HACETTEPE UNIVERSITY
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

ELE 447 MICROWAVE TECHNIQUES LABORATORY-I
Transmission Line and Waveguide Design Term Project-Fall 2019 Part-II

Name: Didem DİNÇER

PROJECT GROUP MEMBERS:
Didem DİNÇER
Yunus Emre TORUN
İlyas Emre VERGİLİ

Contents

List of Figures

1. Question 1

Design a coaxial transmission line and terminate the line with the given loads using AWR (parameters are given for each group, characteristic impedance, Zc=50 Ω). You can use AWR TXline calculator or other calculators from internet. Choose line length as 0.5λ, 5λ and 10λ, respectively and

- Find and draw reflection coefficient and VSWR's of these lines. Compare your results with analytical solutions.
- Perform simulations in the frequency range f-0.2f<f<f+0.2f for the VSWR and reflection coefficient. Plot input impedance, Zin vs frequency.

Frequency(f)(GHz)	Permittivity (Ɛr)(F/m)
2.4	2.94

Figure 1.1 The given parameters

Mathematical Calculation of Designed Coaxial Cable:

$$\lambda = {}^{\nu_p}/_{f} \quad \text{equation 1.1}$$

$$\nu_p = \frac{c}{\sqrt{\varepsilon_r}} \quad \text{equation 1.2}$$

$$\lambda = \frac{c}{f\sqrt{\varepsilon_r}} = \frac{3\times10^8}{24\times10^8\sqrt{2.94}} \quad \text{equation 1.3}$$

$$\lambda = 72.9\ mm \quad \text{equation 1.4}$$

Electrical Length 360° = 1 wavelength:

$$z_0 = \frac{1}{2\pi}\sqrt{\frac{\mu_0}{\varepsilon_0\varepsilon_r}}\ln\left(\frac{b}{a}\right) \quad \text{equation 1.5}$$

$$\ln\left(\frac{b}{a}\right) = \frac{50.2\pi}{\sqrt{\frac{4\pi x10^{-7}}{8.85\times10^{-12}(2.94)}}} \quad \text{equation 1.6}$$

$$\frac{b}{a} = 4.176 \quad \text{equation 1.7}$$

This result match with AWR TX line calculator, it is in following;

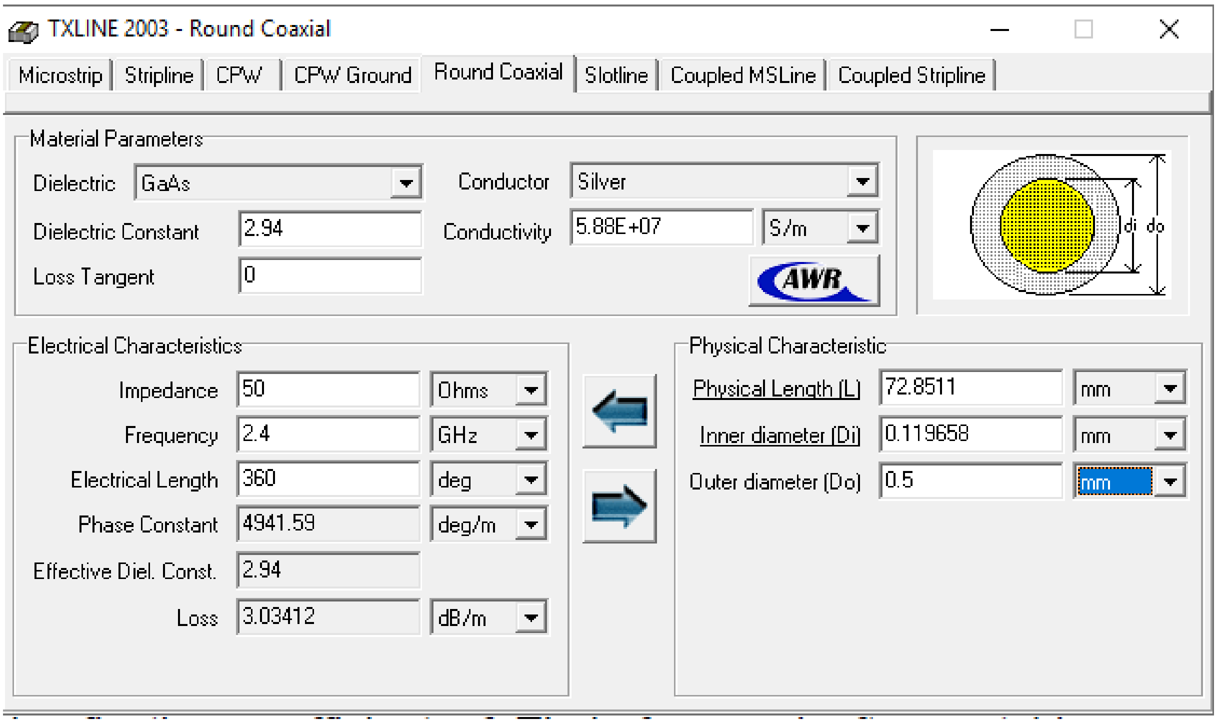

Figure 1.2 Result of AWR TX line calculator

Simulations

In this part NI AWR Design Environment is used for simulation.

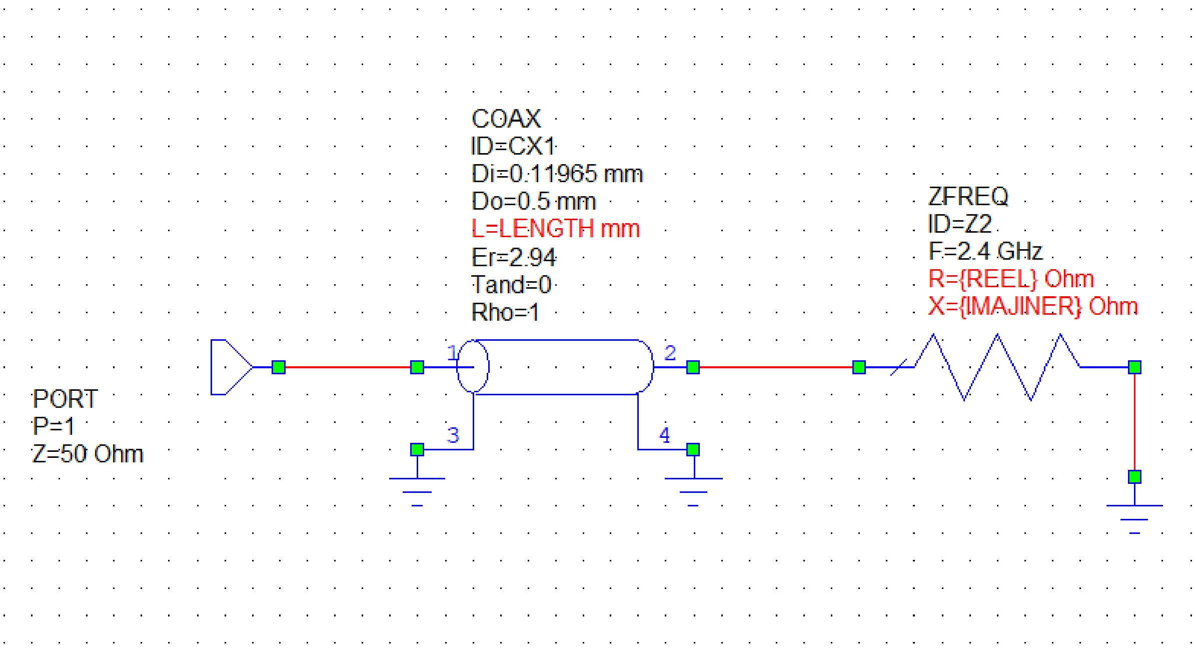

Figure 1.3 designed circuit schematic

Simulation Results and Graphs:

a) $Z_L = 0\ \Omega$

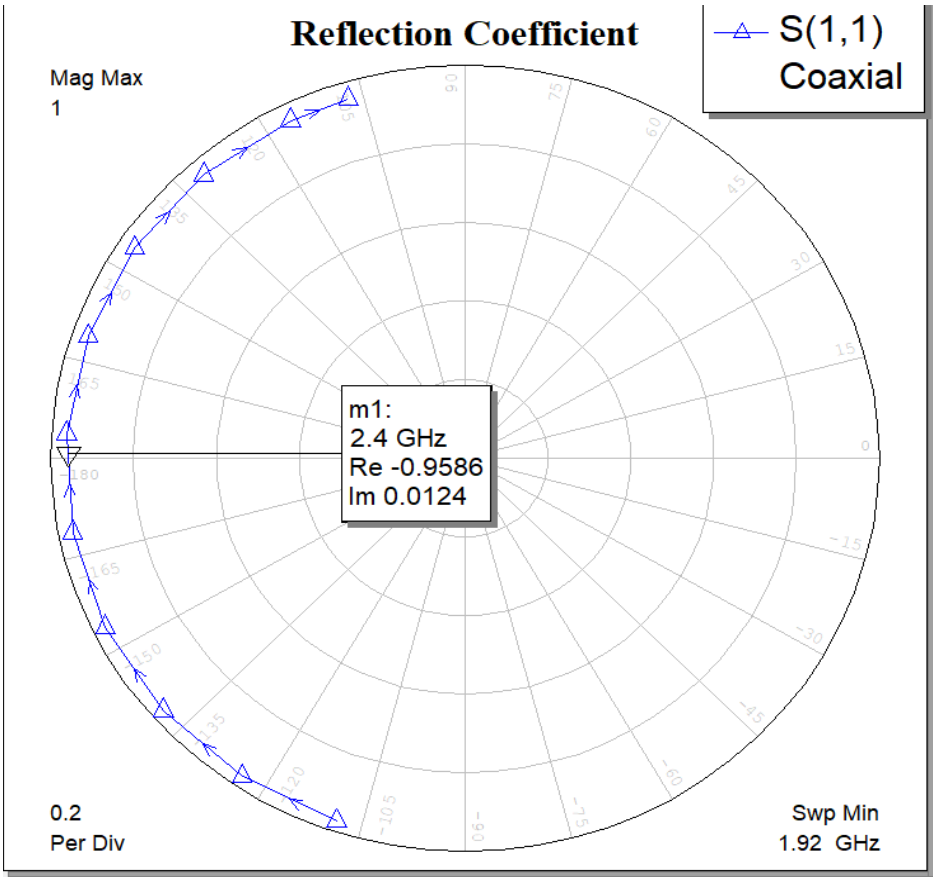

Figure 1.4 The reflection coefficient on Smith Chart when Line Length $=0.5\lambda$

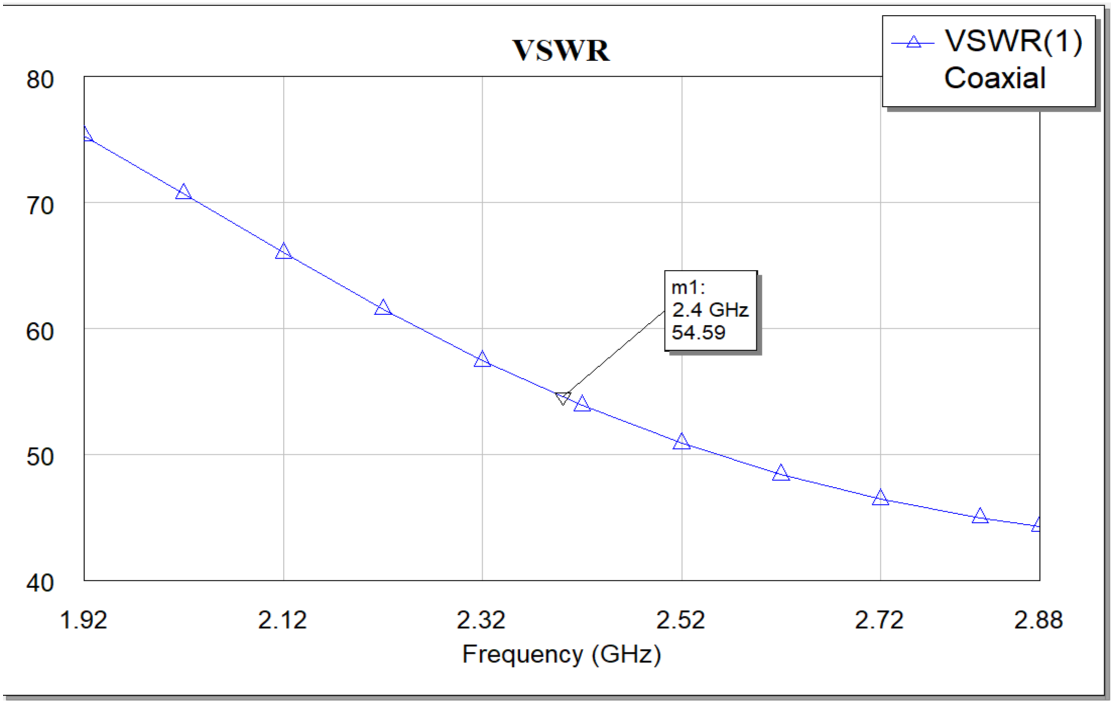

Figure 1.5 The VSWR on Smith Chart when Line Length $=0.5\lambda$

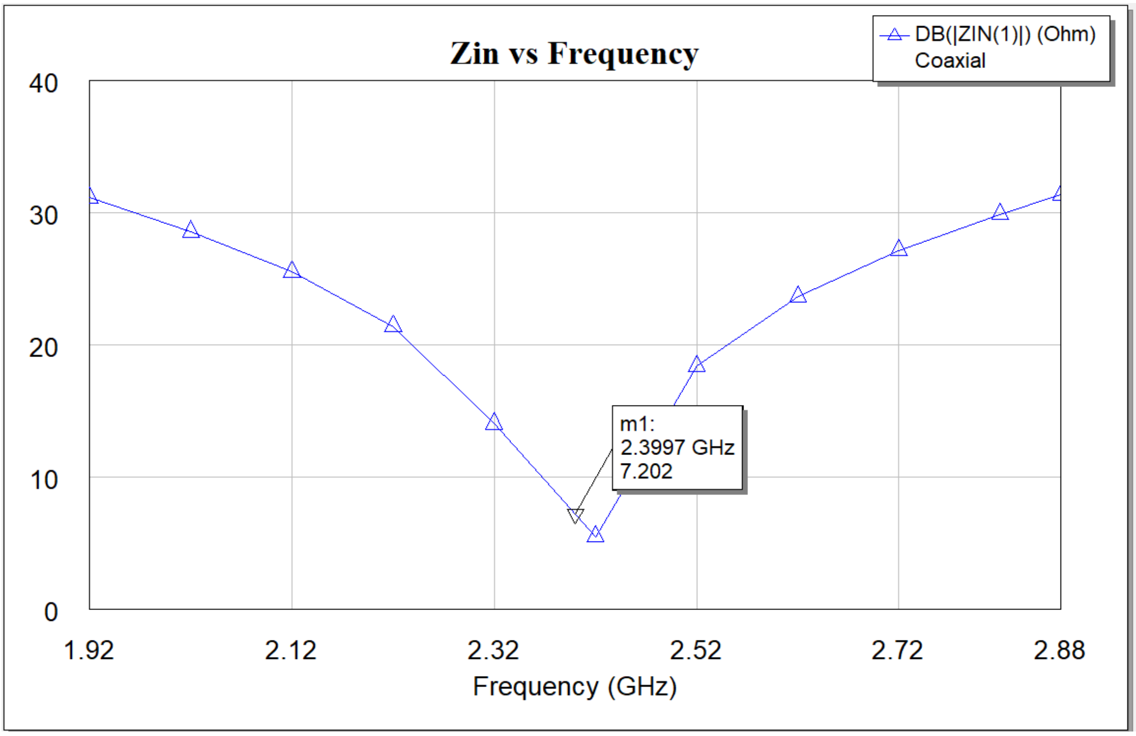

Figure 1.6 The input impedance and frequency on Smith Chart when Line Length $=0.5\lambda$

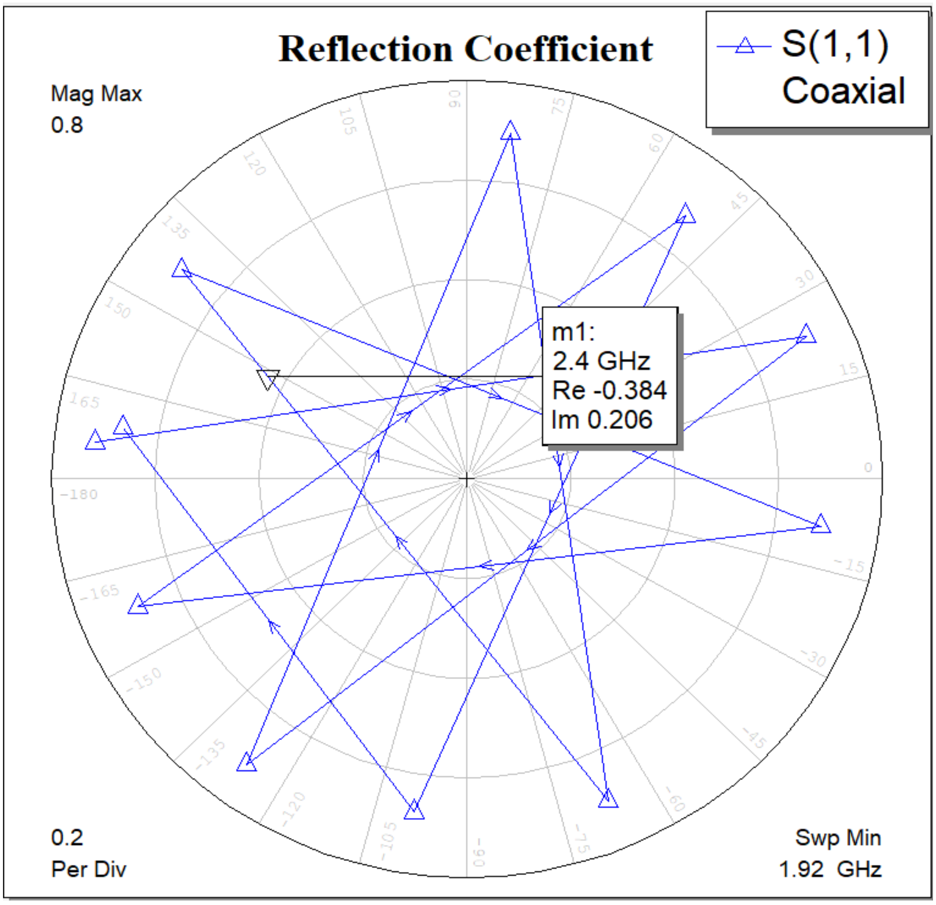

Figure 1.7 The reflection coefficient on Smith Chart when Line Length $=5\lambda$

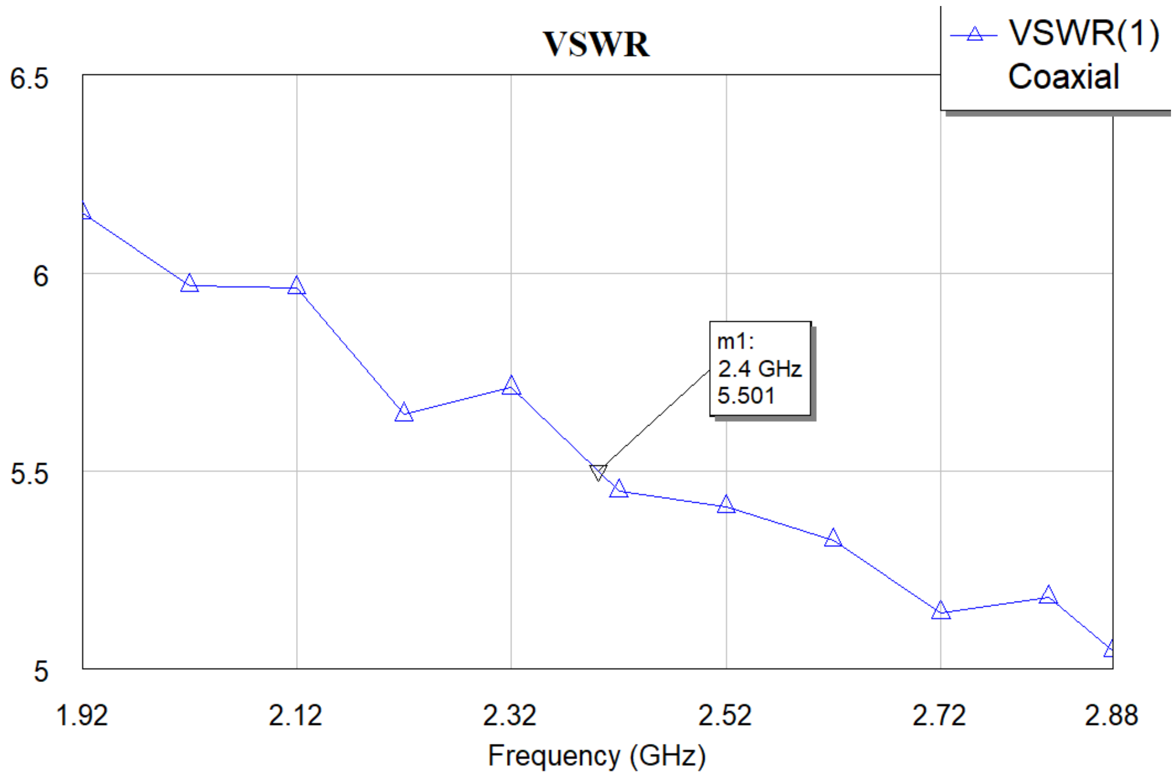

Figure 1.8 The VSWR on Smith Chart when Line Length $=5\lambda$

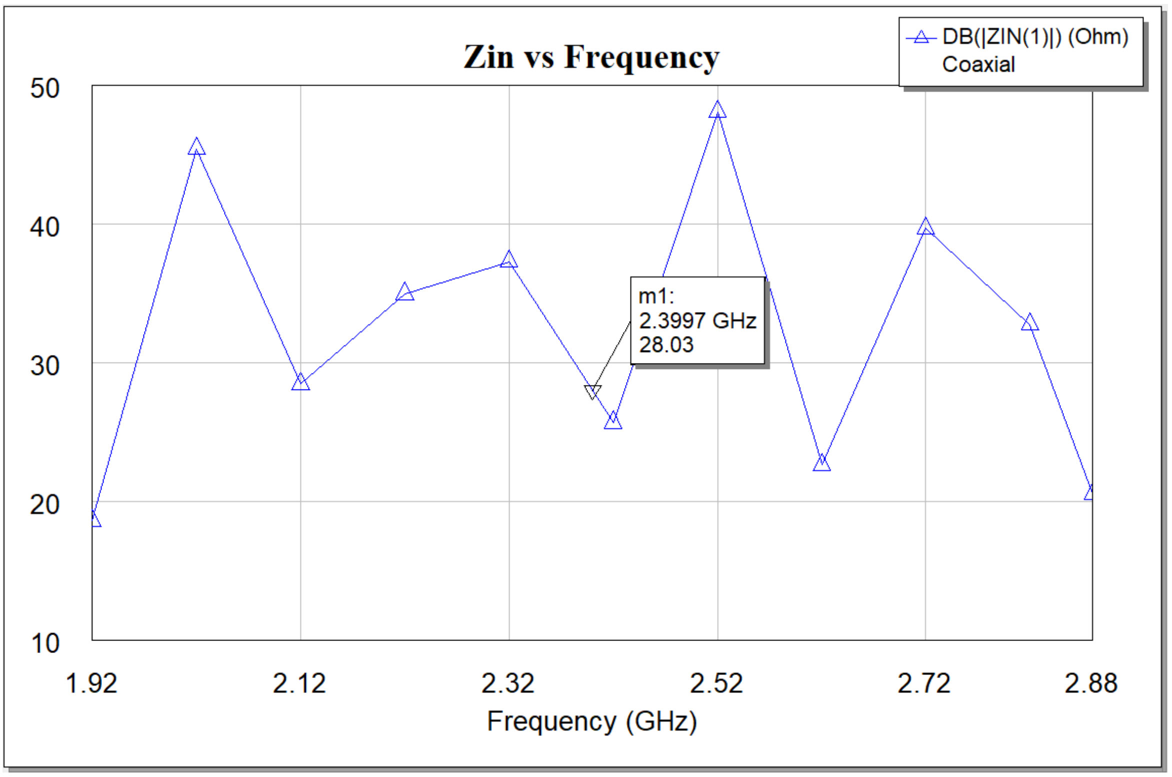

Figure 1.9 The input impedance and frequency on Smith Chart when Line Length $=5\lambda$

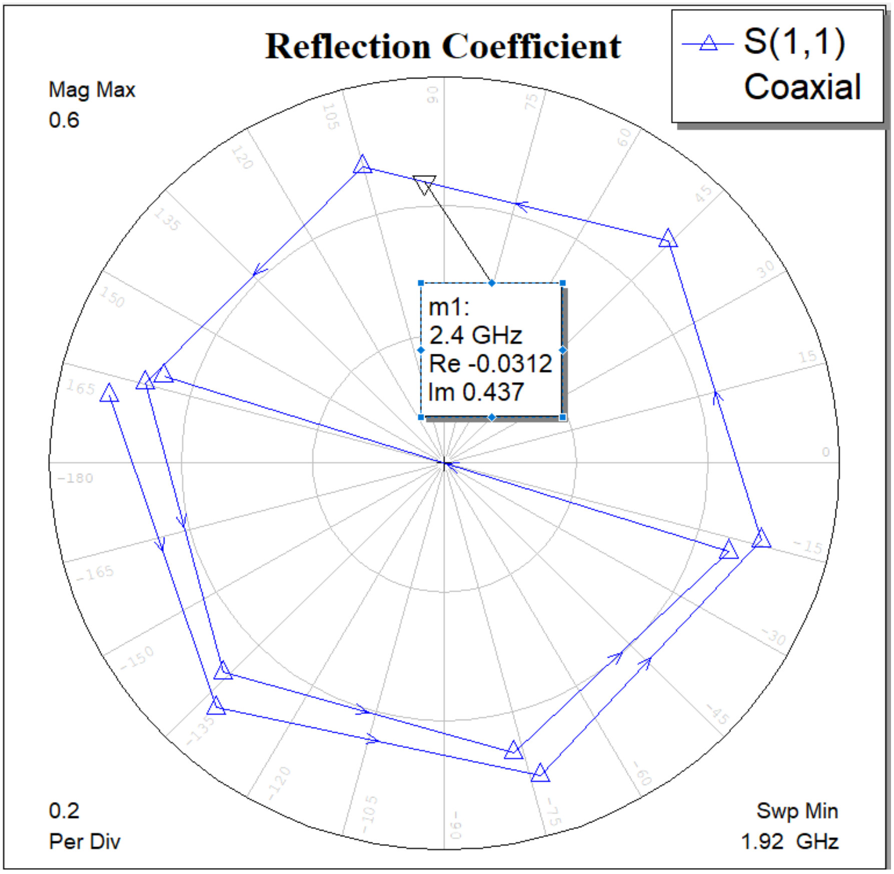

Figure 1.10 The reflection coefficient on Smith Chart when Line Length =10λ

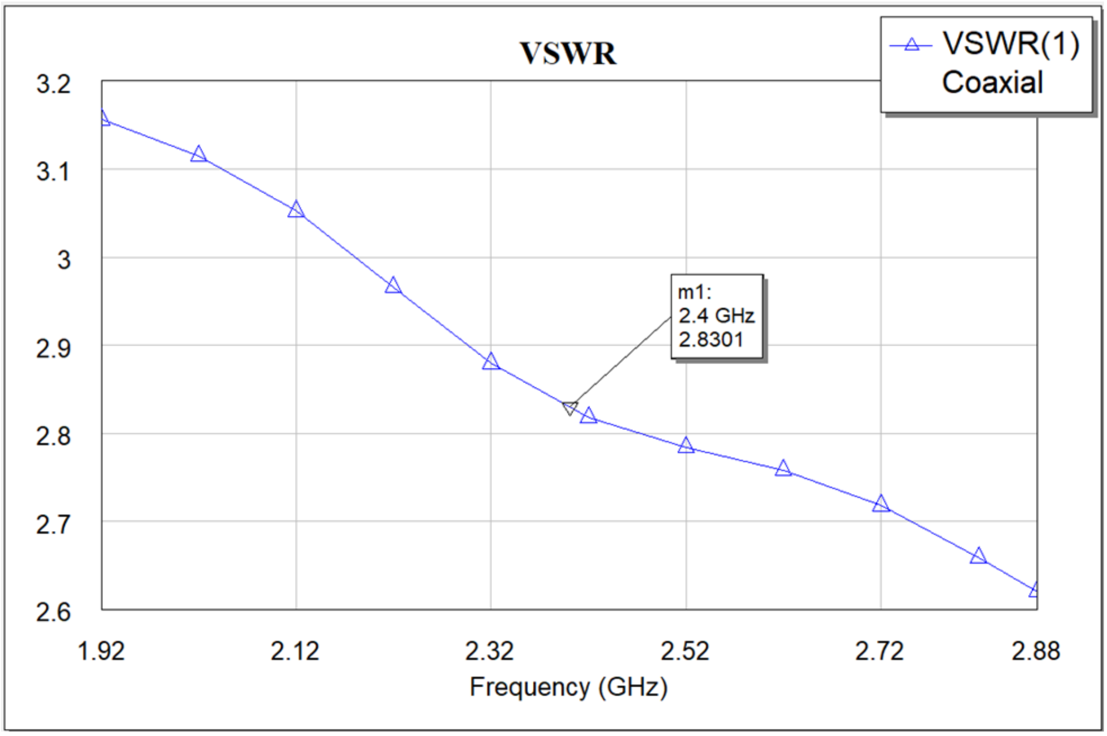

Figure 1.11 The VSWR on Smith Chart when Line Length =10λ

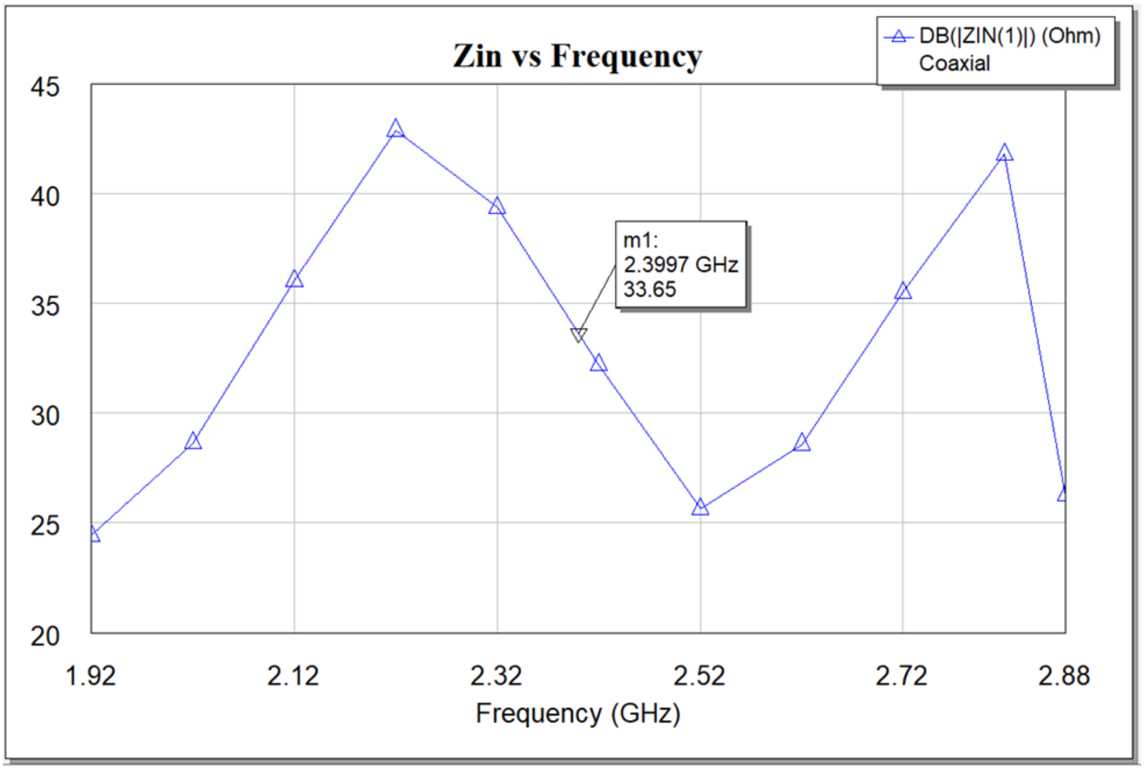

Figure 1.12 The input impedance and frequency on Smith Chart when Line Length =10λ

b) $Z_L = \infty\ \Omega$;

