UNIVERSITY
OF WOLLONGONG
IN DUBAI

Assignment Cover Sheet

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Subject code and name	ECTE213 – Engineering Electromagnetics
Lab Instructor	Mr. Mahmoud Alkakuri
Title of Assignment	Lab 5
Date and time due	11 March 2025, 23.55
Lab Number	5

Student declaration and acknowledgment

By submitting this assignment online, the submitting student declares on behalf of the team that:

1. All team members have read the subject outline for this subject, and this assessment item meets the requirements of the subject detailed therein.
2. This assessment is entirely our work, except where we have included fully documented references to the work of others. The material in this assessment item has yet to be submitted for assessment.
3. Acknowledgement of source information is by the guidelines or referencing style specified in the subject outline.
4. All team members know the late submission policy and penalty.
5. The submitting student undertakes to communicate all feedback with the other team members.

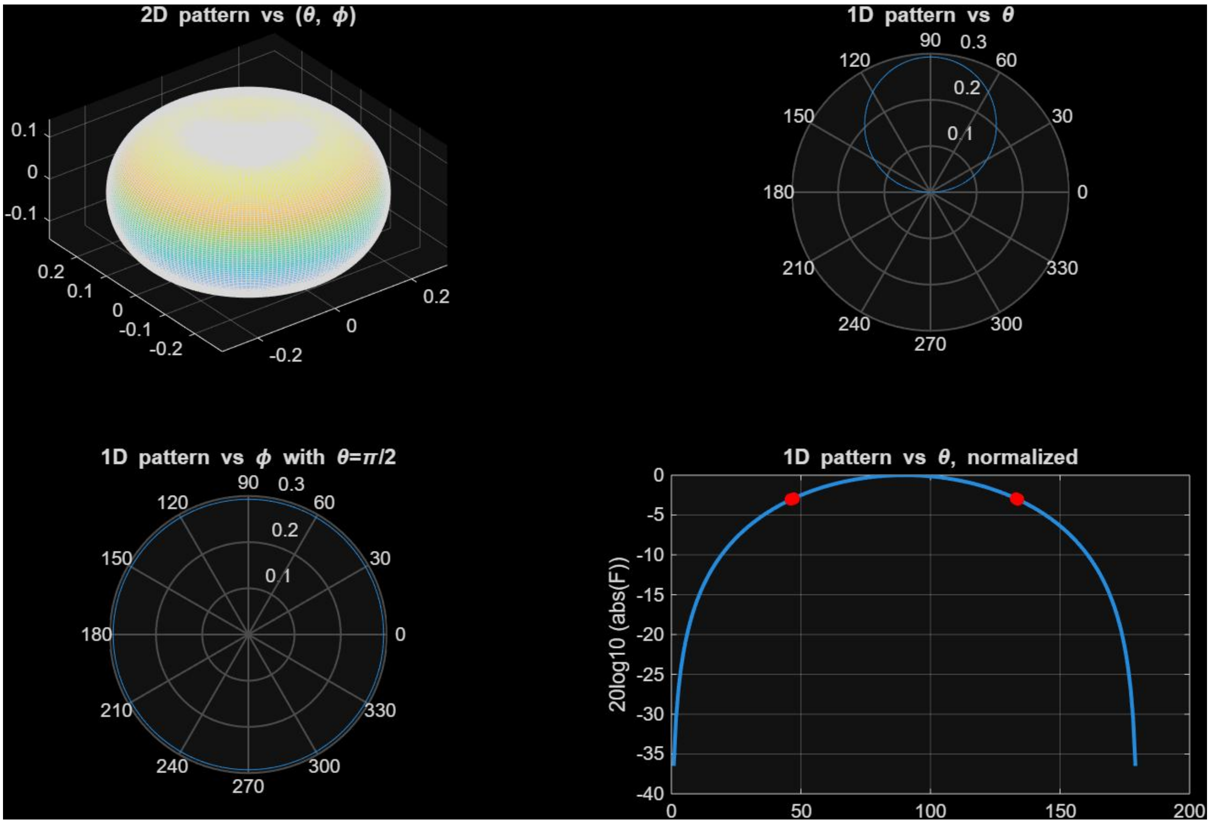
Lab 5

Exercise 5.1

a. $f = 300$ MHz, $\quad l = 0.125\lambda$

```
%Plot 2D pattern
f = 3*10^8; c = 3*10^8; lambda = c/f; k = 2*pi/lambda;
l = 0.125*lambda;
N_theta = 200; N_phi = 200;
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
F = ((cos(k*l*cos(theta))-cos(k*l))./sin(theta));
XD = abs(F).*sin(theta).*cos(phi);
YD = abs(F).*sin(theta).*sin(phi);
ZD = abs(F).*cos(theta);
subplot(2,2,1); surf(XD,YD,ZD);
title('2D pattern vs (\theta, \phi)'); axis image; rotate3d on; grid on;
% Pattern vs \theta in polar coordinates
N_theta = 200;
theta = [0: pi/( N_theta-1):pi];
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta);
subplot(2,2,2)
polar(theta,abs(F))
title('1D pattern vs \theta'); grid on
% Pattern vs \theta in rectangular coordinates
subplot(2,2,4)
% Normalize F for dB calculation
F_normalized = abs(F)/max(abs(F));
F_db = 20*log10(F_normalized);

% Define target dB value
target_db = -3;

% Find ALL indices close to -3 dB (within a small tolerance)
tolerance = 0.1;  % Adjust this value to control how close to -3 dB
indices = find(abs(F_db - target_db) < tolerance);

% Get corresponding theta values in degrees
theta_at_minus3db = theta(indices) * 180/pi;

plot(theta/pi*180, F_db, 'linewidth', 2)
title('1D pattern vs \theta, normalized'); grid on; ylabel('20log10
(abs(F))')

% Print out the -3 dB point values
disp('Theta values at -3 dB:');
for i = 1:length(indices)
    fprintf('Theta = %.4f degrees\n', theta_at_minus3db(i));
end
hold on;
```

```
plot(theta_at_minus3db, F_db(indices), 'ro', 'MarkerFaceColor', 'r');
hold off;


% Calculate and display the difference between max and min theta values at
-3 dB
if length(theta_at_minus3db) > 1
    theta_difference = max(theta_at_minus3db) - min(theta_at_minus3db);
    fprintf('Difference between max and min theta at -3 dB: %.4f
degrees\n', theta_difference);
else
    fprintf('Not enough points to calculate difference\n');
end

% Pattern vs \phi in polar coordinates
subplot(2,2,3)
phi =[0: 2*pi/( N_phi-1):2*pi];
theta = pi/2;
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta)*ones(size(phi));
polar(phi, abs(F))
title('1D pattern vs \phi with \theta=\pi/2'); grid on
```

