Lab3 SMD Components

EERF – 6396
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1. Introduction

Objectives:

a. Characterize the properties of SMD components
b. Model the microstrip RF circuits in the form of lumped elements

Apparatus:

a. Agilent E5071C Network Analyzer (100KHz → 8.5GHz)
b. Calibration Kit
c. SMD component test board
d. 100 Ω 0603 package resistor
e. 47 pF 0603 package capacitor

2. Pre-Lab Discussion

1) The basics of VNA working have been studied
2) SOLT method of VNA calibration and have been studied
3) Basics of soldering were refreshed

3. Procedure

- **2 – port Calibration of VNA**
  1. Press 'CAL' button on VNA
  2. Select 2 Port Calibration
  3. Follow the Short, Open, Load and Through for 2 port calibration
  4. The R.L is measured to be 70 dB after calibration

- **Soldering the SMA connectors to the test board**
  1. The test boards with w = 3 mm and b = 1 mm were tested for continuity
  2. Solder the SMA connectors with sufficient spacing between them

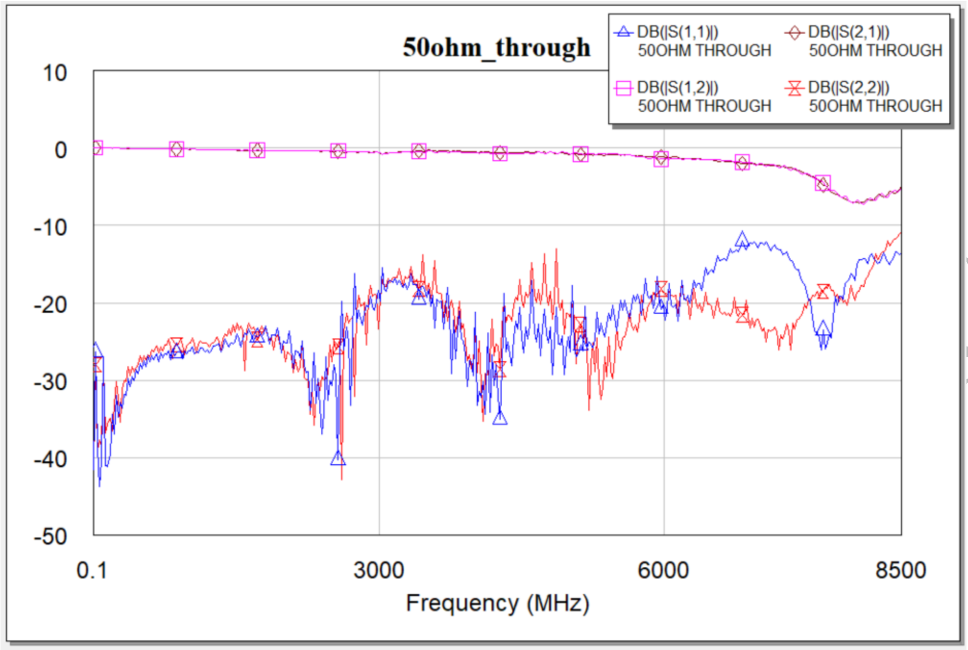
- **S-parameters for 50-ohm "through" line**
  1. Connect the 2 ports of the VNA across the 50 Ω through line
  2. Measure and record S-parameters for 50-ohm "through" line

- **Perform auto-port extension for the 2 open lines**
  1. Connect the VNA across the middle open line
  2. Set frequency sweep from 100 kHz to 4 GHz
  3. Measure the S-parameters, time delay and electrical length
  4. Repeat the procedure for the bottom line

