ECEN5134 HOMEWORK 2

Labib Sharrar

February 6, 2025

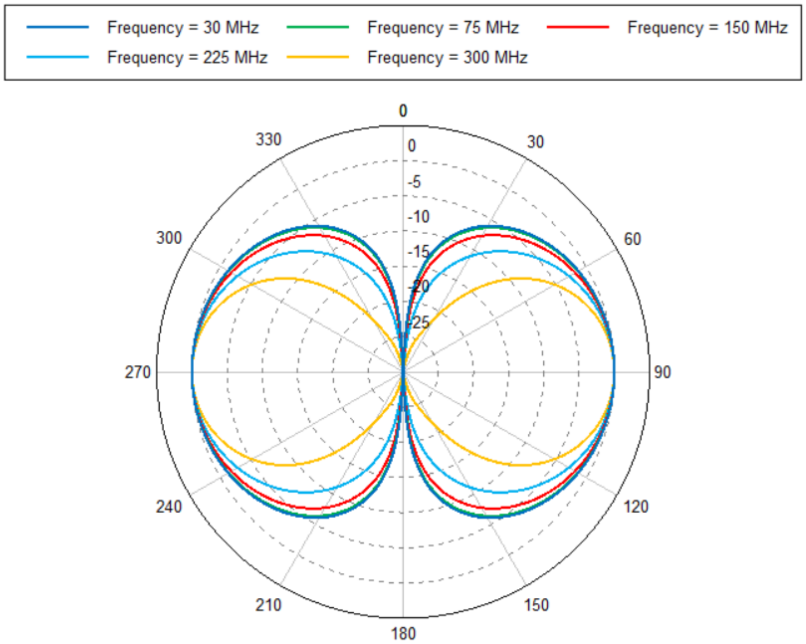
1 Solutions

1.1 (a) Radiation Patterns from Slide 23

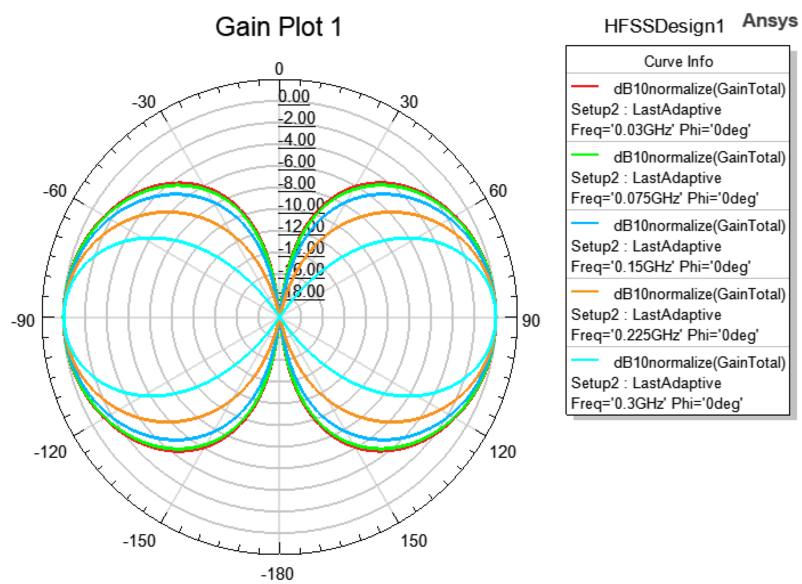
Simulations are done for the frequencies suggested in slide 23 of the third lecture. It should be noted that the dipole is designed to be $1m$ long with a diameter of $5mm$. Before beginning the simulations, the material assigned to the dipole is copper. The different wavelengths and frequencies used for the simulations are illustrated in the following table.

Dipole Length (m)	**Wavelength (m)**	**Frequency (MHz)**
$\frac{\lambda}{10}$	10	30
$\frac{\lambda}{4}$	4	75
$\frac{\lambda}{2}$	2	150
$\frac{3\lambda}{4}$	1.33	225
λ	1	300

Table 1: Dipole length, wavelength, and frequency values.



(a) Radiation pattern in FEKO.



(b) Radiation pattern in HFSS.

