EED4106 ANTENNAS AND PROPAGATION LABORATORY REPORT

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1 Dipol Antenna Parameters

In this experiment, dipol antenna characteristics will be observed by using MATLAB. The antenna parameters which will be obtained are current distribution, radiation intensity, radiated power, radiation resistance, directivity and input resistance. The background information about these antenna related terms were investigated in Laboratory 1 report.

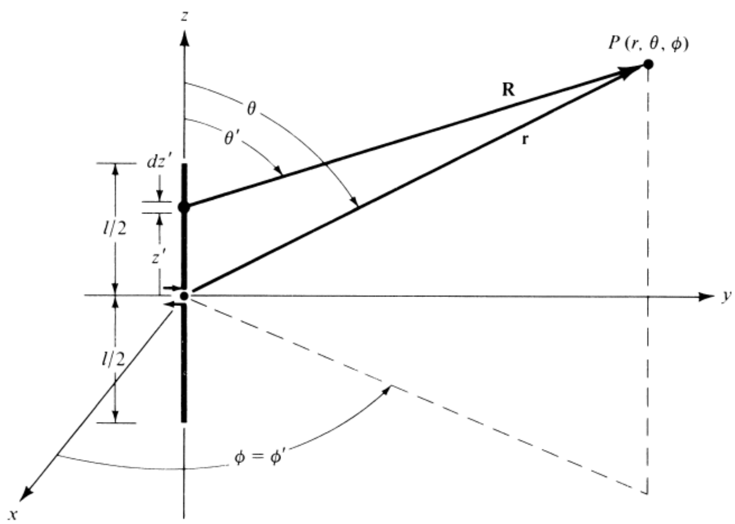

Figure 1: Geometry of dipole antenna[1]

1.1 Current Distribution

Current distribution of the dipol antenna can be modeled mathematically using the equation below,

$$I = \begin{cases} \hat{a}_z I_0 sin[k(\frac{l}{2} + z')] & 0 \leq z' \leq l/2 \\ \hat{a}_z I_0 sin[k(\frac{l}{2} - z')] & -l/2 \leq z' \leq 0 \end{cases}$$

First the code is examined by considering operating frequency as 300MHz, since

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{3 \times 10^8} = 1\,m \tag{1}$$

Length of the antenna for different l_c constants can be seen below,

$$\begin{gathered} l_c = 0.5 \rightarrow l = 0.5 \times 1m = 0.5m \\ l_c = 0.6 \rightarrow l = 0.6 \times 1m = 0.6m \\ l_c = 0.8 \rightarrow l = 0.8 \times 1m = 0.8m \\ l_c = 1 \rightarrow l = 1 \times 1m = 1m \\ l_c = 1.2 \rightarrow l = 1.2 \times 1m = 1.2m \\ l_c = 1.5 \rightarrow l = 1.5 \times 1m = 1.5m \\ l_c = 1.7 \rightarrow l = 1.7 \times 1m = 1.7m \end{gathered}$$

```matlab
function [z,I]=dipole_current_function(freq,lc,n,I0)
%Operating frequency of antenna-freq
%Antenna length constant-lc
%Number of part antenna consists of-n
%Current peak value-I0
c=3e8;
lambda=c/freq;
l=lc*lambda;
k=2*pi/lambda;

I=zeros(1,n); %vector declaration
z=linspace(-l/2,l/2,n); %antenna length divided into smaller parts
    for i=1:length(z)
        if i<101
            %below the z=0 point
            I(i)=I0*sin(k*(l/2+z(i)));
        else
            %above the z=0 point
            I(i)=I0*sin(k*(l/2-z(i)));
        end
    end
end
```

```matlab
str_len_antenna='Distance from the center of antenna (m)';
str_cur_amp='Current Amplitude (A)';

[z,I]=dipole_current_function(3e8,0.5,200,1);
p1=plot(z,I);
set(p1,'LineWidth',2)
hold on
[z,I]=dipole_current_function(3e8,0.6,200,1);
plot(z,I)
hold on
[z,I]=dipole_current_function(3e8,0.8,200,1);
plot(z,I)
hold on
[z,I]=dipole_current_function(3e8,1,200,1);
plot(z,I)
hold on
[z,I]=dipole_current_function(3e8,1.2,200,1);
plot(z,I)
hold on
[z,I]=dipole_current_function(3e8,1.5,200,1);
plot(z,I)
hold on
[z,I]=dipole_current_function(3e8,1.7,200,1);
plot(z,I)
hold on

ax=gca;
ax.XGrid='on'; ax.YGrid='on'; ax.XMinorGrid='on'; ax.YMinorGrid='on';
ax.Title.String = 'Dipole Antenna Current Distribution for 300MHz';
ax.XLabel.String = str_len_antenna; ax.YLabel.String = str_cur_amp;
legend({'0.5m','0.6m','0.8m','1m','1.2m','1.5m','1.7m'},'FontSize',12);

[z,I]=dipole_current_function(2.5e9,0.5,200,1);
p1=plot(z,I);
```

```
set(p1,'LineWidth',2)
hold on
[z,I]=dipole_current_function(2.5e9,0.6,200,1);
plot(z,I)
hold on
[z,I]=dipole_current_function(2.5e9,0.8,200,1);
plot(z,I)
hold on
[z,I]=dipole_current_function(2.5e9,1,200,1);
plot(z,I)
hold on
[z,I]=dipole_current_function(2.5e9,1.2,200,1);
plot(z,I)
hold on
[z,I]=dipole_current_function(2.5e9,1.5,200,1);
plot(z,I)
hold on
[z,I]=dipole_current_function(2.5e9,1.7,200,1);
plot(z,I)

ax=gca;
ax.XGrid='on'; ax.YGrid='on'; ax.XMinorGrid='on'; ax.YMinorGrid='on';
ax.Title.String = 'Dipole Antenna Current Distribution for 2500MHz';
ax.XLabel.String = str_len_antenna; ax.YLabel.String = str_cur_amp;
legend({'60mm','72mm','96mm','120mm','144mm','180mm','204mm'},'FontSize',12);
axis([min(z) max(z) min(I) max(I)])
```

