UNIVERSITY
OF WOLLONGONG
IN DUBAI

Assignment Cover Sheet

Student Name	Student number
Taha Yaseen Parker	8243578

Subject code and name	ECTE213 – Engineering Electromagnetics
Lab Instructor	Mr. Mahmoud Alkakuri
Title of Assignment	Lab 4
Date and time due	25 February 2025, 23.55
Lab Number	4

Student declaration and acknowledgment

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

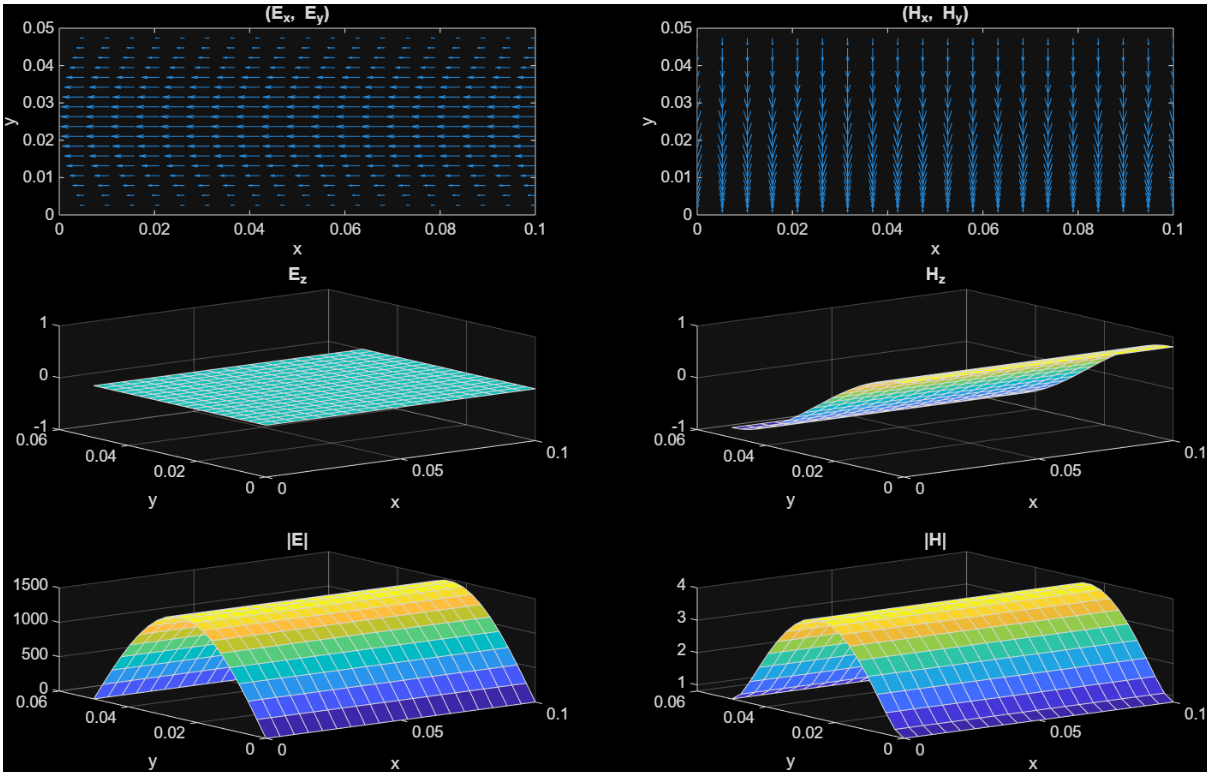
1. All team members have read the subject outline for this subject, and this assessment item meets the requirements of the subject detailed therein.
2. This assessment is entirely our work, except where we have included fully documented references to the work of others. The material in this assessment 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 4

Task 4.1 (a)

1. TE_{01}

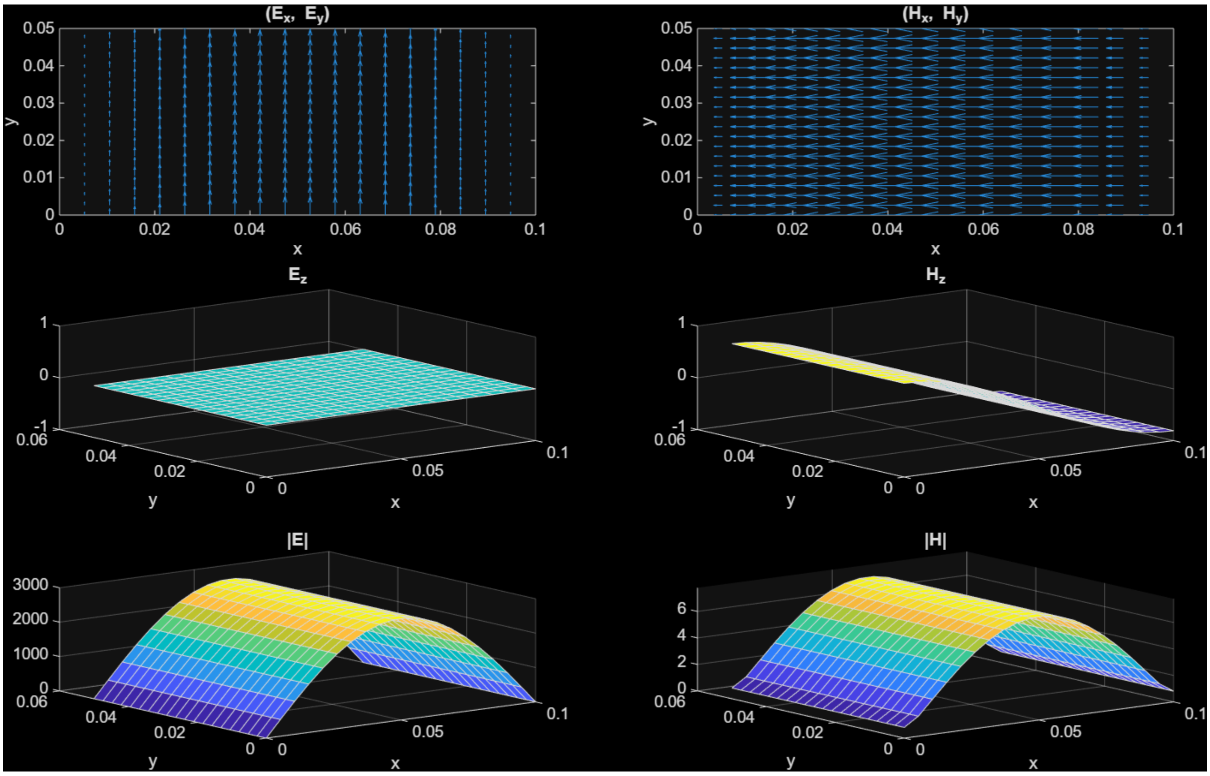
```
function [E_x, E_y, E_z, H_x, H_y,
H_z]=Example4_2_TEWave2DXY_Plot(epsilon_r,mu_r,H0,m,p,a,b,z,f,t)
    %% Function: Demonstrate the field components of a TE21 mode wave with
H0=1
    %  Input:    Parameters are same as for TEWave2DXY
    epsilon_r=1;
    mu_r=1;
    H0=1;
    m=0;
    p=1;
    a=0.1;
    b=0.05;
    f=2*10^10;
    z=0;
    t=0.1/f;

    %% Compute and plot the field components
    Na = 20;
    Nb = 20;
    [x,y] = meshgrid([0:a/(Na-1):a], [0:b/(Nb-1):b]);
    [E_x, E_y, E_z, H_x, H_y,
H_z]=TEWave2DXY(epsilon_r,mu_r,H0,m,p,a,b,z,f, t, Na, Nb);
    figure
    subplot(3,2,1); quiver(x,y,E_x, E_y );                           % Use
quiver to plot the Ex, Ey components in the 2D plane
    axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(E_x, E_y)')
    subplot(3,2,3); surf(x,y, E_z);                                  % Use
surf to plot the Ez component for points on the 2D plane
    title('E_z');xlabel('x'); ylabel('y');
    subplot(3,2,5); surf(x,y,
sqrt(abs(E_x.^2)+abs(E_y.^2)+abs(E_z.^2)))     % Plot the magnitude of the E
field
    title('|E|'); rotate3d on;xlabel('x'); ylabel('y');
    subplot(3,2,2); quiver(x,y,H_x, H_y, 2)                          % Plot
the Hx, Hy components
    axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(H_x, H_y)')
    subplot(3,2,4); surf(x,y, H_z)                                   % Plot
Hz component
    title('H_z');xlabel('x'); ylabel('y');
    subplot(3,2,6); surf(x,y,
sqrt(abs(H_x.^2)+abs(H_y.^2)+abs(H_z.^2)))     % Plot the magnitude of the H
field
    title('|H|'); rotate3d on; xlabel('x'); ylabel('y');
```