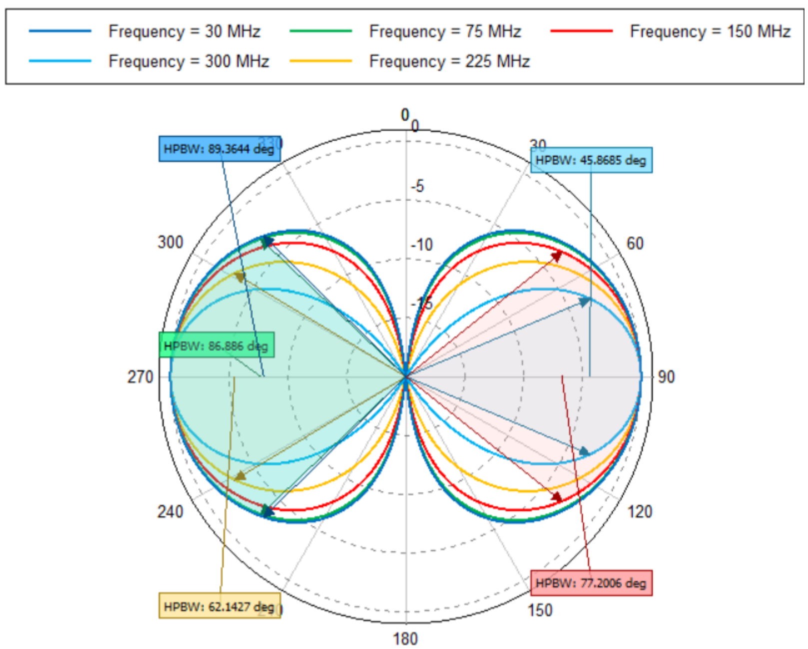
Figure 1: Radiation patterns in FEKO and HFSS for different frequencies.

1.2 (b) Comparing the patterns in FEKO and HFSS

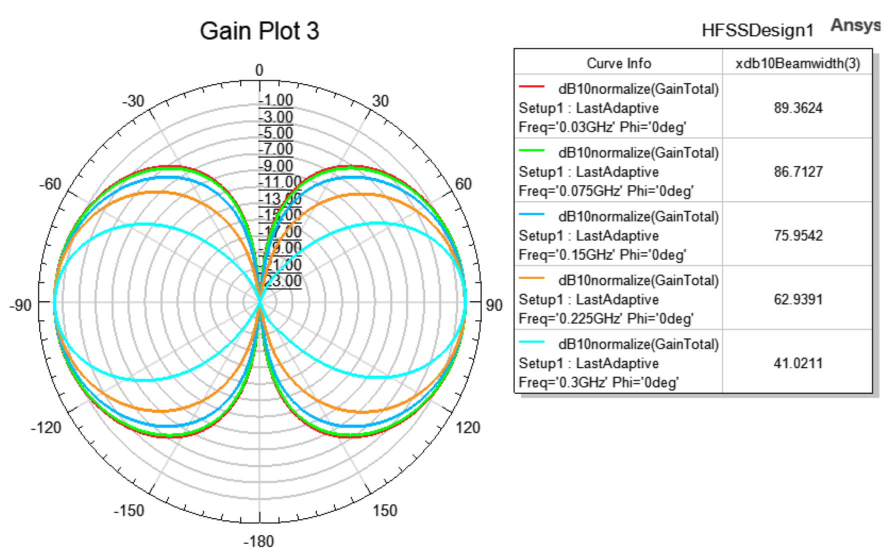
The radiation patterns generated for the different frequencies in FEKO and HFSS are very similar. This becomes evident when we analyze their half-power beam width (HPBW) of each pattern. The following table illustrates the HPBW measured for the various frequencies in both software. The marked HPBW values can also be viewed in Figure 2.

Frequency (MHz)	HPBW (°) FEKO	HPBW (°) HFSS
30	89.36	89.36
75	86.71	87.29
150	75.95	77.20
225	62.94	62.14
300	41.02	45.87

Table 2: HPBW at different frequencies in FEKO and HFSS.



(a) HPBW marked in FEKO.

