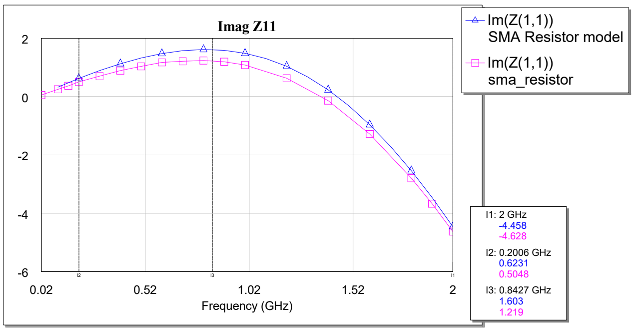
Figure 7: SMA connector with soldered $50\ \Omega$ resistor model



(a) Tunning



(b) Real part of input impedance Z11



(c) Imaginary part of input impedance Z11

Figure 8: SMA connector with soldered 50 Ω resistor tunning and simulation results

The circuit shown in Figure 7 was simulated a larger range (20 MHz - 10 GHz) to determine the resonance frequency. Figure 9 shows the resulting imaginary part of the input impedance Z11 of this simulation. The resonance happens when the imaginary part is nulled and here it at 5.3059 GHz.

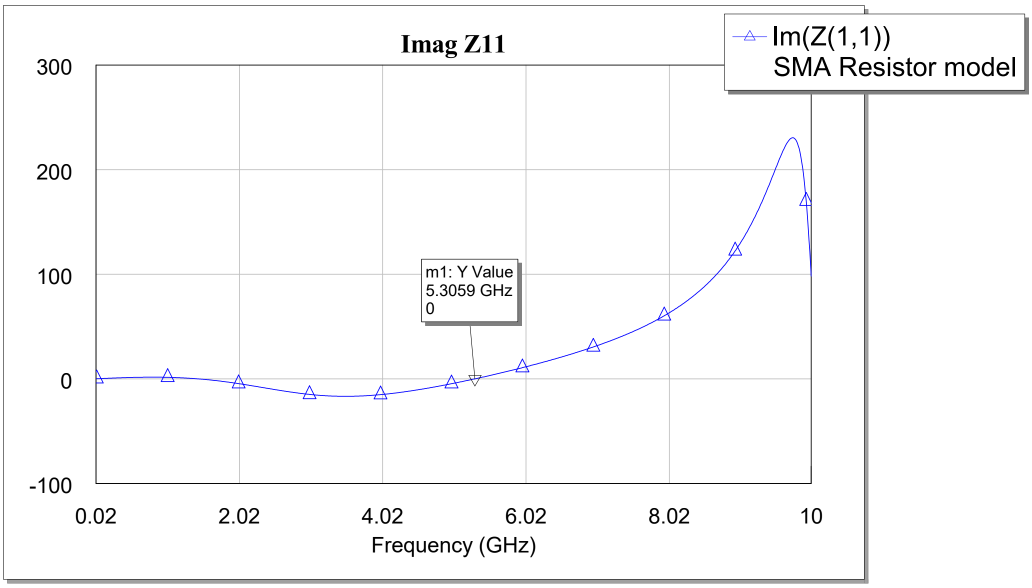


Figure 9: Resulting imaginary part of input impedance of Figure 7 over a wider frequency range

The values that resulted in the different tuned responses are $R1 = 51\ \Omega$, $L1 = 1.59\ nH$, and $C1 = 445\ fF$.

The different parasitics resulted in the previous circuit and responses. R1 is the resistance from the resistive material in the actual resistor which dominates almost all the real part of Z11 over the lower frequency range. R(f) is resistance from the center pin of the SMA and as discussed in section 1.2, it is frequency dependent due to the skin effect and it dominates the real part of Z11 at high frequency as shown in Figure 8. As shown in Figure 9, the parallel capacitance C1 dominates over the lover frequency range (around 4 GHz) and it arises from the dielectric material in the SMA connector and the resistive material in the resistor. However, the inductance L1 dominates over the higher frequencies (above 6 GHz) and it is due to the center pin and the metal pads and edges of the resistor.

