For a single, 18 cm diameter, circular loop of wire (14 AWG, $\sigma_{wire} = 3 \times 10^7$ S/m) in free space, centered on the *x*-*y* plane and fed where it crosses the positive *x*-axis, use NEC-2 to:

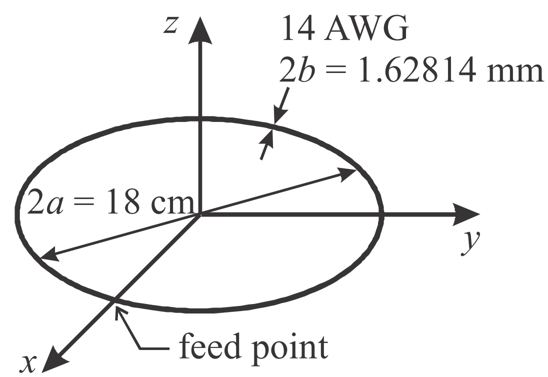
a) Determine the input impedance over normalized frequency range $0.1 \le ka \le 2$. On a single graph, plot R_{ant} and X_{ant} versus *ka*.

b) **EE 483 only**: In a table, list *ka* = 0.1, the anti-resonant & resonant frequencies (*ka* & MHz), R_{ant}, X_{ant}, and antenna efficiency η. Format: col. 1 *ka*, col. 2 *f* (MHz), col. 3 R_{ant}, col. 4 X_{ant}, col. 5 η, and col. 6 description (e.g., small loop, resonance #1 …) **EE 583 only**: In a table, list *ka* = 0.1, the anti-resonant & resonant frequencies (*ka* & MHz), R_{ant}, X_{ant}, R_{rad}, R_{loss}, and η. Format: Col. 1 *ka*, col. 2 *f* (MHz), col. 3 R_{ant}, col. 4 X_{ant}, col. 5 R_{rad}, , col. 6 R_{loss}, col. 7 η, and col. 8 description (e.g., small loop, resonance #1 …)

c) Determine the current distribution at *ka* = 0.1 and the first resonant frequency. On a single graph, plot the <u>normalized</u> current magnitudes (normalize each trace independently so that its maximum is 1) versus the fractional circumference (e.g., 0 ≤ distance/circumference < 1).

d) **Extra credit:** At *ka* = 0.1 and the first resonant frequency, determine the far-zone E-plane (*x*-*y* plane) and H-plane (*x*-*z* plane) power gain radiation patterns (in dBi). On two polar graphs, plot the <u>relative</u> power radiation patterns for the E-plane and H-plane scaled so that the center of each plot is at –30 dB and the outer ring is at 0 dB. Tabulate the maximum and minimum gain in each plane at each frequency.

****



a) 14 AWG wire diameter = $2b$ = 1.62814 mm ⇒ **<u>wire radius = *b* = 0.81407 mm</u>**

Loop circumference $C = 2\pi a = \pi$ (18 cm) ⇒ **<u>*C* = 56.54866776 cm</u>**

Determine the lower and upper frequencies.

$ka = C/\lambda_{low} = 0.1 \rightarrow \lambda_{low} = 56.54866776 \text{ cm}/0.1 = 5.654866776$ m

$f_{low} = c/\lambda_{low} = 2.998\times10^8/5.654866776 \Rightarrow$ **<u>f_{low} = 53.01628 MHz</u>**

$ka = C/\lambda_{high} = 2 \rightarrow \lambda_{high} = 56.54866776 \text{ cm}/2 = 0.28274334$ m

$f_{high} = c/\lambda_{high} = 2.998\times10^8/0.28274334 \Rightarrow$ **<u>f_{high} = 1060.3256 MHz</u>**

Try a segment for every 5° of arc, # of segments will be $N = 360°/5°$ $\Rightarrow$ $\underline{\boldsymbol{N = 72}}$

Segment length $\Delta = C/N = 56.548668$ cm/72 $\Rightarrow$ $\underline{\boldsymbol{\Delta = 0.7854 \text{ cm}}}$

Check to see if the resulting segment length Δ is acceptable.