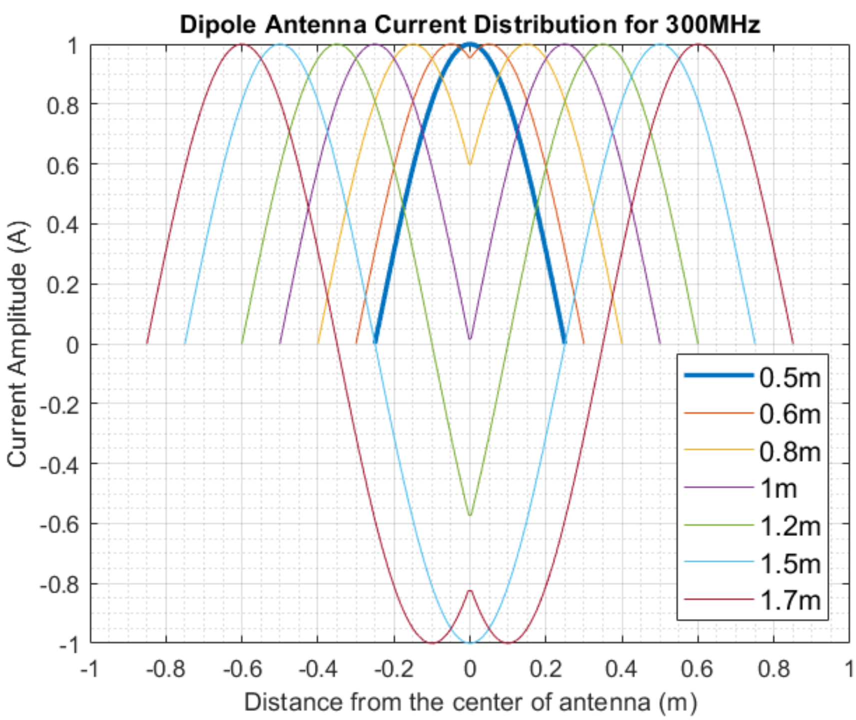

Figure 2: Current distribution of dipole antenna for 300MHz

In Fig.2, dipole antenna current distribution is observed for several wavelengths. The thickest one represents half-wave dipole current distribution since l_c is 0.5. Also, the waveform was drawn for different the wavelengths. As the wavelength increases antenna wavelength increases.

For wavelengths $\lambda < l < \frac{3\lambda}{2}$, there is 180° phase shift between some parts of the antenna. The phase shifted part can be seen between two positive parts of the wave. This phenomenon is due to the cyclic spatial variations.

