Familiarization with ADS

Lab Exercises on December, 2021

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PUL074BEX007

1 Objective

To setup and execute S-parameter simulation, to display simulation data, and to use SNP files in ADS.

Note: Refer lab sheet for background theory.

2 Lab Exercises

Problem 1

S-parameter simulation using SNP file in MA format

The given S-matrix for a two-port network with port impedance $Z_0 = 50\Omega$ is,

$$S_{50\Omega} = \begin{bmatrix} \frac{5}{13} & j\frac{12}{13} \\ j\frac{12}{13} & \frac{5}{13} \end{bmatrix}$$

Since the given network is a 2-port network, a *s2p* file with the following content is created.

```
#  GHz  S  MA  R  50
! freq magS11 angS11 magS21 angS21 magS12 angS12 magS22 angS22
! freq 5/13 0 deg 12/13 90 deg 12/13 90 deg 5/13 0 deg
1.0 0.3846153846 0 0.923076923 90 0.923076923 90 0.3846153846 0
2.0 0.3846153846 0 0.923076923 90 0.923076923 90 0.3846153846 0
```

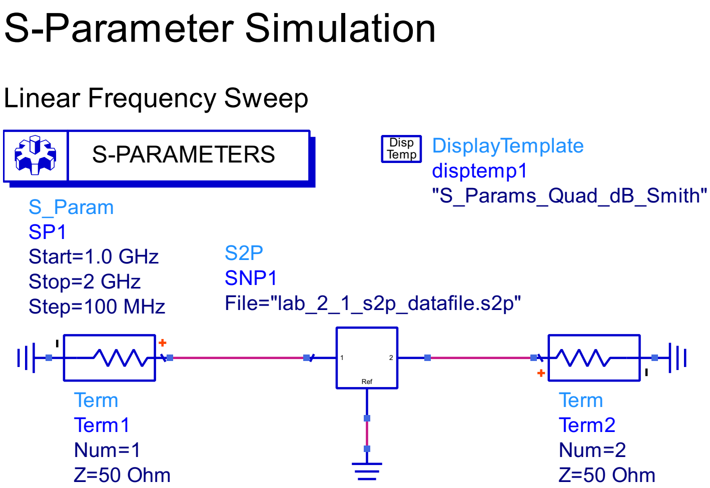

Figure 1: Schematic for simulating S-parameters using SNP file

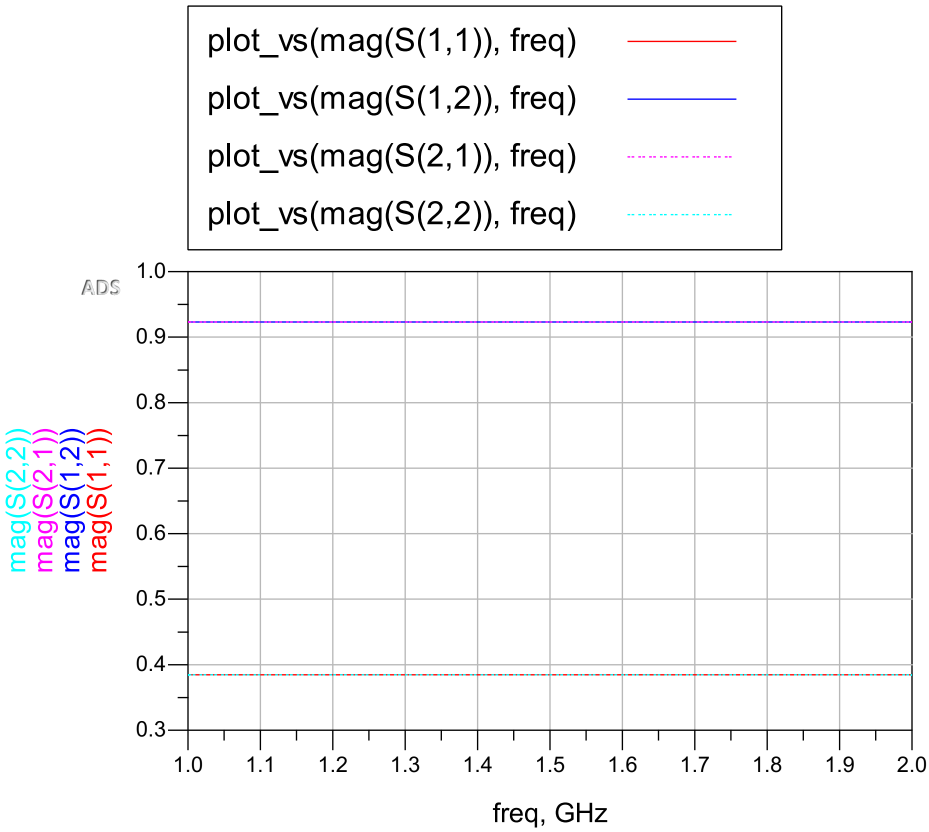

Figure 2: Magnitude of S-parameters vs Frequency

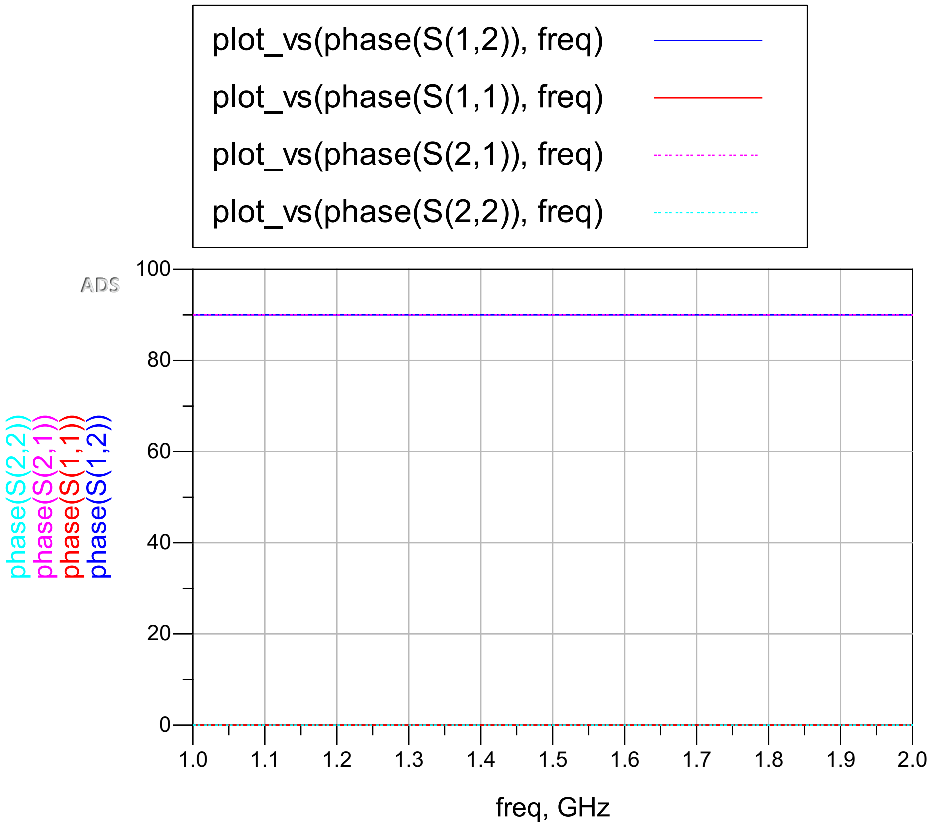

Figure 3: Phase (deg) of S-parameters vs Frequency

freq	var("S")			
	(1,1)	(1,2)	(2,1)	(2,2)
1.000 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000
1.100 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000
1.200 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000
1.300 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000
1.400 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000
1.500 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000
1.600 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000
1.700 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000
1.800 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000
1.900 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000
2.000 GHz	0.385 / 0.000	0.923 / 90.000	0.923 / 90.000	0.385 / 0.000

Figure 4: List plot of S-parameters vs Frequency

Problem 2

S-parameter simulation using SNP file in RI format

The given S-matrix for a two-port network with port impedance $Z_0 = 50\Omega$ is,

$$S_{50\Omega} = \begin{bmatrix} 0.3 + j0.7 & j0.6 \\ j0.6 & 0.3 - j0.7 \end{bmatrix}$$

Since the given network is a 2-port network, a *s2p* file with the following content is created.

```
#  GHz  S  RI  R  50
! freq realS11 imagS11 realS21 imagS21 realS12 imagS12 realS22 imagS22
! freq 0.3 0.7 0 0.6 0 0.6 0.3 -0.7
1.0 0.3 0.7 0 0.6 0 0.6 0.3 -0.7
2.0 0.3 0.7 0 0.6 0 0.6 0.3 -0.7
```