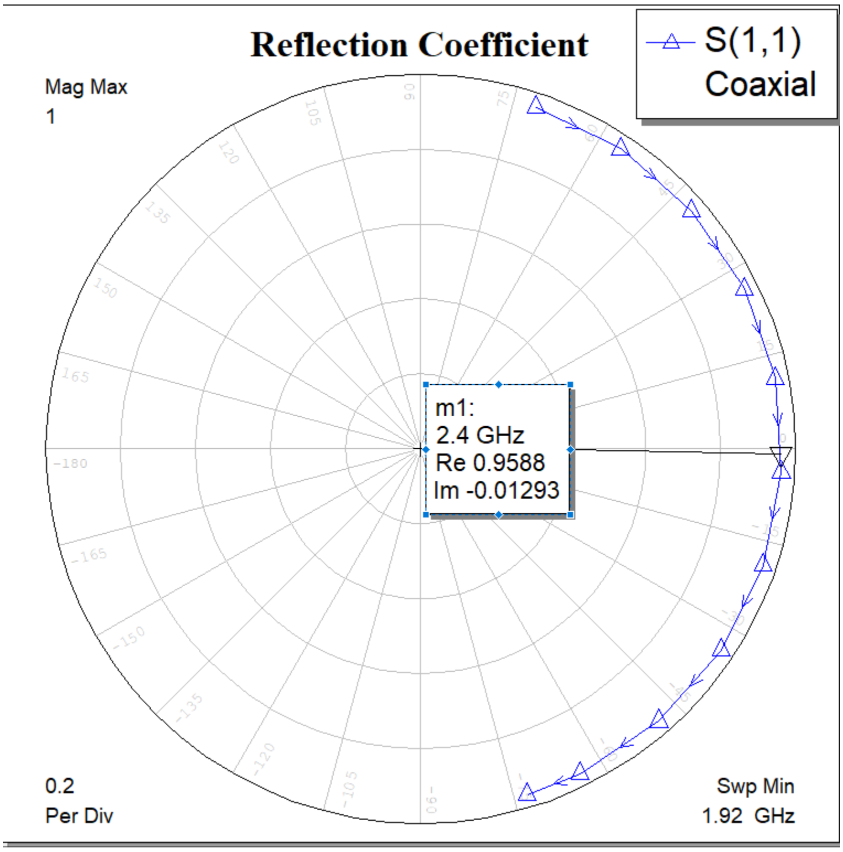

Figure 1.13 The reflection coefficient on Smith Chart when Line Length =0.5λ

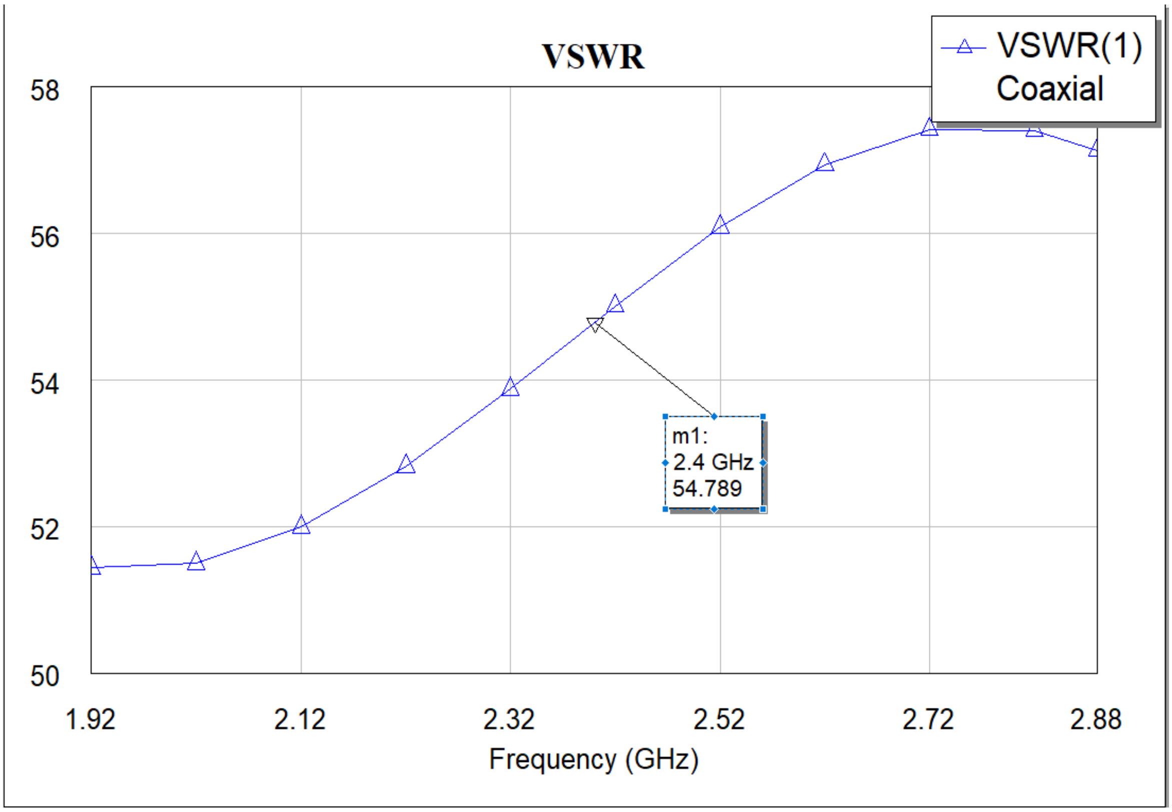

Figure 1.14 The VSWR on Smith Chart when Line Length =0.5λ

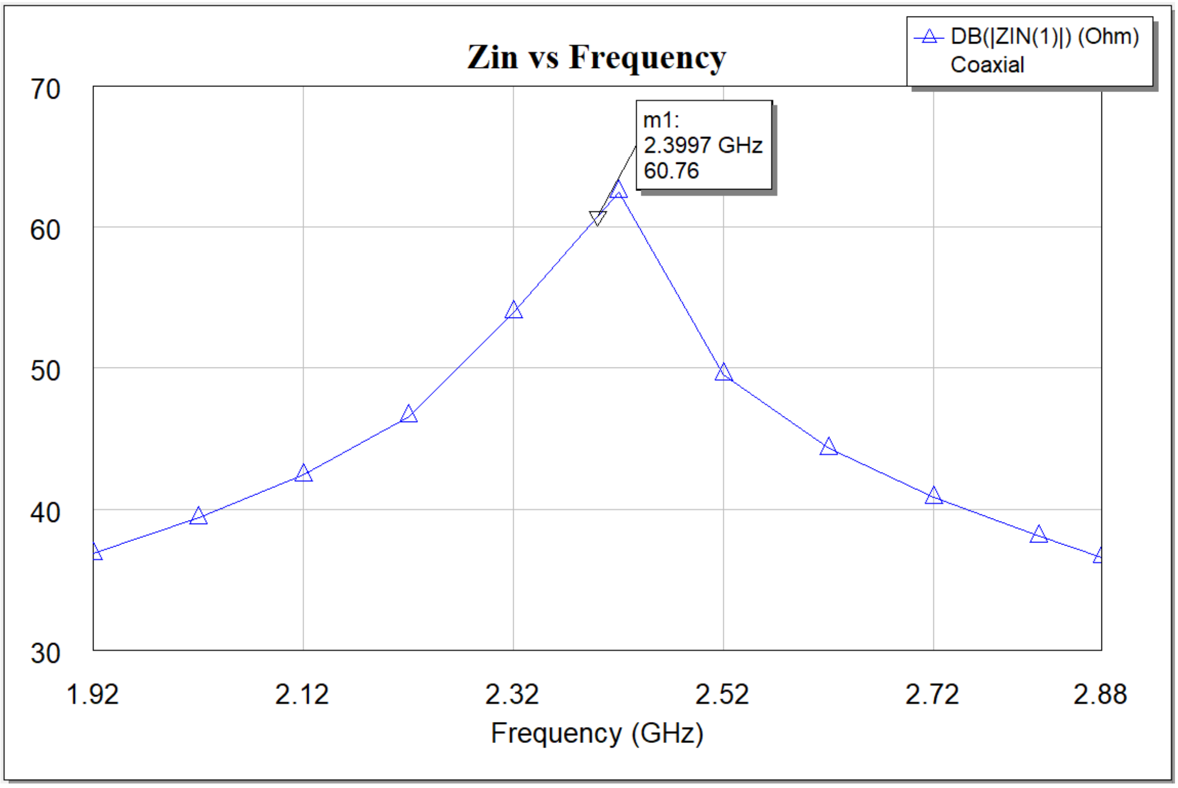

Figure 1.15 The input impedance and frequency on Smith Chart when Line Length =0.5λ

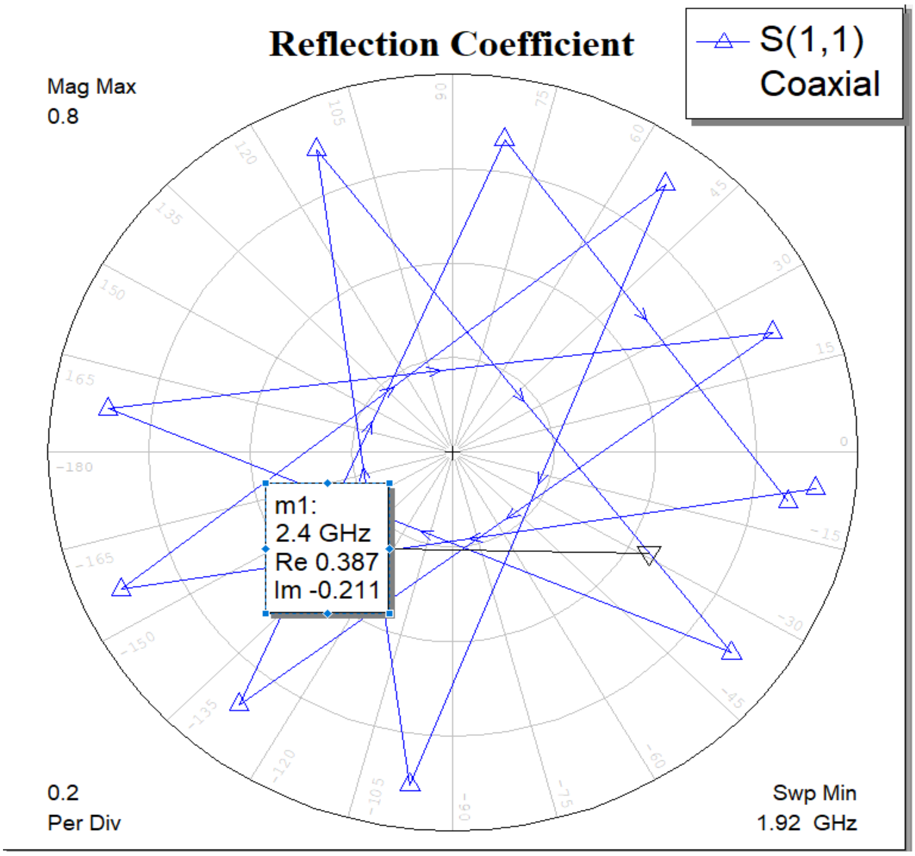

Figure 1.16 The reflection coefficient on Smith Chart when Line Length =5λ

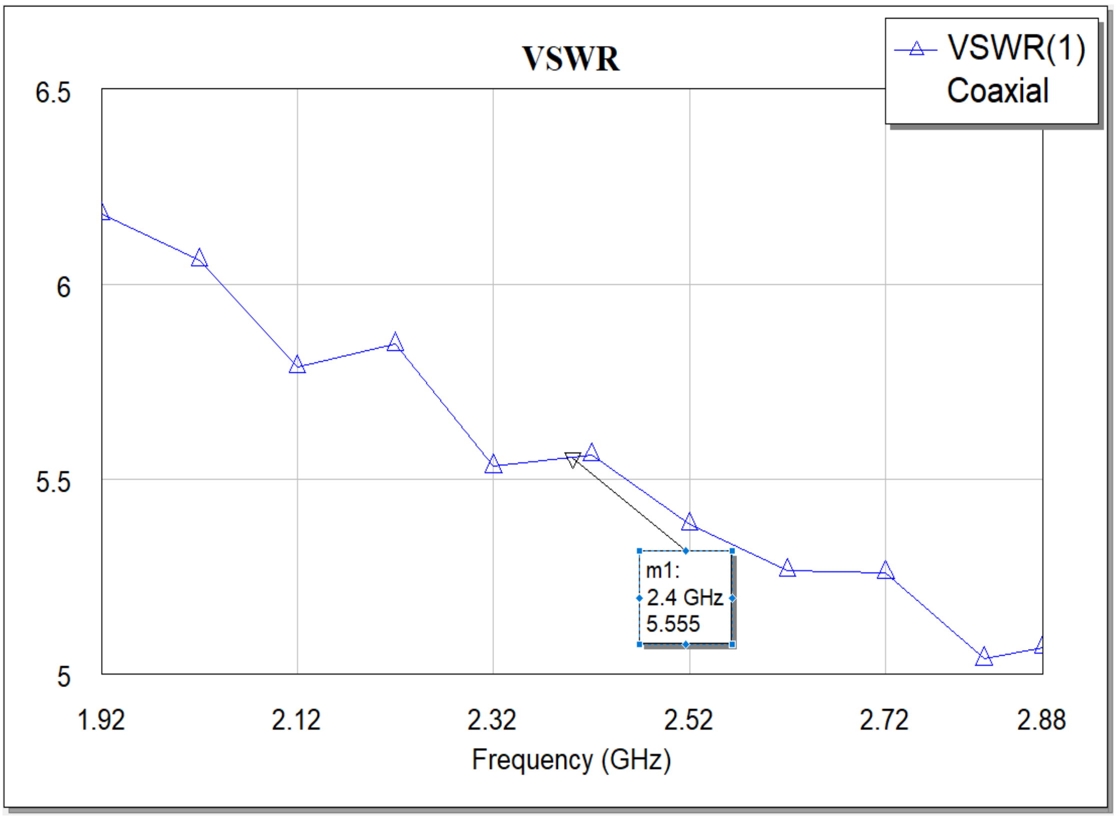

Figure 1.17 The VSWR on Smith Chart when Line Length =5λ

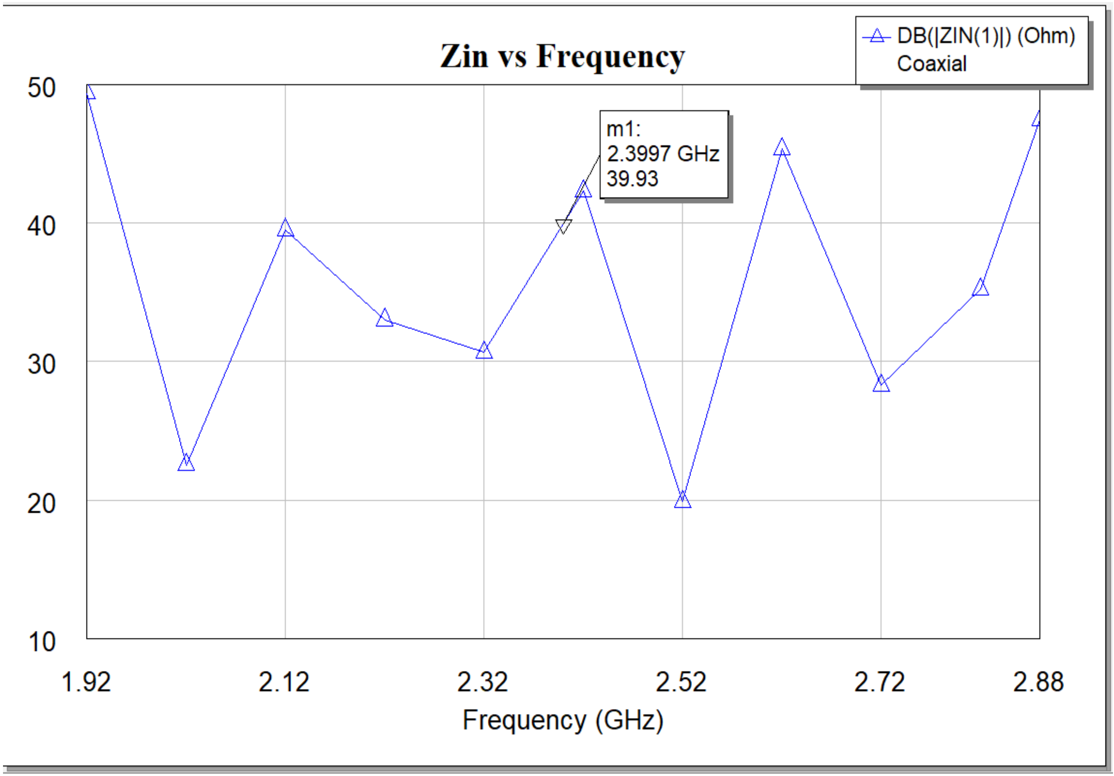

Figure 1.18 The input impedance and frequency on Smith Chart when Line Length $=5\lambda$

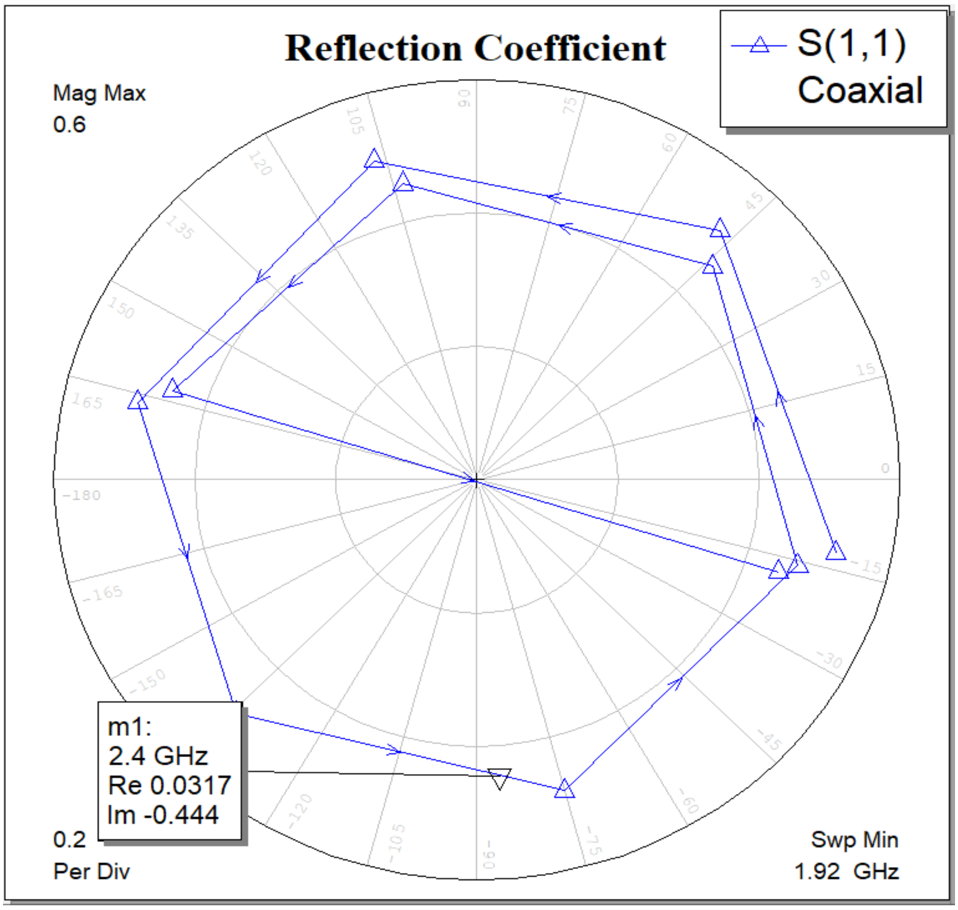

Figure 1.19 The reflection coefficient on Smith Chart when Line Length $=10\lambda$

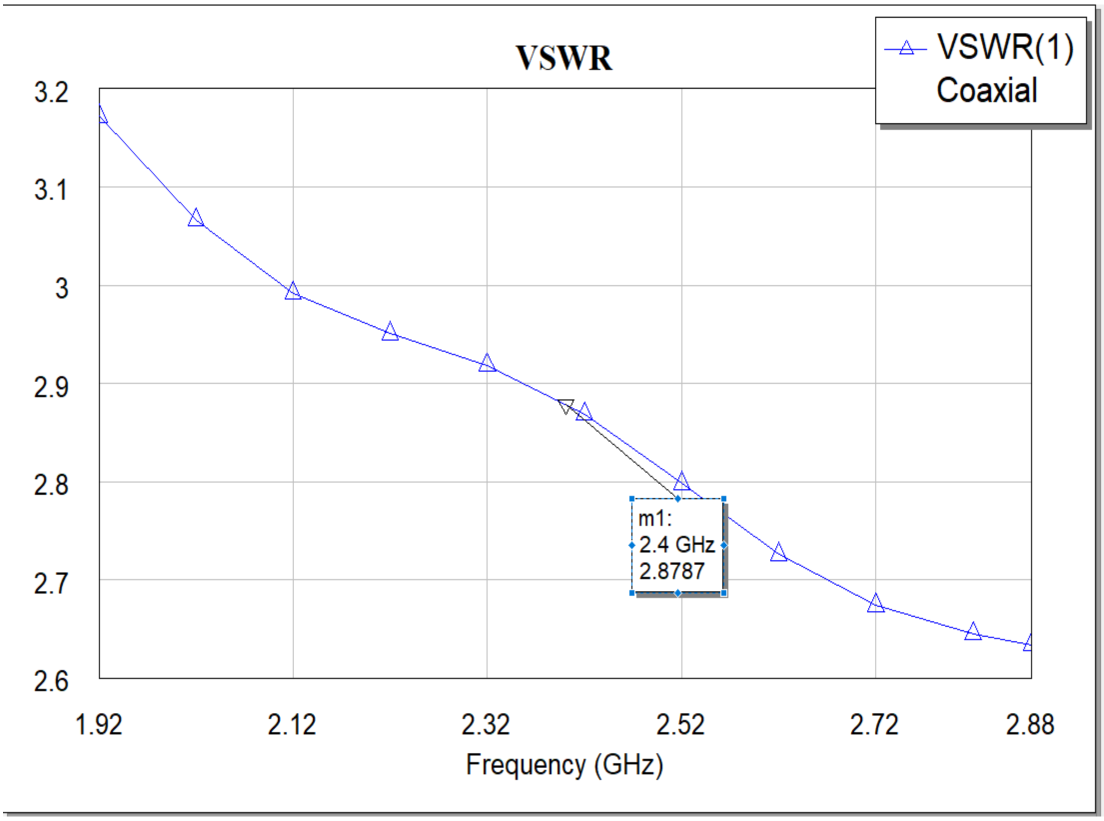

Figure 1.20 The VSWR on Smith Chart when Line Length =10λ

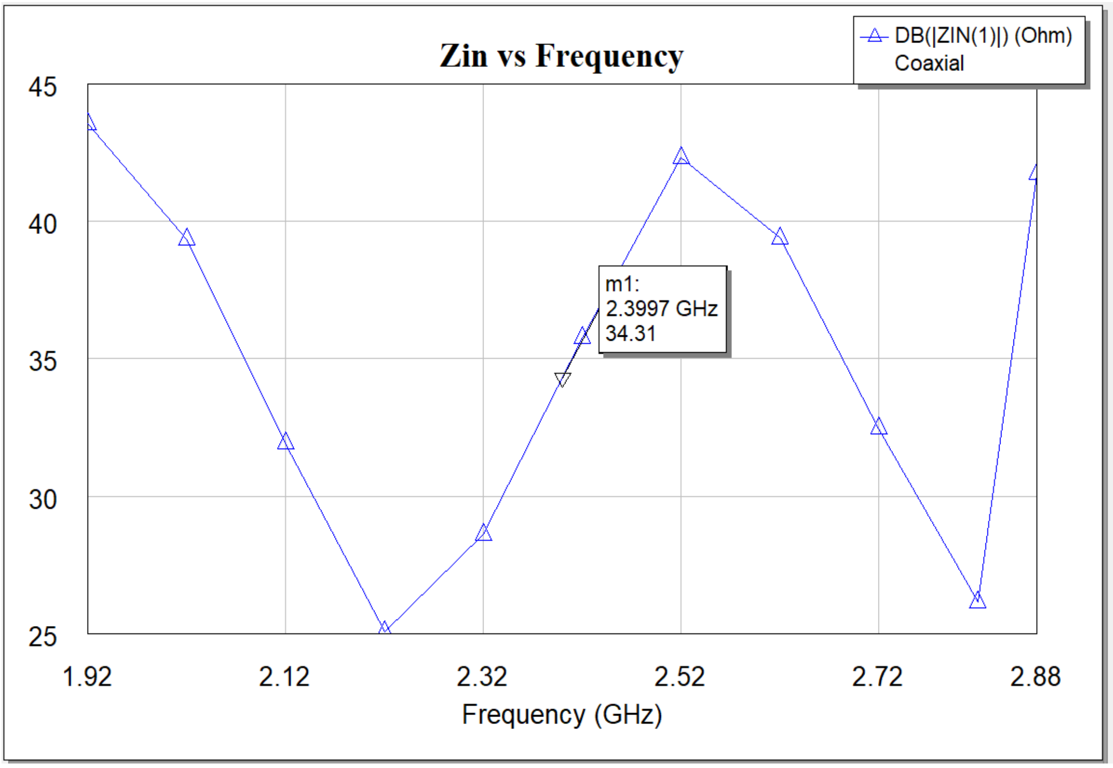

Figure 1.21 The input impedance and frequency on Smith Chart when Line Length =10λ

c) $Z_L = -j75\ \Omega$;

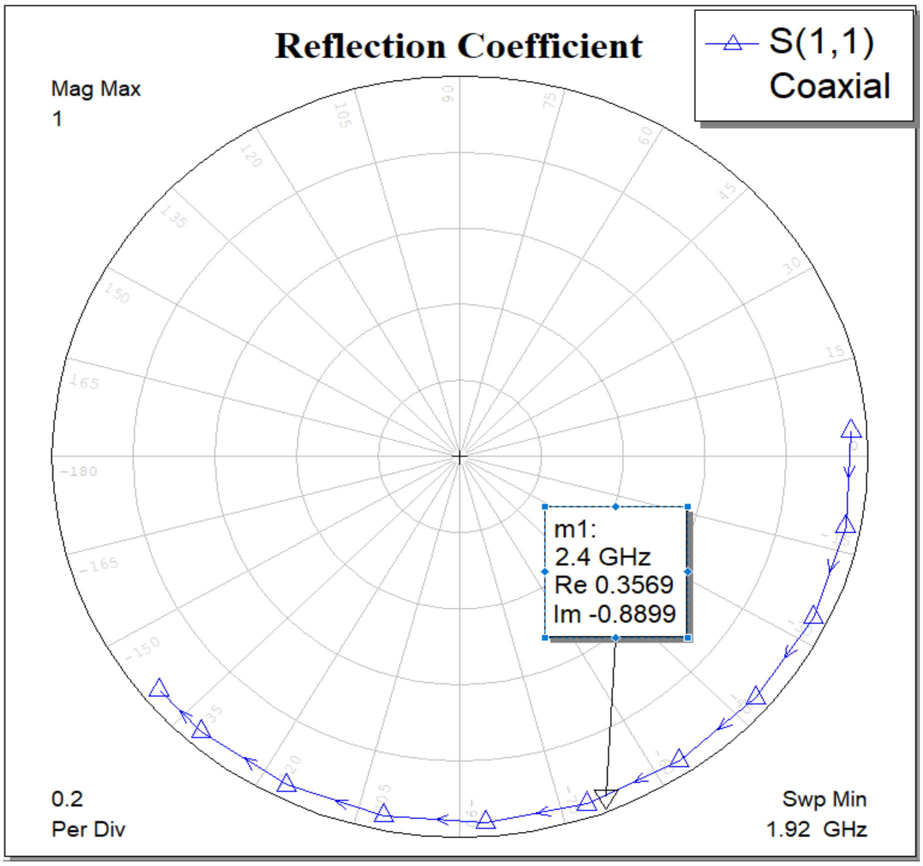

Figure 1.22 The reflection coefficient on Smith Chart when Line Length =0.5λ

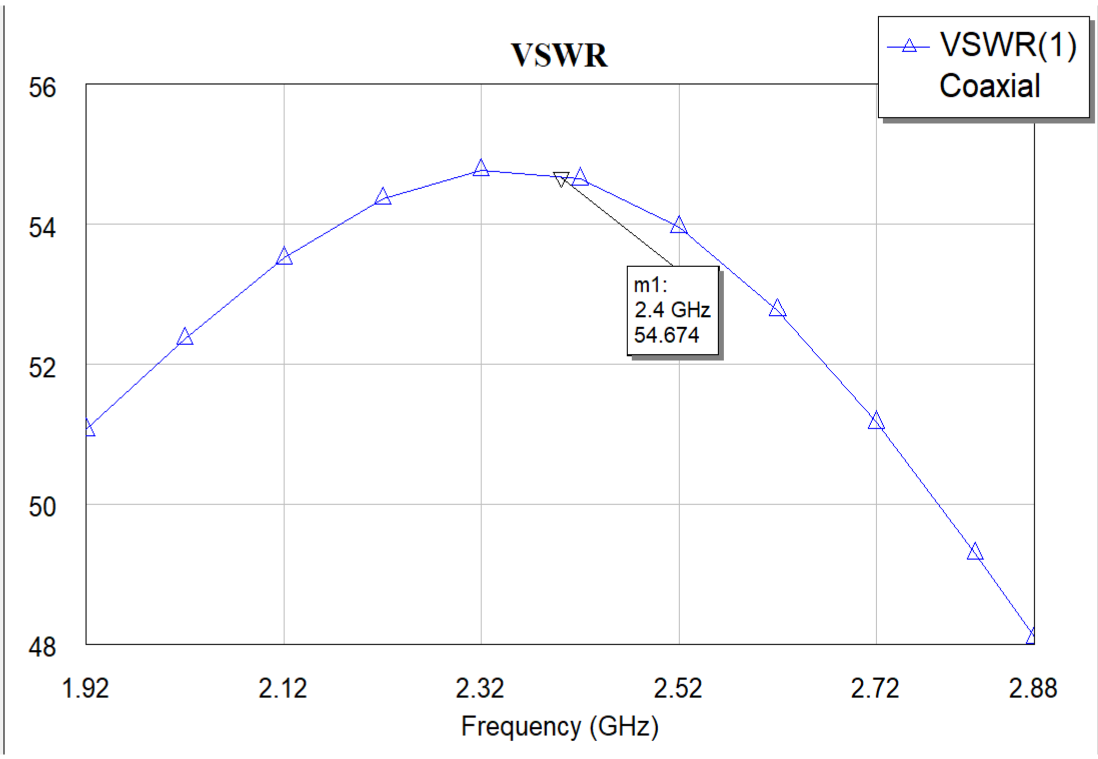

Figure 1.23 The VSWR on Smith Chart when Line Length =0.5λ

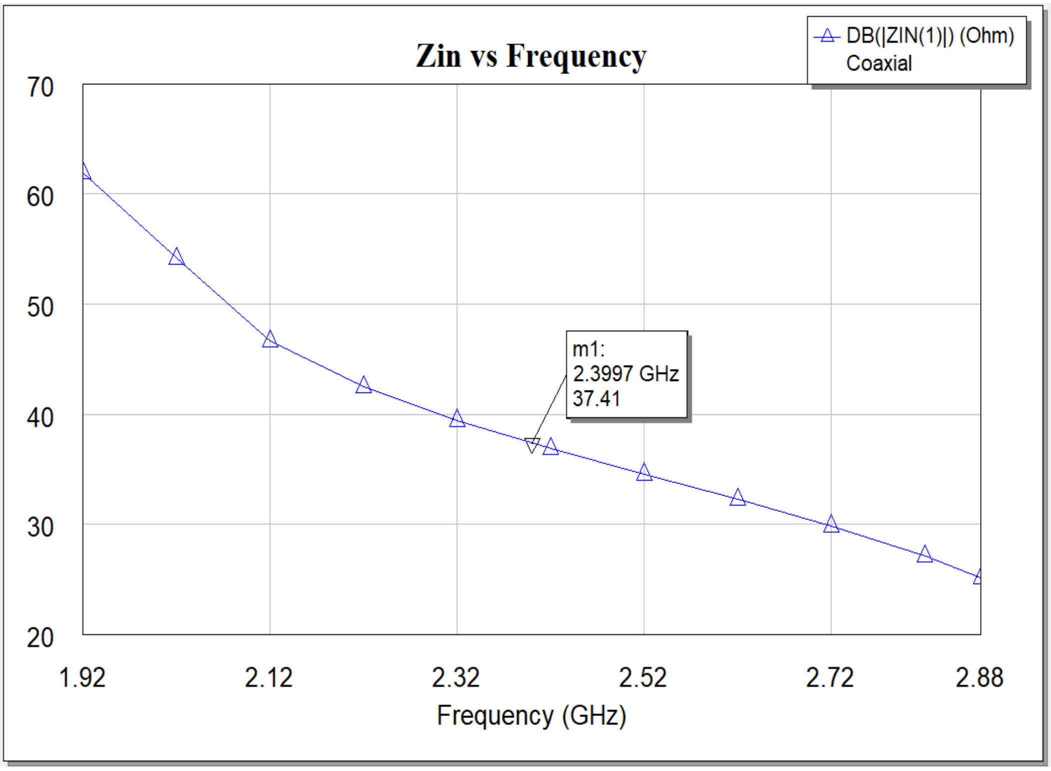

Figure 1.24 The input impedance and frequency on Smith Chart when Line Length $=0.5\lambda$

