MATLAB Assignment: Radiation Pattern Simulation and Directivity Analysis

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1 Objective

The objective of this assignment is to simulate and analyze the radiation patterns of omnidirectional dipole antennas for various length-to-wavelength (l/λ) ratios, and investigate how directivity varies with antenna length.

2 Radiation Patterns for Different l/λ Ratios

2.1 Theory

An omnidirectional dipole antenna radiates electromagnetic waves in a pattern that depends on its electrical length. The electric field magnitude is given by:

$$E(\theta) = \frac{\cos(\beta l \cos\theta) - \cos(\beta l)}{\sin\theta \cdot (1 - \cos(\beta l))} \tag{1}$$

where:

- $\beta = 2\pi/\lambda$ (propagation constant)
- l = physical length of the dipole
- θ = elevation angle from the z-axis

2.2 Simulated l/λ Ratios

We analyze six different antenna lengths:

- $l/\lambda = 0.1$: Very short dipole (Hertzian dipole approximation)
- $l/\lambda = 0.25$
- $l/\lambda = 0.5$
- $l/\lambda = 0.625$
- $l/\lambda = 0.75$
- $l/\lambda = 0.9999$

2.3 E vs θ (Elevation Pattern)

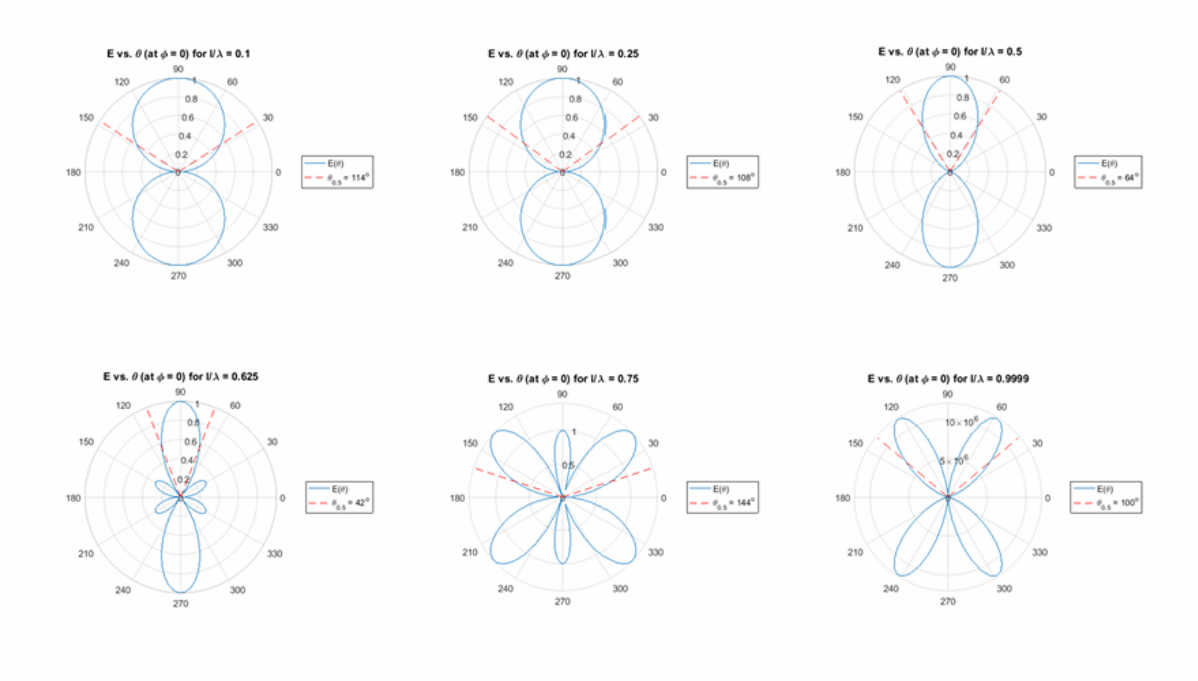

Figure 1: Electric field magnitude vs elevation angle for different l/λ ratios

Analysis:

- $l/\lambda = 0.1$: Nearly perfect figure-eight pattern, similar to a Hertzian dipole
- $l/\lambda = 0.25 - 0.5$: Pattern becomes more directional, null at $\theta = 0$ and 180
- $l/\lambda = 0.625$: Maximum directivity, beam narrows in elevation plane
- $l/\lambda = 0.75 - 1.0$: Pattern develops side lobes, energy spreads to off-axis angles