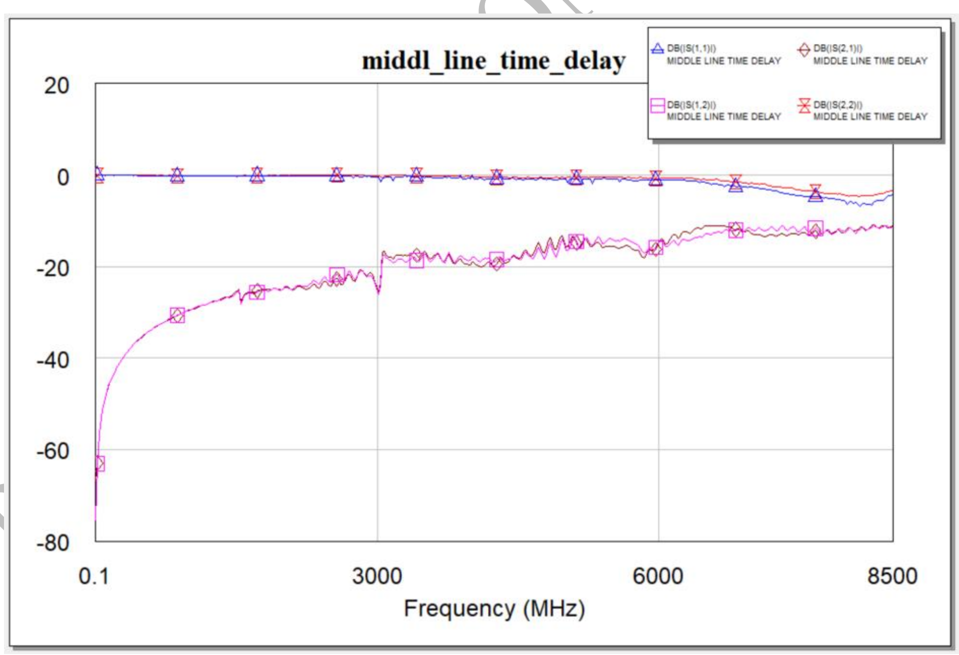
- **Measure the response of Capacitor and Resistor**
  1. Solder the capacitor and measure the S-parameters once with auto port extension ON and once with auto port extension OFF
  2. Solder the resistor on the bottom line and measure the S-parameters once with auto port extension ON and once with auto port extension OFF

4. Plots and Measurements

- **S-parameters for 50-ohm “through” line**

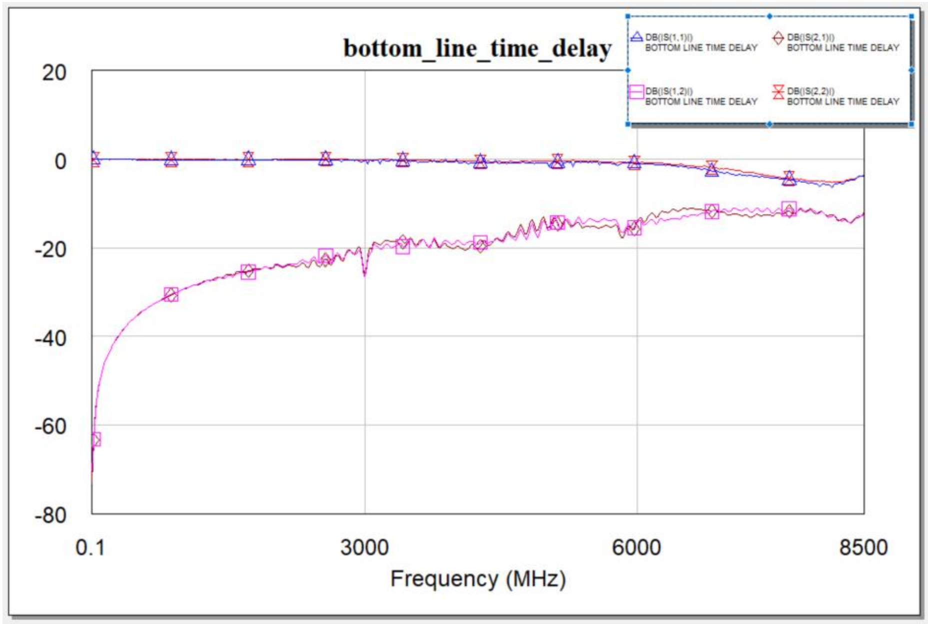


- **S-parameters of middle open-circuit 50-ohm lines (without SMD component installed)**