3. Task 2-3: Define equivalent circuit for inductor connected to SMA-connector

In this task, a 3-round coil that soldered to an SMA-connector in a similar fashion will be modeled. Definition of the equivalent circuit of the air insulated 3-round coil is shown in Figure 10.

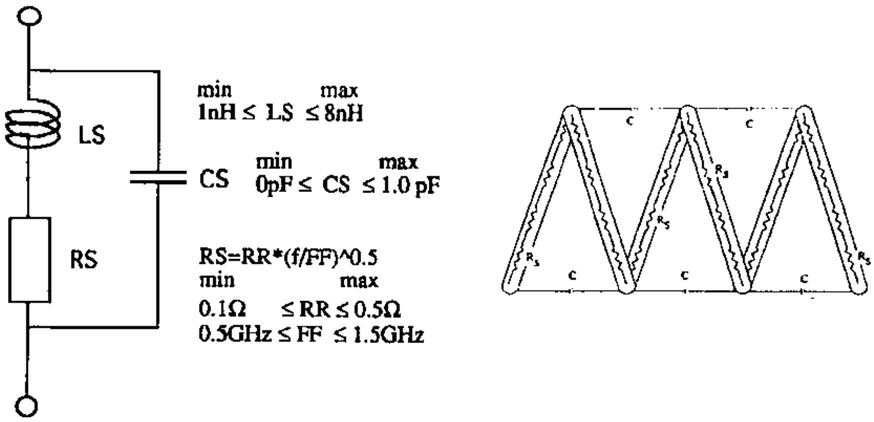


Figure 10: Equivalent circuit of the coil

The developed model is shown in Figure 11 and the tunning and simulation results are shown in Figure 12. ”sma_inductor” is the response loaded from the measurement data file whereas the ”SMA Inductor model” is the result of simulating the circuit. Both, real and imaginary parts of the simulated input impedance Z11 match the imported data over the entire frequency range. The phase of the input reflection coefficient S11 matches the imported data over the whole frequency, but the magnitude doesn’t fit well the provided data and there a mismatch of about 0.15 dB.

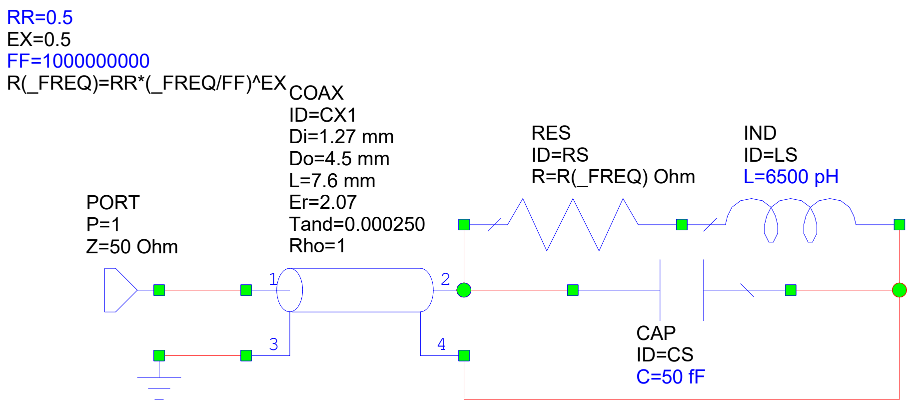
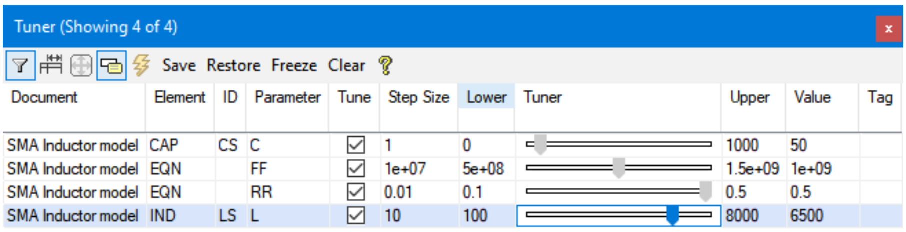
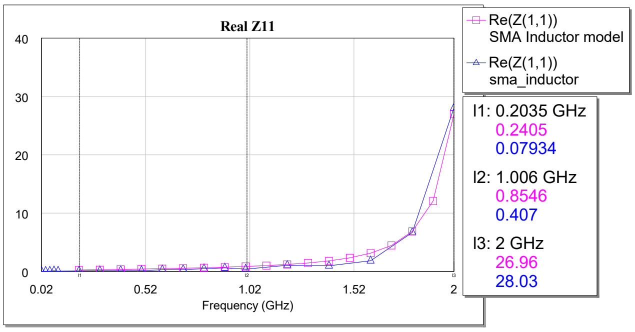