2.4 E vs ϕ (Azimuthal Pattern)

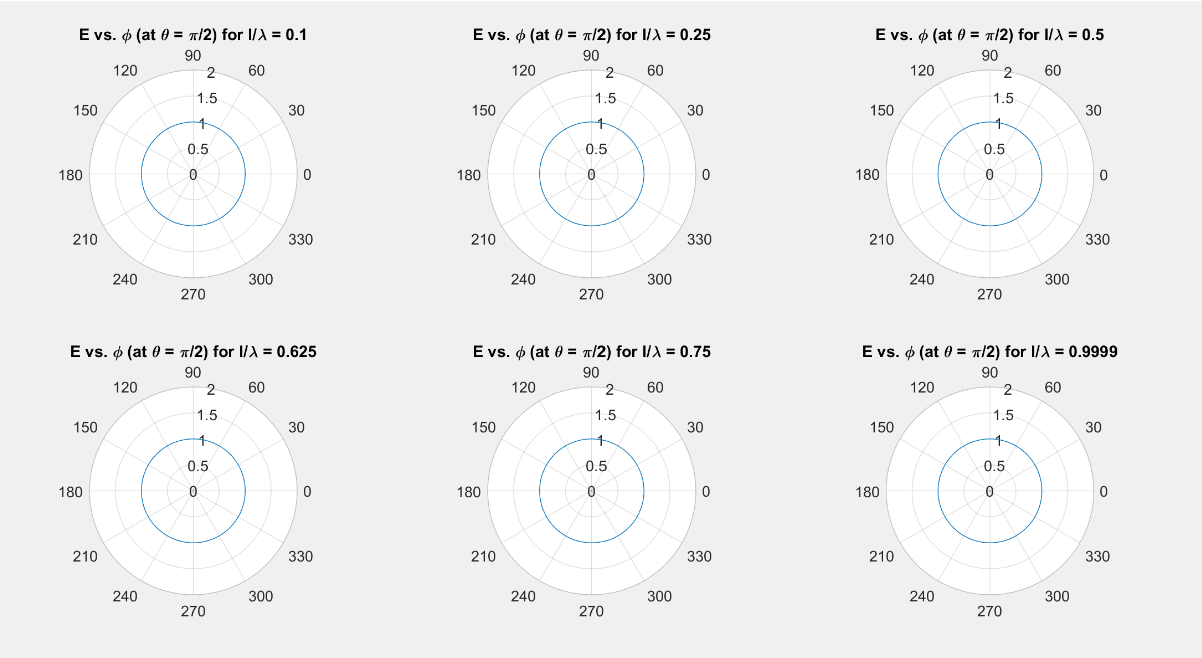

Figure 2: Electric field magnitude vs azimuthal angle for different l/λ ratios

Analysis:

The azimuthal pattern remains **omnidirectional** (circular) for all l/λ ratios because:

- A vertical dipole radiates equally in all horizontal directions
- The pattern is independent of the azimuthal angle ϕ
- This is a fundamental characteristic of linear dipole antennas