(E_x, E_y)
(H_x, H_y)
E_z
H_z
|E|
|H|
x
y

2. TE_{10}

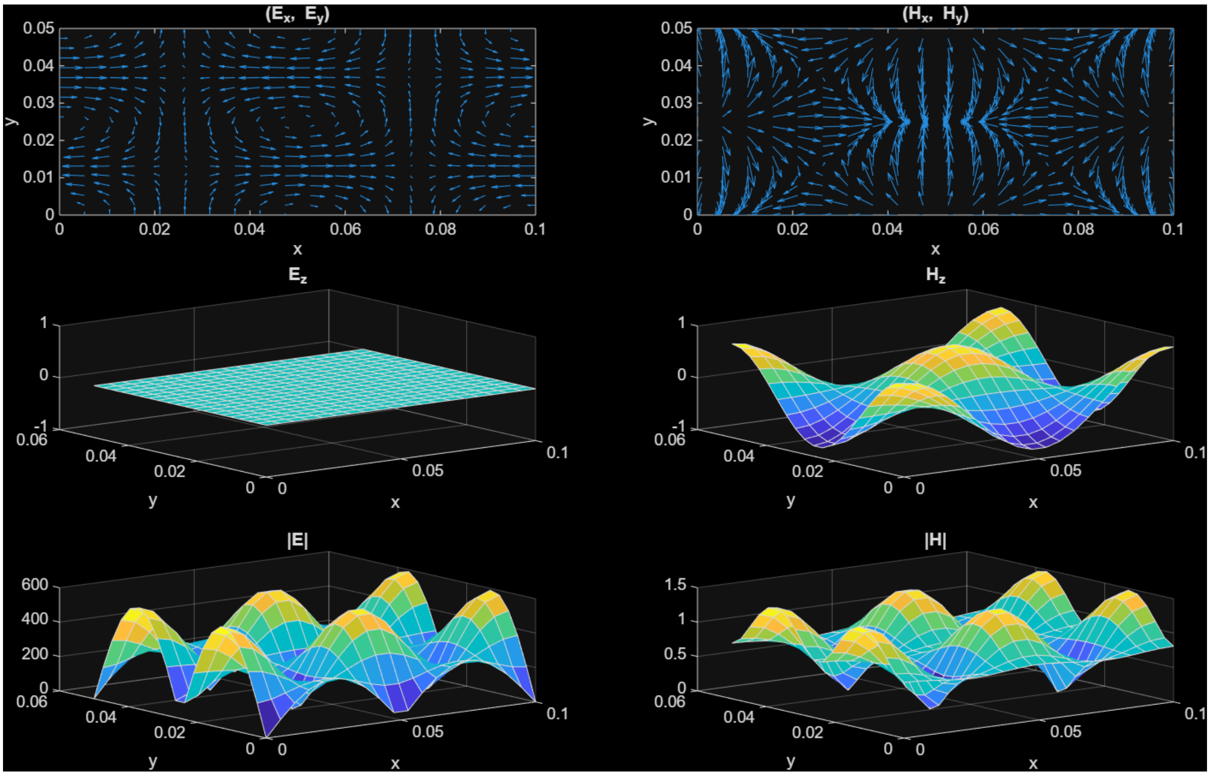
```
function [E_x, E_y, E_z, H_x, H_y,
H_z]=Example4_2_TEWave2DXY_Plot(epsilon_r,mu_r,H0,m,p,a,b,z,f,t)
    %% Function: Demonstrate the field components of a TE21 mode wave with
H0=1
    %  Input:    Parameters are same as for TEWave2DXY
    epsilon_r=1;
    mu_r=1;
    H0=1;
    m=1;
    p=0;
    a=0.1;
    b=0.05;
    f=2*10^10;
    z=0;
    t=0.1/f;

    %% Compute and plot the field components
    Na = 20;
    Nb = 20;
    [x,y] = meshgrid([0:a/(Na-1):a], [0:b/(Nb-1):b]);
    [E_x, E_y, E_z, H_x, H_y,
H_z]=TEWave2DXY(epsilon_r,mu_r,H0,m,p,a,b,z,f, t, Na, Nb);
    figure
    subplot(3,2,1); quiver(x,y,E_x, E_y );                          % Use
quiver to plot the Ex, Ey components in the 2D plane
    axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(E_x, E_y)')
    subplot(3,2,3); surf(x,y, E_z);                                 % Use
surf to plot the Ez component for points on the 2D plane
    title('E_z');xlabel('x'); ylabel('y');
    subplot(3,2,5); surf(x,y,
sqrt(abs(E_x.^2)+abs(E_y.^2)+abs(E_z.^2)))    % Plot the magnitude of the E
field
    title('|E|'); rotate3d on;xlabel('x'); ylabel('y');
    subplot(3,2,2); quiver(x,y,H_x, H_y, 2)                         % Plot
the Hx, Hy components
    axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(H_x, H_y)')
    subplot(3,2,4); surf(x,y, H_z)                                  % Plot
Hz component
    title('H_z');xlabel('x'); ylabel('y');
    subplot(3,2,6); surf(x,y,
sqrt(abs(H_x.^2)+abs(H_y.^2)+abs(H_z.^2)))    % Plot the magnitude of the H
field
    title('|H|'); rotate3d on; xlabel('x'); ylabel('y');
```



(Ex, Ey)
(Hx, Hy)
Ez
Hz
|E|
|H|

3. TE_{22}

```
function [E_x, E_y, E_z, H_x, H_y,
H_z]=Example4_2_TEWave2DXY_Plot(epsilon_r,mu_r,H0,m,p,a,b,z,f,t)
    %% Function: Demonstrate the field components of a TE21 mode wave with
H0=1
    %  Input:    Parameters are same as for TEWave2DXY
    epsilon_r=1;
    mu_r=1;
    H0=1;
    m=2;
    p=2;
    a=0.1;
    b=0.05;
    f=2*10^10;
    z=0;
    t=0.1/f;

    %% Compute and plot the field components
    Na = 20;
    Nb = 20;
    [x,y] = meshgrid([0:a/(Na-1):a], [0:b/(Nb-1):b]);
    [E_x, E_y, E_z, H_x, H_y,
H_z]=TEWave2DXY(epsilon_r,mu_r,H0,m,p,a,b,z,f, t, Na, Nb);
    figure
    subplot(3,2,1); quiver(x,y,E_x, E_y );                            % Use
quiver to plot the Ex, Ey components in the 2D plane
    axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(E_x, E_y)')
    subplot(3,2,3); surf(x,y, E_z);                                   % Use
surf to plot the Ez component for points on the 2D plane
    title('E_z');xlabel('x'); ylabel('y');
    subplot(3,2,5); surf(x,y,
sqrt(abs(E_x.^2)+abs(E_y.^2)+abs(E_z.^2)))     % Plot the magnitude of the E
field
    title('|E|'); rotate3d on;xlabel('x'); ylabel('y');
    subplot(3,2,2); quiver(x,y,H_x, H_y, 2)                           % Plot
the Hx, Hy components
    axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(H_x, H_y)')
    subplot(3,2,4); surf(x,y, H_z)                                    % Plot
Hz component
    title('H_z');xlabel('x'); ylabel('y');
    subplot(3,2,6); surf(x,y,
sqrt(abs(H_x.^2)+abs(H_y.^2)+abs(H_z.^2)))     % Plot the magnitude of the H
field
    title('|H|'); rotate3d on; xlabel('x'); ylabel('y');
```

