

Figure 1 (a) Rhombic Antenna, (b) detail view of feed, and (c) detail view of load.

For this assignment, you will write the NEC-2 commands needed to model and obtain data for/about the rhombic antenna, located on  $x$ - $z$  plane symmetrically about  $z=0$ , shown in Figure 1. The antenna is meant to operate from 100 - 300 MHz. To drive the antenna, place a voltage source centered on section 1. The antenna is terminated with a resistive load centered on section 6. As shown, lines through sections 2 & 4 converge at origin. Let  $c = 2.998 \times 10^8$  m/s to agree with NEC-2.

- 1) Using geometry & trigonometry, find the points  $P_{ij}$  where the sections connect as well as the lengths  $l_i$  of sections 1 - 6. Clearly shown work in appendix titled 'Geometry Calculations'. Keep up to 6-7 significant figures. Use units of **meters**.

$$\underline{P_{12}(0.1 \text{ m}, 0, 0.0726543 \text{ m})} \quad \underline{P_{14}(0.1 \text{ m}, 0, -0.0726543 \text{ m})}$$

$$\underline{P_{23}(2.8 \text{ m}, 0, 2.034319 \text{ m})} \quad \underline{P_{45}(2.8 \text{ m}, 0, -2.034319 \text{ m})}$$

$$\underline{P_{36}(5.5 \text{ m}, 0, 0.0726543 \text{ m})} \quad \underline{P_{56}(5.5 \text{ m}, 0, -0.0726543 \text{ m})}$$

$$\underline{l_1 = 0.1453085 \text{ m}} \quad \underline{l_2 = 3.337384 \text{ m}} \quad \underline{l_3 = 3.337384 \text{ m}}$$

$$\underline{l_4 = 3.337384 \text{ m}} \quad \underline{l_5 = 3.337384 \text{ m}} \quad \underline{l_6 = 0.1453085 \text{ m}}$$

- 2) All sections are made with the same wire. Select segment sizes  $\Delta_{16}$  and  $\Delta_{25}$  (**in cm**) for sections 1 & 6 as well as sections 2 - 5. Note:  $\Delta_{16}$  and  $\Delta_{25}$  may or may not be equal. Restrictions: Each section must have an integer number of segments and do NOT exceed **250 segments** in total. Justify your design decisions in appendix titled 'Segment Selection'. List the number of segments used for each section as well as the total number of segments  $N_\Delta$ . Is the extended thin-wire kernel necessary? Why?

$$\underline{\Delta_{16} = 2.90617 \text{ cm}} \quad \underline{\Delta_{25} = 5.56231 \text{ cm}}$$

$$N_1 = \underline{5} \quad N_2 = \underline{60} \quad N_3 = \underline{60} \quad N_4 = \underline{60}$$

$$N_5 = \underline{60} \quad N_6 = \underline{5} \quad \underline{N_\Delta = 250}$$

EK? YES, since the segments sizes are  $\Delta_{16}/a = 3.63 < 8$  and  $\Delta_{25}/a = 6.95 < 8$ .

- 3) Write the geometry commands necessary to model the wires for the rhombic antenna for the segment sizes selected. Assume the antenna is in free space. Assign TAG numbers to wires based on the section numbering shown in Figure 1. Use up to 6-7 significant figures for dimensions.

```

GW 1  5  0.1 0.0 -0.0726543  0.1 0.0  0.0726543  0.008  ! Section 1 (feed)
GW 2  60 0.1 0.0  0.0726543  2.8 0.0  2.034319  0.008  ! Section 2 (top)
GW 3  60 2.8 0.0  2.034319  5.5 0.0  0.0726543  0.008  ! Section 3 (top)
GW 4  60 0.1 0.0 -0.0726543  2.8 0.0 -2.034319  0.008  ! Section 4 (bottom)
GW 5  60 2.8 0.0 -2.034319  5.5 0.0 -0.0726543  0.008  ! Section 5 (bottom)
GW 6  5  5.5 0.0 -0.0726543  5.5 0.0  0.0726543  0.008  ! Section 6 (load)
GE 0  ! No ground plane, antenna in free space

```

- 4) Write the program control commands needed to either use the standard or extended thin-wire kernel, model the antenna as being made with wires with a conductivity of  $3 \times 10^7 \text{ S/m}$ , and place a  $750 \Omega$  resistive load centered on antenna section 6.