2.5 3D Radiation Patterns

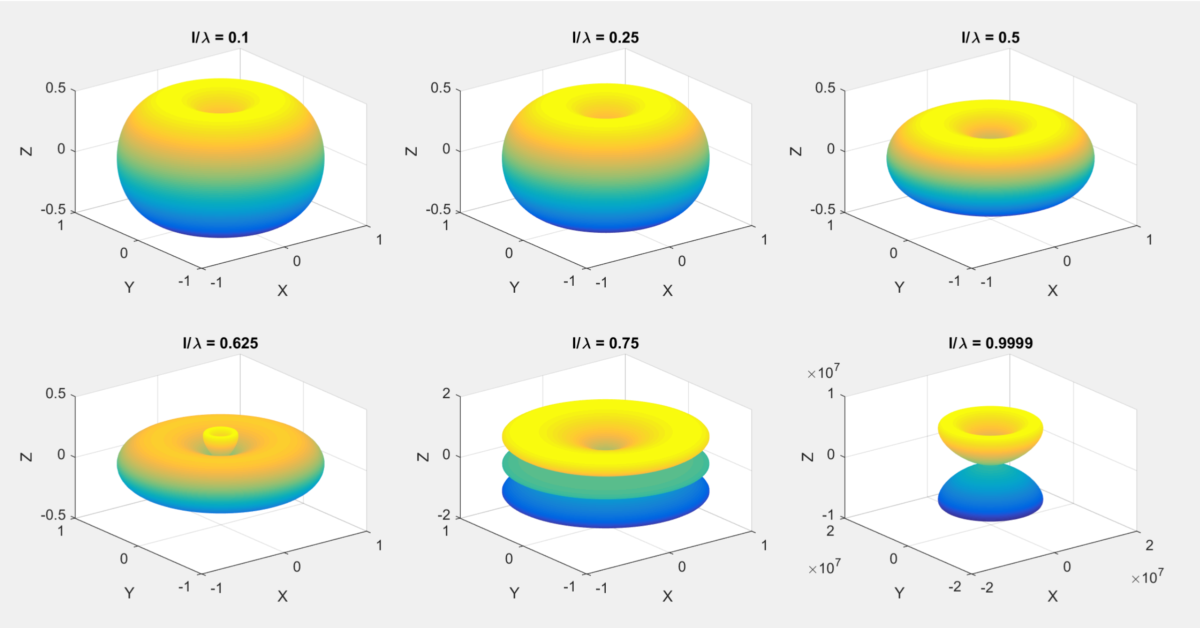

Figure 3: Three-dimensional radiation patterns for different l/λ ratios

Analysis:

The 3D patterns clearly show the evolution of the radiation characteristics:

- $l/\lambda = 0.1$: Toroidal (donut) shape with maximum radiation perpendicular to the antenna
- $l/\lambda = 0.25 - 0.5$: Toroid becomes more compressed toward the equatorial plane
- $l/\lambda = 0.625$: Most concentrated radiation pattern, highest directivity
- $l/\lambda = 0.75 - 1.0$: Multiple lobes emerge, indicating less efficient radiation

2.6 Main Code

```
% Define theta and phi ranges
theta = linspace(0, pi, 100);  % theta from 0 to pi
phi = linspace(0, 2*pi, 100);  % phi from 0 to 2*pi
[Theta, Phi] = meshgrid(theta, phi);
l_to_lambda_ratios = [0.1, 0.25, 0.5, 0.625, 0.75, 0.9999];
% Create figures for subplots
figure_theta = figure;
figure_phi = figure;
figure_3D = figure;
for i = 1:length(l_to_lambda_ratios)
    ratio = l_to_lambda_ratios(i);
    beta_l = 2 * pi * ratio;
    % Calculate the E-field pattern
    E_theta = (cos(beta_l .* cos(theta)) - cos(beta_l)) ./ (sin(theta) .* (1 - cos(beta_l)));
    E_3D = (cos(beta_l .* cos(Theta)) - cos(beta_l)) ./ (sin(Theta) .* (1 - cos(beta_l)));
    % 3D pattern as a function of theta and phi
    % Calculate theta_0_5
    E_max = max(abs(E_theta));
    theta_0_5 = theta(find(abs(E_theta) >= E_max / 2, 1, 'first'));
    % Plot E vs. theta for a constant phi (0)
    figure(figure_theta);
    subplot(2, 3, i);
    polarplot(theta, abs(E_theta));
    hold on;
    polarplot([theta_0_5 theta_0_5], [0 E_max], 'r ');
    polarplot([theta_0_5 -theta_0_5], [0 -E_max], 'r ');
    hold off;
    title(['E vs. \theta (at \phi = 0) for l/\lambda = ' num2str(ratio)]);
    legend('E(\theta)', ['\theta_{0.5} = ' num2str(2 * round(radtodeg(pi/2 - theta_0_5))) '^o']);
    grid on;
    % Plot E vs. phi for a constant theta (pi/2)
    figure(figure_phi);
    subplot(2, 3, i);
    E_phi = sin(pi/2) * ones(size(phi));  % Constant E for theta = pi/2
    polarplot(phi, E_phi);
    title(['E vs. \phi (at \theta = \pi/2) for l/\lambda = ' num2str(ratio)]);
    grid on;
    % Plot the 3D radiation pattern
    figure(figure_3D);
    subplot(2, 3, i);
    [X, Y, Z] = sph2cart(Phi, pi/2 - Theta, E_3D);  % Convert to Cartesian coordinates
```

```
    surf(X, Y, Z);
    title(['l/\lambda = ' num2str(ratio)]);
    xlabel('X');
    ylabel('Y');
    zlabel('Z');
    shading interp;
grid on;
 end
```