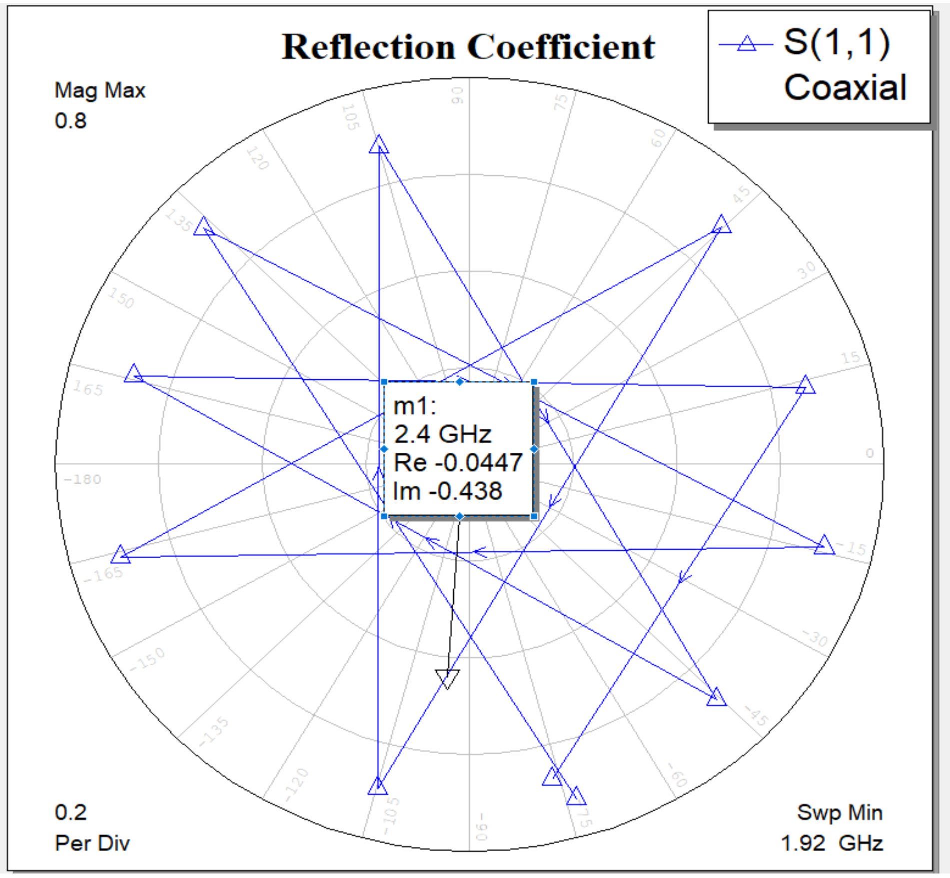

Figure 1.25 The reflection coefficient on Smith Chart when Line Length $=5\lambda$

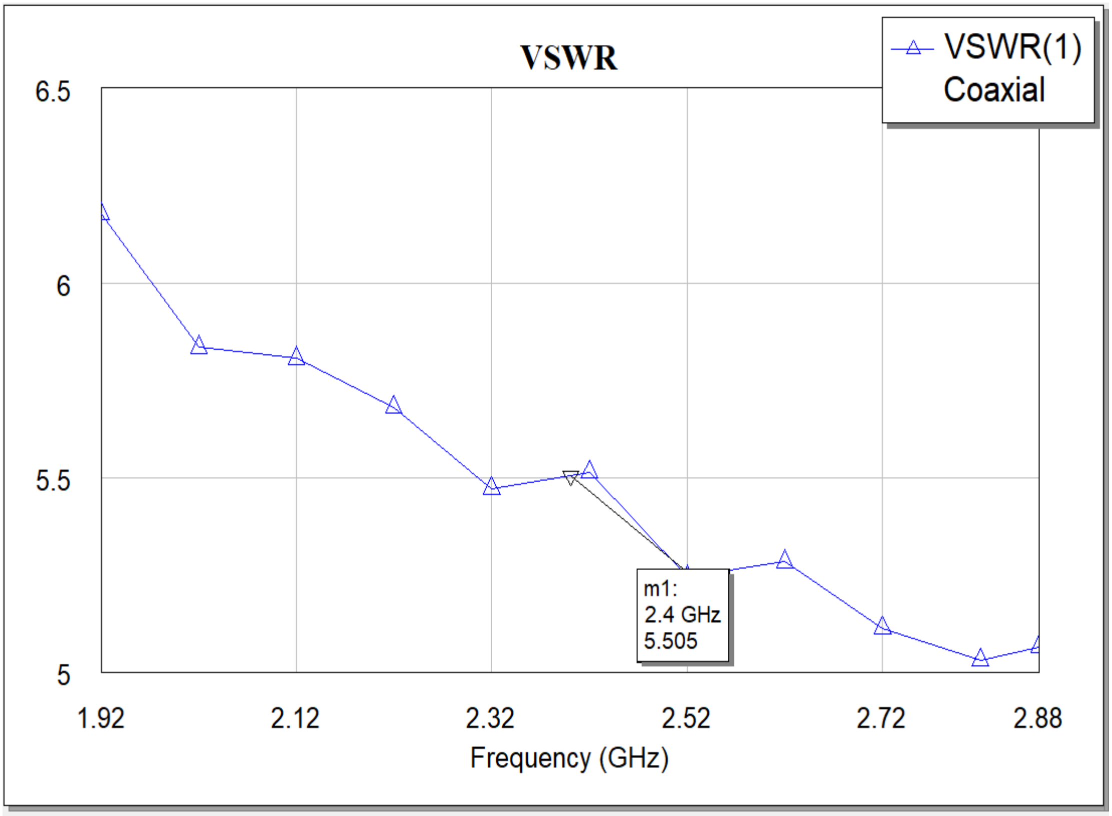

Figure 1.26 The VSWR on Smith Chart when Line Length =5λ

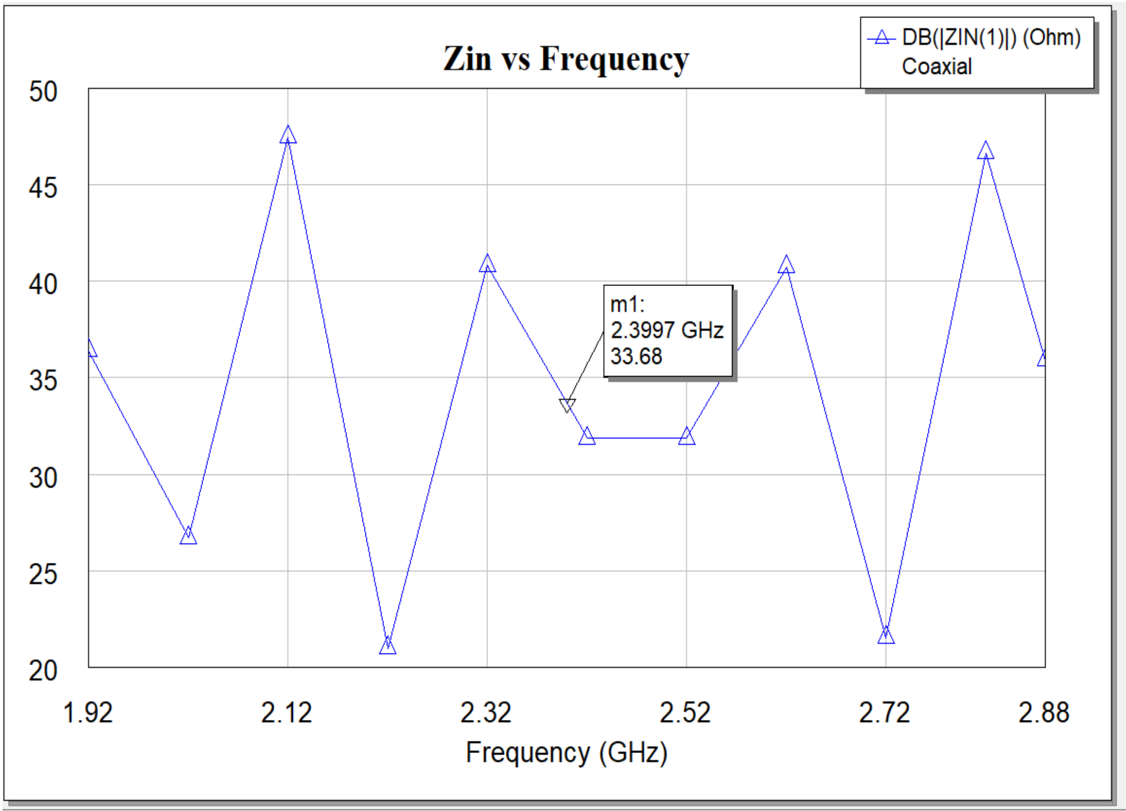

Figure 1.27 The input impedance and frequency on Smith Chart when Line Length =5λ

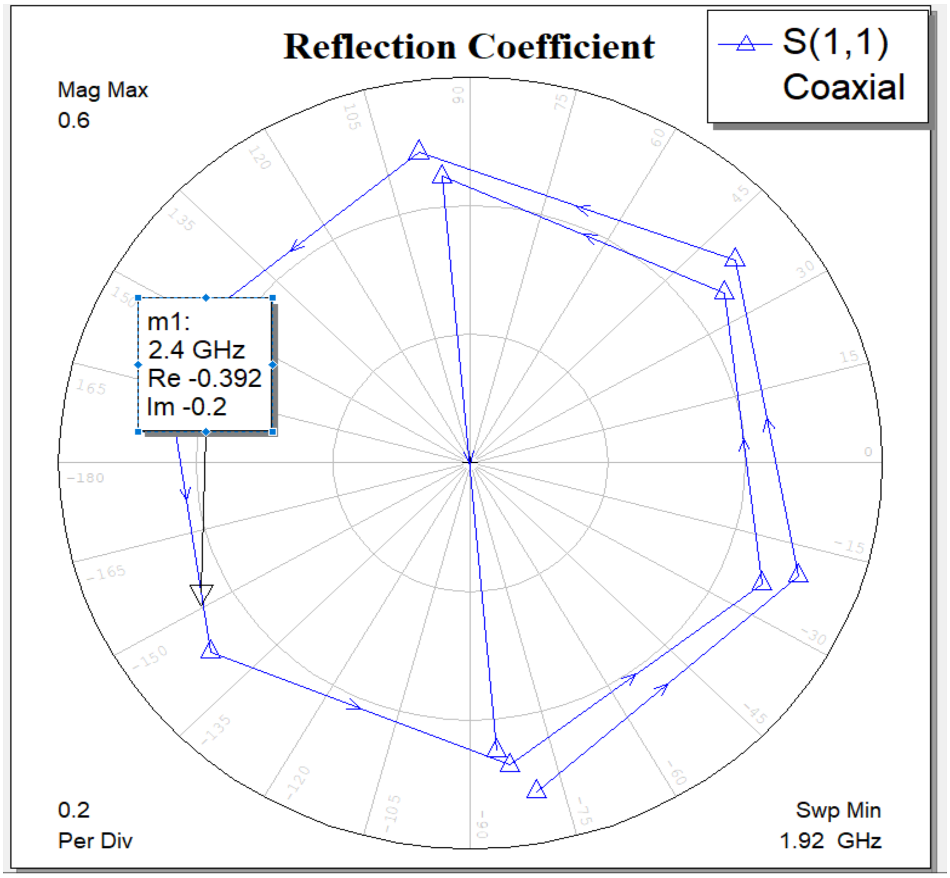

Figure 1.28 The reflection coefficient on Smith Chart when Line Length =10λ

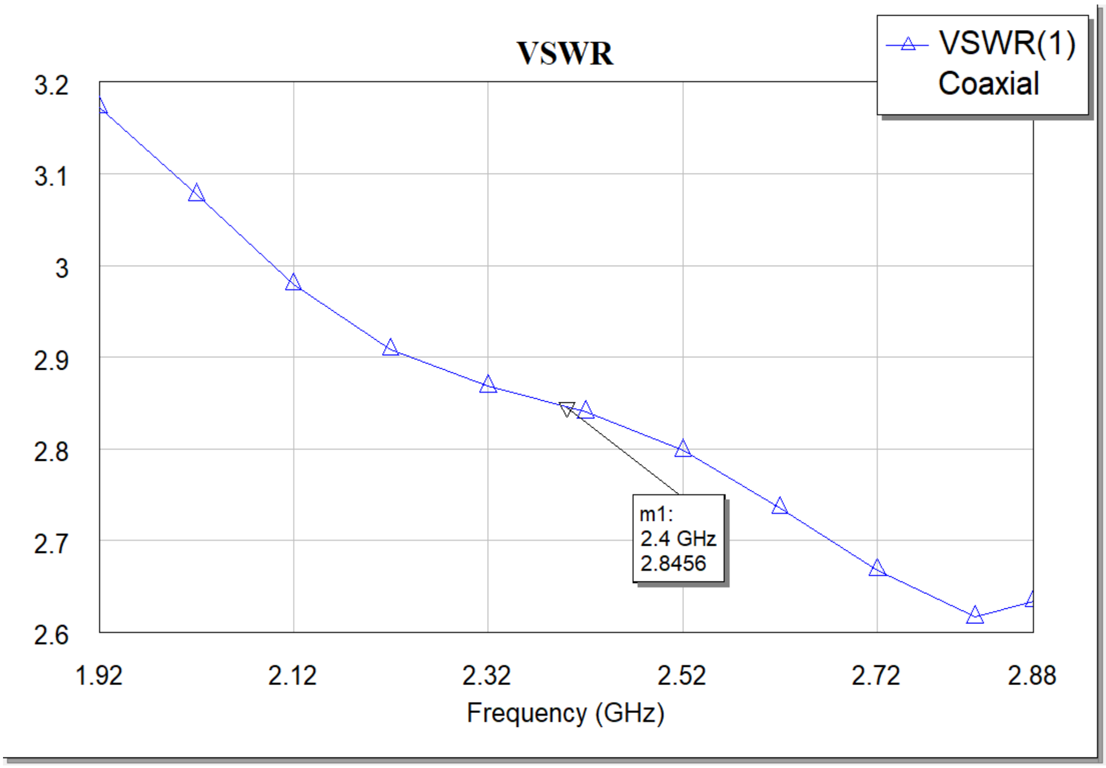

Figure 1.29 The VSWR on Smith Chart when Line Length =10λ

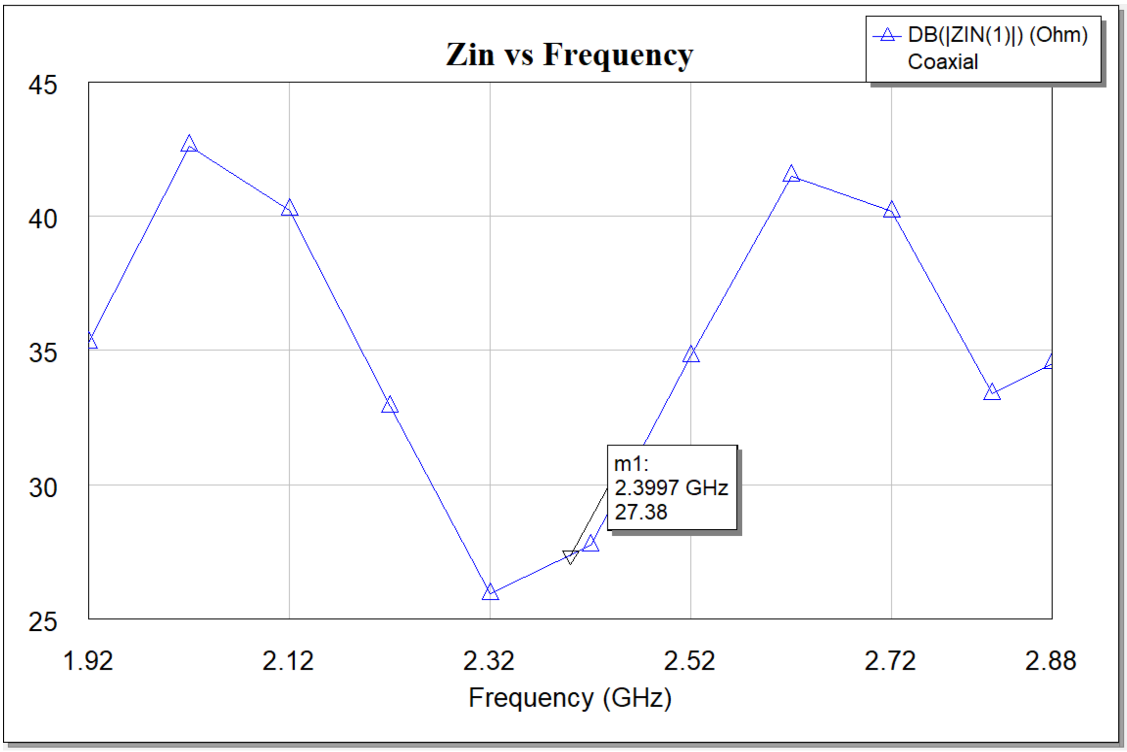

Figure 1.30 The input impedance and frequency on Smith Chart when Line Length $=10\lambda$

d) $Z_L = 50\ \Omega$;

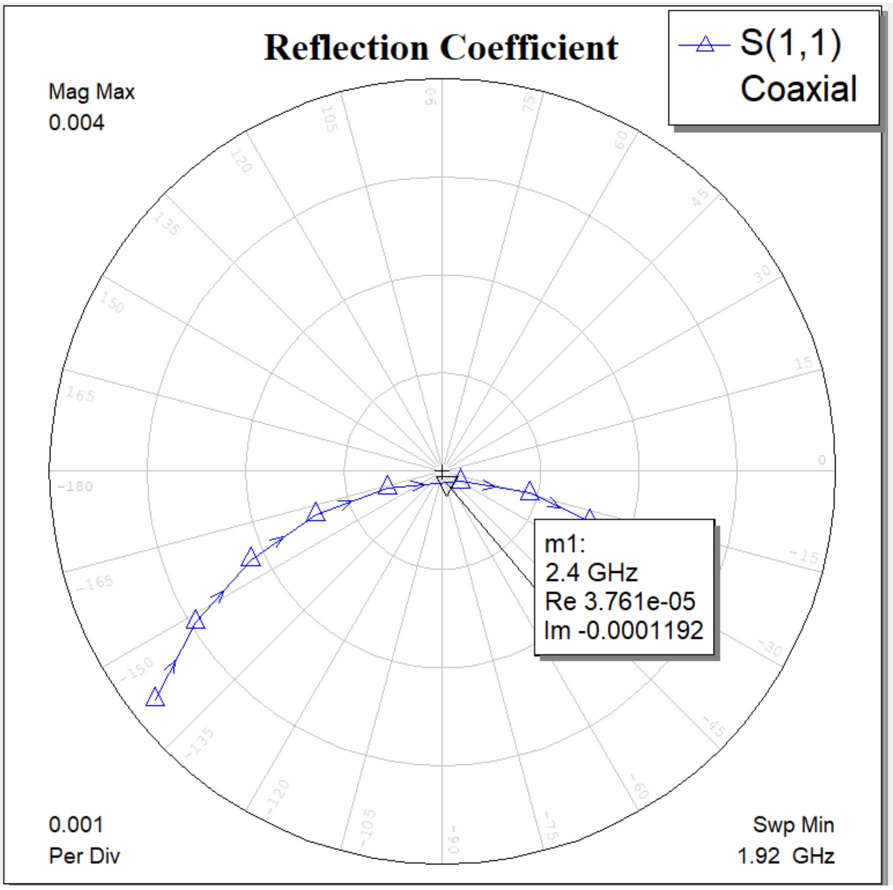

Figure 1.31 The reflection coefficient on Smith Chart when Line Length $= 0.5\lambda$

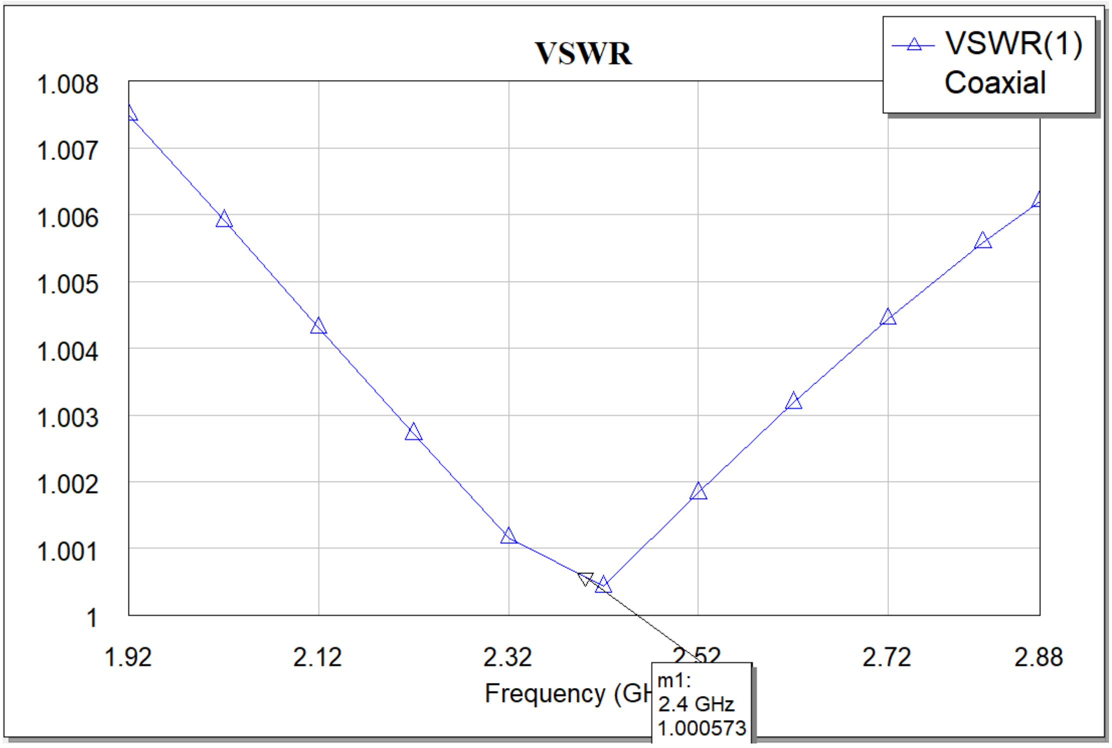

Figure 1.32 The VSWR on Smith Chart when Line Length = 0.5λ

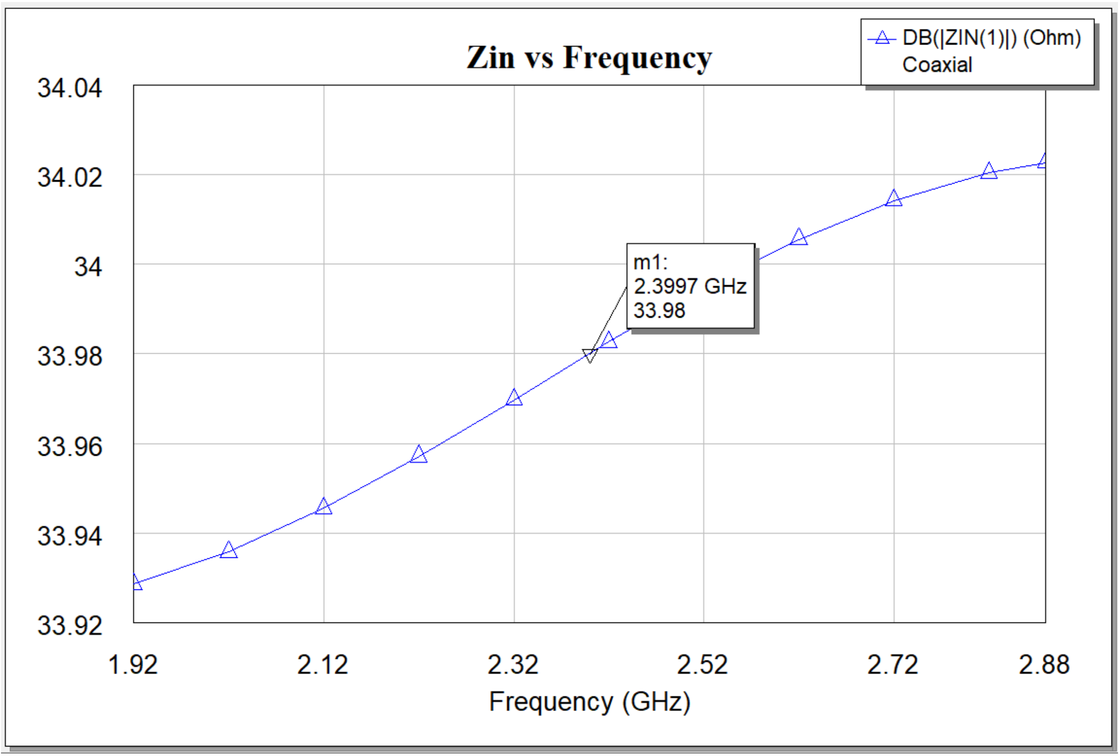

Figure 1.33 The input impedance and frequency on Smith Chart when Line Length = 0.5λ

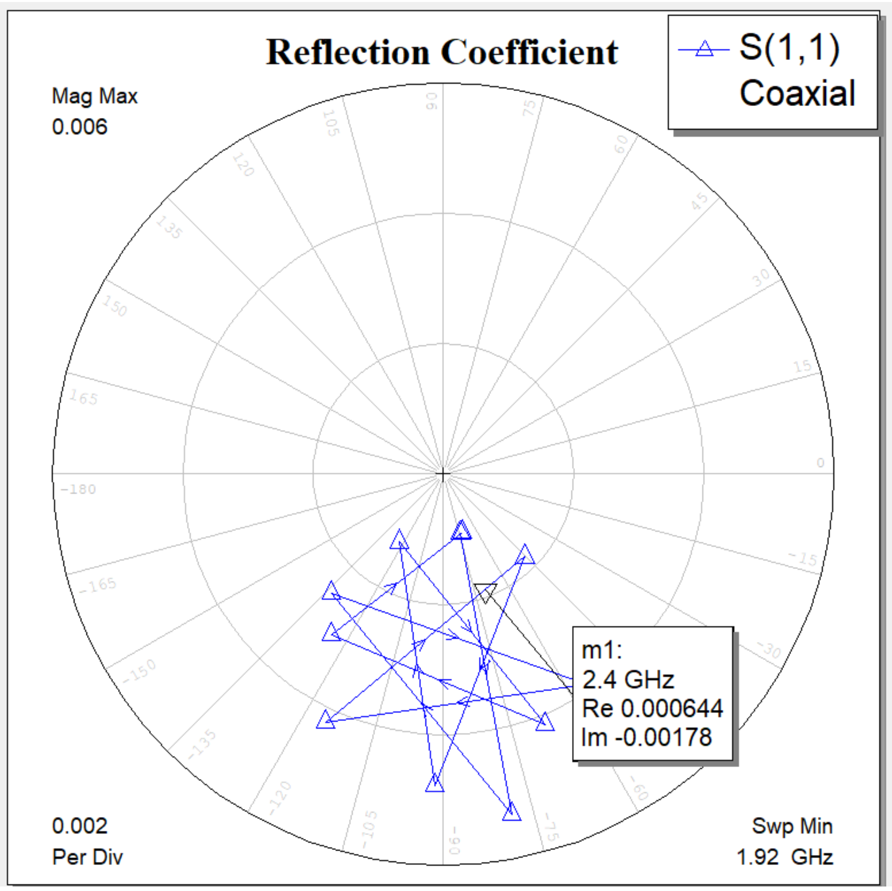

Figure 1.34 The reflection coefficient on Smith Chart when Line Length = 5λ

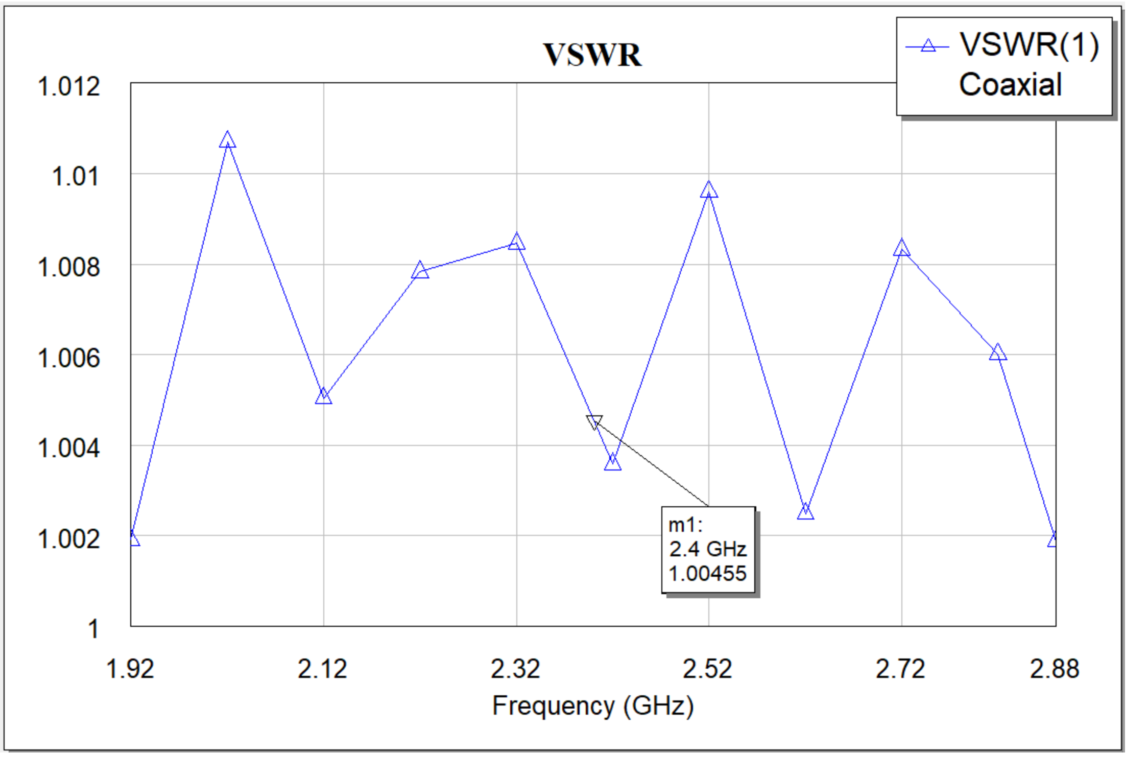

Figure 1.35 The VSWR on Smith Chart when Line Length = 5λ

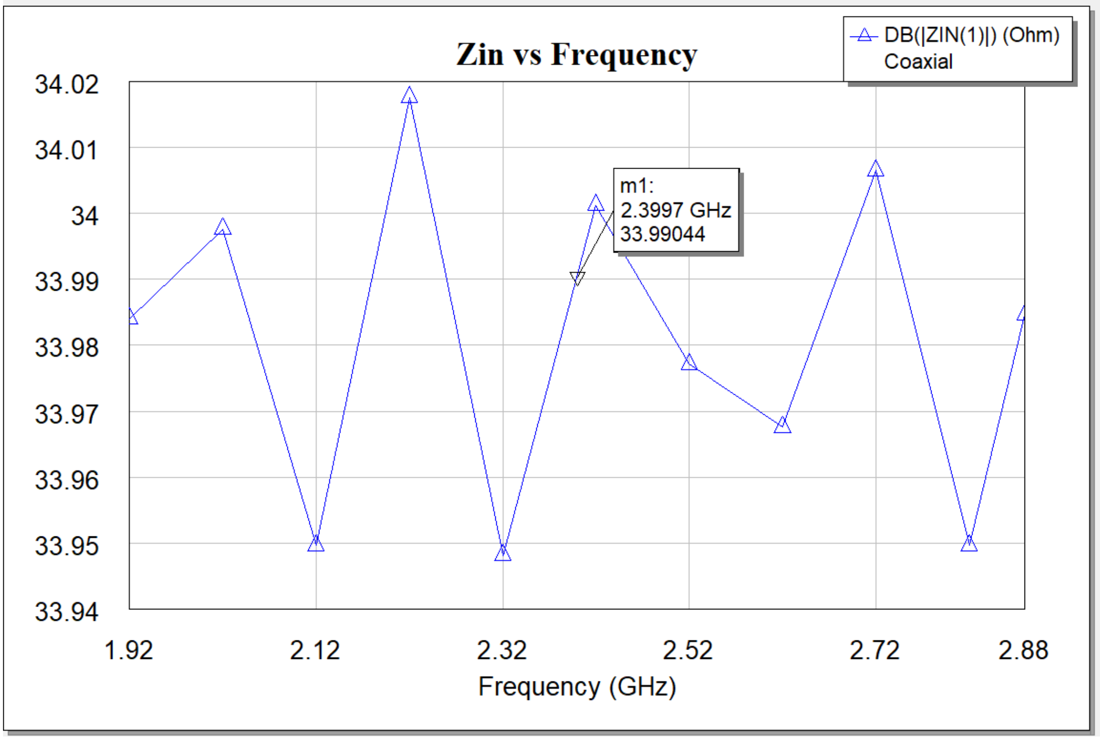

Figure 1.36 The input impedance and frequency on Smith Chart when Line Length $= 5\lambda$

