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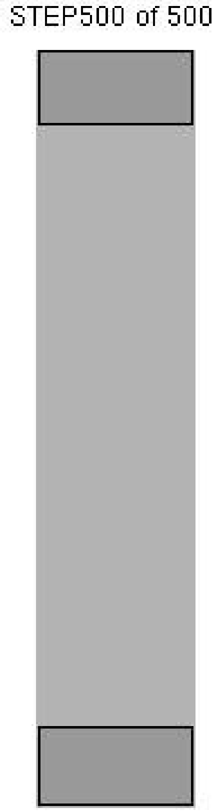
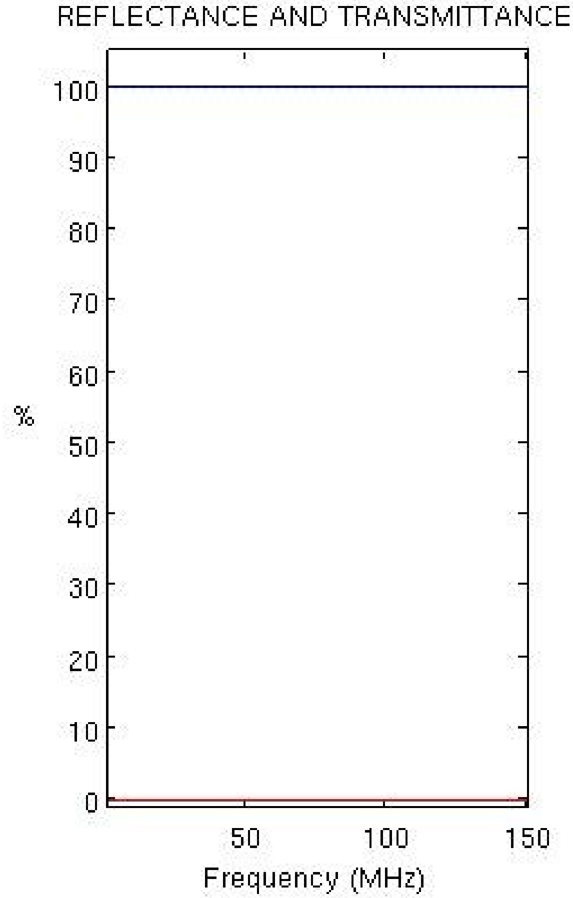
EEL 5390 – Special Topics (FDTD)
HW #9

Notes:

Compute TRN and FREF of Planewave with No Material






```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Initialization of Parameters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

Nx = 41;
Ny = 200;
NPML = [0 0 20 20];
dx = 0.1;
dy = 0.1;
dt = 1.6e-10;
tau = 3.3e-9;
STEPS = 500;

% FREQ Parameters

NFREQ = 150;
fmax = 150*megahertz;
fmin = 1*megahertz;
FREQ = linspace(fmin, fmax, NFREQ);



%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Grid Parameters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```matlab
% Compute Grid Axis
xa = [0:Nx-1]*dx;
ya = [0:Ny-1]*dy;

% Compute 2x Grid
Nx2 = 2*Nx;
Ny2 = 2*Ny;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Calculate PML Parameters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Compute sigx
sigx = zeros(Nx2, Ny2);
for nx=1:2*NPML(1)
  i = 2*NPML(1) - nx + 1;
  sigx(i, :) = (0.5*e0/dt)*(nx/2/NPML(1))^3;
end
for nx=1:2*NPML(2)
  i = Nx2 - 2*NPML(2) + nx;
  sigx(i, :) = (0.5*e0/dt)*(nx/2/NPML(2))^3;
end


% Compute sigy
sigy = zeros(Nx2, Ny2);
for ny=1:2*NPML(3)
  j = 2*NPML(3) - ny + 1;
  sigy(:,j) = (0.5*e0/dt)*(ny/2/NPML(3))^3;
end
for ny=1:2*NPML(4)
  j = Ny2 - 2*NPML(4) + ny;
  sigy(:,j) = (0.5*e0/dt)*(ny/2/NPML(4))^3;
end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%FDTD Initialization
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


% Material Properties
URxx = ones(Nx,Ny);
URyy = ones(Nx,Ny);
ERzz = ones(Nx,Ny);


% Update Coefficients
sigHx = sigx(1:2:Nx2, 2:2:Ny2);
sigHy = sigy(1:2:Nx2, 2:2:Ny2);

mHx0 = (1/dt) + (sigHy/(2*e0));
mHx1 = ((1/dt) - (sigHy/(2*e0)))./mHx0;
mHx2 = -(c0./URxx)./mHx0;
mHx3 = -((c0*dt/e0)*(sigHx./URxx))./mHx0;
```

```
sigHx = sigx(2:2:Nx2, 1:2:Ny2);
sigHy = sigy(2:2:Nx2, 1:2:Ny2);
mHy0 = (1/dt)+(sigHx/(2*e0));
mHy1 = ((1/dt) - (sigHx/(2*e0)))./mHy0;
mHy2 = -(c0./URyy)./mHy0;
mHy3 = -((c0*dt/e0)*sigHy./URyy)./mHy0;

sigDx = sigx(1:2:Nx2, 1:2:Ny2);
sigDy = sigy(1:2:Nx2, 1:2:Ny2);
mDz0 = (1/dt) + ((sigDx + sigDy)/(2*e0)) + (sigDx.*sigDy)*dt/(4*e0^2);
mDz1 = ((1/dt) - ((sigDx + sigDy)/(2*e0)) - (sigDx.*sigDy)*dt/(4*e0^2)) ./mDz0;
mDz2 = c0./mDz0;
mDz4 = - (dt/e0^2)*sigDx.*sigDy./mDz0;

mEz1 = 1./ERzz;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Source
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
t0 = 6*tau;
ta = [0:STEPS-1]*dt;
ny_src = Ny/2;%NPML(3)+2;
A = -sqrt(ERzz(1,ny_src)/URyy(1,ny_src));    % H Amplitude
deltsrc = 0.5*dy/c0 + dt/2; % Delay between E and H


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  REF and TRN
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

K = exp(-1i*2*pi*dt*FREQ); %Kernels for sweep across grid
EREF = zeros(Nx, NFREQ);  % Steady-State Reflected
ETRN = zeros(Nx, NFREQ);  % Steady-State Transmitted
SRC = zeros(1, NFREQ);    % Source transform

% Position of Recording planes
ny_ref = NPML(3) + 1;
ny_trn = Ny - NPML(4);

% Refractive indices in Recodring planes
nref = sqrt(ERzz(1,ny_ref));
ntrn = sqrt(ERzz(1,ny_trn));


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%FDTD Initialization
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Fields
Hx = zeros(Nx,Ny);
Hy = zeros(Nx,Ny);
Dz = zeros(Nx,Ny);
Ez = zeros(Nx,Ny);

%Curl Terms
CEx = zeros(Nx,Ny);
CEy = zeros(Nx,Ny);
CHz = zeros(Nx,Ny);
```

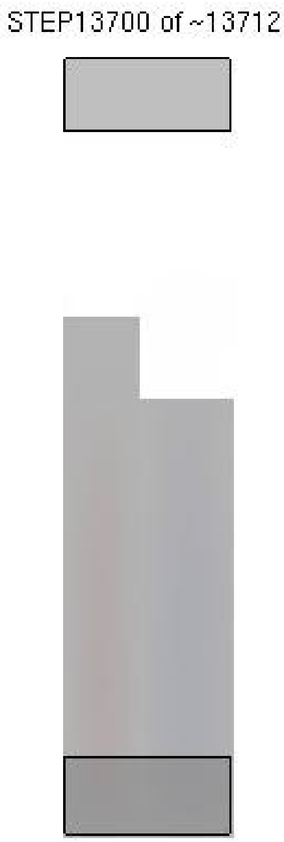
```
%Integration Terms
ICEx = zeros(Nx,Ny);
ICEy = zeros(Nx,Ny);
IDz = zeros(Nx,Ny);

figure('Color', 'w');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Execute Simulation
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

for T = 1:STEPS

  % Compute Curl of E

  %%% CEx
  for ny=1:Ny-1
    for nx=1:Nx
      CEx(nx,ny) = (Ez(nx,ny+1) - Ez(nx,ny))/dy;
    end
  end

  for nx=1:Nx
    CEx(nx,Ny) = (Ez(nx,1) - Ez(nx,Ny))/dy;
  end


  %%% CEy
  for nx=1:Nx-1
    for ny=1:Ny
      CEy(nx,ny) = - (Ez(nx+1,ny) - Ez(nx,ny))/dx;
    end
  end

  for ny=1:Ny
    CEy(Nx,ny) = - (Ez(1,ny) - Ez(Nx,ny))/dx;
  end


  % TF/SF Source
  Ezsrc = exp(-((T*dt-t0)/tau).^2);
  CEx(:,ny_src-1) = CEx(:,ny_src-1) - Ezsrc/dy;


  % Update H Integrations
  ICEx = ICEx + CEx;
  ICEy = ICEy + CEy;

  % Update H Field
  Hx = mHx1.*Hx + mHx2.*CEx + mHx3.*ICEx;
  Hy = mHy1.*Hy + mHy2.*CEy + mHy3.*ICEy;



  %Update Curl of H
  CHz(1,1) = (Hy(1,1) - Hy(Nx,1))/dx - (Hx(1,1) - Hx(1,Ny))/dy;
```

