

# ECEN5134 Homework 8

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## 1 Problem 1

In this part of the assignment, we are asked to compare the H-plane radiation patterns of circular loop antennas of radii  $0.1\lambda$ ,  $0.5\lambda$  and  $1\lambda$  in FEKO and the patterns generated using the equation on slide 17. Using the given equations, we generate the patterns using MATLAB. For simplicity, we set the simulation frequency to  $300MHz$ , resulting in  $\lambda = 1$ . Thus, the radii of each loop are 0.1, 0.5 and 1.

The normalized radiation patterns from MATLAB match those of FEKO, but only if the loop in the simulation setup has multiple power sources as shown in the following image.

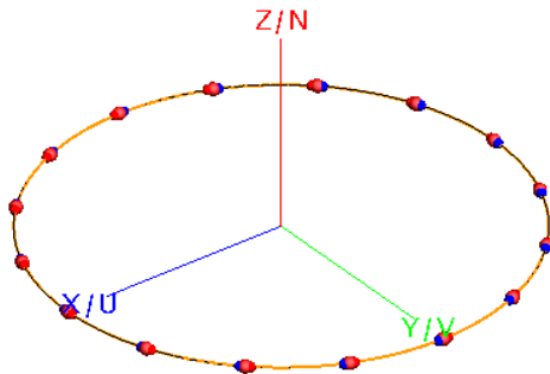
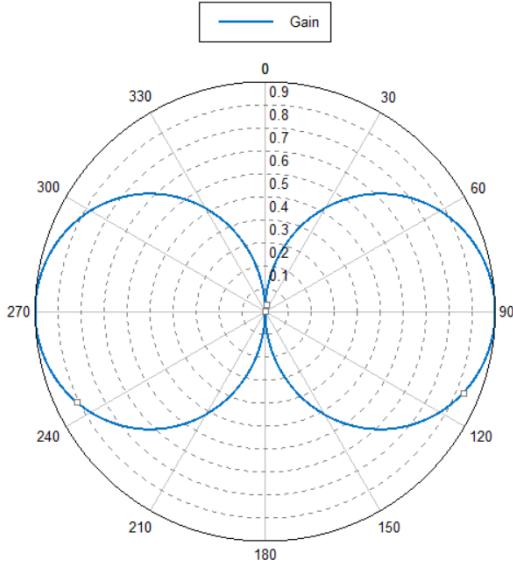
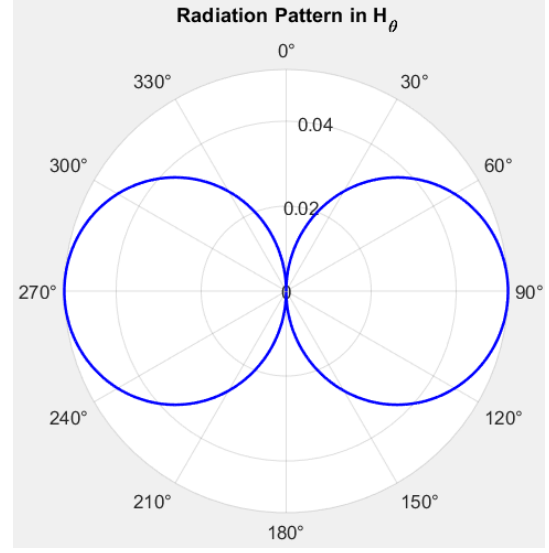


Figure 1: Loop in FEKO with 16 voltage sources.

With multiple sources, the radiation patterns of the three loops are compared in FEKO and MATLAB as shown in the images below.

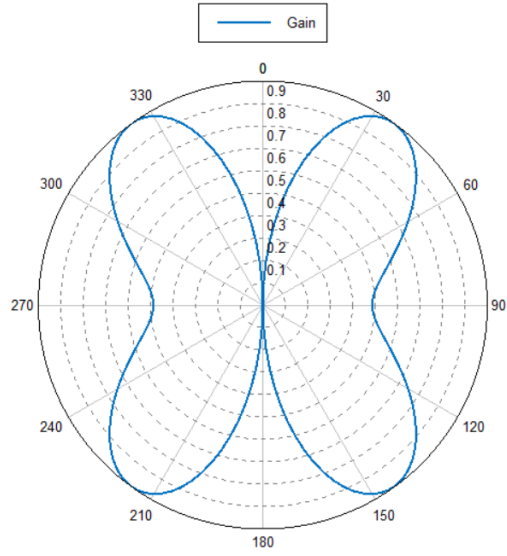


(a) FEKO radiation pattern

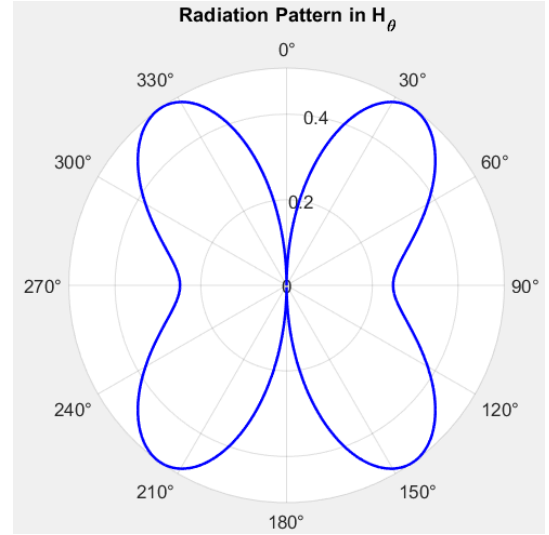


(b) MATLAB radiation pattern

Figure 2: Radiation patterns in the H-field for circular loop of radius  $0.1\lambda$ .