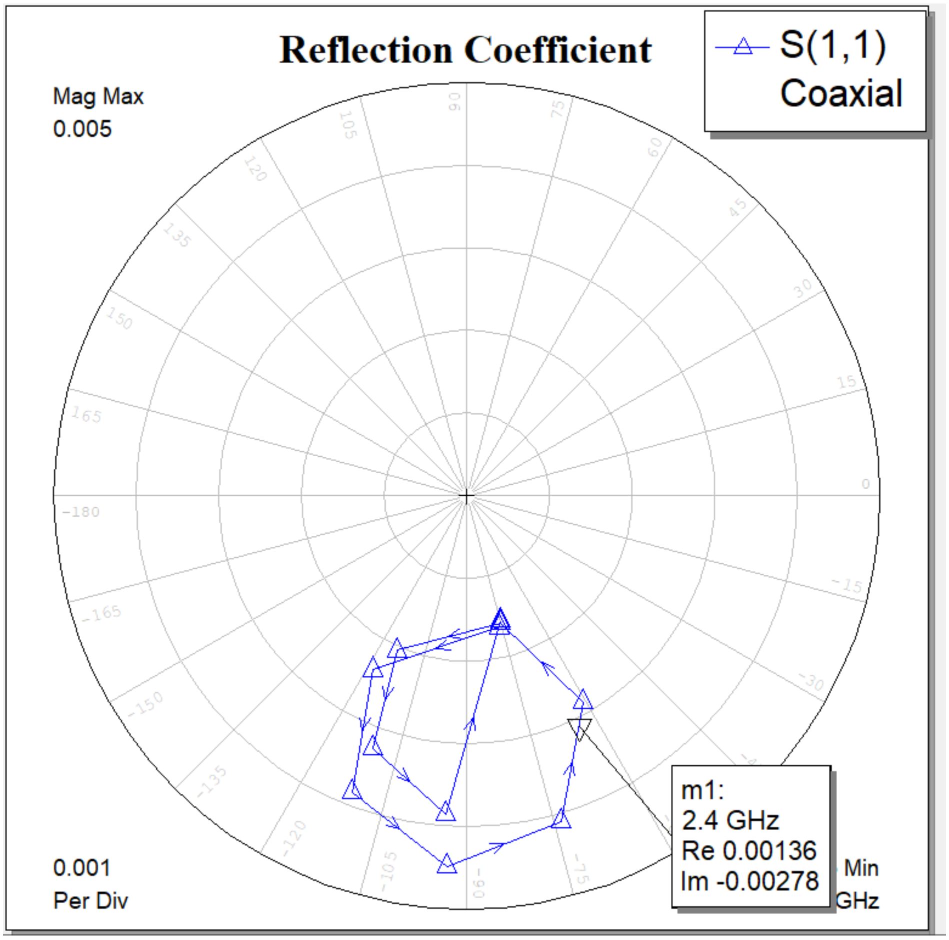

Figure 1.37 The reflection coefficient on Smith Chart when Line Length $= 10\lambda$

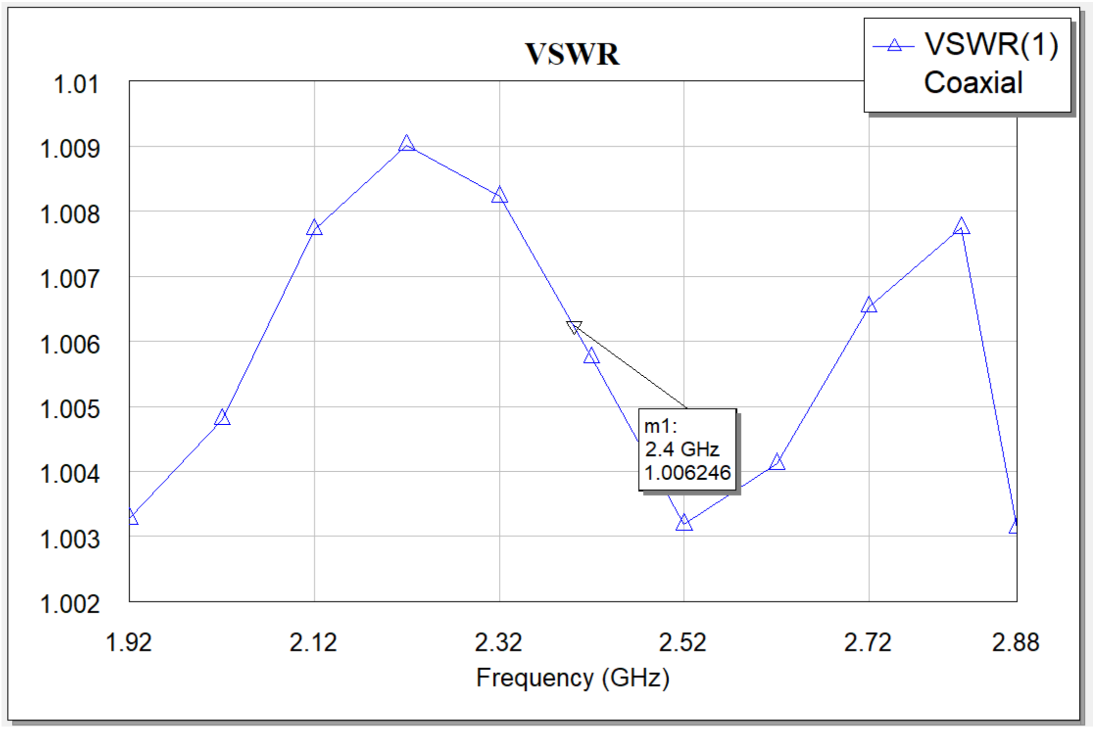

Figure 1.38 The VSWR on Smith Chart when Line Length = 10λ

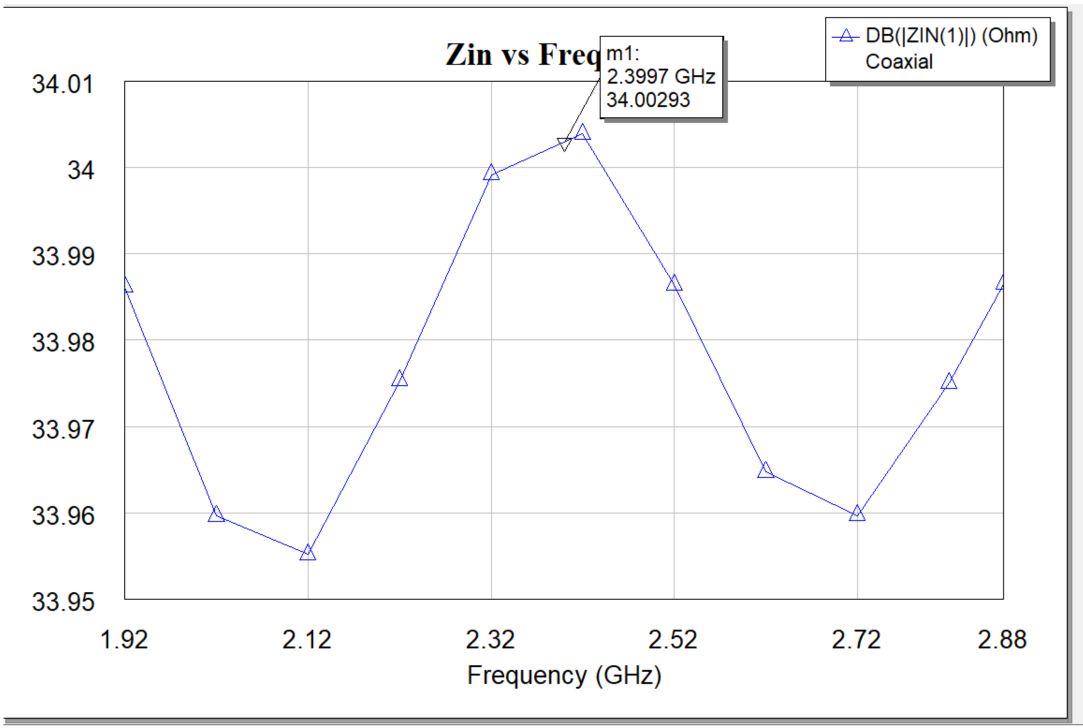

Figure 1.39 The input impedance and frequency on Smith Chart when Line Length = 10λ

e) Z_L = -j50 Ω;

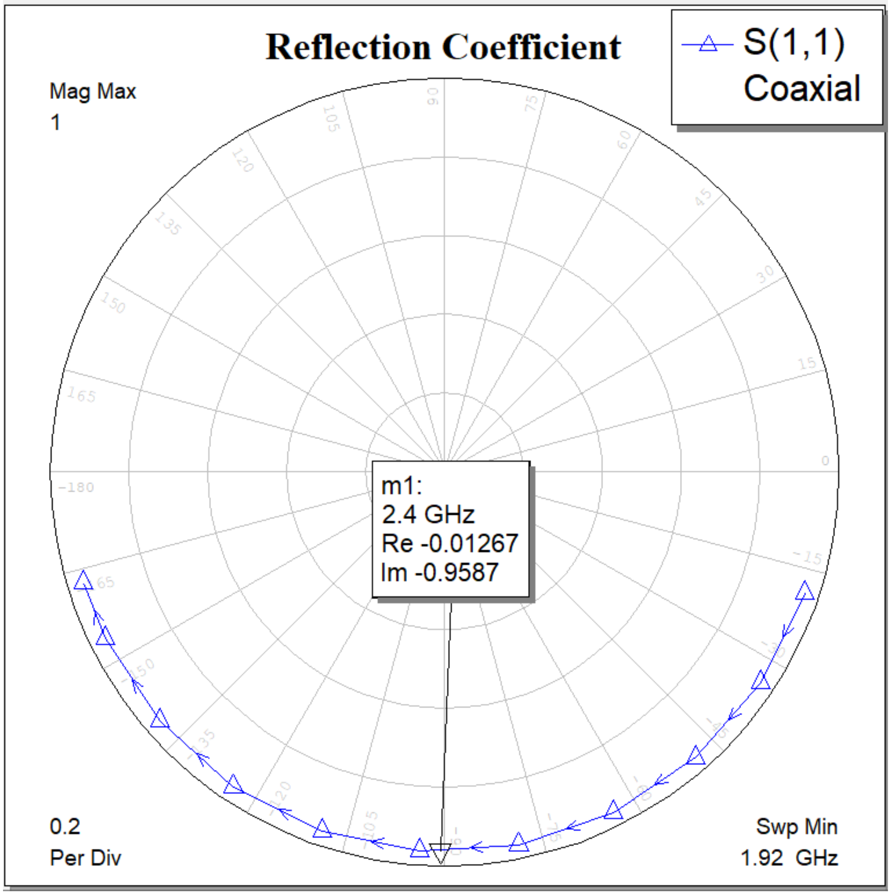

Figure 1.40 The reflection coefficient on Smith Chart when Line Length = 0.5λ

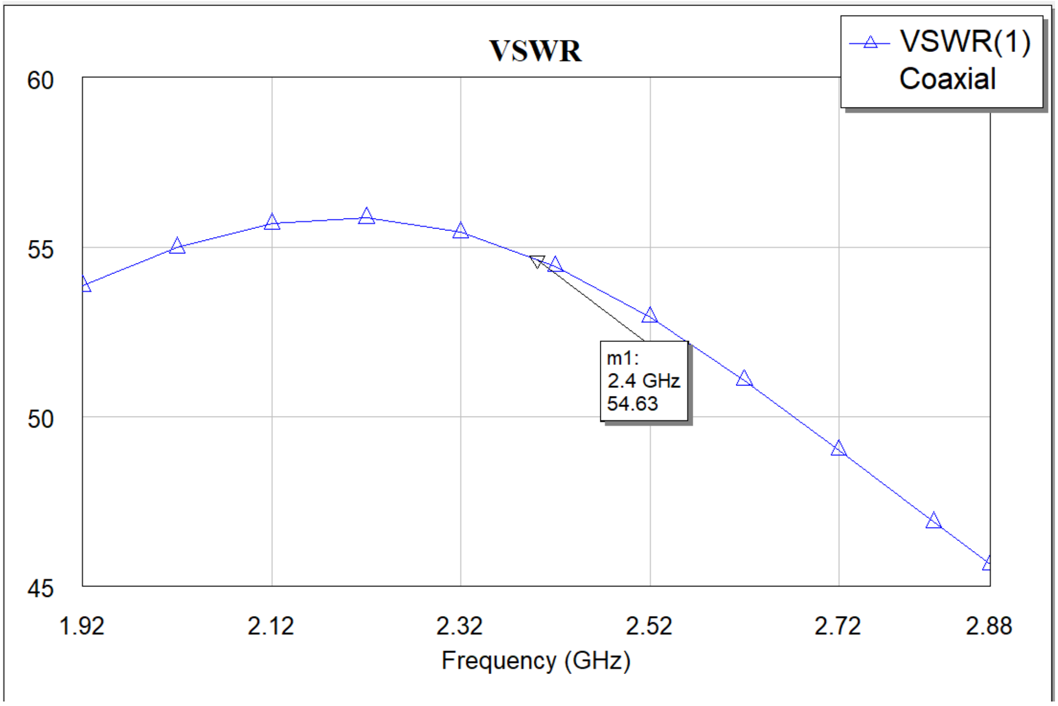

Figure 1.41 The VSWR on Smith Chart when Line Length = 0.5λ

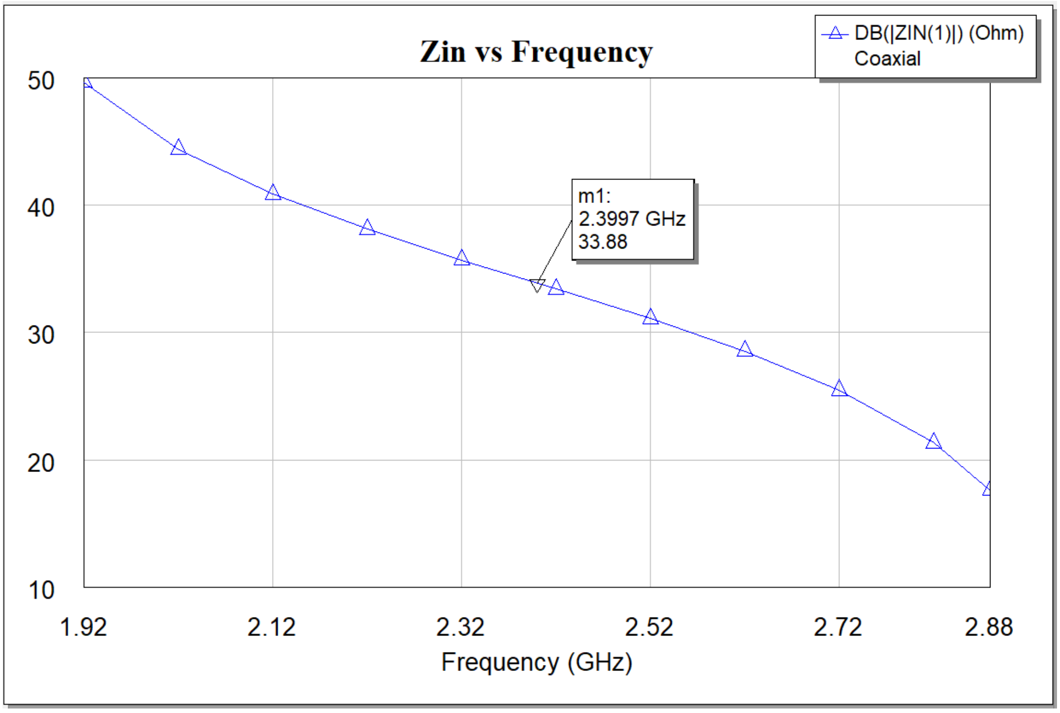

Figure 1.42 The input impedance and frequency on Smith Chart when Line Length $= 0.5\lambda$

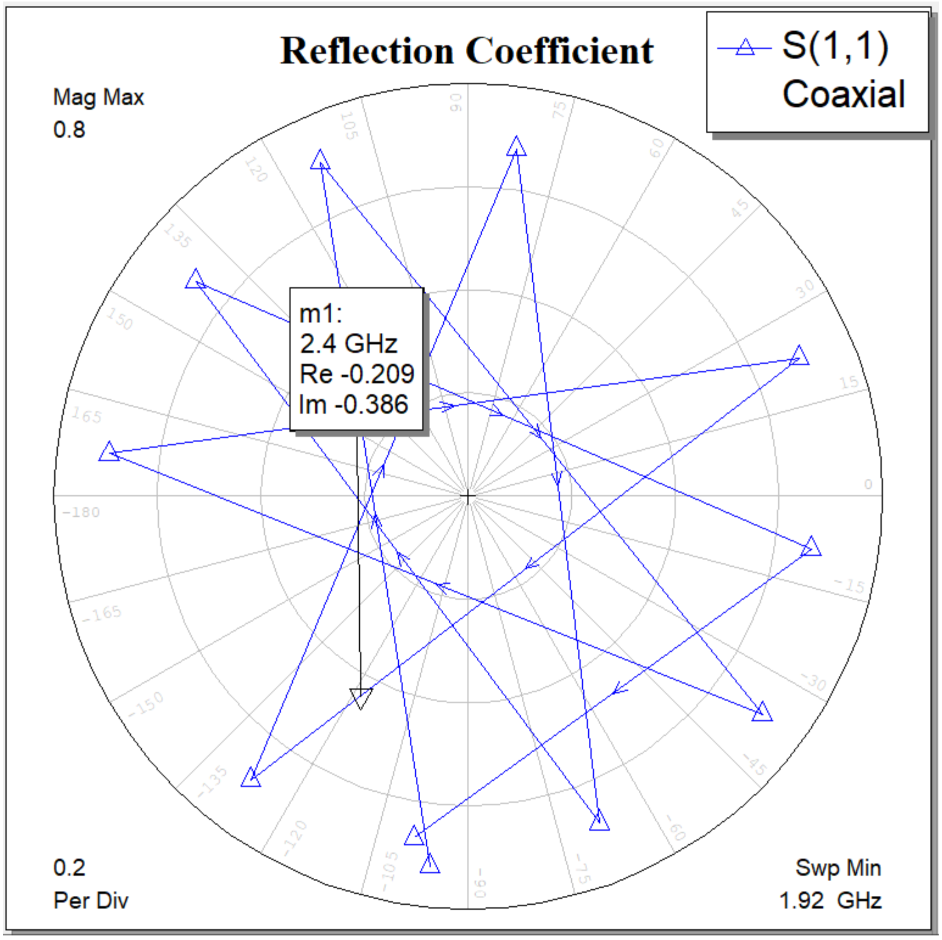

Figure 1.43 The reflection coefficient on Smith Chart when Line Length $= 5\lambda$

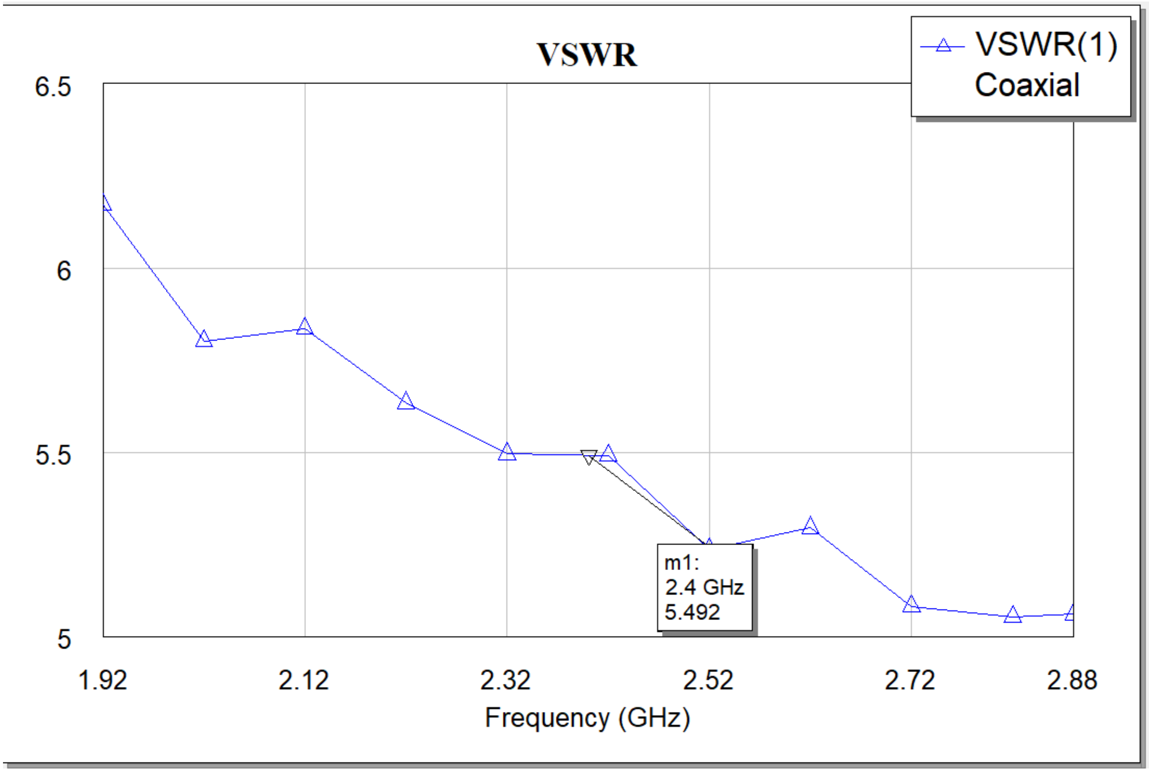

Figure 1.44 The VSWR on Smith Chart when Line Length = 5λ

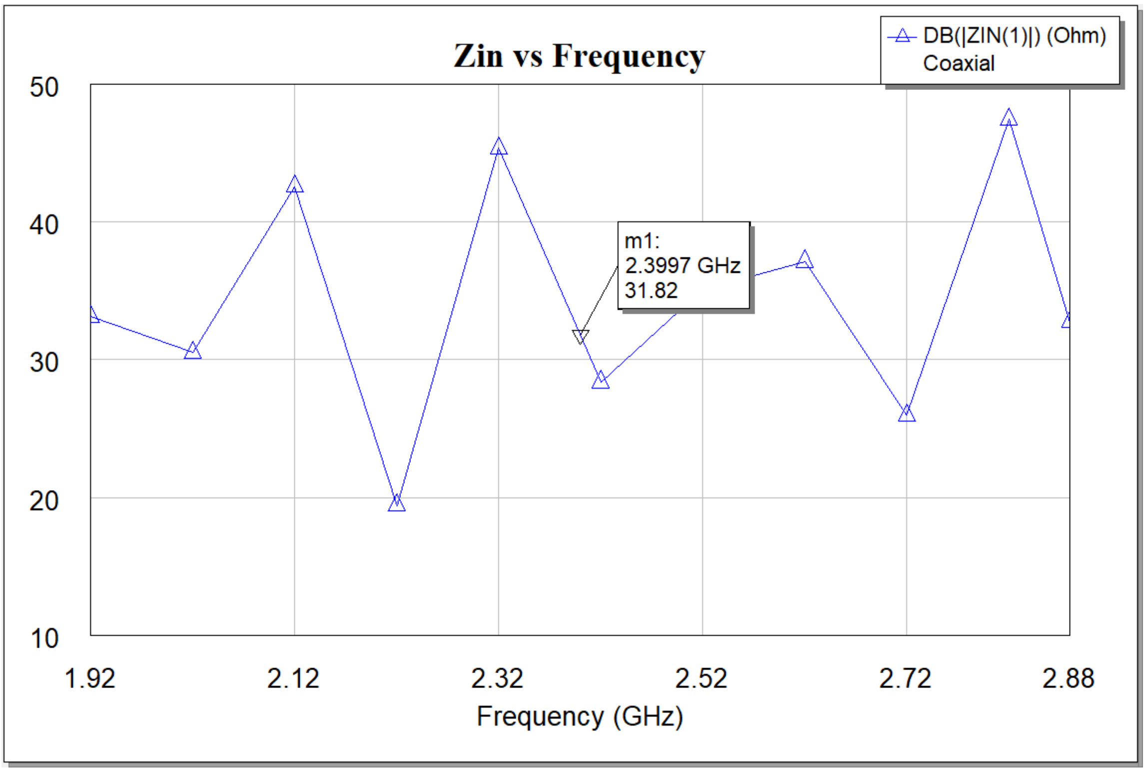

Figure 1.45 The input impedance and frequency on Smith Chart when Line Length = 5λ

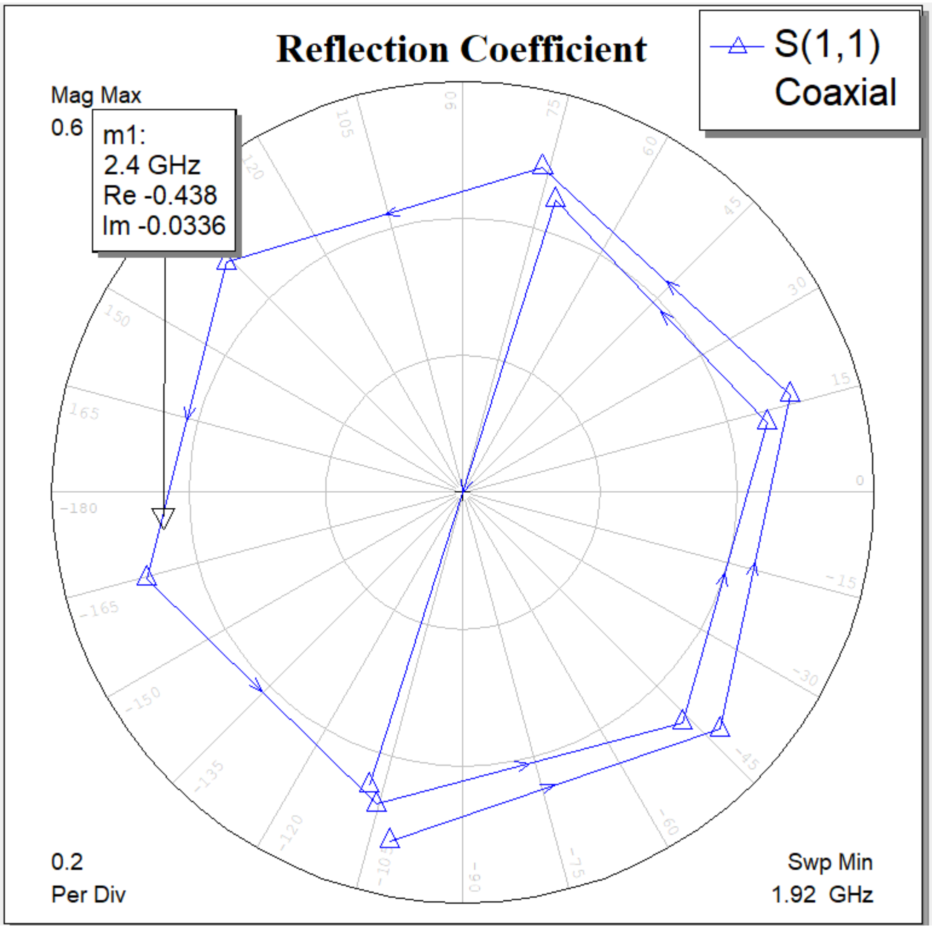

Figure 1.46 The reflection coefficient on Smith Chart when Line Length = 10λ

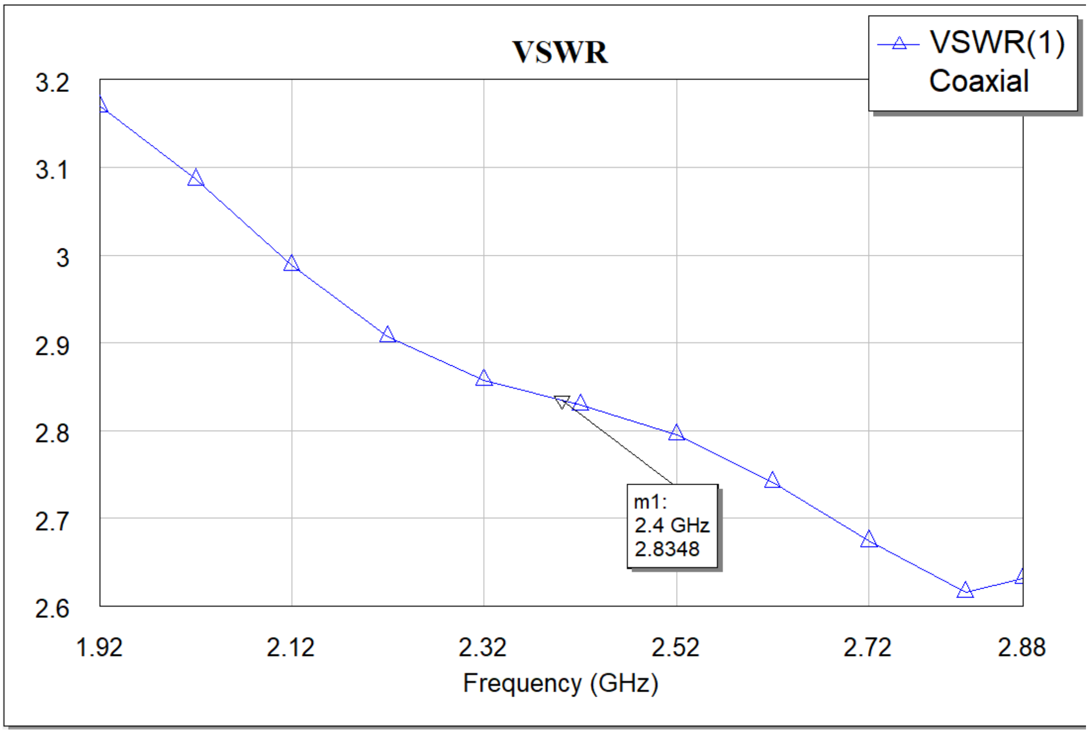

Figure 1.47 The VSWR on Smith Chart when Line Length = 10λ

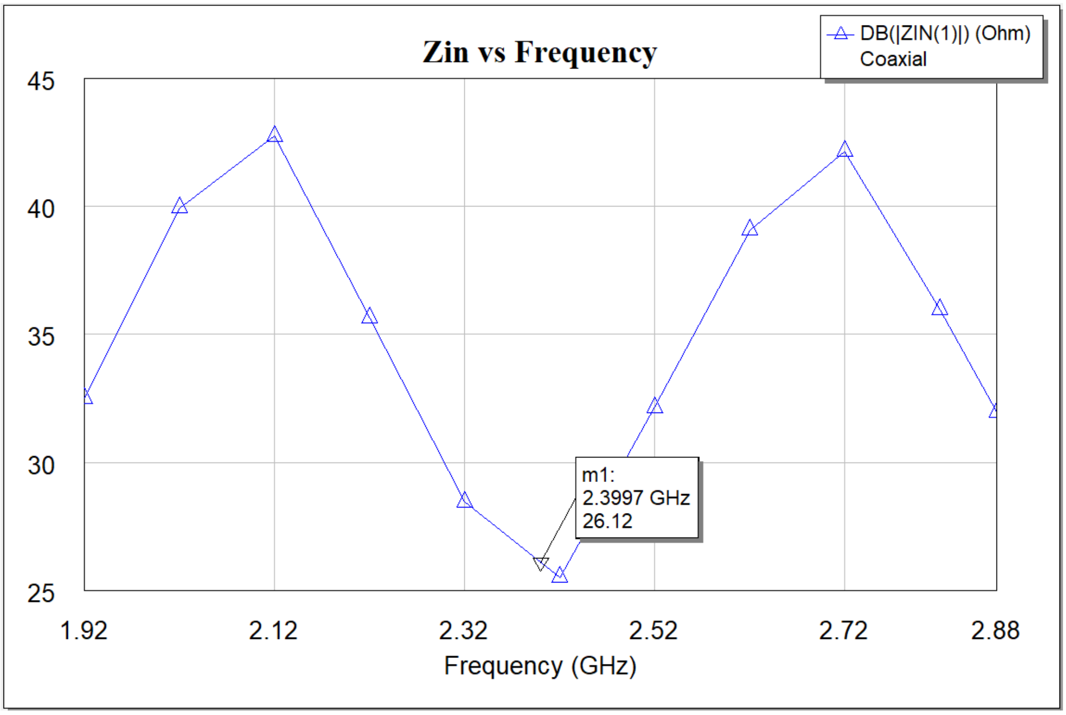

Figure 1.48 The input impedance and frequency on Smith Chart when Line Length $= 10\lambda$

2. Question 2

Design a matched line using single stub short circuit line for the given loads shown below. Use coaxial transmission line in your designs. By using AWR, find and draw VSWR and reflection coefficient of TL before and after matching. (parameters are given for each group, Zc=50Ω). Comment on the results.

We calculated length of stub and distance of transmission line project part 1 so we use that values in this question.