Listing 1: Radiation pattern simulation and plotting

3 Directivity Analysis

3.1 Theory

Directivity (D) measures how well an antenna concentrates energy in a particular direction compared to an isotropic radiator:

$$D = \frac{2}{\int_0^\pi E^2(\theta)\sin\theta\, d\theta} \tag{2}$$

In decibels:

$$D_{dB} = 10\log_{10}(D) \tag{3}$$

3.2 Directivity vs l/λ Plot

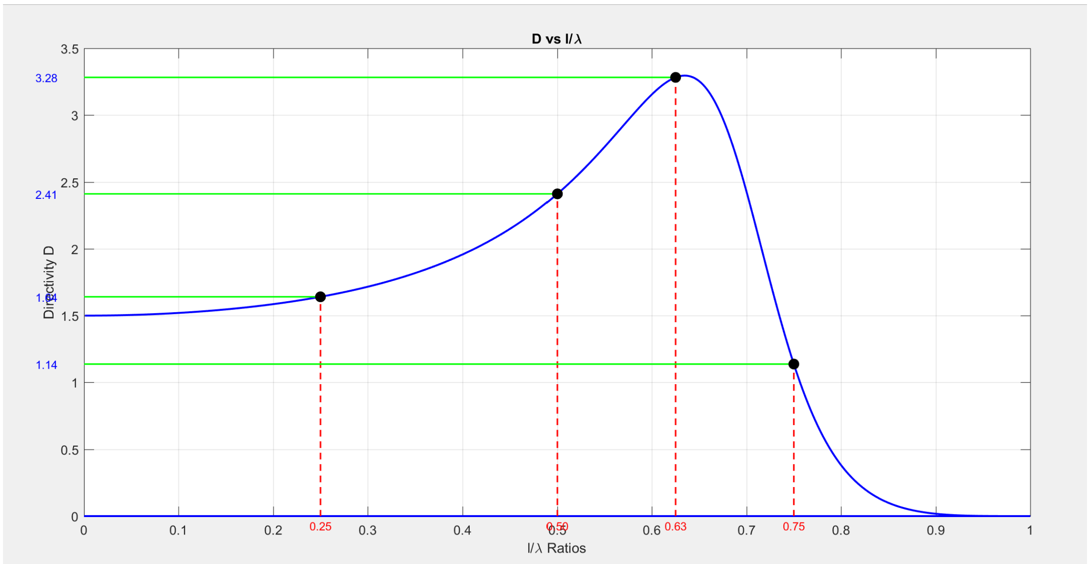

Figure 4: Directivity in dB as a function of l/λ ratio

```matlab
l_to_lambda_ratios = 0:0.001:1;
 beta_l = 2 .* pi .* l_to_lambda_ratios;
 % Calculate the E-field pattern
 D = zeros(length(beta_l));
 for i=1:length(beta_l)
 den = @(theta) ((cos(beta_l(i) .* cos(theta)) - cos(beta_l(i))) ./(sin(theta) .* (1 - cos(beta_l(i))))).^2 .* sin(theta);
 D(i) = 2 ./ (integral(den, 0, pi));
 end
 % 3D pattern as a function of theta and phi
 figure;
 plot(l_to_lambda_ratios, D, 'b-', 'LineWidth', 1.5);
hold on;
 xlabel('l/\lambda Ratios');
 ylabel('Directivity D');
 title('D vs l/\lambda');
 grid on;
 % Specific l/lambda ratios to highlight
 specific_ratios = [0.25, 0.5, 0.625, 0.75];
 yLim = ylim;
 % Find the corresponding values of D for these ratios
 specific_D = zeros(size(specific_ratios));
 for j = 1:length(specific_ratios)
 % Find index for the specific ratio
 [~, idx] = min(abs(l_to_lambda_ratios - specific_ratios(j)));
specific_D(j) = D(idx); % Get corresponding D value
 % Plot vertical line using 'plot'
 plot([specific_ratios(j), specific_ratios(j)], [0, specific_D(j)], 'r--', 'LineWidth', 1.2);
 % Plot horizontal line using 'plot'
 plot([0, specific_ratios(j)], [specific_D(j), specific_D(j)], 'g ', 'LineWidth', 1.2);
 text(specific_ratios(j), -0.07, sprintf('%.2f', specific_ratios(j)), 'HorizontalAlignment', 'center', 'Color', 'r', 'FontSize', 9);
 text(-0.04, specific_D(j), sprintf('%.2f', specific_D(j)), 'HorizontalAlignment', 'center', 'Color', 'b', 'FontSize', 9);
 end
  % Add markers at the intersection points
 plot(specific_ratios, specific_D, 'ko', 'MarkerSize', 8, 'MarkerFaceColor', 'k');
 % Add a legend
 hold off;
```

Listing 2: Simulating the Directivity of Omni-directional Dipoles as a Function of l