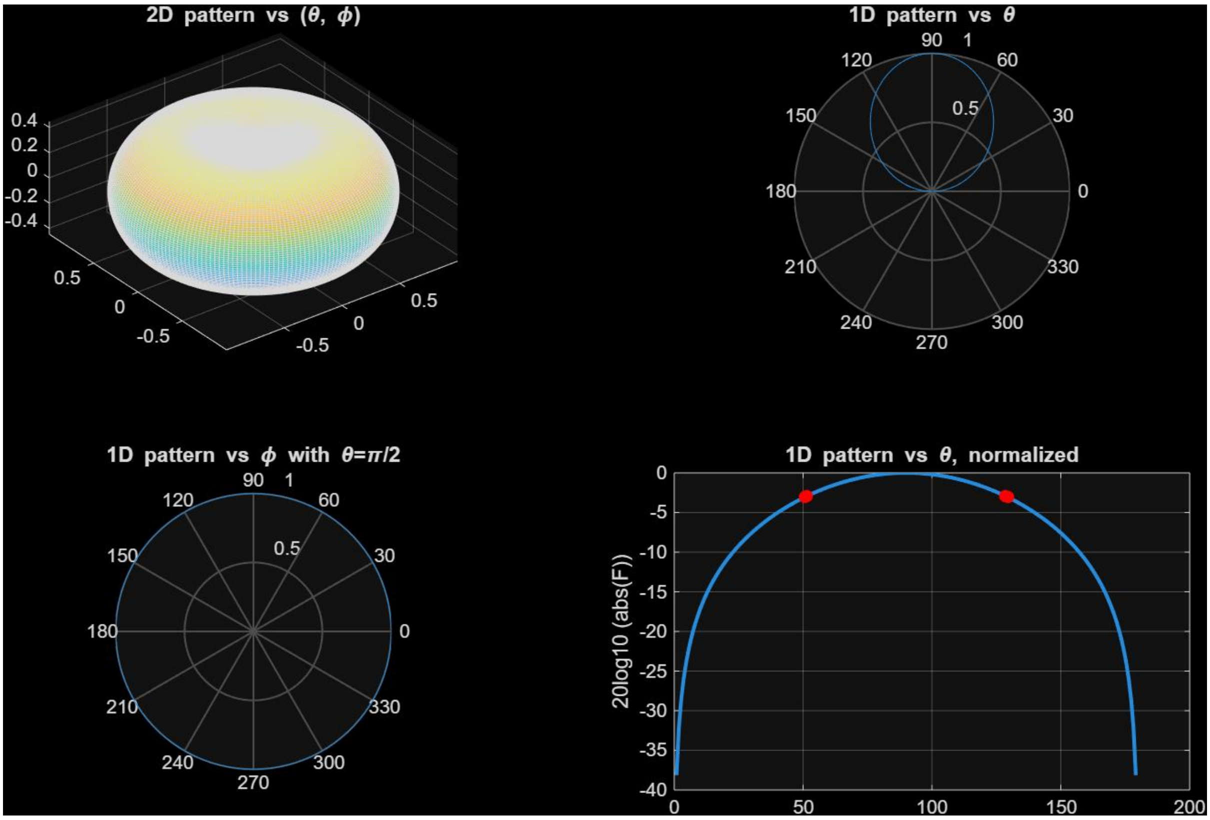


Number of mainbeams: 1; 3dB mainbeam width: 87.7387; Sidebeam level: NA

b. $f = 300$ MHz, $l = 0.25\lambda$

```
%Plot 2D pattern
f = 3*10^8; c = 3*10^8; lambda = c/f; k = 2*pi/lambda;
l = 0.25*lambda;
N_theta = 200; N_phi = 200;
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
F = ((cos(k*l*cos(theta))-cos(k*l))./sin(theta));
XD = abs(F).*sin(theta).*cos(phi);
YD = abs(F).*sin(theta).*sin(phi);
ZD = abs(F).*cos(theta);
subplot(2,2,1); surf(XD,YD,ZD);
title('2D pattern vs (\theta, \phi)'); axis image; rotate3d on; grid on;
% Pattern vs \theta in polar coordinates
N_theta = 200;
theta = [0: pi/( N_theta-1):pi];
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta);
subplot(2,2,2)
polar(theta,abs(F))
title('1D pattern vs \theta'); grid on
% Pattern vs \theta in rectangular coordinates
subplot(2,2,4)
% Normalize F for dB calculation
F_normalized = abs(F)/max(abs(F));
F_db = 20*log10(F_normalized);

% Define target dB value
target_db = -3;

% Find ALL indices close to -3 dB (within a small tolerance)
tolerance = 0.1;  % Adjust this value to control how close to -3 dB
indices = find(abs(F_db - target_db) < tolerance);

% Get corresponding theta values in degrees
theta_at_minus3db = theta(indices) * 180/pi;

plot(theta/pi*180, F_db, 'linewidth', 2)
title('1D pattern vs \theta, normalized'); grid on; ylabel('20log10
(abs(F))')

% Print out the -3 dB point values
disp('Theta values at -3 dB:');
for i = 1:length(indices)
    fprintf('Theta = %.4f degrees\n', theta_at_minus3db(i));
end
hold on;
plot(theta_at_minus3db, F_db(indices), 'ro', 'MarkerFaceColor', 'r');
hold off;

% Calculate and display the difference between max and min theta values at
-3 dB
```

```
if length(theta_at_minus3db) > 1
    theta_difference = max(theta_at_minus3db) - min(theta_at_minus3db);
    fprintf('Difference between max and min theta at -3 dB: %.4f
degrees\n', theta_difference);
else
    fprintf('Not enough points to calculate difference\n');
end

% Pattern vs \phi in polar coordinates
subplot(2,2,3)
phi =[0: 2*pi/( N_phi-1):2*pi];
theta = pi/2;
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta)*ones(size(phi));
polar(phi, abs(F))
title('1D pattern vs \phi with \theta=\pi/2'); grid on
```

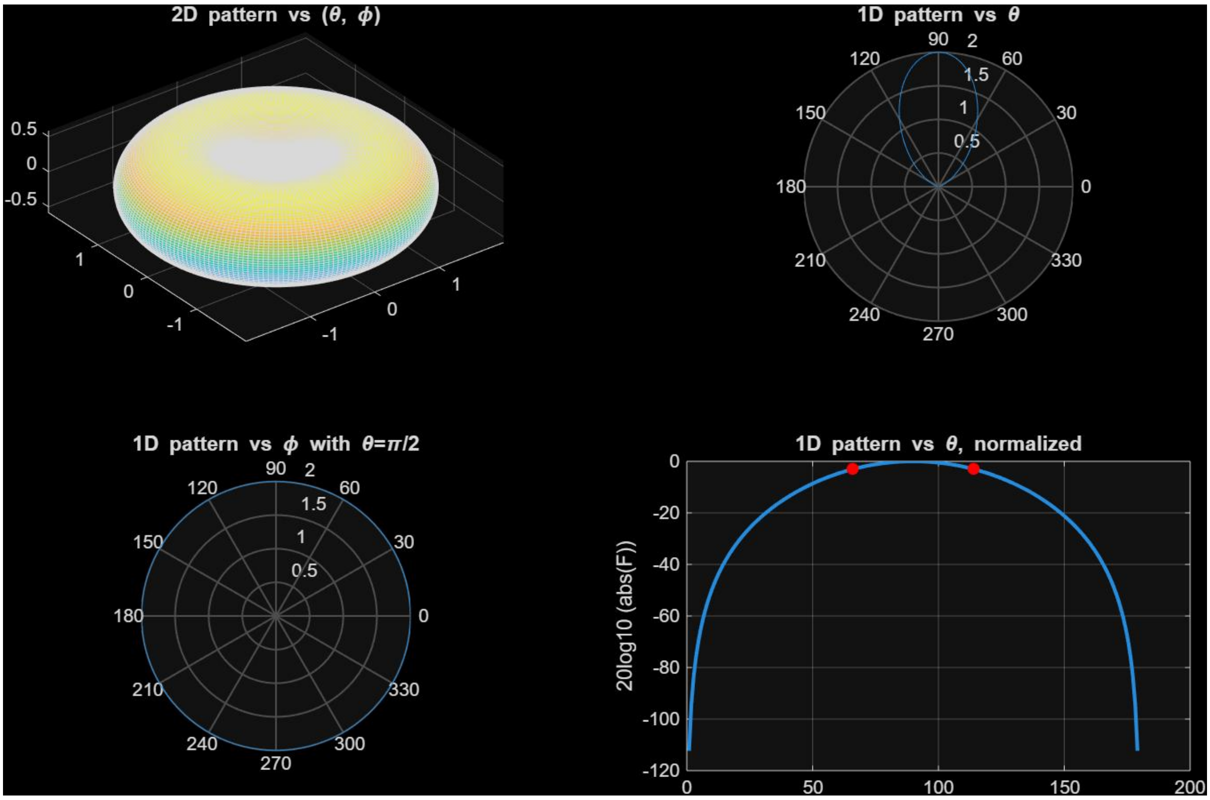


Number of mainbeams: 1; 3dB mainbeam width: 78.6935; Sidebeam level: NA

c. $f = 300$ MHz, $l = 0.5\lambda$

```
%Plot 2D pattern
f = 3*10^8; c = 3*10^8; lambda = c/f; k = 2*pi/lambda;
l = 0.5*lambda;
N_theta = 200; N_phi = 200;
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
F = ((cos(k*l*cos(theta))-cos(k*l))./sin(theta));
XD = abs(F).*sin(theta).*cos(phi);
YD = abs(F).*sin(theta).*sin(phi);
ZD = abs(F).*cos(theta);
subplot(2,2,1); surf(XD,YD,ZD);
title('2D pattern vs (\theta, \phi)'); axis image; rotate3d on; grid on;
% Pattern vs \theta in polar coordinates
N_theta = 200;
theta = [0: pi/( N_theta-1):pi];
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta);
subplot(2,2,2)
polar(theta,abs(F))
title('1D pattern vs \theta'); grid on
% Pattern vs \theta in rectangular coordinates
subplot(2,2,4)
% Normalize F for dB calculation
F_normalized = abs(F)/max(abs(F));
F_db = 20*log10(F_normalized);

% Define target dB value
target_db = -3;

% Find ALL indices close to -3 dB (within a small tolerance)
tolerance = 0.1;  % Adjust this value to control how close to -3 dB
indices = find(abs(F_db - target_db) < tolerance);

% Get corresponding theta values in degrees
theta_at_minus3db = theta(indices) * 180/pi;

plot(theta/pi*180, F_db, 'linewidth', 2)
title('1D pattern vs \theta, normalized'); grid on; ylabel('20log10
(abs(F))')

% Print out the -3 dB point values
disp('Theta values at -3 dB:');
for i = 1:length(indices)
    fprintf('Theta = %.4f degrees\n', theta_at_minus3db(i));
end
hold on;
plot(theta_at_minus3db, F_db(indices), 'ro', 'MarkerFaceColor', 'r');
hold off;

% Calculate and display the difference between max and min theta values at
-3 dB
```

```
if length(theta_at_minus3db) > 1
    theta_difference = max(theta_at_minus3db) - min(theta_at_minus3db);
    fprintf('Difference between max and min theta at -3 dB: %.4f
degrees\n', theta_difference);
else
    fprintf('Not enough points to calculate difference\n');
end

% Pattern vs \phi in polar coordinates
subplot(2,2,3)
phi =[0: 2*pi/( N_phi-1):2*pi];
theta = pi/2;
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta)*ones(size(phi));
polar(phi, abs(F))
title('1D pattern vs \phi with \theta=\pi/2'); grid on
```

