EEC133 Pre-Lab 1: Dipole Antennas and Noise

Tao Wang

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Contents

Part 1: Dipole Antenna Design

- **Operating frequency:** 1.5 GHz
- **Length:** short dipole ($l \leq \frac{\lambda}{10}$)
- **Wire radius:** 0.5mm
- **Input impedance:** no requirement

Questions:

1. $l = 20$ mm

   We can find the wavelength λ by $\lambda = \frac{c}{f} = \frac{3\times10^8\,\mathrm{m\,s^{-1}}}{1.5\times10^9\,\mathrm{Hz}} = 0.2\,\mathrm{m}$.

   The length of the dipole antenna is $l \leq \frac{\lambda}{10} = 20\,\mathrm{mm}$.

   Since the radiated power depends quadratically on l, the maximum l gives the maximum radiated power.

2. $$R_{rad} = 20\pi^2\left(\frac{l}{\lambda}\right)^2 = (20\pi^2)\left(\frac{0.02}{0.2}\right)^2 = 1.97\,\Omega$$

   $$D_0 = 1.5$$

   $$F(\theta,\phi) = \sin^2(\theta)$$

   $$\text{HPBW} = \theta_2 - \theta_1 = 0.785 - (-0.785) = 1.57$$

   $$\text{Far Field Requirement}: kr >> 1 \implies r >> \frac{\lambda}{2\pi} = 0.03\,\mathrm{m}$$

3. The normalized radiation intensity is radiation intensity of all direction normalized by the maximum radiation intensity.

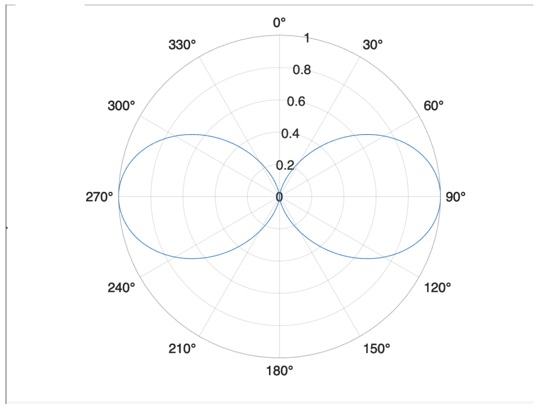

Figure 1: Normalized Radiation Intensity of the Dipole Antenna

4. HFSS Simulation

   (a) Dipole Antenna Model

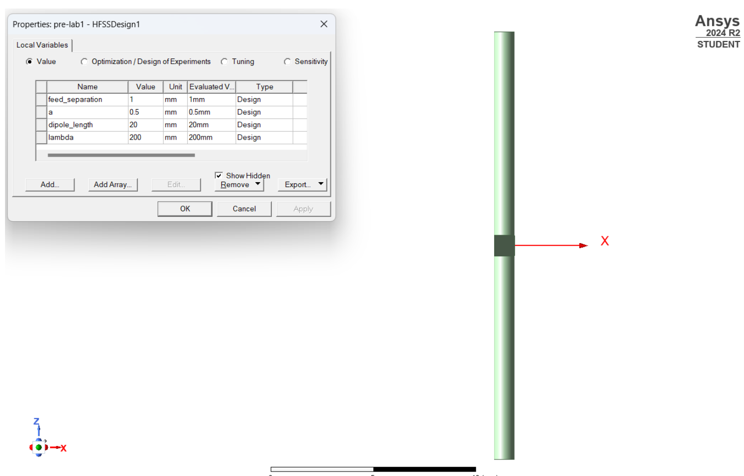

Figure 2: Dipole Antenna Model

   (b) S-Parameter The S-Parameter frequency sweep plot shows that as the frequency increases, less of the input wave is reflected back.