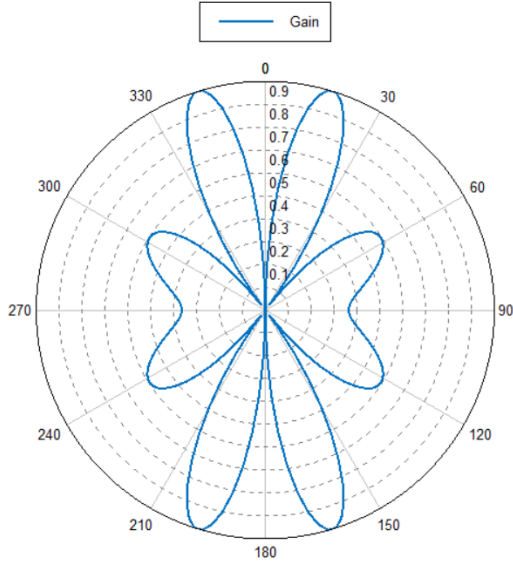


(a) FEKO radiation pattern

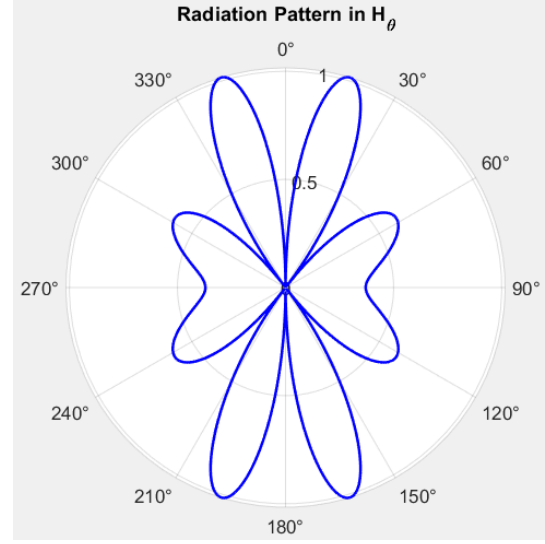


(b) MATLAB radiation pattern

Figure 3: Radiation patterns in the H-field for circular loop of radius  $0.5\lambda$ .



(a) FEKO radiation pattern



(b) MATLAB radiation pattern

Figure 4: Radiation patterns in the H-field for circular loop of radius  $1\lambda$ .

As we can observe from the above images, with multiple sources around the loop, the radiation patterns from both FEKO and MATLAB are identical. A reason for this, is that when multiple sources are placed around the loop, the current distribution in the loop is more uniformly distributed. The H-field formula given in slide 17 is derived with the assumption that the current throughout the loop is uniform. This explains why the radiation patterns from FEKO and MATLAB match.

This, however, is not the case when there is only one voltage source or feed point on the loop, as we can observe from the following images. The single feed point on the loop is placed at position  $\phi = 0^\circ$  and  $\theta = 90^\circ$ .

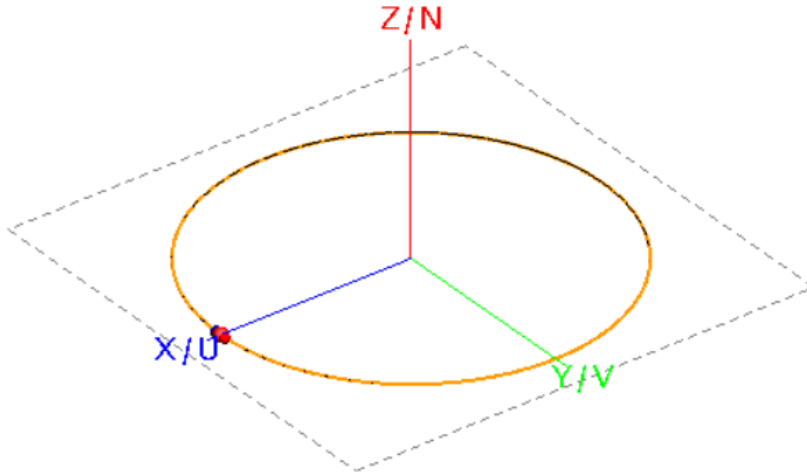
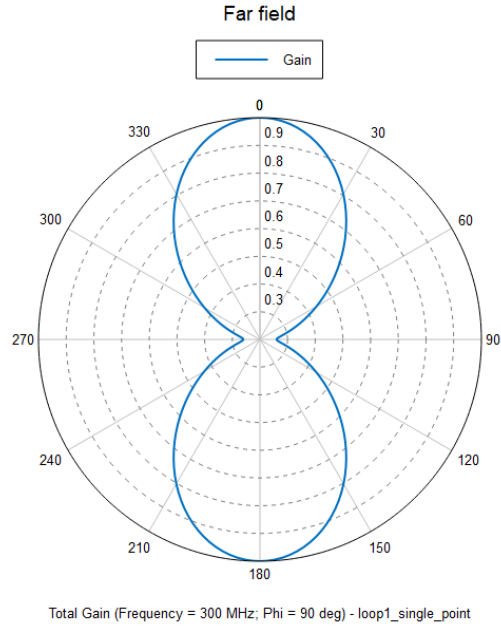
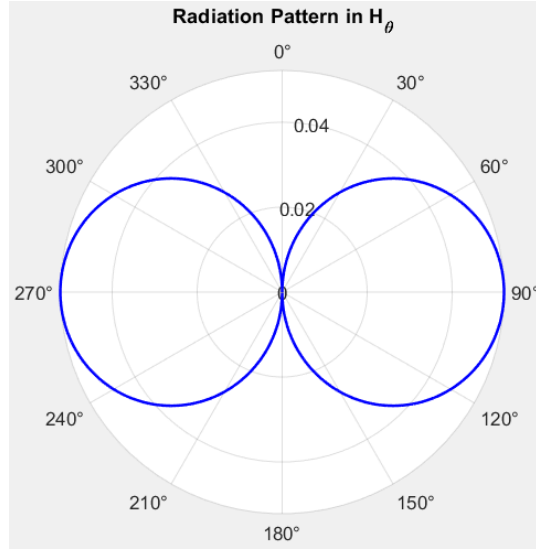