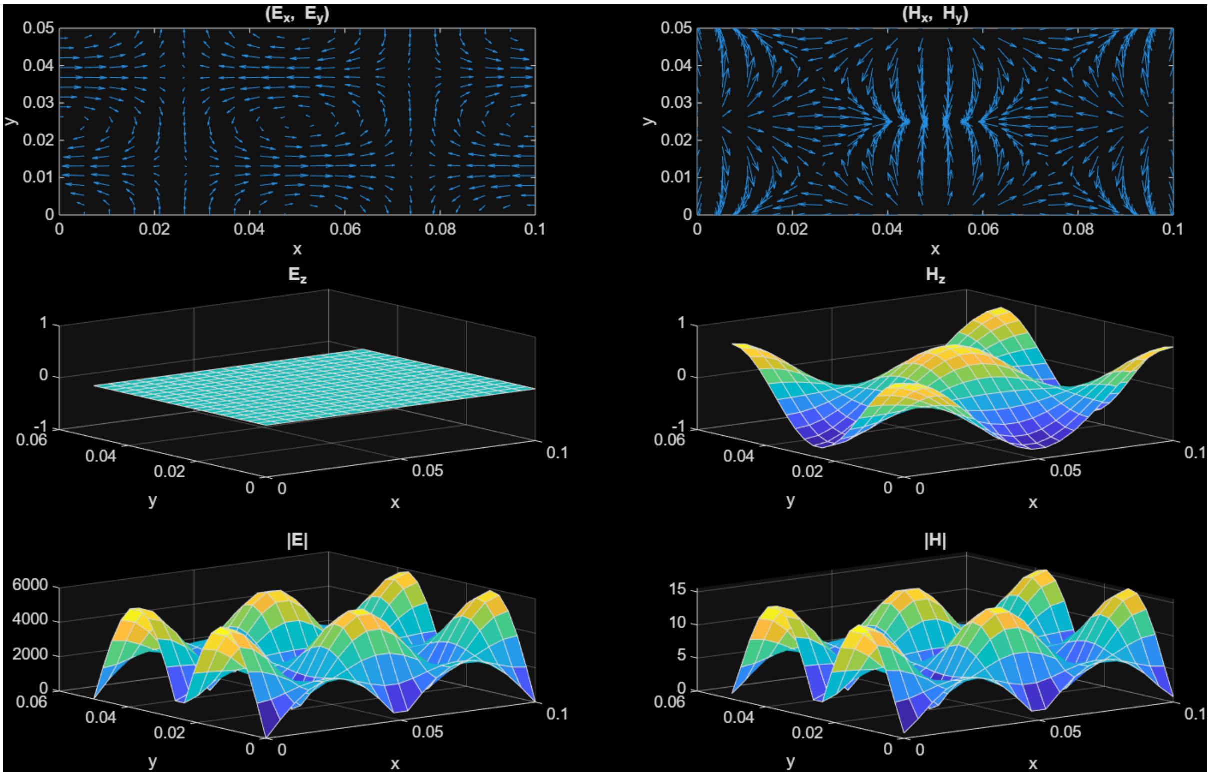


Key Differences:

The first and second plots have the opposite mode numbers, which results in opposite patterns. The patterns vary predominantly along a single axis. However, in the third plot, higher mode numbers are used, which results in a more complex pattern in both x and y directions.

4. TE_{22} ($f = 20 \times 10^{10}$)

```
function [E_x, E_y, E_z, H_x, H_y,
H_z]=Example4_2_TEWave2DXY_Plot(epsilon_r,mu_r,H0,m,p,a,b,z,f,t)
    %% Function: Demonstrate the field components of a TE21 mode wave with
H0=1
    %  Input:    Parameters are same as for TEWave2DXY
    epsilon_r=1;
    mu_r=1;
    H0=1;
    m=2;
    p=2;
    a=0.1;
    b=0.05;
    f=20*10^10;
    z=0;
    t=0.1/f;

    %% Compute and plot the field components
    Na = 20;
    Nb = 20;
    [x,y] = meshgrid([0:a/(Na-1):a], [0:b/(Nb-1):b]);
    [E_x, E_y, E_z, H_x, H_y,
H_z]=TEWave2DXY(epsilon_r,mu_r,H0,m,p,a,b,z,f, t, Na, Nb);
    figure
    subplot(3,2,1); quiver(x,y,E_x, E_y );                          % Use
quiver to plot the Ex, Ey components in the 2D plane
    axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(E_x, E_y)')
    subplot(3,2,3); surf(x,y, E_z);                                 % Use
surf to plot the Ez component for points on the 2D plane
    title('E_z');xlabel('x'); ylabel('y');
    subplot(3,2,5); surf(x,y,
sqrt(abs(E_x.^2)+abs(E_y.^2)+abs(E_z.^2)))     % Plot the magnitude of the E
field
    title('|E|'); rotate3d on;xlabel('x'); ylabel('y');
    subplot(3,2,2); quiver(x,y,H_x, H_y, 2)                         % Plot
the Hx, Hy components
    axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(H_x, H_y)')
    subplot(3,2,4); surf(x,y, H_z)                                  % Plot
Hz component
    title('H_z');xlabel('x'); ylabel('y');
    subplot(3,2,6); surf(x,y,
sqrt(abs(H_x.^2)+abs(H_y.^2)+abs(H_z.^2)))     % Plot the magnitude of the H
field
    title('|H|'); rotate3d on; xlabel('x'); ylabel('y');
```



Key Differences:

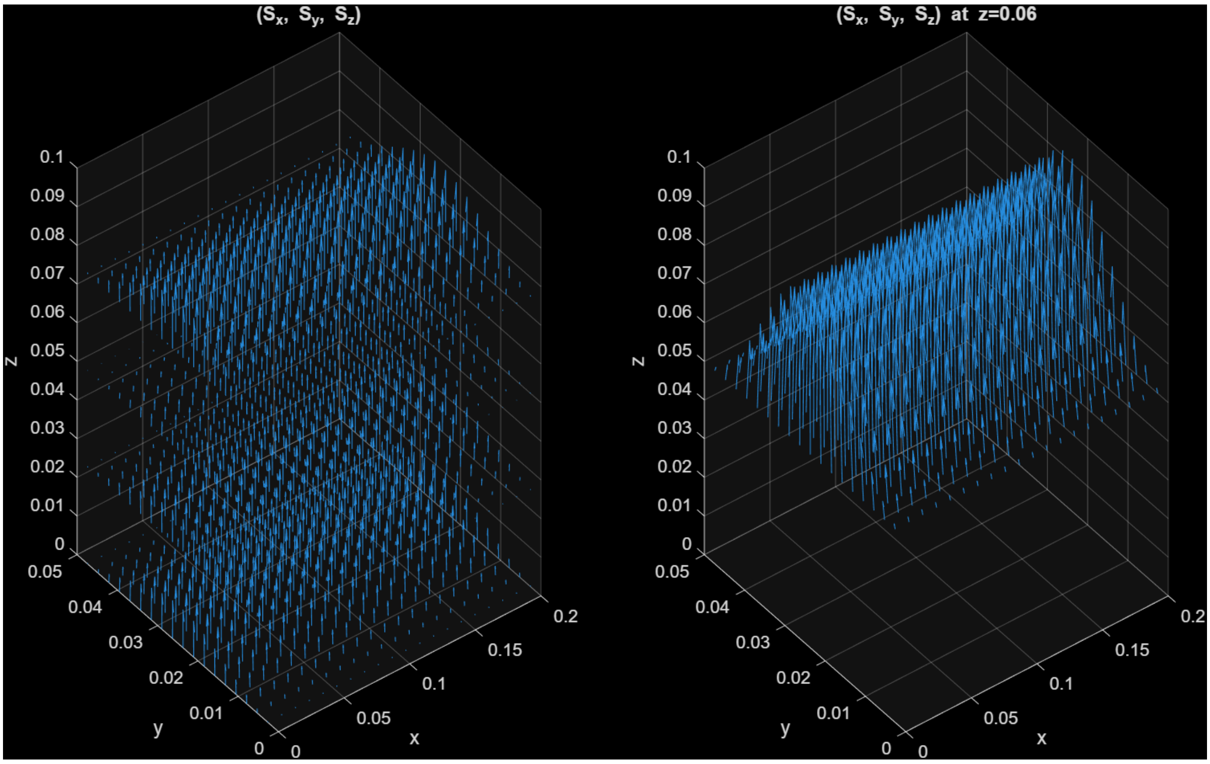
At the higher frequency, the electric and magnetic field patterns show more rapid variations with a greater number of oscillations within the same waveguide dimensions, compared to the lower frequency which exhibits fewer, longer-wavelength variations, though both maintain the characteristic TE_{22} mode structure.

