Computational Electromagnetics

Hw7-Q1

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1401/10/10

```
clear; clc; close all;
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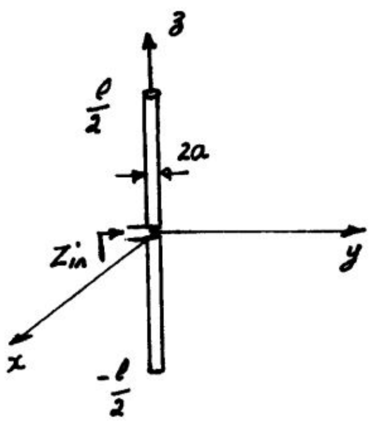
Q-1):



۱- آنتن استوانه‌ای به طول l و شعاع a از وسط تغذیه می‌گردد.

الف) با استفاده از روش ممان توزیع جریان روی آنتن را به‌ازای مقادیر مختلف $l = \frac{\lambda}{4}$، $\frac{\lambda}{2}$، $\frac{3\lambda}{4}$ و λ بدست آورید و امپدانس ورودی آنتن را محاسبه نمائید. a/λ را برابر 0.001 درنظر بگیرید.

ب) پترن آنتن در صفحات $\varphi=0$ (θ متغیر) و $\theta=\frac{\pi}{2}$ (φ متغیر) را در هر حالت محاسبه و رسم نمائید

ج) یافته‌های خود را با آنچه که از تحلیل کلاسیک آنتن‌های دی‌پل انتظار دارید مقایسه کنید و در جنبه‌های مختلف روش ممان که در عمل به آن برمی‌خورید بحث نمائید.

- The Main point in this question, is to find the current over the wire! -- >> The geometry of this problem is defined as a simple dipole on a thined wire with diameter equal to **2a**

Thined wire is defined as a wire with diameter which is small in comparison to wave length!

The MoM is applied to $L\{f\} = g$ and results in Current over the wire! -- >> This Current is then used to find the Scattered Field and then the Total Field!

Incident Wave can be modeled as both:

1) Gap Generator

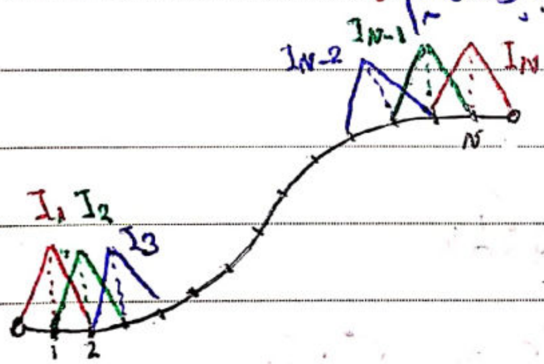
2) A plane wave propagating in the area

$L\{f\}$ is defined as:

$$E^i = \mathrm{jw}\mu_0 \hat{\ell} . \int I(\ell')\frac{e^{-\mathrm{jkR}}}{4\pi R}d\ell' - \frac{1}{\mathrm{jw}\epsilon_0}\hat{\ell}.\nabla\int\frac{\partial}{\partial\ell'}I(\ell')\frac{e^{-\mathrm{jkR}}}{4\pi R}d\ell' \ ;$$

where E^i equals to the rigth side of the $L\{f\} = g$ equation !

To apply Method of moments, first we must write our f in terms of corresponding expansion functions!

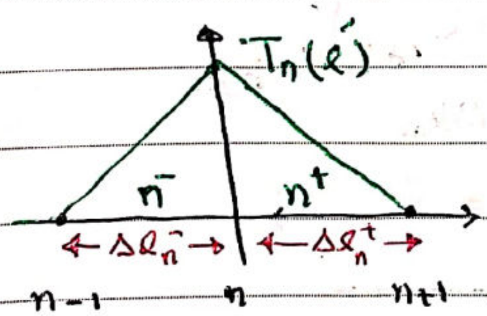


سعی می‌کنیم با روش ممان و توابع پایه مثلثی به تحلیل مسئله بپردازیم؛
اگر N+1 نقطه روی سیم در نظر بگیریم؛ تقریبی تکه‌ای -
خطی از توزیع جریان به ما خواهد داد و می‌دانیم در ابتدا و انتها
با جریان صفر انتخاب بسیار خوبی است؛

$$I(\ell') = \sum_{n=1}^{N} I_n T_n(\ell')$$

After choosing Expansion Function, the Second Step is considered Done!

$$I(\ell') = \sum_{n=1} I_n T_n(\ell')$$



گام اول: جایگذاری عبارت بالا در معادلات به دست آمده:

$$E^i_\ell(\ell) = \sum_{n=1}^{N} I_n \Big\{ j\omega\mu_0\, \hat{\ell}\cdot\underset{\hat{\ell}'\ \text{یا}}{\hat{\ell}_n}\int_{n-1}^{n+1} T_n(\ell')\frac{e^{-jkR}}{4\pi R}d\ell'$$

$$-\frac{1}{j\omega\epsilon_0}\frac{\partial}{\partial \ell}\int_{n-1}^{n+1}\frac{\partial T_n(\ell')}{\partial \ell'}\cdot\frac{e^{-jkR}}{4\pi R}d\ell' \Big\}$$

$\Rightarrow E^i = \mathrm{jw}\mu_0 \hat{\ell}. \int \sum_{n=1} I_n T_n(\ell') \frac{e^{-\mathrm{jkR}}}{4\pi R} d\ell' - \frac{1}{\mathrm{jw}\epsilon_0} \hat{\ell}. \nabla \int \frac{\partial}{\partial \ell'} \sum_{n=1} I_n T_n(\ell') \frac{e^{-\mathrm{jkR}}}{4\pi R} d\ell'$ $\Rightarrow$ due to linearity of operators we have:

$\Rightarrow E^i = \mathrm{jw}\mu_0 \hat{\ell}. \sum_n \int I_n T_n(\ell') \frac{e^{-\mathrm{jkR}}}{4\pi R} d\ell' - \frac{1}{\mathrm{jw}\epsilon_0} \hat{\ell}. \sum_n \nabla \int \frac{\partial}{\partial \ell'} I_n T_n(\ell') \frac{e^{-\mathrm{jkR}}}{4\pi R} d\ell' \Rightarrow$ -- >> Now, it is time to choose W_m for the weighting functions at:

$< W_m, g > \; = \; < W_m , L\{f\} >$ => For Galerkin we have:

گام دوم : ضرب داخلی طرفین با توابع تست و انتخاب ما روش Galerkin است : $W_m = T_m(\ell)$

$$[Z_{mn}] \cdot [I_n] = [V_m] \quad ; \quad V_m = \int_{m-1}^{m+1} T_m(\ell) E^i_\ell(\ell) d\ell$$

$$Z_{mn} = F_{mn} + C_{mn}$$

بخش ترکیبی I ← آنه بخش ما پارامترهای

MENHAJ

$$< W_m , E^i > \; = V_m \; = \; \mathrm{jw}\mu_0 \hat{\ell}. \sum_n \int W_m \int I_n T_n(\ell') \frac{e^{-\mathrm{jkR}}}{4\pi R} d\ell' d\ell - \frac{1}{\mathrm{jw}\epsilon_0} \hat{\ell}. \sum_n \int W_m \nabla \int \frac{\partial}{\partial \ell'} I_n T_n(\ell') \frac{e^{-\mathrm{jkR}}}{4\pi R} d\ell' d\ell$$

Due to the fact that we are facing an antenna problem, it is desired to have our f value equal to 0 at both ends of the antenna!

To calculate the distance one shall use Reff where:

$$\psi(m,n) = \frac{1}{\Delta l_m \cdot \Delta l_n} \int_{\Delta l_m} \int_{\Delta l_n} \frac{e^{-jkR}}{4\pi R} dl' dl \cong \frac{e^{-jkR_{eff}}}{4\pi R_{eff}}$$

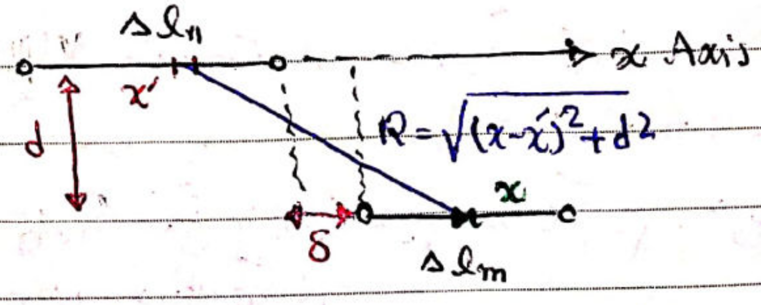
$$\frac{1}{R_{eff}} = \frac{1}{\Delta l_m \Delta l_n} \int_{\Delta l_m} \int_{\Delta l_n} \frac{1}{R} dl' dl$$

$$\Psi(m,n) = \frac{e^{-\mathrm{jk}R_{\mathrm{eff}}}}{4\pi R_{\mathrm{eff}}} \quad \text{where} \quad R_{\mathrm{eff}} = \frac{\mathrm{delta}_{\ell_m} * \mathrm{delta}_{\ell_n}}{M};$$

For a single wire, M equals to:

حالت‌های مختلف قطعات جریان :

(الف) در قطعه (طول) موازی



$$\int_0^{\Delta l_n}\int_{\Delta l_n+\delta}^{\Delta l_n+\delta+\Delta l_m} \frac{dx'\,dx}{\sqrt{(x-x')^2+d^2}}$$

Assuming :

$$\int \frac{dx}{\sqrt{x^2+a^2}} = \sinh^{-1}\left(\frac{x}{a}\right)+C \quad ; \quad \int \sinh^{-1}\left(\frac{x}{a}\right)dx = x\sinh^{-1}\left(\frac{x}{a}\right) - \sqrt{x^2+a^2}+C$$

اگر تعریف کنیم :

$\alpha = \Delta l_n + \Delta l_m + \delta$ ، $\beta = \Delta l_n + \delta$ ، $\gamma = \Delta l_m + \delta$

$$\alpha = \mathrm{delta}_{\ell_n} + \mathrm{delta}_{\ell_m} + \delta \;;\quad \beta = \mathrm{delta}_{\ell_n} + \delta\;;\quad \gamma = \mathrm{delta}_{\ell_m} + \delta\;;$$

$$M = \alpha\,.\sinh^{-1}\left(\frac{\alpha}{d}\right) - \beta.\sinh^{-1}\left(\frac{\beta}{d}\right) - \gamma\,.\sinh^{-1}\left(\frac{\gamma}{d}\right) + \delta\,.\sinh^{-1}\left(\frac{\delta}{d}\right) - \sqrt{\alpha^2+d^2} + \sqrt{\beta^2+d^2} + \sqrt{\gamma^2+d^2} - \sqrt{\delta^2+d^2}$$

For **self-terms** we get:

$\delta = -\Delta l_n$ ، $\Delta l_m = \Delta l_n$ ، $d = a$ for Self Term

$\Rightarrow \beta = \gamma = 0 \;,\; \alpha = \Delta l$

$$\boxed{M = 2\Delta l\,.\sinh^{-1}\left(\frac{\Delta l}{a}\right) - 2\sqrt{\Delta l^2+a^2} + 2a \text{ (for Self Term)}}$$

$$\delta = \delta_{\ell_n} \;, \mathrm{delta}_{\ell_m} = \mathrm{delta}_{\ell_n}; \quad d = a;$$

$\Rightarrow \beta = \gamma = 0; \ \ \alpha = \text{delta}_\ell \, ;$

$$M = 2\text{delta}_\ell \, . \sinh^{-1}\left(\frac{\text{delta}_\ell}{a}\right) - 2\sqrt{\text{delta}_\ell^2 + a^2} + 2a$$