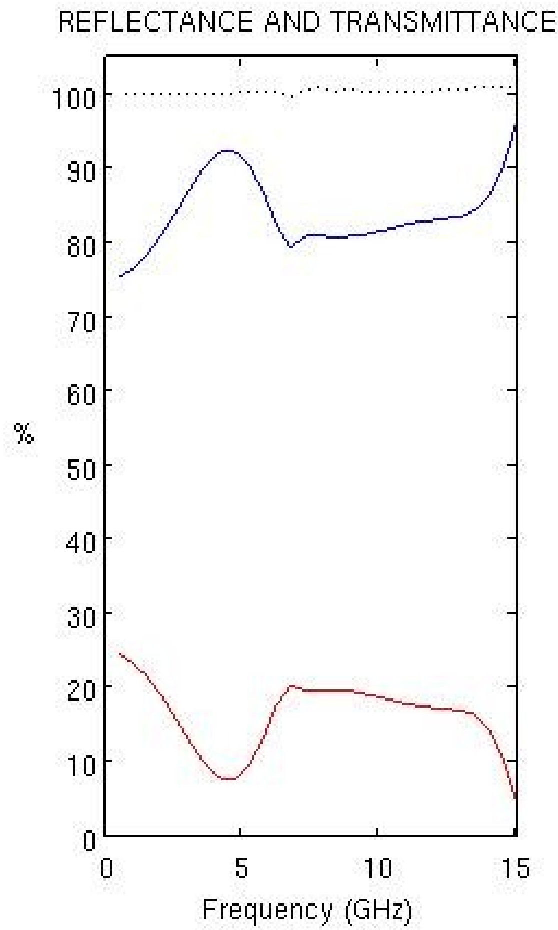
```
for nx=2:Nx
  CHz(nx,1) = (Hy(nx,1)-Hy(nx-1,1))/dx - (Hx(nx,1)-Hx(nx,Ny))/dy;
end

for ny=2:Ny
    CHz(1,ny) = (Hy(1,ny)-Hy(Nx,ny))/dx - (Hx(1,ny)-Hx(1,ny-1))/dy;
  for nx=2:Nx
    CHz(nx,ny) = (Hy(nx,ny)-Hy(nx-1,ny))/dx - (Hx(nx,ny)-Hx(nx,ny-1))/dy;
  end
end

% TF/SF Source
Hx_src = A*exp(-((T*dt-t0+deltsrc)/tau).^2);
CHz(:,ny_src) = CHz(:,ny_src) - Hx_src/dy;

%Update D Integrations
IDz = IDz + Dz;

% Update Dz
Dz = mDz1.*Dz + mDz2.*CHz + mDz4.*IDz;


% Update Ez
Ez = mEz1.*Dz;


%%%%%%%%%%%%%%%%%% Compute Power %%%%%%%%%%%%%%%%%%%%

for f = 1:NFREQ
  EREF(:,f) = EREF(:,f) + (K(f)^T*Ez(:,ny_ref))*dt;
  ETRN(:,f) = ETRN(:,f) + (K(f)^T*Ez(:,ny_trn))*dt;
  SRC(f) = SRC(f) + (K(f)^T*Ezsrc)*dt;
end;



if mod(T,10) == 0
  subplot(121);
  draw2d(xa,ya, ERzz, Ez, NPML, 0.03);
  axis equal tight off;
  title(['STEP' num2str(T) ' of ' num2str(STEPS)]);
  drawnow;

  REF = zeros(1,NFREQ);
  TRN = zeros(1,NFREQ);

  for f = 1: NFREQ
    %Wave Vector Components
    lam0 = c0/FREQ(f);
    k0 = 2*pi/lam0;
    kzinc = k0*nref;
    m = [-floor(Nx/2):floor(Nx/2)]';
    kx = -2 * pi*m/(Nx*dx);
    kzR = sqrt((k0*nref)^2 - kx.^2);
    kzT = sqrt((k0*ntrn)^2 - kx.^2);

    %REF
    ref = EREF(:,f)/SRC(f);
```

```
      ref = fftshift(fft(ref))/Nx;
      ref = real(kzR/kzinc) .* abs(ref).^2;
      REF(f) = sum(ref);


      %TRN
      trn = ETRN(:,f)/SRC(f);
      trn = fftshift(fft(trn))/Nx;
      trn = real(kzT/kzinc) .* abs(trn).^2;
      TRN(f) = sum(trn);
    end

    CON = REF + TRN;

    subplot(122);
    plot(FREQ/megahertz,100*REF,'-r'); hold on;
    plot(FREQ/megahertz,100*TRN,'-b');
    plot(FREQ/megahertz,100*CON,':k'); hold off;
    axis([FREQ(1)/megahertz FREQ(NFREQ)/megahertz -1 105]);
    xlabel('Frequency (MHz)');
    ylabel('%','Rotation',0,'HorizontalAlignment','right');
    title('REFLECTANCE AND TRANSMITTANCE');
  end

end
```