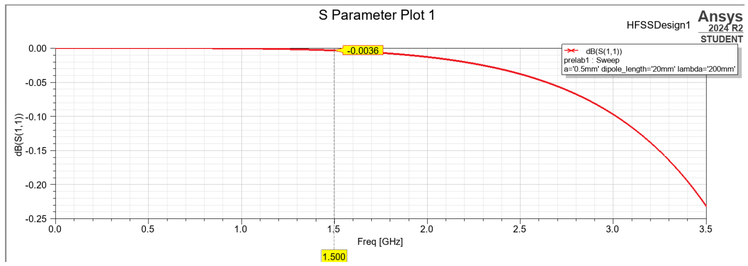

Figure 3: S-Parameter Frequency Sweep

(c) 3D Directivity Pattern

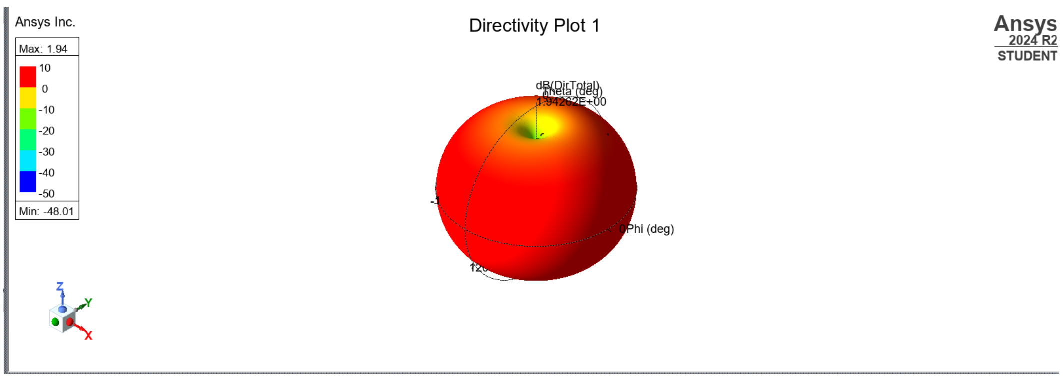

Figure 4: 3D Directivity Pattern

(d) Input impedance

$$Z_{in} = 1.81 - j658.82$$

The real part of the z parameter is less than the radiation resistance calculated in (2). The reactance make sense because the dipole antenna is geometrically similar to a capacitor. As a result, it has high reactance at low frequency, and low reactance at high frequency.