Wavelength at the 2.5GHz frequency was calculated as below,

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{2.5 \times 10^9} = 0.12\,m \tag{2}$$

Length of the antenna for different l_c constants can be seen below,

$$l_c = 0.5 \rightarrow l = 0.5 \times 0.12m = 60mm$$
$$l_c = 0.6 \rightarrow l = 0.6 \times 0.12m = 72mm$$
$$l_c = 0.8 \rightarrow l = 0.8 \times 0.12m = 96mm$$
$$l_c = 1 \rightarrow l = 1 \times 0.12m = 120mm$$
$$l_c = 1.2 \rightarrow l = 1.2 \times 0.12m = 144mm$$
$$l_c = 1.5 \rightarrow l = 1.5 \times 0.12m = 180mm$$
$$l_c = 1.7 \rightarrow l = 1.7 \times 0.12m = 204mm$$

For the 2500MHz operation frequency, antenna physical length decreases one-to-tenth. This can be deduced by comparing Fig.(2) and Fig.(3). The thickest waveform in Fig.(3) represent half-wave dipole in 2500MHz frequency. The current peak is not affected from this change.

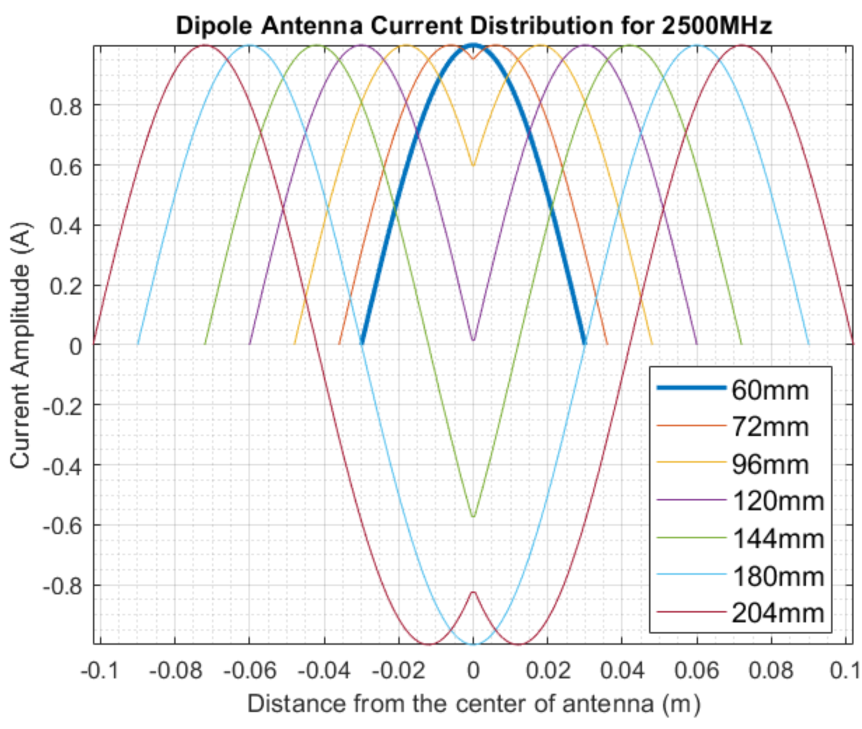

Figure 3: Current distribution of dipole antenna for 2500MHz

1.2 Radiation Intensity

Radiation intensity of the dipole antenna can be calculated by using the formula,

$$U = \eta \frac{|I_0|^2}{8\pi^2}\left(\frac{cos(\frac{kl}{2}cos(\theta)) - cos(\frac{kl}{2})}{sin(\theta)}\right)^2 \tag{3}$$

```matlab
function [theta, U]=radiation_intensity_function(freq,lc,n,I0)
%Operating frequency of antenna-freq
%Antenna length constant-lc
%Angle resolution-n
%Current peak value-I0
eta=120*pi;
c=3e8;
lambda=c/freq;
k=2*pi/lambda;
l=lambda*lc;
theta=linspace(0,2*pi,n);

U=((eta*abs(I0)^2)/(8*pi^2)).*((cos((k*l/2).*cos(theta))-cos((k*l/2)))./(sin(theta))).^2;

end
```

```matlab
%0.02 wavelength small dipole antenna
[theta,U]=radiation_intensity_function(2.5e9,0.02,400,1)
polarplot(U)
hold on
%0.5 wavelength half wave dipole antenna
[theta,U]=radiation_intensity_function(2.5e9,0.5,400,1)
polarplot(U)
hold on
%1 wavelength dipole antenna
[theta,U]=radiation_intensity_function(2.5e9,1,400,1)
polarplot(U)
hold on
%1.5 wavelength dipole antenna
[theta,U]=radiation_intensity_function(2.5e9,1.5,400,1)
polarplot(U)
hold on
%graphical tools
ax=gca
ax.ThetaZeroLocation = 'top';  ax.RMinorGrid = 'on'; ax.ThetaMinorGrid = 'on';
ax.Title.String = 'Dipole Antenna Radiation Intensity for 2500MHz';
legend({'0.02\lambda','0.5\lambda','1\lambda','1.5\lambda'},'FontSize',12);
```