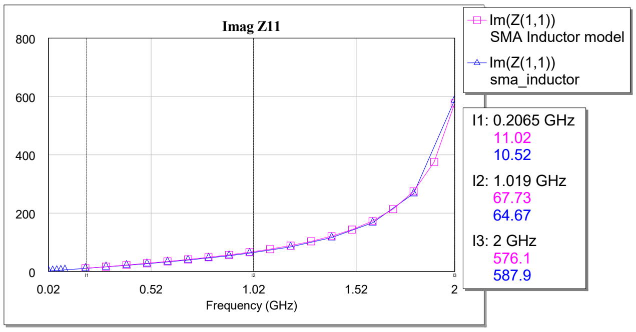
Figure 11: SMA connector with soldered coil model



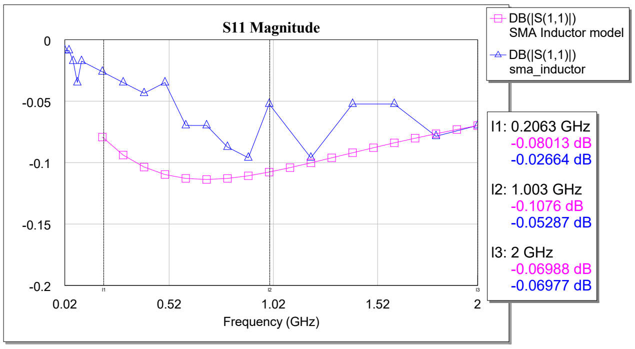
(a) Tunning



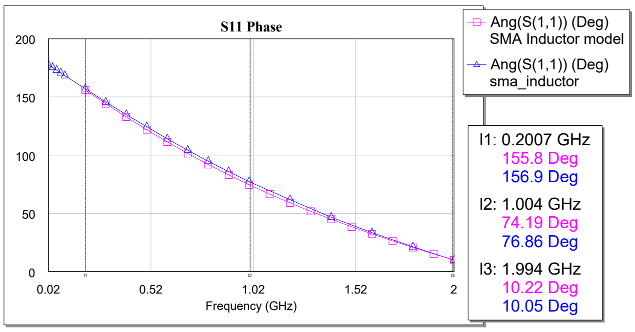
(b) Real part of input impedance Z11



(c) Imaginary part of input impedance Z11



(d) Magnitude of input reflection coefficient S11



(e) Phase of input reflection coefficient S11

Figure 12: SMA connector with soldered coil tunning and simulation results

The values that resulted in the different tuned responses are $RR = 0.5\,\Omega$, $FF = 1\,GHz$, $LS = 6.5\,nH$, and $CS = 50\,fF$.

As discussed previously, the resistance RS(f) is the resulting from the center pin of the SMa connector, but in te case of the inductor, the resistance of the wire and turns contributes also to RS(f). The capacitance CS is resulting from the mutual interaction of the coil turns and between the coil package pads.

4. Task 2-4 : Inductor at resonance

In this task, the equivalent circuit for the 3-round coil is analyzed more. After fitting and tunning the inductor model in the previous task, the series and parallel circuit of the inductor itself (without the connector effect) is studied.