Task 4.1 (b)

1. TE_{01}

```
function TEWave3D_VaryingTime( )
% Function: Animate the TE wave propagation direction at different time
% Input: The width a, the height b, the length c
%        Frequency of the wave: f (Hz)
%        The mode numbers: m, p
%        Dielectrics parameters: epsilon_r, mu_r
%        Amplitude of the H field: H0
%        Time of simulation: e.g., T = [0:0.1/f: 2*1/f]
%        Numbers of grid points in the x, y, z directions: Na, Nb, Nc
%        Pausetime: time interval of displaying results for next time
instant

a=0.2; b=0.05; c=0.1;
f=10*10^10;
m=0; p=1;
epsilon_r=2; mu_r=1;
H0=1;
T = [0:0.03/f: 0.15*1/f];
Na = 20;  Nb = 20;  Nc = 5;
pausetime = 0.5;


%% Compute and simulate the waves
[x,y,z] = ndgrid([0:a/(Na-1):a], [0:b/(Nb-1):b], [0:c/(Nc-1):c]);
Sx = zeros(Na, Nb, Nc);   Sy = zeros(Na, Nb, Nc);  Sz = zeros(Na, Nb, Nc);

for k=1:1:length(T)
    t= T(k);
    [E_x, E_y, E_z, H_x, H_y, H_z] = TEWave3D(epsilon_r,mu_r,H0,m,p,a,b,c,
f, t, Na, Nb, Nc);
    for na=1:1:Na
        for nb=1:1:Nb
            for nc=1:1:Nc
                E = [E_x(na,nb,nc) E_y(na,nb,nc) E_z(na,nb,nc)];
                H = [H_x(na,nb,nc) H_y(na,nb,nc) H_z(na,nb,nc)];
                S = cross(E,H);
                S_x(na,nb,nc) = S(1);
                S_y(na,nb,nc) = S(2);
                S_z(na,nb,nc) = S(3);
            end
        end
    end

    subplot(1,2,1);
    quiver3(x,y,z, S_x, S_y ,S_z, 4);
    axis([0 a 0 b 0 c]); xlabel('x'); ylabel('y'); zlabel('z');
title('(S_x, S_y, S_z)');rotate3d on;
```

```
    subplot(1,2,2);
    posz = ceil(Nc/2);
    quiver3(x(:,:,posz),y(:,:,posz),z(:,:,posz), S_x(:,:,posz),
S_y(:,:,posz) ,S_z(:,:,posz), 4);
    axis([0 a 0 b 0 c]); xlabel('x'); ylabel('y'); zlabel('z');
title(strcat('(S_x, S_y, S_z) at z=',num2str(posz*c/Nc))); rotate3d on;
end

%% Compute the cutoff frequency
c0 = 3e8; % Speed of light in vacuum (m/s)

fcmp = (c0 / (2 * pi * sqrt(mu_r * epsilon_r))) * sqrt((m * pi / a)^2 + (p
* pi / b)^2);

fprintf('Cutoff Frequency: %.2f GHz\n', fcmp / 1e9);
```