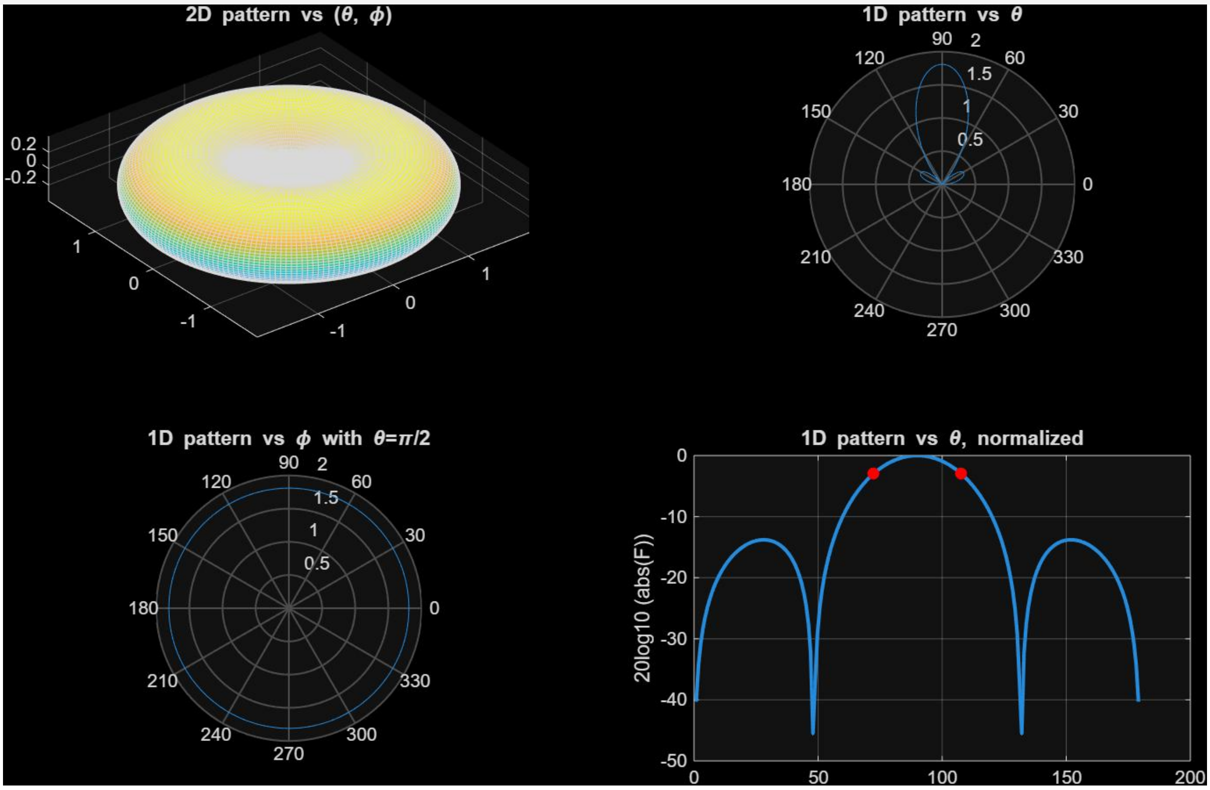


Number of mainbeams: 1; 3dB mainbeam width: 47.9397; Sidebeam level: NA

d. $f = 300$ MHz, $l = 0.6\lambda$

```
%Plot 2D pattern
f = 3*10^8; c = 3*10^8; lambda = c/f; k = 2*pi/lambda;
l = 0.6*lambda;
N_theta = 200; N_phi = 200;
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
F = ((cos(k*l*cos(theta))-cos(k*l))./sin(theta));
XD = abs(F).*sin(theta).*cos(phi);
YD = abs(F).*sin(theta).*sin(phi);
ZD = abs(F).*cos(theta);
subplot(2,2,1); surf(XD,YD,ZD);
title('2D pattern vs (\theta, \phi)'); axis image; rotate3d on; grid on;
% Pattern vs \theta in polar coordinates
N_theta = 200;
theta = [0: pi/( N_theta-1):pi];
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta);
subplot(2,2,2)
polar(theta,abs(F))
title('1D pattern vs \theta'); grid on
% Pattern vs \theta in rectangular coordinates
subplot(2,2,4)
% Normalize F for dB calculation
F_normalized = abs(F)/max(abs(F));
F_db = 20*log10(F_normalized);

% Define target dB value
target_db = -3;
% Find ALL indices close to -3 dB (within a small tolerance)
tolerance = 0.1;  % Adjust this value to control how close to -3 dB
indices = find(abs(F_db - target_db) < tolerance);
% Get corresponding theta values in degrees
theta_at_minus3db = theta(indices) * 180/pi;
plot(theta/pi*180, F_db, 'linewidth', 2)
title('1D pattern vs \theta, normalized'); grid on; ylabel('20log10
(abs(F))')
% Print out the -3 dB point values
disp('Theta values at -3 dB:');
for i = 1:length(indices)
    fprintf('Theta = %.4f degrees\n', theta_at_minus3db(i));
end
hold on;
plot(theta_at_minus3db, F_db(indices), 'ro', 'MarkerFaceColor', 'r');
hold off;
% Calculate and display the difference between max and min theta values at -3 dB
if length(theta_at_minus3db) > 1
    theta_difference = max(theta_at_minus3db) - min(theta_at_minus3db);
    fprintf('Difference between max and min theta at -3 dB: %.4f
degrees\n', theta_difference);
else
    fprintf('Not enough points to calculate difference\n');
```

```
end

% Pattern vs \phi in polar coordinates
subplot(2,2,3)
phi =[0: 2*pi/( N_phi-1):2*pi];
theta = pi/2;
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta)*ones(size(phi));
polar(phi, abs(F))
title('1D pattern vs \phi with \theta=\pi/2'); grid on

% Find peaks in dB scale, with theta as x-axis values
[pks, locs] = findpeaks(F_db, theta * 180/pi);  % locs contains theta
values in degrees

% Identify main lobe (highest peak)
[main_lobe_peak, main_index] = max(pks);
main_lobe_theta = locs(main_index);  % Main lobe theta
% Remove the main lobe from consideration
pks(main_index) = [];
locs(main_index) = [];  % locs already contains theta values in degrees
% Find the highest remaining peak (side lobe)
if ~isempty(pks)
    [side_lobe_peak, side_index] = max(pks);
    fprintf('Side lobe peak: %.4f dB\n', side_lobe_peak);
else
    fprintf('No side lobe detected.\n');
end
```