```
c = 3e+08;   % Electromagnetics wave's  speed in  Air
f = 10e+06; % 10MHz



Lambda = c/f; % Wavelength


a = 1e-3*Lambda;
r = a;    % Radius of Wires
D = 2*a;  % Diameter of each Wire
L = Lambda/2 ; % Antenna Length (sum of Dipole's length)
```

```
N = 7;


delta_l = L/(N+1);
delta_l_index = 100; % Each Triangle Delta_l is equal to 100 indexes in l_vec

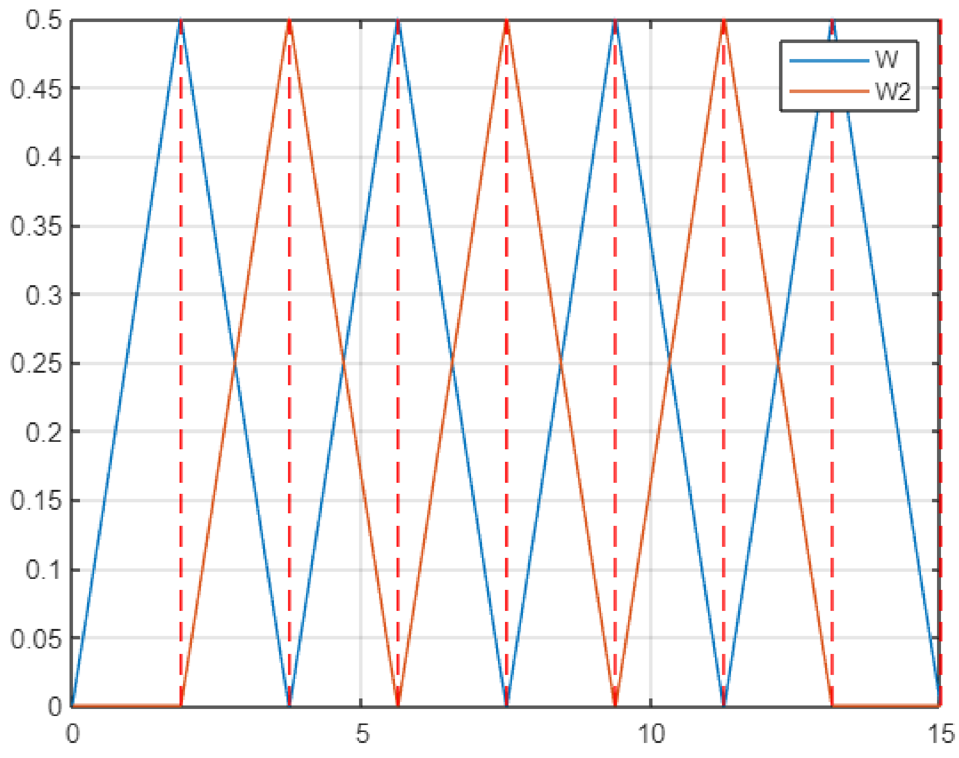


l_vec = linspace(0,L,(N+1)*delta_l_index);
```

```
[W,W2] = W_calc(N,delta_l_index,l_vec);
```

```
% close 1
figure(1)
plot(l_vec,W);

grid on
hold on
plot(l_vec , W2)
for i=1:N+1
    plot( i*delta_l*ones(1,10) , linspace(0,max(W),10),'r--');
end
legend("W","W2")
```




```
V = zeros(N+1,1);
E_i = zeros(1,(N+1)*delta_l_index)  ;

mid_point = floor(length(E_i)/2) ; % Tahrik az vasat

E_i(mid_point) = 1  ;
for m = 1:N+1
    V(m)  = G_m_calc(W , E_i , m ,l_vec , delta_l_index);
```

```
end



M = zeros(N+1,N+1);
Z = M;
PSAI = M;
PSAI_f = PSAI;

d = a;
k = 2*pi/Lambda;  % wave number

w = 2*pi*f; % Rad/m

mu0  = 4*pi*1e-07; % H/m
eps0 = 8.85*1e-12; % F/m




for m = 1:N+1
    for n=1:N+1
        M(m,n)    = M_calc( m , n , delta_l , d );
        Reff      =  (delta_l*delta_l)/M(m,n);
        PSAI(m,n) = exp(-1j*k*Reff)/(4*pi*Reff);
        % PSAI_f(m,n) =   ;

        if( (m==N+1) || (n==N+1)  )
            Z(m,n)    = 1j*w*mu0*delta_l*delta_l*PSAI(m,n) + ...
                (1/(1j*w*eps0)*( 0+PSAI(m,n)- 0 - 0 ) ) ;
        else
            Z(m,n)    = 1j*w*mu0*delta_l*delta_l*PSAI(m,n) +...
                (1/(1j*w*eps0)*( PSAI(m+1,n+1)+PSAI(m,n)- PSAI(m+1,n) - PSAI(m,n+1) ) ) ;
        end

    end
end
```

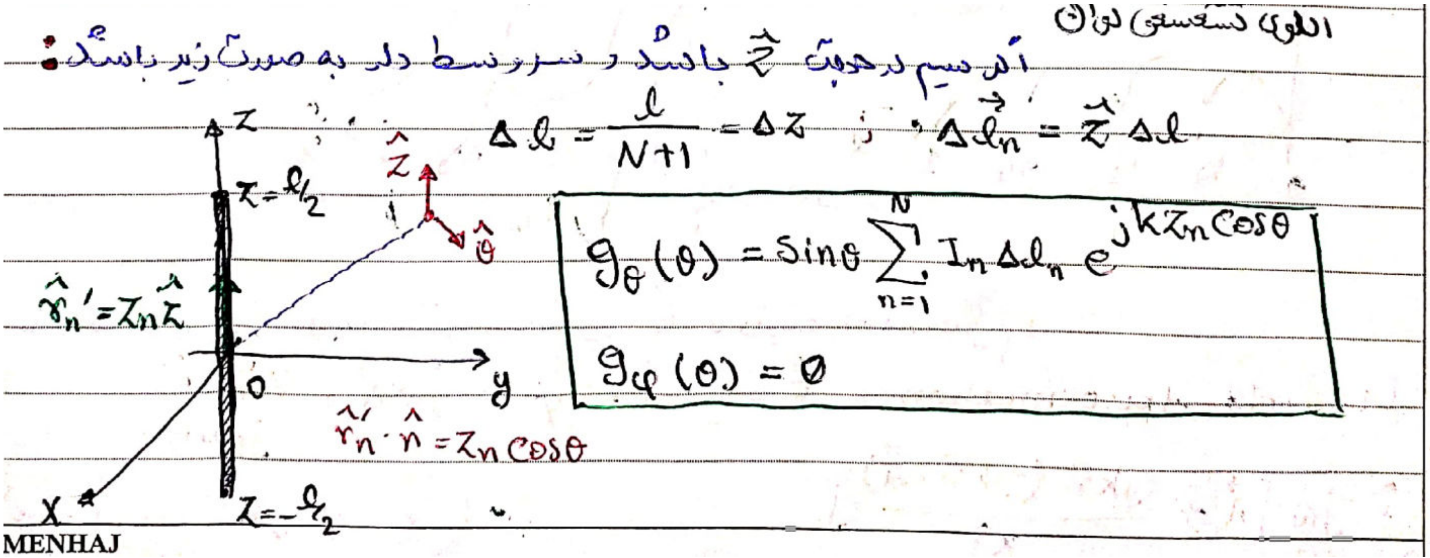
```
I = inv(Z)*V;

