For a single, 7.5 inch diameter, circular loop of wire (14 AWG, $\sigma = 5 \times 10^7$ S/m) in free space, centered on *x*-*y* plane and fed where it crosses the positive *x*-axis, use NEC-2 to:

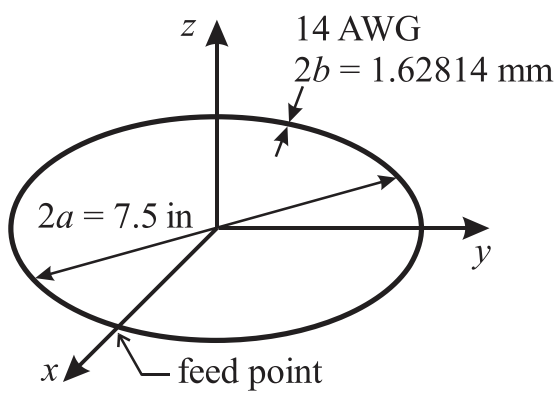
a) Determine the input impedance over normalized frequency range $0.1 \le ka \le 2$. On a **single** graph, plot R_A and X_A versus *ka*. Use vertical scale of -1000 Ω to 1500 Ω for both R_A and X_A. [Hint: $k = \omega/c = 2\pi f/c = 2\pi/\lambda$.]

b) **EE 483 only**: In a table, list *ka* equal to 0.1 as well as for the anti-resonant & resonant frequencies within the range $0.1 \le ka \le 2$, frequency *f* (MHz), R_A, X_A, and antenna efficiency η. Format: col. 1 *ka*, col. 2 *f* (MHz), col. 3 R_A, col. 4 X_A, col. 5 η, and col. 6 description (e.g., small loop, resonance #1 …) **EE 583 only**: In a table, list *ka* equal to 0.1 as well as for the anti-resonant & resonant frequencies within the range $0.1 \le ka \le 2$, frequency *f* (MHz), R_A, X_A, R_r, R_l, and η. Format: Col. 1 *ka*, col. 2 *f* (MHz), col. 3 R_A, col. 4 X_A, col. 5 $R_{\text{rad,}}$, col. 6 R_{loss}, col. 7 η, and col. 8 description (e.g., small loop, resonance #1 …)

c) Determine the current distributions at *ka* = 0.1 and the first resonant frequency. On a single graph, plot the normalized current **magnitudes** versus the fractional circumference (e.g., 0 ≤ distance/circumference < 1) starting at the positive *x*-axis. Normalize each current magnitude independently so that its maximum is 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 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.

****



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

Loop circumference $C = 2\pi a = \pi$ (7.5 in)(2.54 cm/in) ⇒ **C = 59.84734 cm**

Determine the lower and upper frequencies.

$$ka = C/\lambda_{\text{low}} = 0.1 \rightarrow \lambda_{\text{low}} = 0.5984734/0.1 = 5.984734 \text{ m}$$

$$f_{\text{low}} = c/\lambda_{\text{low}} = 2.998\times10^8/5.984734 \Rightarrow \underline{f_{\text{low}} = 50.094 \text{ MHz}}$$

$$ka = C/\lambda_{high} = 2 \;\longrightarrow\; \lambda_{high} = 0.5984734/2 = 0.2992367 \text{ m}$$

$$f_{high} = c/\lambda_{high} = 2.998\times10^{8}/0.2992367 \;\Rightarrow\; \underline{\mathbf{f_{high} = 1001.882\ MHz}}$$

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

Segment length $\Delta = C/N = 59.84734 \text{ cm}/72 \Rightarrow \mathbf{\Delta = 0.831213\ cm}$