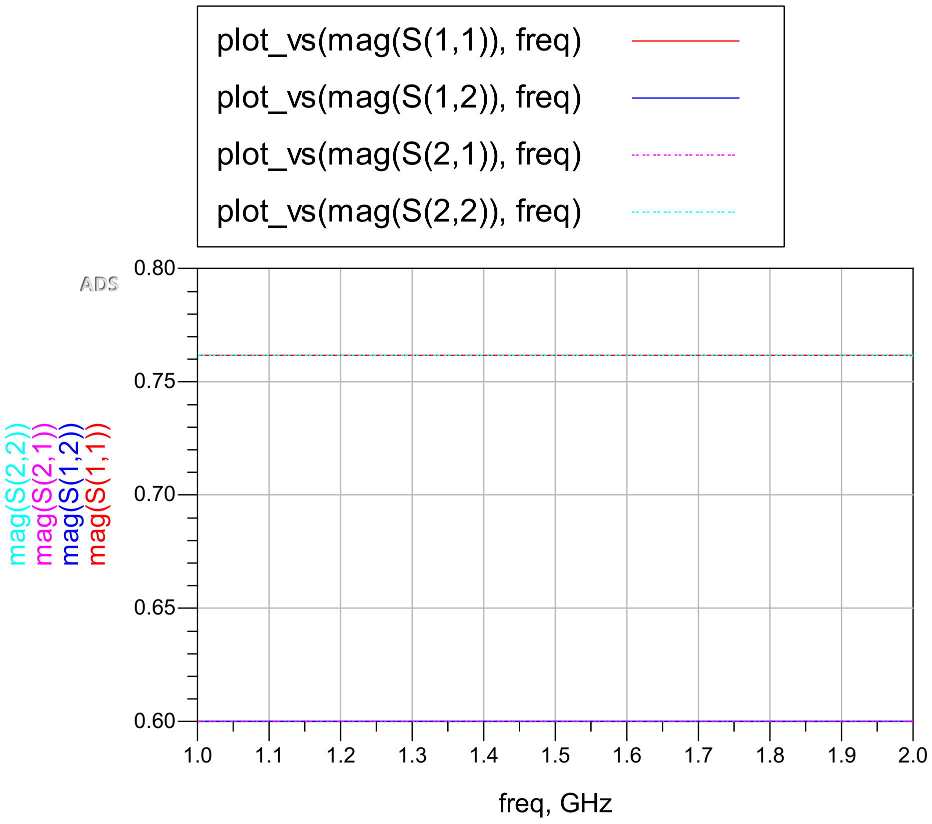

Figure 5: Magnitude of S-parameters vs Frequency

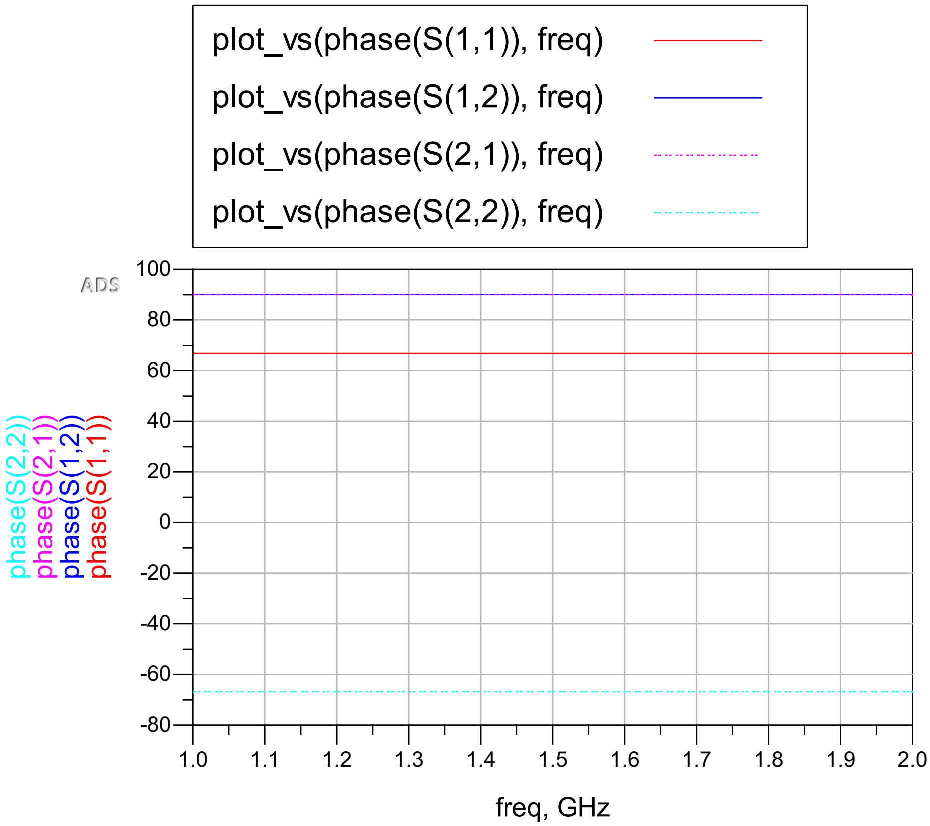

Figure 6: Phase (deg) of S-parameters vs Frequency

freq	var("S")			
	(1,1)	(1,2)	(2,1)	(2,2)
1.000 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801
1.100 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801
1.200 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801
1.300 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801
1.400 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801
1.500 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801
1.600 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801
1.700 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801
1.800 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801
1.900 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801
2.000 GHz	0.762 / 66.801	0.600 / 90.000	0.600 / 90.000	0.762 / -66.801

Figure 7: List plot of S-parameters vs Frequency

Problem 3

S-parameters for a 3 dB attenuator circuit

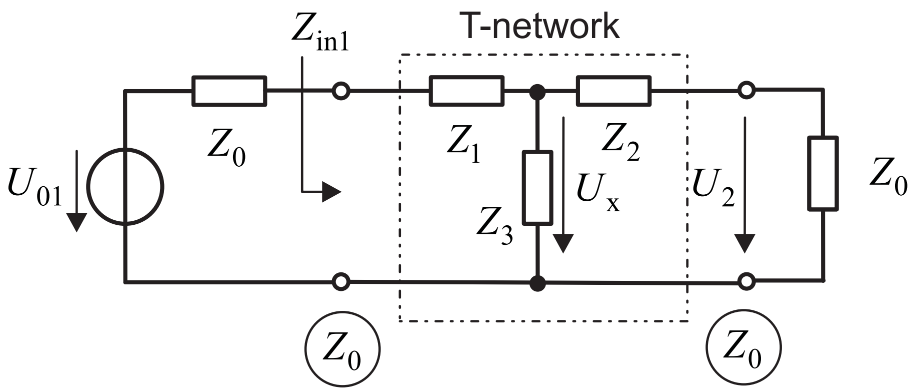

Figure 8: General T-network

The input impedance Z_{in1} can be calculated as,

$$Z_{in1} = Z_1 + Z_3||(Z_2 + Z_0) = Z_1 + \frac{Z_3(Z_2 + Z_0)}{Z_3 + Z_2 + Z_0} = \frac{Z_1Z_3 + Z_1Z_2 + Z_1Z_0 + Z_2Z_3 + Z_3Z_0}{Z_3 + Z_2 + Z_0}$$

A specific s-parameter S_{ij} can be defined in terms of normalized voltages a and b as,

$$S_{ij} = \left.\frac{b_i}{a_j}\right|_{a_k=0,\text{ where } k\neq j}$$

So,

$$\begin{aligned} S_{11} &= \left.\frac{b_1}{a_1}\right|_{a_2=0} \\ &= \frac{Z_{in1} - Z_0}{Z_{in1} + Z_0} \\ &= \frac{Z_1Z_2 + Z_1Z_3 + Z_2Z_3 + Z_1Z_0 - Z_0Z_2 - Z_0^2}{Z_1Z_2 + Z_1Z_3 + Z_2Z_3 + Z_1Z_0 + 2Z_0Z_3 + Z_0Z_2 + Z_0^2} \end{aligned} \tag{1}$$

