The Numerical Electromagnetics Code, Ver 2 (NEC-2)

→ Based on the numerical solution of integral equations by the Method of Moments (MoM) → single freq. method (time-harmonic assumption)

→ Combines an electric field integral equation for modeling thin wires with a magnetic field integral equation for closed perfectly conducting (PEC) surfaces

What can be modeled?

→ wires
→ metal patches
→ lumped loads (R, L, C)
→ voltage sources } single or multiple frequencies
→ incident EM plane waves } single or multiple frequencies
→ Transmission lines
→ ground (PEC or lossy dielectric)

⋮

What kind of outputs can you get from NEC?

→ currents on structure(s)

→ charge distributions

→ near field $\bar{E}$ + $\bar{H}$

→ radiated (i.e., far-field) $\bar{E}$ + $\bar{H}$

→ input impedance

→ gain / directivity

⋮

Limitations

→ can handle structures up to several λ in size

→ Matrices grow as N^2 where N is the # of segments (Memory + speed requirements!)

→ Best suited for symmetric structures

Modeling Guidelines

→ we are making structures out of straight wire segments and flat surface patches

→ critical to select enough segments & patches for accuracy while minimizing their total number (speed & memory concerns)

Wire Modeling → wire segments

→ defined by two end points and its radius

→ For curves, try to follow path as closely as possible (piece-wise linear fit) & keep length of piece-wise linear approximation as close as possible to curve being modeled

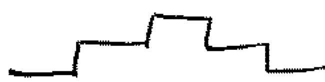
→ Segment length (Δ)

☆ → want $\Delta < \lambda/10$ (can stretch to $\lambda/8$ in a pinch)
But $\Delta > \lambda/1000$

→ use smaller segments for critical areas (e.g., curves, feed area, ...)

→ can use longer segments on long straight pieces

→ Current is computed at center of segments (more segments – more current resolution)