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

$$\Delta / b = 0.831213\times10^{-2} / 0.81407\times10^{-3} = 10.21 \text{ (OK, but use EK 0 command)}$$

$$2\pi b/ \lambda_{high} = 2\pi(0.81407\times10^{-3}) / 0.2992367 = 0.01709 \ll 1/10 \text{ (OK)}$$

$$2\pi b/ \lambda_{low} = 2\pi(0.81407\times10^{-3}) / 5.984734 = 0.000855 \ll 1/10 \text{ (OK)}$$

$$\Delta / \lambda_{high} = 0.8312\times10^{-2} / 0.2992367 = 0.02778 = 1/36 < 1/10 \text{ (OK)}$$

$$\Delta / \lambda_{low} = 0.8312\times10^{-2} / 5.984734 = 0.0013889 = 1/720 < 1/10 \text{ (OK)}$$

NEC-2 input file

```
CM 7_5in_14awg_loop_Zin.txt
CM This file is used to determine the input impedance for the
CM frequency range ka = 0.1 (50.094 MHz) to ka = 2 (1001.882 MHz)
CM for a 14 AWG loop antenna with a diameter of 7.5 inches
CM (loop radius= a = 9.525 cm), wire radius = 0.81407 mm, and
CM wire conductivity = 5*10^7 S/m.
CM Place loop on x-y plane w/ drive point where it crosses the
CM positive x-axis.  DRIVEN SEGMENT IS #1.
CM Used 72 segments.  Segment length = 0.8312 cm
CE
GA 1 72 9.525e-2 -2.5 357.5 0.81407e-3  ! Generate loop
GM 0 0 90.0 0 0 0 0 0  ! Rotate loop onto x-y plane
GE 0 ! Free space
EK 0  ! Use extended kernel
FR 0 40 0 0 50.094 24.4 ! start at 50.094 MHz
EX 0 1 1 01 1.0 0.0 ! excitation on segment 1
LD 5 0 0 0 5.0e7  ! conductivity (S/m)
PT -1  ! suppress currents
XQ 0
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.

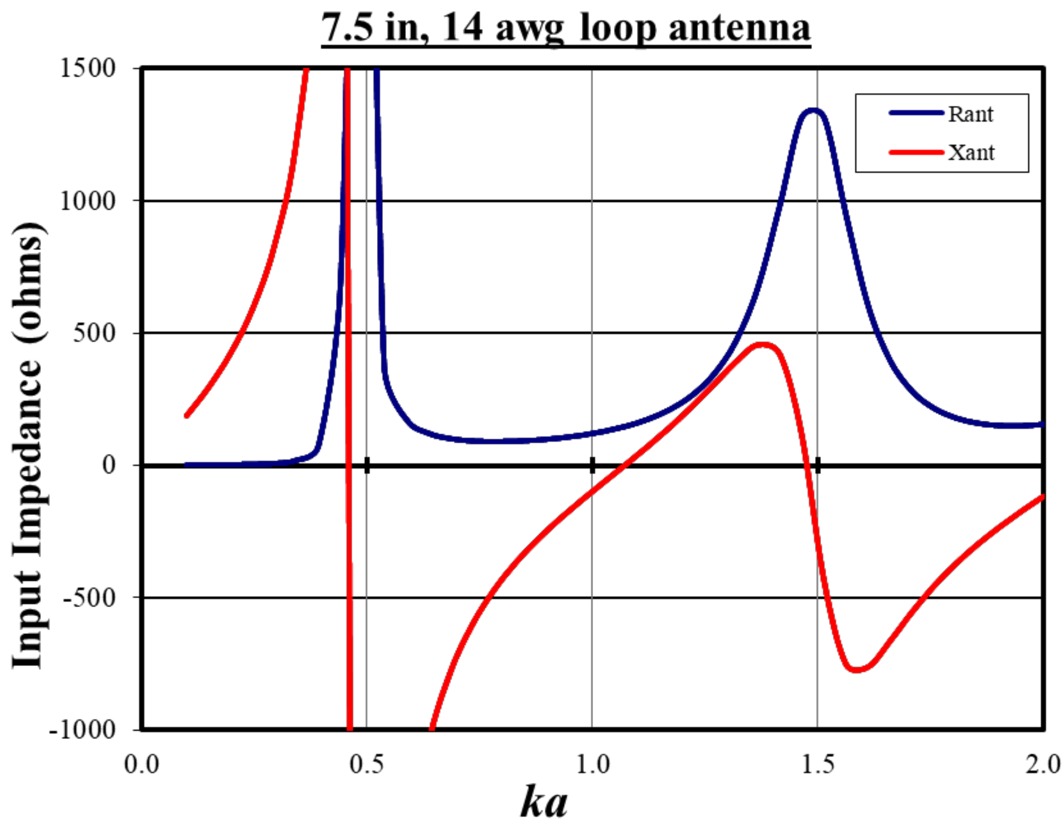


Figure 1 Plot of input impedance versus *ka*

From Figure 1, we can observe

- **Anti-resonance is a bit below *ka* = 0.5 ⇒ *ka* ≈ 0.473 (*f* ≈ 237.009 MHz).**
- **First resonance is a bit above *ka* = 1 ⇒ *ka* ≈ 1.069 (*f* ≈ 535.63 MHz).**
- **Second resonance/anti-resonance is a bit below *ka* = 1.5 ⇒ *ka* ≈ 1.475 (*f* ≈ 738.816 MHz).**

b) **EE 483 only**: In a table, list ka equal to 0.1 as well as for the anti-resonant & resonant frequencies within the range $0.1 \le ka \le 2$, frequency f (MHz), R_A, X_A, and antenna efficiency η. Format: col. 1 ka, col. 2 f (MHz), col. 3 R_A, col. 4 X_A, col. 5 η, and col. 6 description (e.g., small loop, resonance #1 …) **EE 583 only**: In a table, list ka equal to 0.1 as well as for the anti-resonant & resonant frequencies within the range $0.1 \le ka \le 2$, frequency f (MHz), R_A, X_A, R_r, R_l, and η. Format: Col. 1 ka, col. 2 f (MHz), col. 3 R_A, col. 4 X_A, col. 5 $R_{rad,}$, col. 6 R_{loss}, col. 7 η, and col. 8 description (e.g., small loop, resonance #1 …)

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