In this code, radiation intensity of the dipole antenna is calculated. Then, the results are displayed in polar coordinates. In Fig.(4) small dipole radiation intensity can be observed. Its radiation characteristic can be compared with the ones in Fig.(5). The antenna physical length has an impact on the radiation intensity.

By comparision of the Fig.(4) and Fig.(5), especially 0.5λ and λ, it can be deduced that radiation intensity peak value increases as the antenna length increases. It is important to emphasize that the power radiated in antenna is the same, the direction it radiates changes with the dipol antenna length.

In Fig.(5), as the length of dipole increases more than one wavelength number of lobes increases.

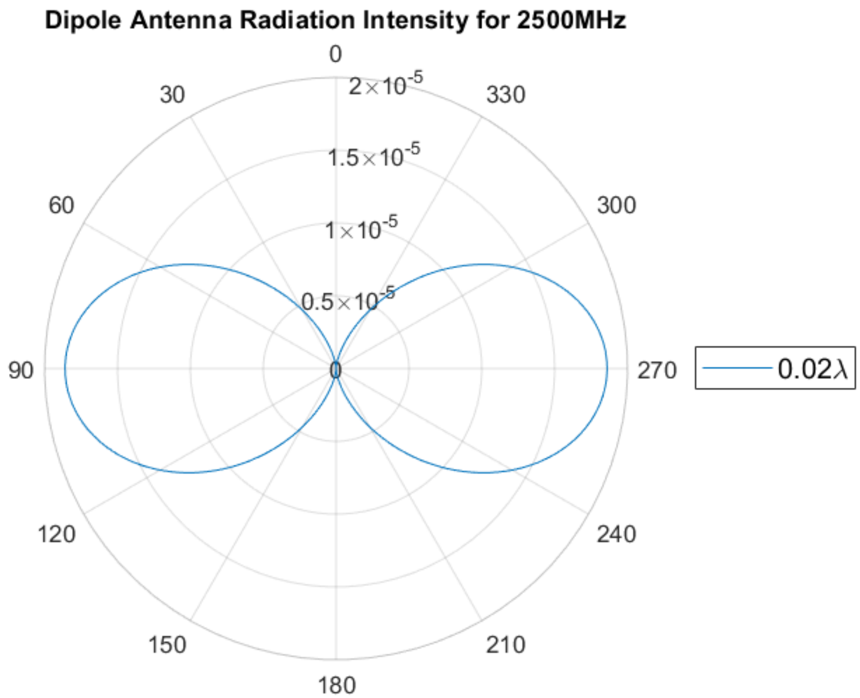

Figure 4: Radiation intensity of small dipol

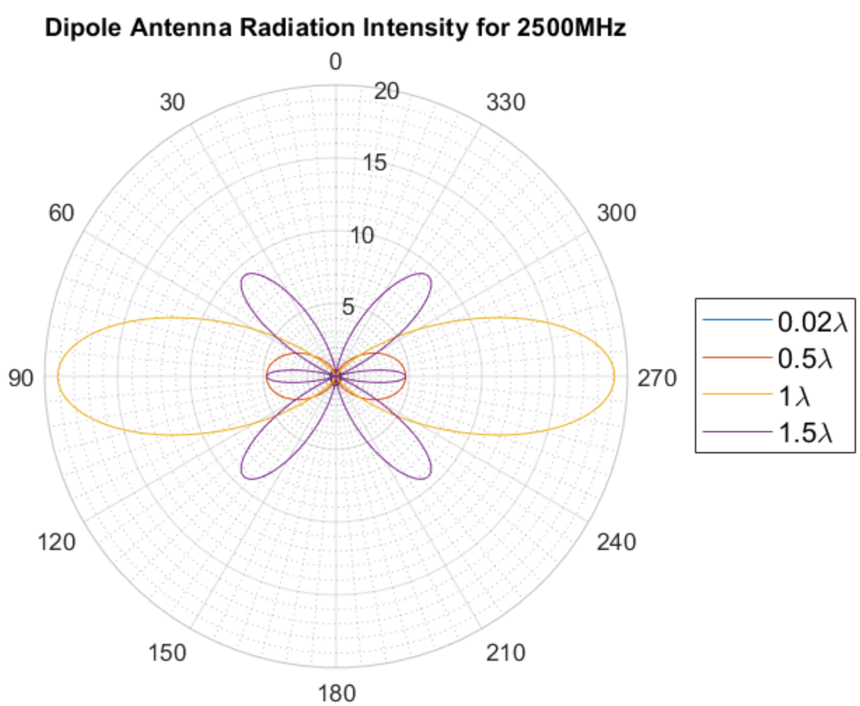

Figure 5: Radiation intensity of dipole antenna for several wavelengths

1.3 Radiated Power

Radiated power of the dipole antenna can be calculated from the Eq.4

$$P_{rad} = \eta \frac{|I_0|^2}{4\pi} \int_0^{\pi} \frac{(cos(\frac{kl}{2}cos(\theta)) - cos(\frac{kl}{2}))^2}{sin(\theta)}\,\mathrm{d}\theta \tag{4}$$