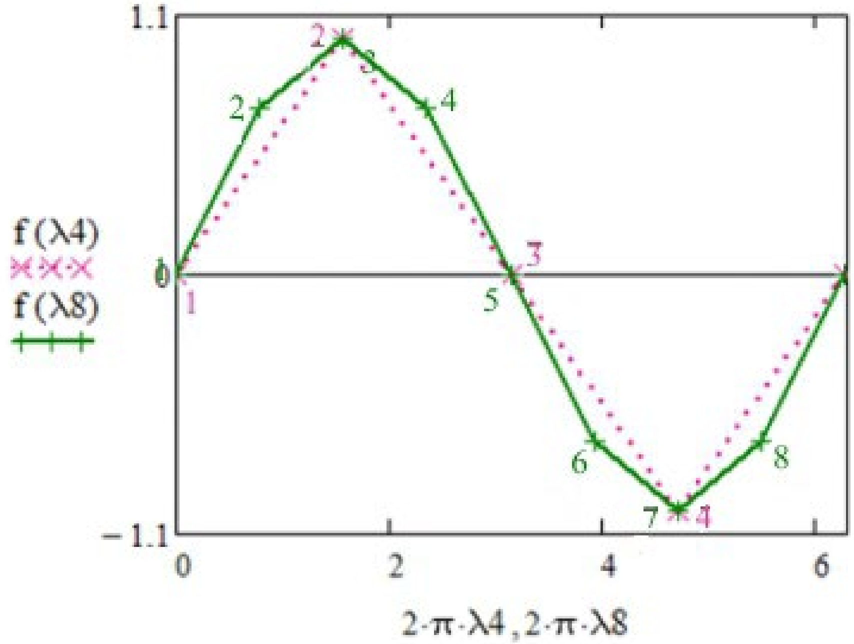


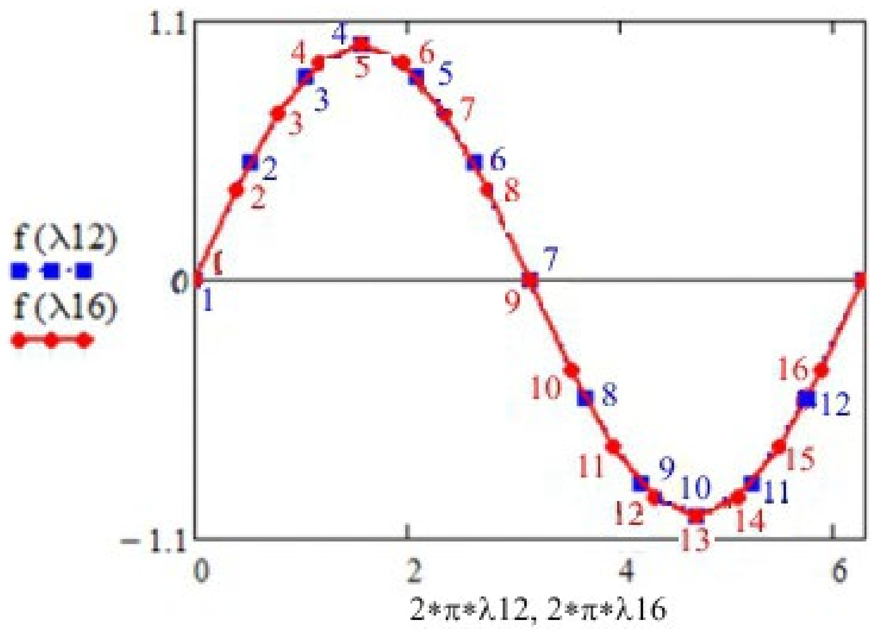
ex current values

Plot a sinusoid for one wavelength using different segment (Δ) sizes

$f(x) := \sin(2\cdot\pi\cdot x)$

4 segments	$n4 := 0..4$	$\lambda4_{n4} := \frac{n4}{4}$
8 segments	$n8 := 0..8$	$\lambda8_{n8} := \frac{n8}{8}$
12 segments	$n12 := 0..12$	$\lambda12_{n12} := \frac{n12}{12}$
16 segments	$n16 := 0..16$	$\lambda16_{n16} := \frac{n16}{16}$





Wire Modeling cont.

→ wire radius 'a' is important as NEC makes a "thin wire" approximation that currents are axial NOT transverse

→ So, what is Thin (filimentary)?

$$\frac{C}{\lambda} = \frac{2\pi a}{\lambda} << 1$$ (Rule of thumb is 1/10 or less is OK)

→ How are Δ + a inter-related?

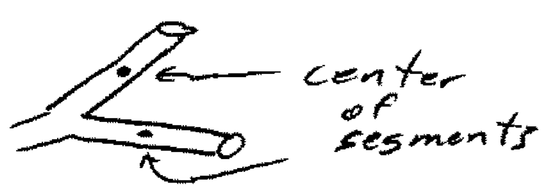
⇒ avoid $\Delta/a \leq 0.5$ (hockey puck),

$\Delta/a \gtrsim 2$ is better, and $\frac{\Delta}{a} \geq 8$ is best

[use extended kernel (EK card/command) if $\Delta/a < 8$]

→ end points of connected wires should match (a slop factor of $10^{-3}\,\Delta_{longest}$ is allowed)

→ Be careful with wires intersecting at acute angles



If the center of one segment is within the volume of another segment → big errors

Example Select a segment length Δ to model a 20.8 cm long dipole antenna made from a 1/2" (O.D.) aluminum rod for a frequency range from 600 MHz to 900 MHz.

From above, **$\ell = 20.8$ cm** and **$d = 2a = 0.5" = 1.27$ cm** or **$a = 0.25" = 0.635$ cm**

Find longest wavelength λ_{low} (lowest frequency)

$$\lambda_{low} = c/f_{low} = 2.998 \cdot 10^8 / 600 \cdot 10^6 \Rightarrow \mathbf{\lambda_{low} = 0.49967\ m = 49.967\ cm}$$

and the dipole is a bit under a half wavelength: $\ell/\lambda_{low} = 20.8/49.967 \Rightarrow \mathbf{\ell/\lambda_{low} = 0.4163}$

Find shortest wavelength λ_{high} (highest frequency)

$$\lambda_{high} = c/f_{high} = 2.998 \cdot 10^8 / 900 \cdot 10^6 \Rightarrow \mathbf{\lambda_{high} = 0.33311\ m = 33.311\ cm}$$

and the dipole is a bit over a half wavelength: $\ell/\lambda_{high} = 20.8/33.311 \Rightarrow \mathbf{\ell/\lambda_{high} = 0.6244}$

Segment length Δ selection process

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

   ⇒ **Yes/pretty good** as $\pi d/\lambda_{high} = \pi(1.27)/33.311 = 0.12 << 1$.

2) Want $\Delta < \lambda/10$ and $\Delta > \lambda/1000$ for the worst cases, i.e., $\lambda_{low}/1000 < \Delta < \lambda_{high}/10$

   ⇒ **$0.05 < \Delta < 3.33$ cm**

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

   ⇒ **$\Delta > 2a = 1.27$ cm**

4) For a finite-length ($\ell > 0.1\lambda$) dipole antenna, we expect a sinusoidal current distribution. Earlier we saw that having 12 segments per wavelength (or more) is desirable for a good representation of a sinusoid. For the worst case, i.e., at λ_{high}, that implies

   $\Delta < \lambda_{high}/12 = 33.311/12 \Rightarrow$ **$\Delta < 2.776$ cm**

5) Doing a logical 'OR' on items 2) - 4), we get a narrowed segment range of

   ⇒ **$1.27 < \Delta < 2.78$ cm**

6) For a center-fed dipole, we need an **odd integer** number of segments in order to have a centered segment. for the range above, we get

   20.8/1.27 = 16 segments whereas 20.8/2.78 = 7.5 segments

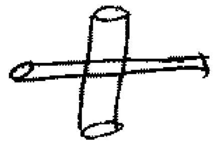
7) I will choose to use 11 segments. Therefore, my segment length is:

   $\Delta = \ell/11 = 20.8/11 \Rightarrow$ **$\Delta = 1.891$ cm (DONE!)**

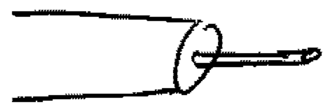
8) Check Δ/a ratio to see if extended kernel (EK) command is needed.