```
<snip>
                    FREQUENCY= 5.0094E+01 MHZ
<snip>
                         - - - ANTENNA INPUT PARAMETERS - - -
 TAG   SEG.    VOLTAGE (VOLTS)       CURRENT (AMPS)       IMPEDANCE (OHMS)  <snip>
 NO.   NO.    REAL       IMAG.      REAL       IMAG.          REAL       IMAG.     <snip>
   1     1 1.00000E+00 0.00000E+00 7.57522E-06-5.26305E-03 2.73476E-01 1.90004E+02 <snip>
<snip>
                        - - - POWER BUDGET - - -
                          INPUT POWER   = 3.7876E-06 WATTS
                          RADIATED POWER= 3.0575E-07 WATTS
                          STRUCTURE LOSS= 3.4819E-06 WATTS
                          NETWORK LOSS  = 0.0000E+00 WATTS
                          EFFICIENCY    =   8.07 PERCENT
<snip>
```

So, |I| = 0.005263055 A, and

$R_{rad} = 2\,P_{rad}\,/\,|I|^2 = 2(3.0575E\text{-}07)/\,0.005263055^2 \Rightarrow R_{rad} = 0.022076\ \Omega$

$R_{loss} = 2\,P_{loss}\,/\,|I|^2 = 2(3.4819E\text{-}06)/\,0.005263055^2 \Rightarrow R_{loss} = 0.251403\ \Omega$

****

At ***ka* = 0.473 (anti-resonance)**, calculate R_{rad} & R_{loss}. From the NEC-2 output file:

```
<snip>
                    FREQUENCY= 2.3701E+02 MHZ
<snip>
                         - - - ANTENNA INPUT PARAMETERS - - -
 TAG   SEG.    VOLTAGE (VOLTS)       CURRENT (AMPS)       IMPEDANCE (OHMS)   <snip>
 NO.   NO.    REAL       IMAG.      REAL       IMAG.      REAL       IMAG.     <snip>
   1     1 1.00000E+00 0.00000E+00 3.04316E-05 7.38681E-09 3.28605E+04-7.97639E+00 <snip>
                        - - - POWER BUDGET - - -
                          INPUT POWER   = 1.5216E-05 WATTS
                          RADIATED POWER= 1.4835E-05 WATTS
                          STRUCTURE LOSS= 3.8119E-07 WATTS
                          NETWORK LOSS  = 0.0000E+00 WATTS
                          EFFICIENCY    =  97.49 PERCENT
```

So, |I| = 3.04316E-5 A, and

$R_{rad} = 2\,P_{rad} / |I|^2 = 2(1.4835E\text{-}05)/(3.04316E\text{-}5)^2 \Rightarrow R_{rad} = \mathbf{32{,}038.2\ \Omega}$

$R_{loss} = 2\,P_{loss} / |I|^2 = 2(3.8119E\text{-}07)/(3.04316E\text{-}5)^2 \Rightarrow R_{loss} = \mathbf{823.2\ \Omega}$

****

At ***ka* = 1.069 (resonance #1)**, calculate R_{rad} & R_{loss}. From NEC-2 output file:

<snip>

FREQUENCY= **5.3563E+02 MHZ**

<snip>

```
                    - - - ANTENNA INPUT PARAMETERS - - -
 TAG   SEG.   VOLTAGE (VOLTS)      CURRENT (AMPS)       IMPEDANCE (OHMS)   <snip>
 NO.   NO.    REAL      IMAG.      REAL          IMAG.      REAL       IMAG. <snip>
  1     1 1.00000E+00 0.00000E+00 6.93996E-03-4.64634E-07 1.44093E+02 9.64710E-03 <snip>

                    - - - POWER BUDGET - - -
                      INPUT POWER   = 3.4700E-03 WATTS
                      RADIATED POWER= 3.4607E-03 WATTS
                      STRUCTURE LOSS= 9.2622E-06 WATTS
                      NETWORK LOSS  = 0.0000E+00 WATTS
                      EFFICIENCY    =  99.73 PERCENT
```

<snip>

So, |I| = 0.00693996 A, and

$R_{rad} = 2\,P_{rad} / |I|^2 = 2(3.4607E\text{-}03)/ 0.00693996^2 \Rightarrow R_{rad} = \mathbf{143.708\ \Omega}$

$R_{loss} = 2\,P_{loss} / |I|^2 = 2(9.2622E\text{-}06)/ 0.00693996^2 \Rightarrow R_{loss} = \mathbf{0.385\ \Omega}$

****

At ***ka* = 1.475 ('resonance' #2)**, calculate R_{rad} & R_{loss}. From NEC-2 output file:

<snip>

FREQUENCY= **7.3882E+02 MHZ**

<snip>