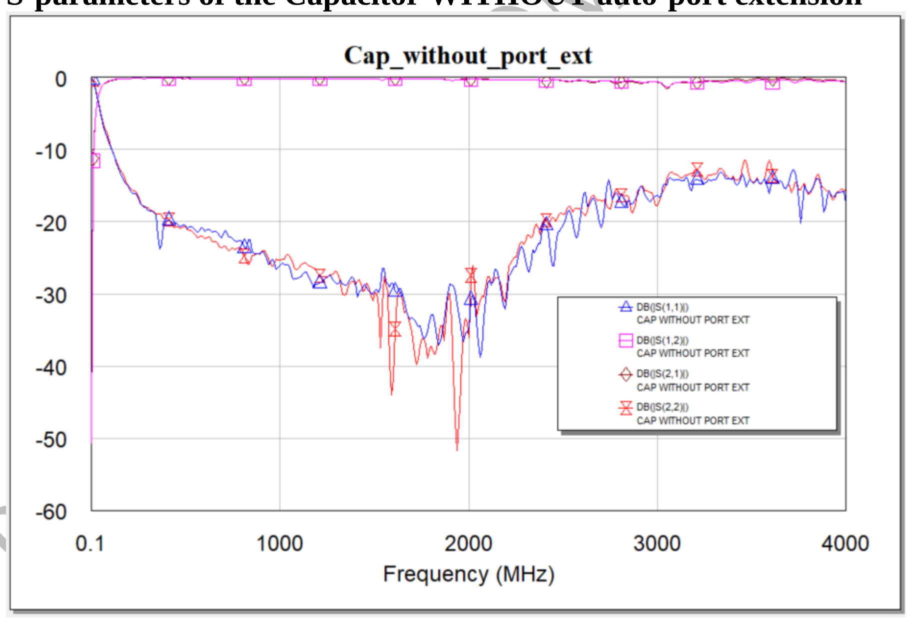
Time Delay for middle right Tx line: 166.38 ps → 49.879mm
Time Delay for middle left Tx line: 160.15 ps → 48.012mm

- **S-parameters of bottom open-circuit 50-ohm lines (without SMD component installed)**

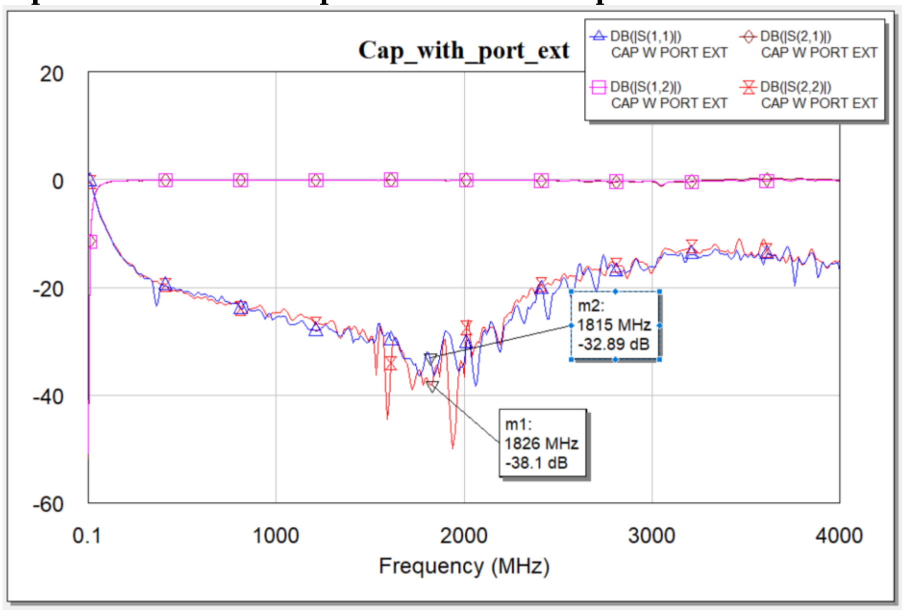


Time Delay for bottom right Tx line: 166.62 ps → 49.951mm
Time Delay for bottom left Tx line: 161.00 ps → 48.267mm

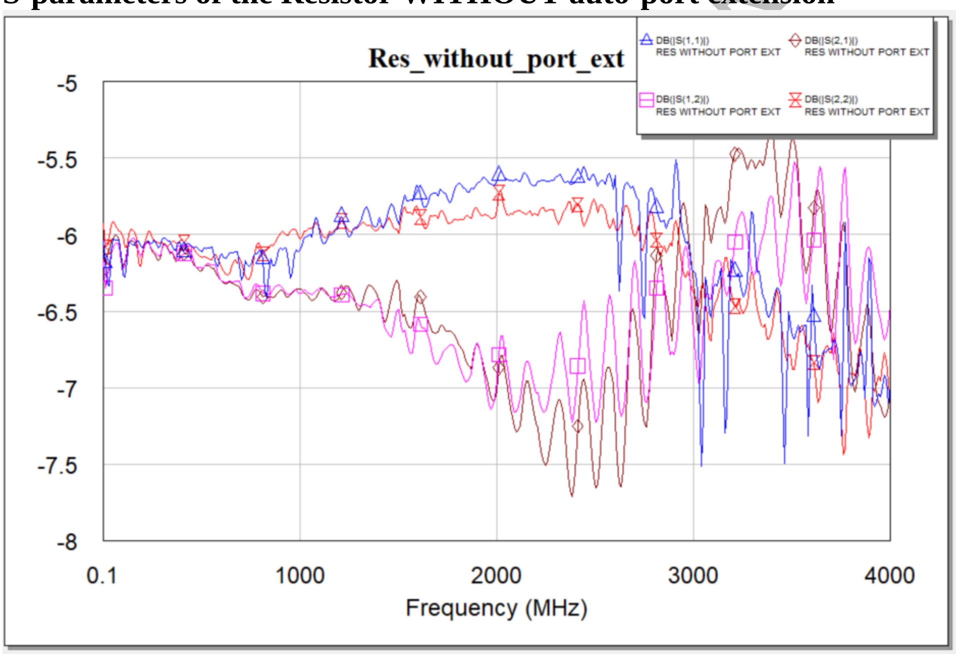
- **S-parameters of the Capacitor WITHOUT auto-port extension**