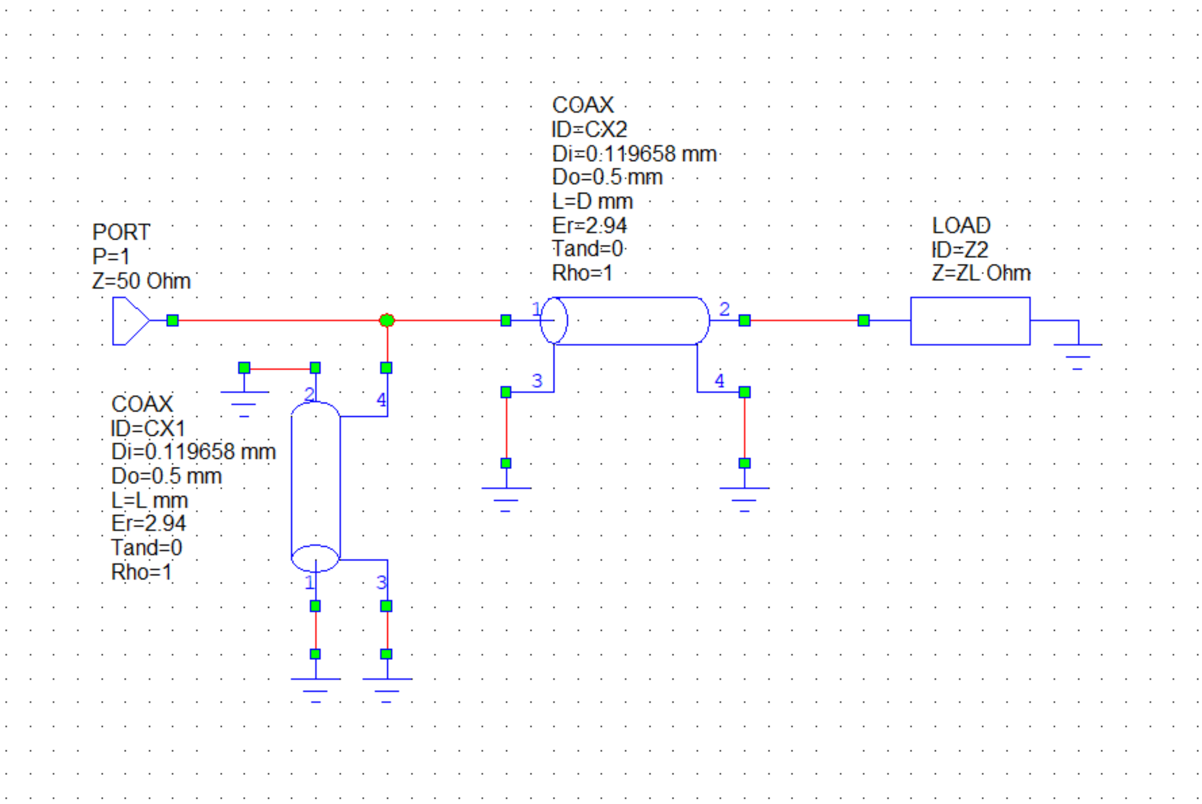

Figure 2.0 Matched line using single stub short circuit line for different D and L

a) ZL=0

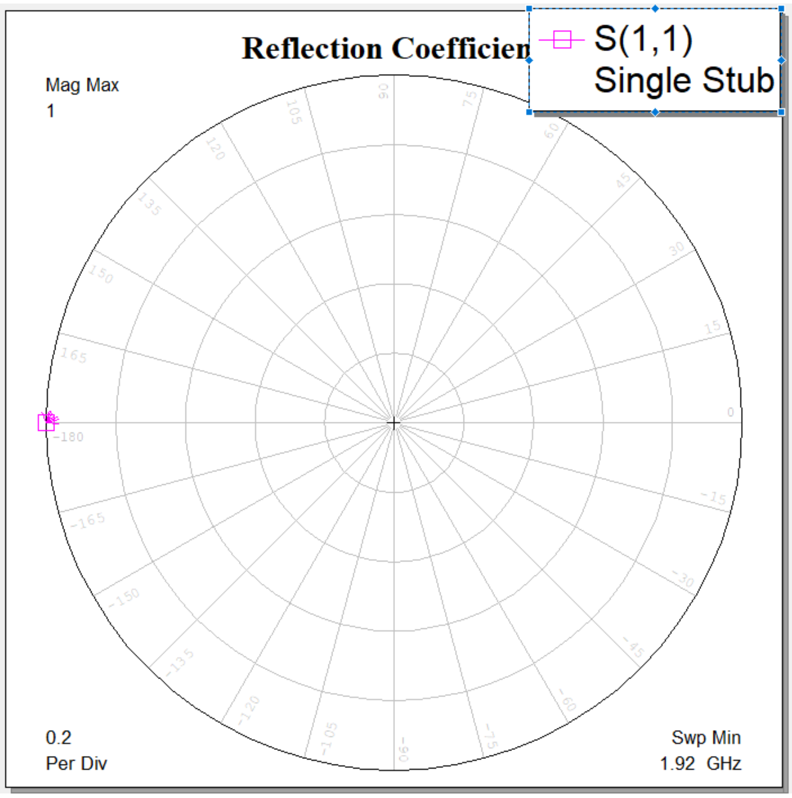

Figure 2.1 The reflection coefficient on Smith Chart

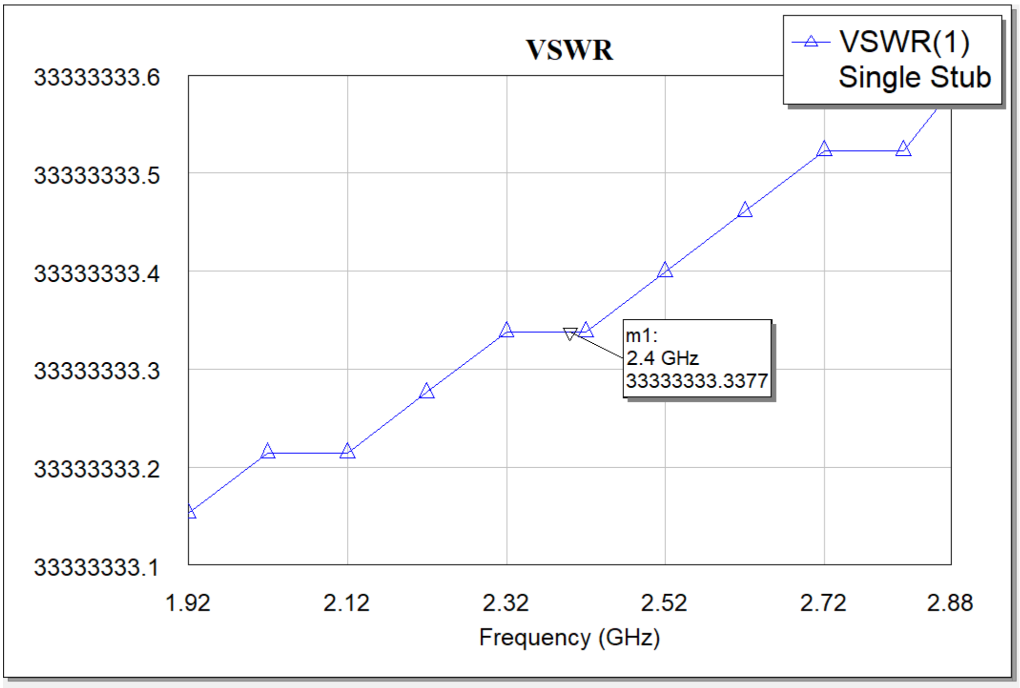

Figure 2.2 The VSWR

b) ZL=∞

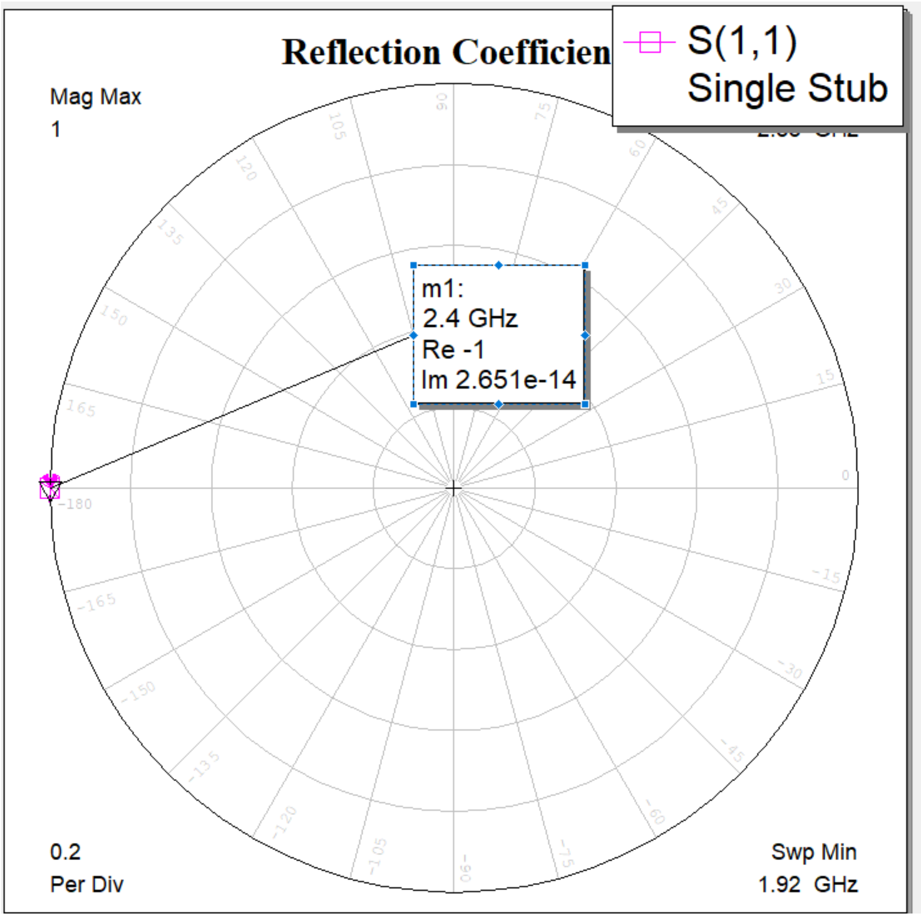

Figure 2.3 The reflection coefficient on Smith Chart

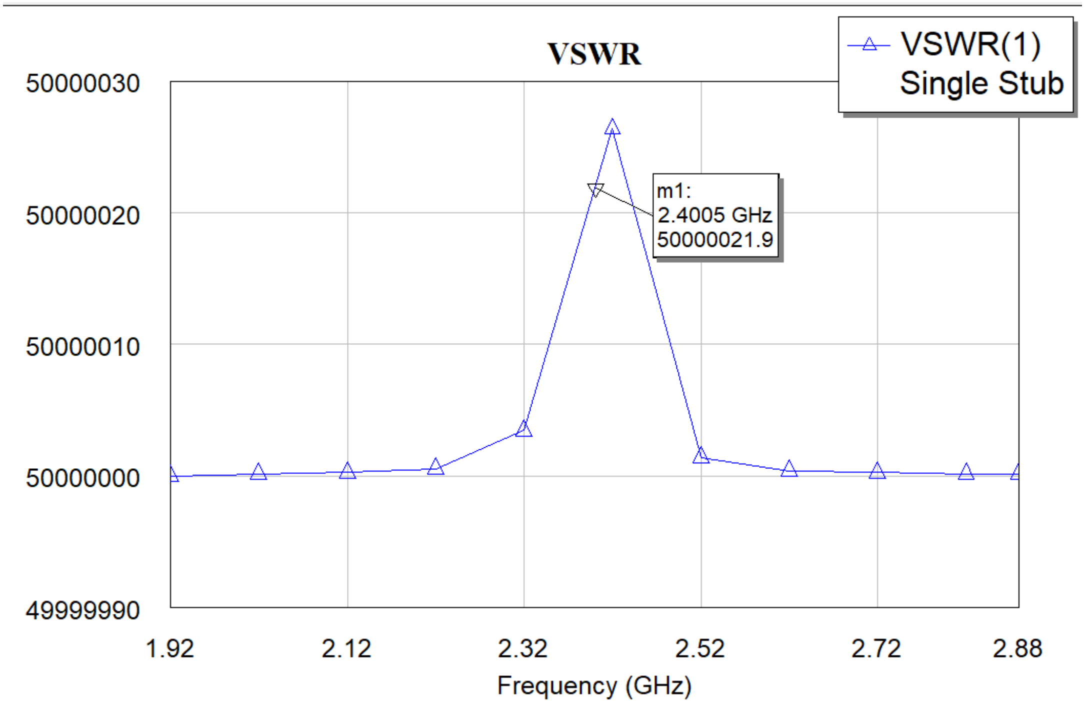

Figure 2.4 The VSWR

c) ZL= j75 Ω

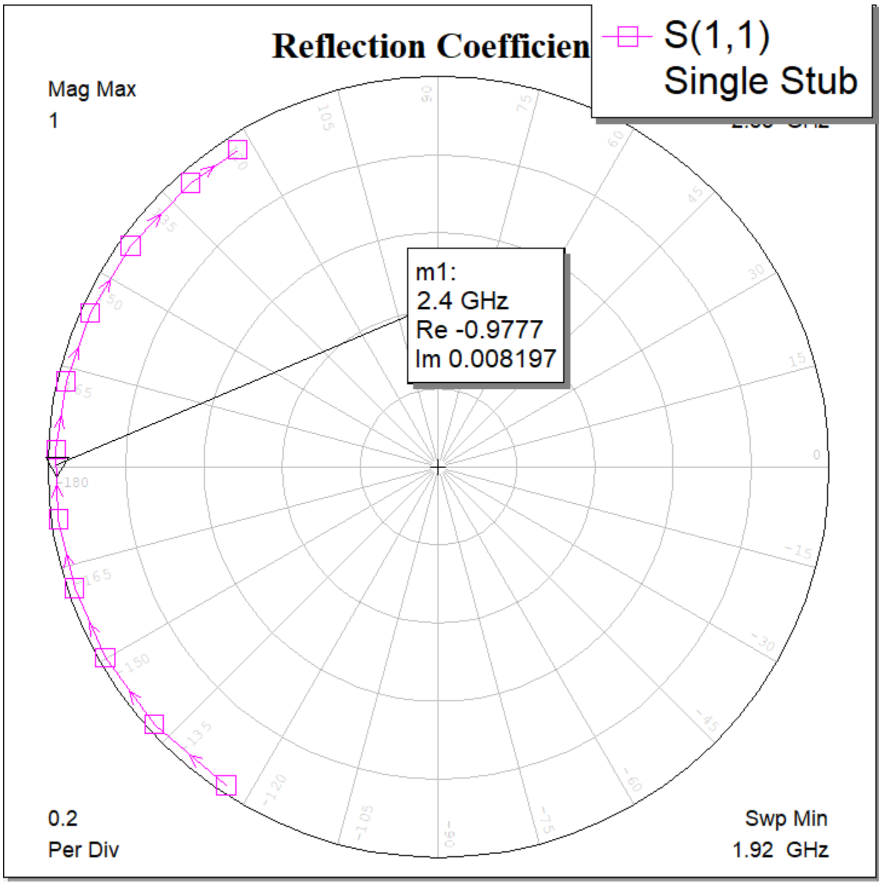

Figure 2.5 The reflection coefficient on Smith Chart

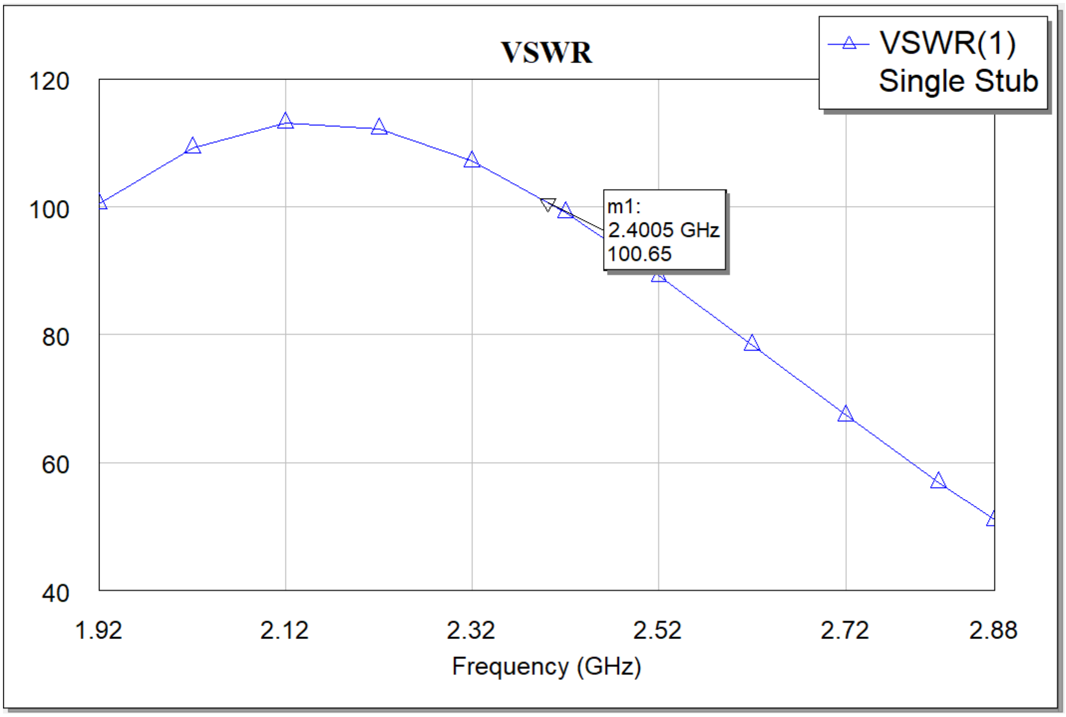

Figure 2.6 The VSWR

d) ZL=75 Ω

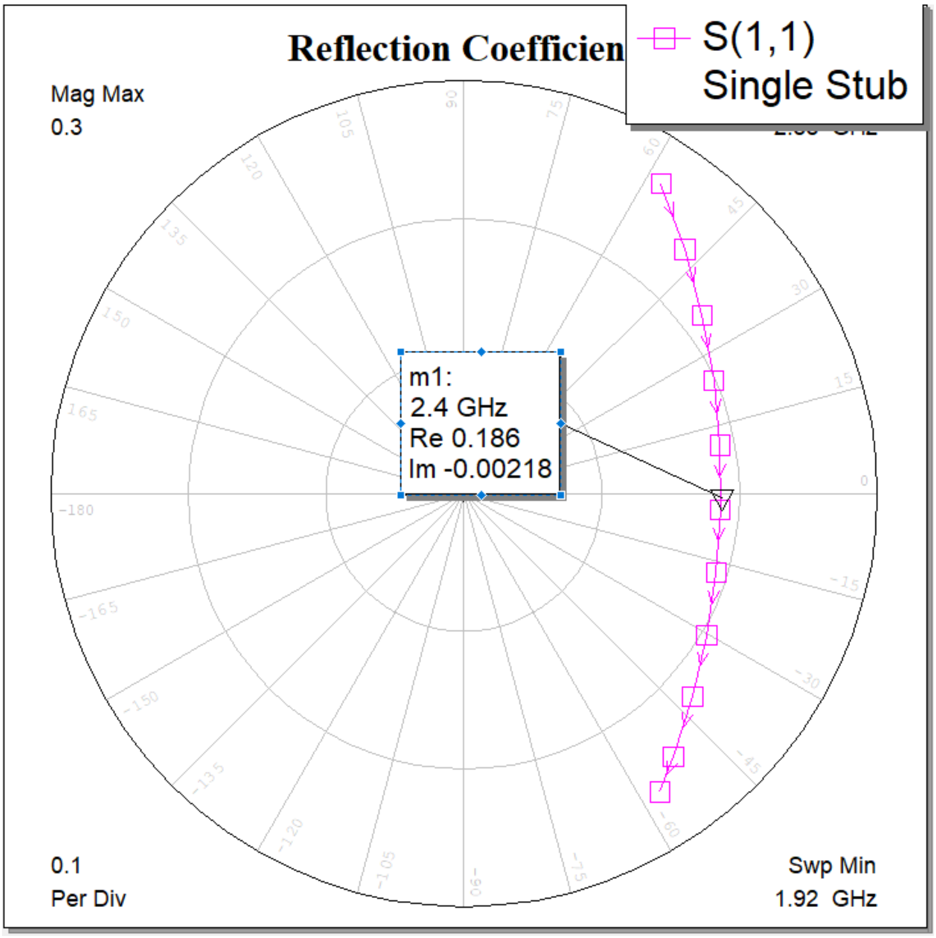

Figure 2.7 The reflection coefficient on Smith Chart

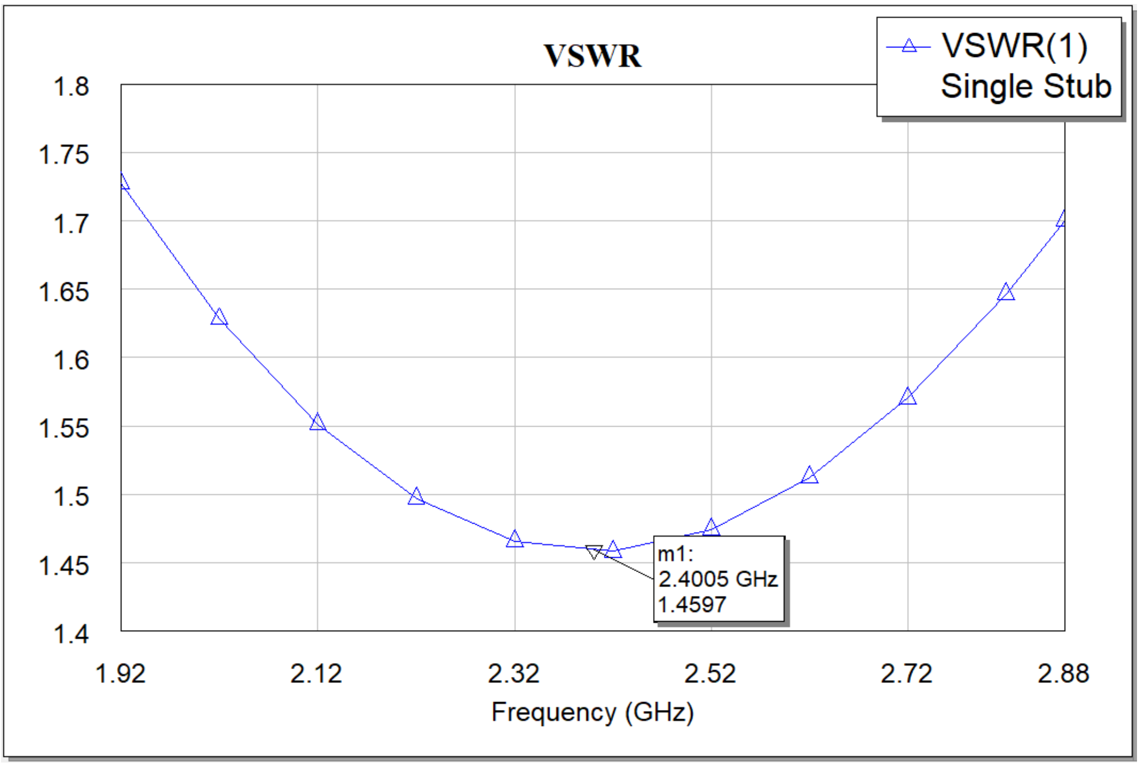

Figure 2.8 The VSWR

e) ZL=50 Ω

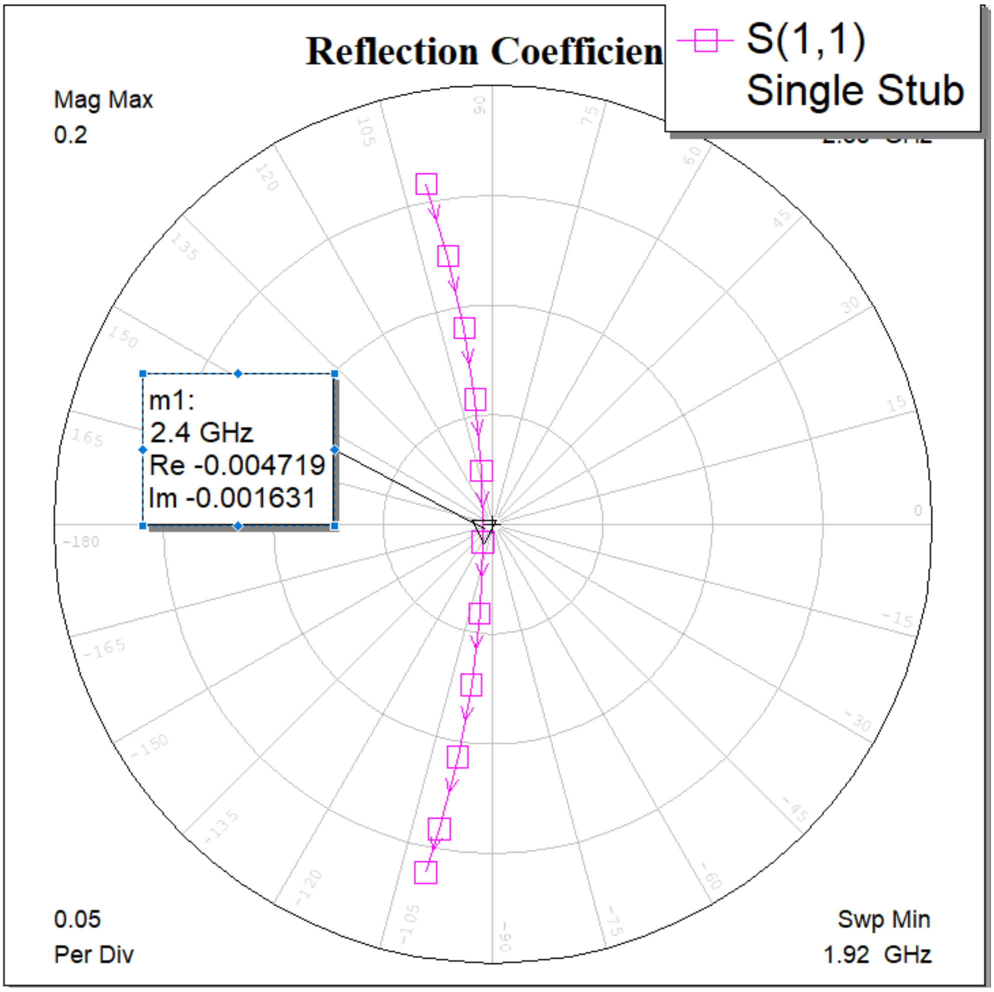

Figure 2.9 The reflection coefficient on Smith Chart

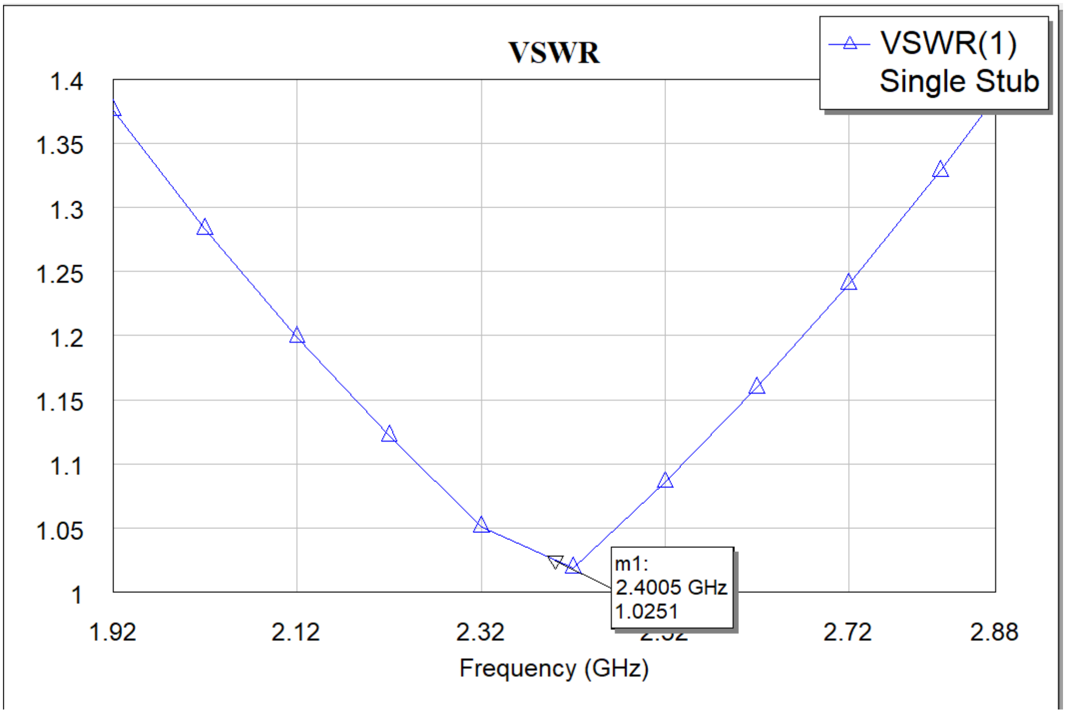

Figure 2.10 The VSWR

3. Question 3

Design a 50-Ohm coaxial transmission line (for the given parameters for each group by your laboratory assistant) using ANSYS HFSS. Draw return loss of the transmission line for a frequency range (f-0.2f<f<f+0.2f). Comment on the results.

In this question, a coaxial transmission line is designed with 50 Ω characteristic impedance. The diameter parameters which is calculated in question 1 is used for design. For simulation, ANSYS HFSS software is used.

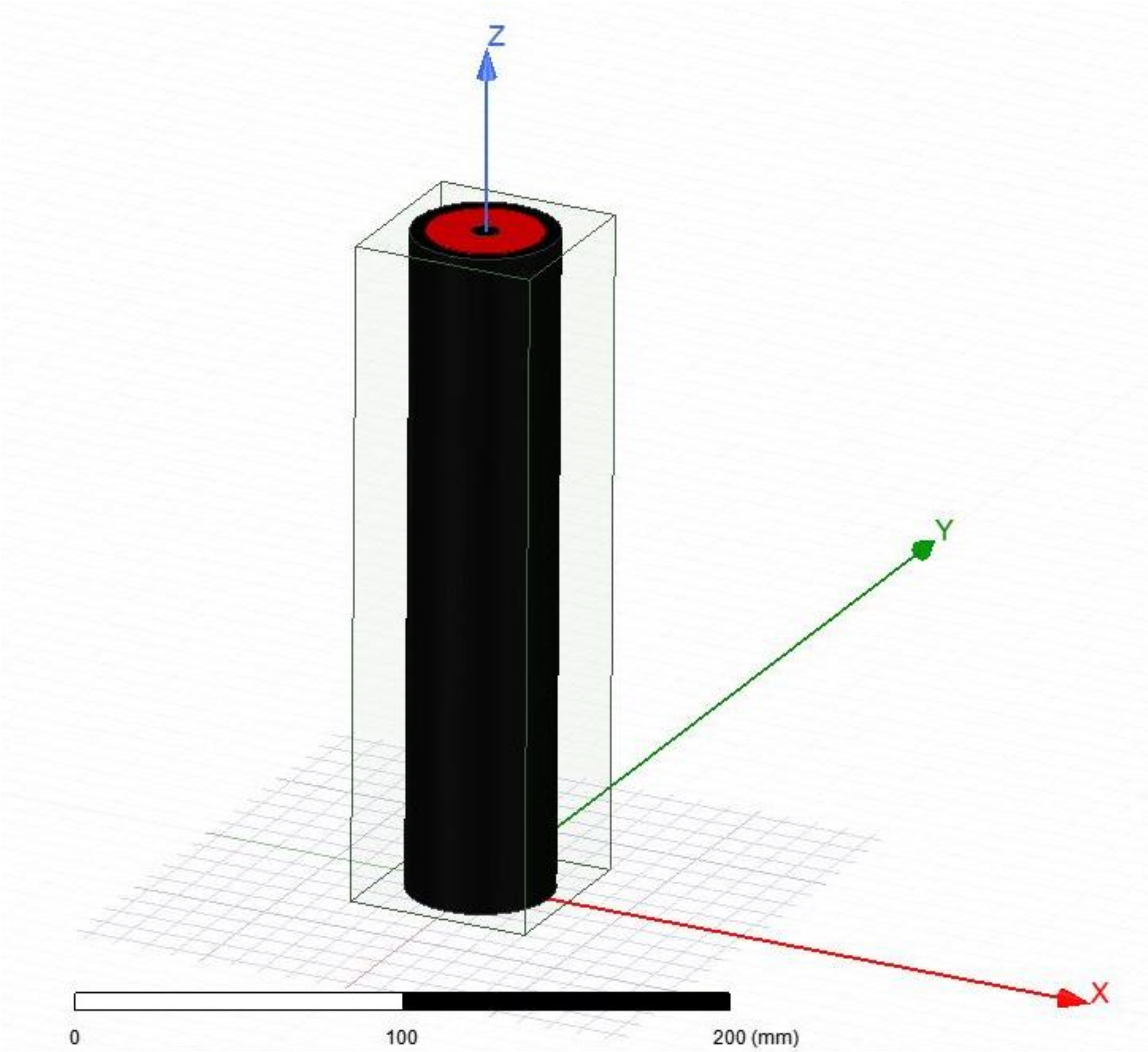

Figure 3.1 The coaxial transmission line design schematic

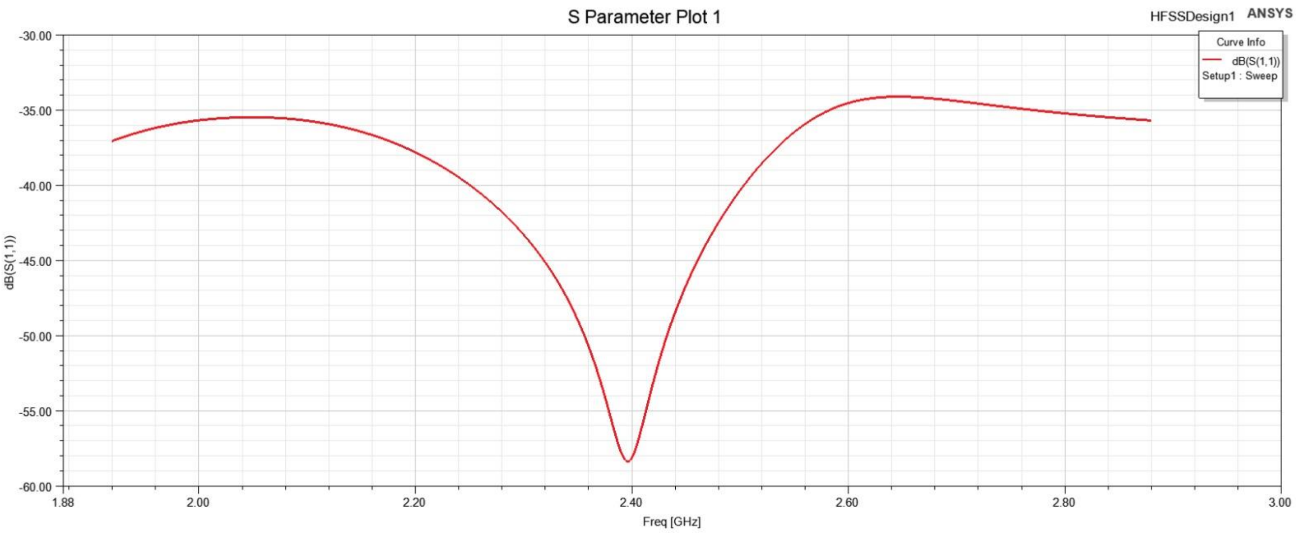

Figure 3.2 Return Loss plot of coaxial transmission line

Return loss is a measure of VSWR (Voltage Standing Wave Ratio), expressed in decibels (db). The return-loss is caused due to impedance mismatch between two or more circuits. For a simple cable assembly, there will be a mismatch where the connector is mated with the cable. There may be an impedance mismatch caused by nick or cuts in a cable. At microwave frequencies, the material properties as well as the dimensions of the cable or connector plays important role in determining the impedance match or mismatch. A high value of return-loss denotes better quality of the system under test (or device under test).