$$\Delta / b = 0.7854\times10^{-2} / 0.81407\times10^{-3} = 9.6478 \text{ (OK, but use EK 0 command)}$$

$$2\pi b/ \lambda_{high} = 2\pi(0.81407\times10^{-3}) / 0.28274334 = 0.01809 << 1/10 \text{ (~OK)}$$

$$2\pi b/ \lambda_{low} = 2\pi(0.81407\times10^{-3}) / 5.654866776 = 0.0009045 << 1/10 \text{ (OK)}$$

$$\Delta / \lambda_{high} = 0.7854\times10^{-2} / 0.28274334 = 0.02778 = 1/36 < 1/10 \text{ (OK)}$$

$$\Delta / \lambda_{low} = 0.7854\times10^{-2} / 5.654866776 = 0.0013889 = 1/720 < 1/10 \text{ (OK)}$$

NEC-2 input file

```
CM 18cm_14awg_loop_zin.txt
CM
CM This file is used to determine the input impedance
CM for ka = 0.1 (53.01628 MHz) to ka = 2 (1060.3256 MHz)
CM for a 14 AWG loop antenna with a diameter of 18 cm,
CM wire radius = 0.81407 mm,& wire conductivity = 3*10^7 S/m,
CM
CM Place the loop on the x-y plane with the drive point
CM where it crosses the positive x-axis.  DRIVEN SEGMENT IS #1.
CM Used 72 segments. segment length = 0.7854 cm
CE
GA 1  72 9.0e-2 -2.5 357.5 0.81407e-3 !Generate 9cm radius loop
GM 0 0 90.0 0 0 0 0 0 ! Rotate loop onto x-y plane
GE 0 ! No ground plane
EK 0 ! Extended kernel
FR 0 20 0 0 53.0163 10.073
EX 0 1 1 01 1.0 0.0 ! voltage excitation on segment 1
LD 5 0 0 0 3.0e7 ! conductivity loading
PT -1 ! suppress currents
XQ 0 ! execute
EN
```

The data generated was imported into MS-Excel and plotted. Plots of R_{ant} and X_{ant} versus ka are on the next page.