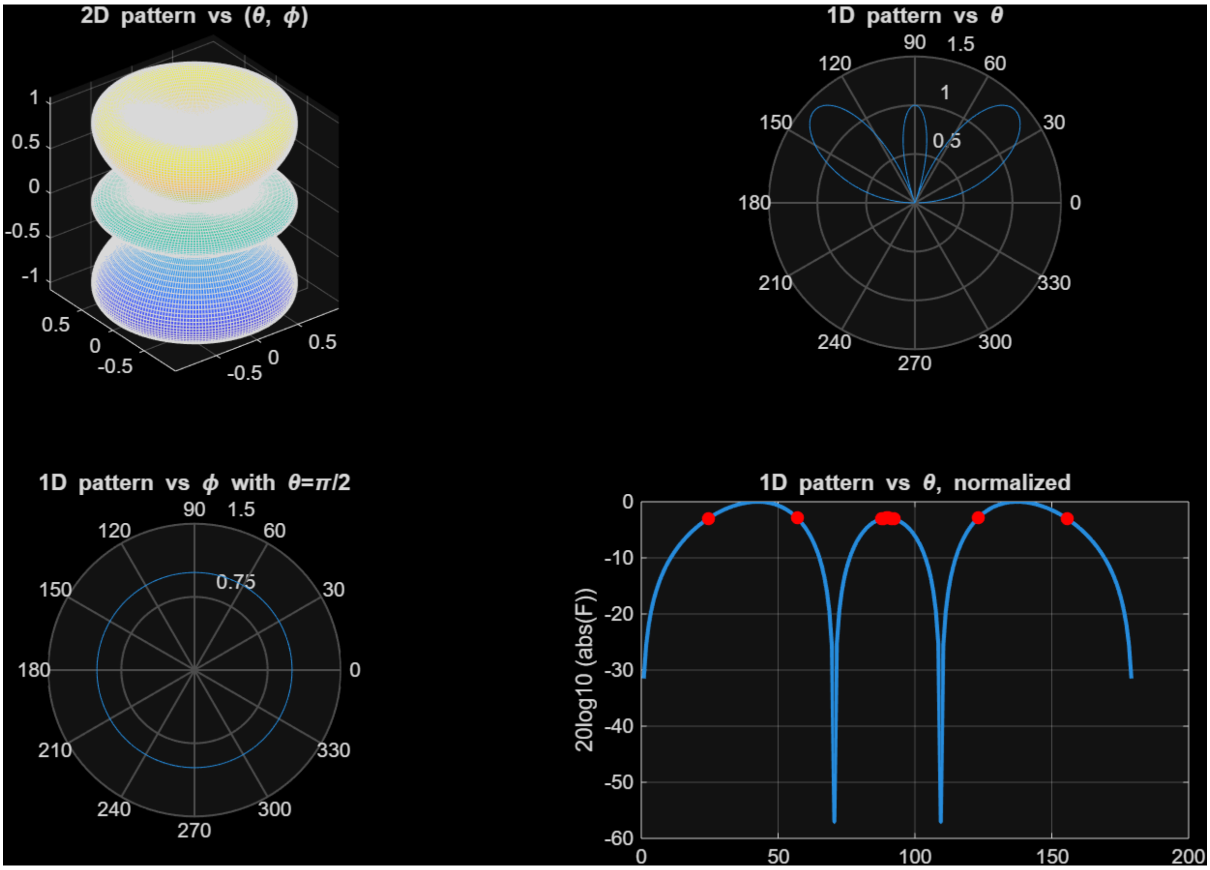


Number of mainbeams: 1; 3dB mainbeam width: 35.2764; Sidebeam level: -13.791

e. $f = 300$ MHz, $l = 0.75\lambda$

```
%Plot 2D pattern
f = 3*10^8; c = 3*10^8; lambda = c/f; k = 2*pi/lambda;
l = 0.75*lambda;
N_theta = 200; N_phi = 200;
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
F = ((cos(k*l*cos(theta))-cos(k*l))./sin(theta));
XD = abs(F).*sin(theta).*cos(phi);
YD = abs(F).*sin(theta).*sin(phi);
ZD = abs(F).*cos(theta);
subplot(2,2,1); surf(XD,YD,ZD);
title('2D pattern vs (\theta, \phi)'); axis image; rotate3d on; grid on;
% Pattern vs \theta in polar coordinates
N_theta = 200;
theta = [0: pi/( N_theta-1):pi];
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta);
subplot(2,2,2)
polar(theta,abs(F))
title('1D pattern vs \theta'); grid on
% Pattern vs \theta in rectangular coordinates
subplot(2,2,4)
% Normalize F for dB calculation
F_normalized = abs(F)/max(abs(F));
F_db = 20*log10(F_normalized);

% Define target dB value
target_db = -3;

% Find ALL indices close to -3 dB (within a small tolerance)
tolerance = 0.1;  % Adjust this value to control how close to -3 dB
indices = find(abs(F_db - target_db) < tolerance);

% Get corresponding theta values in degrees
theta_at_minus3db = theta(indices) * 180/pi;

plot(theta/pi*180, F_db, 'linewidth', 2)
title('1D pattern vs \theta, normalized'); grid on; ylabel('20log10
(abs(F))')

% Print out the -3 dB point values
disp('Theta values at -3 dB:');
for i = 1:length(indices)
    fprintf('Theta = %.4f degrees\n', theta_at_minus3db(i));
end

% Calculate and display the difference between max and min theta values at
-3 dB
if length(theta_at_minus3db) > 1
    theta_difference = max(theta_at_minus3db) - min(theta_at_minus3db);
```

```
    fprintf('Difference between max and min theta at -3 dB: %.4f
degrees\n', theta_difference);
else
    fprintf('Not enough points to calculate difference\n');
end
hold on;
plot(theta_at_minus3db, F_db(indices), 'ro', 'MarkerFaceColor', 'r');
hold off;

% Pattern vs \phi in polar coordinates
subplot(2,2,3)
phi =[0: 2*pi/( N_phi-1):2*pi];
theta = pi/2;
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta)*ones(size(phi));
polar(phi, abs(F))
title('1D pattern vs \phi with \theta=\pi/2'); grid on

% Find peaks in dB scale, with theta as x-axis values
[pks, locs] = findpeaks(F_db, theta * 180/pi);  % locs contains theta
values in degrees

% Identify main lobe (highest peak)
[main_lobe_peak, main_index] = max(pks);
main_lobe_theta = locs(main_index);  % Main lobe theta

% Remove the main lobe from consideration
pks(main_index) = [];
locs(main_index) = [];  % locs already contains theta values in degrees

% Define a small tolerance to filter out values too close to the main lobe
peak
tolerance = max(eps, 1e-6);  % Use machine epsilon or a small threshold

% Remove any values that are effectively the same as the main lobe peak
valid_indices = abs(pks - main_lobe_peak) > tolerance;
pks = pks(valid_indices);
locs = locs(valid_indices);

% Find the highest remaining peak (side lobe)
if ~isempty(pks)
    [side_lobe_peak, side_index] = max(pks);

    fprintf('Side lobe peak: %.4f dB\n', side_lobe_peak);
else
    fprintf('No side lobe detected.\n');
end
```



Number of mainbeams: 2; 3dB mainbeam width: 32.5628; Sidebeam level: -2.9221

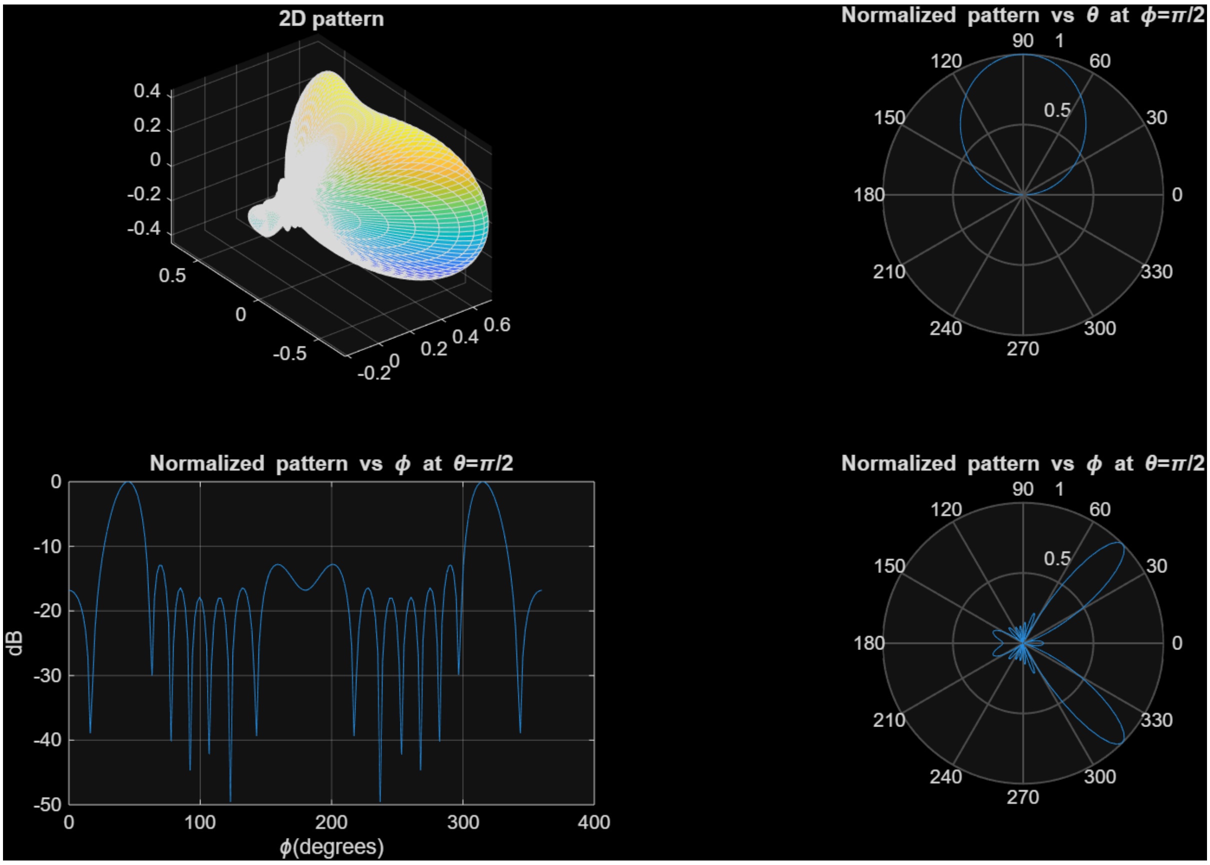
Frequency	Length of the Dipole	Number of mainbeams	3dB mainbeam width	Sidebeam level
300 MHz	0.125	1	87.7387	NA
300 MHz	0.25	1	78.6935	NA
300 MHz	0.5	1	47.9397	NA
300 MHz	0.6	1	35.2764	-13.791
300 MHz	0.75	2	32.5628	-2.9221

As the dipole length increases, the mainbeam becomes narrower, and sidebeams start to appear and grow stronger. For shorter lengths, there is only one mainbeam, but at 0.75λ, a second mainbeam forms. This shows that longer dipoles change the beam shape, making it more focused but also adding side lobes.

Exercise 5.2

a.