Z_in = V(floor(mid_point/delta_l_index))/I(floor(mid_point/delta_l_index));

disp((Z_in))
```

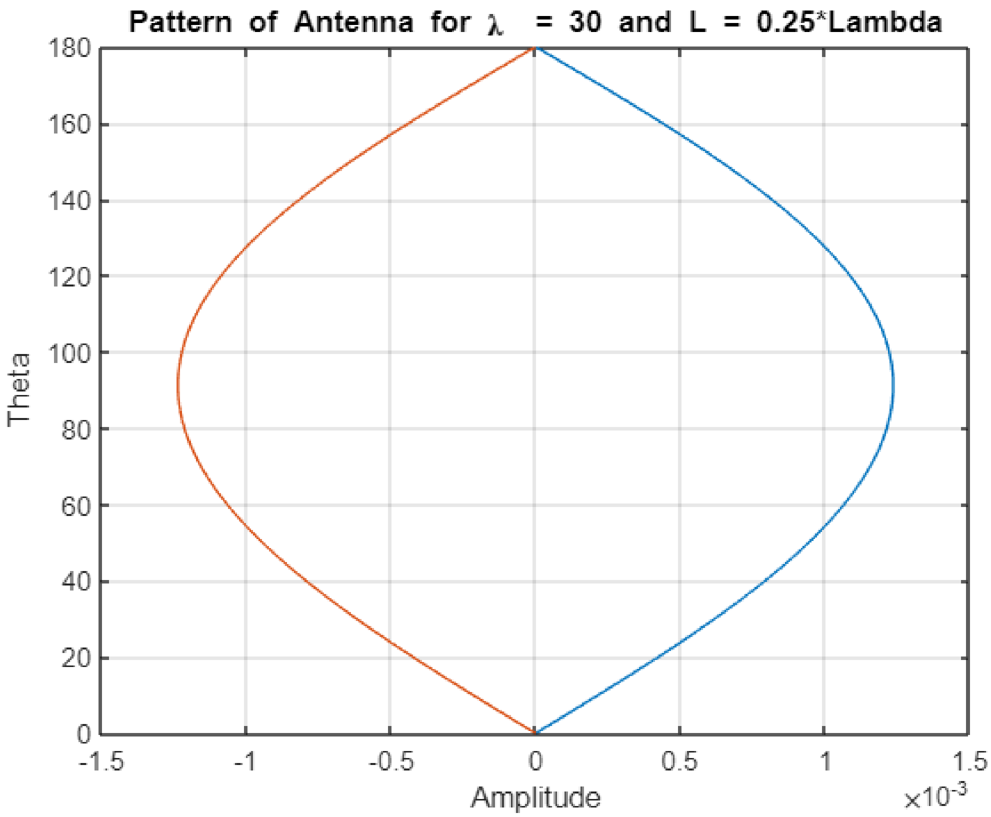
```
-9.9462e+00 - 4.6961e+02i
```

Part B: Draw Pattern

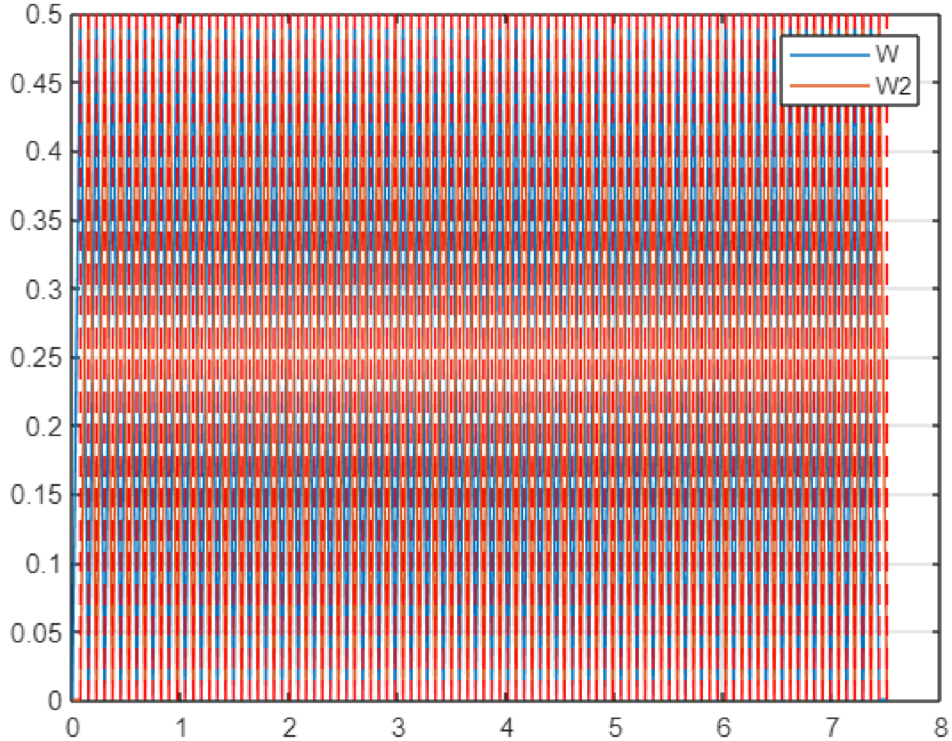



```
theta = 0.01: 0.1 :180 ;
zn = linspace(-L/2,L/2,length(I))';
Pattern = sind(theta).*sum( delta_l*I.*exp(1j*k*zn*cosd(theta)) ) ;

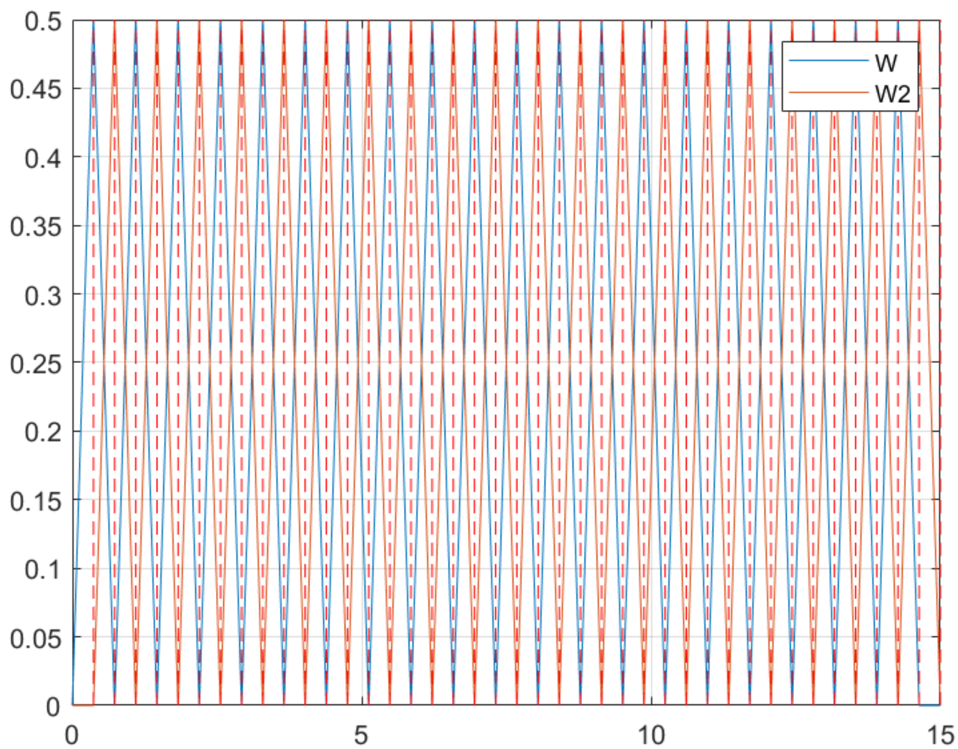
figure(3)
plot( abs(Pattern) , theta )
hold on
plot( -abs(Pattern) , theta )
title("Pattern of Antenna for \lambda  = "+Lambda+" and L = "+L/Lambda+"*Lambda")
grid on
xlabel("Amplitude")
ylabel("Theta")
```



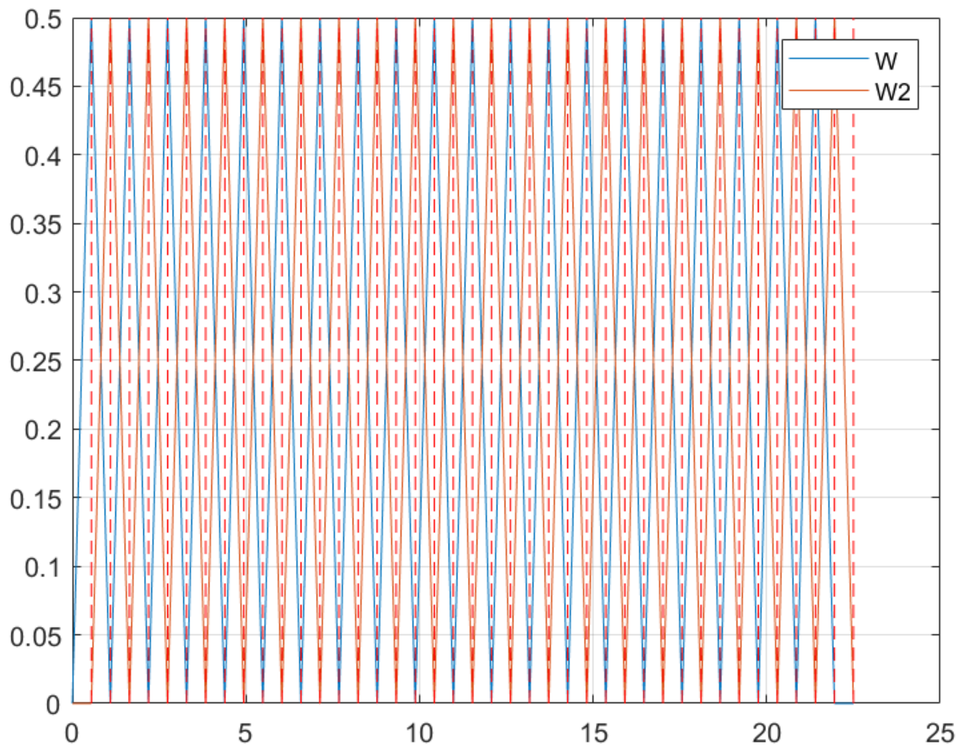