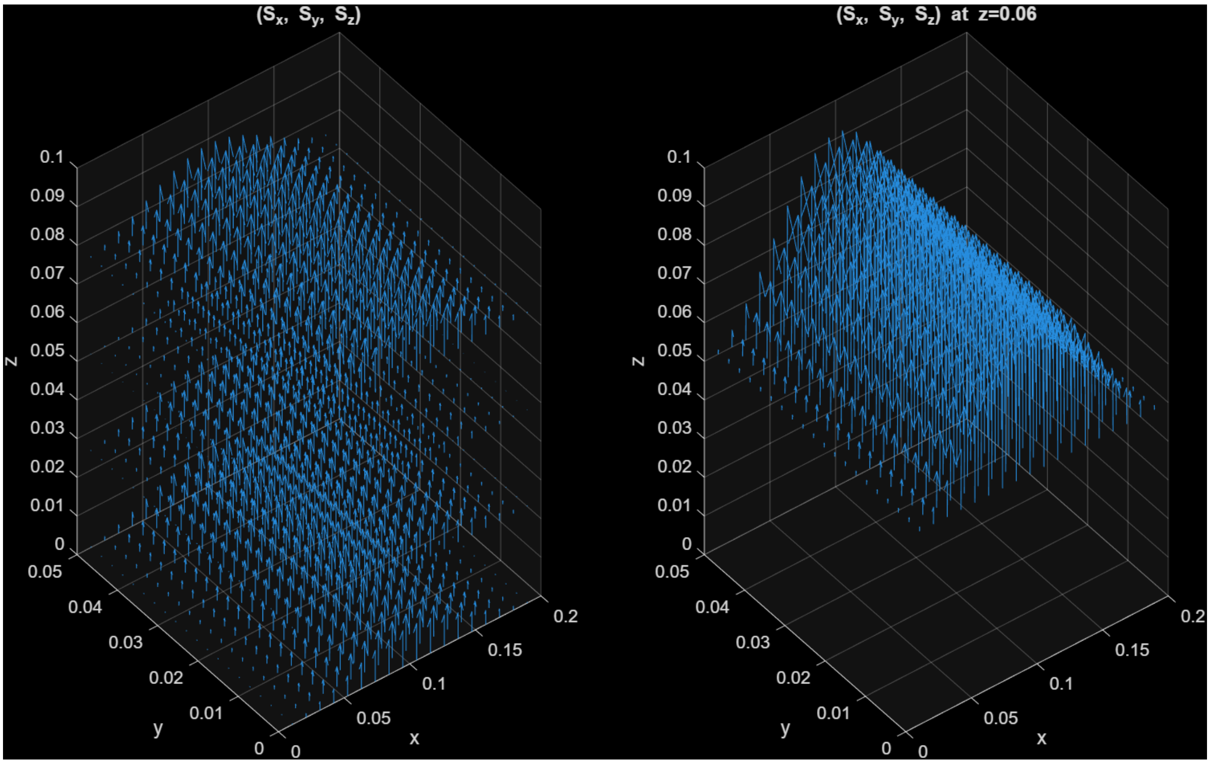


Cutoff Frequency: 2.12 GHz

2. TE_{10}

```
function TEWave3D_VaryingTime( )
% Function: Animate the TE wave propagation direction at different time
% Input: The width a, the height b, the length c
%         Frequency of the wave: f (Hz)
%         The mode numbers: m, p
%         Dielectrics parameters: epsilon_r, mu_r
%         Amplitude of the H field: H0
%         Time of simulation: e.g., T = [0:0.1/f: 2*1/f]
%         Numbers of grid points in the x, y, z directions: Na, Nb, Nc
%         Pausetime: time interval of displaying results for next time
instant

a=0.2; b=0.05; c=0.1;
f=10*10^10;
m=1; p=0;
epsilon_r=2; mu_r=1;
H0=1;
T = [0:0.03/f: 0.15*1/f];
Na = 20;  Nb = 20;  Nc = 5;
pausetime = 0.5;


%% Compute and simulate the waves
[x,y,z] = ndgrid([0:a/(Na-1):a], [0:b/(Nb-1):b], [0:c/(Nc-1):c]);
Sx = zeros(Na, Nb, Nc);   Sy = zeros(Na, Nb, Nc);  Sz = zeros(Na, Nb, Nc);

for k=1:1:length(T)
    t= T(k);
    [E_x, E_y, E_z, H_x, H_y, H_z] = TEWave3D(epsilon_r,mu_r,H0,m,p,a,b,c,
f, t, Na, Nb, Nc);
    for na=1:1:Na
        for nb=1:1:Nb
            for nc=1:1:Nc
                E = [E_x(na,nb,nc) E_y(na,nb,nc) E_z(na,nb,nc)];
                H = [H_x(na,nb,nc) H_y(na,nb,nc) H_z(na,nb,nc)];
                S = cross(E,H);
                S_x(na,nb,nc) = S(1);
                S_y(na,nb,nc) = S(2);
                S_z(na,nb,nc) = S(3);
            end
        end
    end

    subplot(1,2,1);
    quiver3(x,y,z, S_x, S_y ,S_z, 4);
    axis([0 a 0 b 0 c]); xlabel('x'); ylabel('y'); zlabel('z');
title('(S_x, S_y, S_z)');rotate3d on;

    subplot(1,2,2);
```

```
    posz = ceil(Nc/2);
    quiver3(x(:,:,posz),y(:,:,posz),z(:,:,posz), S_x(:,:,posz),
S_y(:,:,posz) ,S_z(:,:,posz), 4);
    axis([0 a 0 b 0 c]); xlabel('x'); ylabel('y'); zlabel('z');
title(strcat('(S_x, S_y, S_z) at z=',num2str(posz*c/Nc))); rotate3d on;
end

%% Compute the cutoff frequency
c0 = 3e8; % Speed of light in vacuum (m/s)

fcmp = (c0 / (2 * pi * sqrt(mu_r * epsilon_r))) * sqrt((m * pi / a)^2 + (p
* pi / b)^2);

fprintf('Cutoff Frequency: %.2f GHz\n', fcmp / 1e9);
```

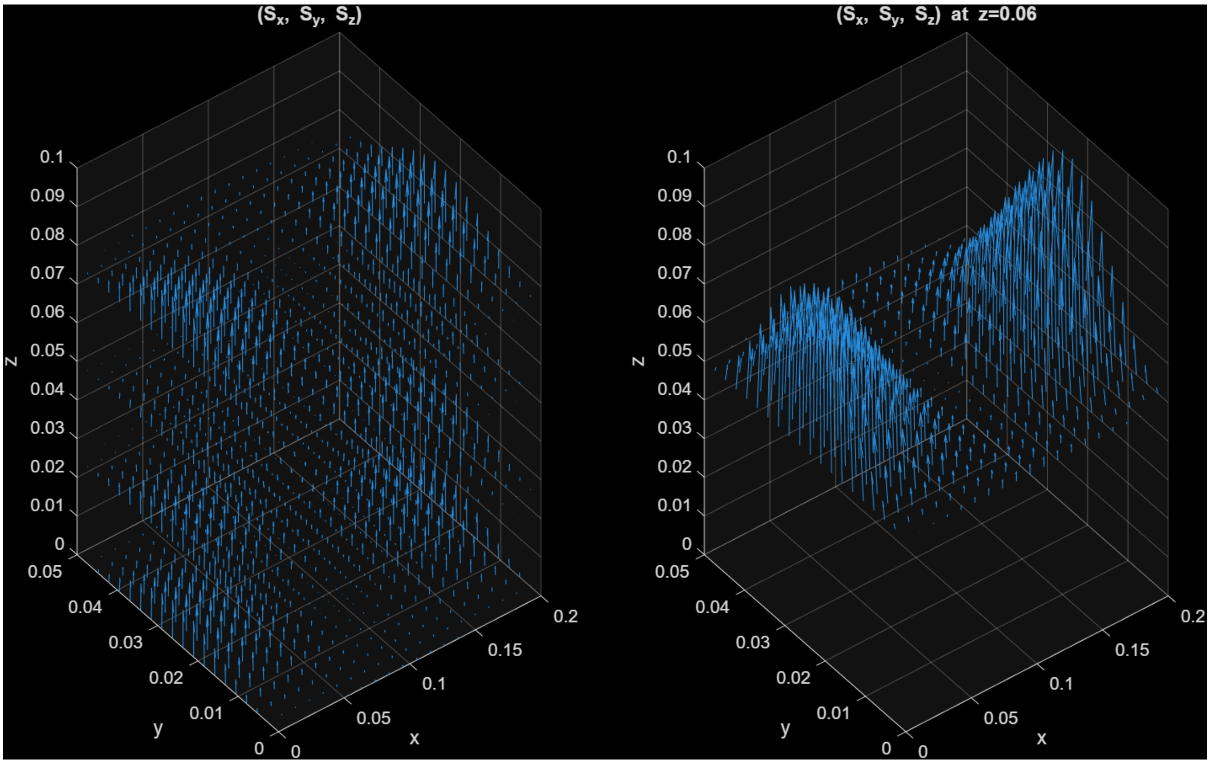


Cutoff Frequency: 0.53 GHz

3. TE_{11}

```
function TEWave3D_VaryingTime( )
% Function: Animate the TE wave propagation direction at different time
% Input: The width a, the height b, the length c
%         Frequency of the wave: f (Hz)
%         The mode numbers: m, p
%         Dielectrics parameters: epsilon_r, mu_r
%         Amplitude of the H field: H0
%         Time of simulation: e.g., T = [0:0.1/f: 2*1/f]
%         Numbers of grid points in the x, y, z directions: Na, Nb, Nc
%         Pausetime: time interval of displaying results for next time
instant

a=0.2; b=0.05; c=0.1;
f=10*10^10;
m=1; p=1;
epsilon_r=2; mu_r=1;
H0=1;
T = [0:0.03/f: 0.15*1/f];
Na = 20;  Nb = 20;  Nc = 5;
pausetime = 0.5;


%% Compute and simulate the waves
[x,y,z] = ndgrid([0:a/(Na-1):a], [0:b/(Nb-1):b], [0:c/(Nc-1):c]);
Sx = zeros(Na, Nb, Nc);   Sy = zeros(Na, Nb, Nc);  Sz = zeros(Na, Nb, Nc);

for k=1:1:length(T)
    t= T(k);
    [E_x, E_y, E_z, H_x, H_y, H_z] = TEWave3D(epsilon_r,mu_r,H0,m,p,a,b,c,
f, t, Na, Nb, Nc);
    for na=1:1:Na
        for nb=1:1:Nb
            for nc=1:1:Nc
                E = [E_x(na,nb,nc) E_y(na,nb,nc) E_z(na,nb,nc)];
                H = [H_x(na,nb,nc) H_y(na,nb,nc) H_z(na,nb,nc)];
                S = cross(E,H);
                S_x(na,nb,nc) = S(1);
                S_y(na,nb,nc) = S(2);
                S_z(na,nb,nc) = S(3);
            end
        end
    end

    subplot(1,2,1);
    quiver3(x,y,z, S_x, S_y ,S_z, 4);
    axis([0 a 0 b 0 c]); xlabel('x'); ylabel('y'); zlabel('z');
title('(S_x, S_y, S_z)');rotate3d on;

    subplot(1,2,2);
```

```
    posz = ceil(Nc/2);
    quiver3(x(:,:,posz),y(:,:,posz),z(:,:,posz), S_x(:,:,posz),
S_y(:,:,posz) ,S_z(:,:,posz), 4);
    axis([0 a 0 b 0 c]); xlabel('x'); ylabel('y'); zlabel('z');
title(strcat('(S_x, S_y, S_z) at z=',num2str(posz*c/Nc))); rotate3d on;
end

%% Compute the cutoff frequency
c0 = 3e8; % Speed of light in vacuum (m/s)

fcmp = (c0 / (2 * pi * sqrt(mu_r * epsilon_r))) * sqrt((m * pi / a)^2 + (p
* pi / b)^2);

fprintf('Cutoff Frequency: %.2f GHz\n', fcmp / 1e9);
```