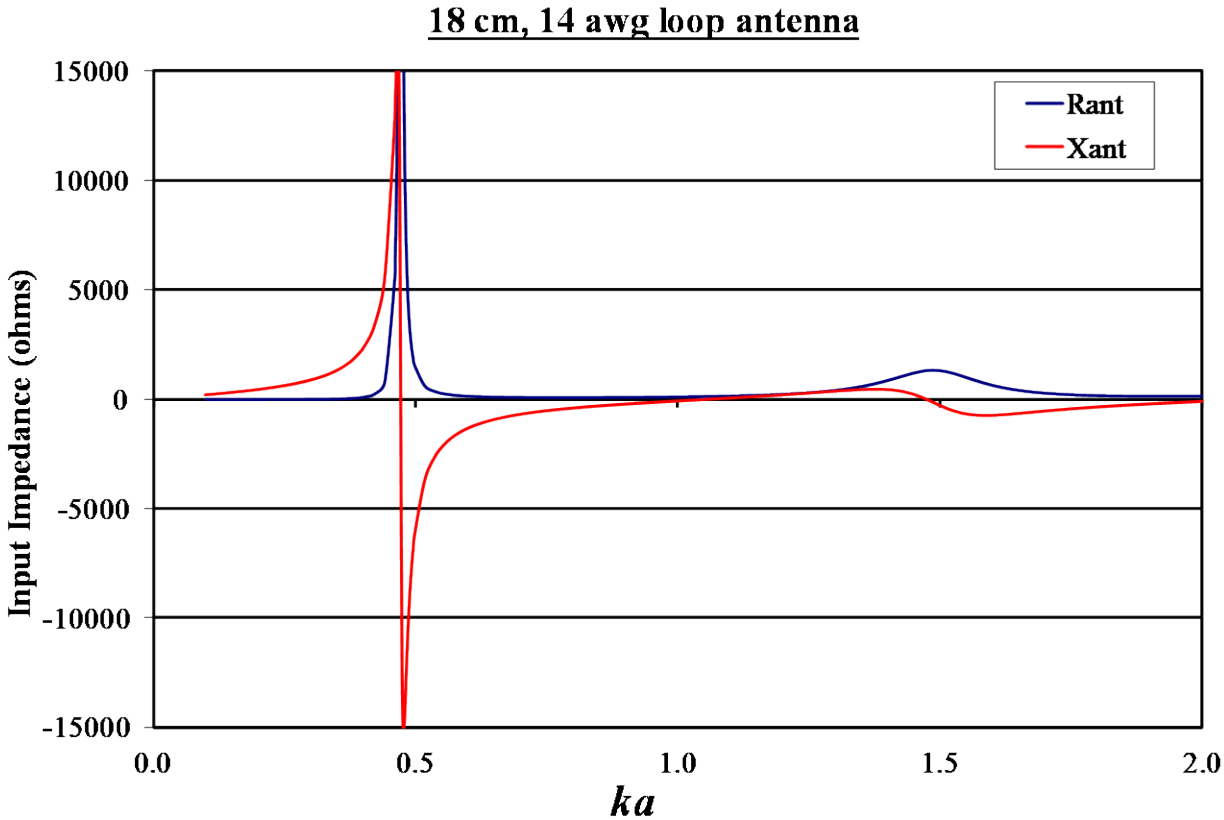


Figure 1 Input impedance versus *ka*

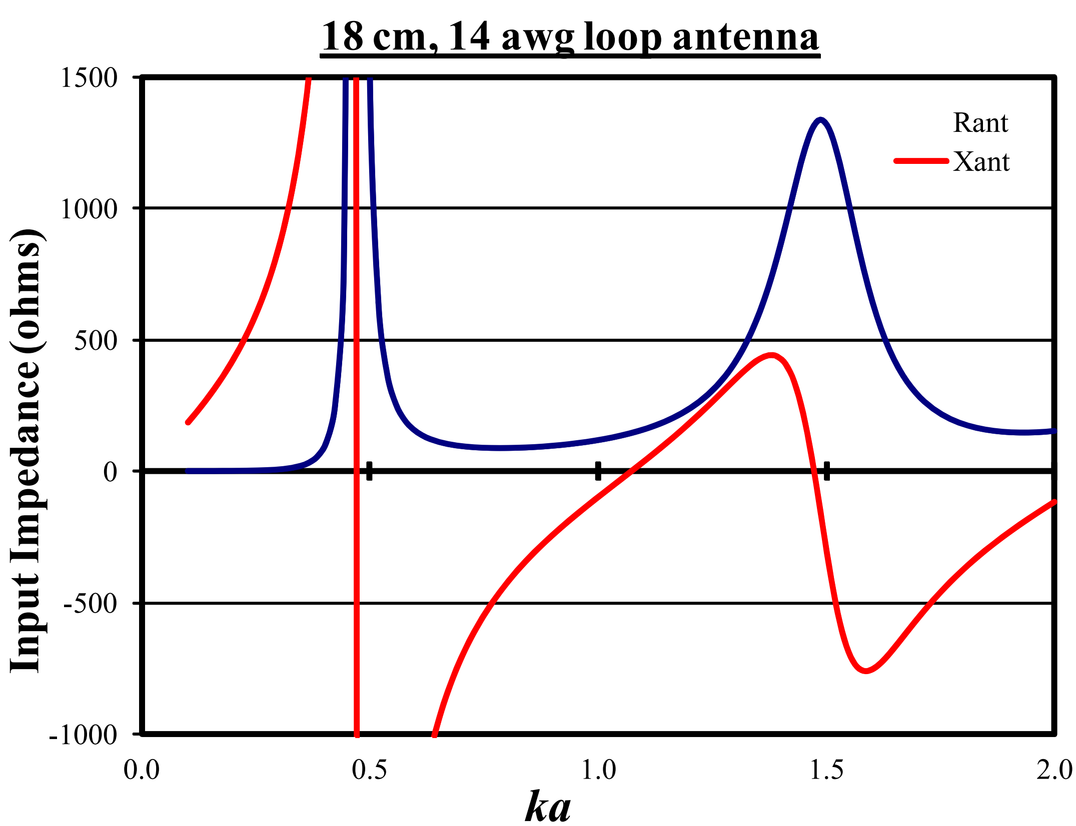


Figure 2 Close-up of input impedance versus *ka*

b) Calculations and table follow with the anti-resonant and resonant frequencies (ka and in MHz) in this range. Then, the R_{ant}, R_{rad}, R_{loss}, and the antenna efficiency at ka = 0.1 and the resonant frequencies are determined.