Figure 5: Loop in FEKO with a single feed point.

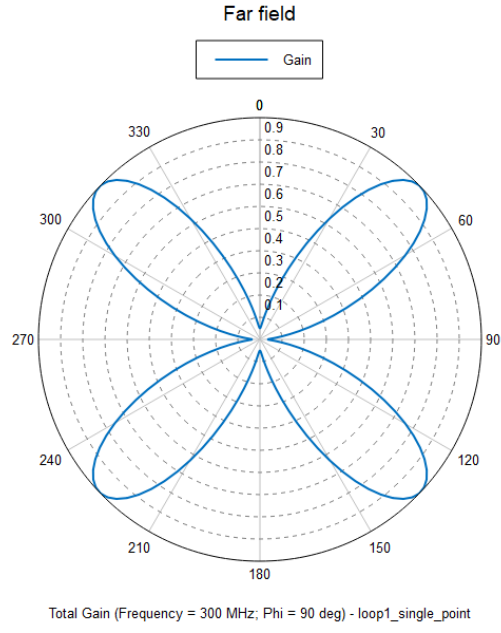


(a) FEKO radiation pattern at  $\phi = 0^\circ$  cut.

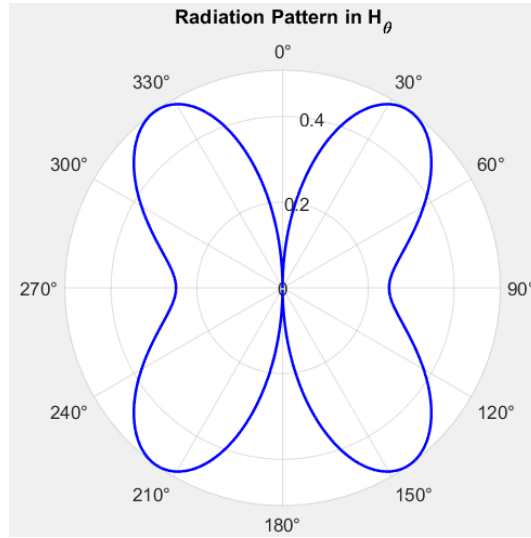


(b) MATLAB radiation pattern

Figure 6: Radiation patterns in the H-field for circular loop of radius  $0.1\lambda$  with single feed point.

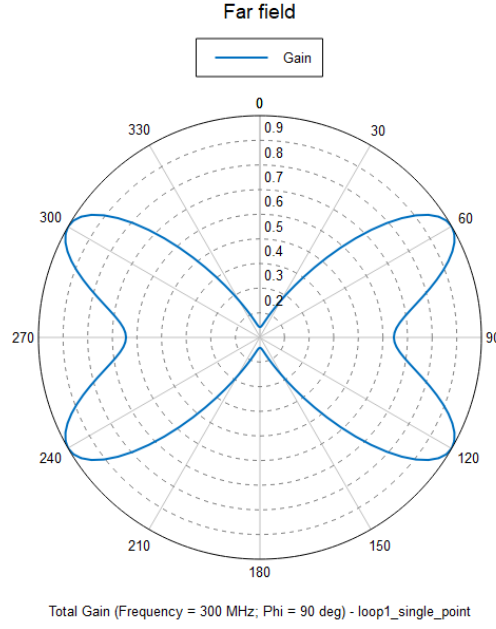


(a) FEKO radiation pattern at  $\phi = 0^\circ$  cut.

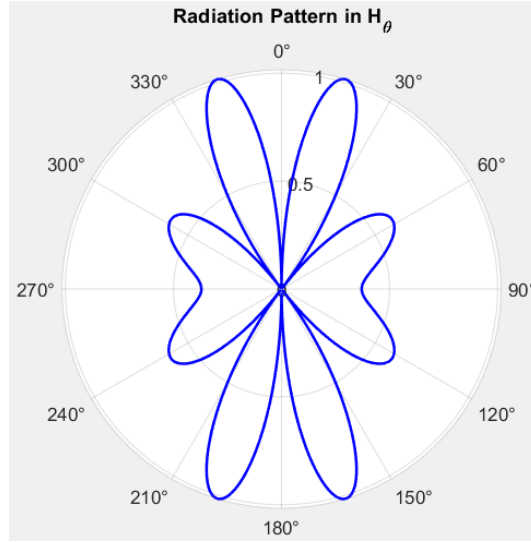


(b) MATLAB radiation pattern

Figure 7: Radiation patterns in the H-field for circular loop of radius  $0.5\lambda$  with single feed point.