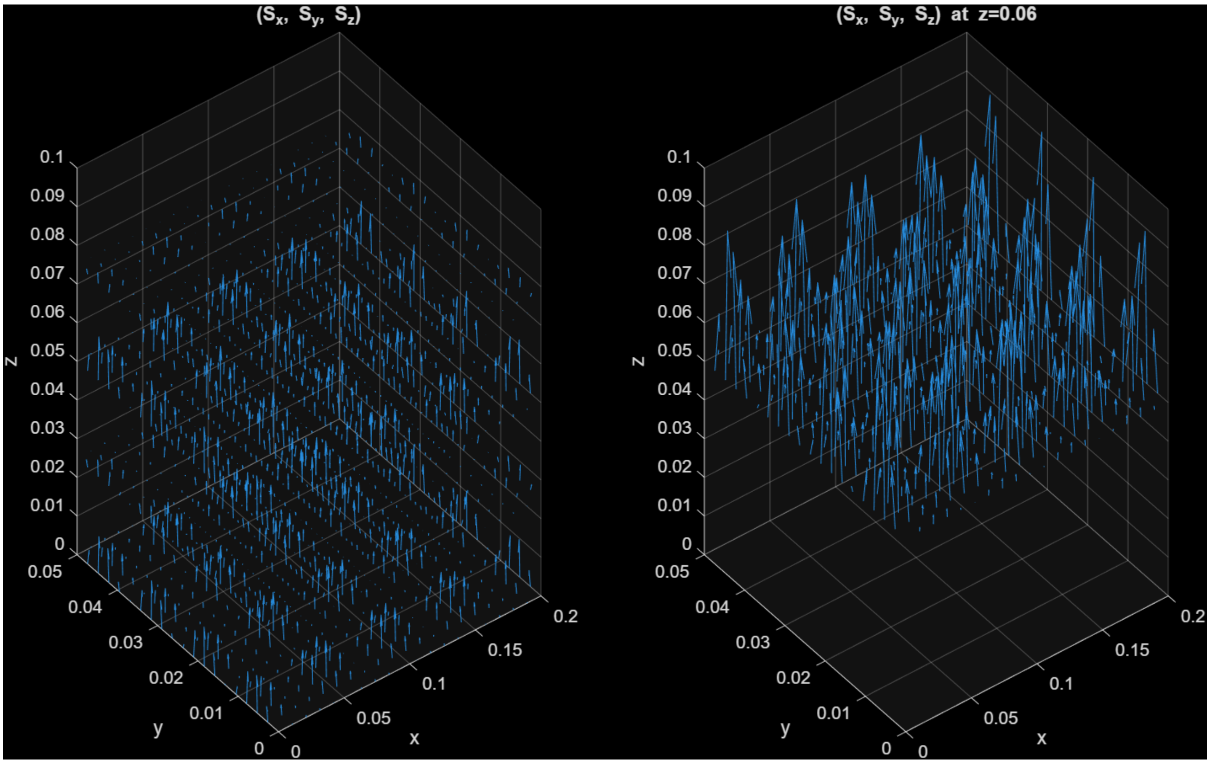


Cutoff Frequency: 2.19 GHz

4. TE_{44}

```
function TEWave3D_VaryingTime( )
% Function: Animate the TE wave propagation direction at different time
% Input: The width a, the height b, the length c
%         Frequency of the wave: f (Hz)
%         The mode numbers: m, p
%         Dielectrics parameters: epsilon_r, mu_r
%         Amplitude of the H field: H0
%         Time of simulation: e.g., T = [0:0.1/f: 2*1/f]
%         Numbers of grid points in the x, y, z directions: Na, Nb, Nc
%         Pausetime: time interval of displaying results for next time
instant

a=0.2; b=0.05; c=0.1;
f=10*10^10;
m=4; p=4;
epsilon_r=2; mu_r=1;
H0=1;
T = [0:0.03/f: 0.15*1/f];
Na = 20;  Nb = 20;  Nc = 5;
pausetime = 0.5;


%% Compute and simulate the waves
[x,y,z] = ndgrid([0:a/(Na-1):a], [0:b/(Nb-1):b], [0:c/(Nc-1):c]);
Sx = zeros(Na, Nb, Nc);   Sy = zeros(Na, Nb, Nc);  Sz = zeros(Na, Nb, Nc);

for k=1:1:length(T)
    t= T(k);
    [E_x, E_y, E_z, H_x, H_y, H_z] = TEWave3D(epsilon_r,mu_r,H0,m,p,a,b,c,
f, t, Na, Nb, Nc);
    for na=1:1:Na
        for nb=1:1:Nb
            for nc=1:1:Nc
                E = [E_x(na,nb,nc) E_y(na,nb,nc) E_z(na,nb,nc)];
                H = [H_x(na,nb,nc) H_y(na,nb,nc) H_z(na,nb,nc)];
                S = cross(E,H);
                S_x(na,nb,nc) = S(1);
                S_y(na,nb,nc) = S(2);
                S_z(na,nb,nc) = S(3);
            end
        end
    end

    subplot(1,2,1);
    quiver3(x,y,z, S_x, S_y ,S_z, 4);
    axis([0 a 0 b 0 c]); xlabel('x'); ylabel('y'); zlabel('z');
title('(S_x, S_y, S_z)');rotate3d on;

    subplot(1,2,2);
```

```
    posz = ceil(Nc/2);
    quiver3(x(:,:,posz),y(:,:,posz),z(:,:,posz), S_x(:,:,posz),
S_y(:,:,posz) ,S_z(:,:,posz), 4);
    axis([0 a 0 b 0 c]); xlabel('x'); ylabel('y'); zlabel('z');
title(strcat('(S_x, S_y, S_z) at z=',num2str(posz*c/Nc))); rotate3d on;
end

%% Compute the cutoff frequency
c0 = 3e8; % Speed of light in vacuum (m/s)

fcmp = (c0 / (2 * pi * sqrt(mu_r * epsilon_r))) * sqrt((m * pi / a)^2 + (p
* pi / b)^2);

fprintf('Cutoff Frequency: %.2f GHz\n', fcmp / 1e9);
```



Cutoff Frequency: 8.75 GHz

Key Differences:

For TE_{01}, the Poynting vector primarily varies along the y direction, showing a simple transverse pattern. Conversely, for TE_{10}, the Poynting vector varies along the x-direction while remaining uniform along the y-direction, creating a different field distribution compared to TE_{01}. For TE_{11}, both x and y-variations are present, leading to a more complex interaction between electric and magnetic fields. For TE_{44}, we can see highly intricate wave pattern with multiple oscillations in both x and y directions, resulting in a dense energy distribution.