- From ‘Segment selection’ appendix, the extended kernel is necessary

**EK 0 ! Initiate use of the extended-kernel**

**LD 5 0 0 0 3.0e7 ! Load all wire segments w/ wire conductivity**

**LD 0 6 3 3 750.0 ! Put 750ohm series resistor @ middle segment of section 6**

- 5) Write the program control commands necessary to simulate the antenna from 100 to 300 MHz in 10 MHz steps (generate an impedance table) and to place a voltage source of  $100\angle 0^\circ \text{ V}$  centered on antenna section 1.

**FR 0 21 0 0 100.0 10.0 ! Take 21 linear steps of 10 MHz from 100 to 300 MHz**

**EX 0 1 3 01 100.0 0.0 1.0 ! 100V source on middle segment of tag 1, collect Zin**

Note: “FR 0 21 100.0 10.0” results in “STOP CARD ERROR statement executed” in the Command Window and a line in the output file of “\*\*\*\*\* CARD ERROR - INVALID NUMBER AT INTEGER POSITION 3”.

- 6) Write the program control command(s) necessary to output **only** the currents for the segments on antenna sections 2 and 3.

Must use absolute segment numbers. Section 2 starts at absolute segment 6 after the five segments in section 1. Then, sections 2 & 3 have 60 segments/each numbered consecutively.

**PT 0 0 6 125 ! Output currents for section 2 & section 3**

Note: “PT 0 2”, “PT 0 2 0 0”, “PT 0 3”, &/or “PT 0 3 0 0” result in the currents for ALL segments being printed.

**PT 0 2 1 60 ! Output currents for section 2**

**PT 0 3 1 60 ! Output currents for section 3**

Note: Using the above commands in a single input file on sequential lines will result in the **ONLY** the section 3 currents being printed, PT commands overwrite.

- 7) Write the program control commands necessary to output the far-field radiation patterns for **only** the  $x$ - $z$  plane (elevation) for  $-179^\circ \leq \theta \leq 180^\circ$  in  $1^\circ$  increments and **only** the  $x$ - $y$  plane (azimuthal) for  $0 \leq \phi \leq 359^\circ$  in  $1^\circ$  increments. Output the unnormalized gain with no averaging.

**RP 0 360 1 0000 -179.0 0.0 1.0 0.0 ! x-z plane elevation radiation pattern**

**RP 0 1 360 0000 90.0 0.0 0.0 1.0 ! x-y plane azimuthal radiation pattern**

Note: In a NEC-2 run with multiple frequencies, using the above commands in a single input file on sequential lines would result in the first RP command being executed for all frequencies as the RP command initiates program execution. The second RP command will only be executed at the last frequency. See page 72 of NEC-2 User's Guide.

8) Write the program control command(s) to mark the end of the input file.

EN ! All done

- 9) **EE 483 only:** Use work in prior steps as the basis for a NEC-2 input file to simulate this rhombic antenna **only** at 200 MHz to determine the input impedance, efficiency (%), maximum gain (dBi), corresponding angle(s)  $\theta$  &  $\phi$  (deg) where the maximum gain occurs (check both azimuthal and elevation planes), and the half-power beamwidths (deg) in the elevation and azimuthal planes. Add comment lines at the beginning of the input file (e.g., filename, course, *your name*, date, etcetera) as well as at the end of each line to describe what you are doing. Include a listing of your NEC-2 input file and excerpts from output file with desired quantities in **bold**. Consolidate answers in a table (put table before output file excerpts).
- 10) **EE 583 only:** Use work in prior steps <snip> to simulate this rhombic antenna **only** at 200 MHz to determine the input impedance, efficiency (%), maximum gain (dBi), corresponding angle(s)  $\theta$  &  $\phi$  (deg) where the maximum gain occurs (check both azimuthal and elevation planes), and the half-power beamwidths (deg) in the elevation and azimuthal planes. In addition, plot the azimuthal and elevation radiation patterns (clearly labeled, in dB, normalized, & with center at -30 dB). Add comment lines at the beginning of the input file (e.g., filename, course, *your name*, date, etcetera) as well as at the end of each line to describe what you are doing. Include a listing of your NEC-2 input file and excerpts from output file with desired quantities in **bold**. Consolidate answers in a table (put table before output file excerpts).