(a) FEKO radiation pattern at  $\phi = 0^\circ$  cut.



(b) MATLAB radiation pattern

Figure 8: Radiation patterns in the H-field for circular loop of radius  $1\lambda$  with single feed point.

From what can see in the above images, when there is a single feed-point in FEKO, the simulated radiation patterns are widely different from the ones computed in MATLAB. This occurs because the current distribution in the loop is not uniform. As such, the formula given in slide 17 is no longer valid. It should, however, be noted that for smaller loops, even with a single feed point, there are similarities between the radiation patterns in FEKO and MATLAB. This is quite evident when we look at Figure 7. This is because the extent of uneven current distribution is lower in smaller loops than in larger ones.

## 2 Problem 2

In this section, we attempt to replicate the plots shown in slides 25 and 26. The radius of the loop antenna  $a$  is set to  $1m$ .

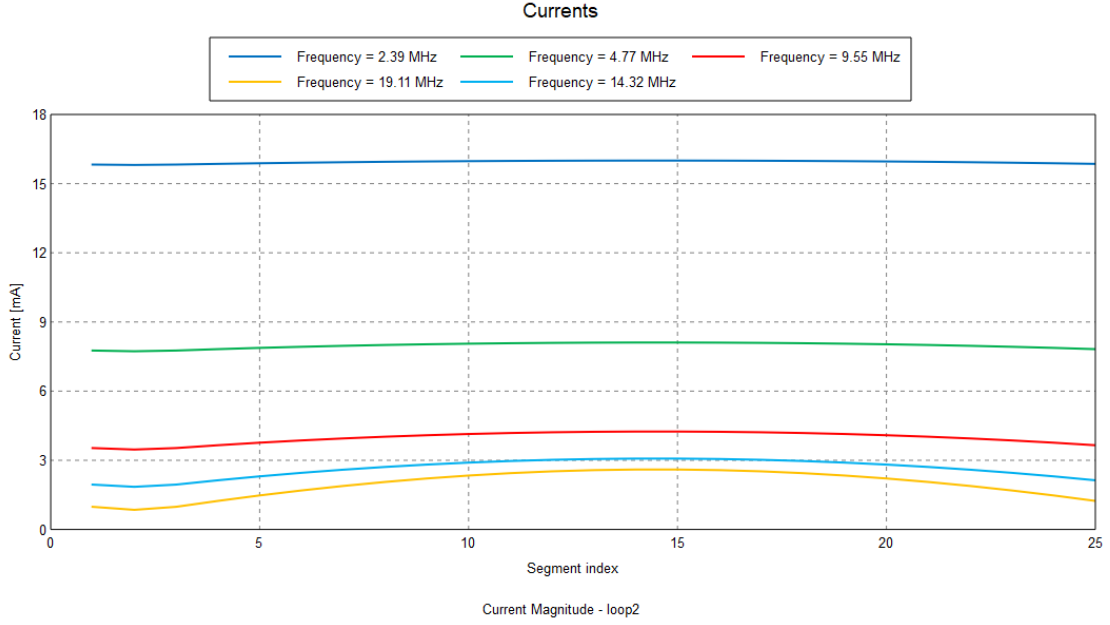


Figure 9: The current magnitude across the loop at different frequencies.

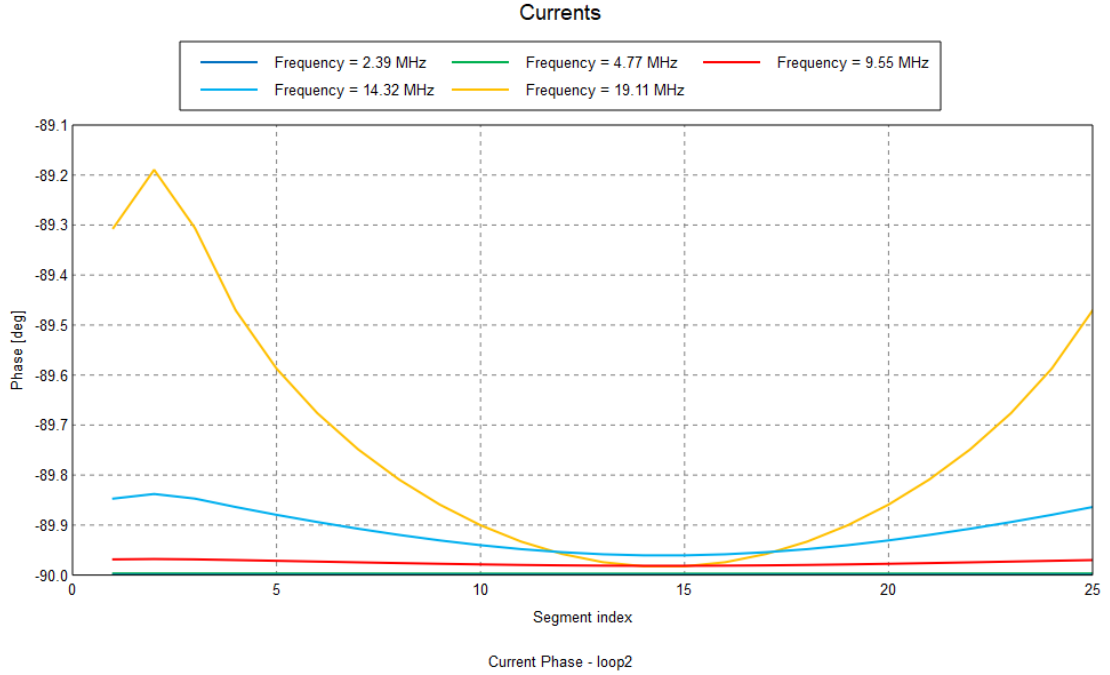


Figure 10: The current phase across the loop at different frequencies.