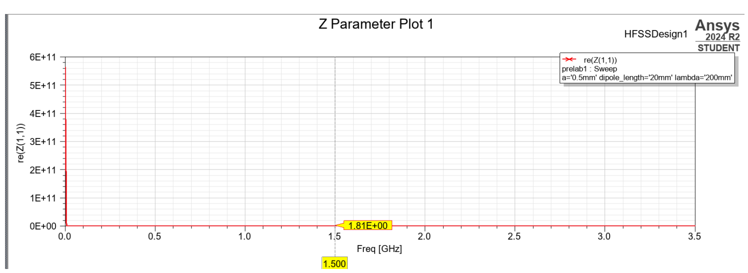

Figure 5: $re(Z(1,1))$

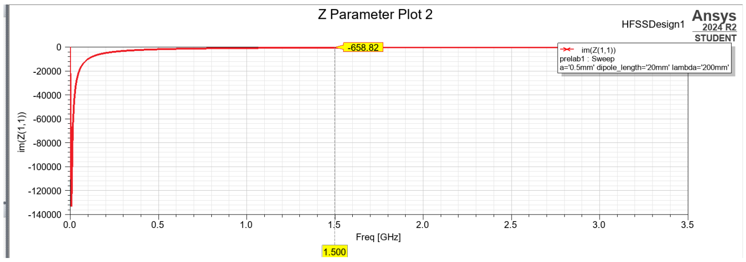

Figure 6: $im(Z(1,1))$

(e) The Electric Field

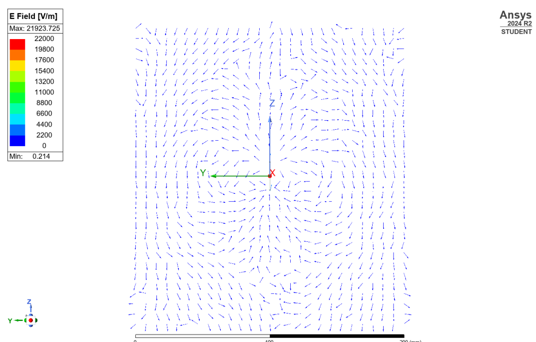

Figure 7: $\vec{E}$ Field

(f) The Magnetic Field

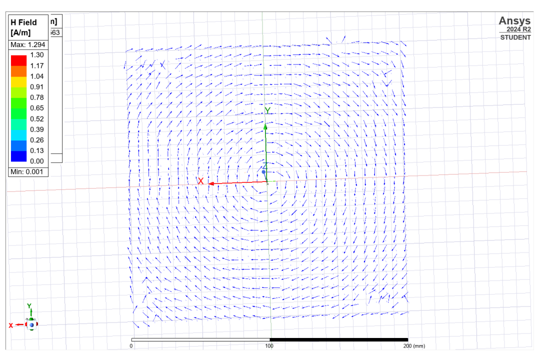

Figure 8: $\vec{H}$ Field

(g) The antenna is not a good transmitter because R_{rad} is small, so it's hard to match its impedance and reduce reflected power. Moreover, most of the power sent to the antenna will get reflected because of the large S-parameter.

Part 2: Basic Noise Calculations

1. Approximate Noise Level = $-102\,\mathrm{dBm}$

2. $$P_n = \left(1.38 \times 10^{-23}\frac{\mathrm{J}}{\mathrm{K}}\right)(298.15\mathrm{K})(1 \times 10^6\mathrm{Hz}) = 4.1 \times 10^{-15}\mathrm{W}$$

   $$\text{Expected Noise Level} = 10\log\left(\frac{P_{in}}{10^{-3}}\right) = -113.9\ \mathrm{dBm}$$

3. $$P = (1\ \mathrm{mW})\left(10^{\frac{-102\mathrm{dBm}}{10\mathrm{dBm}}}\right) = 6.3 \times 10^{-14}\mathrm{W}$$

4. In both cases, spikes could be observed in the 2.4 - 2.4 GHz range. However, the spikes are bigger when the antenna is attached. These spikes are from the bluetooth signals.

5. Yes, the electric field from the bluetooth wave induces current oscillations in the transmission line. The time-varying current carries AC power, which is plotted on the network analyzer. When the transmission line is opened at the end, the impedance is purely reactive, thus no power is dissipated. Therefore, no power is detected in the analyzer except those from the resistor's thermal noise. As a result, we only see a weak signal because it's only caused by the thermal noise.