At ***ka* = 0.1 (small loop)**, calculate R_{rad} and R_{loss}. From the NEC-2 output file:

<snip>

```
      FREQUENCY= 5.3016E+01 MHZ
      WAVELENGTH= 5.6549E+00 METERS
```

<snip>

```
      - - - ANTENNA INPUT PARAMETERS - - -
TAG SEG VOLTAGE (V) CURRENT (A)         IMPEDANCE (OHMS)    ADMITTANCE (MHOS)       POWER
NO. NO. REAL IMAG.  REAL   IMAG.        REAL        IMAG.   REAL   IMAG.              (W)
1   1  1.00 0.00 9.63599E-06 -5.32277E-03 3.4011E-01 1.87872E+02 9.63599E-06-5.3228E-03 4.81799E-06

      - - - POWER BUDGET - - -
      INPUT POWER    = 4.8180E-06 WATTS
      RADIATED POWER= 3.1283E-07 WATTS
      STRUCTURE LOSS= 4.5052E-06 WATTS
      NETWORK LOSS   = 0.0000E+00 WATTS
      EFFICIENCY     =   6.49 PERCENT
```

So, |I| = 0.005322779 A, and

$R_r = 2\,P_{rad} / |I|^2 = 2(3.1283E\text{-}07)/0.005322779^2$ ⇒ $R_r = 0.02208\ \Omega$

$R_L = 2\,P_{loss} / |I|^2 = 2(4.5052E\text{-}06)/0.005322779^2$ ⇒ $R_L = 0.31803\ \Omega$

****

At ***ka* = 0.472 (anti-resonant #1)**, calculate R_{rad} and R_{loss}. From NEC-2 output file:

<snip>

```
      FREQUENCY= 2.5000E+02 MHZ
      WAVELENGTH= 1.1992E+00 METERS
```

<snip>

```
     - - - ANTENNA INPUT PARAMETERS - - -
TAG SEG VOLTAGE (V) CURRENT (A)         IMPEDANCE (OHMS)    ADMITTANCE (MHOS)       POWER
NO. NO. REAL IMAG.  REAL   IMAG.        REAL        IMAG.   REAL   IMAG.              (W)
 1   1   1.0 0.00 3.09770E-05-5.59523E-06 3.12621E+04 5.64672E+03 3.0977E-05-5.5952E-06 1.54885E-05

    - - - POWER BUDGET - - -
    INPUT POWER    = 1.5489E-05 WATTS
    RADIATED POWER= 1.4998E-05 WATTS
    STRUCTURE LOSS= 4.9070E-07 WATTS
    NETWORK LOSS   = 0.0000E+00 WATTS
    EFFICIENCY     =  96.83 PERCENT
```

So, |I| = 3.147826437E-5 A, and

$R_{rad} = 2\,P_{rad} / |I|^2 = 2(1.4998E\text{-}05)/(\ 3.147826437E\text{-}5)^2$ ⇒ $R_r = 30272.05\ \Omega$

$R_{loss} = 2\,P_{loss} / |I|^2 = 2(4.907E\text{-}07)/(\ 3.147826437E\text{-}5)^2$ ⇒ $R_L = 990.43\ \Omega$

****

At ***ka* = 1.070 (resonant)**, calculate R_{rad} and R_{loss}. From the NEC-2 output file:

<snip>

```
      FREQUENCY= 5.6750E+02 MHZ
      WAVELENGTH= 5.2828E-01 METERS
```

<snip>

```
    - - - ANTENNA INPUT PARAMETERS - - -
TAG SEG VOLTAGE (V) CURRENT (A)         IMPEDANCE (OHMS)    ADMITTANCE (MHOS)       POWER
NO. NO. REAL IMAG.  REAL   IMAG.        REAL         IMAG.  REAL    IMAG.             (W)
1    1 1.00 0.00 6.92448E-03 1.83300E-06 1.44415E+02-3.82286E-02 6.92448E-03 1.833E-06 3.46224E-03

    - - - POWER BUDGET - - -
    INPUT POWER    = 3.4622E-03 WATTS
    RADIATED POWER= 3.4507E-03 WATTS
    STRUCTURE LOSS= 1.1584E-05 WATTS
    NETWORK LOSS   = 0.0000E+00 WATTS
    EFFICIENCY     =  99.67 PERCENT
```

