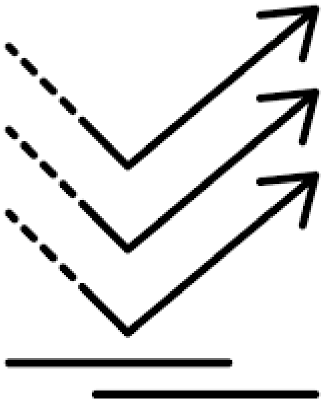
Faculty of Science and Engineering

Department of Electrical and Electronic Engineering

Contemporary Engineering Themes A -

Ray Tracing Coursework



ACADEMIC YEAR 2023/2024

Course Code: EEEE1043 UNMC

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Function Declaration

```
function [Ef, Ef2] = calculateEfield(n,iy,iy2)
    % Constants
    f = 2.4 * 10^9; % adjust as needed
    c = 3 * 10^8;
    beta = 2 * pi * f / c;
    rf1 = 1;
    rf2 = 3;


    % Transmitter,receiver and image coordinates
    ix = 0 ;ix2 = 0; %image x top and bottom
    iz = 2; iz2 = 2; %image z top and bottom
    tx = 0; ty = 4; tz = 2; % Transmitter
    rx = 10; ry = 3; rz = 2; % Receiver
    rxv = rx:.01:22; % Simulation range


    % Top to rx reflection
    % Finding angle
    d = sqrt(((ix - rxv).^2) + ((iy - ry)^2) + ((iz - rz)^2)); %distance
travelled by the reflected rays
    iangle = asin(rxv./d); %find incident angle
    tangle = asin(sin(iangle)./sqrt(rf2/rf1));  %find transmission angle


    % Finding field strength
    rcof = (cos(iangle)-
sqrt(rf2/rf1).*cos(tangle))./(cos(iangle)+sqrt(rf2/rf1).*cos(tangle)); %findin
g reflective coefficients
    Ef(1,:) = ((1./d) .* exp(-1i * beta * d)).*rcof.^n; %find electric field
strength for the particular order only


    % Bottom to rx reflection
    d2 = sqrt(((ix2 - rxv).^2) + ((iy2 - ry)^2) + ((iz2 - rz)^2));
    iangle2 = asin(rxv./d2);
    tangle2 = asin(sin(iangle2)./sqrt(rf2/rf1));


    % Finding field strength
    rcof2 = (cos(iangle2)-
sqrt(rf2/rf1).*cos(tangle2))./(cos(iangle2)+sqrt(rf2/rf1).*cos(tangle2));
    Ef2(1,:) = ((1./d2) .* exp(-1i * beta * d2)).*rcof2.^n;
end
```

This is the function for calculating the electric field strength from point *p* to point *q* for top and bottom paths. The required parameters for the function are the y-coordinates of the final image to the receiver where *iy* is the y-coordinate of the image if the ray chooses to reflect from the top wall first and *iy2* is the y-coordinate of the image accounting for the bottom path.

Note that only the y-coordinates of the image are passed in as parameters as the x-coordinate of the image will always be on the same axis as the receiver while the z-coordinate will always be the same as all points are assumed to be on the same height.

The constants are declared at the top of the function, this includes the frequency, the speed of light, beta, reflective index for air and the wall and the coordinates for the transmitter and receiver. *rxv* is declared as a variable array which simulates the x-coordinate of point *p* moving to point *q* which is the distance from 10*m* to 22*m* with a step of 0.01*m*. The parameters required to calculate the electric field strength from one point to the other are simply the distance travelled by the ray to the receiver and if it is a reflected ray, the reflective coefficient which requires the incident and transmission angle of the reflected angle.

As we know, the wall is assumed to be a perfect electrical conductor (PEC). The electric field component parallel to the surface must be zero at the boundary which is why the angle of incidence is the same as the angle of reflection. This means that throughout all reflections the angle of incidence will be the same, which induces the angle of transmission to be the same as well. Therefore, the reflective coefficient that depends on both those variables will also be the same throughout the whole path travelled. In conclusion, to find the electric field strength for a reflected ray, the the electric field strength of the reflected ray is calculated, and multiplied with the reflective coefficient with the number of times it reflects off the wall, i.e the order of the reflected ray.