```
% For N = 100;
N =40;
L1 = Lambda/4;
A_L1   = Total_Worker(N,L1,a,f,c,0);
```



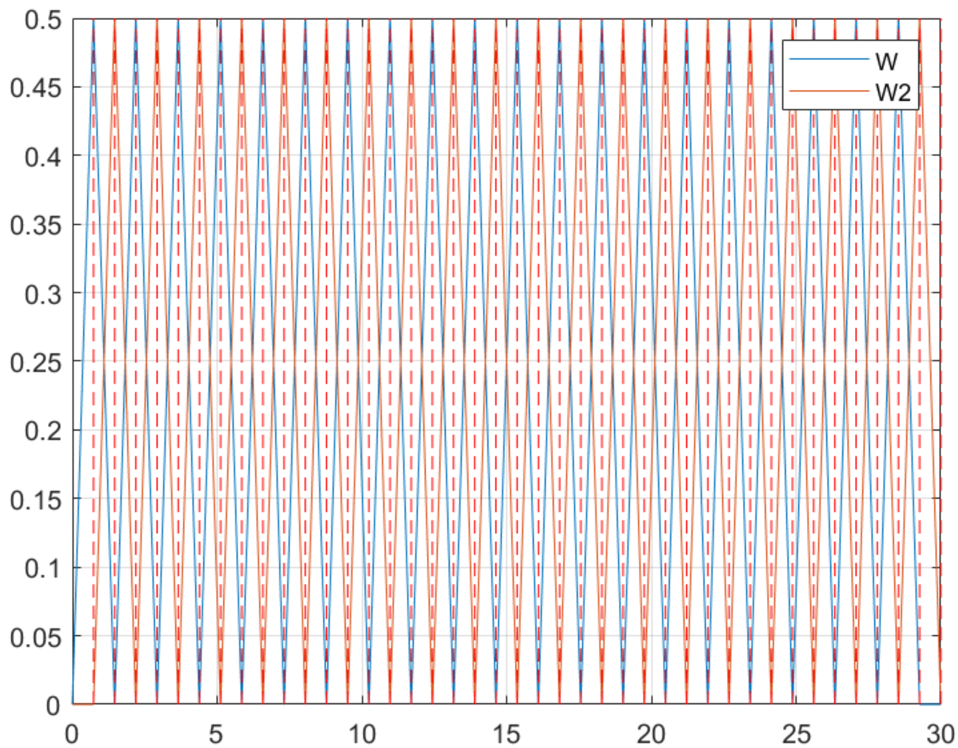

```
L2 = Lambda/2;
A_L2   = Total_Worker(N,L2,a,f,c,0);
```



```
L3 = 3*Lambda/4;
A_L3    = Total_Worker(N,L3,a,f,c,0);
```

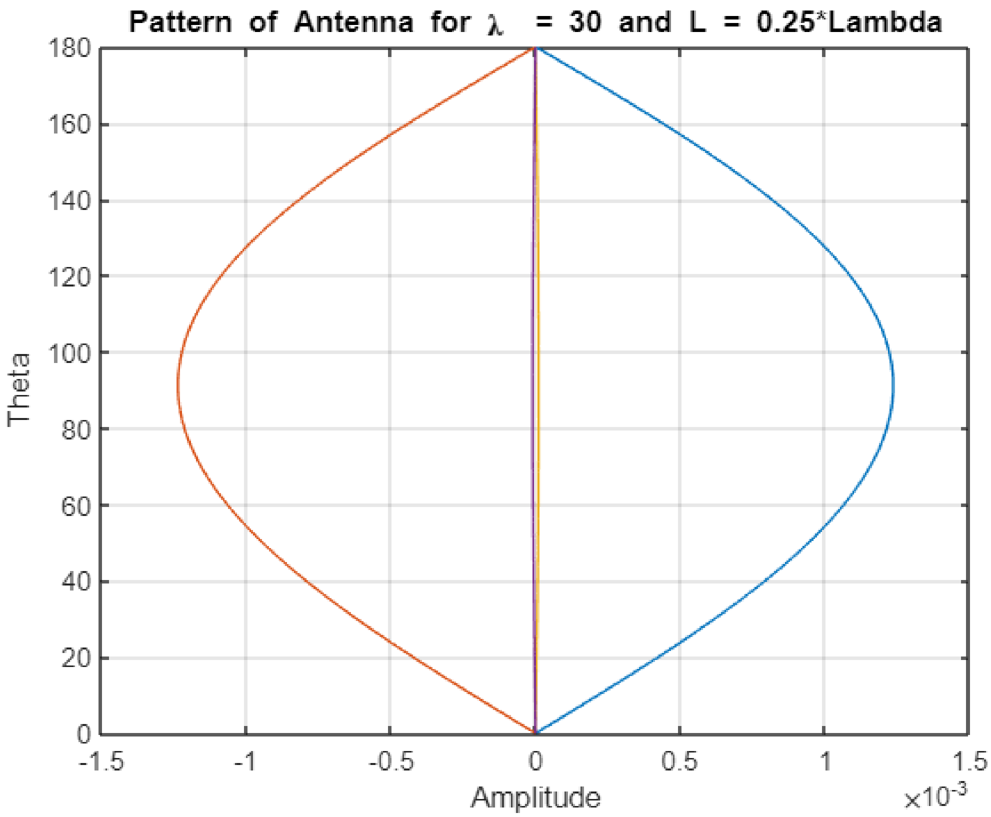



```
L4 = 1*Lambda;
A_L4    = Total_Worker(N,L4,a,f,c,0);
```



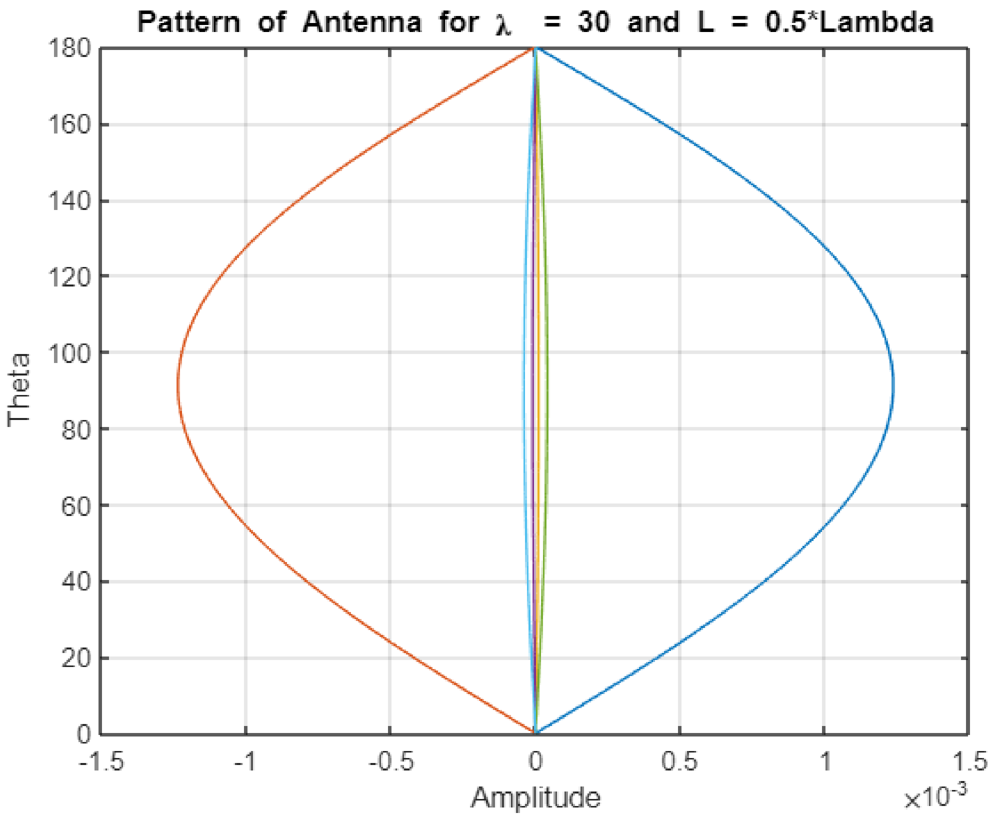
L = Lambda/4 Pattern:

```
Pattern_draw(A_L1);
```



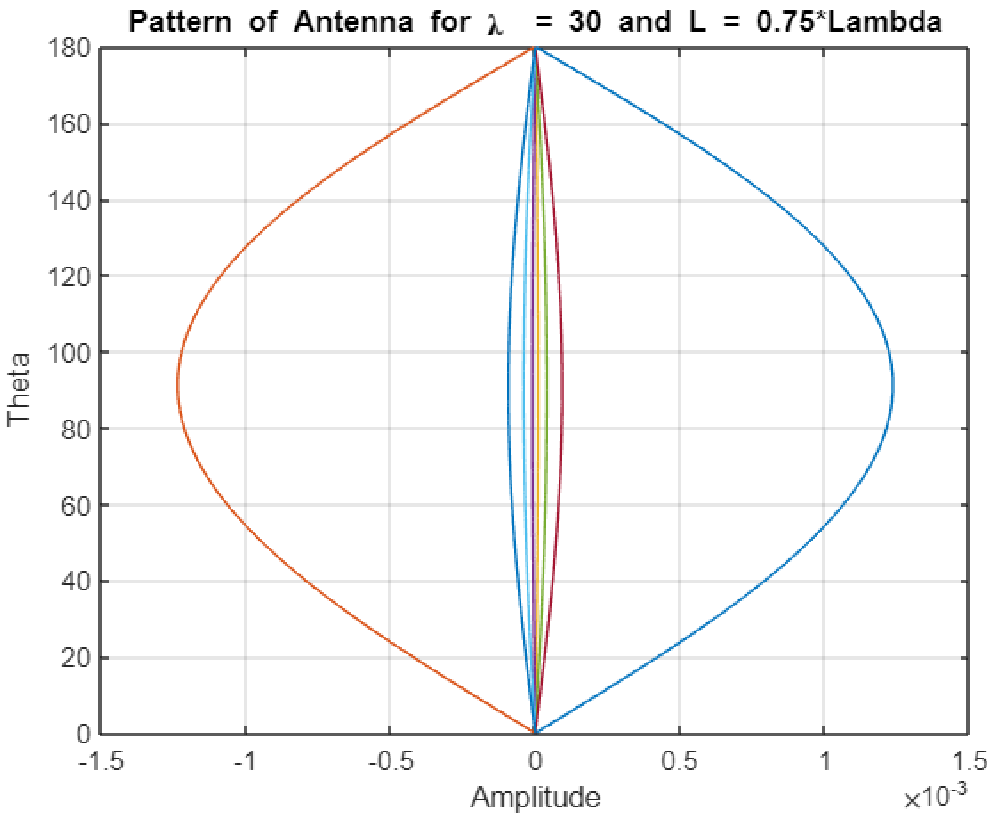
L = Lambda/2 Pattern

```
Pattern_draw(A_L2);
```



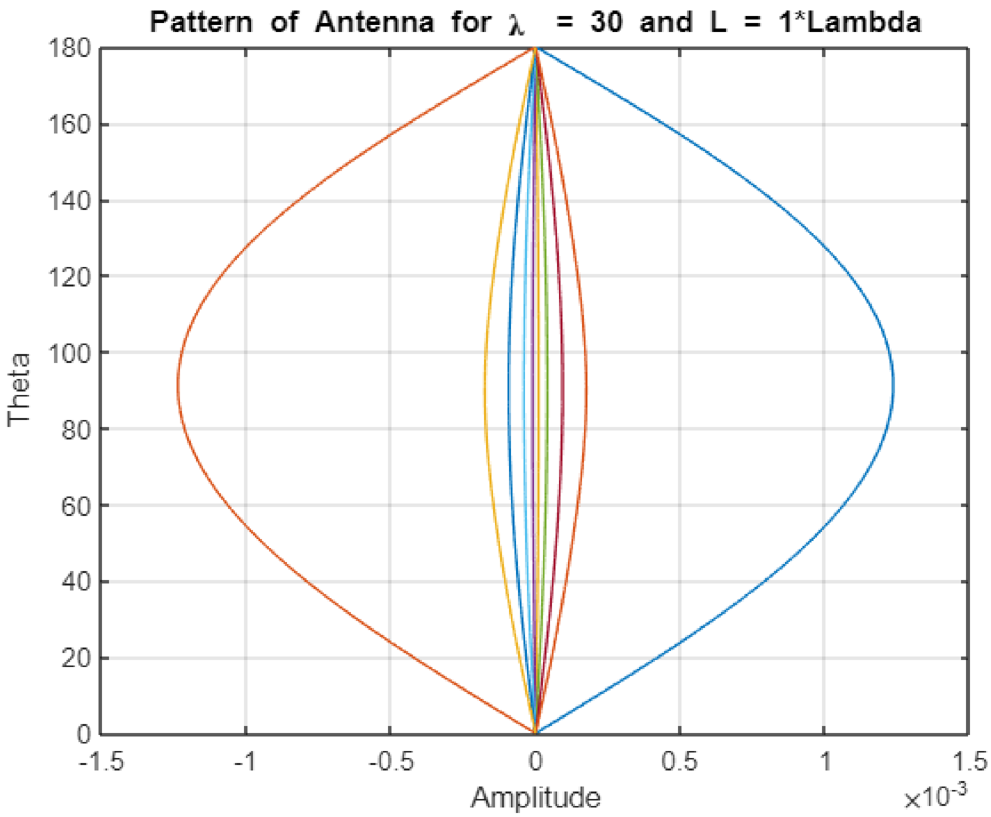
L = 3*Lambda/4 Pattern

```
Pattern_draw(A_L3);
```



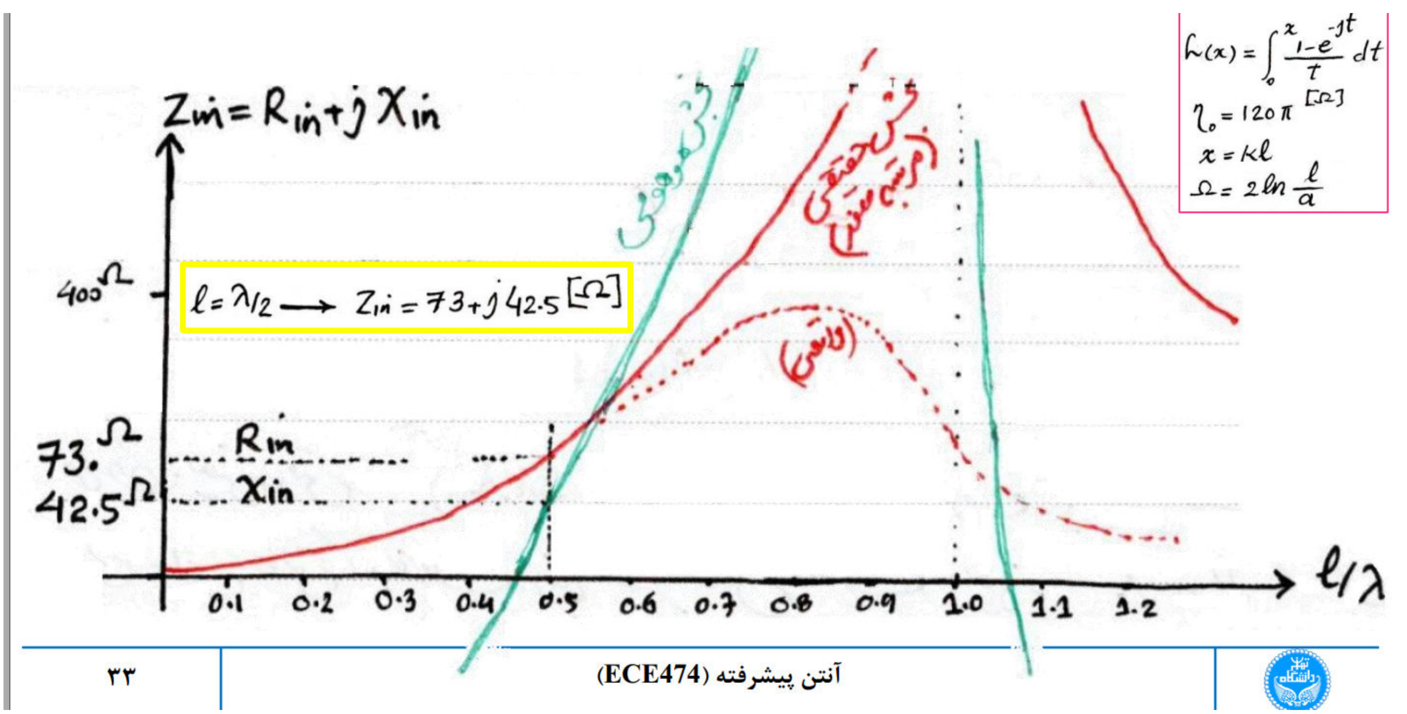
L = Lambda Pattern:

```
Pattern_draw(A_L4);
```



Part C:

Compare our results with analyticall solution obtained from classical analysis of the dipole antenna:



From Balanis we have also:

$$R_{in} = \left[\frac{I_0}{I_{in}}\right]^2 R_r \tag{4-77a}$$

where

R_{in} = radiation resistance at input (feed) terminals
R_r = radiation resistance at current maximum Eq. (4-70)
I_0 = current maximum
I_{in} = current at input terminals

where the radiation resistance of dipole antenna is considered:

The radiation resistance can be obtained using (4-18) and (4-68) and can be written as

$$\boxed{\begin{aligned} R_r = \frac{2P_{\text{rad}}}{|I_0|^2} = \frac{\eta}{2\pi}\{&C + \ln(kl) - C_i(kl) \\ &+ \tfrac{1}{2}\sin(kl) \times [S_i(2kl) - 2S_i(kl)] \\ &+ \tfrac{1}{2}\cos(kl) \times [C + \ln(kl/2) + C_i(2kl) - 2C_i(kl)]\} \end{aligned}} \tag{4-70}$$

Shown in Figure 4.9 is a plot of R_r as a function of l (in wavelengths) when the antenna is radiating into free-space ($\eta \simeq 120\pi$).

and for different values of ℓ , in figure 4.9 of balanis book we get to see the variation of Radiation resistance and input resistance of the dipole antenna:

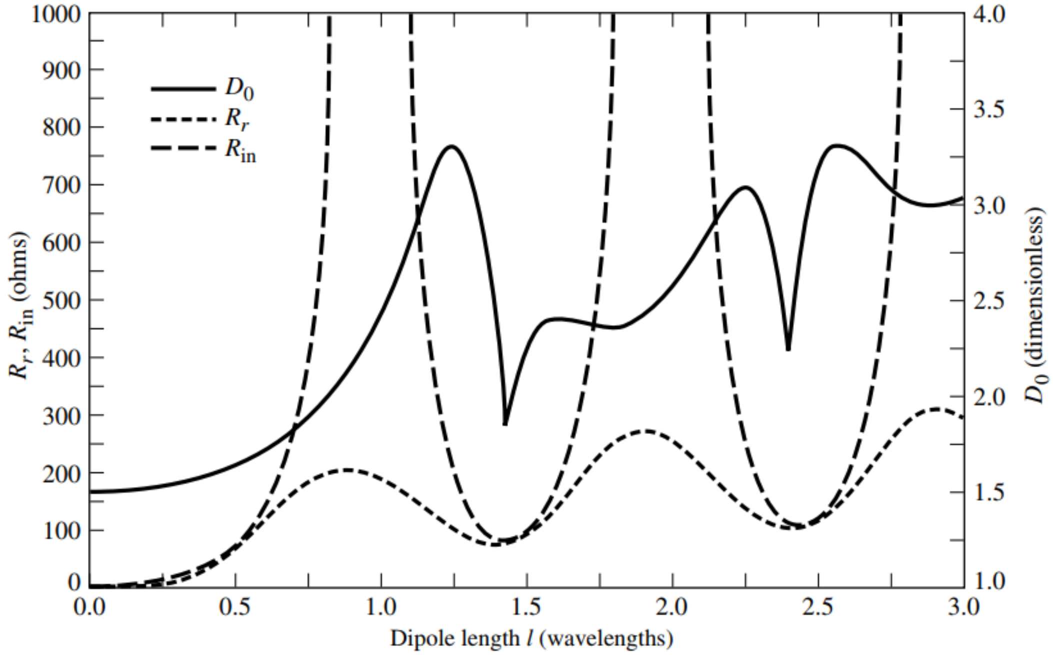


Figure 4.9 Radiation resistance, input resistance and directivity of a thin dipole with sinusoidal current distribution.

and for the Imaginary part of the input impedance, we can use the below equation:

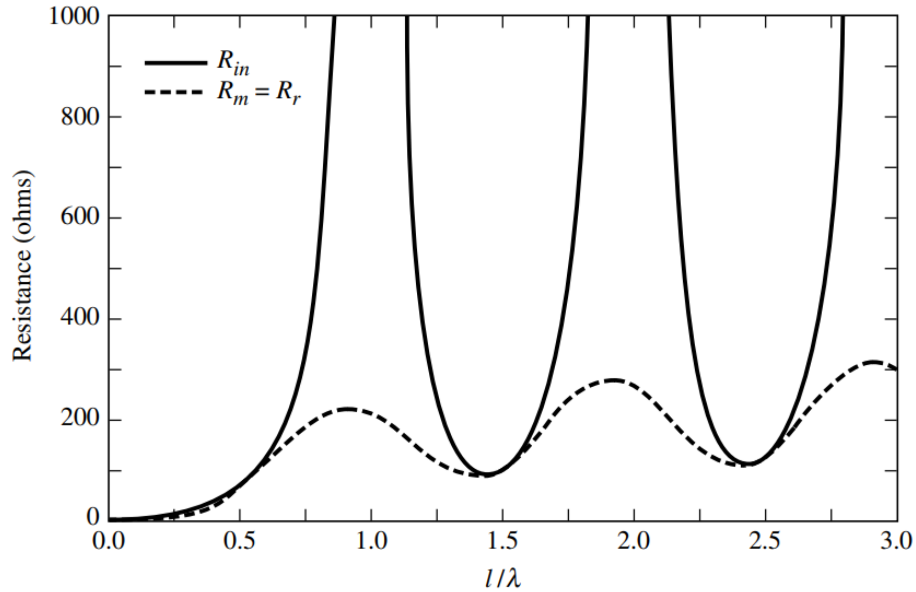
$$X_m = \frac{\eta}{4\pi}\left\{2S_i(kl) + \cos(kl)[2S_i(kl) - S_i(2kl)] - \sin(kl)\left[2C_i(kl) - C_i(2kl) - C_i\left(\frac{2ka^2}{l}\right)\right]\right\} \quad (4\text{-}70a)$$

in above equations, Ci(x) and Si(x) are used which are fresnel cosine and sine integrals defined as:

$$C_i(x) = -\int_x^\infty \frac{\cos y}{y}\,dy = \int_\infty^x \frac{\cos y}{y}\,dy \quad (4\text{-}68a)$$

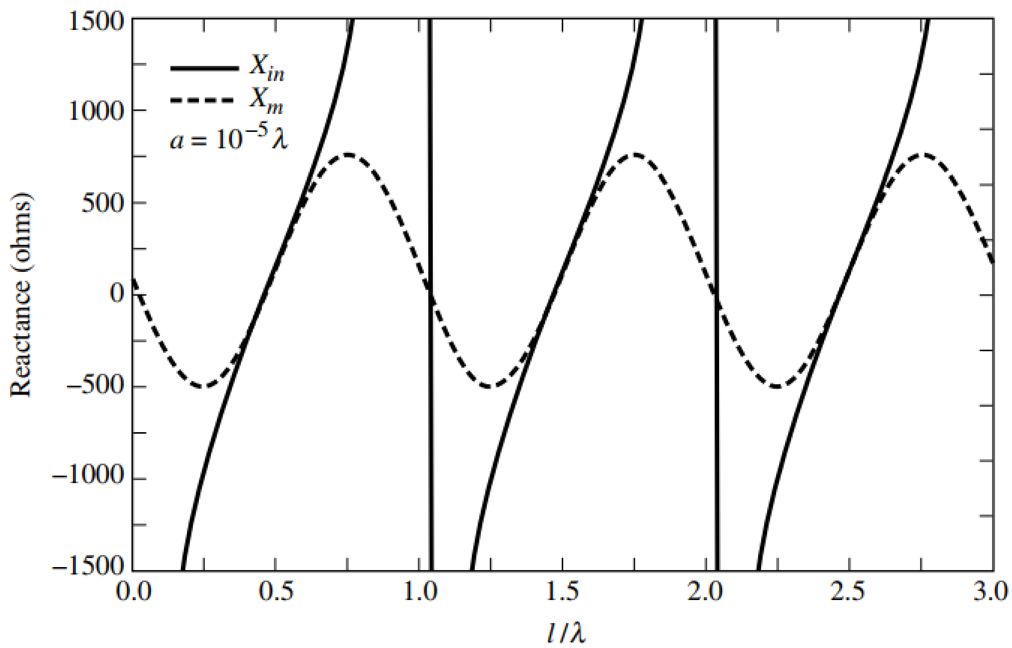
$$S_i(x) = \int_0^x \frac{\sin y}{y}\,dy \quad (4\text{-}68b)$$

For l/Lambda from 0 to 3 we get the figures below to express the difference between input resistance and the radiation resistance:



(a) Resistance

(a) Resistance



(b) Reactance

Figure 8.16 Self-resistance and self-reactance of dipole antenna with wire radius of 10^{-5} λ.