So, |I| = 0.0069244 A, and

$R_{\text{rad}} = 2\,P_{\text{rad}} / |I|^2 = 2(3.4507\text{E-}03)/\ 0.0069244^2$ $\Rightarrow$ $R_r = 143.9372\ \Omega$

$R_{\text{loss}} = 2\,P_{\text{loss}} / |I|^2 = 2(1.1584\text{E-}05)/\ 0.0069244^2$ $\Rightarrow$ $R_L = 0.4832\ \Omega$

****

At ***ka* = 1.473 (anti-resonant #2)**, calculate R_{rad} & R_{loss}. From NEC-2 output file:

<snip>

```
      - - - - - - FREQUENCY - - - - - -
      FREQUENCY= 7.8110E+02 MHZ
      WAVELENGTH= 3.8382E-01 METERS

      - - - ANTENNA INPUT PARAMETERS - - -
TAG SEG VOLTAGE (V) CURRENT (A)         IMPEDANCE (OHMS)    ADMITTANCE (MHOS)       POWER
NO. NO. REAL IMAG.  REAL   IMAG.        REAL         IMAG.  REAL    IMAG.             (W)
1    1 1.00 0.00 7.59545E-04-1.89447E-08 1.31658E+03 3.28382E-02 7.59545E-04-1.8945E-08 3.79773E-04

      - - - POWER BUDGET - - -
      INPUT POWER    = 3.7977E-04 WATTS
      RADIATED POWER= 3.7849E-04 WATTS
      STRUCTURE LOSS= 1.2854E-06 WATTS
      NETWORK LOSS   = 0.0000E+00 WATTS
      EFFICIENCY     =  99.66 PERCENT
```

So, |I| = 0.000759545 A, and

$R_{\text{rad}} = 2\,P_{\text{rad}} / |I|^2 = 2(3.7849\text{E-}04)/\ 0.000759545^2$ $\Rightarrow$ $R_r = 1312.1316\ \Omega$

$R_{\text{loss}} = 2\,P_{\text{loss}} / |I|^2 = 2(1.2854\text{E-}06)/\ 0.000759545^2$ $\Rightarrow$ $R_L = 4.4562\ \Omega$

****

EE 483 only:

ka	*f* (MHz)	R_{ant} (ohms)	X_{ant} (ohms)	η (%)	Description
0.1	53.016	0.340	187.872	6.49	small loop
0.472	250	31262.1	5646.72	96.83	anti-resonant #1
1.070	567.5	144.415	-0.0382	99.67	resonant
1.473	781.1	1316.58	0.0328	99.66	anti-resonant #2

EE 583 only:

ka	*f* (MHz)	R_{ant} (ohms)	X_{ant} (ohms)	R_{rad} (ohms)	R_{loss} (ohms)	η (%)	Description
0.1	53.016	0.340	187.872	0.02208	0.31803	6.49	small loop
0.472	250	31262.1	5646.72	30272.05	990.43	96.83	anti-resonant
1.070	567.5	144.415	-0.0382	143.9372	0.4832	99.67	resonant
1.473	781.1	1316.58	0.0328	1312.132	4.4562	99.66	anti-resonant #2