```
                    - - - ANTENNA INPUT PARAMETERS - - -
 TAG   SEG.   VOLTAGE (VOLTS)      CURRENT (AMPS)       IMPEDANCE (OHMS)
ADMITTANCE (MHOS)     POWER
 NO.   NO.    REAL      IMAG.       REAL        IMAG.         REAL       IMAG.     <snip>
  1     1 1.00000E+00 0.00000E+00 7.36166E-04-1.34695E-09 1.35839E+03 2.48542E-03 <snip>
                    - - - POWER BUDGET - - -
                      INPUT POWER   = 3.6808E-04 WATTS
                      RADIATED POWER= 3.6709E-04 WATTS
                      STRUCTURE LOSS= 9.9413E-07 WATTS
                      NETWORK LOSS  = 0.0000E+00 WATTS
                      EFFICIENCY    =  99.73 PERCENT
```

So, |I| = 0.000891265 A, and

$R_{rad} = 2\,P_{rad} / |I|^2 = 2(3.6709E\text{-}4)/ 7.36166E\text{-}4^2 \Rightarrow R_{rad} = \mathbf{1354.72\ \Omega}$

$R_{loss} = 2\,P_{loss} / |I|^2 = 2(9.9413E\text{-}7)/ 7.36166E\text{-}4^2 \Rightarrow R_{loss} = \mathbf{3.67\ \Omega}$

****

EE 483 only:

ka	f (MHz)	R_{ant} (ohms)	X_{ant} (ohms)	η (%)	Description
0.1	50.094	0.319	177.062	6.93	small loop
0.473	237.009	32,860.5	-7.9764	97.49	anti-resonance
1.069	535.63	144.093	9.6471E-3	99.73	resonance #1
1.475	738.816	1358.39	2.4854E-3	99.73	'resonance' #2

EE 583 only:

ka	f (MHz)	R_{ant} (ohms)	X_{ant} (ohms)	R_{rad} (ohms)	R_{loss} (ohms)	η (%)	Description
0.1	50.094	0.319	177.062	0.0221	0.29684	6.93	small loop
0.473	237.01	32,860.5	-7.9764	32,038.2	823.2	97.49	anti-resonance
1.069	535.63	144.093	9.6471E-3	143.708	0.385	99.73	resonance #1
1.475	738.816	1358.39	2.4854E-3	1354.72	3.67	99.73	'resonance' #2

****

c) Determine the current distribution at ka = 0.1 and the first resonant frequency.

NEC-2 input file