The equivalent series and parallel circuit of the inductor is shown in Figure 13.

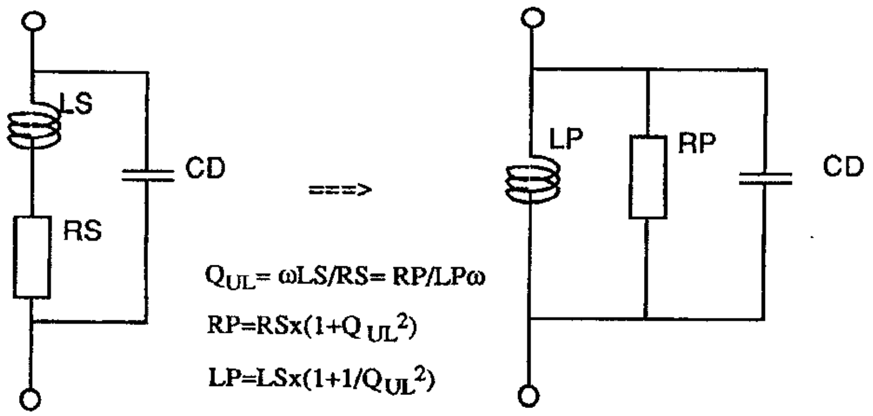


Figure 13: Series and parallel equivalent circuits of the coil

The series equivalent circuit of the inductor, shown in Figure 14, is simulated and the real part of the resulting input impedance Z11 is shown in Figure 15.