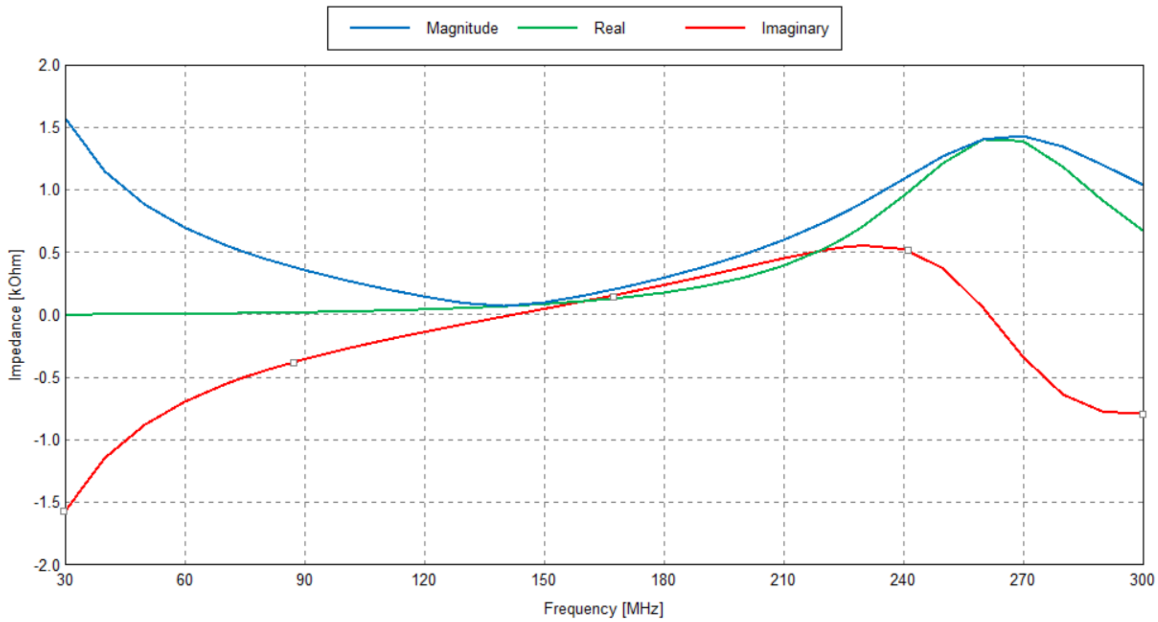


(b) HPBW marked in HFSS.

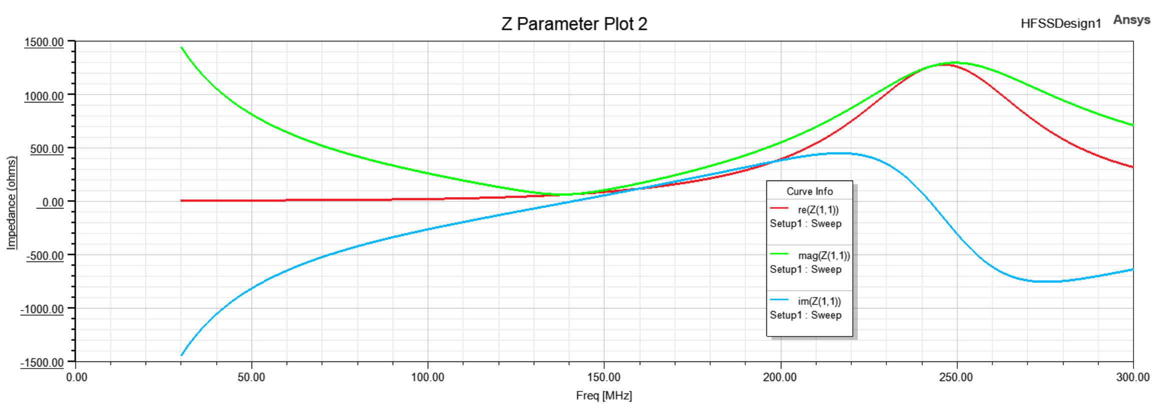
Figure 2: HPBW levels marked in FEKO and HFSS for different frequencies.

1.3 (c) Impedance at Different Frequencies

From Table 1, we can see that the simulation frequency extends from 30Mhz to 300Mhz. The trend in impedance values across this frequency range is displayed in Figure 3 for both FEKO and HFSS.



(a) Impedance trend in FEKO.



(b) Impedance trend in HFSS.

Figure 3: Impedance across different frequencies in FEKO and HFSS.

When we compare the plots in Figure 3, we can observe that the impedance (magnitude, real and imaginary part) trend is almost identical for the two software. For further analysis, the impedance values at the frequencies listed in slide 23 are displayed in Table 3.