```
CM 7_5in_14awg_loop_I.txt
CM Find current distribution at ka=0.1 (50.094 MHz)and the
CM first resonant frequency at ka = 1.069 (535.63 MHz) for a
CM 14 AWG loop antenna with a diameter of 7.5 inches
CM (loop radius= a = 9.525 cm), wire radius = 0.81407 mm, and
CM wire conductivity = 5*10^7 S/m.
CM Place loop on x-y plane w/ drive point where it crosses the
CM positive x-axis.  DRIVEN SEGMENT IS #1.
CM Used 72 segments.  Segment length = 0.8312 cm
CE
GA 1 72 9.525e-2 -2.5 357.5 0.81407e-3  ! Generate loop
GM 0 0 90.0 0 0 0 0 0  ! Rotate loop onto x-y plane
GE 0 ! Free space
EK 0  ! Use extended kernel
FR 0 2 0 0 50.094 485.536 ! 50.094 & 535.63 MHz
EX 0 1 1 00 1.0 0.0 ! excitation on segment 1
LD 5 0 0 0 5.0e7  ! conductivity (S/m)
XQ 0
EN
```

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

		ka = 0.1, f = 50.094 MHz		ka = 1.069, f = 535.63 MHz	
SEG. NO.	**fractional circumference**	**|I| (A)**	**|I| / |I|max**	**|I| (A)**	**|I| / |I|max**
1	0	0.0052631	0.946856	0.00694	1.000000
2	0.013888889	0.0052874	0.951228	0.0069185	0.996902
3	0.027777778	0.0053098	0.955258	0.0068522	0.987349
4	0.041666667	0.0053281	0.958550	0.0067372	0.970778
5	0.055555556	0.0053446	0.961518	0.0065733	0.947161
6	0.069444444	0.0053598	0.964253	0.0063611	0.916585
7	0.083333333	0.0053739	0.966790	0.0061021	0.879265
8	0.097222222	0.0053872	0.969182	0.0057978	0.835418
9	0.111111111	0.0053998	0.971449	0.0054505	0.785375
10	0.125	0.0054117	0.973590	0.0050631	0.729553
11	0.138888889	0.0054231	0.975641	0.0046387	0.668401
12	0.152777778	0.0054338	0.977566	0.004181	0.602450
13	0.166666667	0.005444	0.979401	0.0036945	0.532349
14	0.180555556	0.0054537	0.981146	0.0031845	0.458862
15	0.194444444	0.0054629	0.982801	0.0026579	0.382983
16	0.208333333	0.0054716	0.984366	0.0021248	0.306167
17	0.222222222	0.0054799	0.985859	0.0016037	0.231081
18	0.236111111	0.0054877	0.987263	0.0011387	0.164078
19	0.25	0.0054951	0.988594	0.00085347	0.122978
20	0.263888889	0.0055021	0.989853	0.00094108	0.135602
21	0.277777778	0.0055086	0.991023	0.001328	0.191354
22	0.291666667	0.0055147	0.992120	0.0018263	0.263156