Task 4.2 (a)

1. TM_{11}

```
function TEWave3D_VaryingTime( )
% Function: Animate the TE wave propagation direction at different time

a=0.15; b=0.05;
m=1; p=1;
epsilon_r=8; mu_r=1;
H0=1;

%% Compute the cutoff frequency
c0 = 3e8; % Speed of light in vacuum (m/s)

fcmp = (c0 / (2 * pi * sqrt(mu_r * epsilon_r))) * sqrt((m * pi / a)^2 + (p
* pi / b)^2);

fprintf('Cutoff Frequency: %.2f GHz\n', fcmp / 1e9);
```

Cutoff Frequency: 1.12 GHz

2. TM_{21}

```
function TEWave3D_VaryingTime( )
% Function: Animate the TE wave propagation direction at different time

a=0.15; b=0.05;
m=2; p=1;
epsilon_r=8; mu_r=1;
H0=1;

%% Compute the cutoff frequency
c0 = 3e8; % Speed of light in vacuum (m/s)

fcmp = (c0 / (2 * pi * sqrt(mu_r * epsilon_r))) * sqrt((m * pi / a)^2 + (p
* pi / b)^2);

fprintf('Cutoff Frequency: %.2f GHz\n', fcmp / 1e9);
```

Cutoff Frequency: 1.27 GHz

Task 4.2 (b)

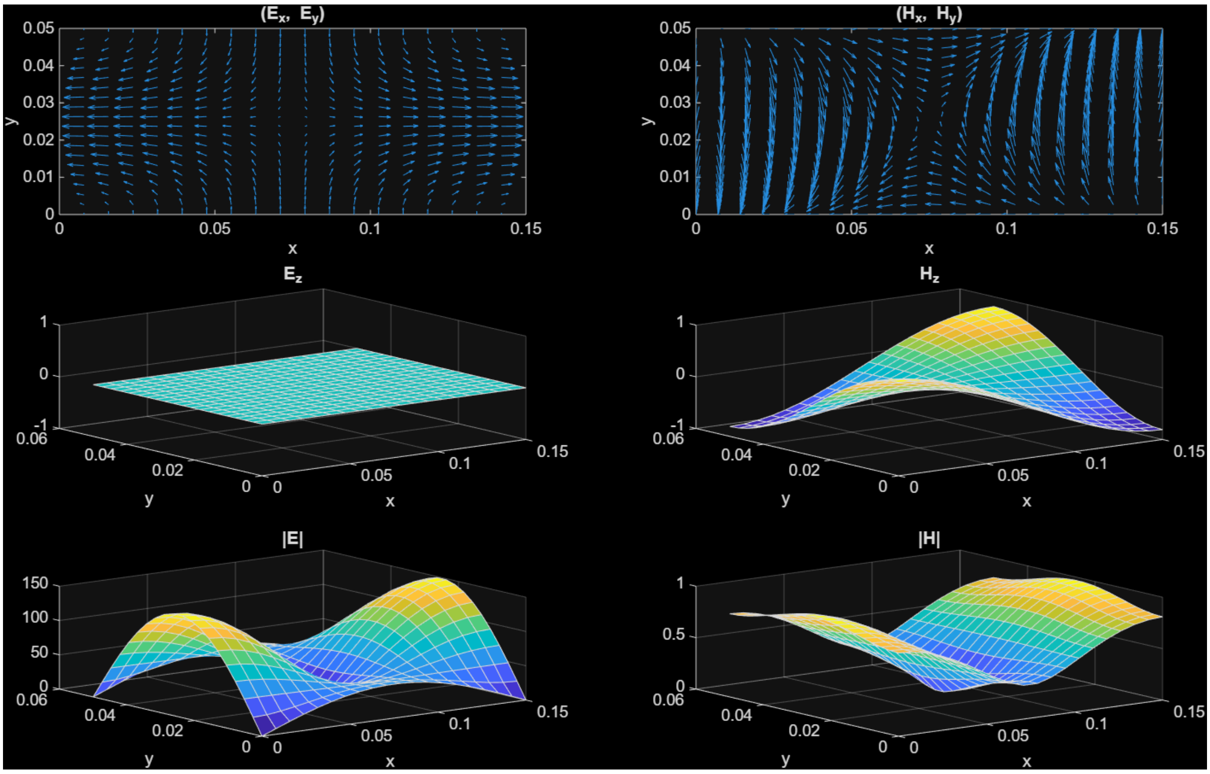
1. TEWave

TEWave2DXY.m

```
function [E_x, E_y, E_z, H_x, H_y, H_z] =
TEWave2DXY(epsilon_r,mu_r,H0,m,p,a,b,z,f, t, Na, Nb)
% Function: Compute the field components for a TEmp wave at a given time
and z-coordidate
% Input:     epsilon_r: relative permittivity
%            mu_r: relative permeability
%            H0: peak intensity of H_z
%            m,p: mode numbers
%            a,b: width and height of the waveguide
%            z: depth of waveguide
%            t: time instant
%            Na, Nb: number of grid points to evaluate on the x and y axis
% Output:    E_x, E_y, E_z: x-, y-, z-components of E field
%            H_x, H_y, H_z: x-, y-, z-components of H field


%% Parameters initialization
[x,y] = meshgrid([0:a/(Na-1):a], [0:b/(Nb-1):b]);
epsilon0=8.8542*10^(-12);
mu0=4*pi*10^(-7);
epsilon=epsilon0*epsilon_r;
mu=mu0*mu_r;
c0=3*10^8; % speed of light
v=c0/sqrt(epsilon_r*mu_r);
omega=2*pi*f;
k=omega/v;
f_cut=v/2*sqrt((m/a)^2+(p/b)^2); % cutoff frequency
km=m*pi/a;
kp=p*pi/b;
kmp=sqrt(km^2+kp^2);
beta_mp=sqrt(k^2-kmp^2);

%% TE mode field components
E_x= real(1j*omega*mu*(kp/(kmp^2))*H0*cos(km*x).*sin(kp*y).*exp(-
1j*beta_mp*z)*exp(j*omega*t));
E_y=real(-1j*omega*mu*(km/(kmp^2))*H0*sin(km*x).*cos(kp*y).*exp(-
1j*beta_mp*z)*exp(j*omega*t));
E_z = zeros(size(E_x));
H_x=real(1j*beta_mp*(km/(kmp^2))*H0*sin(km*x).*cos(kp*y).*exp(-
1j*beta_mp*z)*exp(j*omega*t));
H_y=real(1j*beta_mp*(kp/(kmp^2))*H0*cos(km*x).*sin(kp*y).*exp(-
1j*beta_mp*z)*exp(j*omega*t));
H_z=real(H0*cos(km*x).*cos(kp*y).*exp(-1j*beta_mp*z)*exp(j*omega*t));
```

TEWave2DXY_Plot.m

```
function [E_x, E_y, E_z, H_x, H_y,
H_z]=TEWave2DXY_Plot(epsilon_r,mu_r,E_0,m,p,a,b,z,f,t)
%% Function: Demonstrate the field components of a TE21 mode wave with
E_0=1
%  Input:    Parameters are same as for TEWave2DXY
epsilon_r=8;
mu_r=1;
E_0=1;
m=1;
p=1;
a=0.15;
b=0.05;
f=2*1.12*10^9;
z=0;
t=0.1/f;

%% Compute and plot the field components
Na = 20;
Nb = 20;
[x,y] = meshgrid([0:a/(Na-1):a], [0:b/(Nb-1):b]);
[E_x, E_y, E_z, H_x, H_y, H_z]=TEWave2DXY(epsilon_r,mu_r,E_0,m,p,a,b,z,f,
t, Na, Nb);
figure
subplot(3,2,1); quiver(x,y,E_x, E_y );                          % Use
quiver to plot the Ex, Ey components in the 2D plane
axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(E_x, E_y)')
subplot(3,2,3); surf(x,y, E_z);                                 % Use surf
to plot the Ez component for points on the 2D plane
title('E_z');xlabel('x'); ylabel('y');
subplot(3,2,5); surf(x,y, sqrt(abs(E_x.^2)+abs(E_y.^2)+abs(E_z.^2)))    %
Plot the magnitude of the E field
title('|E|'); rotate3d on;xlabel('x'); ylabel('y');
subplot(3,2,2); quiver(x,y,H_x, H_y, 2)                         % Plot the
Hx, Hy components
axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(H_x, H_y)')
subplot(3,2,4); surf(x,y, H_z)                                  % Plot Hz
component
title('H_z');xlabel('x'); ylabel('y');
subplot(3,2,6); surf(x,y, sqrt(abs(H_x.^2)+abs(H_y.^2)+abs(H_z.^2)))    %
Plot the magnitude of the H field
title('|H|'); rotate3d on; xlabel('x'); ylabel('y');
```