### NEC-2 Input file (good for both EE 483 & EE 583)

CM NEC2\_rhombic\_200MHz\_input.txt

CM Spring 2022 EE 483/583 HW#5

CM Thomas P. Montoya

CM Model the rhombic antenna described in HW #5 and shown (Figure 1) at 200 MHz.

CE

GW 1 5 0.1 0.0 -0.0726543 0.1 0.0 0.0726543 0.008 ! Section 1 (feed)

GW 2 60 0.1 0.0 0.0726543 2.8 0.0 2.034319 0.008 ! Section 2 (top)

GW 3 60 2.8 0.0 2.034319 5.5 0.0 0.0726543 0.008 ! Section 3 (top)

GW 4 60 0.1 0.0 -0.0726543 2.8 0.0 -2.034319 0.008 ! Section 4 (bottom)

GW 5 60 2.8 0.0 -2.034319 5.5 0.0 -0.0726543 0.008 ! Section 5 (bottom)

GW 6 5 5.5 0.0 -0.0726543 5.5 0.0 0.0726543 0.008 ! Section 6 (load)

GE 0 ! No ground plane, antenna in free space

EK 0 ! Initiate use of the extended-kernel

LD 5 0 0 0 3.0e7 ! Load all wire segments w/ wire conductivity

LD 0 6 3 3 750.0 ! Place 750ohm series resistor @ middle segment of section 6

FR 0 1 0 0 200.0 10.0 ! single frequency of 200 MHz

EX 0 1 3 01 100.0 0.0 1.0 ! 100V source on middle segment of section 1, collect Zin

PT -1 ! Suppress output of currents

RP 0 360 1 0000 -179.0 0.0 1.0 0.0 ! x-z plane elevation radiation pattern

RP 0 1 360 0000 90.0 0.0 0.0 1.0 ! x-y plane azimuthal radiation pattern

EN

Table 1 EE 483/583 information at 200 MHz

$Z_{in} (\Omega)$	Efficiency (%)	$G_{max}$ (dBi)	Angles (deg)	Elev. HPBW	Azim. HPBW
295.668 - j198.179	80.70	11.91	$\theta = 90$ & $\phi = 0 - 2$	16.65°	48.5°