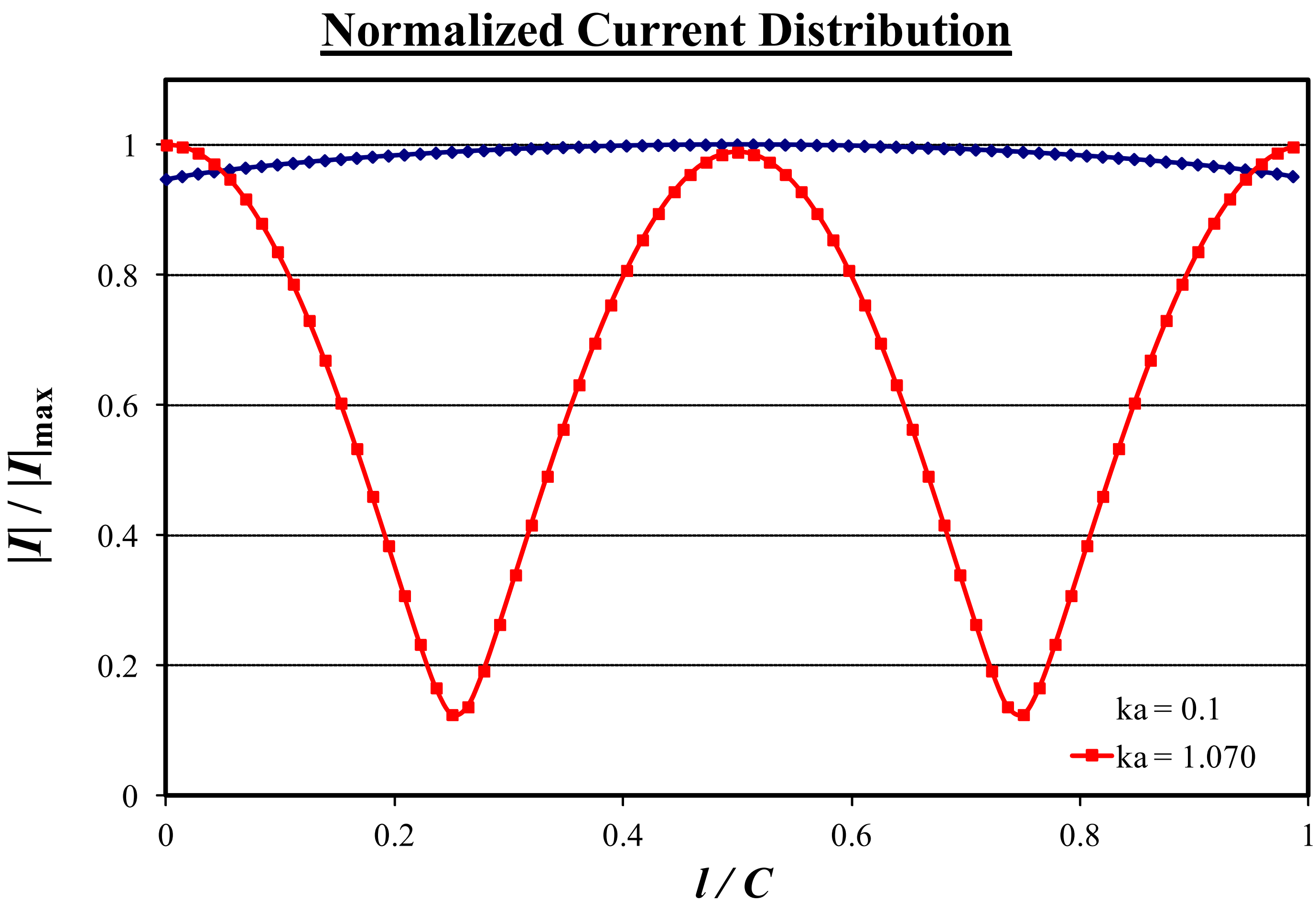
****

c) Determine the current distribution at *ka* = 0.1 and the first resonant frequency. On a single graph, plot the <u>normalized</u> current magnitudes (normalize each trace independently so its maximum is 1) versus the fractional circumference (e.g., 0 ≤ distance/circumference < 1).

NEC-2 input file

```
CM 18cm_14awg_loop_Imag.txt
CM
CM This file is used to determine the current distribution at
CM ka = 0.1 (53.01628 MHz) and the first resonant frequency at
CM ka = 1.070 (567.5 MHz) for a 14 AWG loop antenna with a
CM diameter of 18 cm, wire radius = 0.81407 mm,& wire
CM conductivity = 3*10^7 S/m,
CM
CM Place the loop on the x-y plane with the drive point
CM where it crosses the positive x-axis.  DRIVEN SEGMENT IS #1.
CM Used 72 segments. segment length = 0.7854 cm
CE
GA 1  72 9.0e-2 -2.5 357.5 0.81407e-3 !Generate 9cm radius loop
GM 0 0 90.0 0 0 0 0 0 ! Rotate loop onto x-y plane
GE 0 ! No ground plane
EK 0 ! Extended kernel
FR 0 2 0 0 53.01628 514.48372 ! get two freqs
EX 0 1 1 00 1.0 0.0 ! voltage excitation on segment 1
LD 5 0 0 0 3.0e7 ! conductivity loading
XQ 0 ! execute
EN
```

The current data generated was imported into MS-Excel and plotted as shown.