As the frequency decreases, the magnitude of the current distribution becomes more uniform across the loop. The overall magnitude of the current seems to increase as the frequency decreases, and the current curve also starts to flatten. It should be noted that in the FEKO simulation, the voltage magnitude at the feed point was altered so that the current magnitudes would be similar to the ones shown in slide 25. **It should also be mentioned that the frequencies shown in the above**

images correspond to the  $ka$  values shown on the slides. The calculations are shown as follows.

$$ka = 0.05$$

$$\frac{2\pi}{\lambda_1} = 1$$

$$\lambda_1 = 125.66$$

$$f_1 = 2.39MHz$$

$$ka = 0.1$$

$$\frac{2\pi}{\lambda_2} = 1$$

$$\lambda_2 = 62.83$$

$$f_2 = 4.77MHz$$

$$ka = 0.2$$

$$\frac{2\pi}{\lambda_3} = 1$$

$$\lambda_3 = 31.42$$

$$f_3 = 9.55MHz$$

$$ka = 0.3$$

$$\frac{2\pi}{\lambda_4} = 1$$

$$\lambda_4 = 20.94$$

$$f_4 = 14.32MHz$$

$$ka = 0.4$$

$$\frac{2\pi}{\lambda_5} = 1$$

$$\lambda_5 = 15.9$$

$$f_5 = 19.11MHz$$

The frequencies computed above are used in the simulations. Regarding the current phase, as the frequency decreases, the current phase becomes more uniform. The lower the frequency, the more overall the current phase converges to  $-90^\circ$ . Hence, we can confidently say that we have reproduced the plots from slides 25 and 26.

### 3 Problem 3

The square, rectangular and circular loops shown in slide 39 are simulated for range of frequencies corresponding to their circumference from  $0.05\lambda$  to  $2\lambda$ . For simplicity, the unwrapped length of each loop is set to  $1m$ . Considering this, the minimum frequency ( $f_{min}$ ) and maximum frequency ( $f_{max}$ ) are as shown below. In the following equation, the notation  $C$  represents the unwrapped length.

$$0.05\lambda_1 = C \quad (1)$$

$$0.05\lambda_1 = 1 \quad (2)$$

$$\lambda_1 = 20 \quad (3)$$

$$f_{min} = 15MHz \quad (4)$$

$$2\lambda_2 = C \quad (5)$$

$$2\lambda_2 = 1 \quad (6)$$

$$\lambda_2 = 0.5 \quad (7)$$

$$f_{max} = 600MHz \quad (8)$$

From the above equations, we can see that  $f_{min} = 15MHz$  and  $f_{max} = 600MHz$ . This is the frequency range used to simulate the loop antennas.

To get an unwrapped length of  $1m$ , we compute the radius of the circular loop to be  $1/(2\pi)$ . The thickness of the antenna is set to  $0.1mm$ . As for the square, each side is  $0.25m$ . The length of the rectangular loop is  $\frac{1}{3}m$  and the width is  $\frac{1}{6}$ . The requested plots for each loop antenna are shown below.

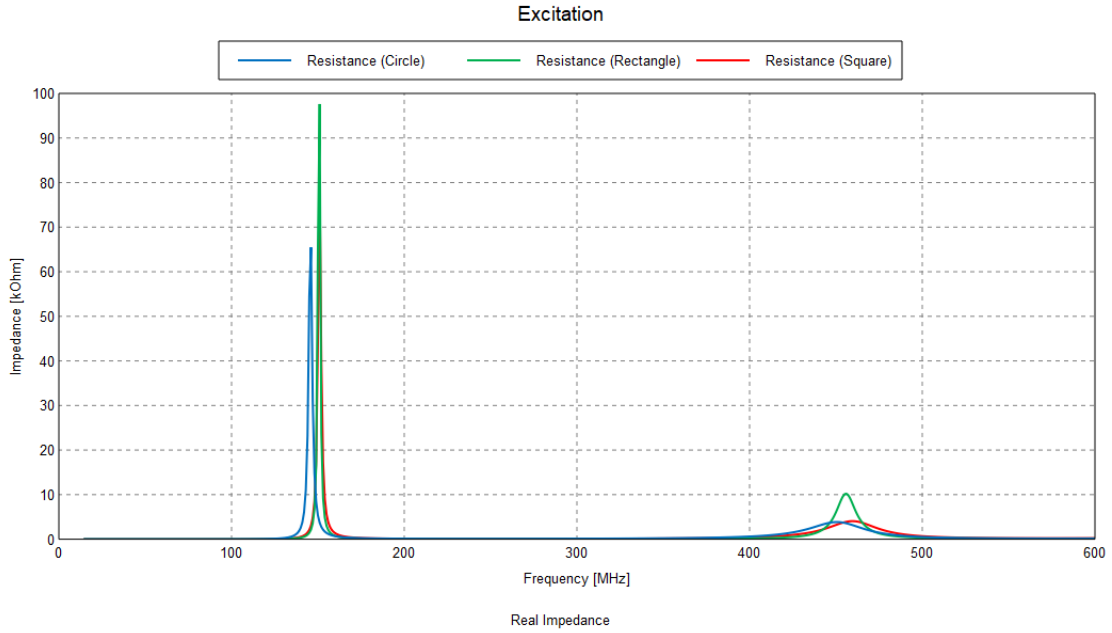


Figure 11: Resistance of the loop antennas across the different frequencies.