   $\Delta/a = 1.891/0.635 = 2.98 < 8$ ⇒ The EK command is necessary.

More wire segment rules ;

→ No overlapping (can lead to singular matrices)  ← No-No

→ Need segment at network connections + where voltage sources located

→ Avoid large changes in wire radius between segments 

→ Try to separate parallel wires by several radii apart (several diameters better). Also, try to align segments (endpoints + centers)

→ No more than 30 wires connected at a junction

→ Try to avoid small loops 
(circumference $< 3 \times 10^{-4} \lambda$)

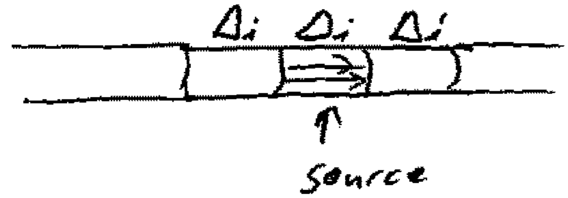
Voltage Source Model

→ important as any mistakes show up in the input impedance, gain, …

applied E-field source model → $E_i = \frac{V_i}{\Delta_i}$

** segments on either side of Δ_i should be same length + preferably co-linear

e.g.



Other possibilities include an elementary current source + a current-slope-discontinuity voltage source (we won't use)

Plane Wave Excitation

→ Linear Polarization

→ RH elliptical

→ LH elliptical

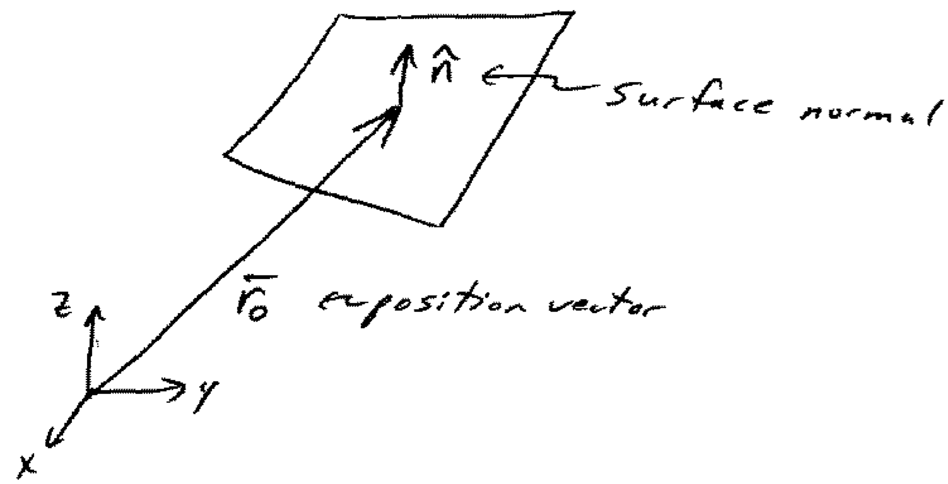
} Remember that circular polarization is a special case of elliptical polarization

Surface Modeling

→ use small flat surface patches to model conducting surfaces

★ → **closed surfaces** ← ★

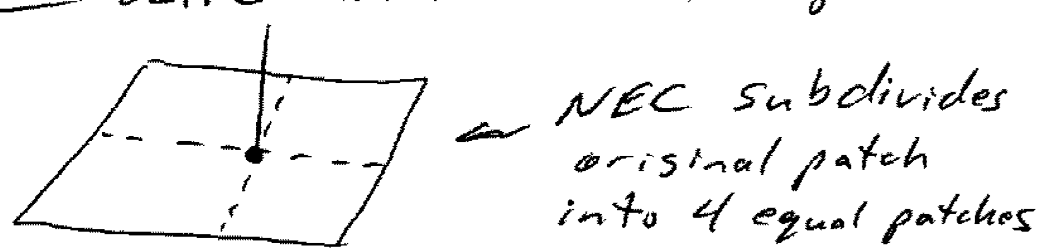
→ Surface patch defined by its center, outward surface normal, and the area



→ patch can have arbitrary shape (e.g. square, rectangular, ...)