**NEC-2 output file excerpts**

```

<snip>
                                NEC2_rhombic_36_200MHz_input.txt
<snip>
                                - - - - - FREQUENCY - - - - -
                                FREQUENCY= 2.0000E+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.    REAL  IMAG.    (W)
1  3  1.00E+2  0.0E+0  2.3337E-1  1.5642E-1  2.95668E+2 -1.9818E+2  2.3337E-3  1.5642E-3  1.1669E+1

                                - - - POWER BUDGET - - -
<snip>
                                EFFICIENCY    =    80.70 PERCENT

                                - - - RADIATION PATTERNS - - -
- ANGLES - - POWER GAINS - - - POLARIZATION - - E(THETA) - - E(PHI) -
THETA PHI MAJOR MINOR TOTAL AXIAL TILT SENSE MAGNITUDE PHASE MAGNITUDE PHASE
DEG DEG  DB    DB    DB RATIO DEG.      VOLTS/M  DEGREES  VOLTS/M  DEGREES
-179.00 0.0 -10.16 -999.99 -10.16 0.0 0.0  LINEAR  8.21399E+00 -178.34  0.0E+00  0.0
<snip>
81.00 0.0 8.36 -999.99  8.36  0.0 0.0  LINEAR  6.92784E+01  51.26  0.0E+00  0.0
82.00 0.0 9.16 -999.99  9.16  0.0 0.0  LINEAR  7.59179E+01  52.39  0.0E+00  0.0
 83.00 0.0 9.84 -999.99  9.84  0.0 0.0  LINEAR  8.20764E+01  53.44  0.0E+00  0.0
<snip>
 89.00 0.0 11.87 -999.99 11.87  0.0 0.0  LINEAR  1.03780E+02  57.06  0.0E+00  0.0
90.0 0.0 11.91 -999.99 11.91  0.0 0.0  LINEAR  1.04266E+02  57.14  0.0E+00  0.0
 91.00 0.0 11.87 -999.99 11.87  0.0 0.0  LINEAR  1.03780E+02  57.06  0.0E+00  0.0
<snip>
 97.00 0.0 9.84 -999.99  9.84  0.0 0.0  LINEAR  8.20764E+01  53.44  0.0E+00  0.0
98.00 0.0 9.16 -999.99  9.16  0.0 0.0  LINEAR  7.59179E+01  52.39  0.0E+00  0.0
99.00 0.0 8.36 -999.99  8.36  0.0 0.0  LINEAR  6.92784E+01  51.26  0.0E+00  0.0
<snip>
180.0 0.0 -9.09 -999.99 -9.09  0.0 0.0  LINEAR  9.28930E+00 -178.52  0.0E+00  0.0
<snip>

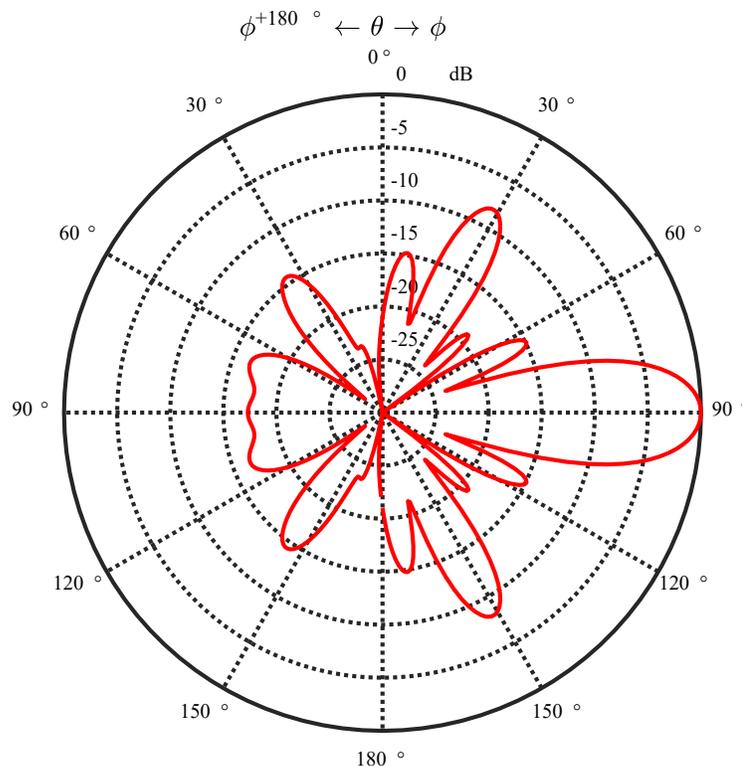
- - ANGLES -- POWER GAINS -- - POLARIZATION - - - - - E(THETA) - - - - E(PHI) - -
THETA PHI MAJOR MINOR TOTAL AXIAL TILT SENSE MAGNITUDE PHASE MAGNITUDE PHASE
DEG DEG  DB    DB    DB RATIO DEG.      VOLTS/M  DEGREES  VOLTS/M  DEGREES
90.0 0.0 11.91 -999.99 11.91  0.0 0.0  LINEAR  1.04266E+02  57.14  0.0E+00  0.0
90.0 1.0 11.91 -999.99 11.91  0.0 0.0  LINEAR  1.04239E+02  57.06  5.12533E-11 -118.26
<snip>
90.0 23.0 9.36 -999.99  9.36  0.0 0.0  LINEAR  7.7668E+01  13.10  7.29385E-10 -168.84
90.0 24.0 9.0 -999.99  9.0  0.0 0.0  LINEAR  7.45146E+01  9.38  7.24565E-10 -173.36
90.0 25.0 8.6 -999.99  8.6  0.0 0.0  LINEAR  7.11714E+01  5.54  7.16305E-10 -178.07
<snip>
90.0 359.0 11.91 -999.99 11.91  0.0 0.0  LINEAR  1.04239E+02  57.06  5.12531E-11  61.74
    
```