```
Antenna_Length = [Lambda/4 , Lambda/2 , 3*Lambda/4 , Lambda ];

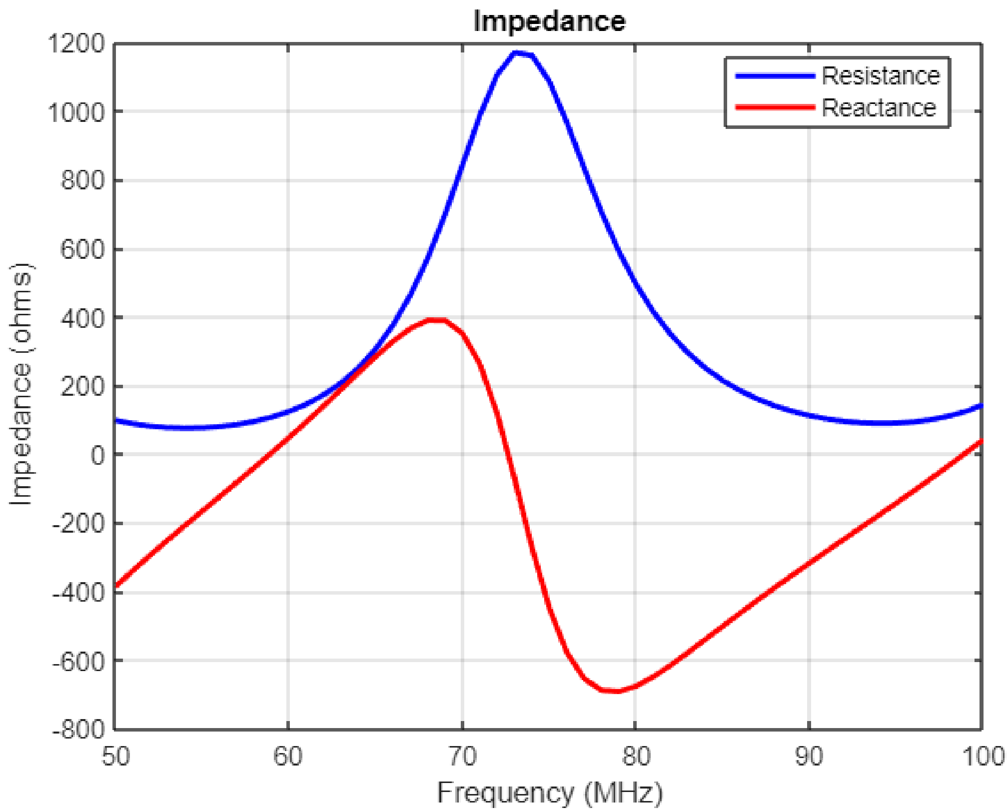
Z_in = zeros(length(Antenna_Length) , 1);

for i=1:length(Antenna_Length)
    Z_in(i) = Dipole_Antenna_exact_Z(Antenna_Length(i),a,Lambda);
    disp("For Dipole with length equal to: "+Antenna_Length(i) )
    disp(Z_in(i));

end
```

```
For Dipole with length equal to: 7.5
  33.7808 +64.3415i
For Dipole with length equal to: 15
  58.4540 +13.9715i
For Dipole with length equal to: 22.5
   2.3536e+02 + 9.3291e+01i
For Dipole with length equal to: 30
   1.5614e+08 + 2.6760e+33i
```

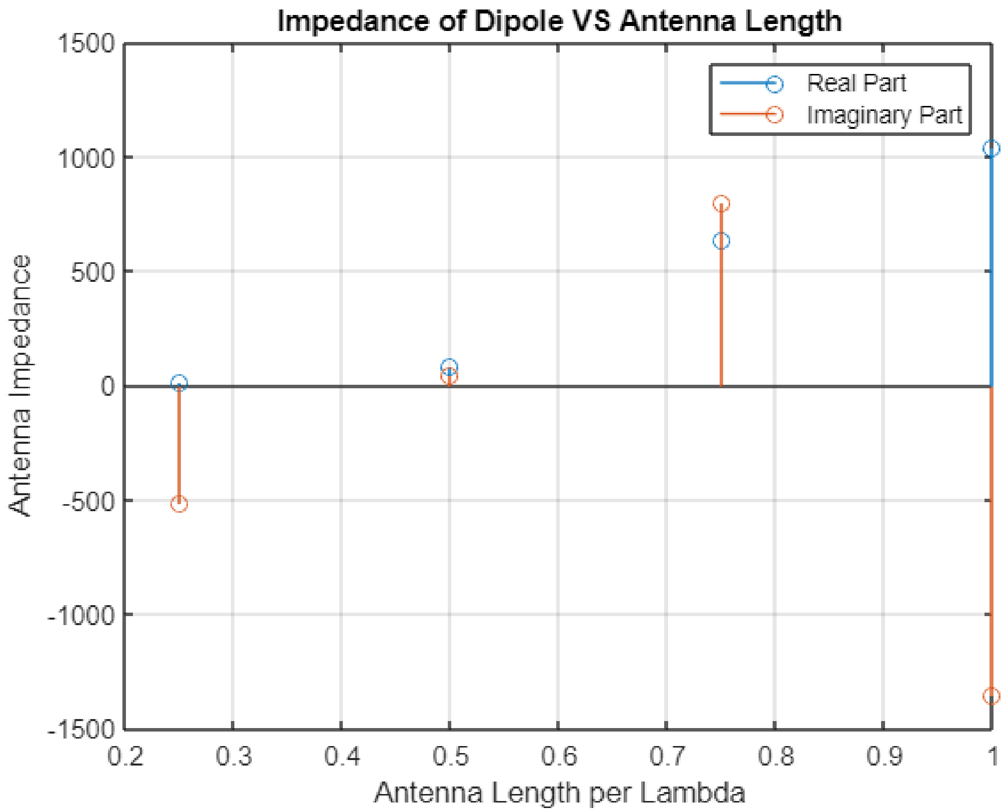
```
% Also we have from MATLAB Antenna ToolBox:
MATLAB_Antenna = dipole('Length',L,'Width',a);
figure(7)
impedance(MATLAB_Antenna,linspace(50e6,100e6,51));
```




```
Z_Matlab_in = zeros(length(Antenna_Length),1);
MATLAB_Antenna_mine  = cell(length(Antenna_Length),1);
for i=1:length(Antenna_Length)
    MATLAB_Antenna_mine{i} = dipole('Length',Antenna_Length(i), 'Width',2*a );
    Z_Matlab_in(i) = impedance(MATLAB_Antenna_mine{i},f);

end

close 8
figure(8)
stem(Antenna_Length/Lambda , real(Z_Matlab_in));
hold on
stem(Antenna_Length/Lambda , imag(Z_Matlab_in));
legend("Real Part" ,"Imaginary Part" );
grid on
title("Impedance of Dipole VS Antenna Length");
xlabel("Antenna Length per Lambda");
ylabel("Antenna Impedance")
```



Convergence Test:

```
L = Lambda/4;
N_vec = [20,50,60,70,80,100,110,130,150,180,200,400,800,1500  ];
N = N_vec(1);
A1_N1 = Total_Worker(N,L,a,f,c,0);

N = N_vec(2);
A1_N2 = Total_Worker(N,L,a,f,c,0);

N = N_vec(3);
A1_N3 = Total_Worker(N,L,a,f,c,0);

N = N_vec(4);
A1_N4 = Total_Worker(N,L,a,f,c,0);

N = N_vec(5);
A1_N5 = Total_Worker(N,L,a,f,c,0);

N = N_vec(6);
A1_N6 = Total_Worker(N,L,a,f,c,0);

N = N_vec(7);
A1_N7 = Total_Worker(N,L,a,f,c,0);
```

```
N = N_vec(8);
A1_N8 = Total_Worker(N,L,a,f,c,0);

N = N_vec(9);
A1_N9 = Total_Worker(N,L,a,f,c,0);

N = N_vec(10);
A1_N10 = Total_Worker(N,L,a,f,c,0);

N = N_vec(11);
A1_N11 = Total_Worker(N,L,a,f,c,0);


N = N_vec(12);
A1_N12 = Total_Worker(N,L,a,f,c,0);

N = N_vec(13);
A1_N13 = Total_Worker(N,L,a,f,c,0);

N = N_vec(14);
A1_N14 = Total_Worker(N,L,a,f,c,0);