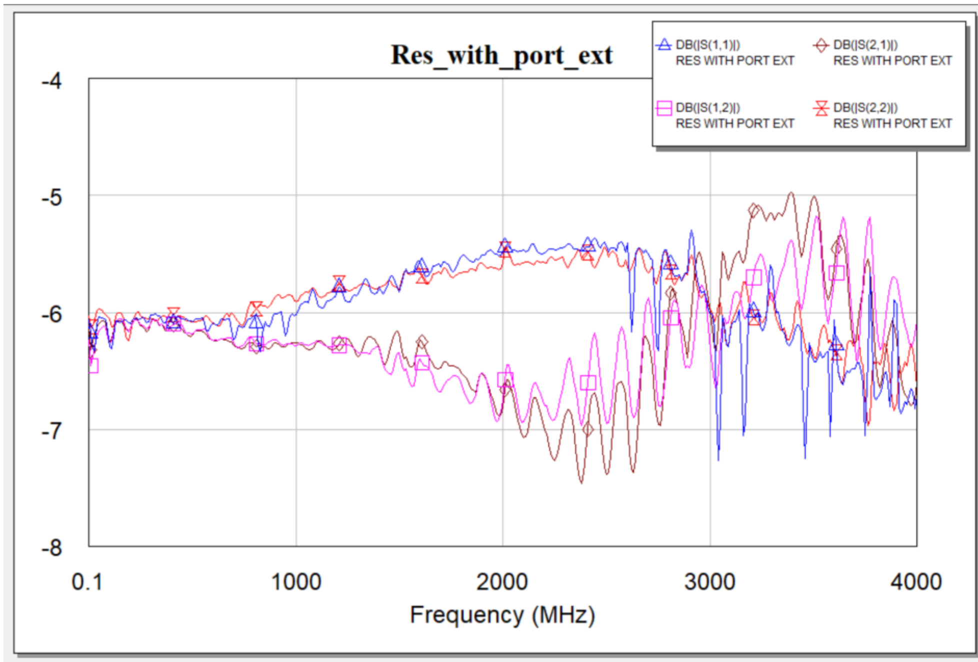
- **S-parameters of the Capacitor WITH auto-port extension**



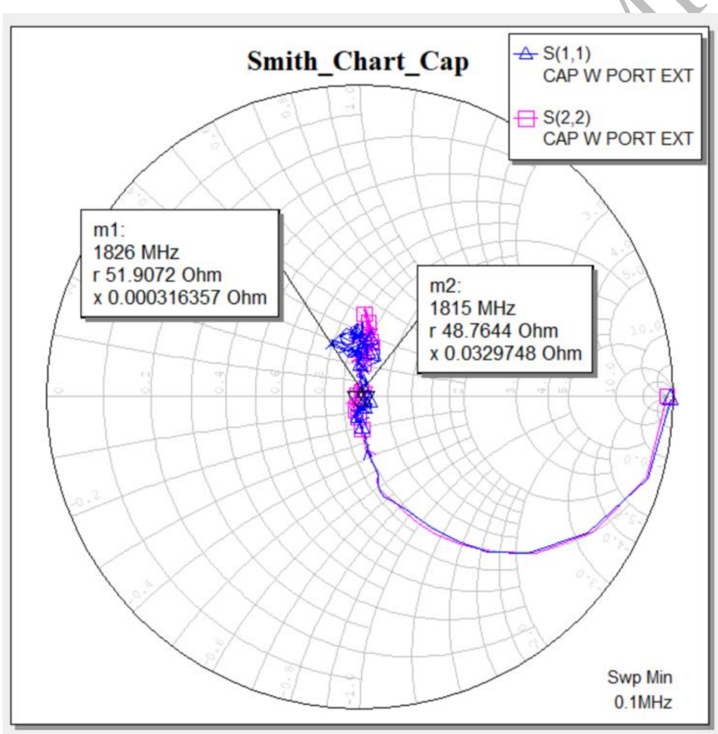
- **S-parameters of the Resistor WITHOUT auto-port extension**