Model Diffraction Through a Grating

@ !0Ghz
Reflectance= 18.8%
Transmittance = 81.8%
Conservation = 100.6%





BinaryGrating.m

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Diffraction Through a Grating
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Initialize MATLAB
close all; clc;
clear all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Problem
%
%
%
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% UNITS
```

```matlab
meters = 1;
decimeters = 1e-1 * meters;
centimeters = 1e-2 * meters;
millimeters = 1e-3 * meters;
inches = 2.54 * centimeters;
feet = 12 * inches;
seconds = 1;
hertz = 1/seconds;
kilohertz = 1e3 * hertz;
megahertz = 1e6 * hertz;
gigahertz = 1e9 * hertz;

% Constants
c0 = 299792458;

% Frequency we want to transmit
f0 = 10 * gigahertz;

NPML = [0 0 20 20];

% Bragg Grating Materials
er1 = 9;

d = 0.75 * centimeters; % the Binary stand height
PeriodWidth = 1.5 * centimeters;  %Width between to Binary stands
dwidth = .5 * PeriodWidth;

%Calculate the Length of our layers.


dc.x = PeriodWidth;
dc.y = d;

Size.x = PeriodWidth;
Size.y = d * 3;

rNx = ceil(Size.x/(centimeters*decimeters)); %This Nz represents real world size
rNy = ceil(Size.y/(centimeters*decimeters));
disp(rNx);
disp(rNy);

% Material Vectors Initialized at Air
rER = ones(rNx,rNy);
rUR = ones(rNx,rNy);

dx = Size.x/rNx;
dy = Size.y/rNy;


% Fill our Stand
for nx=1:floor(dwidth/dx)
  for ny=1:floor(d/dy)
    rER(nx,ny)=er1;
  end
end


% Fill our body
```

```
for nx=1:rNx
  for ny = floor(d/dy)+1:rNy
    rER(nx,ny) = er1;
  end
end


% Add our Materials to the model

% Frequency

freq_start = 0;
freq_end = 15 * gigahertz;

NFREQ = freq_end / (0.5*gigahertz); %Frequencies every 100nm
FREQ = linspace(freq_start, freq_end, NFREQ); %FREQ List

Buffer.x.value = 0;
Buffer.x.e = [-1 -1];
Buffer.x.u = [1 1];

Buffer.y.value = -1;
Buffer.y.e = [1 9];
Buffer.y.u = [1 1];

subplot(121);
imagesc(rER);
% global ERzz;
FDTD2D( dc, Size, rER, rUR, -1, 5e-4, Buffer, NPML, FREQ, NFREQ, 100,
10*gigahertz, 'Binary Grating');
```

FDTD2D. m

```
function FDTD2D( dc, Size, rER, rUR, Steps, EMAX, Buffer, NPML, FREQ, NFREQ,
Update, SSFREQ, Title )

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Pre-Program Work
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% UNITS
meters = 1;
decimeters = 1e-1 * meters;
centimeters = 1e-2 * meters;
millimeters = 1e-3 * meters;
inches = 2.54 * centimeters;
feet = 12 * inches;
seconds = 1;
hertz = 1/seconds;
kilohertz = 1e3 * hertz;
megahertz = 1e6 * hertz;
gigahertz = 1e9 * hertz;

%Constants
c0 = 299792458; %m/s
e0 = 8.854187817*10^-12; %F/m
u0 = 1.256637061*10^-6; %H/m
```

```matlab
N0 = sqrt(u0/e0);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Initialization of Parameters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

fmax = FREQ(length(FREQ));
fmin = FREQ(1);

f0 = SSFREQ;
lam0 = c0/f0;

nmax = Getnmax2D(rER, rUR);