→ a wire must be connected to center of a patch & patch should be square for best results

→ only one wire can connect to a patch



Surface patches cont.

patch size → at least 25 patches per λ^2 of area

→ max size of any individual patch ~ $0.04\lambda^2$

→ can use larger patches in large flat areas

→ smaller patches near curvatures & edges

→ avoid long narrow patches

Ground & Structures

* PEC ground → NEC uses image theory

→ wires should be $> 10^{-6}\lambda$ over gnd & several radii over gnd

* Finite conductivity / lossy ground — structure should be at least several $\lambda/10$ over ground

* Some other options available

Inputs to NEC Program

→ commands read from a text file that is input (NEC asks for names of input file and output file)

Input files

CM
CM
⋮
CE

- CM … } Comment lines
- CE ← last comment line
- } ← Structure geometry lines
- GE ← end geometry input
- } ← Program control command lines (Excitation, outputs, …)
- NX ← Next structure (if desired)
- } Repeat above
- EN ← end of input file

Command Line format

→ Two letter identifier (e.g. CM, GE, GW, ...) in first two columns

→ For CM + CE columns 3-80 are for text

→ For other commands columns 3-80 will first have integer parameters (flags) + then floating-point parameters

→ can separate numbers by blank space(s) or commas

→ must enter <u>zeros</u> for unused integer parameters (on punch cards blanks were the equiv. of zeros)

→ Can put a comment at the end of a command line by terminating line w/ !

e.g. GW 1 7 0 0 -0.25 0 0 0.25 0.001 ! HI

Why 80 columns? From the <u>OLD</u> data card entry (i.e., we used to have to enter commands into computers using cardboard cards w/ holes punched in them that only had 80 columns)

→ 80 column limit may or may not be a problem, depends on how program was compiled

Structure Geometry Inputs

→ defines wires + patches (i.e., the structure)

→ ends w/ the GE command

→ in addition to commands that directly define wires/patches there are commands to move, rotate, copy ... structures

→ user can assign tag numbers to wire pieces or sections (useful for placing loads + voltage sources)

ITAG = 0 (default, identify segments by abs. #, e.g. $1 \to N_{TOT}$)

ITAG = # (can identify segments by Tag # + seg # on that particular wire piece, e.g. ITAG=3, NSEG=4)

GA – wire arc

GE – end geometry input

GF – Read numerical Green's function file

GH – helix/spiral

GM – coordinate transformation

GR – generate cylindrical structure

GS – scale structure dimensions

GW – wire specification

GX – reflection in coordinate plane(s)

SP – surface patch

SM – multiple surface patch

I'll give examples for a couple of the commands

Structure Geometry cont.

Command: End Geometry

GE I1 = GPFLAG ← ground plane flag

I1 = 0 ⇒ no ground plane

I1 = 1 ⇒ a ground plane @ z = 0 (x-y plane), currents interpolated to image structure

I1 = −1 ⇒ a ground plane @ z = 0, no current interpolation (goes to zero @ ground)

Notes: structure dimensions must be in meters (default) when this command is executed

ex. GE 0 ! No ground plane

⇒ Integer flags obey "IN" FORTRAN convention (i.e., variables beginning w/ letters I, J, K, L, M, + N are assumed to be integers, all others are assumed to be floating point, unless otherwise specified.

Structure Geometry cont.

Command: Coordinate Transformation

GM ITG1 NRPT ROX ROY ROZ XS YS ZS IT1 IS1 IT2 IS2

ITG1 → tag #

NRPT → # of new structures (0 indicates to just move the original structure)

ROX → angle in degrees to rotate structure about x-axis (positive ∡ is RH rotation)

ROY, ROZ } ditto for y- & z- axes

XS – amount of shift in x-direction

YS – " y-direction

ZS – " z-direction

IT1–IS2 – leave blank to move entire preceding structure, else start moving w/ segment # given here

Ex. GM 1 1 0.0 0.0 0.0 0.1 0.0 0.0 ! Make one copy of Tag 1 object 0.1 m over in x-dir.

Structure Geometry cont.

Command: Scale Structure Dimensions

GS 0 0 FSCALE

FSCALE → all structure dimensions multiplied by this parameter

Why? Input everything in inches then multiply by 0.0254 to convert to meters.

Ex. GS 0 0 0.0254 ! Multiply all dimensions by 0.0254 to convert inches to meters

Structure Geometry cont.

Command: Straight Wire Specification

GW ITG NS XW1 YW1 ZW1 XW2 YW2 ZW2 RAD

GC 0 0 RDEL RAD1 RAD2 ← optional (only for tapered wires)

ITG – Tag # assigned to all segments of wire

NS – # of segments

XW1, YW1, ZW1 } (X, Y, Z) coordinates of first end of wire

XW2, YW2, ZW2 } (X, Y, Z) coordinates of second end of wire

RAD – radius of wire or 0 for tapered wire option

GC

RDEL – ratio of segment length to length of previous segment in string

RAD1 – radius of first segment

RAD2 – " " last segment

* positive current assumed for current going from first end to second end

Ex. GW 3 24 0.0 0.0 0.0 0.0 0.0 0.3 0.001 ! 1 mm radius wire from origin to z = 0.3 m, Tag #3

Structure Geometry cont.