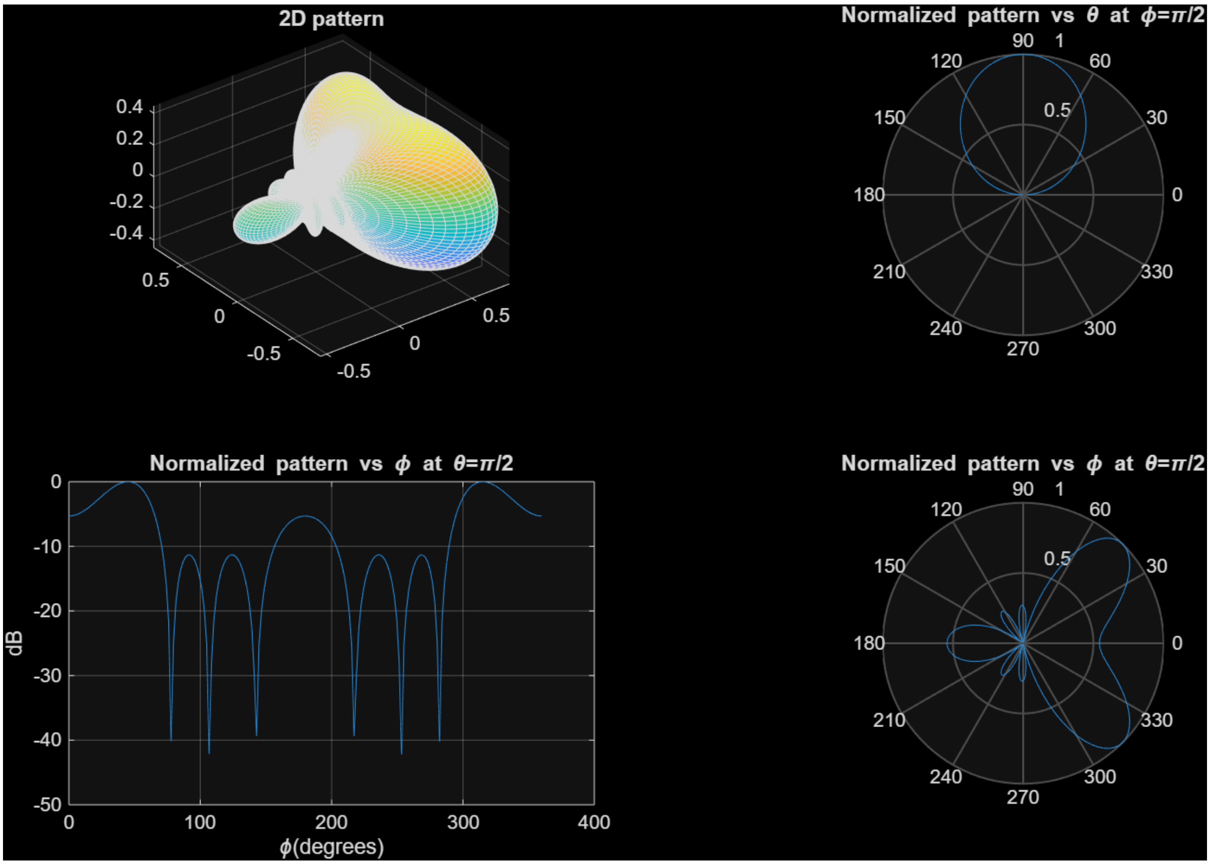
```
N = 8;
f = 3*10^8; c = 3*10^8; lambda = c/f;
l = 0.25*lambda;
d = 0.5*lambda;
k = 2*pi/lambda;
phi_0 = pi/4;
xi = -k * d * cos(phi_0);
N_theta = 100; N_phi = 200;
% Plot 2D pattern (versus (\theta, \phi))
subplot(2,2,1)
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F; % Coefficients irelevant to (\theta,\phi) are ignored
XD = E_mag.*sin(theta).*cos(phi);
YD = E_mag.*sin(theta).*sin(phi);
ZD = E_mag.*cos(theta);
surf(XD,YD,ZD);
title('2D pattern'); axis image; rotate3d on;
% Plot 1D pattern versus \theta with \phi=pi/2
subplot(2,2,2)
phi = pi/2;
theta = [0:pi/(N_theta-1):pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
polar(theta, E_mag/max(E_mag))
title('Normalized pattern vs \theta at \phi=\pi/2')
% Plot 1D pattern versus \phi with \theta=pi/2(H-plane)
subplot(2,2,3)
theta = pi/2;
phi=[0:2*pi/( N_phi-1):2*pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
plot(phi/pi*180, 20*log10(E_mag/max(E_mag)))
title('Normalized pattern vs \phi at \theta=\pi/2'); grid on;
xlabel('\phi(degrees)'); ylabel('dB')

% Polar plot 1D pattern versus \phi with \theta=pi/2
subplot(2,2,4)
polar(phi, E_mag/max(E_mag))
title('Normalized pattern vs \phi at \theta=\pi/2')
```


2D pattern
Normalized pattern vs θ at ϕ=π/2
Normalized pattern vs ϕ at θ=π/2
dB
ϕ(degrees)
Normalized pattern vs ϕ at θ=π/2

b.

1. N = 4

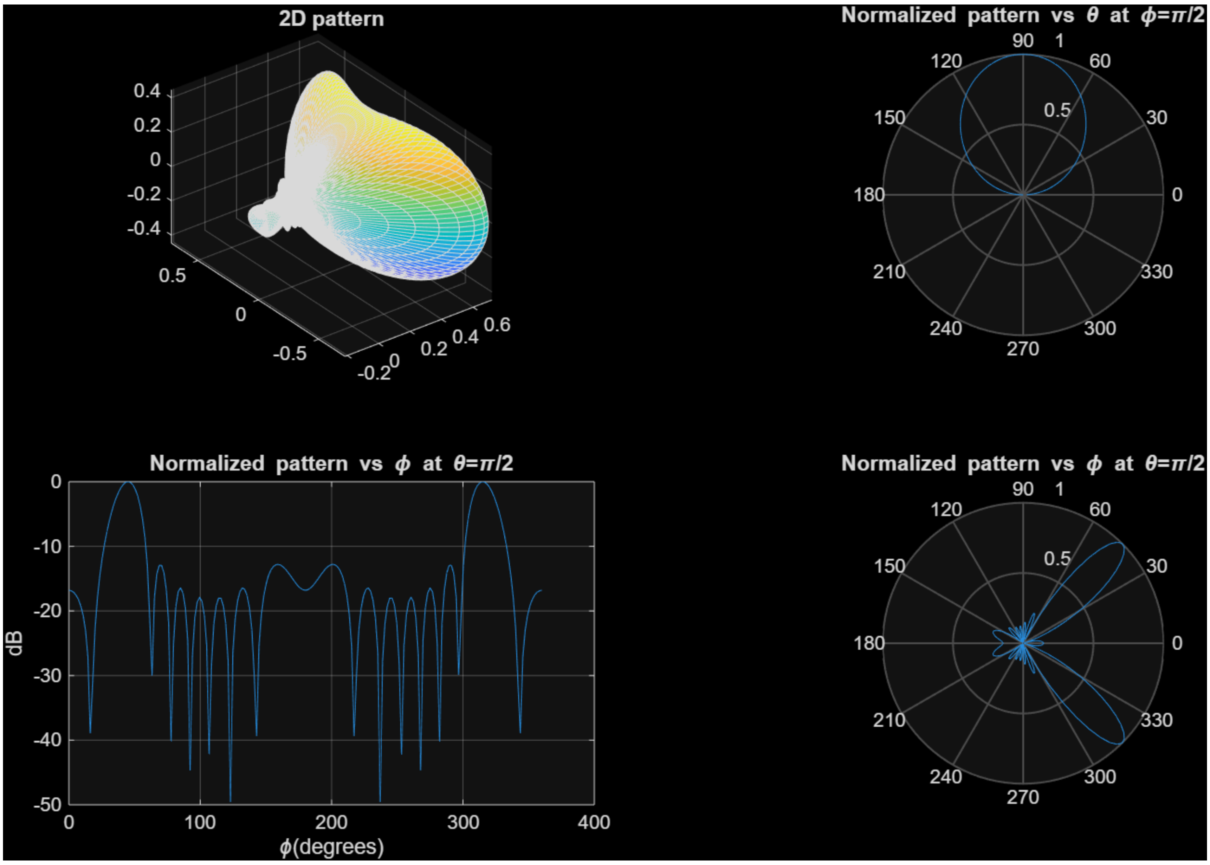
```
N = 4;
f = 3*10^8; c = 3*10^8; lambda = c/f;
l = 0.25*lambda;
d = 0.5*lambda;
k = 2*pi/lambda;
phi_0 = pi/4;
xi = -k * d * cos(phi_0);
N_theta = 100; N_phi = 200;
% Plot 2D pattern (versus (\theta, \phi))
subplot(2,2,1)
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F; % Coefficients irelevant to (\theta,\phi) are ignored
XD = E_mag.*sin(theta).*cos(phi);
YD = E_mag.*sin(theta).*sin(phi);
ZD = E_mag.*cos(theta);
surf(XD,YD,ZD);
title('2D pattern'); axis image; rotate3d on;
% Plot 1D pattern versus \theta with \phi=pi/2
subplot(2,2,2)
phi = pi/2;
theta = [0:pi/(N_theta-1):pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
polar(theta, E_mag/max(E_mag))
title('Normalized pattern vs \theta at \phi=\pi/2')
% Plot 1D pattern versus \phi with \theta=pi/2(H-plane)
subplot(2,2,3)
theta = pi/2;
phi=[0:2*pi/( N_phi-1):2*pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
plot(phi/pi*180, 20*log10(E_mag/max(E_mag)))
title('Normalized pattern vs \phi at \theta=\pi/2'); grid on;
xlabel('\phi(degrees)'); ylabel('dB')

% Polar plot 1D pattern versus \phi with \theta=pi/2
subplot(2,2,4)
polar(phi, E_mag/max(E_mag))
title('Normalized pattern vs \phi at \theta=\pi/2')
```