By symmetry, swapping the indices 1 and 2 we get,

$$\begin{aligned} S_{22} &= \left.\frac{b_2}{a_2}\right|_{a_1=0} \\ &= \frac{Z_1Z_2 + Z_1Z_3 + Z_2Z_3 - Z_1Z_0 + Z_0Z_2 - Z_0^2}{Z_1Z_2 + Z_1Z_3 + Z_2Z_3 + Z_1Z_0 + 2Z_0Z_3 + Z_0Z_2 + Z_0^2} \end{aligned} \tag{2}$$

To calculate the transmission factors the voltage ratio $\frac{U_2}{U_{01}}$ is required. For this, the following voltage ratios are used,

$$\frac{U_2}{U_x} = \frac{Z_0}{Z_2 + Z_0} \quad \text{and} \quad \frac{U_x}{U_{01}} = \frac{Z_3||(Z_2 + Z_0)}{Z_0 + Z_1 + Z_3||(Z_2 + Z_0)}$$

$$\begin{aligned} S_{12} = S_{21} = \frac{2U_2}{U_{01}}\sqrt{\frac{Z_0}{Z_0}} = 2\frac{U_2}{U_x}.\frac{U_x}{U_{01}} &= 2.\frac{Z_0}{Z_2 + Z_0}.\frac{Z_3||(Z_2 + Z_0)}{Z_0 + Z_1 + Z_3||(Z_2 + Z_0)} \\ = \frac{2Z_3Z_0}{Z_1Z_2 + Z_1Z_3 + Z_2Z_3 + Z_1Z_0 + 2Z_0Z_3 + Z_0Z_2 + Z_0^2} \end{aligned} \tag{3}$$

The S-parameters for 3 dB attenuator with following configuration is calculated,

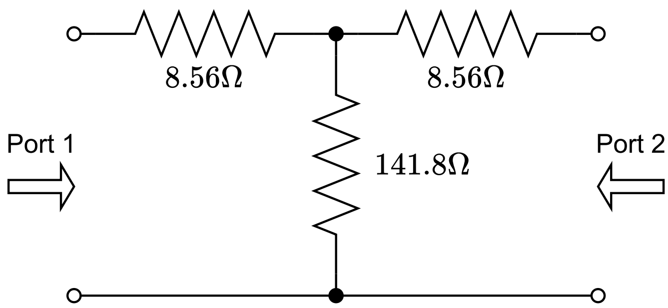

Figure 9: 3 dB attenuator circuit

For $Z_1 = Z_2 = 8.56\Omega$, $Z_3 = 141.8\Omega$ and $Z_0 = 50\Omega$

$$Z_{in1} = 50.00444\Omega$$

$$S_{11} = S_{22} = 0.0044 \approx 0$$

$$S_{12} = S_{21} = 0.707$$

The scattering matrix is, $S = \begin{bmatrix} 0 & 0.707 \\ 0.707 & 0 \end{bmatrix}$.

If the input power is $\frac{|V_1^+|^2}{2Z_0}$, then the output power is $\frac{|V_2^-|^2}{2Z_0} = \frac{|S_{21}V_1^+|^2}{2Z_0} = \frac{|S_{21}|^2|V_1^+|^2}{2Z_0} = \frac{|V_1^+|^2}{4Z_0}$, which is one half (-3 dB) of the input power.

Validation by circuit simulation

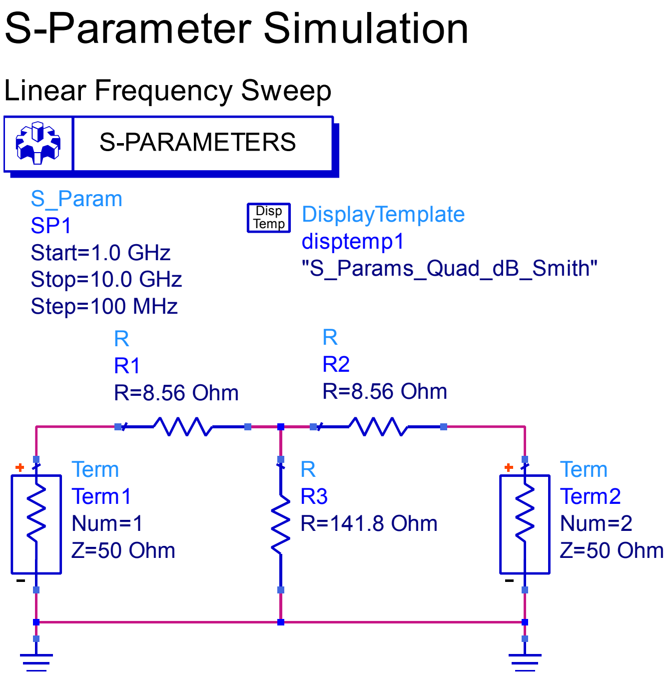

Figure 10: Schematic for comparing calculated S-parameters

freq	var("S")			
	(1,1)	(1,2)	(2,1)	(2,2)
1.000 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000
1.100 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000
1.200 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000
1.300 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000
1.400 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000
1.500 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000
1.600 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000
1.700 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000
1.800 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000
1.900 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000
2.000 GHz	4.440E-5 / 0.000	0.708 / 0.000	0.708 / 0.000	4.440E-5 / 0.000

Figure 11: List plot of S-parameters vs Frequency

Problem 4

Input impedance from reflection coefficient

The given reflection coefficient for an antenna with port impedance $Z_0 = 50\Omega$ is,

$$\Gamma_A = 0.4e^{-j20^\circ} = 0.4(\cos(20^\circ) - j\sin(20^\circ)) = 0.376 - j0.137$$

The input impedance is related with the reflection coefficient of an antenna as,

$$Z_A = Z_0 \frac{1 + \Gamma_A}{1 - \Gamma_A}$$

Solving for Z_A we get,

$$Z_A = (102.9 - j33.51)\Omega$$

Validation by circuit simulation

Since the network is a 1-port network, a *s1p* file with the following content is created.

```
#  GHz  S  MA  R  50
! freq magS11 angS11
!freq 0.4 -20
1.0 0.4 -20
2.0 0.4 -20
```