****

d) Extra credit: At *ka* = 0.1 and the first resonant frequency, determine the far-zone E-plane (*x-y* plane) and H-plane (*x-z* plane) power gain radiation patterns (in dBi). On two polar graphs, plot the relative power radiation patterns for the E-plane and H-plane scaled so that the center of each plot is at –30 dB and the outer ring is at 0 dB. Tabulate the maximum and minimum gain in each plane at each frequency.

```
CM 18cm_14awg_loop_rad_small.txt
CM
CM This file is used to determine the E-plane (x-y) and
CM H-plane (x-z) radiation patterns for ka = 0.1 (53.01628 MHz)
CM for a 14 AWG loop antenna with diameter of 18 cm
CM (loop radius= a = 9 cm), wire radius = 0.81407 mm, and
CM wire conductivity = 3*10^7 S/m.
CM
CM Place the loop on the x-y plane with drive point where it
CM crosses the positive x-axis.  DRIVEN SEGMENT IS #1.
CM Used 72 segments. segment length = 0.7854 cm
```

```
CE
GA 1  72 9.0e-2 -2.5 357.5 0.81407e-3 ! Make 9cm radius loop
GM 0 0 90.0 0 0 0 0 0 ! Rotate onto x-y plane
GE 0 ! No ground plane
EK 0 ! Extended kernel
FR 0 1 0 0 53.01628 0.0
EX 0 1 1 00 1.0 0.0 !voltage excitation at segment 1
LD 5 0 0 0 3.0e7
PT -1 !suppress currents
RP 0 1 360 0000   90.0  0.0 0.0 1.0 ! x-y plane vs phi
RP 0 360 1 0000 -179.0  0.0 1.0 0.0 ! x-z plane vs theta
EN
```

```
CM 18cm_14awg_loop_rad_resonant.txt
CM
CM This file is used to determine the E-plane (x-y) and
CM H-plane (x-z) radiation patterns for ka = 1.070 (567.5 MHz)
CM for a 14 AWG loop antenna with diameter of 18 cm
CM (loop radius= a = 9 cm), wire radius = 0.81407 mm, and
CM wire conductivity = 3*10^7 S/m.
CM
CM Place the loop on the x-y plane with drive point where it
CM crosses the positive x-axis.  DRIVEN SEGMENT IS #1.
CM Used 72 segments. segment length = 0.7854 cm
CE
GA 1  72 9.0e-2 -2.5 357.5 0.81407e-3 ! Make 9cm radius loop
GM 0 0 90.0 0 0 0 0 0 ! Rotate onto x-y plane
GE 0 ! No ground plane
EK 0 ! Extended kernel
FR 0 1 0 0 567.5 0.0
EX 0 1 1 00 1.0 0.0 !voltage excitation at segment 1
LD 5 0 0 0 3.0e7
PT -1 !suppress currents
RP 0 1 360 0000   90.0  0.0 0.0 1.0 ! x-y plane vs phi
RP 0 360 1 0000 -179.0  0.0 1.0 0.0 ! x-z plane vs theta
EN
```