23	0.305555556	0.0055204	0.993146	0.0023562	0.339510
24	0.319444444	0.0055257	0.994099	0.0028885	0.416210
25	0.333333333	0.0055306	0.994981	0.0034093	0.491254
26	0.347222222	0.0055351	0.995790	0.0039101	0.563415
27	0.361111111	0.0055392	0.996528	0.0043847	0.631801
28	0.375	0.0055428	0.997175	0.004828	0.695677
29	0.388888889	0.0055461	0.997769	0.0052357	0.754424
30	0.402777778	0.005549	0.998291	0.0056041	0.807507
31	0.416666667	0.0055516	0.998759	0.00593	0.854467
32	0.430555556	0.0055537	0.999136	0.0062105	0.894885
33	0.444444444	0.0055554	0.999442	0.0064433	0.928429
34	0.458333333	0.0055568	0.999694	0.0066264	0.954813
35	0.472222222	0.0055577	0.999856	0.0067583	0.973818
36	0.486111111	0.0055583	0.999964	0.0068378	0.985274
37	0.5	0.0055585	**1.000000**	0.0068644	0.989107
38	0.513888889	0.0055583	0.999964	0.0068378	0.985274
39	0.527777778	0.0055577	0.999856	0.0067583	0.973818
40	0.541666667	0.0055568	0.999694	0.0066264	0.954813
41	0.555555556	0.0055554	0.999442	0.0064433	0.928429
42	0.569444444	0.0055537	0.999136	0.0062105	0.894885
43	0.583333333	0.0055516	0.998759	0.00593	0.854467
44	0.597222222	0.005549	0.998291	0.0056041	0.807507
45	0.611111111	0.0055461	0.997769	0.0052357	0.754424
46	0.625	0.0055428	0.997175	0.004828	0.695677
47	0.638888889	0.0055392	0.996528	0.0043847	0.631801
48	0.652777778	0.0055351	0.995790	0.0039101	0.563415
49	0.666666667	0.0055306	0.994981	0.0034093	0.491254
50	0.680555556	0.0055257	0.994099	0.0028885	0.416210
51	0.694444444	0.0055204	0.993146	0.0023562	0.339510
52	0.708333333	0.0055147	0.992120	0.0018263	0.263156
53	0.722222222	0.0055086	0.991023	0.001328	0.191354
54	0.736111111	0.0055021	0.989853	0.00094108	0.135602
55	0.75	0.0054951	0.988594	0.00085347	0.122978
56	0.763888889	0.0054877	0.987263	0.0011387	0.164078
57	0.777777778	0.0054799	0.985859	0.0016037	0.231081
58	0.791666667	0.0054716	0.984366	0.0021248	0.306167
59	0.805555556	0.0054629	0.982801	0.0026579	0.382983
60	0.819444444	0.0054537	0.981146	0.0031845	0.458862
61	0.833333333	0.005444	0.979401	0.0036945	0.532349
62	0.847222222	0.0054338	0.977566	0.004181	0.602450