Frequency (MHz)	Impedance (Ω) FEKO	Impedance (Ω) HFSS
30	$1.91 - j1546$	$8.08 - j1442.24$
75	$13 - j495$	$13.47 - j467.17$
150	$86.20 + j46.70$	$88.58 + j56.87$
225	$646.80 + j536.50$	$876.10 + j415.52$
300	$613.20 - j782.20$	$318.25 - j633.99$

Table 3: Impedance values at different frequencies in FEKO and HFSS.

From Table 2, we can see that as the frequency increases, the gap between the real part of the impedances in FEKO and HFSS starts to increase. The imaginary parts of the impedances, on the other hand, remain reasonably close to one another. In addition to this, it should also be noted that the resonant frequencies in HFSS and FEKO are also close to each other. The resonant frequencies are 141.63MHz and 143MHz for HFSS and FEKO respectively.

1.4 (d) Computing Radiation Efficiency at resonance

In order to compute the radiation efficiency we use the equation, $G_0 = e_{cd} D_0$, where G_0 and D_0 are the maximum gain and directivity, respectively. Radiation efficiency is denoted by e_{cd}. To compute $e_c d$ we find G_0 and D_0 from the following polar plot in FEKO. Additionally, it should be noted that this polar plot is obtained at **143MHz**, which is the resonant frequency in FEKO.

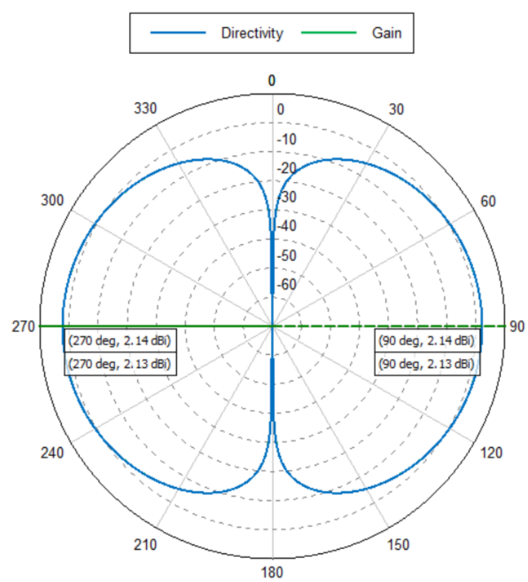


Figure 4: Maximum directivty and gain marked in the polar plot at resonance.

Calculation of the radiation efficiency is shown in the equations below.

$$D_0 = 2.14dBi \approx 1.637 \quad (1)$$
$$G_0 = 2.13dBi \approx 1.634 \quad (2)$$
$$e_{cd} = \frac{G_0}{D_0} \times 100\% \quad (3)$$
$$= \frac{1.634}{1.637} \times 100\% \quad (4)$$
$$= 99.82\% \quad (5)$$

A radiation efficiency of 99.82% is relatable since copper (which is used in the simulations) is a good conductor.

1.5 (e) Computing Beam Efficiency

The radiation pattern at 450MHz is shown in Figure 5. The equation used to compute the beam efficiency is shown below.

$$\frac{\sum_{i=1}^{361}\sum_{j=1}^{\theta+1}|E_{i,j}|^2 sin(\theta_{i,j})\Delta\theta\Delta\phi}{\sum_{i=1}^{361}\sum_{j=1}^{181}|E_{i,j}|^2 sin(\theta_{i,j})\Delta\theta\Delta\phi} \tag{6}$$

In the above equation, $E_{i,j}$ is the electric field strength. We consider both $\Delta\theta$ and $\Delta\phi$ to be 1.