3dB mainbeam width: 40.47

2. N = 8

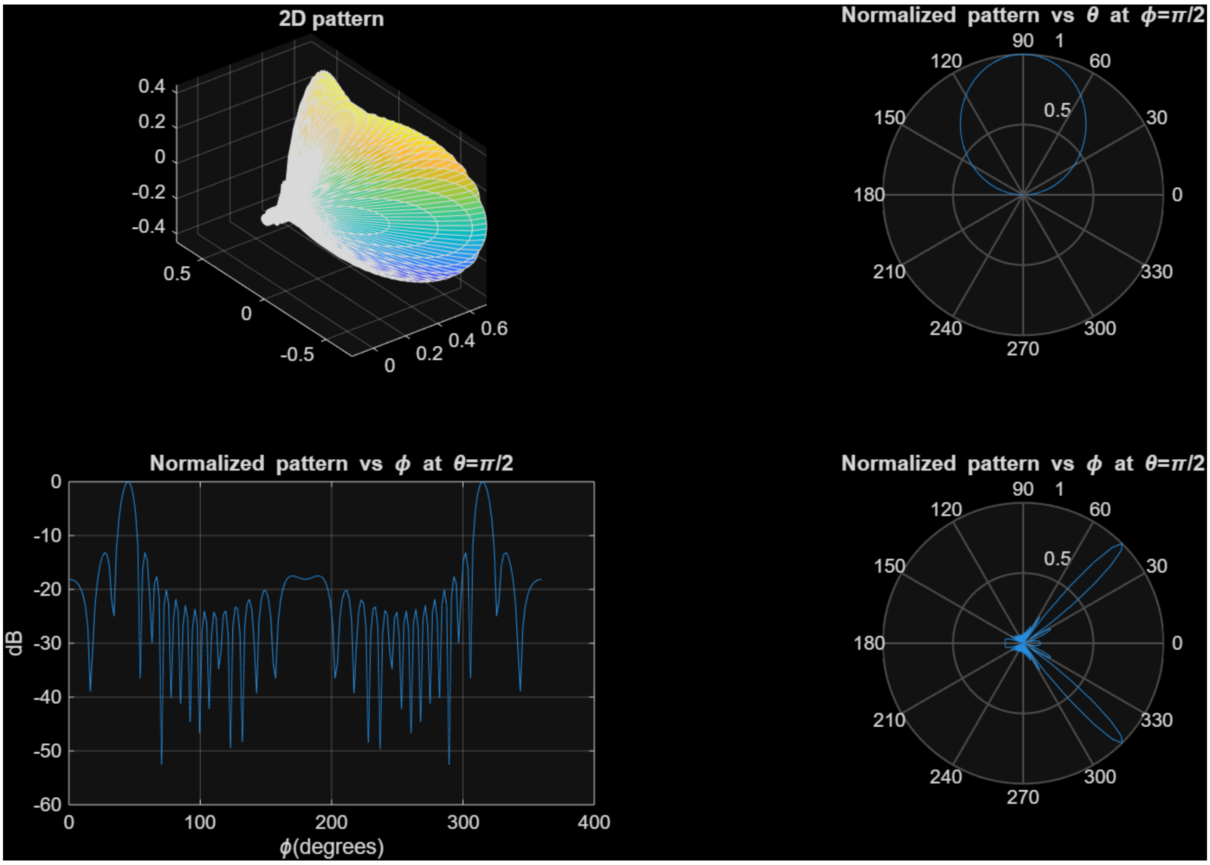
```
N = 8;
f = 3*10^8; c = 3*10^8; lambda = c/f;
l = 0.25*lambda;
d = 0.5*lambda;
k = 2*pi/lambda;
phi_0 = pi/4;
xi = -k * d * cos(phi_0);
N_theta = 100; N_phi = 200;
% Plot 2D pattern (versus (\theta, \phi))
subplot(2,2,1)
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F; % Coefficients irelevant to (\theta,\phi) are ignored
XD = E_mag.*sin(theta).*cos(phi);
YD = E_mag.*sin(theta).*sin(phi);
ZD = E_mag.*cos(theta);
surf(XD,YD,ZD);
title('2D pattern'); axis image; rotate3d on;
% Plot 1D pattern versus \theta with \phi=pi/2
subplot(2,2,2)
phi = pi/2;
theta = [0:pi/(N_theta-1):pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
polar(theta, E_mag/max(E_mag))
title('Normalized pattern vs \theta at \phi=\pi/2')
% Plot 1D pattern versus \phi with \theta=pi/2(H-plane)
subplot(2,2,3)
theta = pi/2;
phi=[0:2*pi/( N_phi-1):2*pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
plot(phi/pi*180, 20*log10(E_mag/max(E_mag)))
title('Normalized pattern vs \phi at \theta=\pi/2'); grid on;
xlabel('\phi(degrees)'); ylabel('dB')

% Polar plot 1D pattern versus \phi with \theta=pi/2
subplot(2,2,4)
polar(phi, E_mag/max(E_mag))
title('Normalized pattern vs \phi at \theta=\pi/2')
```



3dB mainbeam width: 18.25

3. N = 16

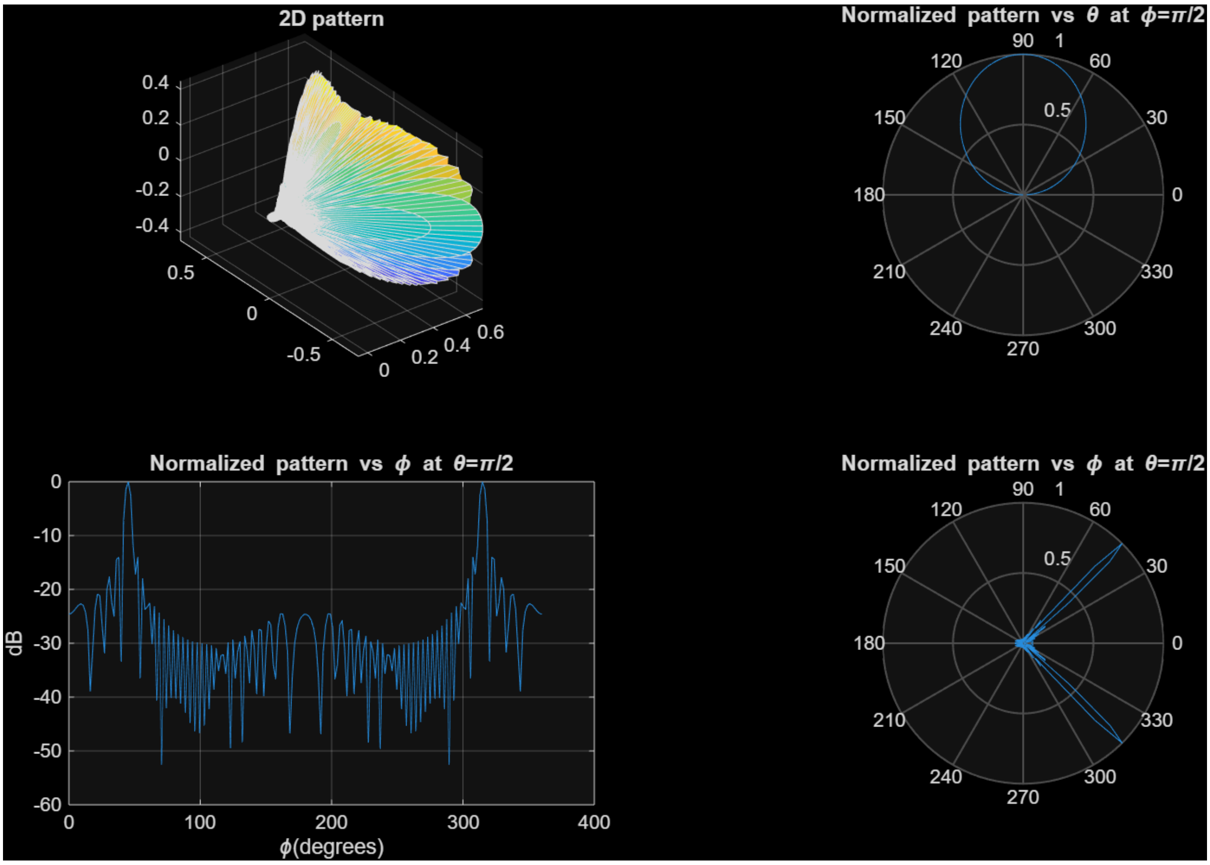
```
N = 16;
f = 3*10^8; c = 3*10^8; lambda = c/f;
l = 0.25*lambda;
d = 0.5*lambda;
k = 2*pi/lambda;
phi_0 = pi/4;
xi = -k * d * cos(phi_0);
N_theta = 100; N_phi = 200;
% Plot 2D pattern (versus (\theta, \phi))
subplot(2,2,1)
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F; % Coefficients irelevant to (\theta,\phi) are ignored
XD = E_mag.*sin(theta).*cos(phi);
YD = E_mag.*sin(theta).*sin(phi);
ZD = E_mag.*cos(theta);
surf(XD,YD,ZD);
title('2D pattern'); axis image; rotate3d on;
% Plot 1D pattern versus \theta with \phi=pi/2
subplot(2,2,2)
phi = pi/2;
theta = [0:pi/(N_theta-1):pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
polar(theta, E_mag/max(E_mag))
title('Normalized pattern vs \theta at \phi=\pi/2')
% Plot 1D pattern versus \phi with \theta=pi/2(H-plane)
subplot(2,2,3)
theta = pi/2;
phi=[0:2*pi/( N_phi-1):2*pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
plot(phi/pi*180, 20*log10(E_mag/max(E_mag)))
title('Normalized pattern vs \phi at \theta=\pi/2'); grid on;
xlabel('\phi(degrees)'); ylabel('dB')

% Polar plot 1D pattern versus \phi with \theta=pi/2
subplot(2,2,4)
polar(phi, E_mag/max(E_mag))
title('Normalized pattern vs \phi at \theta=\pi/2')
```