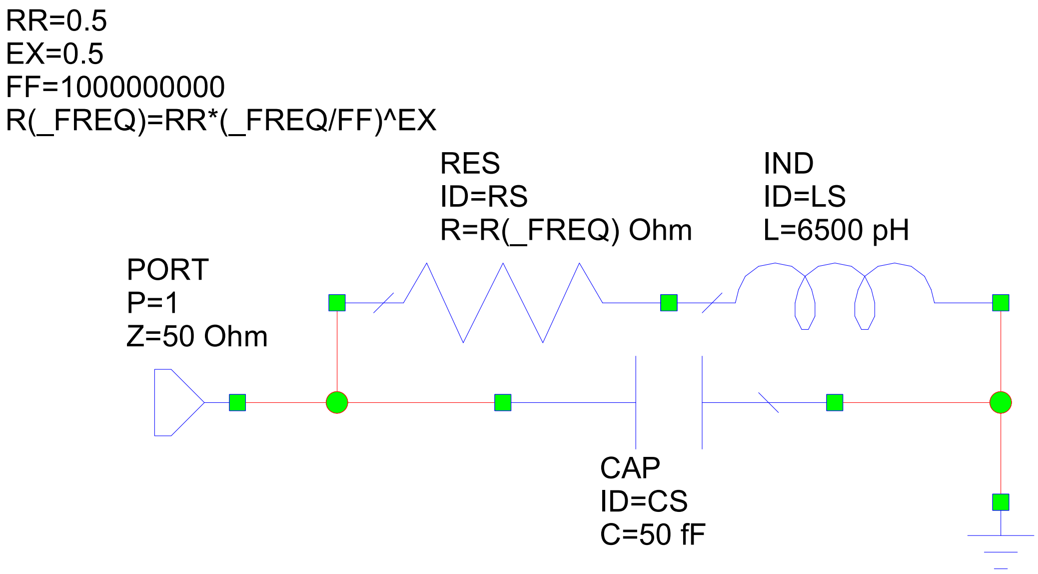


Figure 14: Equivalent series circuit of the inductor

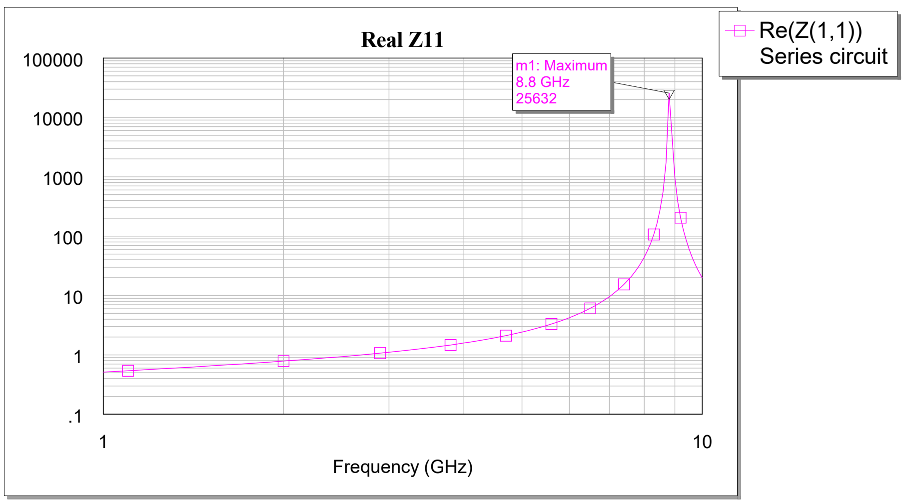


Figure 15: Real part of input impedance Z11 of the series equivalent circuit

At the resonance ($f_0 = 8.8\ GHz$), the real part of the input impedance is 25632 Ω. Also, the series resistance is

$$RS = RR(\frac{f_0}{FF})^{EX} = 0.5 \times \left(\frac{8.8 \times 10^9}{1 \times 10^9}\right)^{0.5} = 1.48\Omega$$

The unloaded quality factor at the resonance is

$$Q_{UL} = \frac{\omega_0 LS}{RS} = \frac{2\pi \times 8.8 \times 10^9 \times 6.5 \times 10^{-9}}{1.48} = 242.84$$

The parallel resistance and inductance at the resonance are

$$RP = RS(1 + Q_{UL}^2) = 87.2765\ k\Omega\ ;\ LP = LS\left(1 + \frac{1}{Q_{UL}^2}\right) \approx RS = 6.5\ nH$$

The parallel equivalent circuit of the inductor, shown in Figure 16, is simulated and the real part of the resulting input impedance Z11 is shown in Figure 17. Remarkably, both the parallel and series equivalent circuits lead to the same response.