(E_x, E_y)
(H_x, H_y)
E_z
H_z
$|E|$
$|H|$

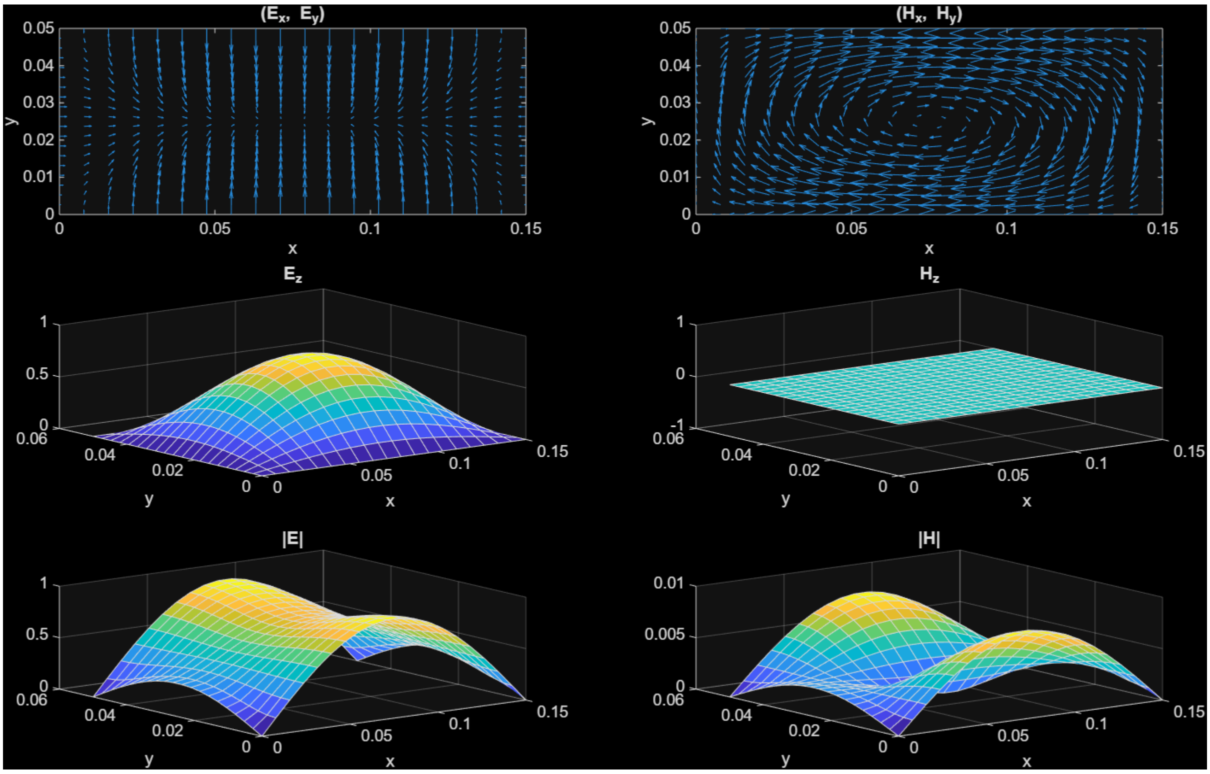
2. TMWave

TMWave2DXY.m

```
function [E_x, E_y, E_z, H_x, H_y, H_z] =
TMWave2DXY(epsilon_r,mu_r,E0,m,p,a,b,z,f, t, Na, Nb)
% Function: Compute the field components for a TEmp wave at a given time
and z-coordidate
% Input:    epsilon_r: relative permittivity
%           mu_r: relative permeability
%           E0: peak intensity of H_z
%           m,p: mode numbers
%           a,b: width and height of the waveguide
%           z: depth of waveguide
%           t: time instant
%           Na, Nb: number of grid points to evaluate on the x and y axis
% Output:   E_x, E_y, E_z: x-, y-, z-components of E field
%           H_x, H_y, H_z: x-, y-, z-components of H field


%% Parameters initialization
[x,y] = meshgrid([0:a/(Na-1):a], [0:b/(Nb-1):b]);
epsilon0=8.8542*10^(-12);
mu0=4*pi*10^(-7);
epsilon=epsilon0*epsilon_r;
mu=mu0*mu_r;
c0=3*10^8; % speed of light
v=c0/sqrt(epsilon_r*mu_r);
omega=2*pi*f;
k=omega/v;
f_cut=v/2*sqrt((m/a)^2+(p/b)^2); % cutoff frequency
km=m*pi/a;
kp=p*pi/b;
kmp=sqrt(km^2+kp^2);
beta_mp=sqrt(k^2-kmp^2);

%% TM mode field components
E_x = real(-1j*beta_mp*(km/(kmp^2))*E0*cos(km*x).*sin(kp*y).*exp(-
1j*beta_mp*z)*exp(j*omega*t));

E_y = real(-1j*beta_mp*(kp/(kmp^2))*E0*sin(km*x).*cos(kp*y).*exp(-
1j*beta_mp*z)*exp(j*omega*t));

E_z = real(E0*sin(km*x).*sin(kp*y).*exp(-1j*beta_mp*z)*exp(j*omega*t));

H_x = real(1j*omega*epsilon*(kp/(kmp^2))*E0*sin(km*x).*cos(kp*y).*exp(-
1j*beta_mp*z)*exp(j*omega*t));

H_y = real(-1j*omega*epsilon*(km/(kmp^2))*E0*cos(km*x).*sin(kp*y).*exp(-
1j*beta_mp*z)*exp(j*omega*t));

H_z = zeros(size(H_x));
```

TMWave2DXY_Plot.m

```
function [E_x, E_y, E_z, H_x, H_y,
H_z]=TMWave2DXY_Plot(epsilon_r,mu_r,E0,m,p,a,b,z,f,t)
%% Function: Demonstrate the field components of a TE21 mode wave with E0=1
%  Input:    Parameters are same as for TEWave2DXY
epsilon_r=8;
mu_r=1;
E0=1;
m=1;
p=1;
a=0.15;
b=0.05;
f=1.12*2*10^9;
z=0;
t=0.1/f;

%% Compute and plot the field components
Na = 20;
Nb = 20;
[x,y] = meshgrid([0:a/(Na-1):a], [0:b/(Nb-1):b]);
[E_x, E_y, E_z, H_x, H_y, H_z]=TMWave2DXY(epsilon_r,mu_r,E0,m,p,a,b,z,f, t,
Na, Nb);
figure
subplot(3,2,1); quiver(x,y,E_x, E_y );                              % Use
quiver to plot the Ex, Ey components in the 2D plane
axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(E_x, E_y)')
subplot(3,2,3); surf(x,y, E_z);                                     % Use surf
to plot the Ez component for points on the 2D plane
title('E_z');xlabel('x'); ylabel('y');
subplot(3,2,5); surf(x,y, sqrt(abs(E_x.^2)+abs(E_y.^2)+abs(E_z.^2)))    %
Plot the magnitude of the E field
title('|E|'); rotate3d on;xlabel('x'); ylabel('y');
subplot(3,2,2); quiver(x,y,H_x, H_y, 2)                             % Plot the
Hx, Hy components
axis([0 a 0 b]); xlabel('x'); ylabel('y'); title('(H_x, H_y)')
subplot(3,2,4); surf(x,y, H_z)                                      % Plot Hz
component
title('H_z');xlabel('x'); ylabel('y');
subplot(3,2,6); surf(x,y, sqrt(abs(H_x.^2)+abs(H_y.^2)+abs(H_z.^2)))    %
Plot the magnitude of the H field
title('|H|'); rotate3d on; xlabel('x'); ylabel('y');
```



Key Differences:

TE mode is characterized by zero E_z component with non-zero H_z showing a distinct peak, while TM mode displays the opposite pattern with zero H_z and significant E_z component. This fundamental difference is further evidenced by the contrasting vector field orientations where TE shows flow patterns along waveguide boundaries and TM exhibits rotational magnetic field patterns.

xxxxxxx