- **S-parameters of the Resistor WITH auto-port extension**

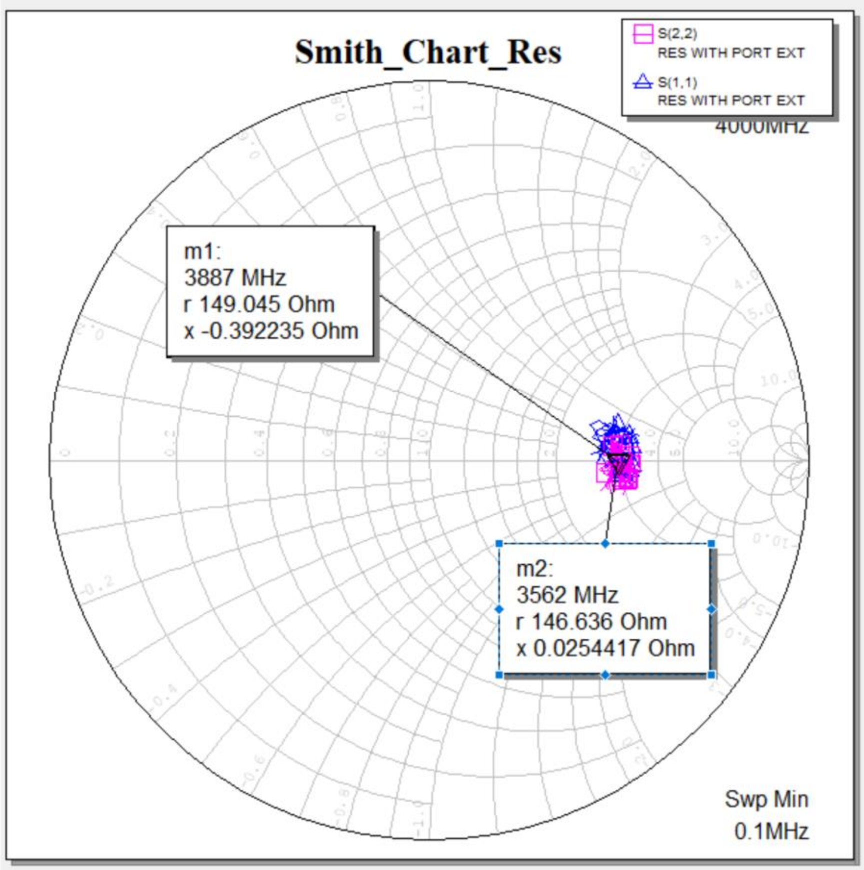


- **Smith chart (S11 & S22) [put a marker at the resonant frequency of the capacitor]**



Resonant frequency from S_{11} = 1826 MHz Z = 51.9072 + j0.000316
Resonant frequency from S_{22} = 1815 MHz Z = 48.7644 + j0.0329

- **Smith chart (S11 & S22) [put a marker at the resonant frequency of the resistor]**



The response of resistor over the entire frequency range (0.1 – 4000 MHz) is close to the real axis which is high desirable and close to ideal

Resonant frequency from S_{11} = 3887 MHz   Z = 149.045 – j0.39

Resonant frequency from S_{22} = 3562 MHz   Z = 146.636 + j0.025

5. Modelling the components as lumped elements

a) For Capacitor:

Resonant frequency from S_{11} = 1826 MHz   Z = 51.9072 + j0.000316 Ω

Resonant frequency from S_{22} = 1815 MHz   Z = 48.7644 + j0.0329 Ω

Now at any arbitrary frequency say f = 100 MHz: Z = 46.6 – j33.67 Ω

So, $$X_c = \frac{1}{2\times\pi\times f_c\times C}$$

Therefore, $$C = \frac{1}{2\times\pi\times f_c\times X_c} = \frac{1}{2\times\pi\times 100\times 10^6\times 33.67} = 47.26\text{pF}$$