3dB mainbeam width: 8.83

4. N = 32

```
N = 32;
f = 3*10^8; c = 3*10^8; lambda = c/f;
l = 0.25*lambda;
d = 0.5*lambda;
k = 2*pi/lambda;
phi_0 = pi/4;
xi = -k * d * cos(phi_0);
N_theta = 100; N_phi = 200;
% Plot 2D pattern (versus (\theta, \phi))
subplot(2,2,1)
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F; % Coefficients irelevant to (\theta,\phi) are ignored
XD = E_mag.*sin(theta).*cos(phi);
YD = E_mag.*sin(theta).*sin(phi);
ZD = E_mag.*cos(theta);
surf(XD,YD,ZD);
title('2D pattern'); axis image; rotate3d on;
% Plot 1D pattern versus \theta with \phi=pi/2
subplot(2,2,2)
phi = pi/2;
theta = [0:pi/(N_theta-1):pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
polar(theta, E_mag/max(E_mag))
title('Normalized pattern vs \theta at \phi=\pi/2')
% Plot 1D pattern versus \phi with \theta=pi/2(H-plane)
subplot(2,2,3)
theta = pi/2;
phi=[0:2*pi/( N_phi-1):2*pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
plot(phi/pi*180, 20*log10(E_mag/max(E_mag)))
title('Normalized pattern vs \phi at \theta=\pi/2'); grid on;
xlabel('\phi(degrees)'); ylabel('dB')

% Polar plot 1D pattern versus \phi with \theta=pi/2
subplot(2,2,4)
polar(phi, E_mag/max(E_mag))
title('Normalized pattern vs \phi at \theta=\pi/2')
```



3dB mainbeam width: 4.22

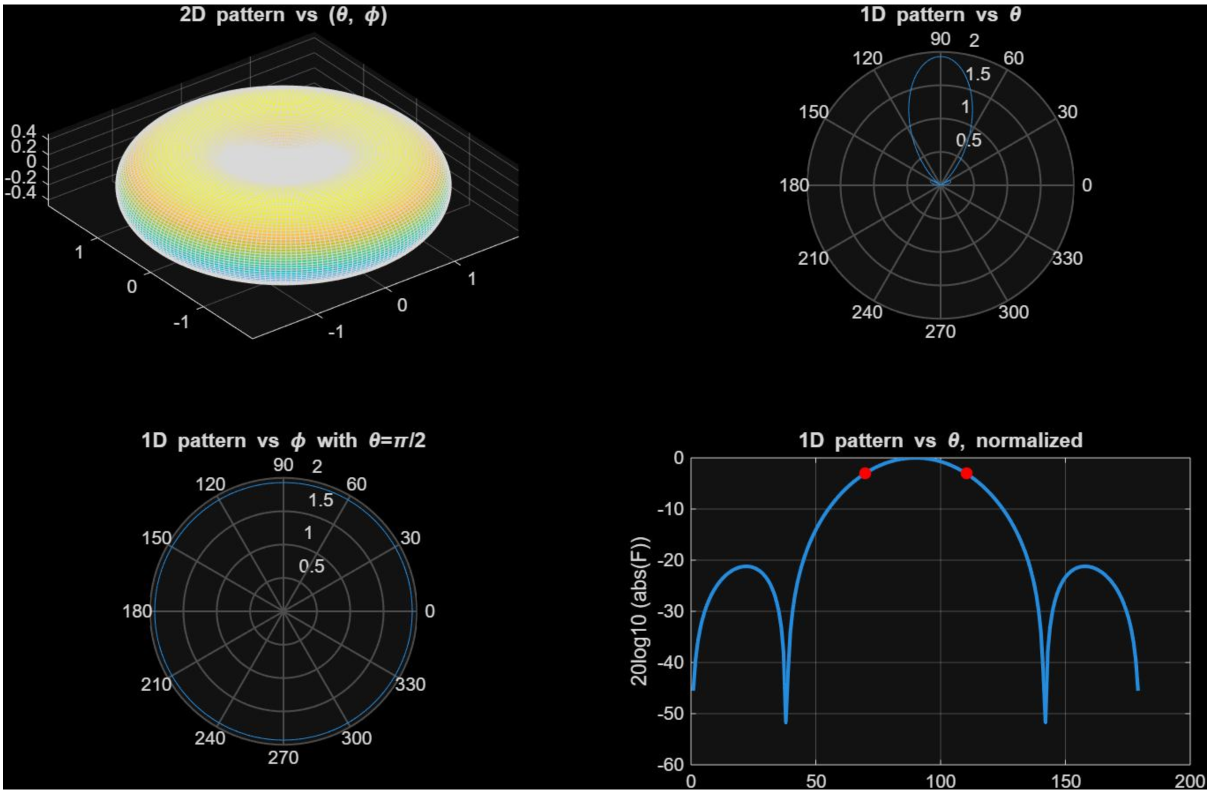
Number of antennas	3dB mainbeam width
4	40.47
8	18.25
16	8.83
32	4.22

As the number of antennas increases, the mainbeam becomes narrower, improving directionality and reducing beamwidth. This shows that larger arrays enhance beam focusing, leading to a more concentrated radiation pattern.

Task 5.1

```
% Plot 2D pattern
f = 3*10^8; c = 3*10^8; lambda = c/f; k = 2*pi/lambda;
l = 0.56*lambda;
N_theta = 200; N_phi = 200;
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
F = ((cos(k*l*cos(theta))-cos(k*l))./sin(theta));
XD = abs(F).*sin(theta).*cos(phi);
YD = abs(F).*sin(theta).*sin(phi);
ZD = abs(F).*cos(theta);
subplot(2,2,1); surf(XD,YD,ZD);
title('2D pattern vs (\theta, \phi)'); axis image; rotate3d on; grid on;
% Pattern vs \theta in polar coordinates
N_theta = 200;
theta = [0: pi/( N_theta-1):pi];
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta);
subplot(2,2,2)
polar(theta,abs(F))
title('1D pattern vs \theta'); grid on
% Pattern vs \theta in rectangular coordinates
subplot(2,2,4)
% Normalize F for dB calculation
F_normalized = abs(F)/max(abs(F));
F_db = 20*log10(F_normalized);

% Define target dB value
target_db = -3;

% Find ALL indices close to -3 dB (within a small tolerance)
tolerance = 0.1;  % Adjust this value to control how close to -3 dB
indices = find(abs(F_db - target_db) < tolerance);

% Get corresponding theta values in degrees
theta_at_minus3db = theta(indices) * 180/pi;

plot(theta/pi*180, F_db, 'linewidth', 2)
title('1D pattern vs \theta, normalized'); grid on; ylabel('20log10
(abs(F))')
hold on;
plot(theta_at_minus3db, F_db(indices), 'ro', 'MarkerFaceColor', 'r');
hold off;

% Print out the -3 dB point values
disp('Theta values at -3 dB:');
for i = 1:length(indices)
    fprintf('Theta = %.4f degrees\n', theta_at_minus3db(i));
end
```

```
% Calculate and display the difference between max and min theta values at
-3 dB
if length(theta_at_minus3db) > 1
    theta_difference = max(theta_at_minus3db) - min(theta_at_minus3db);
    fprintf('Difference between max and min theta at -3 dB: %.4f
degrees\n', theta_difference);
else
    fprintf('Not enough points to calculate difference\n');
end

% Pattern vs \phi in polar coordinates
subplot(2,2,3)
phi =[0: 2*pi/( N_phi-1):2*pi];
theta = pi/2;
F = (cos(k*l*cos(theta))-cos(k*l))./sin(theta)*ones(size(phi));
polar(phi, abs(F))
title('1D pattern vs \phi with \theta=\pi/2'); grid on

fprintf("Total Length 2l = %.2f\n", 2*l);

% Find peaks in dB scale, with theta as x-axis values
[pks, locs] = findpeaks(F_db, theta * 180/pi);  % locs contains theta
values in degrees

% Identify main lobe (highest peak)
[main_lobe_peak, main_index] = max(pks);
main_lobe_theta = locs(main_index);  % Main lobe theta

% Remove the main lobe from consideration
pks(main_index) = [];
locs(main_index) = [];  % locs already contains theta values in degrees

% Find the highest remaining peak (side lobe)
if ~isempty(pks)
    [side_lobe_peak, side_index] = max(pks);

    fprintf('Side lobe peak: %.4f dB\n', side_lobe_peak);
else
    fprintf('No side lobe detected.\n');
end
```