EEC133 Lab 1 Report

Josias Moreno Ixta, Michael Chen, Tao Wang, Xaviera Azodoh

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Contents

Part 1 Antenna Construction

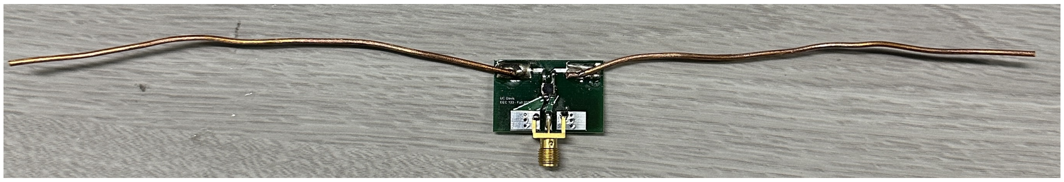

Figure 1: Dipole Antenna

Part 2 Basic VNA Measurements

Step 1

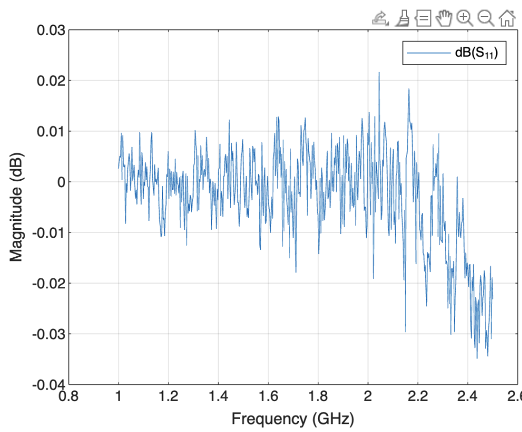

Figure 2: S_{11} of Unterminated Cable

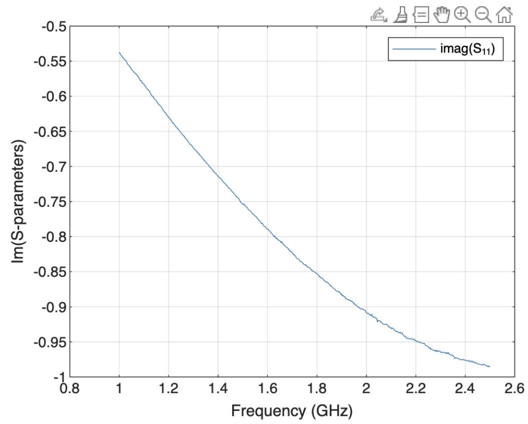

Figure 3: Imaginary S_{11} of Unterminated Cable

Step 2

Cable Length: 25 inches long

Short Circuit S-Parameter

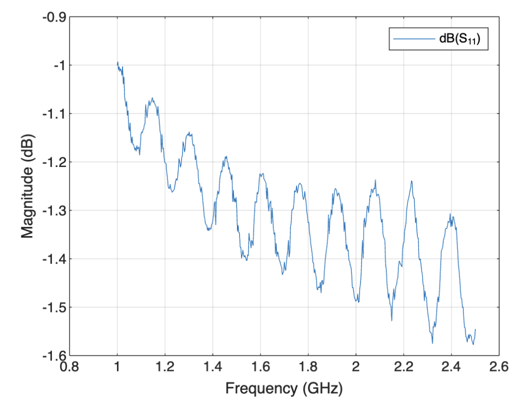

Figure 4: S_{11} in a Short Circuit Transmission Line

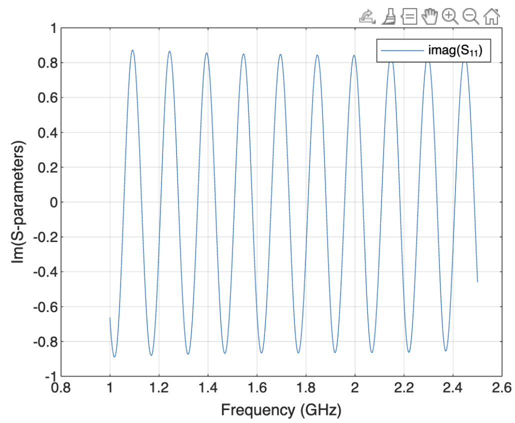

Figure 5: Reactance of S_{11} in a Short Circuit Transmission Line

Open Circuit S-Parameter

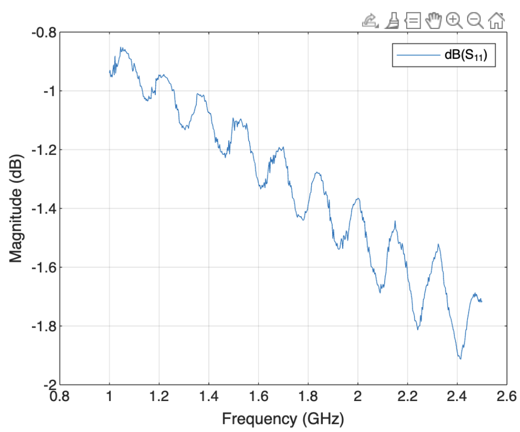

Figure 6: S_{11} in a Open Circuit Transmission Line

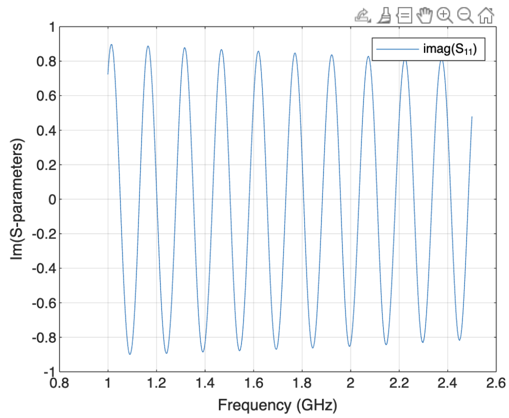

Figure 7: Reactance of S_{11} in a Open Circuit Transmission Line

50Ω **Load Transmission Line S-Parameter**

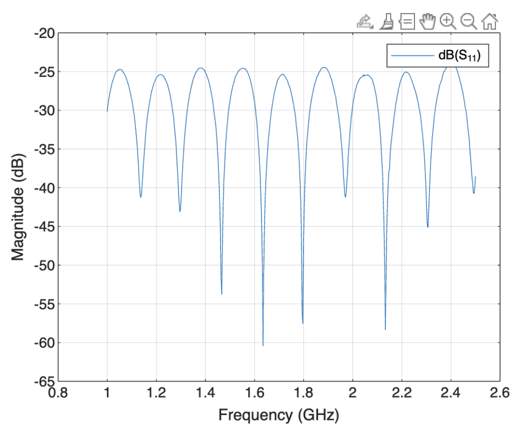

Figure 8: S_{11} in a 50Ω Load Transmission Line

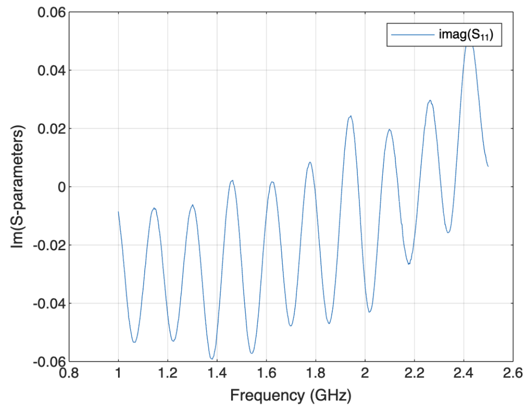