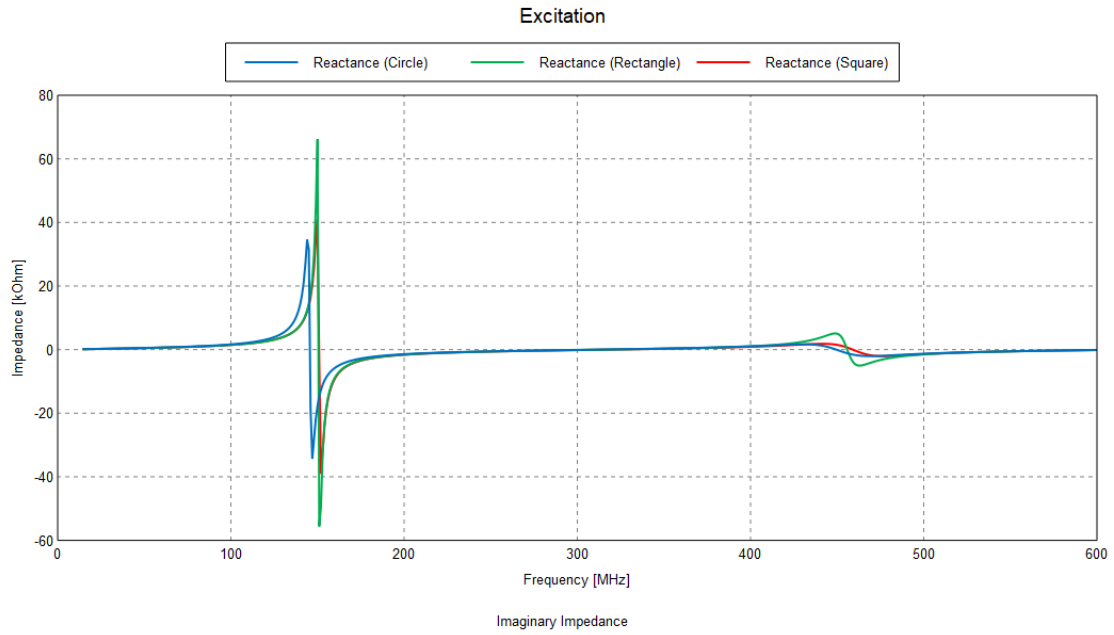


Figure 12: Reactance of the loop antennas across the different frequencies.

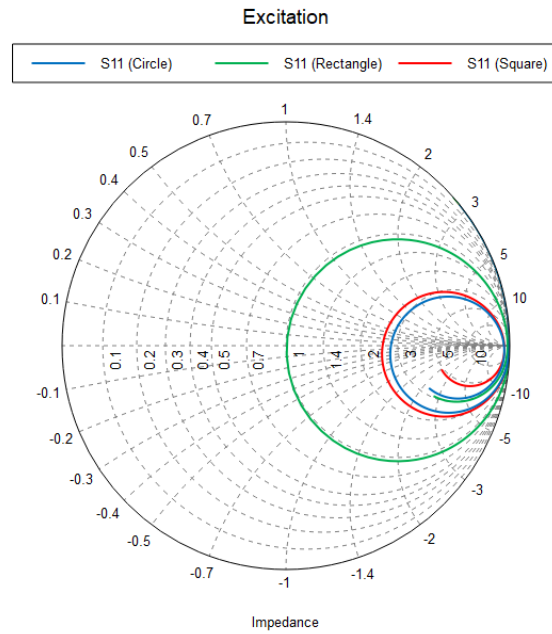


Figure 13: Smith chart for the three types of antenna loops.