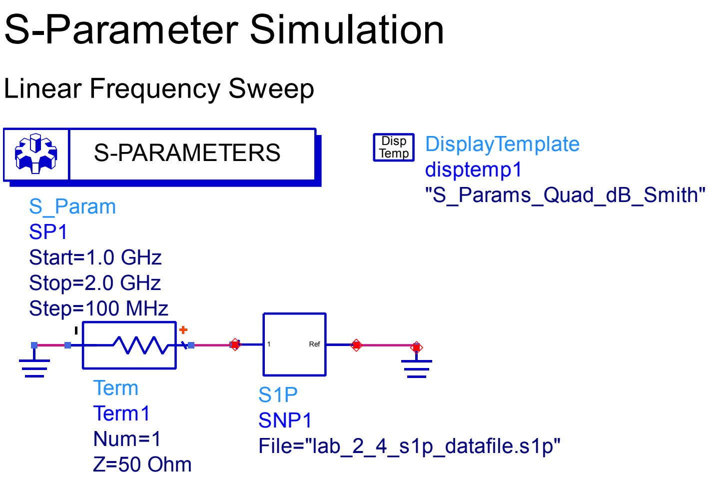

Figure 12: Schematic for simulating S-parameters using SNP file

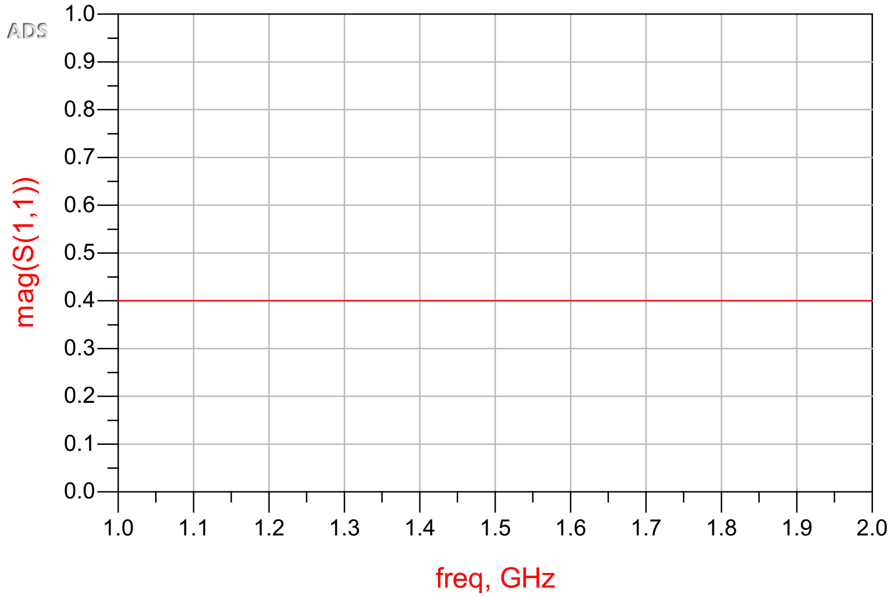

Figure 13: Magnitude of S_{11} (Γ_A) vs Frequency

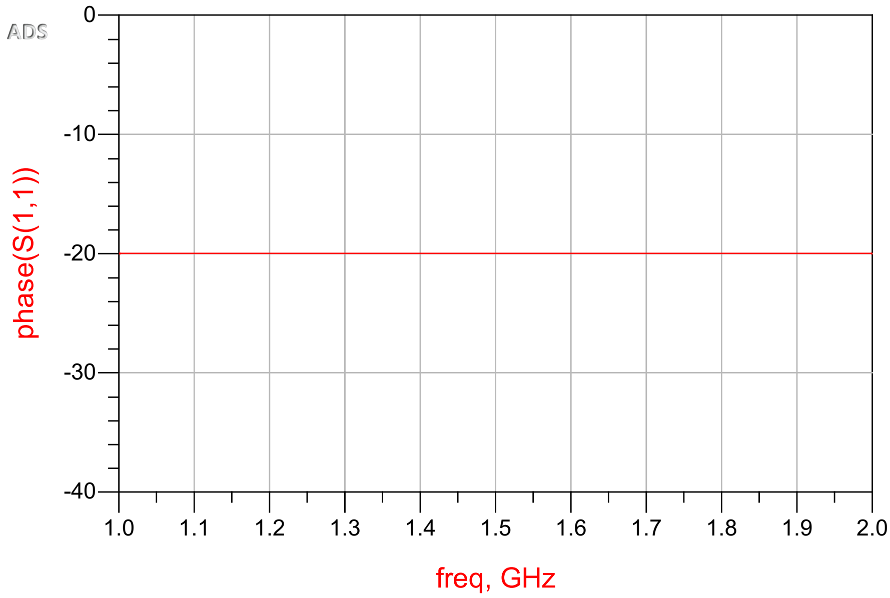

Figure 14: Phase (deg) of S_{11} (Γ_A) vs Frequency

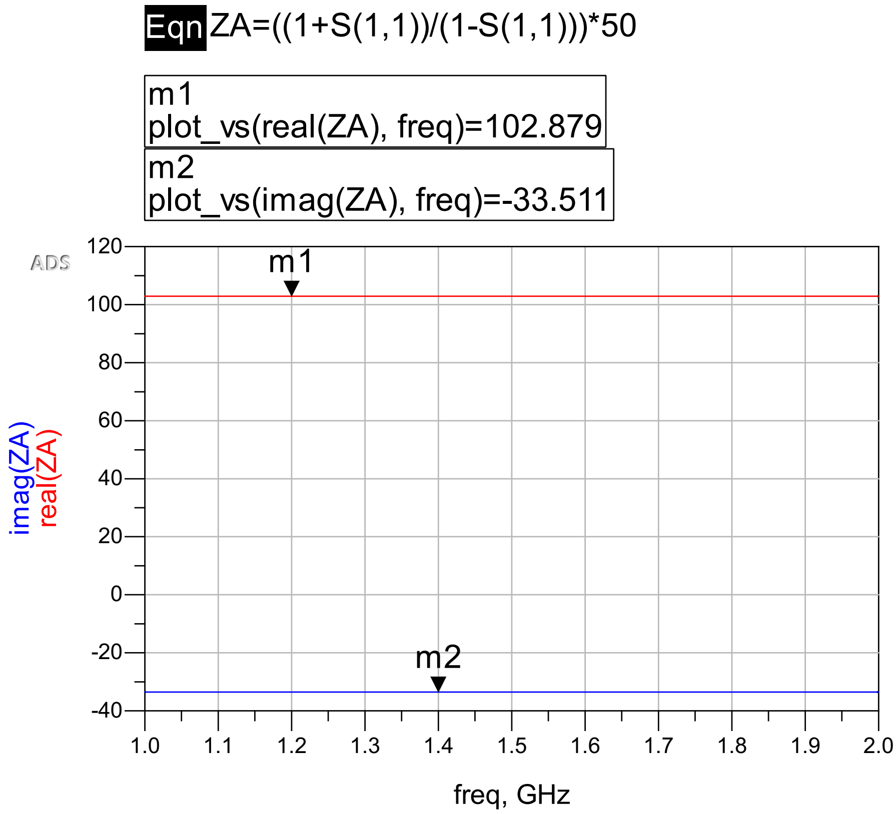

Figure 15: Real and imaginary parts of input impedance vs Frequency

Problem 5

Impedances and reflection coefficients for disconnected terminals network

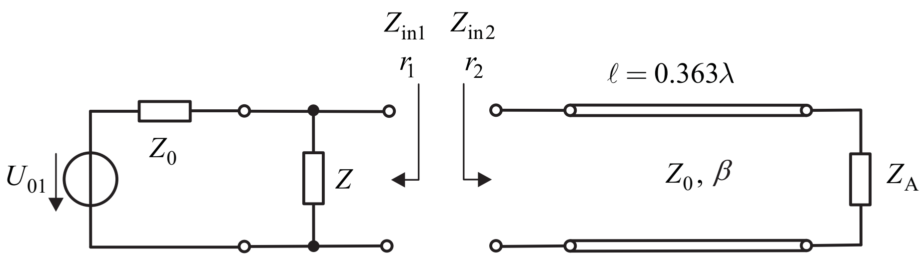

Figure 16: Circuit with disconnected terminals

$Z_0 = 50\Omega$, $Z_A = 100\Omega + j\omega L = 100\Omega + j100\Omega$ where $L = 15.92$ nH and $Z = \dfrac{1}{j\omega C}$ where $C = 5$ pF.

The input impedance Z_{in1} is given as,

$$Z_{in1} = Z_0 || Z = \frac{Z_0(1 - j\omega C Z_0)}{1 + (\omega C Z_0)^2} = (14.42 - j22.65)\Omega$$