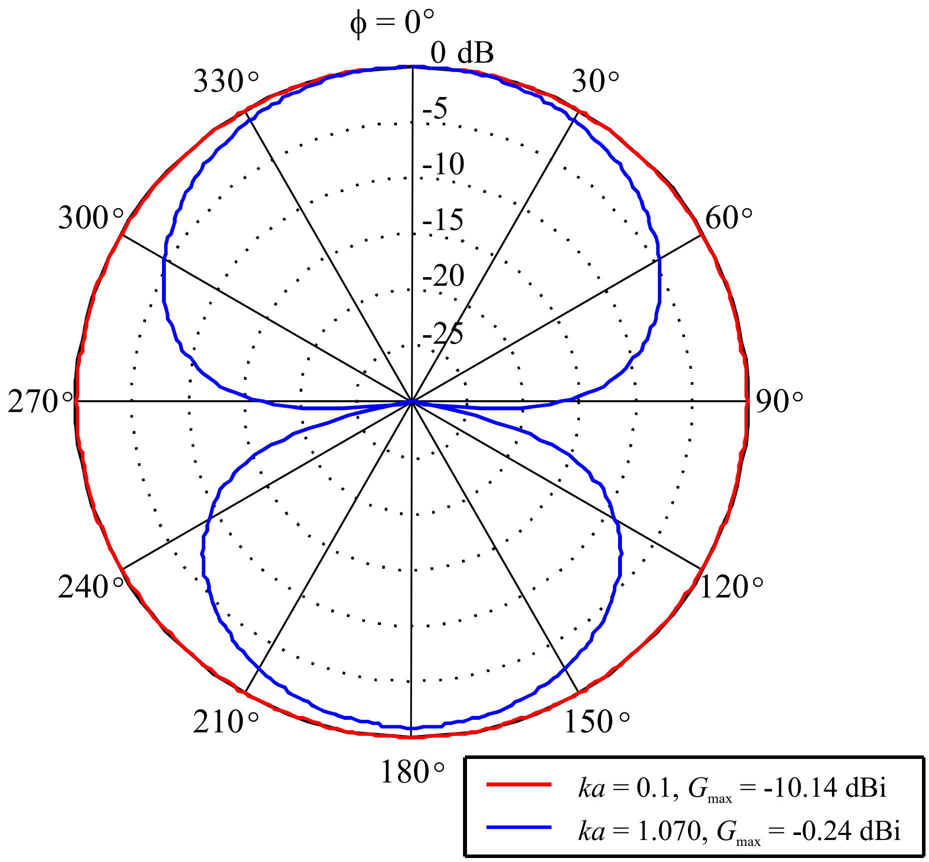
			E-Plane (x-y plane wrt ϕ at $\theta = 90°$)		**H-Plane** (y-z plane wrt θ at $\phi = 90°$)	
Description	ka	f (MHz)	G_{max} (dBi)	G_{min} (dBi)	G_{max} (dBi)	G_{min} (dBi)
small loop	0.1	53.01628	-10.14	-10.27	-10.14	-24.15
resonant	1.070	567.5	-0.24	-33.14	3.69	-1.17

- Put radiation pattern data into MS-Excel spreadsheet, pre-normalized and saved stripped down data to 5-column *.txt files with angle (deg), ka = 0.1 gain (dBi), ka = 1.070 (dBi) gain, ka = 0.1 normalized gain (dB), & ka = 1.070 normalized gain (dB).

```
% H_plane_18cm_14AWG_loop.m
% Plot H-plane radiation pattern (wrt theta at phi = 0 deg) for
% 18 cm 14 AWG loop at small ka=0.1 (f=53.01628 MHz) and
% resonant ka=1.070 (f=567.5 MHz) frequencies.
clear; clc; close all;
M = dlmread('18cm_14AWG_H_plane_rad_patt.txt');
for i =1:360
  theta(i) = M(i,1);
  Gsmall(i) = M(i,4);
  Gres(i) = M(i,5);
end
% ******* Plot Radiation Patterns in dB format *******
radpat(theta,Gsmall,'r-',theta,Gres,'b-')
%
set(findobj('type','line'),'linewidth',1.5)
set(findobj('type','line'),'markersize',14)  % change size of markers
set(findobj('type','axes'),'linewidth',2)
```

```
% E_plane_18cm_14AWG_loop.m
% Plot E-plane radiation pattern (wrt phi at theta = 90 deg) for
% 18 cm 14 AWG loop at small ka=0.1 (f=53.01628 MHz) and
% resonant ka=1.070 (f=567.5 MHz) frequencies.
clear; clc; close all;
M = dlmread('18cm_14AWG_E_plane_rad_patt.txt');
for i =1:360
  phi(i) = M(i,1);
  Gsmall(i) = M(i,4);
  Gres(i) = M(i,5);
end
% ******* Plot Radiation Patterns in dB format *******
radpat(phi,Gsmall,'r-',phi,Gres,'b-')
%
set(findobj('type','line'),'linewidth',1.5)
set(findobj('type','line'),'markersize',14)  % change size of markers
set(findobj('type','axes'),'linewidth',2)
```

E-plane (x-y plane)



H-plane (x-z plane)