%Compute Grid Resolution
% Wave Length Resolution
N_lambda = GetNlambda(rER, rUR);
lambda_min = c0 / (fmax);
d_lambda = lambda_min/N_lambda/nmax;


% Structure Resolution
N_d = 10;
ddx = dc.x/N_d;
ddy = dc.y/N_d;


% Calculate grid resolution dx
dx = min(d_lambda, ddx);
N_prime = 2*ceil(dc.x/dx/2)+1;
dx = dc.x/N_prime;
Nx = ceil(Size.x/dx);

% Calculate grid resolution dy
dy = min(d_lambda, ddy);
N_prime = ceil(dc.y/dy);
dy = dc.y/N_prime;
Ny = ceil(Size.y/dy);

% Add free space buffer and TF/SF
if(Buffer.x.value == -1)
  buffer.x = ceil(0.5*lam0/dx);
  buffer.xt = buffer.x*2;
else
  buffer.x = Buffer.x.value;
  buffer.xt = Buffer.x.value*2;
end

if(Buffer.y.value == -1)
  buffer.y = ceil(0.5*lam0/dy);
  buffer.yt = buffer.y*2+3;
else
  buffer.y = Buffer.y.value;
  buffer.yt = Buffer.y.value*2+3;
end

Nx = Nx + buffer.xt + NPML(1) + NPML(2);
```

```
Ny = Ny + buffer.yt + NPML(3) + NPML(4);


%Compute Time Steps
nsrc = 1;  %Source is injected in air
dt = nsrc * dy/(2*c0); %secs
tau = 0.5/fmax;        % tau parameter
t0 = 6*tau;              % Delay/Pulse Position


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Model
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
 [m n]=size(rER);
 cf.x = floor((Nx - buffer.x*2-NPML(1)-NPML(2))/m); % Conversion factor to convert our real grid to our numerical grid
 cf.y = ceil((Ny - buffer.y*2-3-NPML(3)-NPML(4))/n);

% Material Properties
% global ERzz;
URxx = zeros(Nx,Ny);
URyy = zeros(Nx,Ny);
ERzz = zeros(Nx,Ny);

% disp(size(URxx));
% disp(['buffer x: ' num2str(buffer.x)]);
% disp(['buffer y: ' num2str(buffer.y)]);
% disp(['cf x: ' num2str(cf.x)]);
% disp(['cf y: ' num2str(cf.y)]);
% disp(['dx: ' num2str(dx)]);
% disp(['dy: ' num2str(dy)]);
% disp(['Size x: ' num2str(Nx*dx*centimeters)]);
% disp(['Size y: ' num2str(Ny*dy*centimeters)]);


 % We Need to lay our real materials vectors over our numerical material
 % grid

 % Lets place our real grid in proper location on numerical grid
 for x=0:m-1
    for y=0:n-1
      index.x = buffer.x+NPML(1) + x*cf.x+1;
      index.y = buffer.y+2+NPML(3) + y*cf.y+1;
      ERzz(index.x, index.y) = rER(x+1,y+1);
      URxx(index.x, index.y) = rUR(x+1,y+1);
      URyy(index.x, index.y) = rUR(x+1,y+1);
    end
 end

 %Fill our buffer regions
  ERzz(1:buffer.x+NPML(1),:)=Buffer.x.e(1);
  ERzz(:,1:buffer.y+NPML(3)+2) = Buffer.y.e(1);
  ERzz(Nx-buffer.x-NPML(2)+1:Nx,:) = Buffer.x.e(2);
  ERzz(:,Ny-buffer.y-NPML(4)-1+1:Ny) = Buffer.y.e(2);

  URxx(1:buffer.x+NPML(1),:)=Buffer.x.u(1);
  URxx(:,1:buffer.y+NPML(3)+2) = Buffer.y.u(1);
  URxx(Nx-buffer.x-NPML(2)+1:Nx,:) = Buffer.x.u(2);
```

```
  URxx(:,Ny-buffer.y-NPML(4)-1+1:Ny) = Buffer.y.u(2);