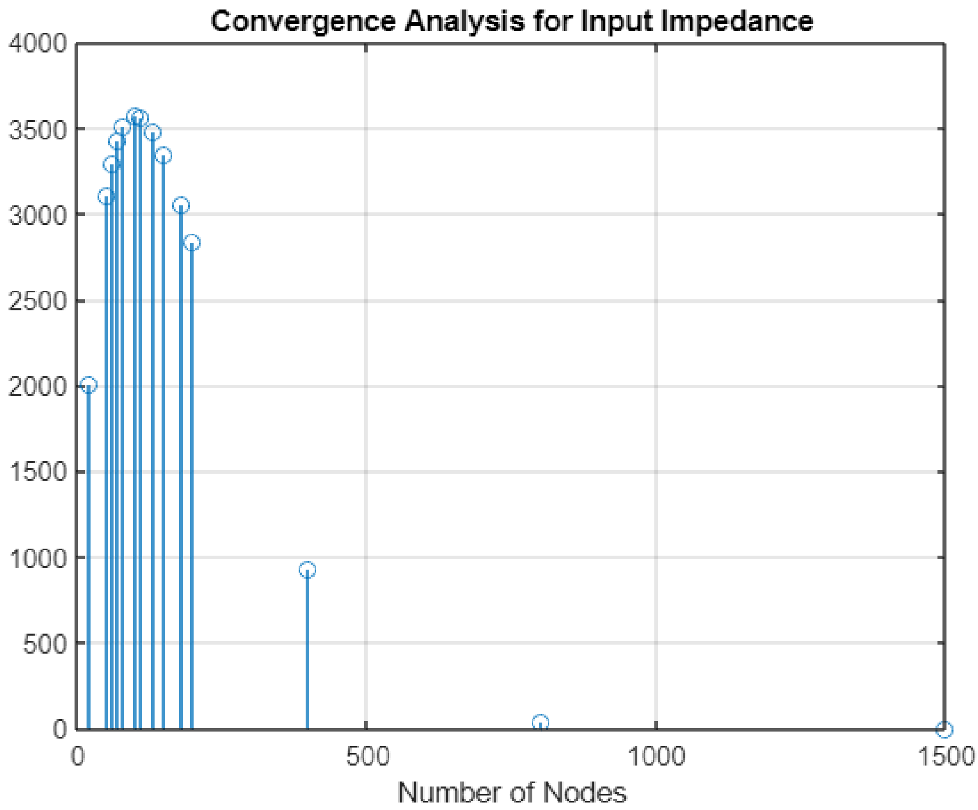
% N = N_vec(15);
% A1_N15 = Total_Worker(N,L,a,f,c,0);

A1_vec = {  A1_N1 , A1_N2 , A1_N3 , A1_N4 ,A1_N5 ,A1_N6 , A1_N7 ,A1_N8 ,A1_N9 ,A1_N10 , A1_N11
Z_A1 = zeros(length(N_vec),1);

for i=1:length(N_vec)
    Temp = A1_vec{i};
    Z_A1(i) =  Temp.Z_in;

end

figure()
stem( N_vec, abs(Z_A1))
title("Convergence Analysis for Input Impedance")
xlabel("Number of Nodes")
grid on
```



Functions:

```
function V_m  = G_m_calc(W , E_i , m ,l_vec , delta_l_index)

    Axis   = zeros(1,length(l_vec));
    Axis(1:2*delta_l_index) = W(1:2*delta_l_index);

    T_m    = circshift( Axis , (m-1)*delta_l_index  ) ;

    V_m    = sum( T_m.*E_i , 'all') ;

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function  M = M_calc( m , n , delta_l , d )

delta = delta_calc(m,n,delta_l);

alpha = 2*delta_l + delta;
```

```
Beta  =  delta_l  + delta;
Gamma =  delta_l  + delta;

if(m==n)% self Term:
         M = 2*delta_l*asinh(delta_l/d) - 2*sqrt(delta_l^2+ d^2) + 2*d;
else
         M = alpha*asinh(alpha/d) - Beta*asinh(Beta/d)  - Gamma*asinh(Gamma/d) + delta*asinh(de
             - sqrt(alpha^2 +d^2) + sqrt(Beta^2 +d^2) + sqrt(Gamma^2 +d^2) - sqrt(delta^2 +d^2)
end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function delta = delta_calc(m,n,delta_l)
    delta = (abs(m-n)-1)*delta_l;
end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function  Z_in = Dipole_Antenna_exact_Z(l,a,Lambda)
    eta = 120*pi;
    k = 2*pi/Lambda;
    C = 0.5772;

    X  = eta/(4*pi) * ( 2*fresnels(k*l) + cos(k*l)*(2*fresnels(k*l) - fresnels(2*k*l) ) ...
                  -sin(k*l)*( 2*fresnelc(k*l)-fresnelc(2*k*l)-fresnelc(2*k*a^2/l)  ) ) ;

    Rr  = eta/(2*pi) * (  ...
         C + log(k*l) - fresnelc(k*l) ...
         + 1/2*sin(k*l)* (fresnels(2*k*l)-2*fresnels(k*l)) ...
         + 1/2*cos(k*l)* (C + log(k*l/2)+ fresnelc(2*k*l) - 2*fresnelc(k*l) ) ...
                     )  ; %  C = 0.5772 (Euler s constant)
    R_in = Rr/(1e-3+sin(k*l/2))^2;
    X_in = X/(sin(k*l/2))^2;

    Z_in = R_in + 1j*X_in;



end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function [W,W2] = W_calc(N,delta_l_index,l_vec)

W = zeros(1,length(l_vec));

for i=1 : N+1
    if(mod(i,2)==1)
        W(1 + (i-1)*delta_l_index:i*delta_l_index) = 0.5*linspace(0,1,delta_l_index);
```

```
    else
        W(1 + (i-1)*delta_l_index:(i)*delta_l_index) =  -0.5*( linspace(1,2,delta_l_index) )+1;
    end
end
W2 =  circshift([W(1:end-delta_l_index),zeros(1,delta_l_index) ],delta_l_index);
if(mod(N,2)==0)
 W(end-delta_l_index:end) = 0;
else
 W2(end-delta_l_index:end) = 0;
end

end


function Pattern_draw(Object_Antenna)

L =Object_Antenna.L ;
I = Object_Antenna.I;
Lambda = Object_Antenna.Lambda;
delta_l =Object_Antenna.delta_l;
k =Object_Antenna.k;

theta = 0.01: 0.1 :180 ;
zn = linspace(-L/2,L/2,length(I))';
Pattern = sind(theta).*sum( delta_l*I.*exp(1j*k*zn*cosd(theta)) ) ;

figure(3)
plot( abs(Pattern) , theta )
hold on
plot( -abs(Pattern) , theta )
title("Pattern of Antenna for \lambda  = "+Lambda+" and L = "+L/Lambda+"*Lambda")
grid on
xlabel("Amplitude")
ylabel("Theta")


end


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function Total_Object = Total_Worker(N,L,a,f,c,draw)



Lambda = c/f ;
delta_l = L/(N+1);
delta_l_index = 100; % Each Triangle Delta_l is equal to 100 indexes in l_vec
l_vec = linspace(0,L,(N+1)*delta_l_index);

Total_Object = struct();
```

```
Total_Object.Lambda        = Lambda;
Total_Object.delta_l       = delta_l;
Total_Object.delta_l_index = delta_l_index ;
Total_Object.l_vec = l_vec;
Total_Object.draw = draw;
Total_Object.N = N;
Total_Object.L = L;
Total_Object.f = f;


[W,W2] = W_calc(N,delta_l_index,l_vec);

if(draw==1)
    figure()
    plot(l_vec,W);

    grid on
    hold on
    plot(l_vec , W2)
    for i=1:N+1
        plot( i*delta_l*ones(1,10) , linspace(0,max(W),10),'r--');
    end
    legend("W","W2")
end


Total_Object.W = W;
Total_Object.W2 = W2;




V = zeros(N+1,1);
E_i = zeros(1,(N+1)*delta_l_index)  ;

mid_point = floor(length(E_i)/2) ; % Tahrik az vasat

E_i(mid_point) = 1  ;
for m = 1:N+1
    V(m)  = G_m_calc(W , E_i , m ,l_vec , delta_l_index);
end

Total_Object.mid_point = mid_point;
Total_Object.E_i = E_i;
Total_Object.V = V;




M = zeros(N+1,N+1);
Z = M;
PSAI = M;
```

```
% PSAI_f = PSAI;

d = a;
k = 2*pi/Lambda;  % wave number

w = 2*pi*f; % Rad/m

mu0  = 4*pi*1e-07; % H/m
eps0 = 8.85*1e-12; % F/m

Total_Object.eps0 = eps0;
Total_Object.mu0 = mu0;
Total_Object.w = w;
Total_Object.d = a;
Total_Object.k = k;



for m = 1:N+1
    for n=1:N+1
        M(m,n)    = M_calc( m , n , delta_l , d );
        Reff      =  (delta_l*delta_l)/M(m,n);
        PSAI(m,n) = exp(-1j*k*Reff)/(4*pi*Reff);
        % PSAI_f(m,n) =   ;

        if( (m==N+1) || (n==N+1)  )
            Z(m,n)    = 1j*w*mu0*delta_l*delta_l*PSAI(m,n) + ...
                (1/(1j*w*eps0)*( 0+PSAI(m,n)- 0 - 0 ) ) ;
        else
            Z(m,n)    = 1j*w*mu0*delta_l*delta_l*PSAI(m,n) +...
                (1/(1j*w*eps0)*( PSAI(m+1,n+1)+PSAI(m,n)- PSAI(m+1,n) - PSAI(m,n+1) ) ) ;
        end

    end
end

Total_Object.M =M;
Total_Object.PSAI = PSAI;


I = inv(Z)*V;

Z_in = V(floor(mid_point/delta_l_index))/I(floor(mid_point/delta_l_index));

% disp("Impedance for Antenna with L = "+L/Lambda+"*Lambda: ")
% disp((Z_in))

Total_Object.Z_in = Z_in;
Total_Object.I = I;
```

```
end
```