```matlab
function [l,Prad]=radiated_power_function(freq,lc,I0)

eta=120*pi;  %intrinsic impedance
c=3e8;  %speed of ligth
lambda=c/freq;  %wavelength @ operating freq
k=2*pi/lambda;  %phase constant
l=lambda*lc;    %antenna length

%radiated power integrand
power_integrand=@(theta) (eta*(abs(I0))^2/(4*pi))*(cos((k*l/2)*cos(theta))-cos(k*l/2)).^2./sin(theta);
%radiated power calculation
Prad=integral(power_integrand,0,pi);

end
```

```matlab
i=0.1:0.05:3;
for k=1:length(i)
    [l(k),Prad(k)]=radiated_power_function(3e8,i(k),1);
end

plot(i,Prad)
ax=gca;
ax.XGrid='on'; ax.YGrid='on'; ax.XMinorGrid='on'; ax.YMinorGrid='on';
ax.XLabel.String = 'Antenna length (\lambda)'; ax.YLabel.String = 'Radiated Power(W)';
```

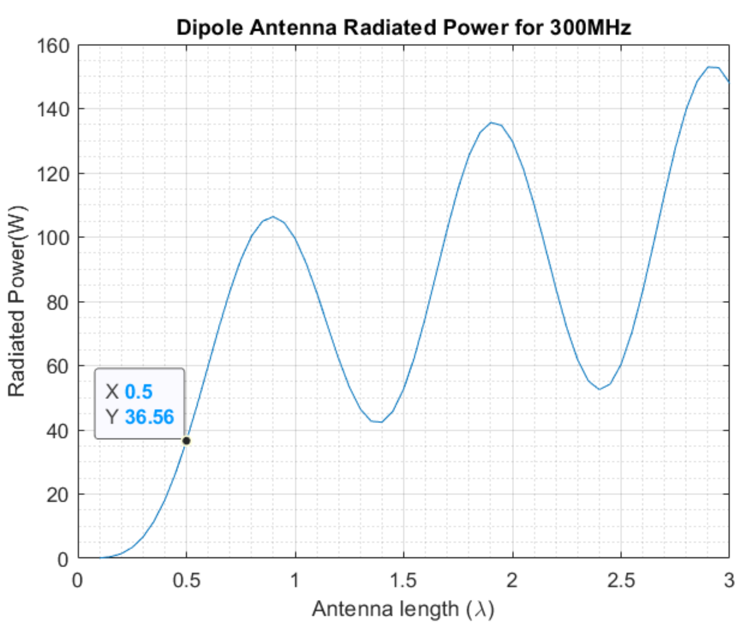

Figure 6: Radiated power for several antenna lengths in terms of wavelengths

As you can see in the above codes, radiated power is calculated for the case which the frequency is 300MHz so the wavelength is 1m, for the sake of simplicity.

In the Fig.(6), there is a label which indicates the half wave dipole radiated power.