  URyy(1:buffer.x+NPML(1),:)=Buffer.x.u(1);
  URyy(:,1:buffer.y+NPML(3)+2) = Buffer.y.u(1);
  URyy(Nx-buffer.x-NPML(2)+1:Nx,:) = Buffer.x.u(2);
  URyy(:,Ny-buffer.y-NPML(4)-1+1:Ny) = Buffer.y.u(2);


 for y=1  : Ny
  for x=2 : Nx
    if(ERzz(x,y) == 0)
      ERzz(x,y) = ERzz(x-1,y);
    end
    if(URxx(x,y) == 0)
      URxx(x,y) = URxx(x-1,y);
    end
    if(URyy(x,y) == 0)
      URyy(x,y) = URyy(x-1,y);
    end
   end
 end


 for x=1  : Nx
   for y=1 : Ny
    if(ERzz(x,y) == 0)
      ERzz(x,y) = ERzz(x,y-1);
    end
    if(URxx(x,y) == 0)
      URxx(x,y) = URxx(x,y-1);
    end
    if(URyy(x,y) == 0)
      URyy(x,y) = URyy(x,y-1);
    end
   end
 end





%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Calculate STEPS
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

STEPS = Steps;
if(STEPS == -1)
  tprop = (nmax*Ny*dy)/c0; % Wave Propagation time;
  T = 12*tau + 5*tprop;
  STEPS = ceil(T/dt)*2;
end

ta = [0:STEPS-1]*dt;     % Time Axis;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Grid Parameters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
% Compute Grid Axis
xa = [0:Nx-1]*dx;
ya = [0:Ny-1]*dy;

% Compute 2x Grid
Nx2 = 2*Nx;
Ny2 = 2*Ny;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Calculate PML Parameters
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

% Compute sigx
sigx = zeros(Nx2, Ny2);
for nx=1:2*NPML(1)
  i = 2*NPML(1) - nx + 1;
  sigx(i, :) = (0.5*e0/dt)*(nx/2/NPML(1))^3;
end
for nx=1:2*NPML(2)
  i = Nx2 - 2*NPML(2) + nx;
  sigx(i, :) = (0.5*e0/dt)*(nx/2/NPML(2))^3;
end


% Compute sigy
sigy = zeros(Nx2, Ny2);
for ny=1:2*NPML(3)
  j = 2*NPML(3) - ny + 1;
  sigy(:,j) = (0.5*e0/dt)*(ny/2/NPML(3))^3;
end
for ny=1:2*NPML(4)
  j = Ny2 - 2*NPML(4) + ny;
  sigy(:,j) = (0.5*e0/dt)*(ny/2/NPML(4))^3;
end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%FDTD Initialization
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%



% Update Coefficients
sigHx = sigx(1:2:Nx2, 2:2:Ny2);
sigHy = sigy(1:2:Nx2, 2:2:Ny2);

mHx0 = (1/dt) + (sigHy/(2*e0));

disp(size(URxx));
disp(size(mHx0));

mHx1 = ((1/dt) - (sigHy/(2*e0)))./mHx0;
mHx2 = -(c0./URxx)./mHx0;
mHx3 = -((c0*dt/e0)*(sigHx./URxx))./mHx0;

sigHx = sigx(2:2:Nx2, 1:2:Ny2);
```

```
sigHy = sigy(2:2:Nx2, 1:2:Ny2);
mHy0 = (1/dt)+(sigHx/(2*e0));
mHy1 = ((1/dt) - (sigHx/(2*e0)))./mHy0;
mHy2 = -(c0./URyy)./mHy0;
mHy3 = -((c0*dt/e0)*sigHy./URyy)./mHy0;

sigDx = sigx(1:2:Nx2, 1:2:Ny2);
sigDy = sigy(1:2:Nx2, 1:2:Ny2);
mDz0 = (1/dt) + ((sigDx + sigDy)/(2*e0)) + (sigDx.*sigDy)*dt/(4*e0^2);
mDz1 = ((1/dt) - ((sigDx + sigDy)/(2*e0)) - (sigDx.*sigDy)*dt/(4*e0^2)) ./mDz0;
mDz2 = c0./mDz0;
mDz4 = - (dt/e0^2)*sigDx.*sigDy./mDz0;

mEz1 = 1./ERzz;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  Source
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
ny_src = NPML(3)+2;
A = -sqrt(ERzz(1,ny_src)/URyy(1,ny_src));    % H Amplitude
deltsrc = 0.5*dy/c0 + dt/2; % Delay between E and H


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%  REF and TRN
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

K = exp(-1i*2*pi*dt*FREQ); %Kernels for sweep across grid
K0 = exp(-1i*2*pi*dt*f0);   %Kernel for our design freq

EREF = zeros(Nx, NFREQ);  % Steady-State Reflected
ETRN = zeros(Nx, NFREQ);  % Steady-State Transmitted
SRC = zeros(1, NFREQ);    % Source transform

if(f0 ~= -1)
  Eref0 = zeros(Nx,1);
  Etrn0 = zeros(Nx,1);
  ssSRC = 0;
end

% Position of Recording planes
ny_ref = NPML(3) + 1;
ny_trn = Ny - NPML(4);