Reflectionis is very low at 2.4GHz frequency. So return loss is lowest in this frequency.

4. Question 4

Design a rectangular waveguide with dimensions *a=2.3 cm* and *b=1.1 cm* using ANSYS HFSS for TE_{10}, TE_{20} and TM_{11} modes at 9 GHz. Simulate your designs for air-filled (ε_r=1) and dielectric-filled (ε_r=4) waveguides. Comment on the results. Hint: You can choose waveguide material as perfect conductor.

$$f_c = \frac{1}{2\pi\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}$$

So our cut-off frequencies are:

	εr=1	εr=4
f_{c10}	6.66 GHz	3.33 GHz
F_{c20}	13.3 GHz	6.66 GHz
f_{c11}	16.4 GHz	8.2 GHz

Table 4.1 The cutoff frequencies

a) Find surface currents on waveguide walls for all modes.

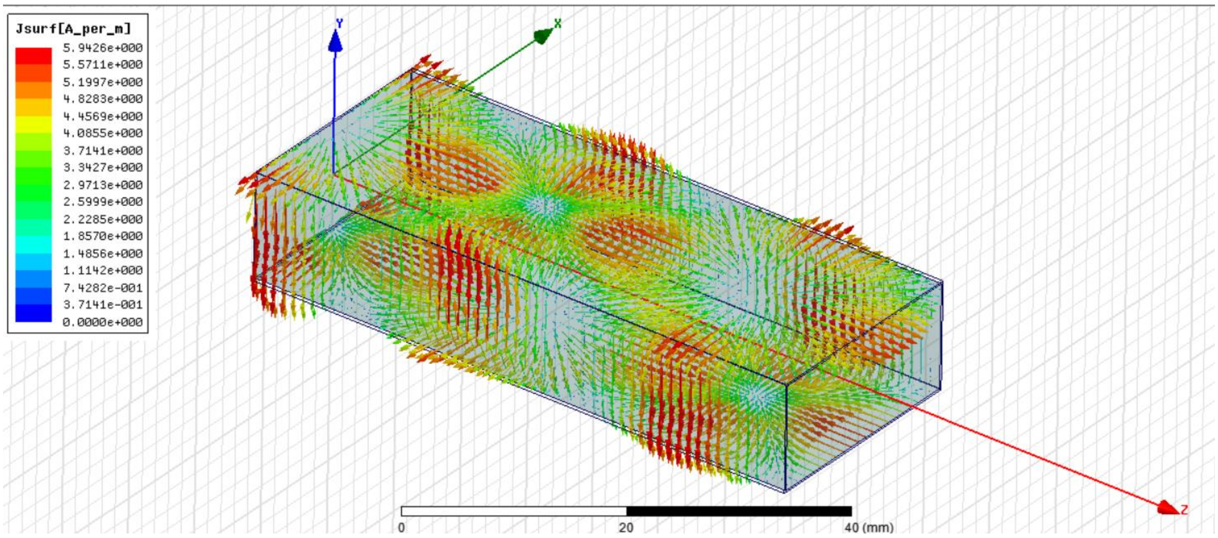

Figure 4.1 The surface current of TE10 mode for for Ɛr=1

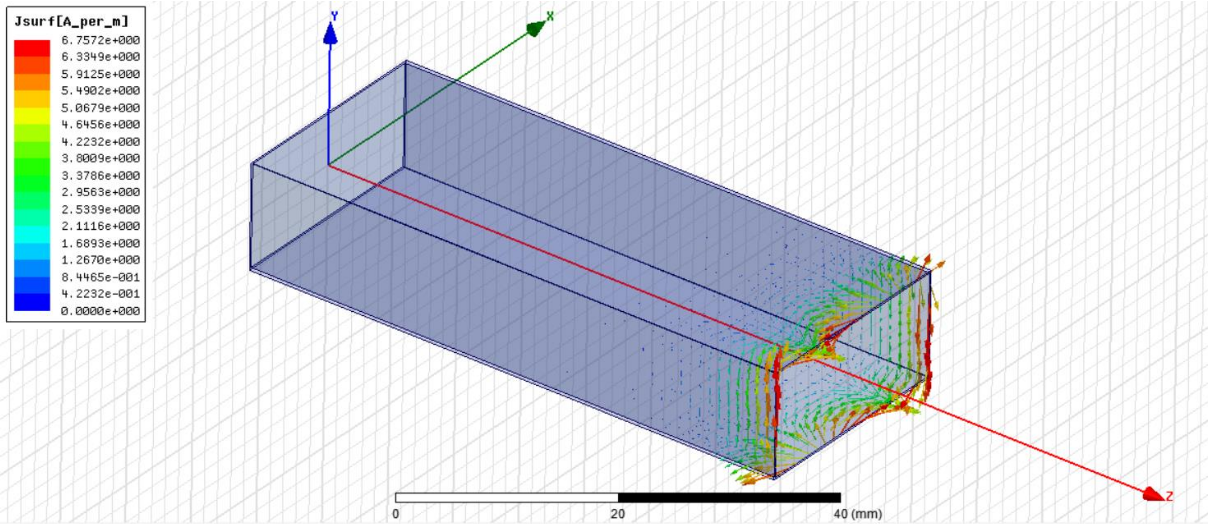

Figure 4.2 The surface current of TE20 mode for Ɛr=1

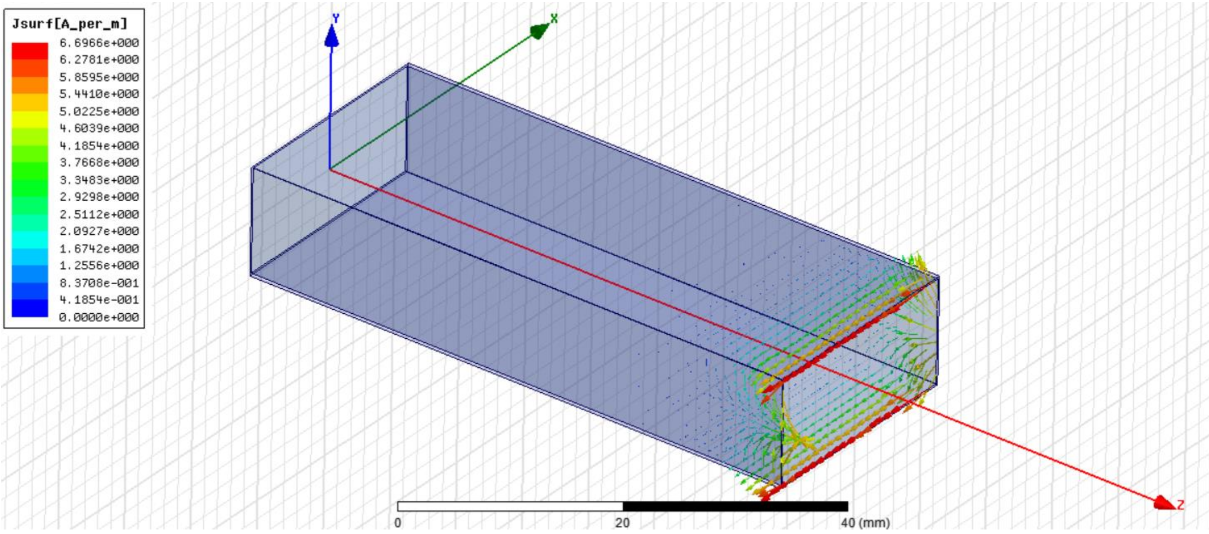

Figure 4.3 The surface current of TM11 mode

b) Find electric and magnetic field lines in waveguide for all modes.

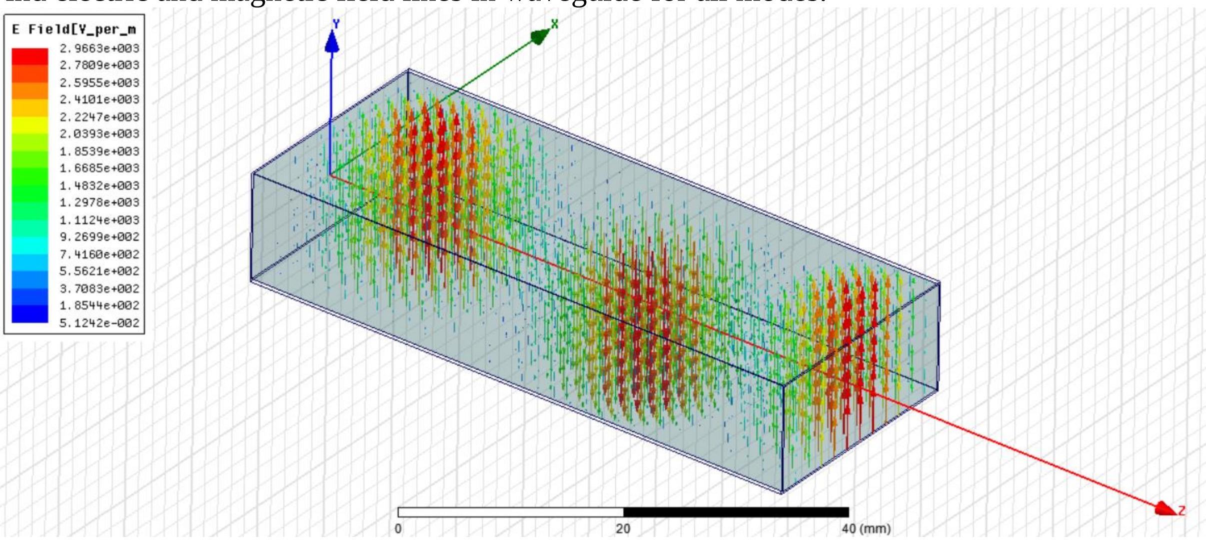

Figure 4.4 The electric field lines of TE10 mode for Ɛr=1

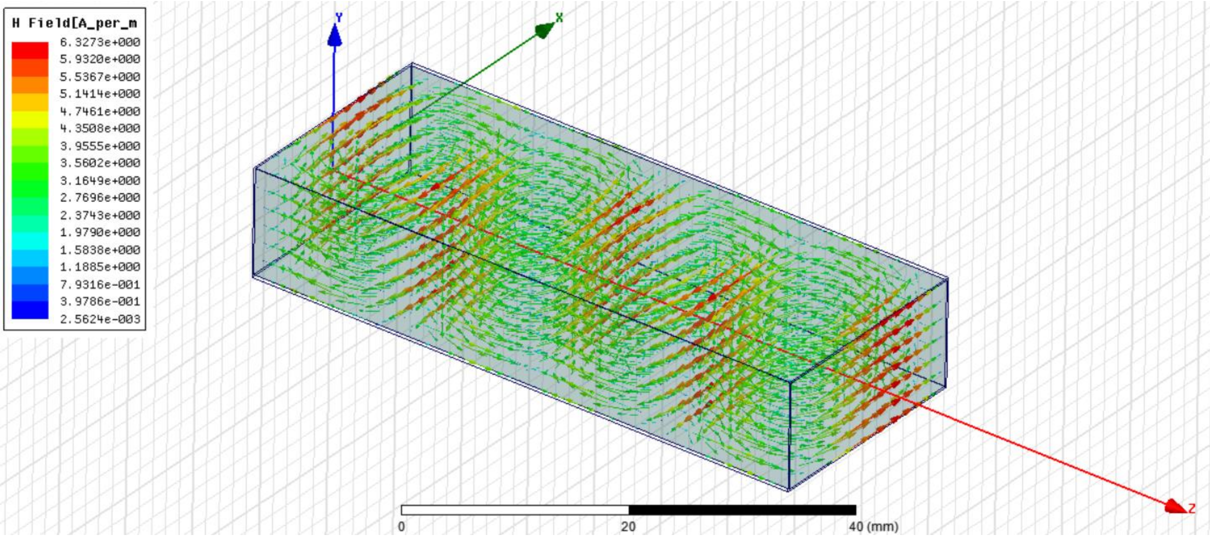

Figure 4.5 The magnetic field lines of TE10 mode for Ɛr=1

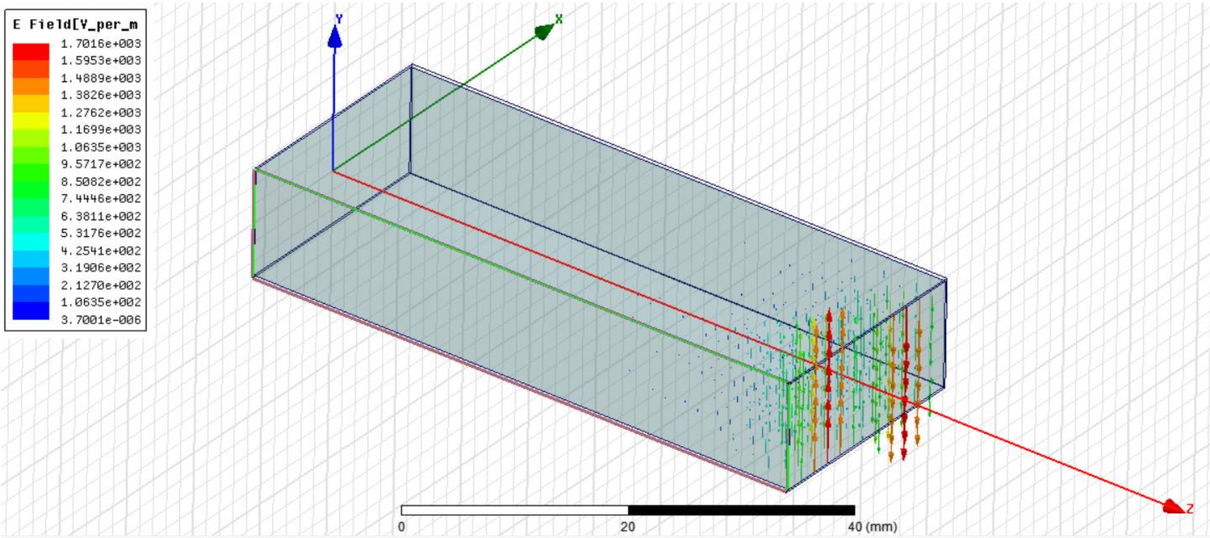

Figure 4.6 The electric field lines of TE20 mode for Ɛr=1

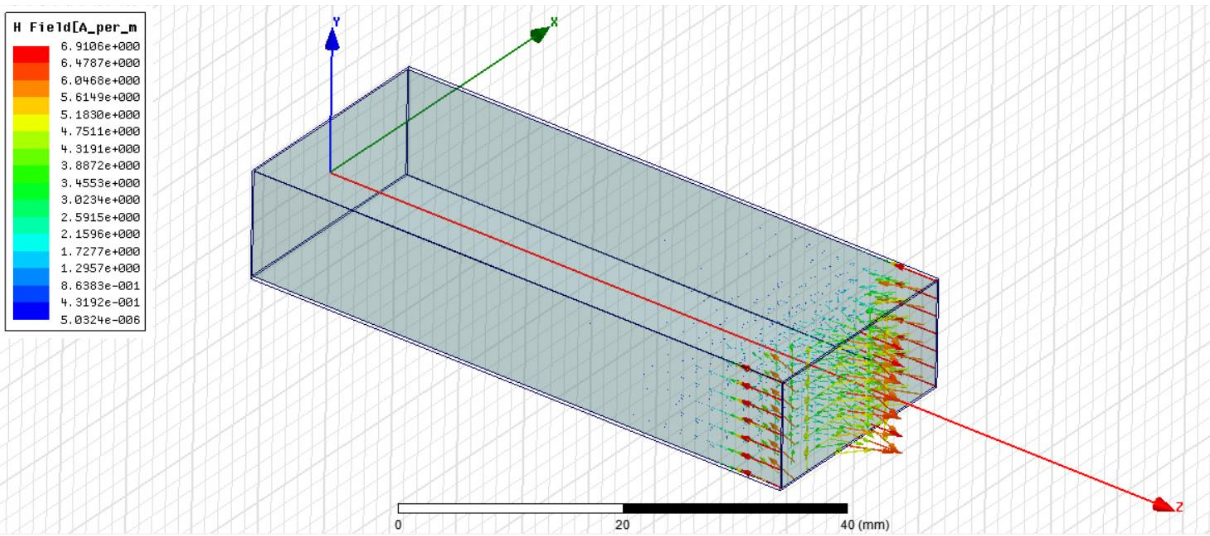

Figure 4.6 The magnetic field lines of TE20 mode for Ɛr=1

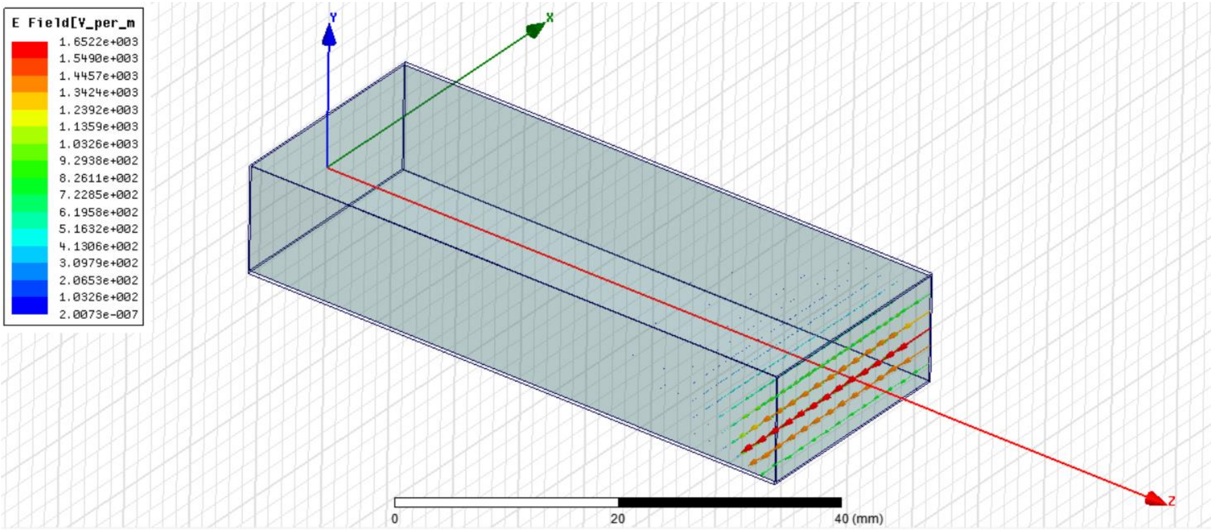

Figure 4.8 The electric field lines of TM11 mode for Ɛr=1

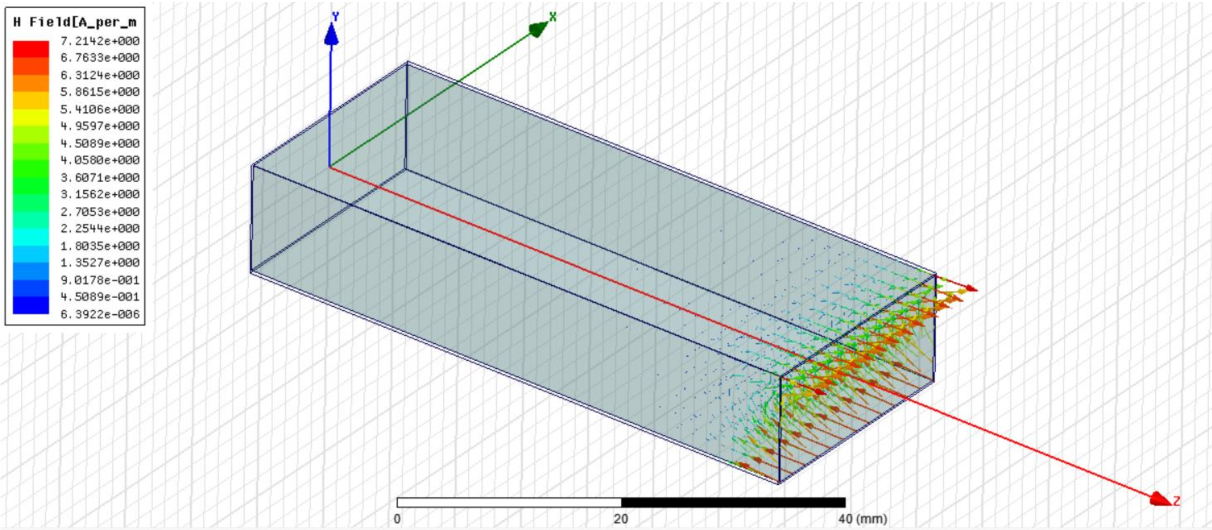

Figure 4.9 The magnetic field lines of TM11 mode for Ɛr=1

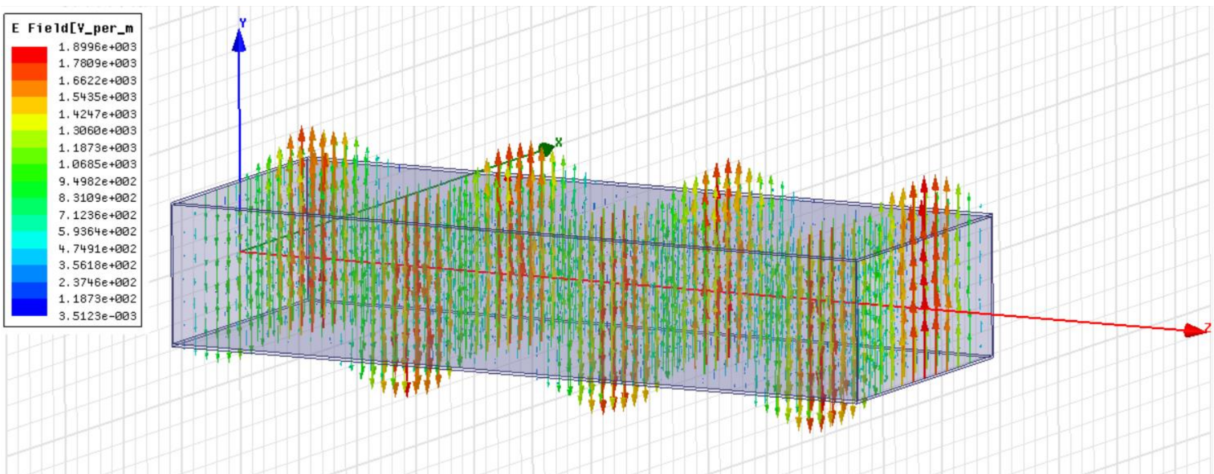

Figure 4.10 The electric field lines of TE10 mode for Ɛr=4

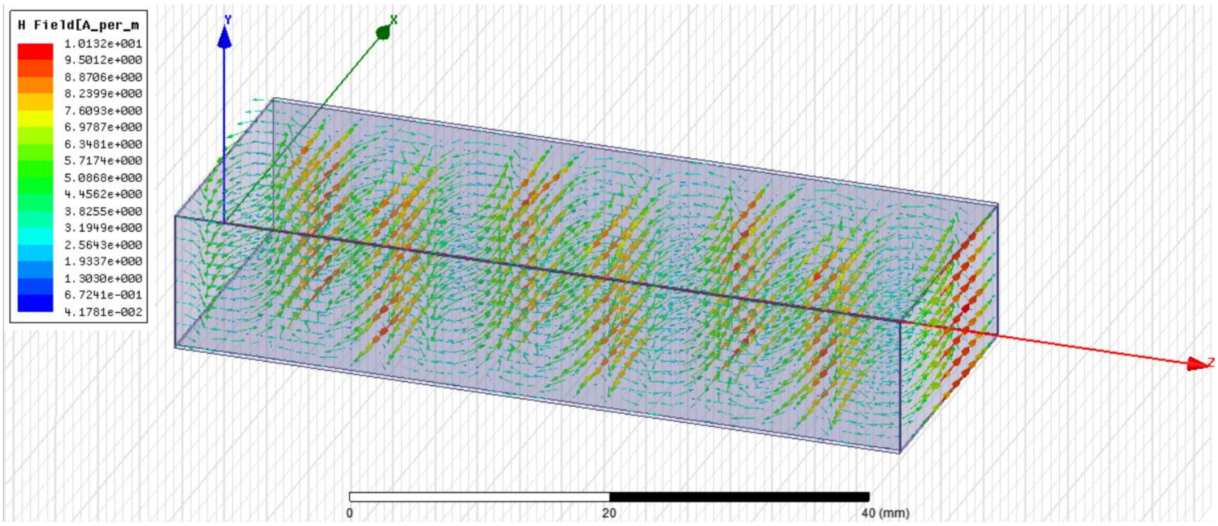

Figure 4.11 The magnetic field lines of TE10 mode for εr=4

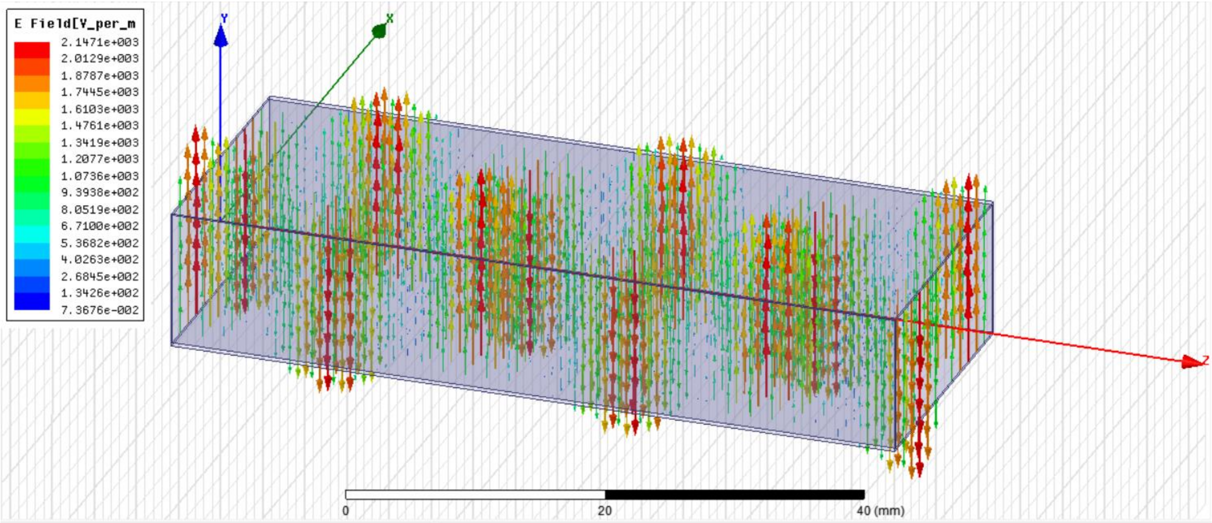

Figure 4.12 The electric field lines of TE20 mode for εr=4

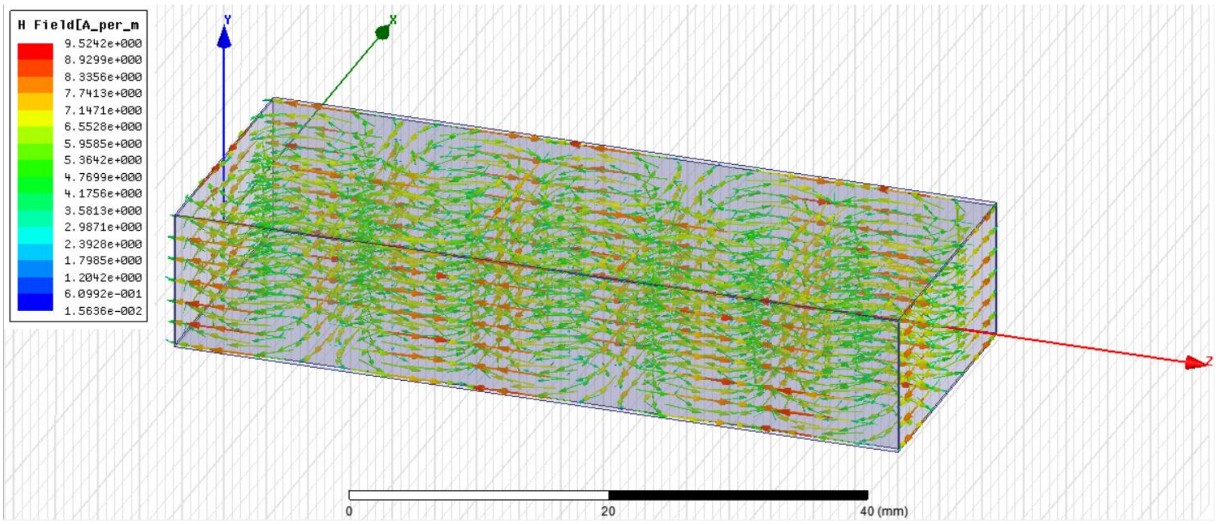

Figure 4.13 The magnetic field lines of TE20 mode for εr=4

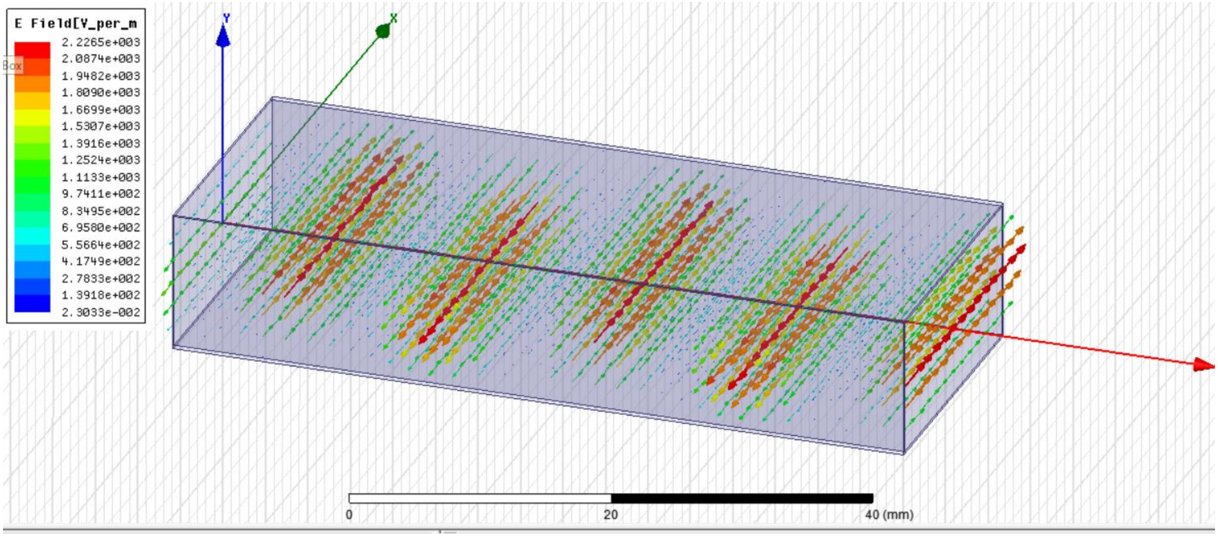

Figure 4.14 The electric field lines of TM11 mode for Ɛr=4

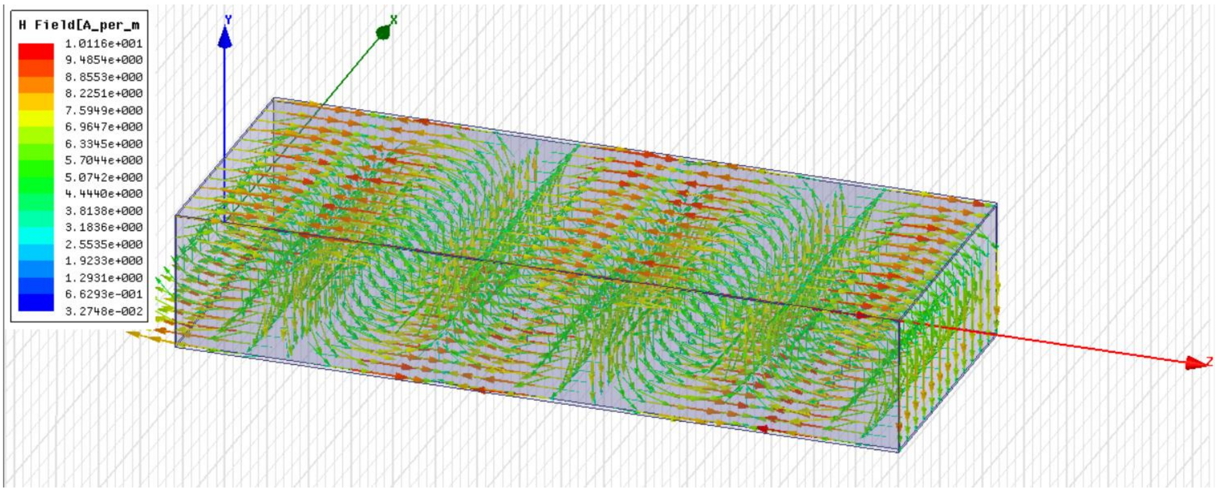

Figure 4.15 The magnetic field lines of TM11 mode for Ɛr=4

c) Find field lines at f=4 GHz for all modes. Comment on the change of εr.