1.4 Radiation Resistance

The radiation resistance calculation formula is

$$R_r = \frac{2P_{rad}}{|I_0|^2} \tag{5}$$

```
%based on the previous radiated power calculations
R_r=2*Prad/abs(I0)^2;
%graphical manipulations
plot(l,R_r)
ax=gca;
ax.XGrid='on'; ax.YGrid='on'; ax.XMinorGrid='on'; ax.YMinorGrid='on';
ax.XLabel.String = 'Antenna length (\lambda)'; ax.YLabel.String = 'Radiation Resistance(Ohm)';
ax.Title.String = 'Dipole Antenna Radiation Resistance';
```

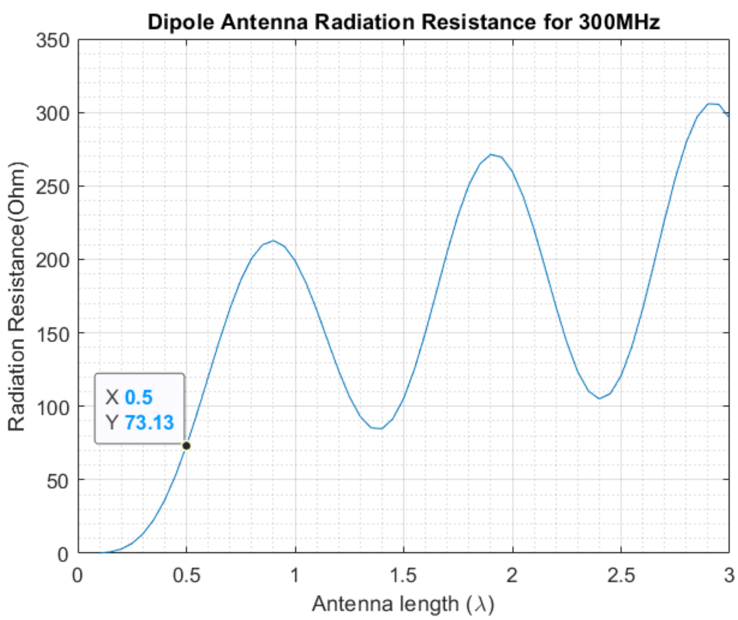

Figure 7: Radiation resistance for several antenna lengths in terms of wavelengths

In Fig.(7) radiation resistance of an antenna is calculated for different wavelengths. In order to check consistency of the calculations, half-wave dipole radiation resistance was controlled. The above calculations are consistent with the standart half-wave dipole characteristic properties.

1.5 Directivity

Maximum directivity, in general, can be calculated in the following manner,

$$D_{max} = D_0 = \frac{4\pi U_{max}}{P_{rad}} \tag{6}$$

In the above equation, the pattern function has parameters of both θ and ϕ. However, for the dipole antennas, due to the no change in the ϕ direction, directivity calculation depends only on θ component of the field. As a result,

$$D_0 = \frac{2F_{max}(\theta)}{\int_0^{\pi} F(\theta) sin(\theta) d\theta} \tag{7}$$

The maximum of the radiation intensity can be found by

$$B_0 = \eta \frac{|I_0|^2}{8\pi^2} \tag{8}$$

And pattern function which depends only on θ can be calculated for a dipole antenna such that [1]

$$F(\theta) = \frac{(cos(\frac{kl}{2} cos(\theta)) - cos(\frac{kl}{2}))^2}{sin^2(\theta)} \tag{9}$$

```
function [l, D]=directivity_function(freq,lc)

c=3e8;  %speed of ligth
lambda=c/freq;  %wavelength @ operating freq
k=2*pi/lambda;  %phase constant
l=lambda*lc;    %antenna length

%definition of theate dependent integrand
pattern_func_integrand=@(theta) (cos((k*l/2)*cos(theta))-cos(k*l/2)).^2./sin(theta);
%calculation of the integral
pattern_integral=integral(pattern_func_integrand,0,pi);
%pattern function max value for pi/2
theta=pi/2;
pattern_max=(cos((k*l/2)*cos(theta))-cos(k*l/2)).^2./(sin(theta))^2;

D=2*pattern_max/pattern_integral;
end
```

```
i=0:0.0001:3;
for m=1:length(i)
    [l(m),D(m)]=directivity_function(3e8,i(m));
end

plot(l,D)
ax=gca;
ax.XGrid='on'; ax.YGrid='on'; ax.XMinorGrid='on'; ax.YMinorGrid='on';
ax.Title.String = 'Dipole Antenna Directivity for 300MHz';
ax.XLabel.String = 'Antenna length (\lambda)'; ax.YLabel.String = 'Directivity';
```

By using the approach, explained above, the directivity of half-wave dipol was calculated as 1.64 .