% Refractive indices in Recodring planes
nref = sqrt(ERzz(1,ny_ref)*URxx(1,ny_ref));
ntrn = sqrt(ERzz(1,ny_trn)*URxx(1,ny_trn));


disp('%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%');
disp('% Parameters');
disp('%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%');

disp(['fmax' num2str(fmax)]);
disp(['lamda_min: ' num2str(lambda_min)]);
disp(['d_lambda: ' num2str(d_lambda)]);
disp(['nmax: ' num2str(nmax)]);
disp(['N_lambda' num2str(N_lambda)]);
```

```
disp(['dcx: ' num2str(dc.x)]);
disp(['dcy: ' num2str(dc.y)]);
disp(['ddx: ' num2str(ddx)]);
disp(['ddy: ' num2str(ddy)]);
disp(['Nx: ' num2str(Nx)]);
disp(['Ny: ' num2str(Ny)]);
disp(['buffer x: ' num2str(buffer.x)]);
disp(['buffer y: ' num2str(buffer.y)]);
disp(['dx: ' num2str(dx)]);
disp(['dy: ' num2str(dy)]);
disp(['Size x: ' num2str(Nx*dx)]);
disp(['Size y: ' num2str(Ny*dy)]);
disp(['dt: ' num2str(dt)]);
disp(['tau: ' num2str(tau)]);
disp(['t0: ' num2str(t0)]);
disp(['STEPS: ' num2str(STEPS)]);
disp(['s: ' num2str(deltsrc)]);
disp(['A: ' num2str(A)]);
disp(['SSFREQ: ' num2str(SSFREQ)]);
% disp(['ER: ' num2str(length(ER))]);
% disp(ER);
% disp(['UR: ' num2str(length(UR))]);;
% disp(UR);
% subplot(122);
% imagesc(ERzz);
%  return;




%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%FDTD Initialization
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%Fields
Hx = zeros(Nx,Ny);
Hy = zeros(Nx,Ny);
Dz = zeros(Nx,Ny);
Ez = zeros(Nx,Ny);

%Curl Terms
CEx = zeros(Nx,Ny);
CEy = zeros(Nx,Ny);
CHz = zeros(Nx,Ny);

%Integration Terms
ICEx = zeros(Nx,Ny);
ICEy = zeros(Nx,Ny);
IDz = zeros(Nx,Ny);

figure('Color', 'w');

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Execute Simulation
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
T = 0;
emax = 1;
```

```matlab
if(EMAX == -1)
  EMAX = 1e-5;
end

while ((emax > EMAX) || (T < STEPS))
  T = T + 1;

  % Compute Curl of E

  %%% CEx
  for ny=1:Ny-1
    for nx=1:Nx
      CEx(nx,ny) = (Ez(nx,ny+1) - Ez(nx,ny))/dy;
    end
  end

  for nx=1:Nx
    CEx(nx,Ny) = (Ez(nx,1) - Ez(nx,Ny))/dy;
  end


  %%% CEy
  for nx=1:Nx-1
    for ny=1:Ny
      CEy(nx,ny) = - (Ez(nx+1,ny) - Ez(nx,ny))/dx;
    end
  end

  for ny=1:Ny
    CEy(Nx,ny) = - (Ez(1,ny) - Ez(Nx,ny))/dx;
  end


  % TF/SF Source
  Ezsrc = exp(-((T*dt-t0)/tau).^2);
  CEx(:,ny_src-1) = CEx(:,ny_src-1) - Ezsrc/dy;


  % Update H Integrations
  ICEx = ICEx + CEx;
  ICEy = ICEy + CEy;

  % Update H Field
  Hx = mHx1.*Hx + mHx2.*CEx + mHx3.*ICEx;
  Hy = mHy1.*Hy + mHy2.*CEy + mHy3.*ICEy;



  %Update Curl of H
  CHz(1,1) = (Hy(1,1) - Hy(Nx,1))/dx - (Hx(1,1) - Hx(1,Ny))/dy;

  for nx=2:Nx
    CHz(nx,1) = (Hy(nx,1)-Hy(nx-1,1))/dx - (Hx(nx,1)-Hx(nx,Ny))/dy;
  end

  for ny=2:Ny
      CHz(1,ny) = (Hy(1,ny)-Hy(Nx,ny))/dx - (Hx(1,ny)-Hx(1,ny-1))/dy;
    for nx=2:Nx
```