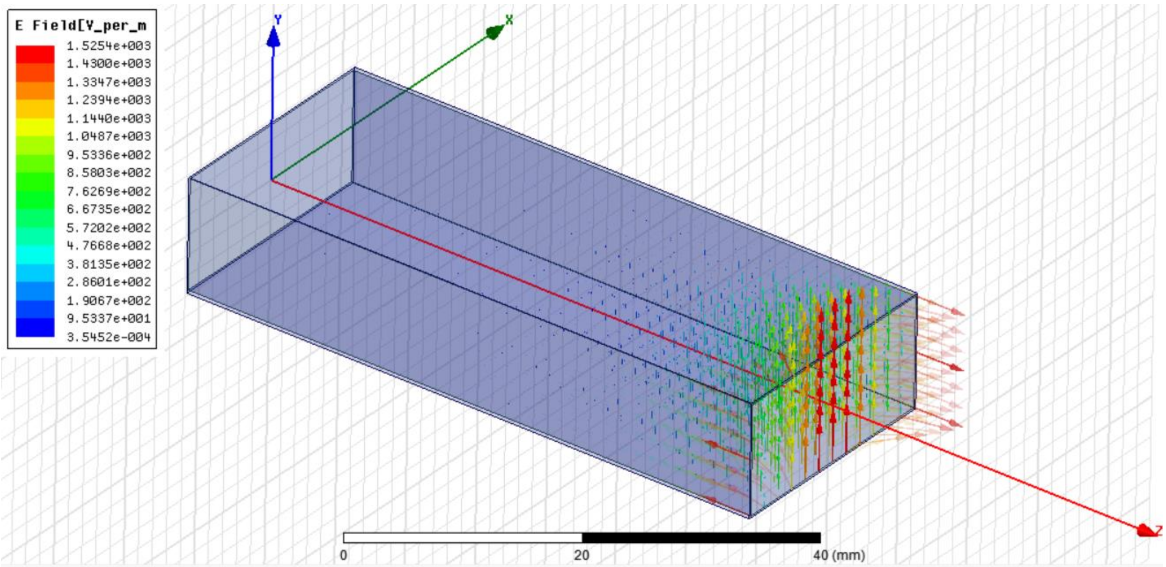

Figure 4.16 The electric field lines of TE10 mode for Ɛr=1 at 4GHz

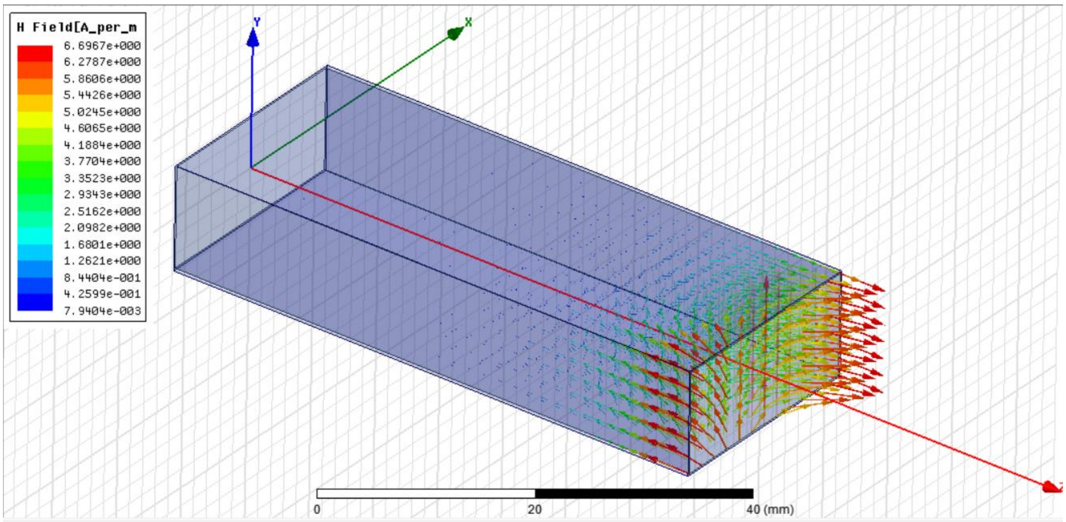

Figure 4.17 The magnetic field lines of TE10 mode for Ɛr=1 at 4GHz

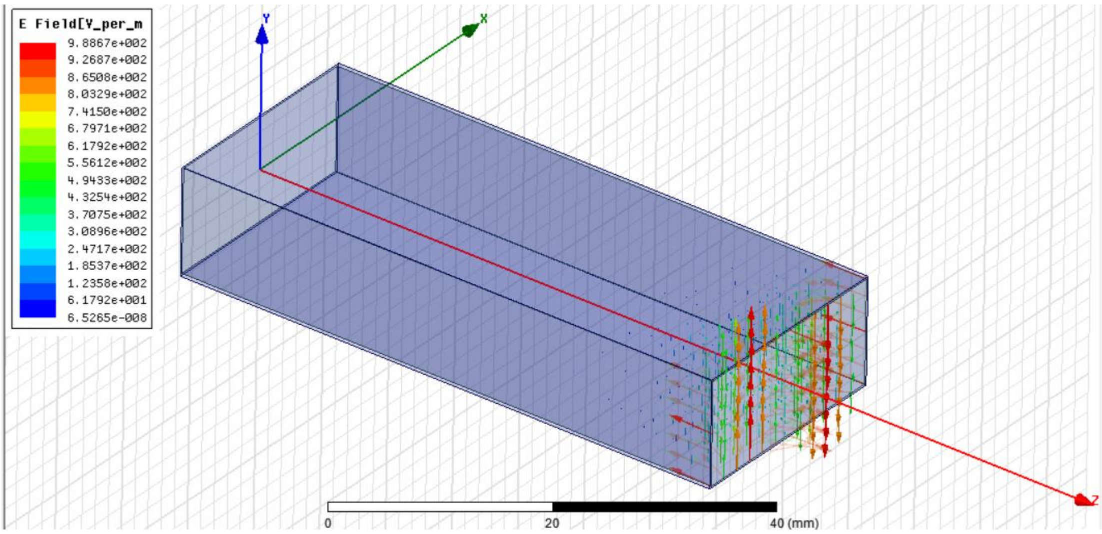

Figure 4.18 The electric field lines of TE20 mode for Ɛr=1 at 4GHz

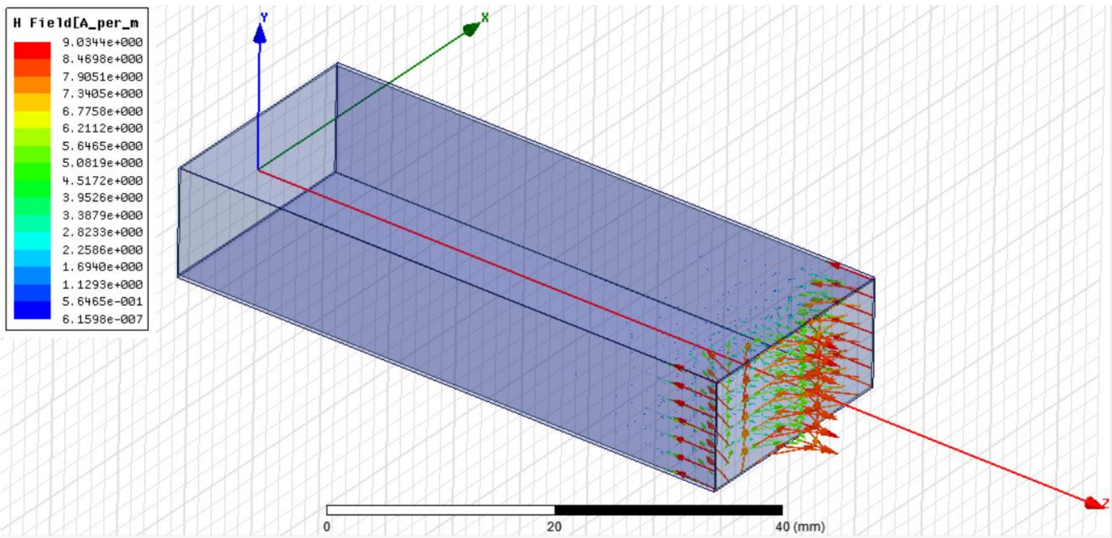

Figure 4.19 The magnetic field lines of TE20 mode for Ɛr=1 at 4GHz

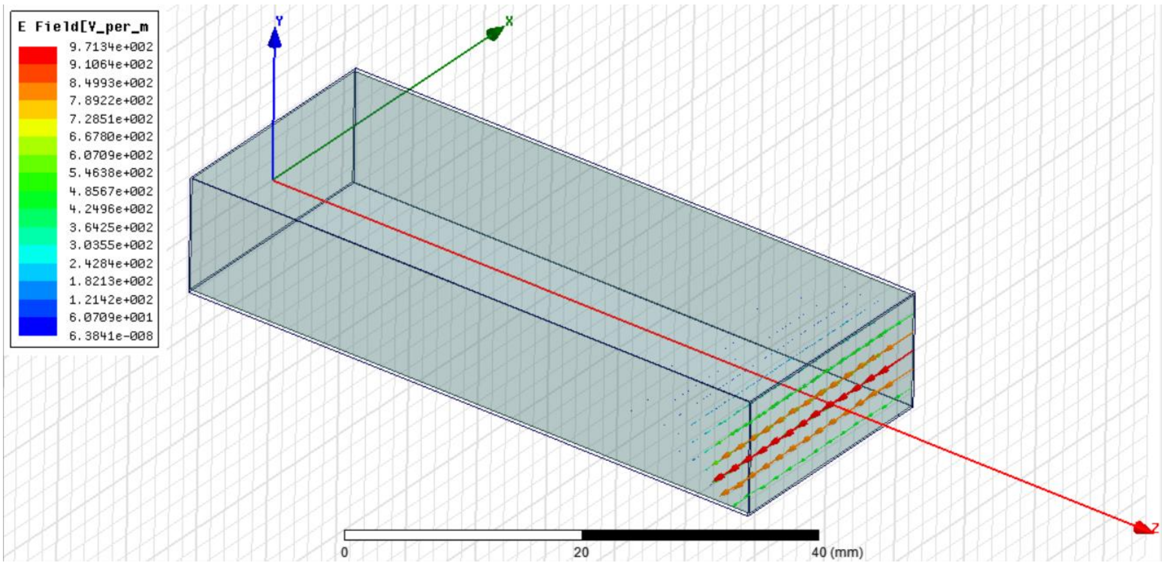

Figure 4.20 The electric field lines of TM11 mode for εr=1 at 4GHz

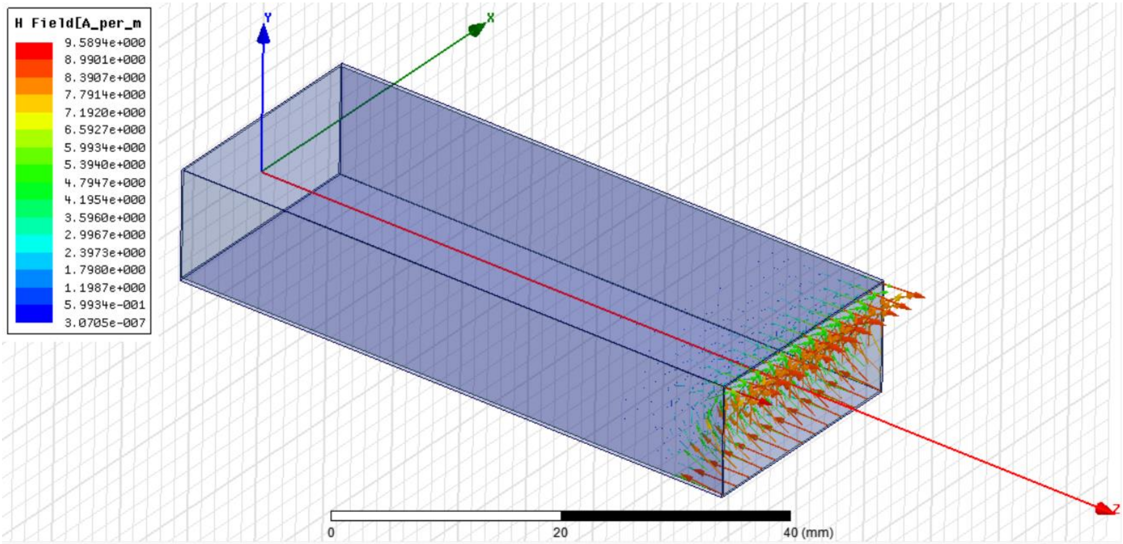

Figure 4.21 The magnetic field lines of TM11 mode for εr=1 at 4GHz

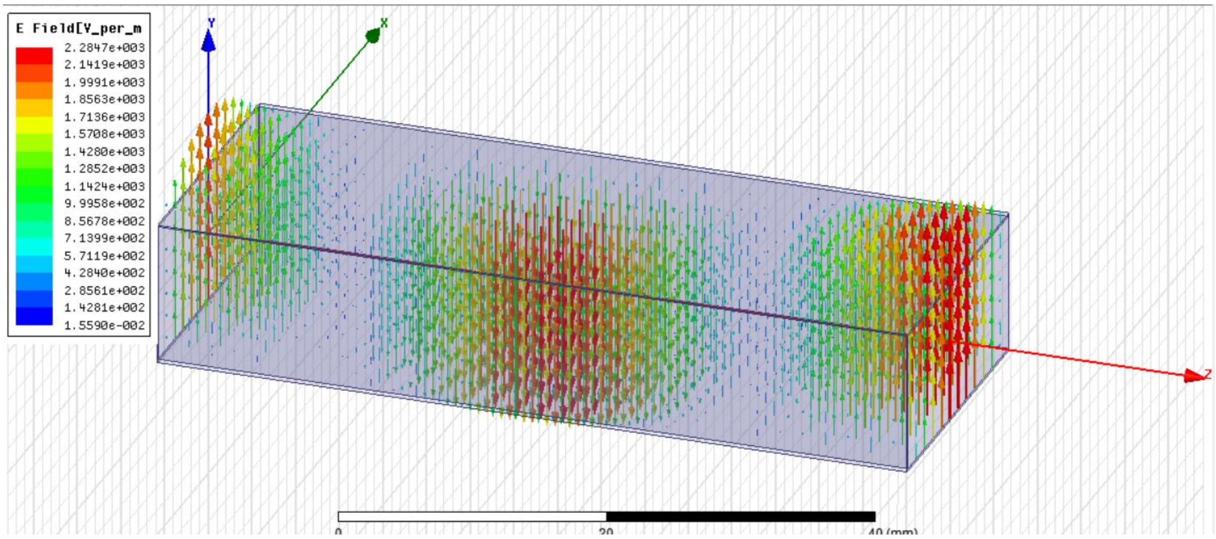

Figure 4.22 The electric field lines of TE10 mode for εr=4 at 4GHz

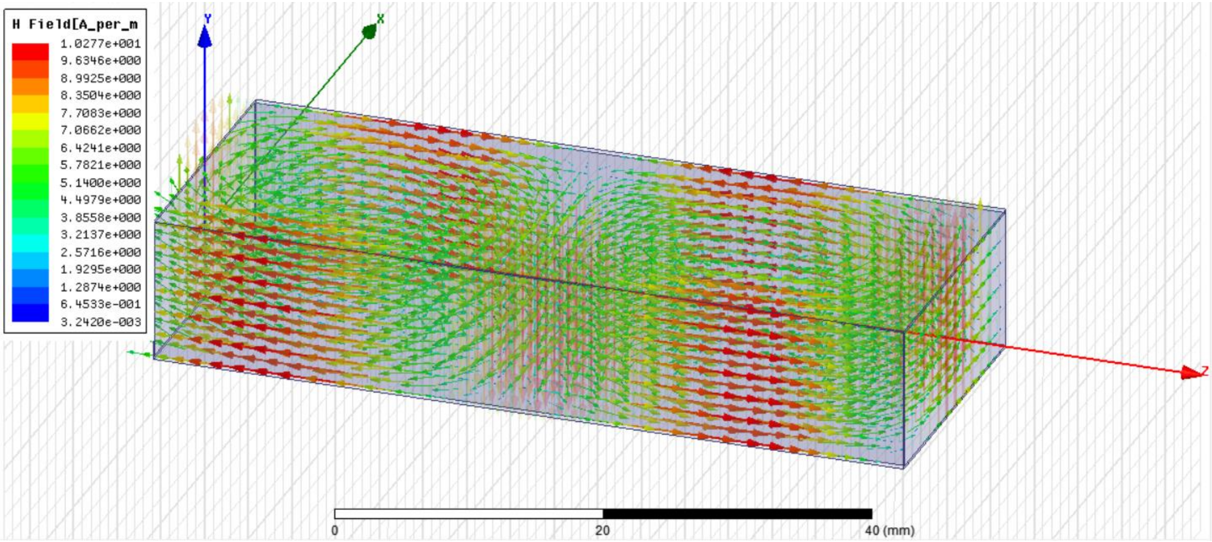

Figure 4.23 The magnetic field lines of TE10 mode for εr=4 at 4GHz

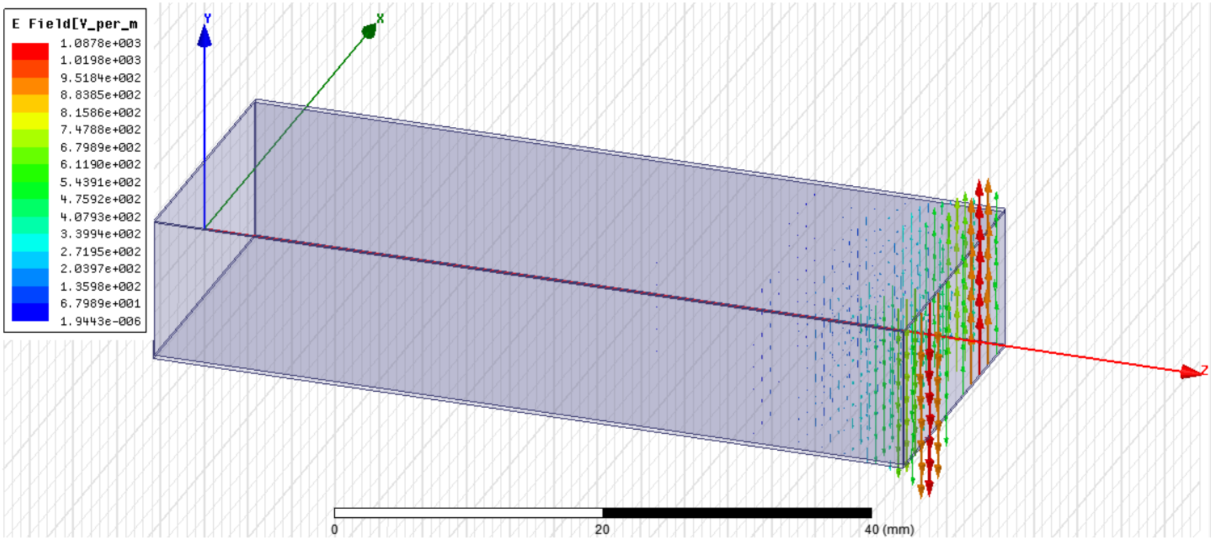

Figure 4.24 The electric field lines of TE20 mode for εr=4 at 4GHz

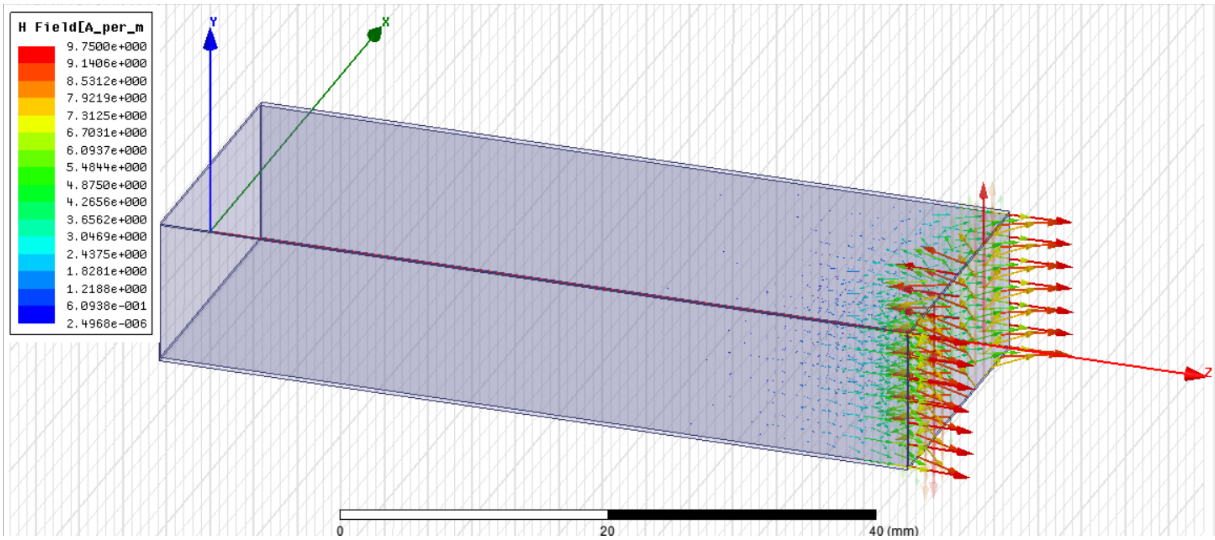

Figure 4.25 The magnetic field lines of TE20 mode for εr=4 at 4GHz

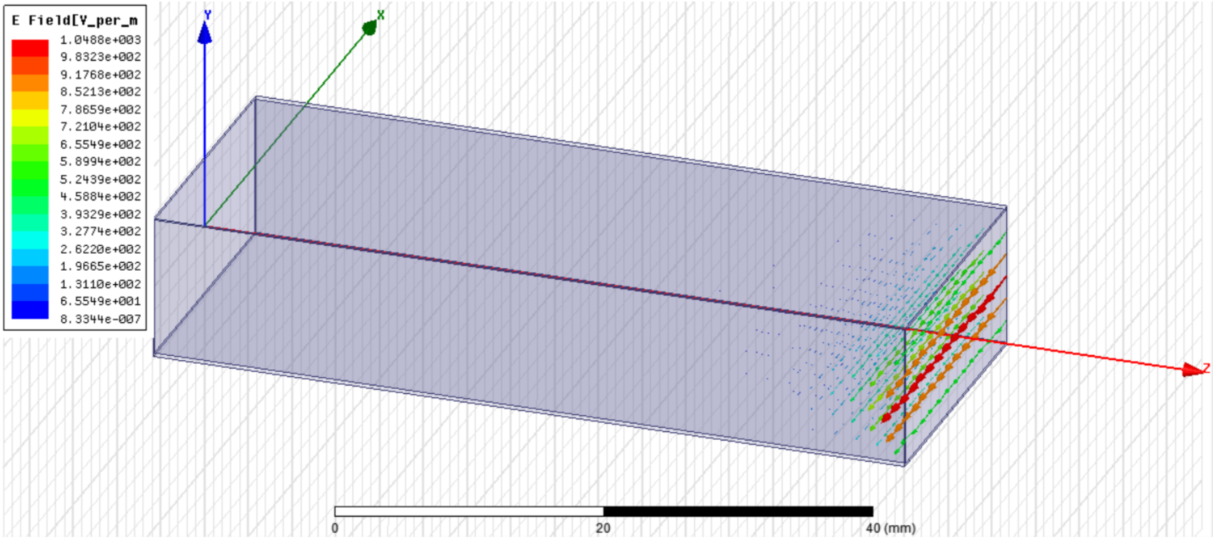

Figure 4.26 The electric field lines of TM11 mode for εr=4 at 4GHz

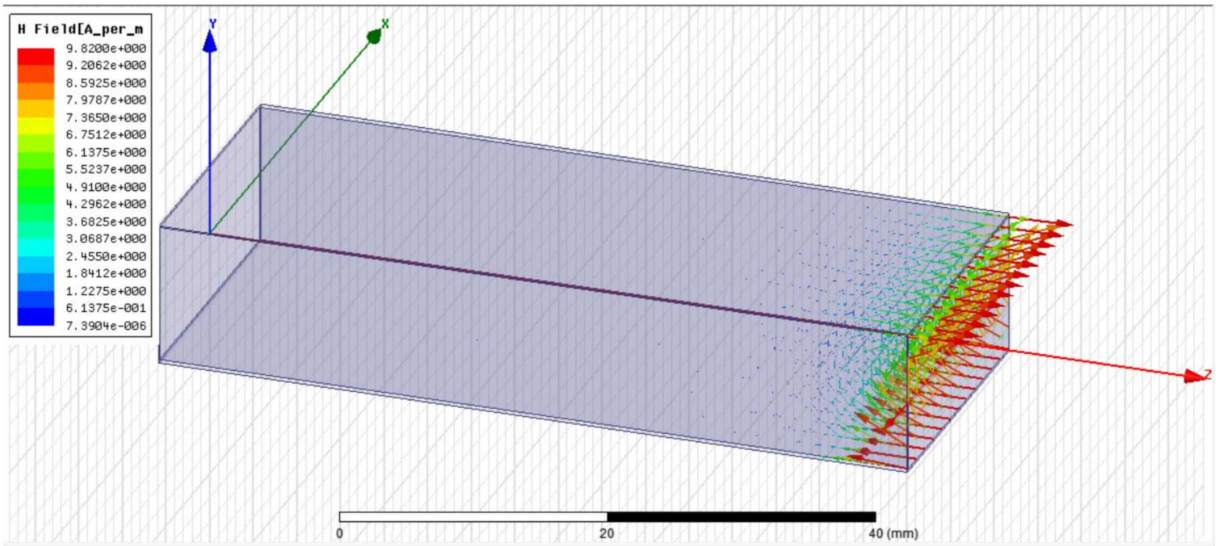

Figure 4.27 The magnetic field lines of TM11 mode for εr=4 at 4GHz

d) If the waveguide is lossy, repeat a and b.