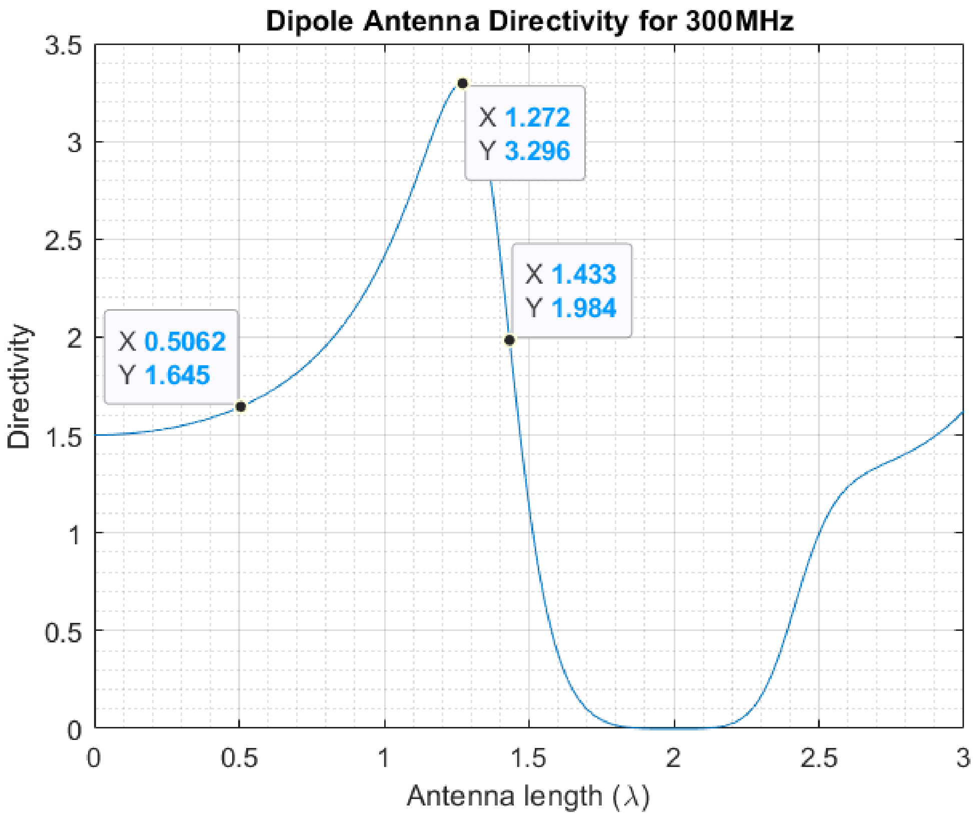

Figure 8: Directivity of dipol antenna for 300MHz

The labels in the Fig.(8) are important. Since the first one indicates half-wave dipole directivity, the others shows the consistency of the results, with respect to the ones obtained in the reference book [1]. However, results become inconsistent for the values above 1.5λ length dipole antenna.

1.6 Input Resistance

Input resistance of dipole antenna can be calculated by using the equation,

$$R_{in} = \frac{R_r}{sin^2(\frac{kl}{2})} \tag{10}$$

```
function [l,R_in]=in_resistance_func(freq,lc,R_r)

c=3e8;  %speed of ligth
lambda=c/freq;  %wavelength @ operating freq
k=2*pi/lambda;  %phase constant
l=lambda*lc;    %antenna length

R_in=R_r./(sin(k.*l/2)).^2;

end
```

```
i=0:0.0001:3;
for m=1:length(i)
    [l(m),R_in(m)]=in_resistance_func(3e8,i(m),R_r(m));
end

subplot(2,2,1)
plot(l(1:9500),R_in(1:9500))
ax=gca;
%ax.Title.String = 'Input Resistance for Antenna Lengths of 0 to \lambda ';
ax.XGrid='on'; ax.YGrid='on'; ax.XMinorGrid='on'; ax.YMinorGrid='on';
ax.XLabel.String = 'Antenna length (\lambda)'; ax.YLabel.String = 'Input Resistance';
subplot(2,2,2)
plot(l(10100:19900),R_in(10100:19900))
ax=gca
ax.XGrid='on'; ax.YGrid='on'; ax.XMinorGrid='on'; ax.YMinorGrid='on';
%ax.Title.String = 'Input Resistance for Antenna Lengths of \lambda to 2\lambda';
ax.XLabel.String = 'Antenna length (\lambda)'; ax.YLabel.String = 'Input Resistance';
subplot(2,2,3)
plot(l(20100:29900),R_in(20100:29900))
ax=gca
ax.XGrid='on'; ax.YGrid='on'; ax.XMinorGrid='on'; ax.YMinorGrid='on';
%ax.Title.String = 'Input Resistance for Antenna Lengths of 2\lambda to 3\lambda';
ax.XLabel.String = 'Antenna length (\lambda)'; ax.YLabel.String = 'Input Resistance';
subplot(2,2,4)
plot(l,R_in)
ax=gca
ax.XGrid='on'; ax.YGrid='on'; ax.XMinorGrid='on'; ax.YMinorGrid='on';
%ax.Title.String = 'Input Resistance for Antenna Lengths 0 to \lambda';
ax.XLabel.String = 'Antenna length (\lambda)'; ax.YLabel.String = 'Input Resistance';
```