The reflection coefficient Γ_1 is given as,

$$\Gamma_1 = \frac{Z_{in1} - Z_0}{Z_{in1} + Z_0} = 0.6176e^{-j128.15^\circ}$$

The reflection coefficient Γ_2' at the end of the line is given as,

$$\Gamma_2' = \frac{Z_A - Z_0}{Z_A + Z_0} = 0.62e^{j29.75^\circ}$$

So, the reflection coefficient at the input of the transmission line is given as,

$$\Gamma_2 = \Gamma_2' e^{-j2\beta l} = 0.62e^{j29.75^\circ} e^{j98.64^\circ} = 0.62e^{j128.39^\circ}$$

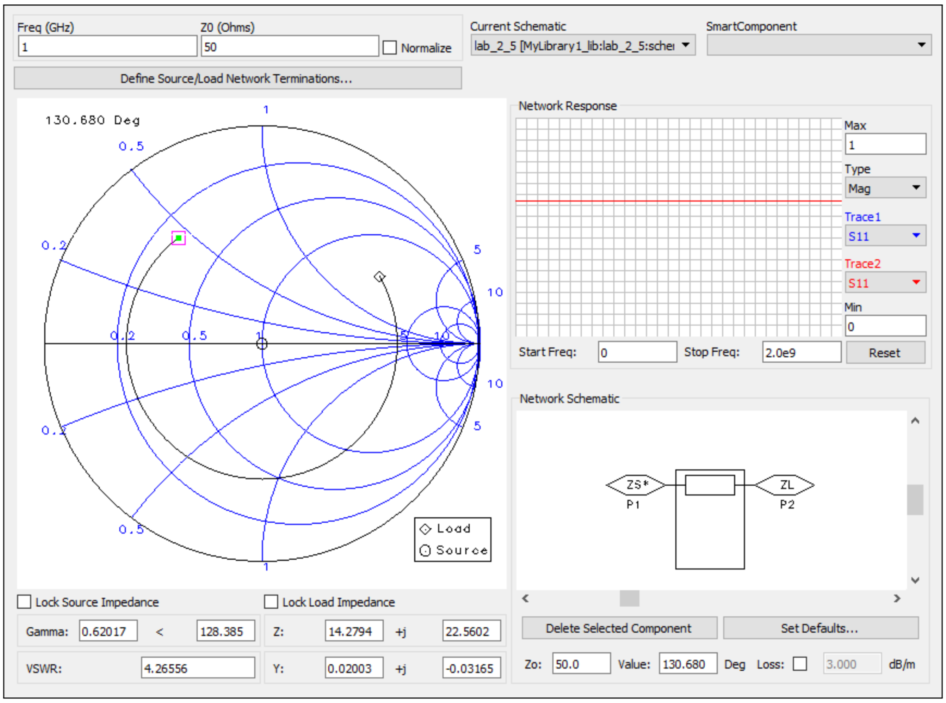

Figure 17: Smith chart utility for determination of Z_{in2}

The input impedance Z_{in2} is determined using the Smith chart utility in ADS. Upon entering the load impedance, reflection coefficient, port reference impedance and the electrical line length, which is, $0.363\lambda = 130.68°$, the input impedance represented by the red square reads $14.279 + j22.56\Omega$.