Figure 9: Reactance of S_{11} in a 50Ω Load Circuit Transmission Line

Part 3 Antenna Measurements

Step 1

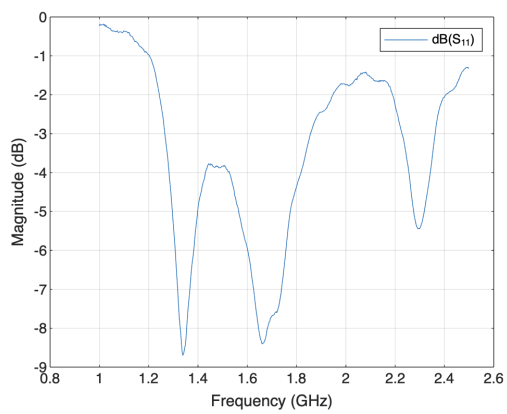

Figure 10: Dipole Antenna's S_{11} Magnitude

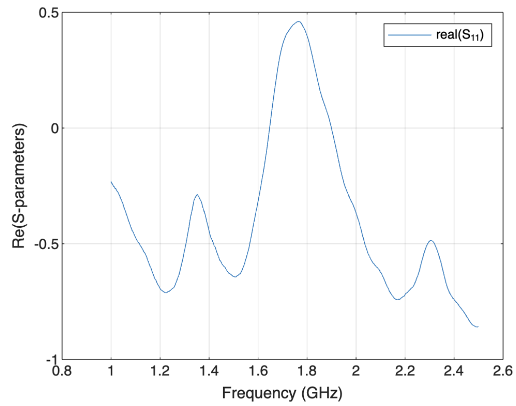

Figure 11: Dipole Antenna's Real Part of S_{11}

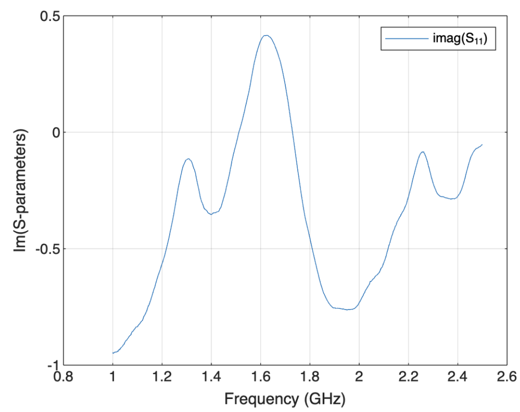

Figure 12: Dipole Antenna's Imaginary Part of S_{11}

Step 2

Distance between the two antennas: 10 feet.

Angle (degrees)	S_{21} **(dB)**
0	-48.0
10	-53.0
20	-50.0
30	-54.8
40	-53.0
50	-45.0
60	-45.04
70	-48.0
80	-54.0
90	-64.0
100	-55.0
110	-47.0
120	-44.0
130	-44.0
140	-44.6
150	-45.6
160	-48.0
170	-50.0
180	-56.0

Table 1: S_{21} when Dipole Antenna Faces Different Angle

Step 3

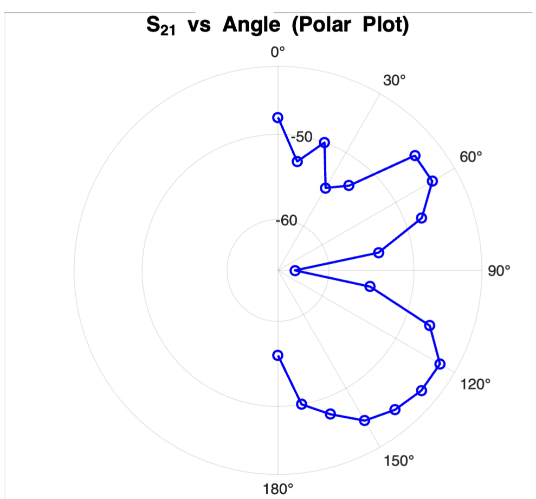

Figure 13: S_{21} when Dipole Antenna Faces Different Angle

Step 4

$S_{21} = -64$ dB at 180 deg and vertical to the floor.

Part 4 Post Lab Questions

Q1

(a) The measurement of the unterminated transmission line matches with the theory. The S_{11} parameter is close to 0 dB, which means all input wave was reflected.

(b) See the plots from Figure 4 to Figure 9. We expect from the transmission line theory that the open and short terminal will reflect the wave entirely, but the 50Ω matched end will allow waves to transmit.

The measurement result largely agrees with the theory. The short and open circuit transmission line has a larger S_{11}, which means most waves were reflected. Furthermore, their imaginary part of S_{11} is out of phase by 180 degrees because their reflection coefficients are 1 and -1.

The matched load measurement results also aligned with the theory. The S_{11} was very small, which means most waves were transmitted.

Q2

The balun ensures a differential signal passes into two ends of the antenna. A signal with near-perfect opposite polarity is important for a dipole antenna because we assumed the signal is symmetrical.

Q3

1. We measured the dipole antenna to have a length of 0.3 meters.
2. Since the PCB board has a relative permittivity of $\epsilon_r \approx 3.2$, the ratio between the dipole length and the wavelength is $\frac{l}{\lambda} = \frac{l\sqrt{\epsilon_r}}{\lambda_0}$, so we have the effective length as 0.54 meters.