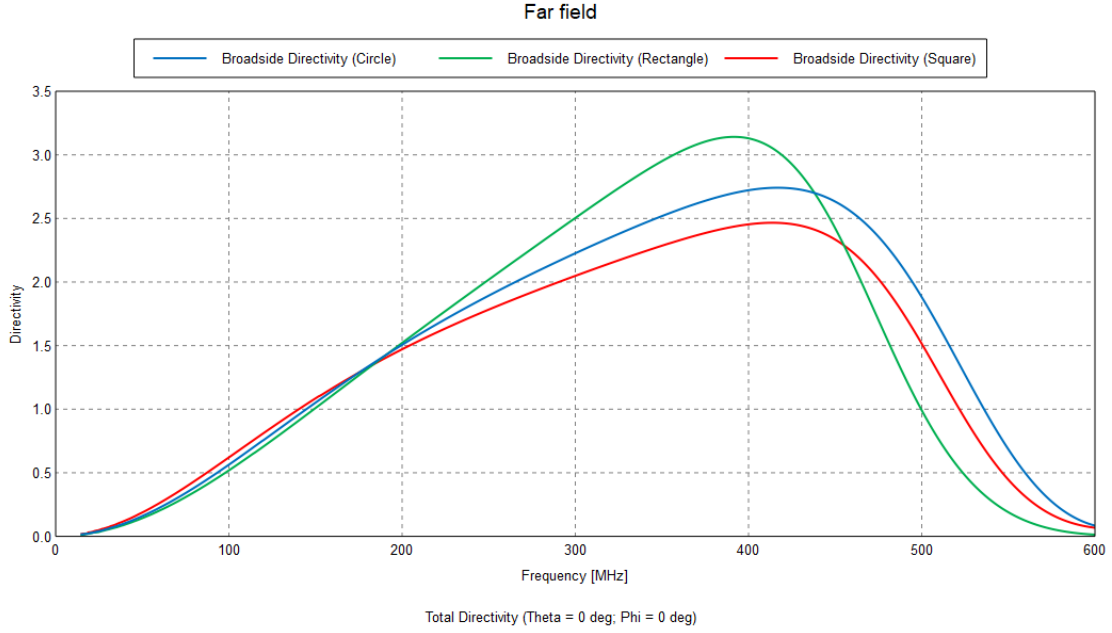


Figure 14: The broadside directivity across different frequencies for the three loop antennas (**plot is in linear scale**).

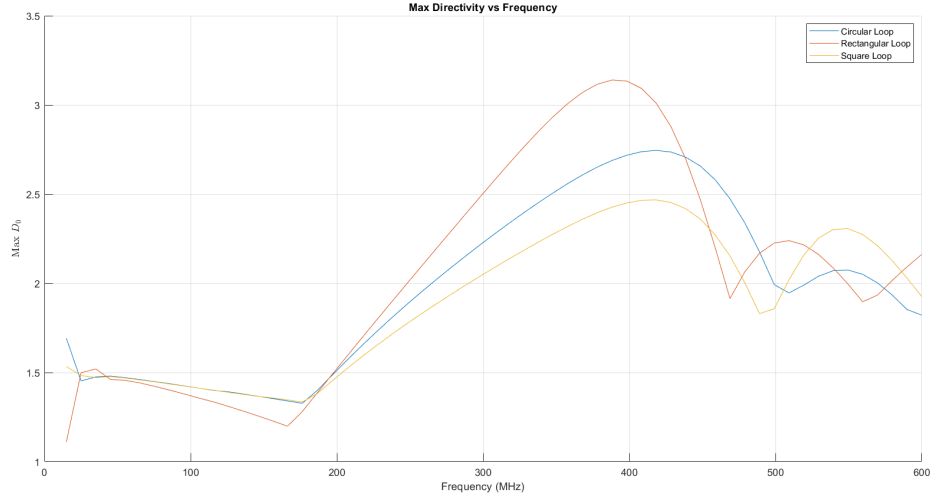


Figure 15: The trend in max directivity of the loop antennas across different frequencies (**plot is in linear scale**).

The resistances and maximum gain of these loop antennas at frequency corresponding to  $C = 1\lambda$ , which is  $300\text{MHz}$  is shown in the following table.

Antenna Type	Frequency at $C = 1\lambda$ (MHz)	Resistance ( $\Omega$ )	Gain (dBi)
Circular Loop	300	125.67	3.48
Square Loop	300	110	3.11
Rectangle Loop	300	45.8	3.98

Table 1: Antenna types with their resistance and gain at frequency corresponding to  $C = 1\lambda$ .

Based on the above table, the resistance and gain of the loop antennas are quite close to the details shown in slide 39. From the Smith charts, we can also see that the impedance of the rectangular loop

reduces to a greater extent compared to the circular and square loops, especially around the frequency of  $300\text{MHz}$ , which corresponds to  $C = \lambda$ . As for the broadside and maximum directivity plots, the three loop antennas have data trend of differing amplitudes, but very similar patterns.

The radiation patterns of each loop with circumference corresponding to  $0.05\lambda$ ,  $0.1\lambda$ ,  $\lambda$  and  $1.5\lambda$  (which are equivalent to  $15\text{MHz}$ ,  $30\text{MHz}$ ,  $300\text{MHz}$  and  $450\text{MHz}$ ) are plotted.

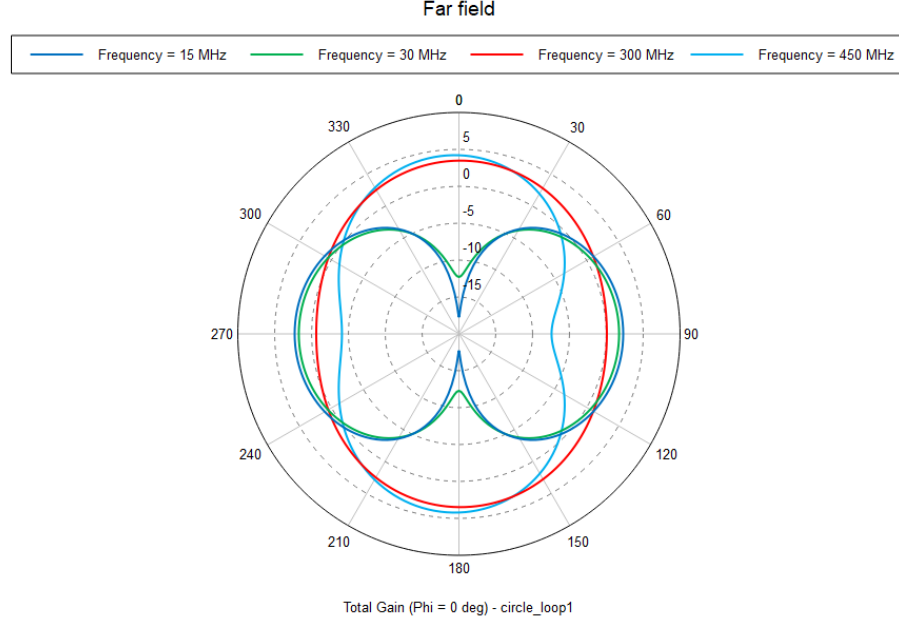


Figure 16: Radiation patterns of the circular loop.