At resonant frequency using S_{11} = 1826 MHz

$$f_o = \frac{1}{2 * \pi * \sqrt{LC}}$$

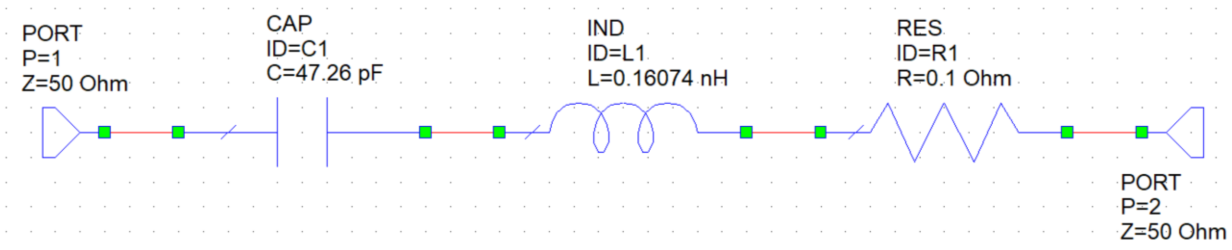
$$\sqrt{LC} = \frac{1}{2 * \pi * f_o}$$

$$\sqrt{L} = \frac{1}{2 * \pi * 1.826 * 10^9 * \sqrt{47.26 \times 10^{-12}}}$$

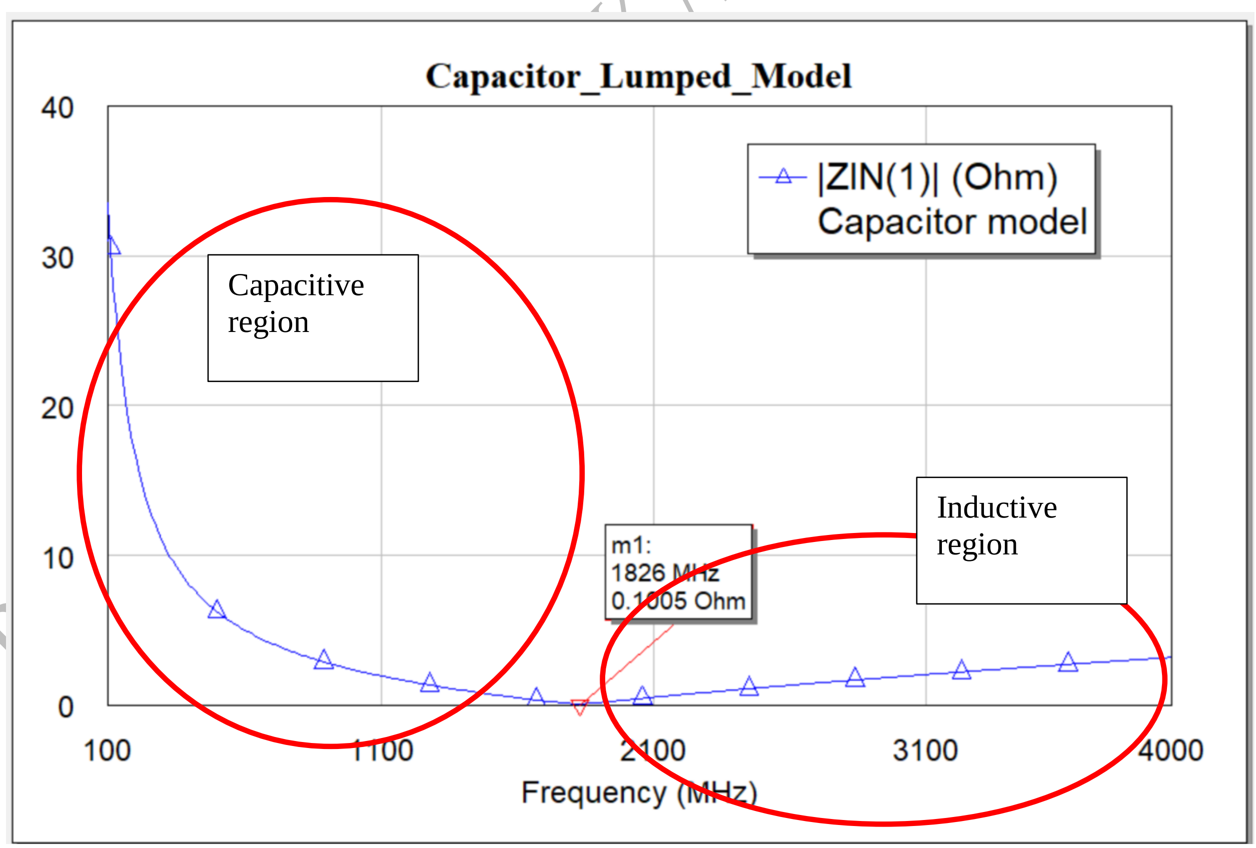
Therefore: L = 160.74 pH

Choosing an arbitrary value of 0.1Ω for the equivalent series resistance

- Equivalent lumped circuit in AWR



- Plot of Z_{in} for the equivalent lumped model



b) For Resistor:

Resonant frequency from S_{11} = 3887 MHz Z = 149.045 – j0.39
Resonant frequency from S_{22} = 3562 MHz Z = 146.636 + j0.025

Now at any arbitrary frequency say f = 500 MHz: Z = 147.533 – j12.018 Ω, the resistance is 147.533 Ω. This observed value is in series with a 50 Ω, the R' = 147.533− 50 = 97.533 Ω. The calculated value is nearly equal to the mounted resistor value, 100 Ω.

So, $X_c = \frac{1}{2\times\pi\times f_c\times C}$

Therefore, $C = \frac{1}{2\times\pi\times f_c\times X_c} = \frac{1}{2\times\pi\times500\times10^6\times12.018}$ = 26.48 pF

At resonant frequency using S_{22} = 3562 MHz

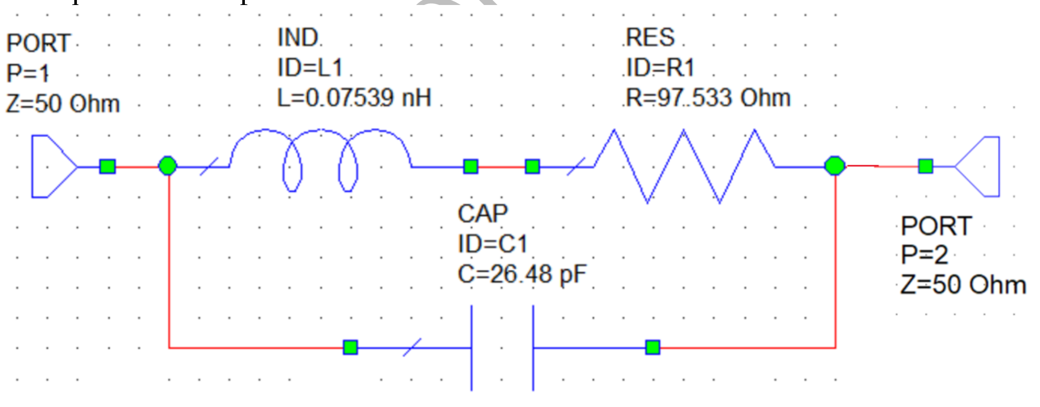
$$f_o = \frac{1}{2*\pi*\sqrt{LC}}$$

$$\sqrt{LC} = \frac{1}{2*\pi*f_o}$$

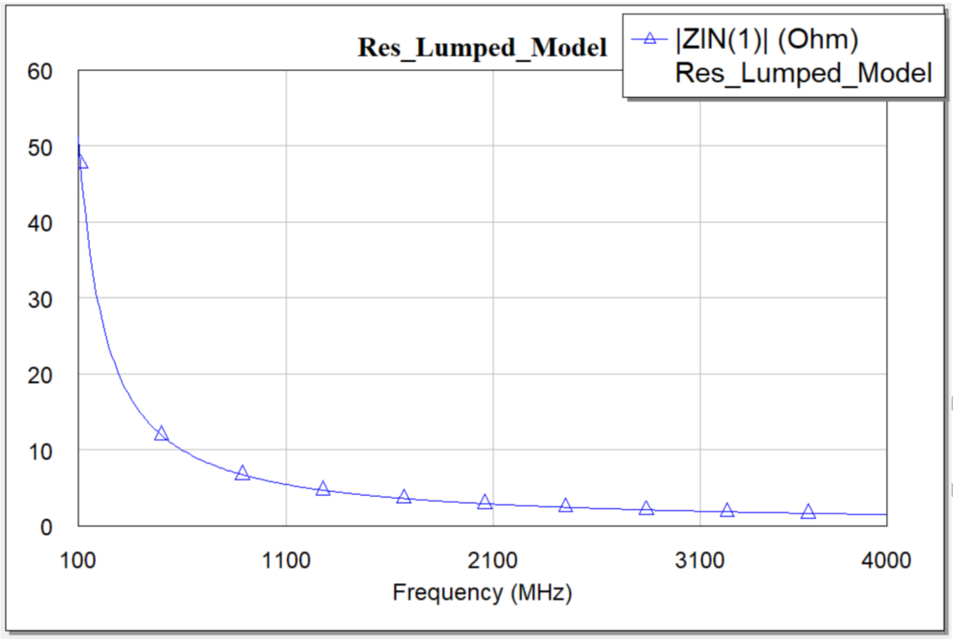
$$\sqrt{L} = \frac{1}{2*\pi*3.562*10^9*\sqrt{26.48\times10^{-12}}}$$