Q4

See plots from Figure 10 to Figure 12 for the return loss. The following table shows the fraction of wavelength the dipole is at different resonant frequency

Frequency (GHz)	Fraction of Wavelength ($\frac{l}{\lambda}$)
1.34	2.41
1.66	2.99
2.29	4.12

Table 2: Dipole Length Fraction at Different Frequency

The result shows that the S_{11} parameter is at the lowest when the dipole length is 1.34 times the wavelength. At this dipole length, the least amount of wave got reflected from the antenna. The length, 0.54 m was used in the calculation because it accounts for the wavelength of the EM wave in different material. This is a more accurate approximation of the dipole length to wavelength ratio.

Q5

We used the following formula to turn the real and imaginary part of the S parameter into the complex input impedance.

$$Z_{in} = Z_0 \left(\frac{1+S_{11}}{1-S_{11}} \right), \text{ where } Z_0 = 50\Omega$$

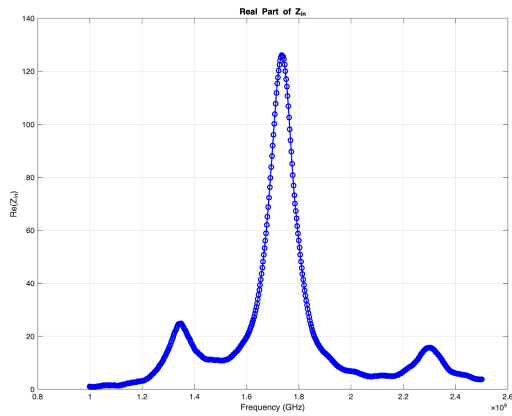

Figure 14: Real Part of Input Impedance

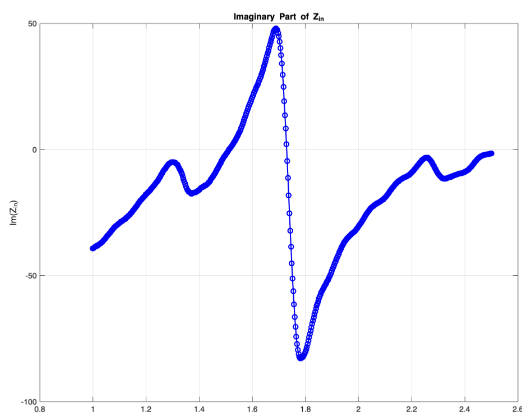

Figure 15: Imaginary Part of Input Impedance

The imaginary part of the input impedance has a similar shape to calculations from the lecture. However, the real part is different from calculations in class. We expected it to be proportional to $\frac{1}{\sin^2(x)}$, but it only has one peak at the resonant frequency.

Q6

See Figure 13 for the radiation plot. The results don't make sense because the minimum wave transmission occurs when the dipole antenna directly faces the reference antenna (90 deg). However, we expected this to be where the maximum transmission occurs because the distance between the two antennas is the closest at that 90 deg angle. The calculation in class shows that the directivity pattern is $1.5\sin^2(\theta)$. Based on this calculation, we would expect the transmission to be more consistent across different angles because the radiation doesn't depend on which angle the dipole antenna faces.

Q7

For step 3, S_{21} is the smallest at 90 deg when the dipole antenna faces the reference antenna directly. This is contrary to the belief that the maximum transmission will occur when the two antennas directly face each other. This could imply that the electric field polarization of the transmitter and receiver antenna are different. As a result, we expect that if we rotate the dipole antenna by 90 deg, S_{22} will be larger. However, the measured data in step 4 shows that S_{22} decreased relative to that of the not rotated dipole antenna. The result deviates from the expectation because we were next to metallic objects, which reflect EM waves. Also, we carried cell phones and electronic devices near the experiment, which changed the electric field originally radiated from the dipole antenna.