### Elevation Radiation Pattern

```
% nec2_rhombic_36_200MHz_elev_rad_patt.m
% Plot elevation (wrt theta) radiation pattern
% for 36 deg rhombic antenna at 200 MHz.
clear; clc; close all;
Mel = dlmread('nec2_rhombic_36_200MHz_elev_rad_patt.txt');
for i =1:360
    theta(i) = Mel(i,1);    Gel(i) = Mel(i,2);
end
% ***** Plot Radiation Patterns in dB format *****
radpat(theta,Gel,'r-'); % Elevation radiation pattern
```

### Matlab Command Window Inputs

Are input values in dB (Y/N) [Y]? Y  
 Normalize to the Maximum Gain Value (Y/N) [Y]? Y  
 Minimum dB value at plot center [-40]? -30  
 Are the angles theta values? (Y/N) [Y]? Y  
 Labels on Vertical or Horizontal axis (V/H) [V]? V  
 Pattern line width [1.25]: 2  
 Line type of grid(-, --, -., :)[:]? :

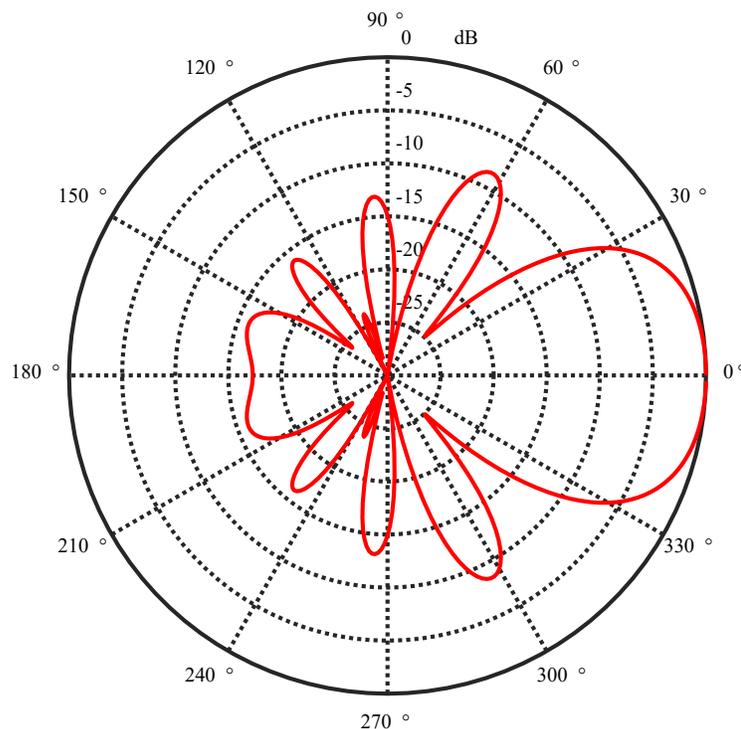


### Azimuthal Radiation Pattern

```
% nec2_rhombic_36_200MHz_azith_rad_patt.m
% Plot azimuthal (wrt phi) radiation pattern
% for 36 deg rhombic antenna at 200 MHz
clear; clc; close all;
Maz = dlmread('nec2_rhombic_36_200MHz_azith_rad_patt.txt');
for i =1:360
    phi(i) = Maz(i,1);    Gaz(i) = Maz(i,2);
end
% ***** Plot Radiation Pattern in dB format *****
radpat(phi,Gaz,'r-');% Azimuthal radiation pattern
```

### Matlab Command Window Inputs

```
Are input values in dB (Y/N)[Y]? Y
Normalize to the Maximum Gain Value (Y/N)[Y]? Y
Minimum dB value at plot center [-40]? -30
Are the angles theta values? (Y/N)[Y]? N
0 deg at North/Top or East/Right (N/E)[N]? E
Labels on Vertical or Horizontal axis (V/H)[V]? V
Pattern line width [1.25]: 2
Line type of grid(-, --, -., :)[:]: :
```



## Geometry calculations

In order to write the geometry commands for the rhombic antenna shown in Figure 1, we need to know the coordinates of each corner.