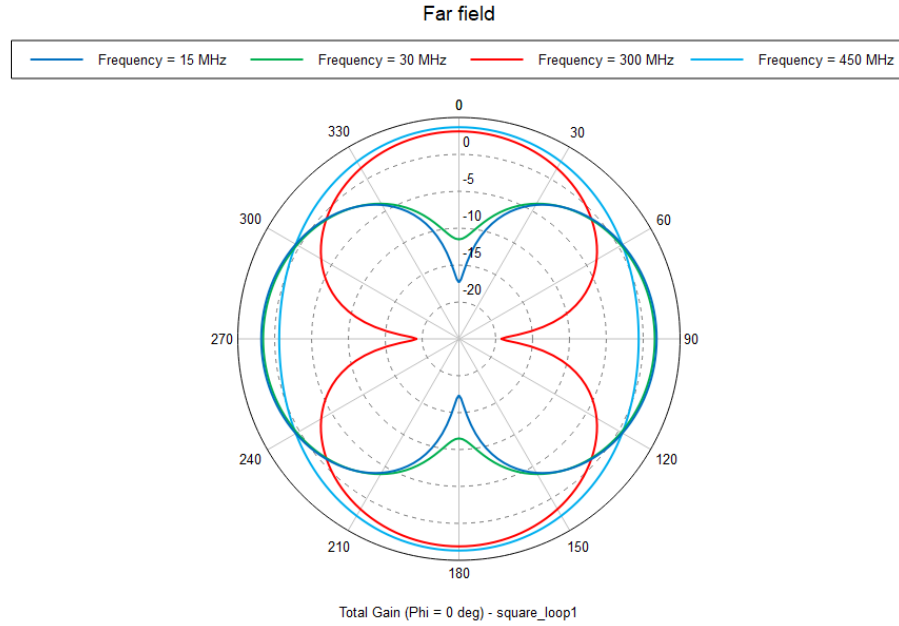


Figure 17: Radiation patterns of the square loop.

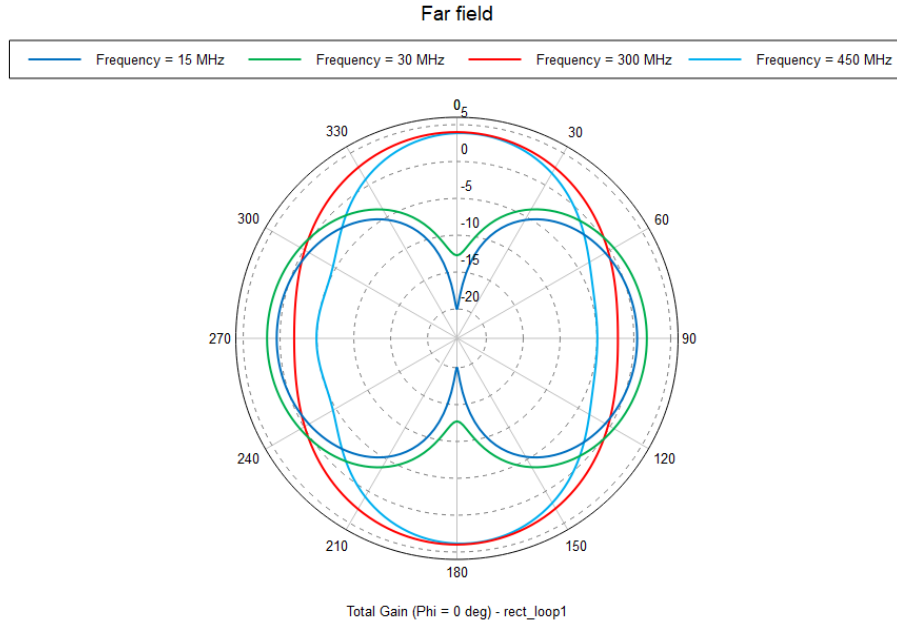


Figure 18: Radiation patterns of the rectangular loop.

From the above images, we can see that the radiation patterns of the circular, rectangular, and square loop antennas show distinct variations in directivity and gain across different frequencies. The circular loop antenna maintains a relatively smooth and symmetrical pattern, with increased directivity at higher frequencies. The rectangular loop antenna exhibits behavior similar to the circular loop. At higher frequencies, both the circular and rectangular loop antennas lose their lobes as well as nulls, and the patterns seem to become more smooth. Unlike the circular and rectangular loop antennas, the square loop antenna still has lobes at resonant frequency (which is  $300\text{MHz}$ ). However, as the frequency goes beyond  $300\text{MHz}$ , its radiation pattern also smooths out and the null effects are greatly reduced.