Therefore: L = 75.39 pH

- Equivalent lumped circuit in AWR



- Plot of Z_{in} for the equivalent lumped model



Analysis:

1. After examining your measured capacitor data, over what frequency range do you feel the capacitor should be used if you want it to behave as:
    a. an RF capacitor for impedance matching?

- The reactive nature of the capacitor is minimum at its resonant frequency. Accordingly, the capacitor can be used for impedance matching around 1.826GHz.

    b. an RF capacitor for DC blocking or for using as a bypass capacitor in a DC bias circuit?

- The capacitive region is below the resonant frequency of f = 1.826GHz. The capacitor can be used to block DC up to 1.826 GHz. Above this it behaves like an inductor and cannot be used to block DC.

2. From your microstrip transmission line measurements what can be determined about the effective dielectric constant of the circuit board used? (Assume each SMA launcher is ~20pS of time delay in your measurement.)

- From the measurements the average time delay is 165.23 ps and the average distance is 49.027 mm

  From the layout of the board,

$$V_p = \frac{\text{distance}}{(2 \times \text{measured time delay}) - \text{time delay of the 2 SMA launchers}}$$

$$= \frac{49.027\ mm}{((2 \times 165.25) - 40)ps} = 168.18 \times 10^6 \text{ m/s}$$

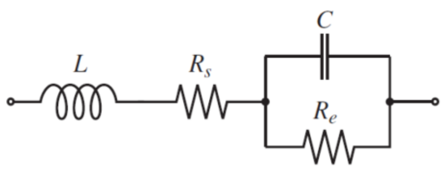
$$\epsilon_{eff} = \left(\frac{c}{Vp}\right)\hat{}2$$

$\therefore \quad \epsilon_{eff} = (3 \times 10^8 \div 168.10 \times 10^6)^2$

$\therefore \quad \epsilon_{eff} = 3.179$

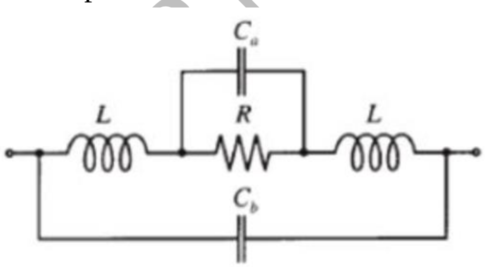
3. Explain your reasons for the chosen models and discuss how the models can be improved to predict the component behavior over the entire measured frequency range.

- The capacitor model:
  The capacitor has dielectric sandwiched between 2 plates. The leads of the capacitor essentially are inductive by nature and also have a finite resistance. Hence the capacitor equivalent model is chosen as a series RLC circuit with appropriate values. The capacitor model can be further improved by considering the imperfections in the dielectric.



L = Lead inductance
R_s = AC resistance of leads
C = Capacitance
R_e = Dielectric loss resistance

- The Resistor model:
  The leads of the resistor impart an inductance and the resistive compound essentially acts as a dielectric which can be modelled by a capacitor in parallel with the series R and L. A more accurate representation is as follows:



Source: http://www.ques10.com

4. What is the measured Q of the (series) capacitor?

- $Q = \frac{1}{\omega RC} = \frac{1}{2\pi \times (1.826 \times 10^9) \times 0.1 \times (47.26 \times 10^{-12})} = 18.44$

Summary:

The capacitor behaves as a capacitor below its resonant frequency. For $f > f_0$ it shows inductive properties. Prover choice of capacitor is extremely essential for the given frequency and purpose. A resistor at high frequency exhibits reactance due to the presence of minute L and C which become prominent at high frequencies.

Conclusion:

The high frequency models of resistor and capacitor have been studied to decomposed to their lumped element equivalent. The usable frequency range for the component were also studied.