Command: Wire Arc Specification

GA ITG NS RADA ANG1 ANG2 RAD

ITG – Tag # assigned to all segments of wire arc

NS – # of segments

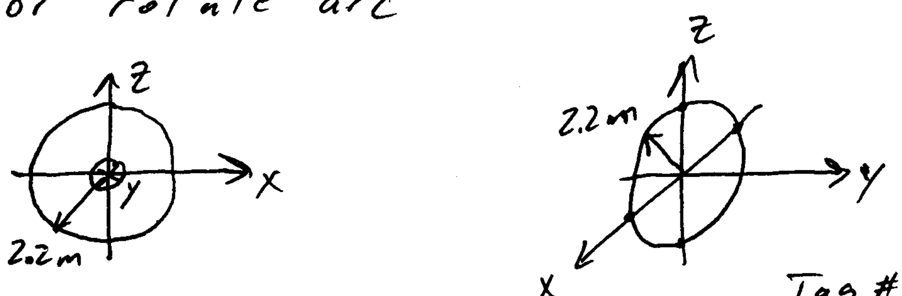
RADA – radius of arc, centered @ origin w/ axis of symmetry the y-axis, i.e., arc on x-z plane

ANG1 – angle in degrees wrt to positive x-axis for first end of arc

ANG2 – angle in degrees wrt to positive x-axis for second end of arc

RAD – radius of wire

Note: Can use GM command to move or rotate arc



Ex. GA 1 60 2.2 0 360 0.01 ! Tag #1, 60 segments 2.2 m circular loop w/ 1cm radius wire

Structure Geometry Cont.

Command: Surface Patch

```
SP  0  NS  X1  Y1  Z1  X2  Y2  Z2
SC  0  0   X3  Y3  Z3  X4  Y4  Z4
```

SC ← optional (used if NS ≠ 0)

NS – patch shape
- 0 – arbitrary (default)
- 1 – rectangular
- 2 – triangular
- 3 – quadrilateral

NS=0

X1, Y1, Z1 } (X, Y, Z) location of patch center

X2 – elevation angle from x-y plane of outward surface normal

Y2 – azimuth angle from pos. x-axis of outward surface normal

Z2 – patch area

NS = 1, 2, or 3

X1, Y1, Z1 } corner 1 of patch

X2, Y2, Z2 } corner 2 of patch

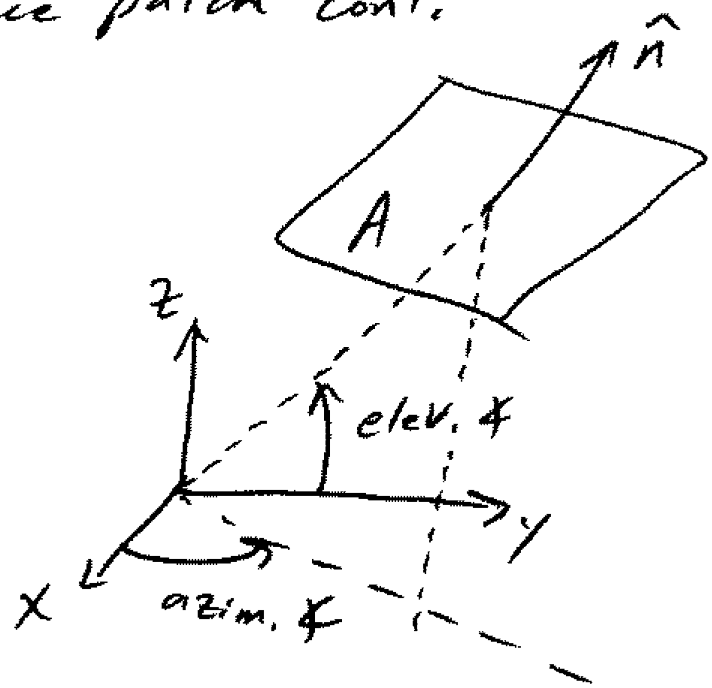
X3, Y3, Z3 } corner 3 of patch

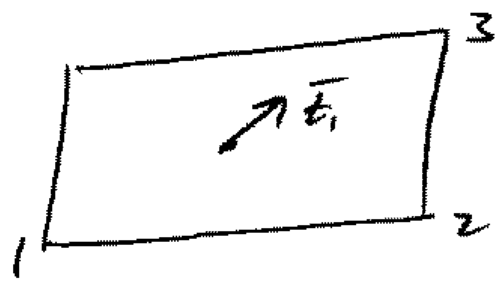
NS=3 only

X4, Y4, Z4 } corner 4 of patch

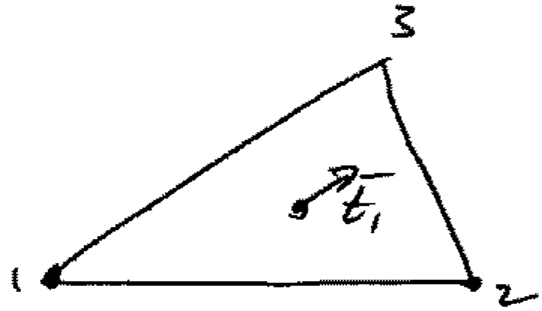
Structure Geometry cont.

Surface patch cont.