$$Z_{in2} = (14.28 + j22.65)\Omega$$

Validation by circuit simulation

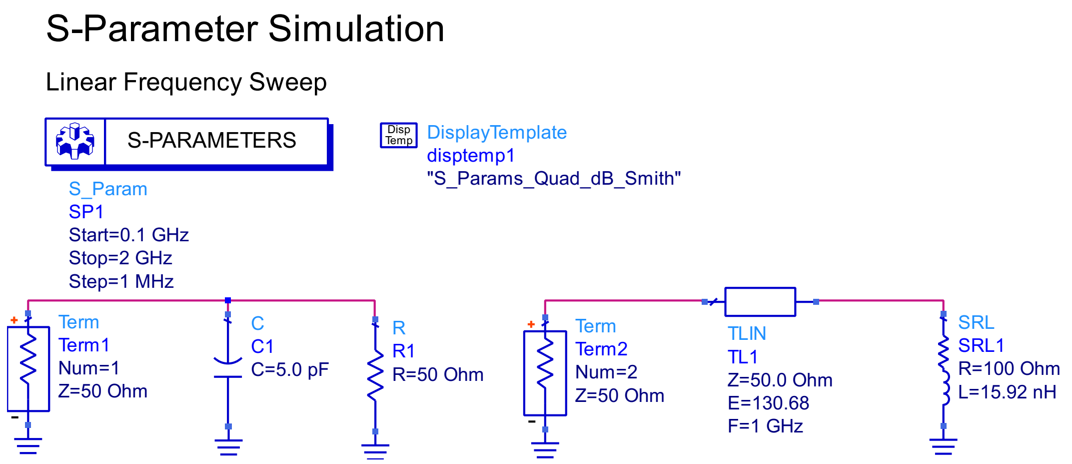

Figure 18: Schematic for comparing calculated impedance and reflection coefficients