In the above code, the input resistance of a dipole antenna is represented for 3 antenna length range. This is due to the Eq(10). *sin()* function becomes 0 for $n\pi$ where n is natural number. Due to discontinuous parts, representation of the input resistance is made by using several figures. Finally, overall waveform can be seen in Fig(9). Discontinuity can be seen as Dirac-delta function at $n\pi$ antenna lengths.

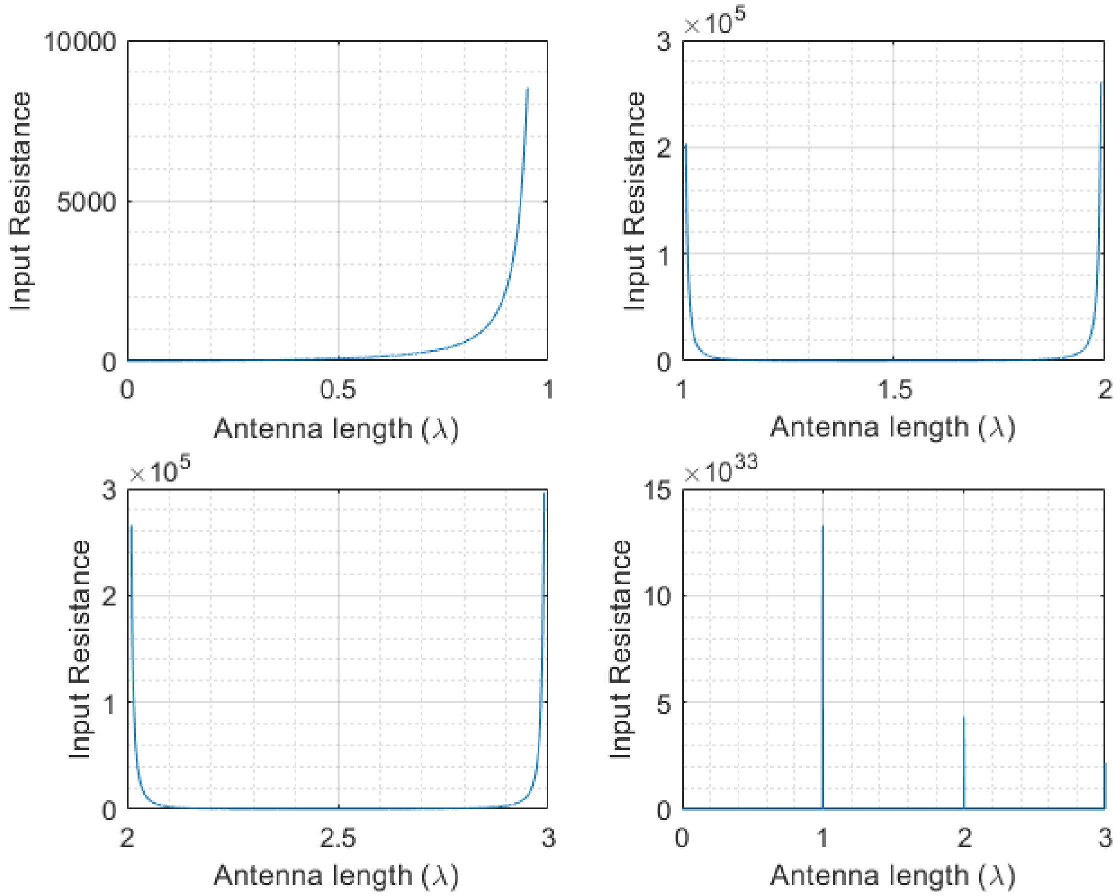

Figure 9: Input resistance of dipole antenna for several antenna lengths at 300MHz

References

[1] BALANIS, C. A., Antenna Theory: Analysis and Design, Wiley-Interscience, 3th edition, 2005.

[2] STUTZMAN, Warren L.; THIELE, Gary A., Antenna Theory and Design. John Wiley Sons, 2012.