63	0.861111111	0.0054231	0.975641	0.0046387	0.668401
64	0.875	0.0054117	0.973590	0.0050631	0.729553
65	0.888888889	0.0053998	0.971449	0.0054505	0.785375
66	0.902777778	0.0053872	0.969182	0.0057978	0.835418
67	0.916666667	0.0053739	0.966790	0.0061021	0.879265
68	0.930555556	0.0053598	0.964253	0.0063611	0.916585
69	0.944444444	0.0053446	0.961518	0.0065733	0.947161
70	0.958333333	0.0053281	0.958550	0.0067372	0.970778
71	0.972222222	0.0053098	0.955258	0.0068522	0.987349
72	0.986111111	0.0052874	0.951228	0.0069185	0.996902
	Imax =	**0.0055585**	**Imax =**	**0.00694**	

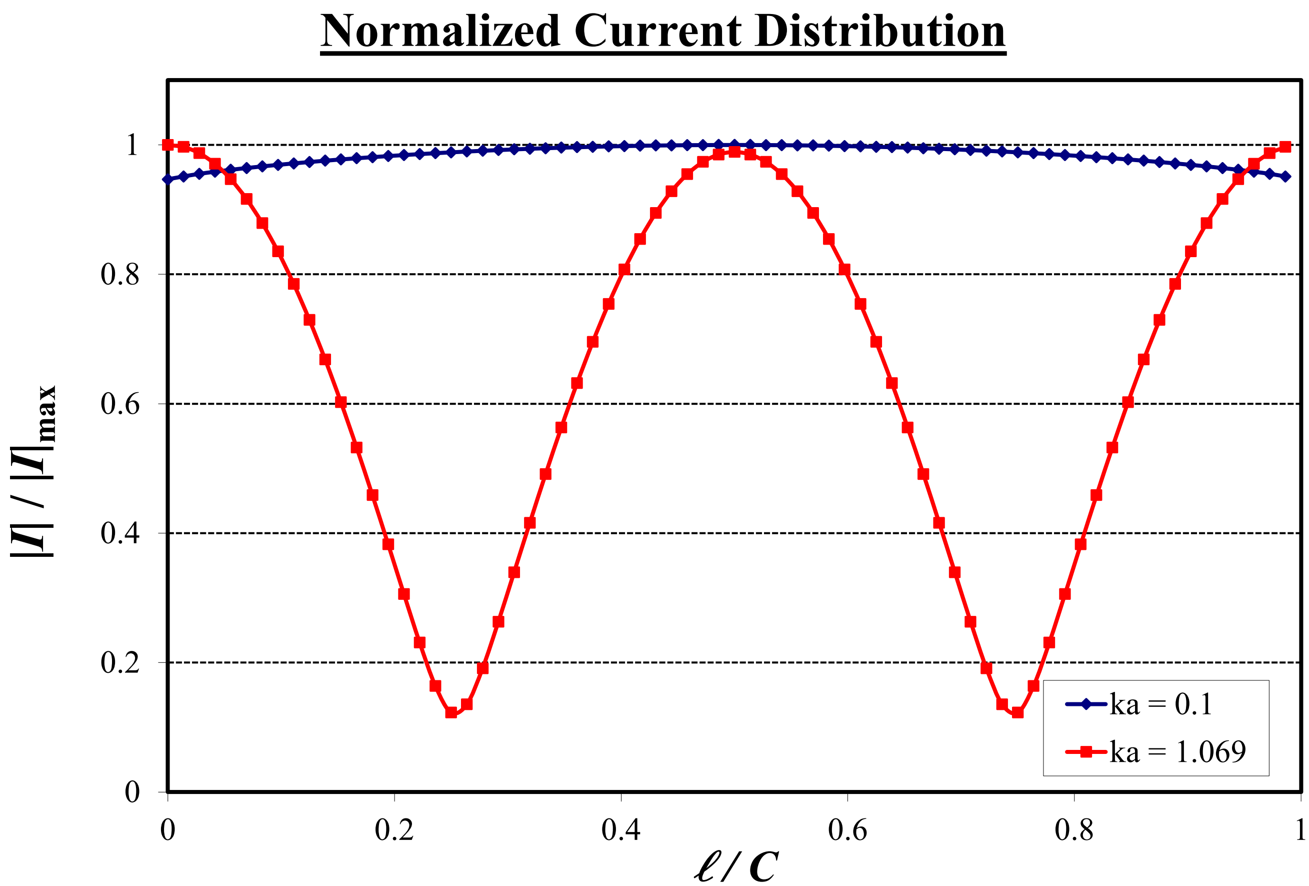


Figure 2 Plot of normalized current magnitude versus fractional circumference

****

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.

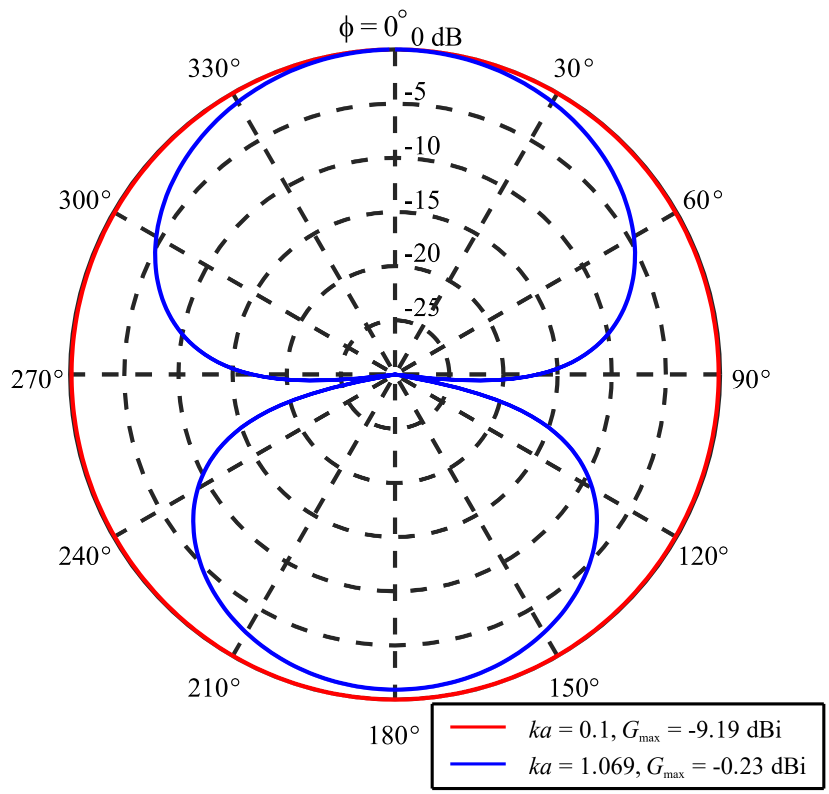
- Put radiation pattern data into MS-Excel spreadsheet. Pre-normalized & saved stripped down data to 5-column *.txt files with angle (deg), ka=0.1 gain (dBi), ka=1.069 (dBi) gain, ka=0.1 normalized gain (dB), & ka=1.069 normalized gain (dB).

			E-Plane (x-y plane wrt ϕ at $\theta = 90°$)		H-Plane (y-z plane wrt θ at $\phi = \pm 90°$)	
Description	ka	f (MHz)	G_{max} (dBi)	G_{min} (dBi)	G_{max} (dBi)	G_{min} (dBi)
small loop	0.1	50.094	-9.19	-9.32	-9.19	-23.21
resonant #1	1.069	535.63	-0.23	-33.14	3.69	-1.15

```
% E_plane_7_5in_14AWG_loop.m
% Plot E-plane radiation pattern (wrt phi at theta = 90 deg) for
% 7.5 in 14 AWG loop at the small loop ka=0.1 (f=50.094 MHz)
% and resonant ka=1.069 (f=535.63 MHz) frequencies.
clear; clc; close all;
M = dlmread('7_5in_14AWG_loop_E_plane_rad_patt_data.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)
```

```
% H_plane_18_5cm_16AWG_loop.m
% Plot H-plane radiation pattern (wrt theta at phi = 0 deg) for
% 7.5 in 14 AWG loop at the small loop ka=0.1 (f=50.094 MHz)
% and resonant ka=1.069 (f=535.63 MHz) frequencies.
clear; clc; close all;
M = dlmread('7_5in_14AWG_loop_H_plane_rad_patt_data.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 (*x*-*y* plane)



H-plane (*x*-*z* plane)

$\phi + 180° \leftarrow \theta \rightarrow \phi$