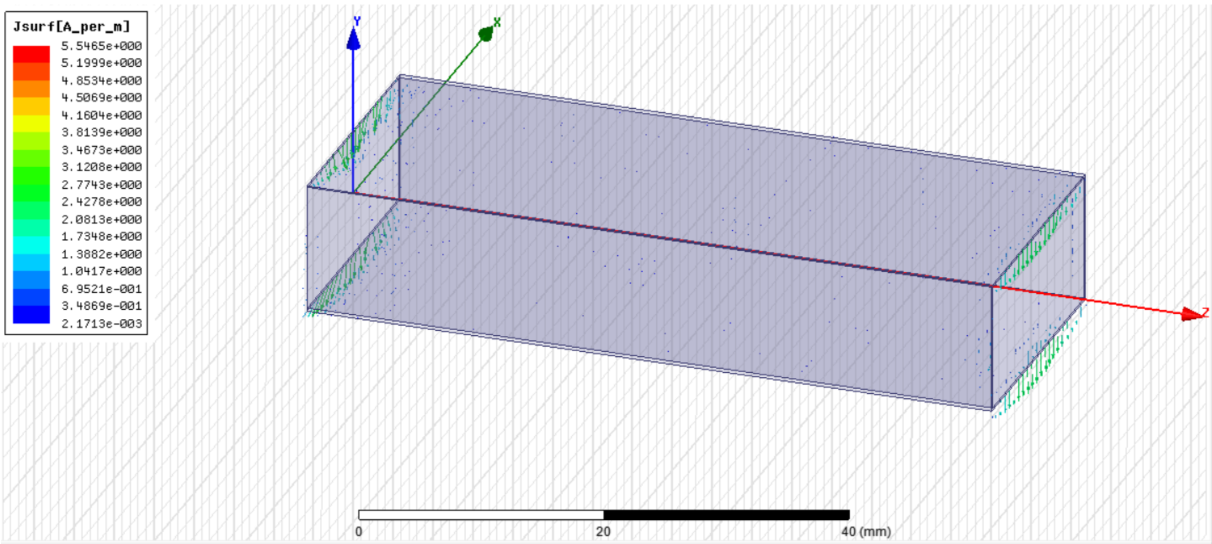

Figure 4.28 The surface current lines of TE10 mode for εr=1 at 9GHz

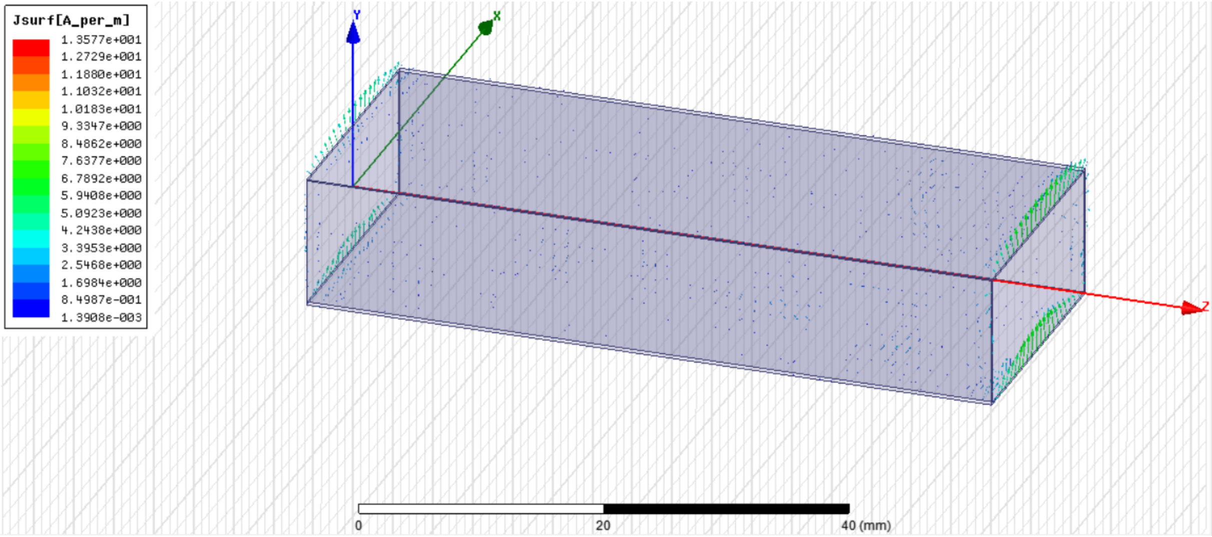

Figure 4.29 The surface current lines of TE10 mode for εr=4 at 9GHz

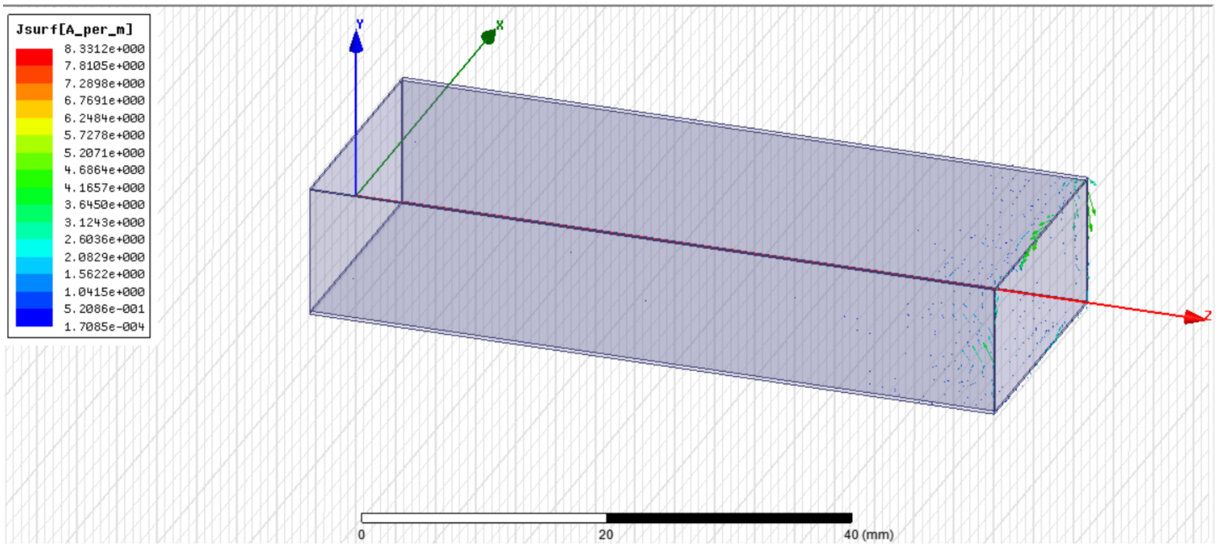

Figure 4.30 The surface current lines of TE20 mode for εr=1 at 9GHz

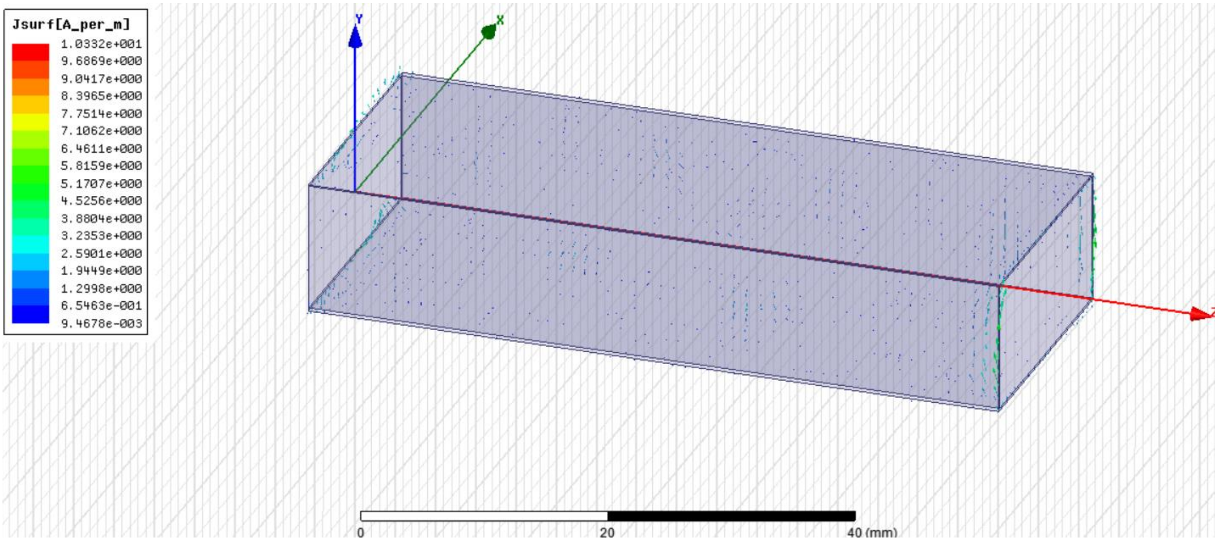

Figure 4.31 The surface current lines of TE20 mode for εr=4 at 9GHz

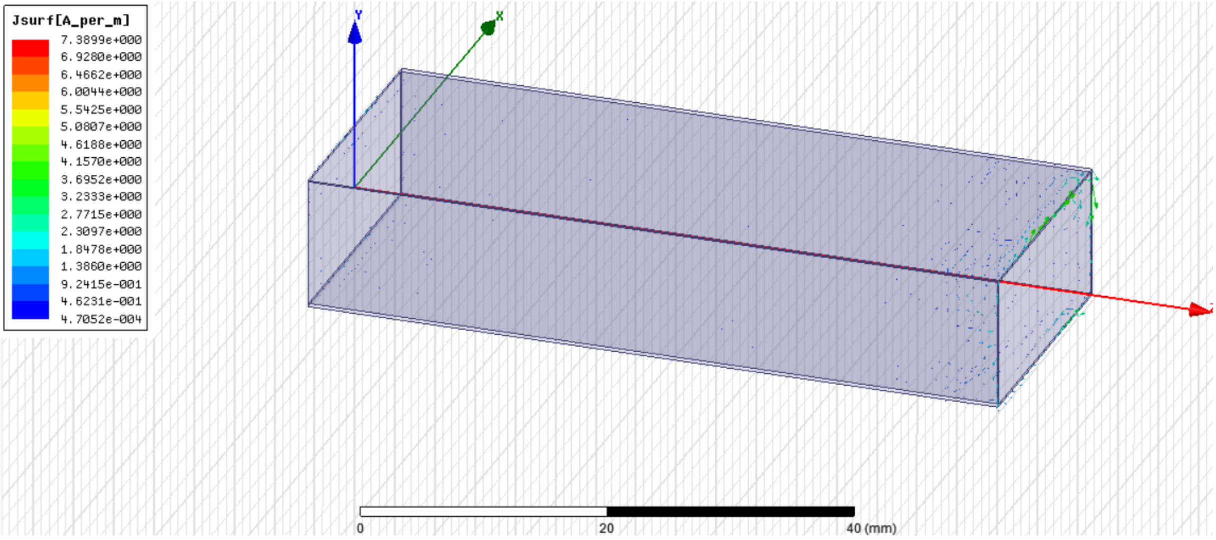

Figure 4.32 The surface current lines of TM11 mode for εr=1 at 9GHz

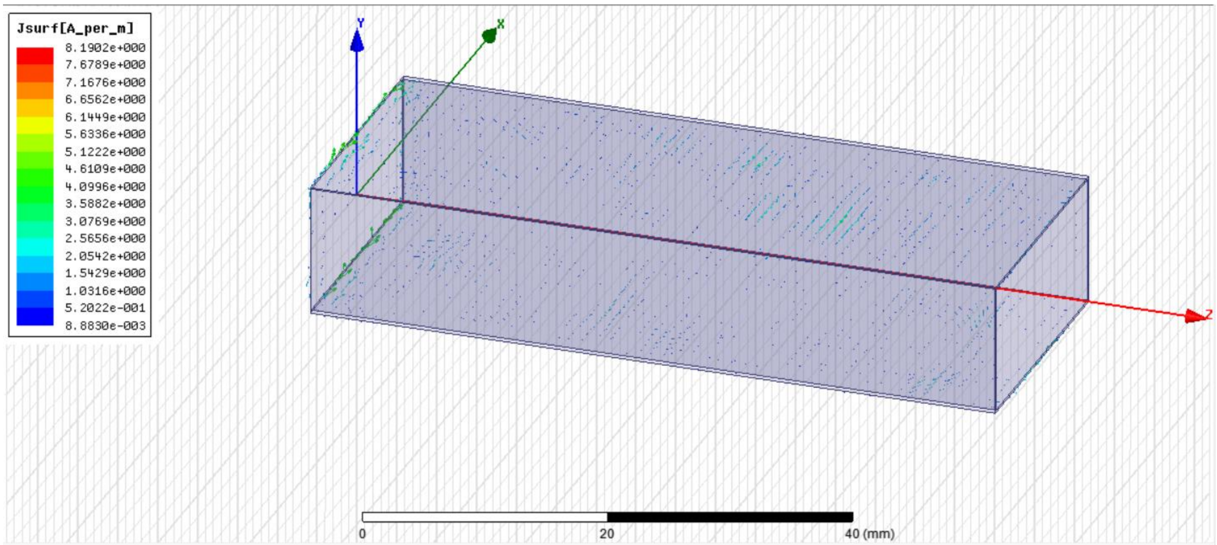

Figure 4.33 The surface current lines of TM11 mode for εr=4 at 9GHz

Electric and magnetic field lines for lossy medium

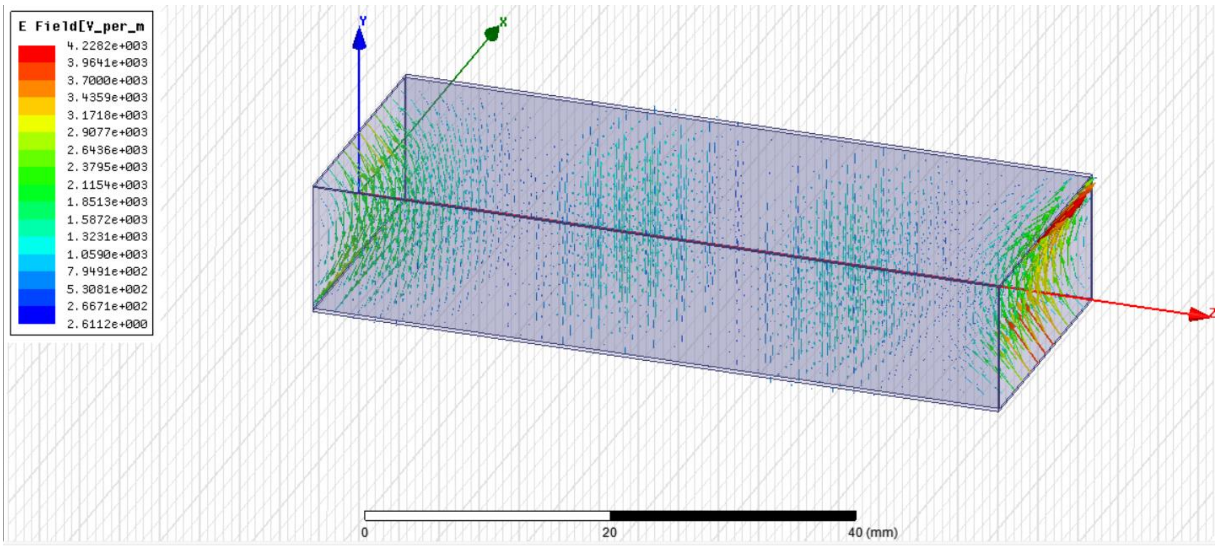

Figure 4.34 The electric field lines of TE10 mode for εr=1 at 9GHz

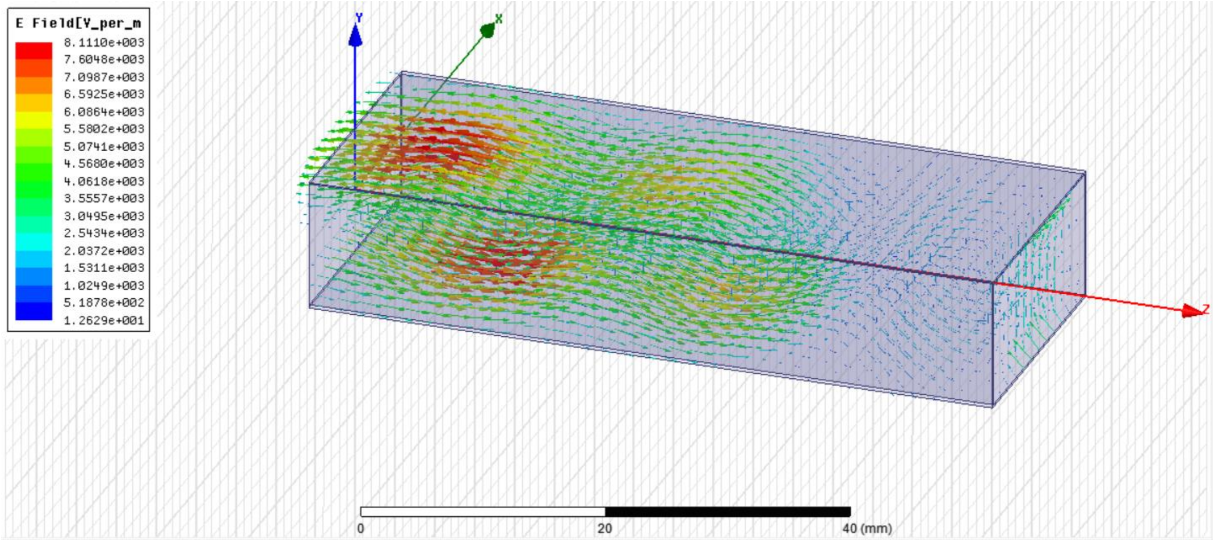

Figure 4.35 The electric field lines of TE10 mode for εr=4 at 9GHz

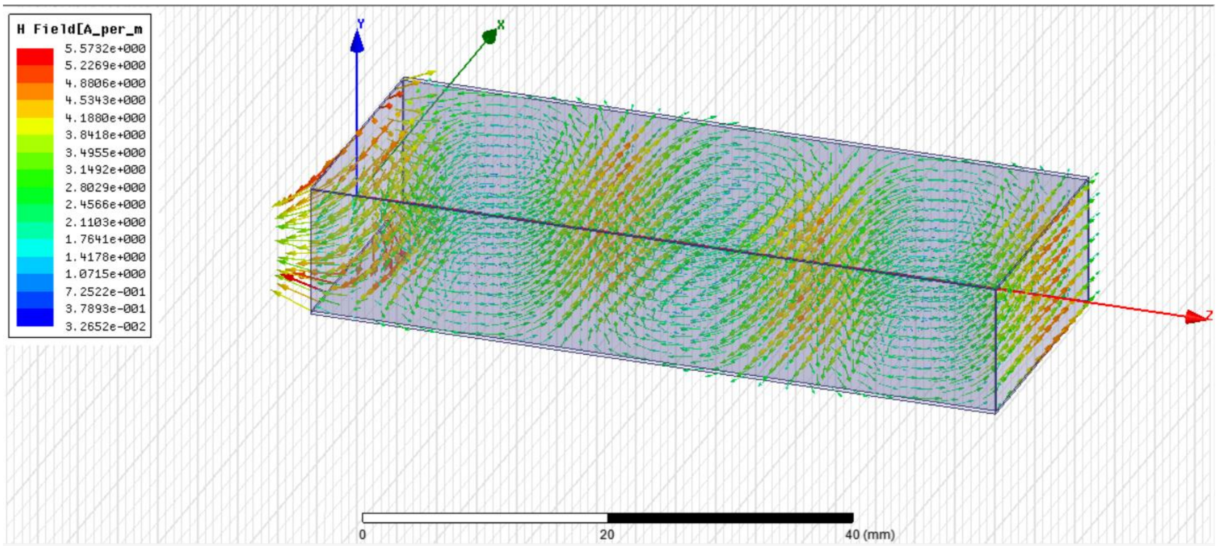

Figure 4.36 The magnetic field lines of TE10 mode for εr=1 at 9GHz

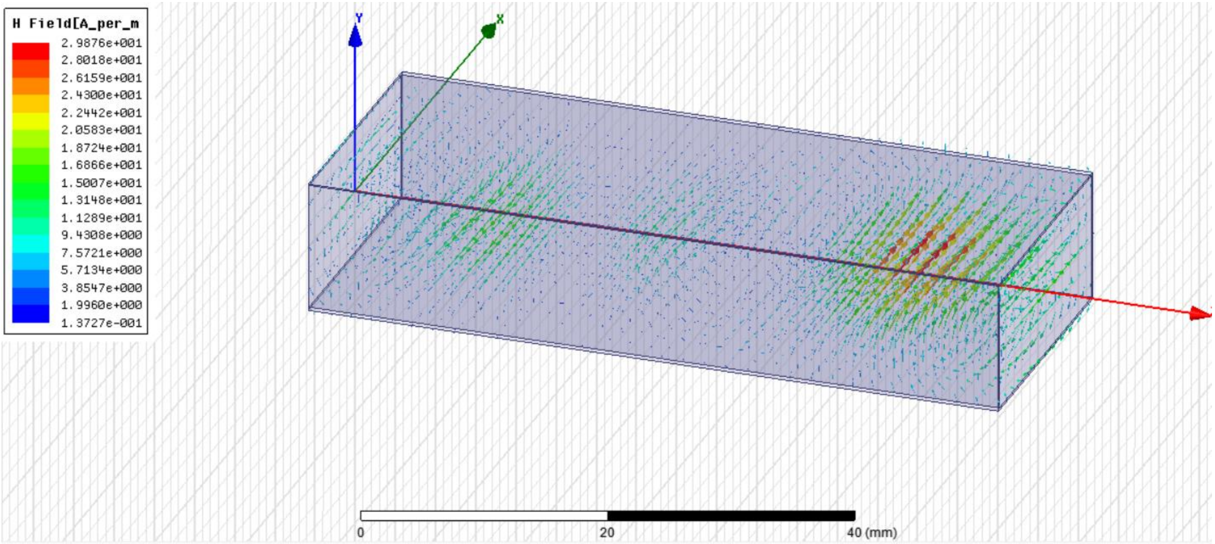

Figure 4.37 The magnetic field lines of TE10 mode for εr=4 at 9GHz

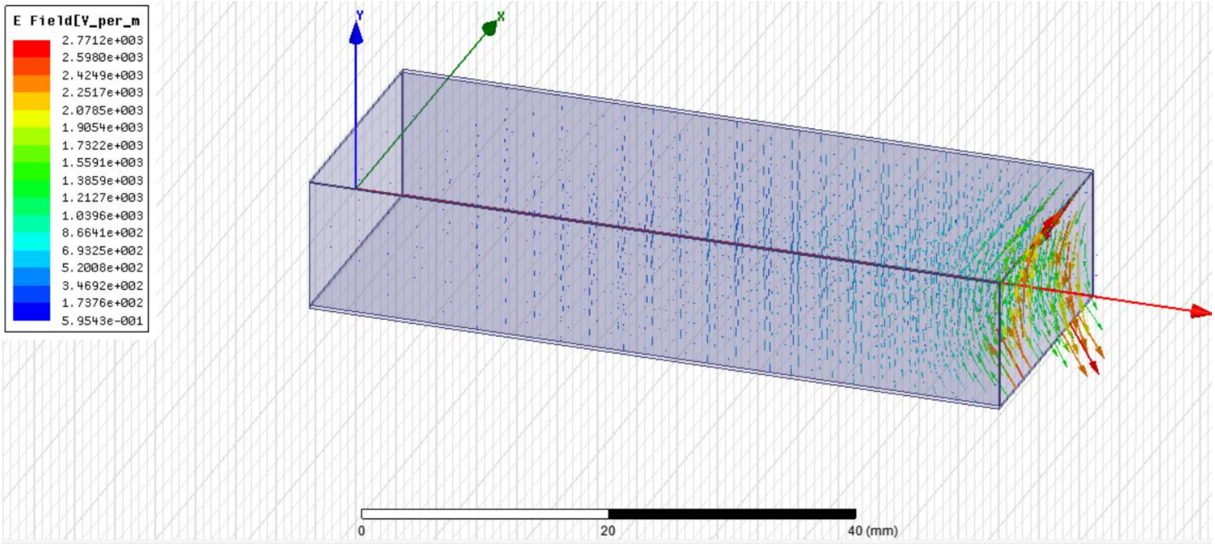

Figure 4.38 The electric field lines of TE20 mode for εr=1 at 9GHz

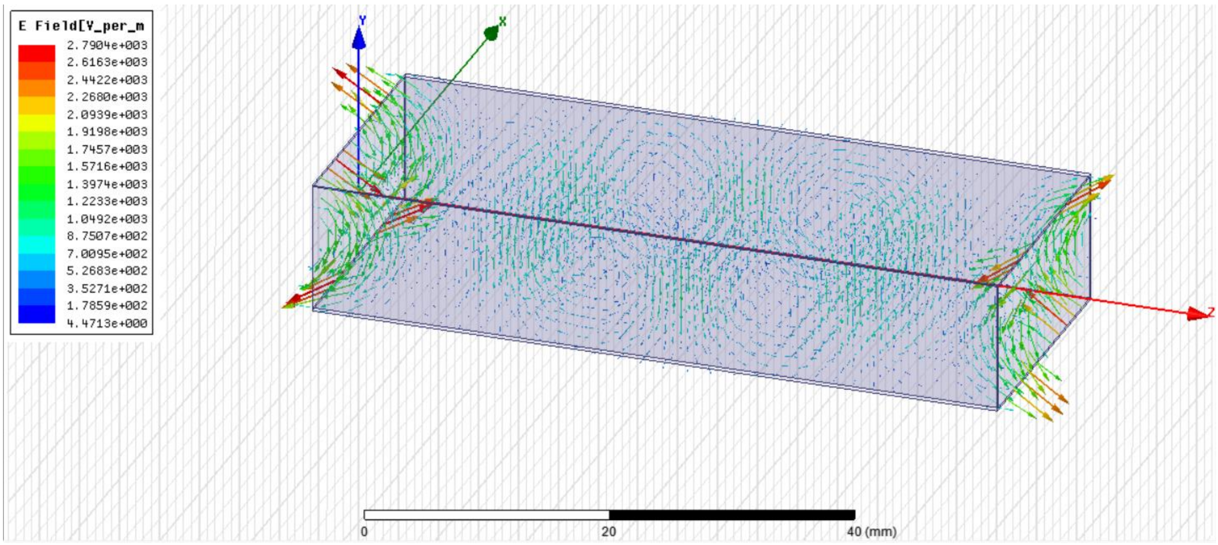

Figure 4.39 The electric field lines of TE20 mode for εr=4 at 9GHz

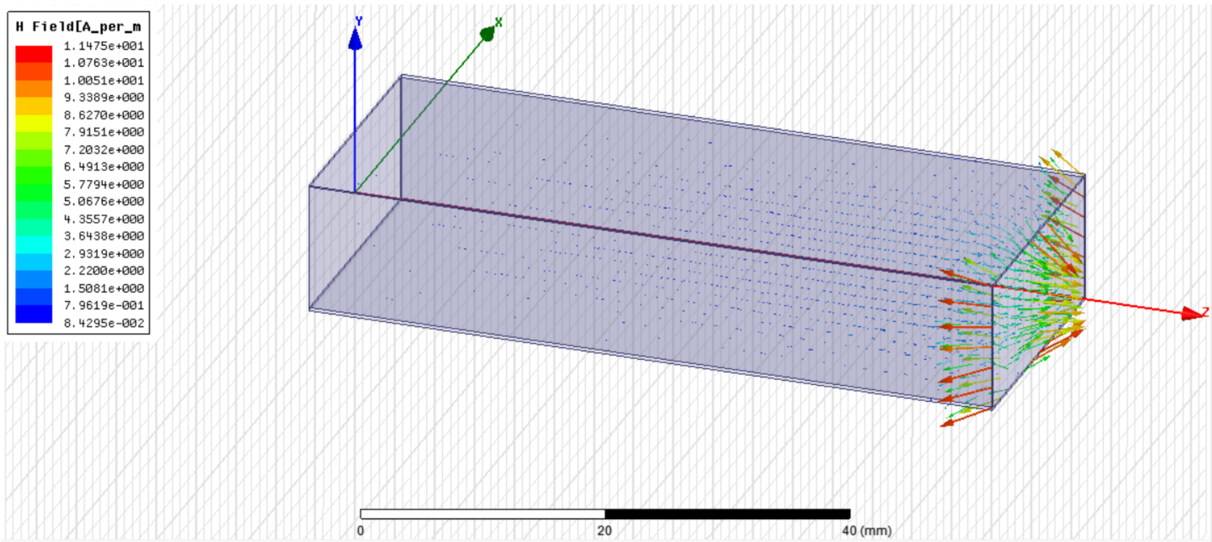

Figure 4.40 The magnetic field lines of TE20 mode for εr=1 at 9GHz

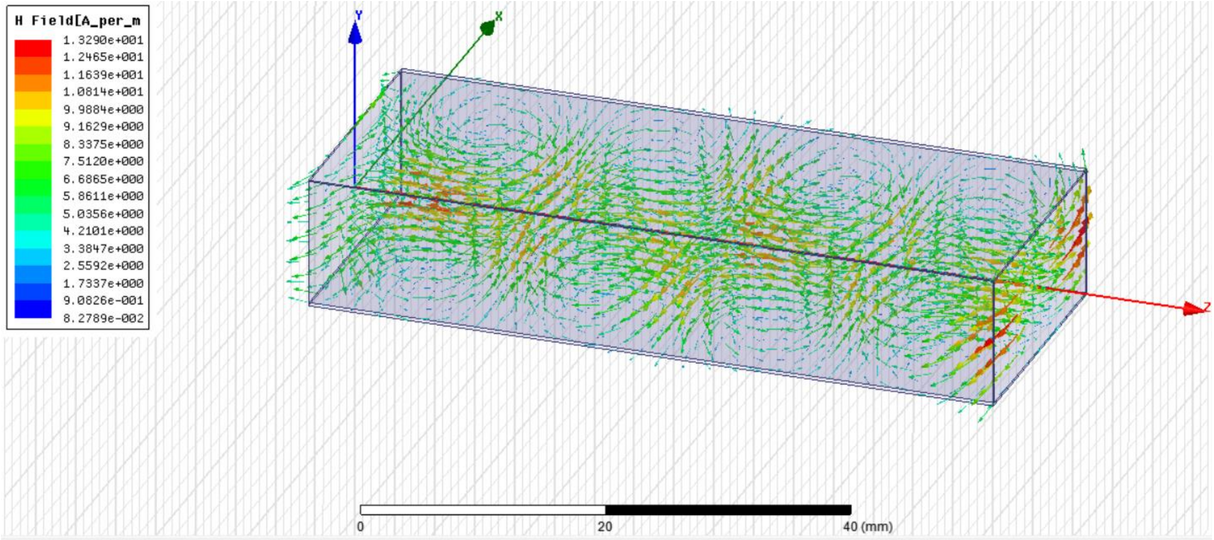

Figure 4.41 The magnetic field lines of TE20 mode for εr=4 at 9GHz

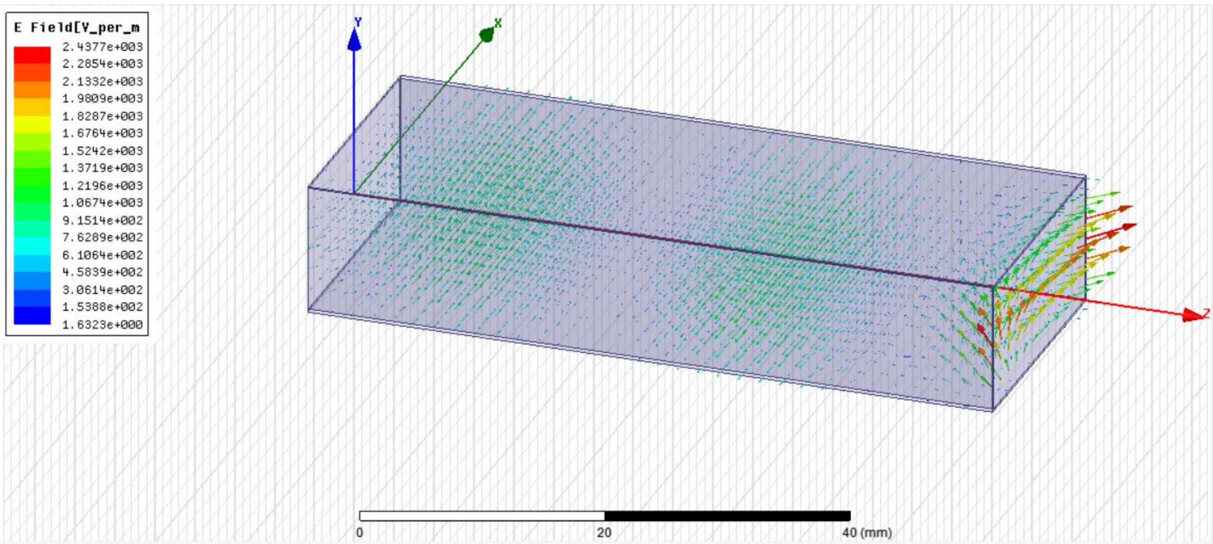

Figure 4.42 The electric field lines of TM11 mode for εr=1 at 9GHz

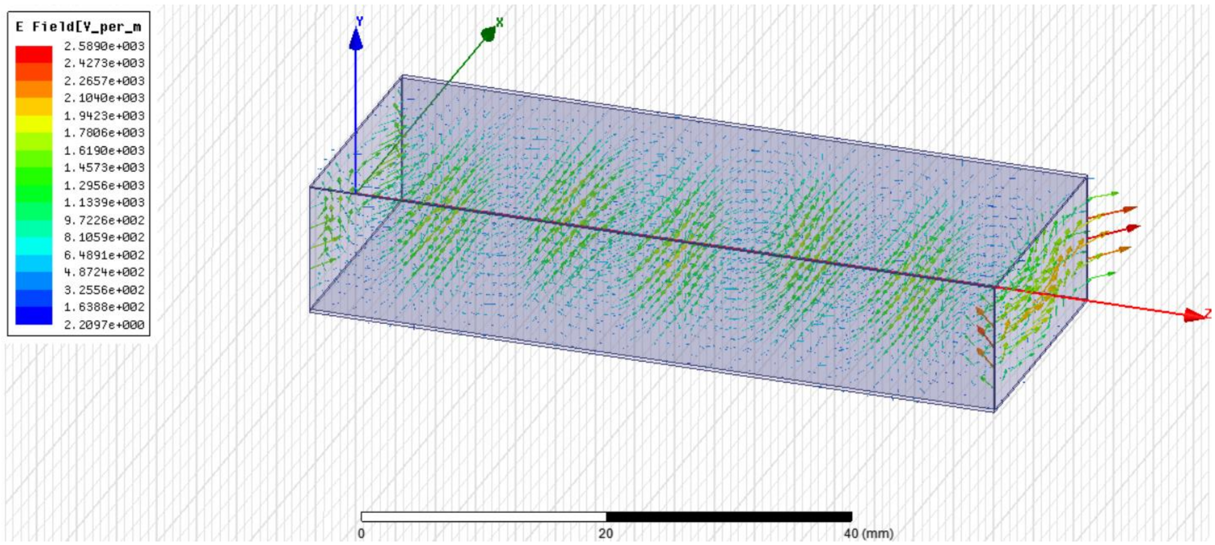

Figure 4.43 The electric field lines of TM11mode for εr=4 at 9GHz

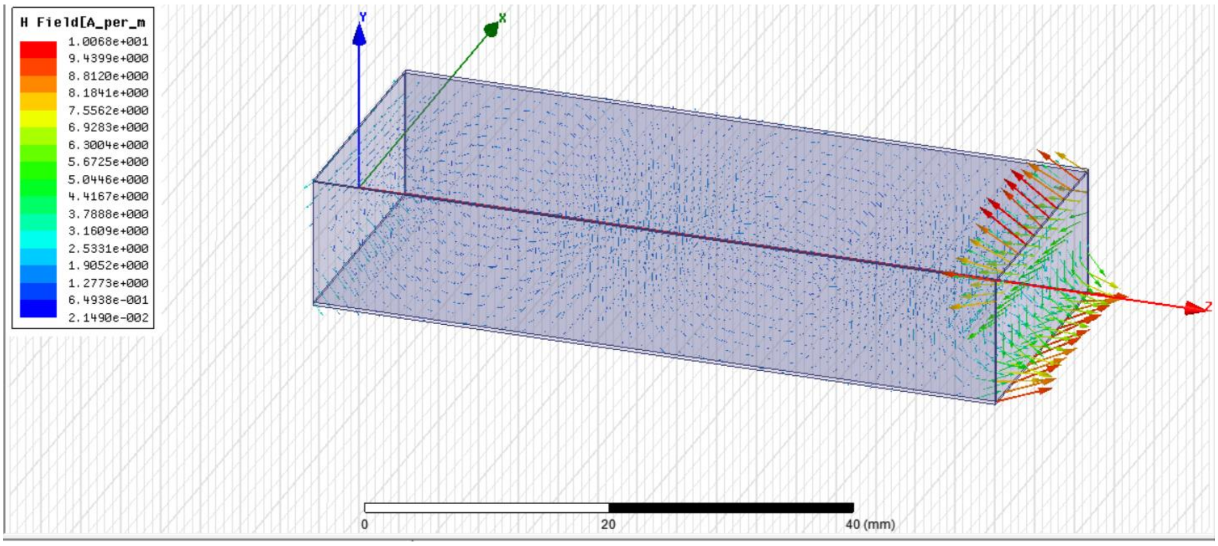

Figure 4.44 The magnetic field lines of TM11mode for εr=1 at 9GHz

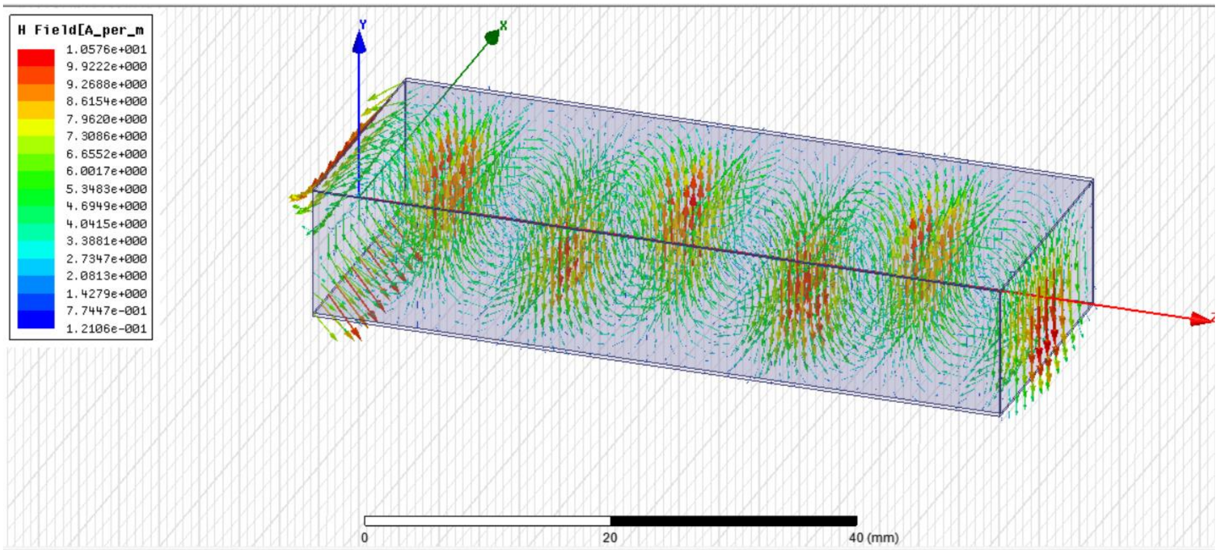

Figure 4.45 The magnetic field lines of TM11mode for εr=4 at 9GHz

On the rectengular waveguide, the transverse electric and transverse magnetic waves are propagate. The cutoff frequecy of TE and TM modes is calculated with same equation so there will be no difference between the TE and TM mode for propagation. The differences of TE and TM mode on the rectengular waveguide are the field lines of electric, magnetic and the surface current. If the cut off frequency of the TE or TM mode is smaller than the frequency of the waveguide, the waves will propagate. If it is not, there will be no propagation on the rectengular waveguide. At diffence frequency, the number of propagation modes will change. For this question, at 9GHz only the TE10 mode propagates, at 4GHz there is no propagation on the waveguide.

When the rectengular waveguide is filled with dielectiric material, for this simulation it is filled with silicon dioxide, the cutoff frequency of modes will be decreased. So at the same frequency, the more modes will propagate on the rectengular waveguide.

5. References

1) http://www.awrcorp.com/products
2) http://www.ansys.com/products/electronics/ansys-hfss
3) https://www.intechopen.com/books/electromagnetic-waves-propagation-in-complex-matter/propagation-in-lossy-rectangular-waveguides
4) https://www.youtube.com/watch?v=F6qOlGe1wrw
5) https://www.youtube.com/watch?v=ry2PImm-Be4
6) David M. Pozar, John Wiley and Sons, Inc.,USA 2005, Microwave Engineering Third Edition.