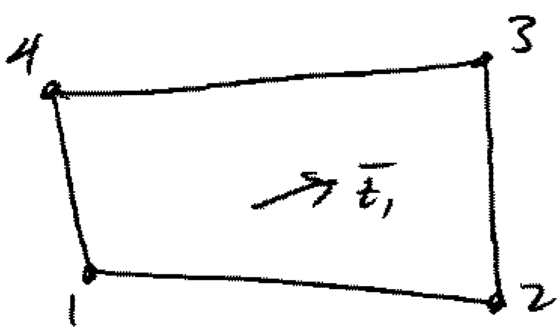




Rectangular Patch (NS=1)



Triangular Patch (NS=2)



Quadrilateral Patch (NS=3)

Structure Geometry cont.

Command: Multiple Patch Surface

SM NX NY X1 Y1 Z1 X2 Y2 Z2

SC 0 0 X3 Y3 Z3

SM

NX → # of patches in width (from corner 1 to 2)

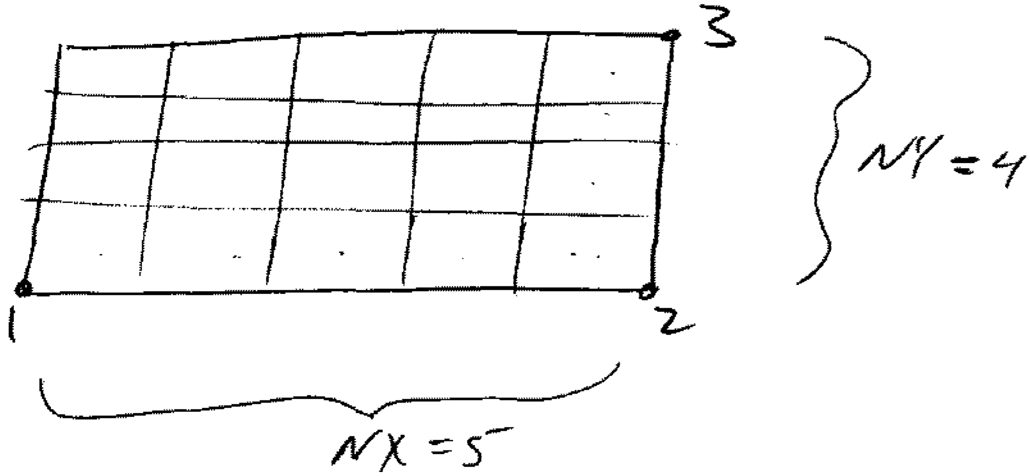
NY → # of patches in height (from corner 2 to 3)

X1, Y1, Z1 } (x, y, z) coordinates of corner 1

X2, Y2, Z2 } " corner 2

SC X3, Y3, Z3 } " corner 3

Outward normal determined using RHR on corners 1, 2, 3



Program Control Commands

→ Follow geometry commands (i.e. after the GE command)

→ solution options, electrical parameters, and they request data computation + outputs

→ Listed by groups where (I) affect entire solution, (II) affect current but not MoM matrix, and (III) only affect results derived from current.

Group I
- EK – extended Thin-wire Kernel flag
- FR – frequency specification
- GN – ground parameter specification
- KH – interaction approx. range
- LD – structure impedance loading

Group II
- EX – structure excitation
- NT – two-port network specification
- TL – transmission line specification

Group III
- CP – coupling calculation
- EN – end of data flag
- GD – addition ground parameter specifications
- NE – Near E-field
- NH – Near H-field

Program Control cont.

Group III cont.

- NX – next structure
- PQ – wire charge density print control
- PT – wire current print control
- RP – radiation pattern request
- WG – write Numerical Green's function
- XQ – execute command

→ No fixed order, however, the commands are read in order + solution will only be affected by commands before solution request.

→ If not set, most commands will go to a default value/state (e.g. default frequency is 299.8MHz or $\lambda = 1m$). For the most part, the command is omitted.

→ Parameters keep set values until changed

→ Let's look at the more frequently used Program Control Commands

Program Control cont.

Command: End of Run

EN

→ No parameters

→ Marks the end of the input data file

Command: Extended Thin-wire Kernel

EK ITEMP1

ITEMP1 = 0 initiate use of extended thin-wire kernel

= −1 return to standard thin-wire Kernel

→ default is to use standard Thin-wire Kernel

→ allows segments where $\Delta/a < 8$ to be used

Ex. EK 0 ! Turn <u>on</u> the extended thin-wire kernel.

Program Control cont.

Command: structure excitation

EX I1 I2 I3 I4 F1 F2 F3 F4 F5 F6

I1 — Type of source

- I1 = 0 applied E-field voltage source
- = 1 linearly polarized incident plane wave
- = 2 RH elliptic " " " "
- = 3 LH " " " " "
- (= 1 to = 3: can get RCS)
- = 4 elementry current source
- = 5 current-slope-discontinuity Voltage source (located at first end of specified segment)

For I1 = 0 or 5:

I2 - tag number of source segment (if I2 = 0, use absolute segment #)

I3 — number of source segment

I4 — set I4 = 01 to collect impedances over freq. loop + print in special format (in Ω as well as normalized per F3) else set I4 = 00

F1 — Real part of voltage

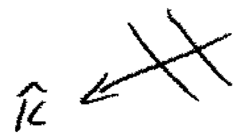
F2 — Imaginary part of voltage

F3 — normalization factor if I4 = 1, if F3 = 0 then impedances normalized by the maximum impedance magnitude

F4, F5, & F6 — leave blank or set to zero

Program Control cont.