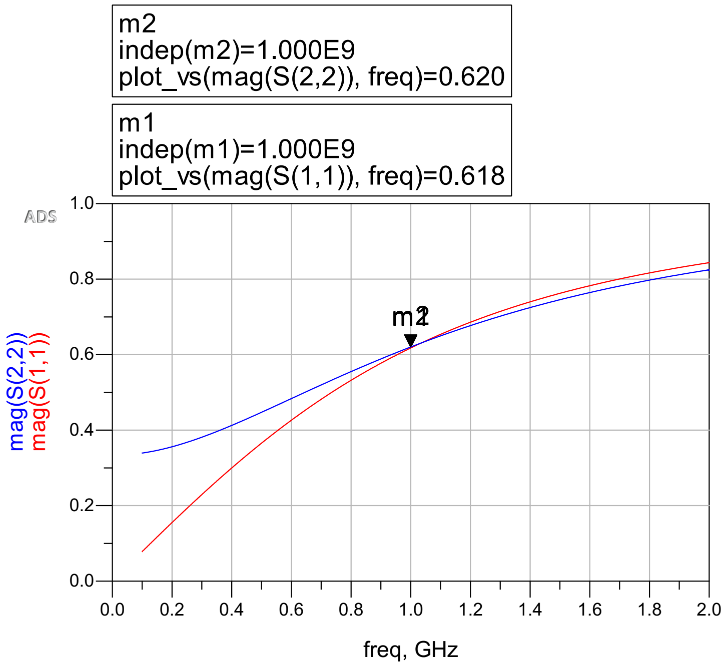

Figure 19: Magnitude of S_{11}, S_{22} vs Frequency

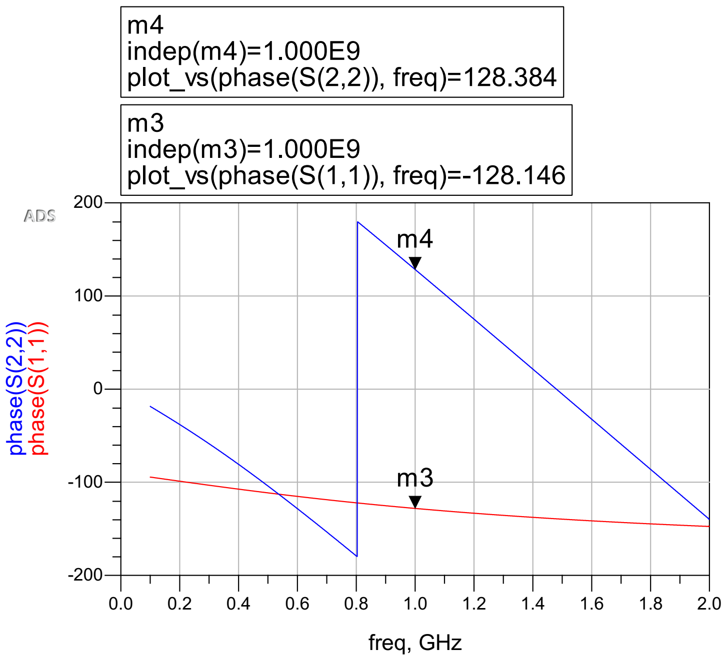

Figure 20: Phase (deg) of S_{11}, S_{22} vs Frequency

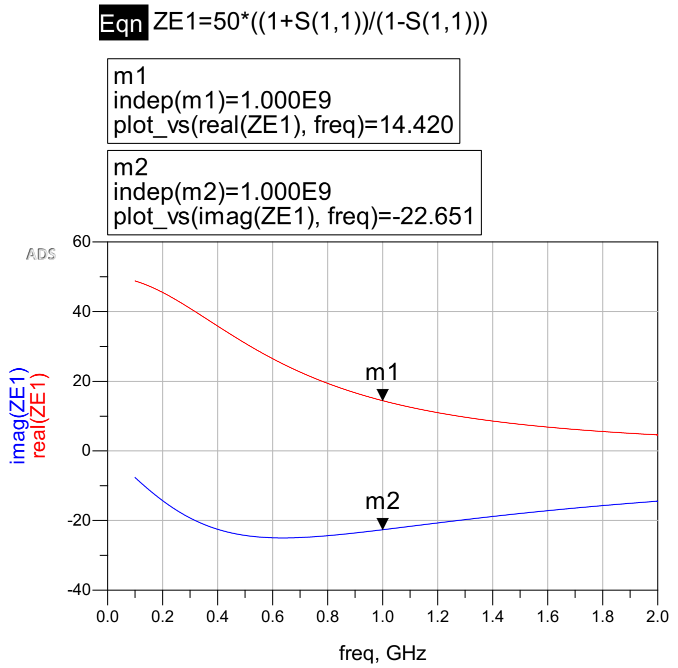