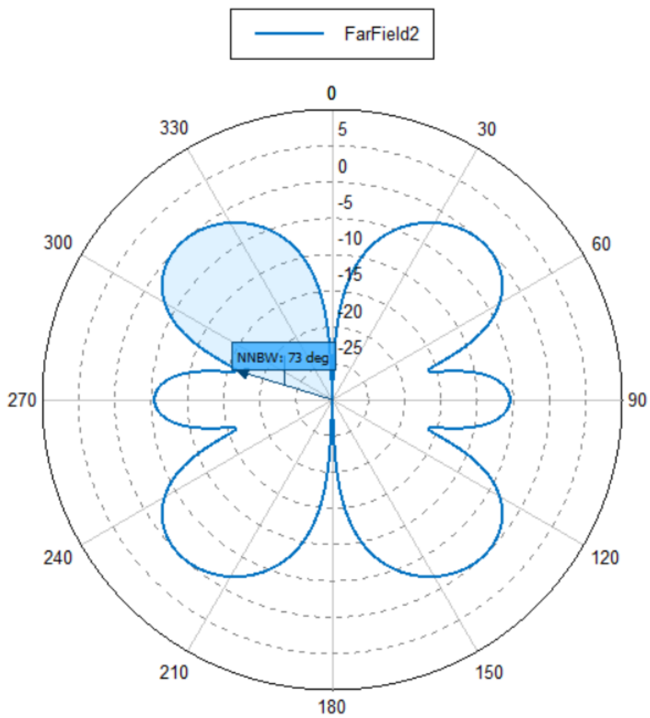


Figure 5: Radiation pattern at 450MHz with HPBW marked.

From Figure 5, we see that the HPBW is 73°. Thus, the integration or summation range for θ is 0° to 73°. Using the MATLAB code in the *Appendix*, and the above equations, the beam efficiency is computed. The MATLAB code outputs a beam efficiency of **44.79**%. This is a reasonable number since the radiation pattern in Figure 5 has a back lobe that is approximately the same size as the main lobe. Based on the MATLAB calculations, the back lobe accounts for 44.84% of the beam energy while small middle lobe contributes 10.52% of the energy. Adding these numbers with the percentage of energy provided by the main lobe gives approximately 100%. This validates that the beam efficiency of 44.79% at 450MHz is accurate.

A Appendix (MATLAB Code)

```
%% Generating Radiation Pattern Table
rad_details = readFEKOFFEFile("far_field2_ver3.ffe", true);
radiation_table = table();

% Index 33 is selected since it holds data for frequency 450MHz
radiation_table.Theta = rad_details.data(33).data.Theta;
radiation_table.Phi = rad_details.data(33).data.Phi;
radiation_table.Gain_Total = rad_details.data(33).data.Gain_Total;
radiation_table.Re_theta = rad_details.data(33).data.Re_Etheta;
radiation_table.Re_phi = rad_details.data(33).data.Re_Ephi;
radiation_table.Im_theta = rad_details.data(33).data.Im_Etheta;
radiation_table.Im_phi = rad_details.data(33).data.Im_Ephi;

%% Saving as .csv file
radiation_table = readtable("rad.csv");

%% Variables
theta_limit = 73;
phi_limit = 360;
delta_theta = 1;
delta_phi = 1;

%% Computing the numerator
N = 0;
for k=1:theta_limit+1
    theta = radiation_table.Theta(k);
    rad1 = radiation_table(radiation_table.Theta == theta,:);
    for j = 1:phi_limit+1
        phi = rad1.Phi(j);
        rad2 = rad1(rad1.Phi == phi,:);

        % Electric field data
        E_re = rad2.Re_theta + rad2.Re_phi;
        E_im = rad2.Im_theta + rad2.Im_phi;
        E_square = (E_re + (E_im*1i)) * conj(E_re + (E_im*1i));

        N = N + ((E_square) * sin(deg2rad(rad2.Theta)))*delta_theta*delta_phi;
        %rad_temp = radiation_table(radiation_table.Theta == radiation_table.Theta(i) & radiation_tab
    end
end

%% Computing the numerator
D = 0;
for k=1:181
    theta = radiation_table.Theta(k);
    rad1 = radiation_table(radiation_table.Theta == theta,:);
    for j = 1:phi_limit+1
        phi = rad1.Phi(j);
        rad2 = rad1(rad1.Phi == phi,:);

        %Electric field data
        E_re = rad2.Re_theta + rad2.Re_phi;
        E_im = rad2.Im_theta + rad2.Im_phi;
        E_square = (E_re + (E_im*1i)) * conj(E_re + (E_im*1i));
```

```
        D = D + ((E_square) * sin(deg2rad(rad2.Theta)))*delta_theta*delta_phi;
        %rad_temp = radiation_table(radiation_table.Theta == radiation_table.Theta(i) & radiation_tab
    end
end

%% Computing Beam Efficiency
beam_efficiency = N/D * 100;
disp(['Beam efficiency: ', num2str(beam_efficiency), '%']);
```