To obtain the angle of incidence, a right-angled triangle can be drawn using the final image location and the receiver as points, where the distance from the image to the receiver is the hypotenuse while the opposite and adjacent components can be formed by connecting the vertical image component and the horizontal receiver component. It is said that alternate angles of parallel angles are equal, the parallel lines being the vertical component of the point of reflection off the wall and the image. The sin rule can then be applied to obtain the incident angle and subsequently the reflective coefficient. With this the electric field strength for a top reflected path at point *p* can be found. The same sequence is repeated for a bottom path sequence.

Main Script

```
clear variables;
 % Constants
    f = 2.4 * 10^9; % adjust as needed
    c = 3 * 10^8;
    beta = 2 * pi * f / c;
    rf1 = 1;
    rf2 = 3;


    % Transmitter and receiver coordinates
    tx = 0; ty = 4; tz = 2; % Transmitter
    rx = 10; ry = 3; rz = 2; % Receiver
    rxv = rx:.01:22; % Simulation range


    % Direct ray
    rd = sqrt(((rxv - tx).^2) + ((ry - ty)^2) + ((rz - tz)^2));  %direct ray
    Ed = (1./rd) .* exp(-1i * beta * rd);  %electric field strength
    Edf = 20 * log10(abs(Ed));  %convert to db
    plot(rxv, Edf);
    xlabel('Line Segment "pq" / m'),ylabel('E-field / dB')
    hold on


% Initialize arrays
Ep = zeros(4, 1201);
Epf = zeros(4, 1201);


% First Order
[Ef1_1, Ef2_1] = calculateEfield(1,8,-4);
Ep(1,:) = Ed + Ef1_1 + Ef2_1; %total electric field strength
Epf(1,:) = 20 * log10(abs(Ep(1,:))); %convert to db
plot(rxv, Epf(1,:));


% Second Order
[ Ef1_2, Ef2_2] = calculateEfield(2,16,-8);
Ep(2,:) = Ed + Ef1_1 + Ef2_1 + Ef1_2 + Ef2_2; %total electric field strength
Epf(2,:) = 20 * log10(abs(Ep(2,:))); %convert to db
plot(rxv, Epf(2,:));


% Third Order
[ Ef1_3, Ef2_3] = calculateEfield(3,20,-16);
Ep(3,:) = Ed + Ef1_1 + Ef2_1 + Ef1_2 + Ef2_2 + Ef1_3 + Ef2_3; %total electric
field strength
Epf(3,:) = 20 * log10(abs(Ep(3,:))); %convert to db
plot(rxv, Epf(3,:));
```

```
% Fourth Order
[ Ef1_4, Ef2_4] = calculateEfield(4,28,-20);
Ep(4,:) = Ed + Ef1_1 + Ef2_1 + Ef1_2 + Ef2_2 + Ef1_3 + Ef2_3 + Ef1_4 +
Ef2_4; %total electric field strength
Epf(4,:) = 20 * log10(abs(Ep(4,:))); %convert to db
plot(rxv, Epf(4,:));


hold off
% Add legends
legend('Direct Ray', 'First Order', 'Second Order', 'Third Order', 'Fourth
Order');
```

To calculate the electric field strength for each order, the electric field strength for previous orders would be added with the electric field strength at the current order. This can be done by using the output returned by the function, electric field strength for top path and bottom path. Each order is converted to decibels and is plotted accordingly on the same graph until the path converges.