Figure 21: Real and imaginary parts of impedance Z_{in1} vs Frequency

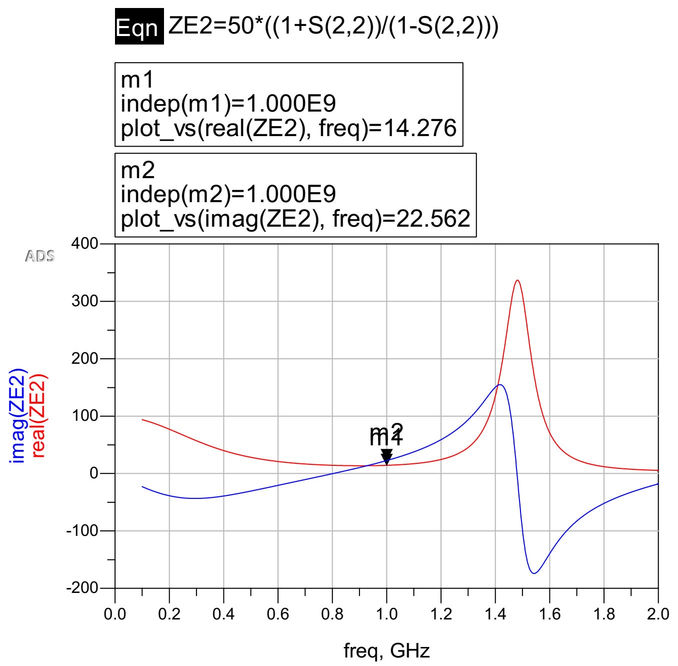

Figure 22: Real and imaginary parts of impedance Z_{in2} vs Frequency

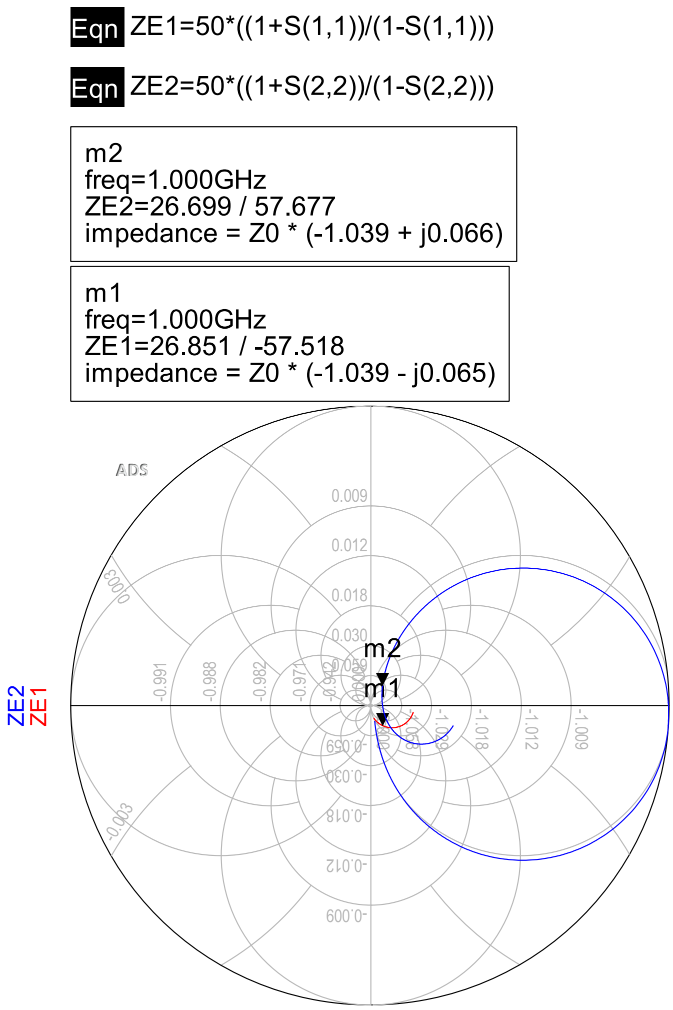

Figure 23: Real and imaginary parts of impedance Z_{in2} vs Frequency