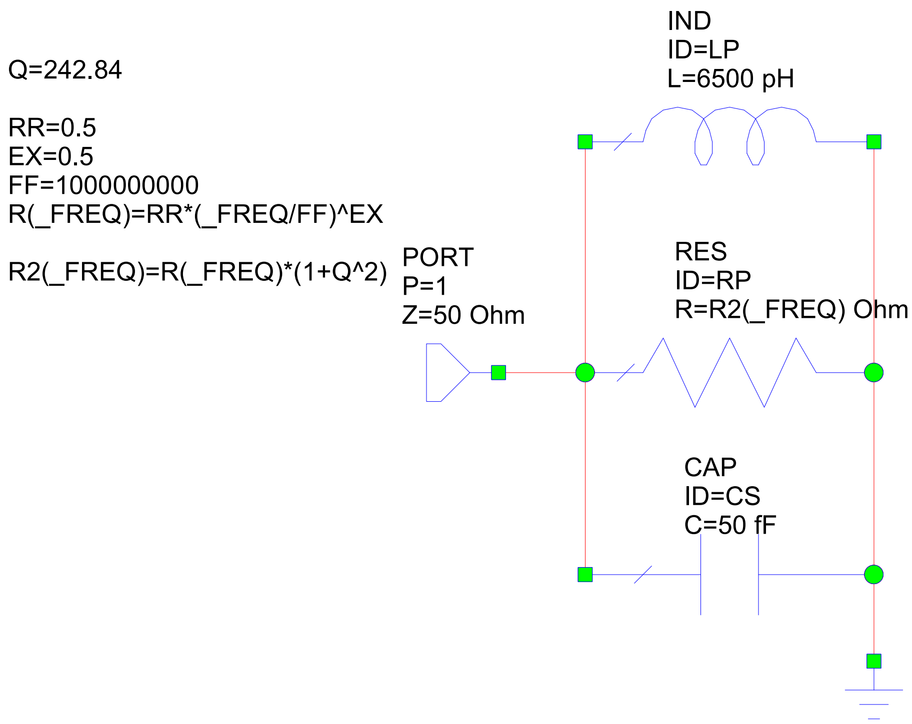


Figure 16: Equivalent parallel circuit of the inductor

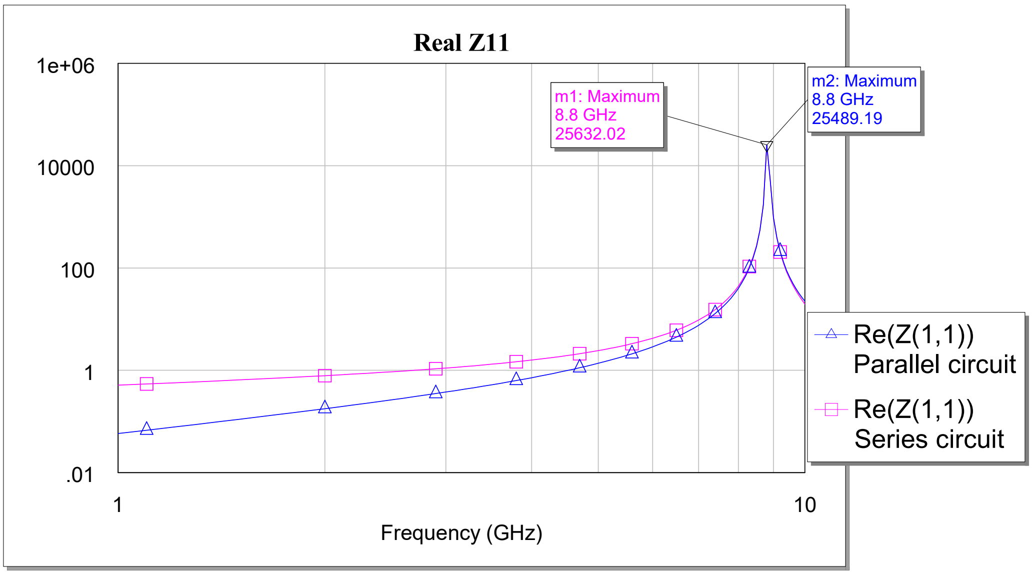


Figure 17: Real part of input impedance Z11 of the series and parallel equivalent circuit

The Q-factor is a measure of the quality factor of a resonant circuit. It is defined as the ratio of energy stored in the circuit to the energy dissipated per cycle.

The Q-value of a resonant circuit is important because it indicates how well the circuit can store and transfer energy at a specific frequency. Higher Q-values indicate that the circuit has lower losses and can sustain oscillations for a longer time, while lower Q-values indicate that the circuit has higher losses and oscillations will decay more quickly.

The Q-value is a key parameter in the design of many electronic circuits, including filters, amplifiers, and oscillators. By optimizing the Q-value of a circuit, designers can achieve better performance, such as sharper frequency response, higher gain, and more stable oscillations [2].

Feedback

- The exercise took about two day. The simulations themselves didn't take much to finish but most of the time was consumed by the finding out what to simulate.
- The exercise was easy.
- The questions were easy.
- From this exercise, I managed to better understand the use of the tune tool and equation in AWR and it increased my understanding of component models.

References

[1] Wikipedia contributors, *Skin effect — Wikipedia, the free encyclopedia*, https://en.wikipedia.org/w/index.php?title=Skin_effect&oldid=1140828364, [Online; accessed 16-April-2023], 2023.

[2] Wikipedia contributors, *Q factor — Wikipedia, the free encyclopedia*, https://en.wikipedia.org/w/index.php?title=Q_factor&oldid=1145543895, [Online; accessed 16-April-2023], 2023.