EX cont.



For I1 = 1, 2, 3 (plane wave excitation)

I2 = # of θ angles desired for incident plane wave

I3 = # of ϕ angles desired " " " "

I4 = 0

F1 = $\angle\theta$ (in degrees) to $\hat{k}$ in spherical coor.

F2 = $\angle\phi$ (in degrees) " " " " "

F3 = polarization angle η (in degrees) between $\hat{a}_\theta$ & $\bar{E}$ for linear polarization or the major ellipse axis of $\bar{E}$

F4 = increment (degrees) to step θ variable

F5 = " " " " ϕ "

F6 = axial ratio $\left(\frac{\text{Major}}{\text{Minor}}\right)$

ex. EX 0 1 4 00 10.0 0.0

- 0 ← voltage source
- 1 ← Tag #1
- 4 ← Segment #4
- 00 ← leave impedances alone
- 10.0 0.0 ← $V_s = 10.0\,V = 10\angle 0^\circ\,V$

Program Control cont.

Command: Set frequencies

FR IFRQ NFRQ 0 0 FMHZ DELFRQ

IFRQ – determines type of freq. stepping

IFRQ = 0 linear
IFRQ = 1 multiplicative

NFRQ – # of freq. steps

FMHZ – Starting frequency in MHz

DELFRQ – Δf (MHz) or size of freq. step for IFRQ = 0,
multiplication factor for IFRQ = 1

ex. FR 0 3 0 0 2000.0 500.0

↑ run NEC @ 2 GHz, 2.5 GHz, + 3 GHz

Note: The pair of zero flags, e.g., '0 0', between NFRQ and FMHZ can NOT be omitted despite the NEC-2 User's Guide saying 'blank'. A blank, i.e., no hole, on an actual cardboard punch card is treated as a zero. However, that is NOT the case when ASCII text files are read into the program.

Program Control cont.

Command: Ground Parameters

GN IPERF NRADL 0 0 EPSR SIG F3 F4 F5 F6

IPERF – ground flag type

IPERF = -1 nullifies previous ground parameters + sets free-space conditions (omit remaining params)

= 0 lossy ground, refl. coefficient approx.

= 1 PEC ground (omit remaining parameters)

= 2 lossy ground, Sommerfeld-Norton method

NRADL – # of radial ground screen wires (0 for no screen)

EPSR – relative dielectric constant ($\epsilon = \epsilon_r \epsilon_0$) of ground

SIG – conductivity in S/m or ℧/m of ground

NRADL > 0 (ground screen centered @ (0,0,0))

F3 – radius of screen

F4 – radius of wires used to make screen.

NRADL = 0 F3–F6 used for a second medium, leave blank for single ground medium

Example- GN 0 0 0 0 3.2 0.002 !Lossy dielectric gnd w/ er=3.2, sigma=0.002 S/m

Program Control cont.

Command: Impedance Loading

LD LDTYP LDTAG LDTAGF LDTAGT ZLR ZLI ZLC

LDTYP – use to pick type of load

LDTYP = -1 Use to erase previous loads (short ckt), leave remaining parameters blank

= 0 Series RLC (Ω, H, F)

= 1 Parallel RLC (Ω, H, F)

= 2 Series RLC (Ω/m, H/m, F/m)

= 3 Parallel RLC (Ω/m, H/m, F/m)

= 4 Impedance in ohms

= 5 wire conductivity in S/m or ℧/m

LDTAG – tag # of wire section w/ load(s), set to zero to use abs. seg #

LDTAGF – first segment on LDTAG w/ load, leave equal to zero to load all segments on LDTAG

LDTAGT – last segment on LDTAG w/ load. Must be $\geq$ LDTAGF. Leave equal to zero to load all segments on LDTAG

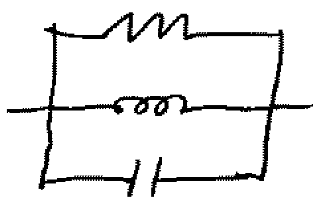
Program Control cont.

LD cont.

LDTYP = 0 (Series RLC)

ZLR = resistance (Ω)
ZLI = inductance (H)
ZLC = capacitance (F)
(set to zero for no cap.)

LDTYP = 1 (Parallel RLC)



ZLR = resistance (Ω)
ZLI = inductance (H)
(Set to zero for no inductor)
ZLC = capacitance (F)

LDTYP = 2 (series RLC per unit length)

ZLR = resistance (Ω/m)
ZLI = inductance (H/m)
ZLC = capacitance (F/m)

LDTYP = 3 (parallel RLC per unit length)

″

LDTYP = 4 (fixed impedance)
→ doesn't change w/ frequency

ZLR = Real resistance (Ω)
ZLI = Reactance (Ω)

LDTYP = 5 (conductivity)

ZLR = σ (S/m)
ZLI = μ_r (defaults to 1)

Program Control cont.