Results

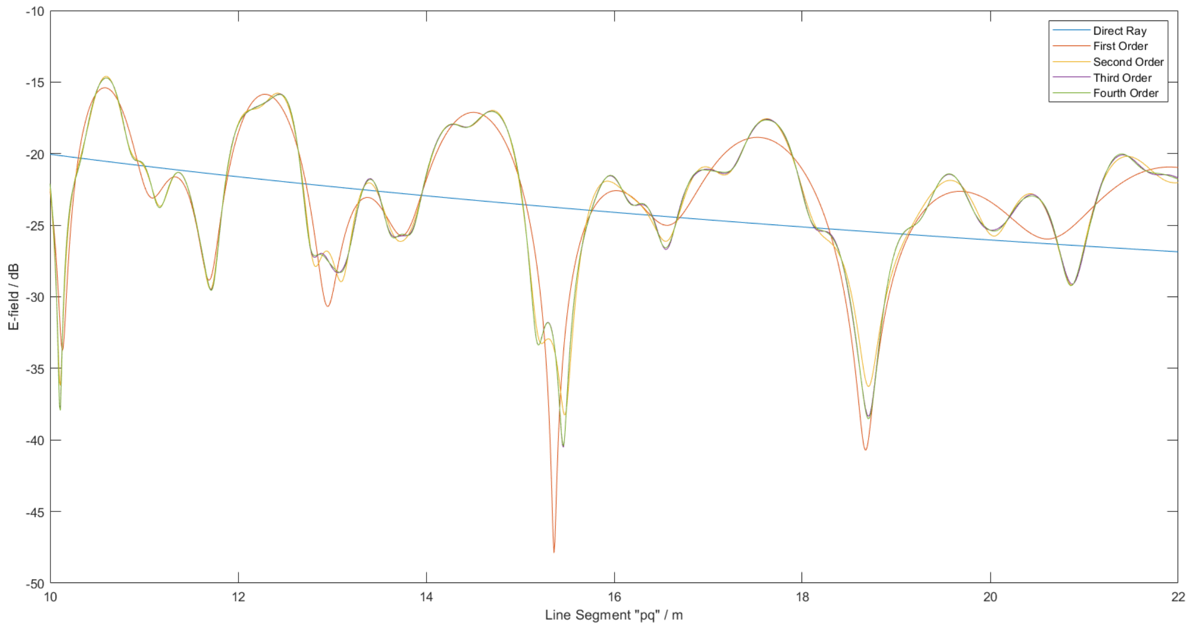

Figure 1: Electric Field Strength for 2.4GHz

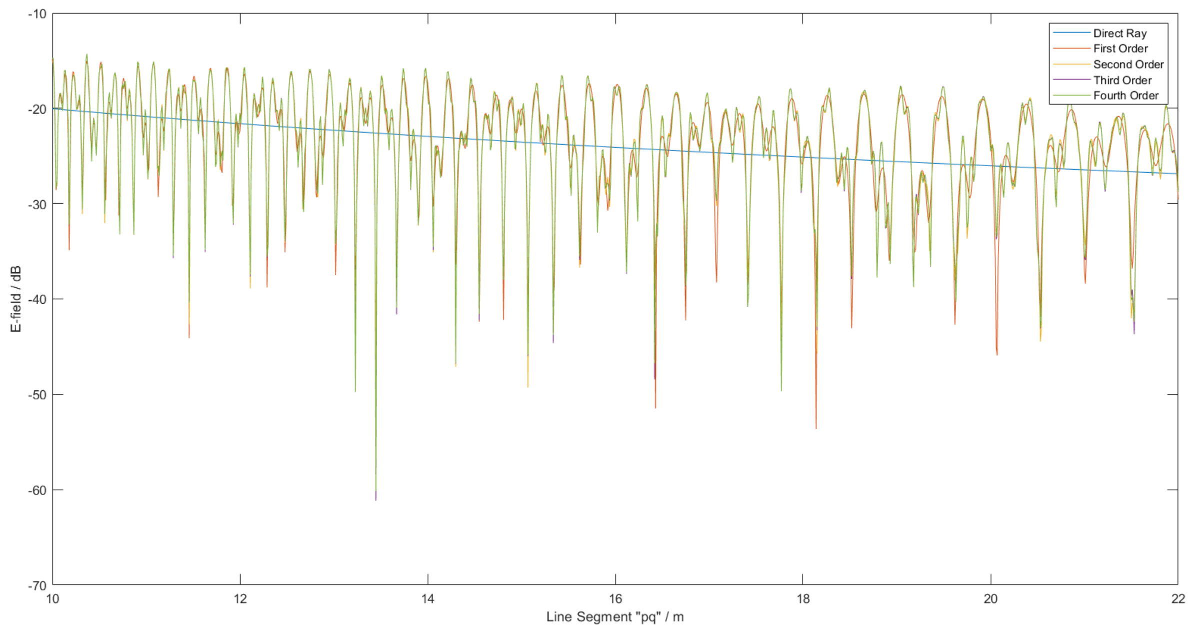

Figure 2: Electric Field Strength for 24GHz

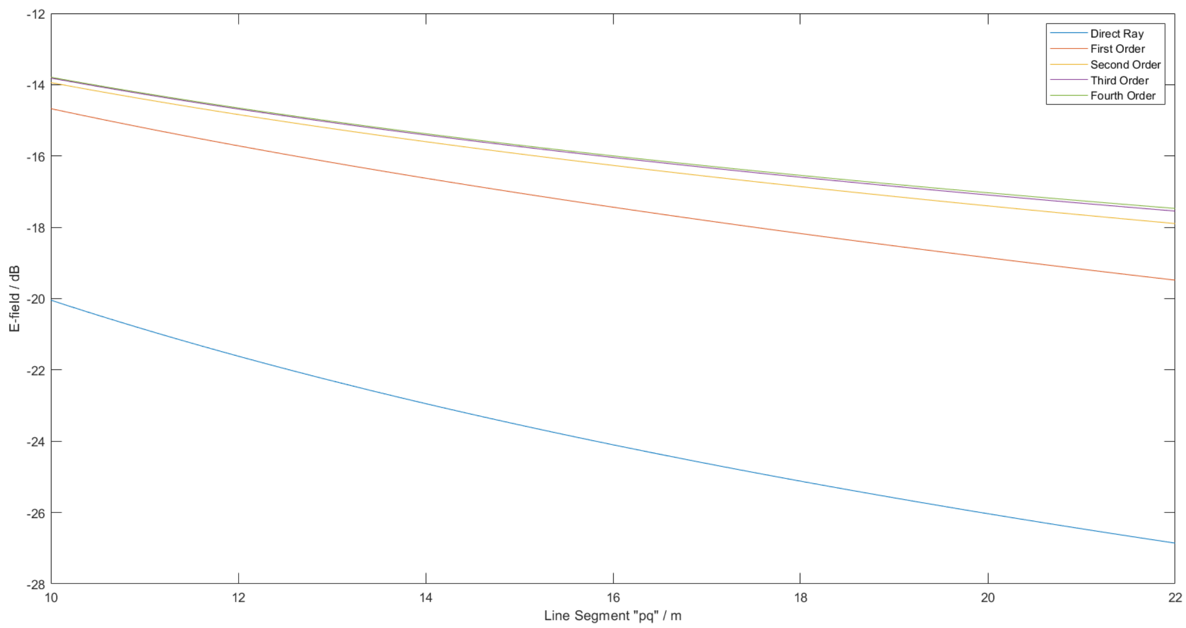

Figure 3: Convergence of Electric-Field Strength

Figure 1 and Figure 2 shows the results for the electric field strength plotted at different orders of reflection at 2.4GHz and 24GHz respectively. From both graphs, it can be seen that the electric field strength fluctuates abruptly. This is due to the addition of complex numbers as the electric field strength consists of real and imaginary components where they represent the magnitude and phase respectively. To determine the order of reflection to take into consideration for the true electric field strength of the ray at point *p* to point *q*, the absolute value of the electric field strength before converting to decibels is taken instead which causes the phase of the electric fields to be ignored, and only plots the magnitude of the rays. This eliminates the fluctuations, causing a smooth line to be plotted. From there, the number of orders it takes for the electric field of the ray to converge can be clearly seen compared to Figure 1 and Figure 2 which includes the phase. It is important to note that the change in frequency would not cause Figure 3 to change, as frequency affects the phase, which is the complex component of the electric field. Therefore, the number of orders it takes for the answers to converge are the same throughout both frequencies, which in this case is found to be four orders of reflections.

Sections	Poor (0-1)	Reasonable (2)	Excellent (3)
Demonstrate own efforts in coding without copying; Elegance of code			
Accuracy of simulation results			
The number of rays considered, convergence of results			
Structure of the submitted file; Quality of figures	2 marks maximum		