```
    CHz(nx,ny) = (Hy(nx,ny)-Hy(nx-1,ny))/dx - (Hx(nx,ny)-Hx(nx,ny-1))/dy;
  end
end

% TF/SF Source
Hx_src = A*exp(-((T*dt-t0+deltsrc)/tau).^2);
CHz(:,ny_src) = CHz(:,ny_src) - Hx_src/dy;

%Update D Integrations
IDz = IDz + Dz;

% Update Dz
Dz = mDz1.*Dz + mDz2.*CHz + mDz4.*IDz;


% Update Ez
Ez = mEz1.*Dz;
emax = max(max(Ez));

%%%%%%%%%%%%%%%%%% Compute Power %%%%%%%%%%%%%%%%%%%%

for f = 1:NFREQ
  EREF(:,f) = EREF(:,f) + (K(f)^T*Ez(:,ny_ref))*dt;
  ETRN(:,f) = ETRN(:,f) + (K(f)^T*Ez(:,ny_trn))*dt;
  SRC(f) = SRC(f) + (K(f)^T*Ezsrc)*dt;
end;

if(f0 ~= -1)
  Eref0 = Eref0 + (K0^T)*Ez(:,ny_ref)*dt;
  Etrn0 = Etrn0 + (K0^T)*Ez(:,ny_trn)*dt;
  ssSRC = ssSRC + (K0^T)*Ezsrc*dt;
end



if(mod(T,Update) == 0 || T == 1)
  subplot(121);
  draw2d(xa,ya, ERzz, Ez, NPML, 0.03);
  axis equal tight off;
  title(['STEP' num2str(T) ' of ~' num2str(STEPS)]);
  drawnow;




  if(f0 ~= -1)
    %%%%%%%%%%%%%%%%%% DESIGN Frequency %%%%%%%%%%%%%%%%%%%%
    %Wave Vector Components
    lam0 = c0/f0;
    k0 = 2*pi/lam0;
    kxinc = 0;
    kyinc = k0*nref;
    m = [-floor(Nx/2):floor(Nx/2)]';
    kx = kxinc -2 * pi*m/(Nx*dx);
    kyR = sqrt((k0*nref)^2 - kx.^2);
    kyT = sqrt((k0*ntrn)^2 - kx.^2);

    %REF
```

```
  ref = Eref0/ssSRC;
  ref = fftshift(fft(ref))/Nx;
  ref = real(kyR/kyinc) .* abs(ref).^2;
  REF = sum(ref);


  %TRN
  trn = Etrn0/ssSRC;
  trn = fftshift(fft(trn))/Nx;
  trn = real(kyT/kyinc) .* abs(trn).^2;
  TRN = sum(trn);

  CON = REF + TRN;

  disp(['Reflectance= ' num2str(100*REF,'%4.1f') '%']);
  disp(['Transmittance = ' num2str(100*TRN,'%4.1f') '%']);
  disp(['Conservation = ' num2str(100*CON,'%4.1f') '%']);
  disp(' ');
  %%%%%%%%%%%%%%%%%% DESIGN Frequency %%%%%%%%%%%%%%%%%%%%
end




REF = zeros(1,NFREQ);
TRN = zeros(1,NFREQ);

for f = 1: NFREQ
  %Wave Vector Components
  lam0 = c0/FREQ(f);
  k0 = 2*pi/lam0;
  kzinc = k0*nref;
  m = [-floor(Nx/2):floor(Nx/2)]';
  kx = -2 * pi*m/(Nx*dx);
  kzR = sqrt((k0*nref)^2 - kx.^2);
  kzT = sqrt((k0*ntrn)^2 - kx.^2);

  %REF
  ref = EREF(:,f)/SRC(f);
  ref = fftshift(fft(ref))/Nx;
  ref = real(kzR/kzinc) .* abs(ref).^2;
  REF(f) = sum(ref);


  %TRN
  trn = ETRN(:,f)/SRC(f);
  trn = fftshift(fft(trn))/Nx;
  trn = real(kzT/kzinc) .* abs(trn).^2;
  TRN(f) = sum(trn);
end

CON = REF + TRN;

subplot(122);
plot(FREQ/gigahertz,100*REF,'-r'); hold on;
plot(FREQ/gigahertz,100*TRN,'-b');
plot(FREQ/gigahertz,100*CON,':k'); hold off;
axis([FREQ(1)/gigahertz FREQ(NFREQ)/gigahertz 0 105]);
```

```
    xlabel('Frequency (GHz)');
    ylabel('%','Rotation',0,'HorizontalAlignment','right');
    title('REFLECTANCE AND TRANSMITTANCE');
  end

end
```