Total Length 2l = 1.12

Side lobe peak: -21.2063 dB

3dB beamwidth: 40.7035 degrees

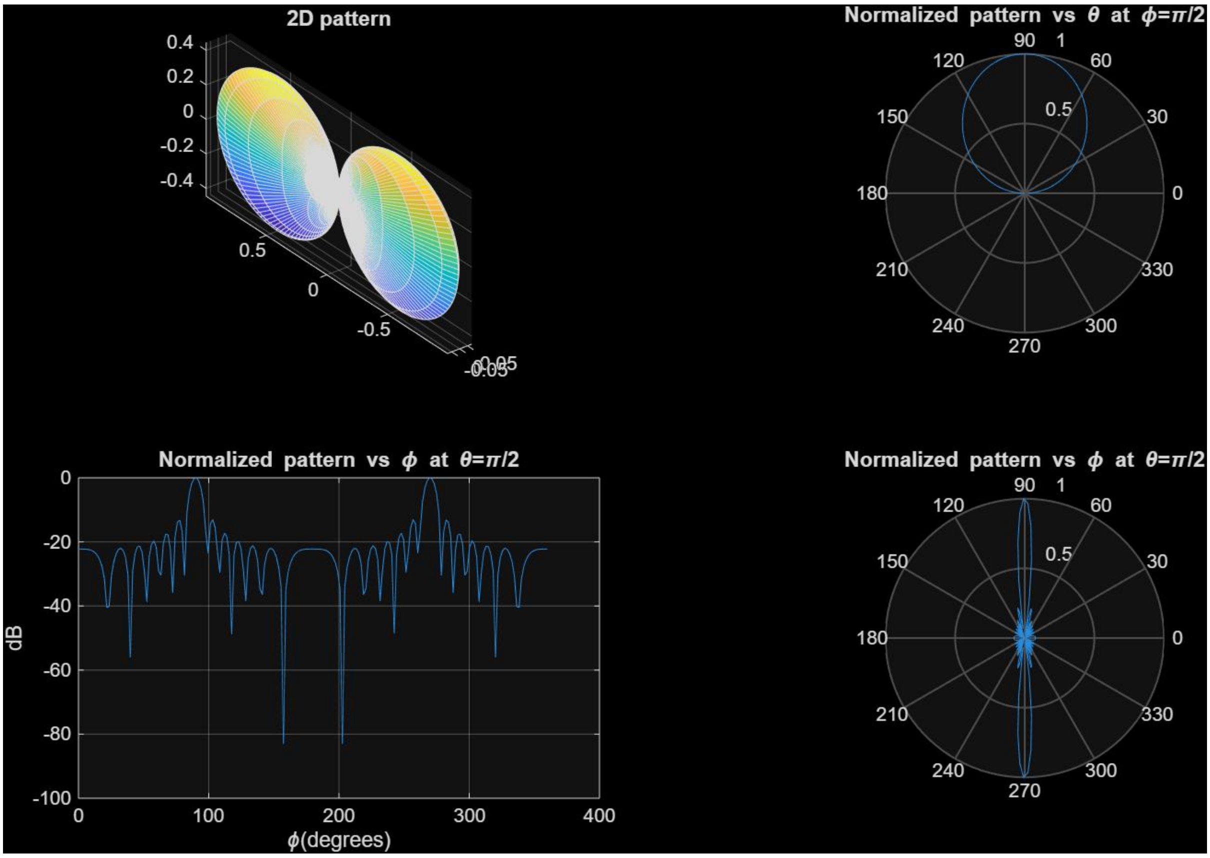
Task 5.2

a.

```
N = 13; xi = 0;
f = 3*10^8; c = 3*10^8; lambda = c/f;
l = 0.25*lambda;
d = 0.5*lambda;
k = 2*pi/lambda;
N_theta = 100; N_phi = 200;
% Plot 2D pattern (versus (\theta, \phi))
subplot(2,2,1)
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F; % Coefficients irelevant to (\theta,\phi) are ignored
XD = E_mag.*sin(theta).*cos(phi);
YD = E_mag.*sin(theta).*sin(phi);
ZD = E_mag.*cos(theta);
surf(XD,YD,ZD);
title('2D pattern'); axis image; rotate3d on;
% Plot 1D pattern versus \theta with \phi=pi/2
subplot(2,2,2)
phi = pi/2;
theta = [0:pi/(N_theta-1):pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
polar(theta, E_mag/max(E_mag))
title('Normalized pattern vs \theta at \phi=\pi/2')
% Plot 1D pattern versus \phi with \theta=pi/2(H-plane)
subplot(2,2,3)
theta = pi/2;
phi=[0:2*pi/( N_phi-1):2*pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
plot(phi/pi*180, 20*log10(E_mag/max(E_mag)))
title('Normalized pattern vs \phi at \theta=\pi/2'); grid on;
xlabel('\phi(degrees)'); ylabel('dB')

% Find all points at 3dB
target_db = -3;
tolerance = 1.5;
indices = find(abs(20*log10(E_mag/max(E_mag)) - target_db) < tolerance);
phi_at_minus3db = phi(indices) * 180/pi;
disp('Phi values at -3 dB:');
for i = 1:length(indices)
```

```
    fprintf('Phi = %.4f degrees\n', phi_at_minus3db(i));
end
if length(phi_at_minus3db) > 1
    phi_difference = max(phi_at_minus3db) - min(phi_at_minus3db);
    fprintf('Difference between max and min phi at -3 dB: %.4f degrees\n',
phi_difference);
else
    fprintf('Not enough points to calculate difference\n');
end

% Polar plot 1D pattern versus \phi with \theta=pi/2
subplot(2,2,4)
polar(phi, E_mag/max(E_mag))
title('Normalized pattern vs \phi at \theta=\pi/2')
```

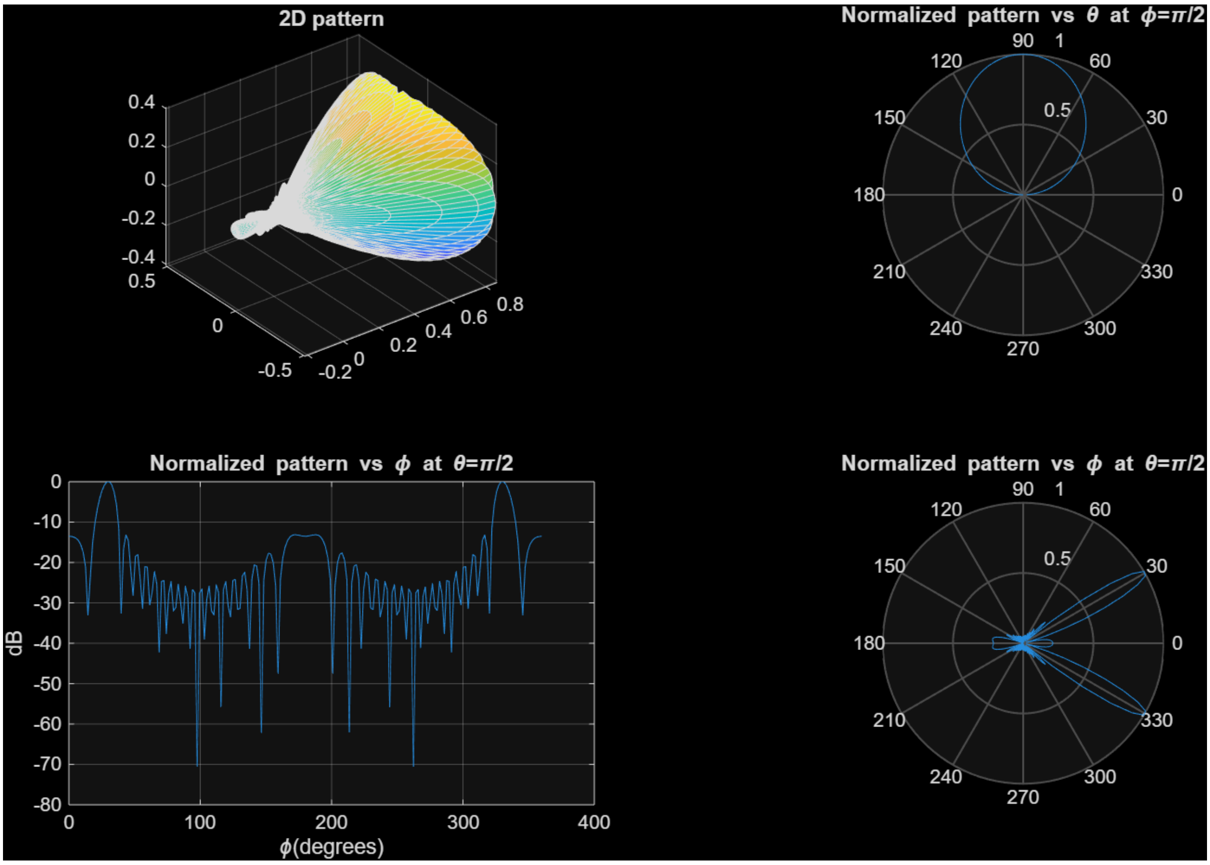
Minimum number of antennas required: 13



b.

```
N = 20;
f = 3*10^8; c = 3*10^8; lambda = c/f;
l = 0.25*lambda;
d = 0.5*lambda;
k = 2*pi/lambda;
phi_0 = pi/6;
xi = -k * d * cos(phi_0);
N_theta = 100; N_phi = 200;
% Plot 2D pattern (versus (\theta, \phi))
subplot(2,2,1)
[theta,phi] = meshgrid(0:pi./(N_theta-1):pi, 0:2*pi./(N_phi-1):2*pi);
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F; % Coefficients irelevant to (\theta,\phi) are ignored
XD = E_mag.*sin(theta).*cos(phi);
YD = E_mag.*sin(theta).*sin(phi);
ZD = E_mag.*cos(theta);
surf(XD,YD,ZD);
title('2D pattern'); axis image; rotate3d on;
% Plot 1D pattern versus \theta with \phi=pi/2
subplot(2,2,2)
phi = pi/2;
theta = [0:pi/(N_theta-1):pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
polar(theta, E_mag/max(E_mag))
title('Normalized pattern vs \theta at \phi=\pi/2')
% Plot 1D pattern versus \phi with \theta=pi/2(H-plane)
subplot(2,2,3)
theta = pi/2;
phi=[0:2*pi/( N_phi-1):2*pi];
psi = xi + k*d*sin(theta).*cos(phi);
A = 1/N*abs(sin(N*psi/2))./abs(sin(psi/2));
F = (abs(((cos(k*l*cos(theta))-cos(k*l))./sin(theta))));
E_mag = A.*F;
plot(phi/pi*180, 20*log10(E_mag/max(E_mag)))
title('Normalized pattern vs \phi at \theta=\pi/2'); grid on;
xlabel('\phi(degrees)'); ylabel('dB')

% Polar plot 1D pattern versus \phi with \theta=pi/2
subplot(2,2,4)
polar(phi, E_mag/max(E_mag))
title('Normalized pattern vs \phi at \theta=\pi/2')
```

Minimum number of antennas required: 20



xxxxxxx