From Figure 1, the antenna is on the  $x$ - $z$  plane. For all points/coordinates  $\Rightarrow y = 0$ .

### Section 1

From Fig. 1, the section 1  $x$ -coordinate is  $\Rightarrow x_1 = 0.1 \text{ m} = 10 \text{ cm}$ .

Using trigonometry, the top & bottom of section 1 are at

$$\pm 0.1 * \tan(36^\circ) \Rightarrow z_{12} = 0.0726543 \text{ m} = 7.26543 \text{ cm} \text{ and } z_{14} = -z_{12}$$

$\Rightarrow$  **Section 1** goes from  $P_{14}(0.1 \text{ m}, 0, -0.0726543 \text{ m})$  to  $P_{12}(0.1 \text{ m}, 0, 0.0726543 \text{ m})$ .

$\Rightarrow$  The length of section 1 is  $l_1 = 2(z_{12}) = 2(0.0726543) \Rightarrow \underline{l_1 = 0.1453085 \text{ m}}$ .

### Sections 2 & 4

From Fig. 1, the start of section 2 is the top of section 1  $\Rightarrow P_{12}$ .

From Fig. 1, the start of section 4 is bottom of section 1  $\Rightarrow P_{14}$ .

From Fig. 1, the  $x$ -coordinate for the right ends of sections 2 & 4 is  $\Rightarrow x_{23} = x_{45} = 2.8 \text{ m}$ .

Using trigonometry, the  $z$ -coordinates for the top/bottom ends of sections 2 & 4 are

$$\pm 2.8 * \tan(36^\circ) \Rightarrow z_{23} = 2.034319 \text{ m} = 203.4319 \text{ cm} \text{ and } z_{45} = -z_{23}$$

$\Rightarrow$  **Section 2** goes from  $P_{12}(0.1 \text{ m}, 0, 0.0726543 \text{ m})$  to  $P_{23}(2.8 \text{ m}, 0, 2.034319 \text{ m})$ .

$\Rightarrow$  **Section 4** goes from  $P_{14}(0.1 \text{ m}, 0, -0.0726543 \text{ m})$  to  $P_{45}(2.8 \text{ m}, 0, -2.034319 \text{ m})$ .

The lengths of sections 2 & 4 are  $l_2 = l_4 = [(2.8 - 0.1)^2 + (2.034319 - 0.0726543)^2]^{0.5} \Rightarrow \underline{l_2 = l_4 = 3.337384 \text{ m}}$ .

### Sections 3, 5, & 6

From Fig. 1, the start of section 3 is the end of section 2  $\Rightarrow P_{23}$ .

From Fig. 1, the start of section 5 is the end of section 4  $\Rightarrow P_{45}$ .

From Fig. 1, the  $x$ -coordinate for section 6 (right ends of 4 & 5) is  $\Rightarrow x_6 = 5.5 \text{ m}$ .

From Fig. 1, top/bottom  $z$ -coordinates of section 6 are even with top/bottom of section 1

$$\Rightarrow z_{36} = z_{12} \text{ and } z_{56} = z_{14}$$

$\Rightarrow$  **Section 3** goes from  $P_{23}(2.8 \text{ m}, 0, 2.034319 \text{ m})$  to  $P_{36}(5.5 \text{ m}, 0, 0.0726543 \text{ m})$ .

$\Rightarrow$  **Section 5** goes from  $P_{45}(2.8 \text{ m}, 0, -2.034319 \text{ m})$  to  $P_{56}(5.5 \text{ m}, 0, -0.0726543 \text{ m})$ .

$\Rightarrow$  **Section 6** goes from  $P_{56}(5.5 \text{ m}, 0, -0.0726543 \text{ m})$  to  $P_{36}(5.5 \text{ m}, 0, 0.0726543 \text{ m})$

The lengths of sections 3 & 5 are same as sections 2 & 4.  $\Rightarrow \underline{l_3 = l_5 = 3.337384 \text{ m}}$ .

$\Rightarrow$  The length of section 6 is the same as section 1.  $\Rightarrow \underline{l_6 = 0.1453085 \text{ m}}$ .

**Segment selection**

Select segment size  $\Delta_{16}$  for sections 1 & 6 and segment size  $\Delta_{25}$  for sections 2 - 5 to model rhombic antenna in Figure 1 for 100 - 300 MHz. Note:  $\Delta_{16}$  may or may not equal  $\Delta_{25}$ . Restriction: Do NOT exceed 250 segments in total. Clearly justify your design decisions.

From Figure 1, the wire diameter is  **$d = 2a = 1.6 \text{ cm}$**  and the radius is  **$a = 0.8 \text{ cm}$** .

From **Geometry calculations**, the lengths of sections 1 & 6 are  **$l_{16} = l_1 = l_6 = 14.53085 \text{ cm}$**  while the lengths of sections 2 through 5 are  **$l_{25} = l_2 = l_3 = l_4 = l_5 = 333.7384 \text{ cm}$** .

Find longest wavelength  $\lambda_{\text{low}}$  (lowest frequency)

$$\lambda_{\text{low}} = c/f_{\text{low}} = 2.998 \cdot 10^8 / 100 \cdot 10^6 \Rightarrow \lambda_{\text{low}} = \mathbf{2.998 \text{ m} = 299.8 \text{ cm}}$$

Find shortest wavelength  $\lambda_{\text{high}}$  (highest frequency)

$$\lambda_{\text{high}} = c/f_{\text{high}} = 2.998 \cdot 10^8 / 300 \cdot 10^6 \Rightarrow \lambda_{\text{high}} = \mathbf{0.9993 \text{ m} = 99.933 \text{ cm}}$$

**Process**

- 1) Is the rod/wire 'thin', i.e.,  $2\pi a/\lambda = \pi d/\lambda \ll 1$ ? Check considering worst case, i.e., shortest wavelength  $\lambda_{\text{high}}$ ,

$$\pi d/\lambda_{\text{high}} = \pi(1.6)/99.933 = 0.0503 \ll 1 \Rightarrow \mathbf{Yes.}$$

- 2) Want  $\Delta < \lambda/10$  and  $\Delta > \lambda/1000$  for the worst cases, i.e.,  $\lambda_{\text{low}}/1000 < \Delta < \lambda_{\text{high}}/10$   
 $\Rightarrow \mathbf{0.2998 < \Delta < 9.993 \text{ cm}}$

- 3) Also, want  $\Delta/a > 2$  minimum. If  $\Delta/a > 8$ , EK command is not needed.

$$\Delta_{\text{min}} > 2a = 1.6 \text{ cm} \Rightarrow \mathbf{1.6 < \Delta < 9.993 \text{ cm}}$$

- 4) For a center feed on section 1 and a centered load on section 6, we need an **odd integer** number of segments. Based on the minimum segment length in the range above, we get  $l_{16}/\Delta_{\text{min}} = 14.53085/1.6 = 9.08$  segments which implies we can use 3, 5, 7, or 9 segments for sections 1 & 6, choose **5 segments**

$$\Rightarrow \Delta_{16} = 14.53085/5 \Rightarrow \mathbf{\Delta_{16} = 2.90617 \text{ cm}}$$

- 5) For **sections 2 – 5**, we can use even or odd number of segments. The total number of segments is to be  $\leq 250$ . After sections 1 & 6, the maximum number of segments left is  $250 - 5 - 5 = 240$ . Using  $240/4 = \mathbf{60 \text{ segments each}}$ , gives:

$$\Delta_{25} = l_{25}/60 = 333.7384/60 \Rightarrow \mathbf{\Delta_{25} = 5.56231 \text{ cm}}$$

$$\mathbf{DONE!} \quad N_{\Delta} = 2*5 + 4*60 \Rightarrow \mathbf{N_{\Delta} = 250}$$

- 6) Check  $\Delta/a$  ratios to see if extended kernel (EK) command is needed.

$$\Delta_{16}/a = 2.90617/0.8 = 3.63 < 8 \quad \text{and} \quad \Delta_{25}/a = 5.56231/0.8 = 6.95 < 8$$

$\Rightarrow$  **The EK command is necessary.**