Command: Next Structure

NX

→ No parameters

→ next line must be CM (comment command)

Command: Printing options for currents

PT IPTFLG IPTAG IPTAGF IPTAGT

IPTFLG – printing options

IPTFLG = -2 print all currents (default)

= -1 do <u>NOT</u> print currents

= 0 only print currents on specific segments using next 3 parameters

= 1
= 2
= 3 } won't use these options

IPTAG – tag # of wire section (0 for absolute seg #)

IPTAGF – first segment #

IPTAGT – last segment #

Example- PT -1 ! Do NOT print any currents

Example- PT 0 2 10 24 ! ONLY output currents for Tag #2 segments 10 through 24

Note: Use ONLY one PT command in an input file for a single structure, the PT commands overwrite. So, only the last PT command is executed.

Program Control cont.

Command: Radiation Pattern

RP I1 NTH NPH XNDA THETS PHIS DTH DPH RFLD GNOR

I1 – calculation mode

$I1 = 0 \rightarrow$ space-wave field in spherical coord.

$= 1 \rightarrow$ total ground wave in cyl. coord. (won't use)

NTH – # of θ values

NPH – # of ϕ values

XNDA → 4 independent flags

X – controls gain format, $X=0 \rightarrow$ major axis, minor axis, + total gain. $X=1 \rightarrow$ vertical, horizontal, + total gain.

N – normalizes gain. $N=0$ don't normalize. $N=1$ major axis normalized. $N=2$ minor axis normalized. $N=3$ vertical axis normalized. $N=4$ horizontal axis normalized. $N=5$ total gain normalized

D – $D=0$ power gain, $D=1$ directive gain

A – ave. power gain. $A=0$ no averaging, $A=1$ ave. gain. $A=2$ ave. gain computed + individual gain + field values suppressed

THETS – first θ angle in degrees

PHIS – " ϕ " " "

DTH – $\Delta\theta$ or θ increment step

DPH – $\Delta\phi$ or ϕ " "

Program Control cont.

RP cont.

RFLD – radial distance in meters from origin. optional – usually left blank or set to zero in which case $\frac{e^{-jkR}}{R}$ dependence of radiated field omitted

GNOR – gain normalization factor

ex. RP 0 30 1 0010 0.0 0.0 6.0 0.0 0 0

↑ 30 θ angles ranging from 0° to 174° in 6° increments @ $\phi = 0°$

Notes:

- The RP command immediately initiates program execution. Make sure all needed commands are input prior to the RP command.
- At a single frequency, any number of RP commands may be used in sequence, i.e., you can do multiple radiation pattern ‘cuts’.
- If multiple frequency steps are used (i.e., NFRQ on the FR command is greater than one), only the **first** RP command will execute as part of the frequency loop. Subsequent RP commands will only execute at the final frequency.

Program Control cont.

Command – Execute

XQ I1

I1 = 0 no radiation patterns
= 1 radiation pattern in x-z plane ($\phi = 0^\circ$) w/ θ going from 0° to 90° in 1° steps
= 2 ditto in y-z plane ($\phi = 90^\circ$)
= 3 both x-z + y-z planes

→ usually only used if RP command not used (RP command will initiate program sol'n)

→ handy if all you are interested in are input impedance(s) and current(s).

Example- XQ 0 ! execute program without radiation patterns

Running NEC-2 Instructions

The Numerical Electromagnetic Code version 2 or NEC-2 (freeware) is available on the web. The executable installed locally is 'nec2dxs1k5.exe' (up to 1500 segments); located at F:\NetApps\NetSoft\Nec_viewer. Other versions of the executable are located at F:\NetApps\NetSoft\Nec_viewer\Nec2dXS_VM.

To run NEC-2 off the server using your Windows 10 computer, you will need to:

1) Bring up a command (DOS) window by clicking:

   Start icon (lower left corner) → Windows System → Command Prompt,

2) go to the appropriate drive & directory in the command window, e.g., type:

   c: <enter>, cd ee483 <enter>),

3) execute (i.e., run on the f: drive server) the program by typing:

   F:\NetApps\NetSoft\Nec_viewer\ nec2dxs1K5.exe <enter>,

4) enter the input filename when prompted (e.g., vee_dipole.txt <enter>),
5) enter the output filename when prompted (e.g., vee_dipole.dat <enter>),
6) wait for NEC-2 program to finish.

To run NEC on your own computer, you will need to:

1) copy executable (i.e., **nec2dxs1K5.exe**) to your own hard drive from

   F:\NetApps\NetSoft\Nec_viewer

2) bring up a command (DOS) window on your computer by clicking

   Start icon (lower left corner) → Windows System → Command Prompt,

3) go to the appropriate drive & directory in the command window, e.g., type:

   c: <enter>, cd ee483 <enter>),

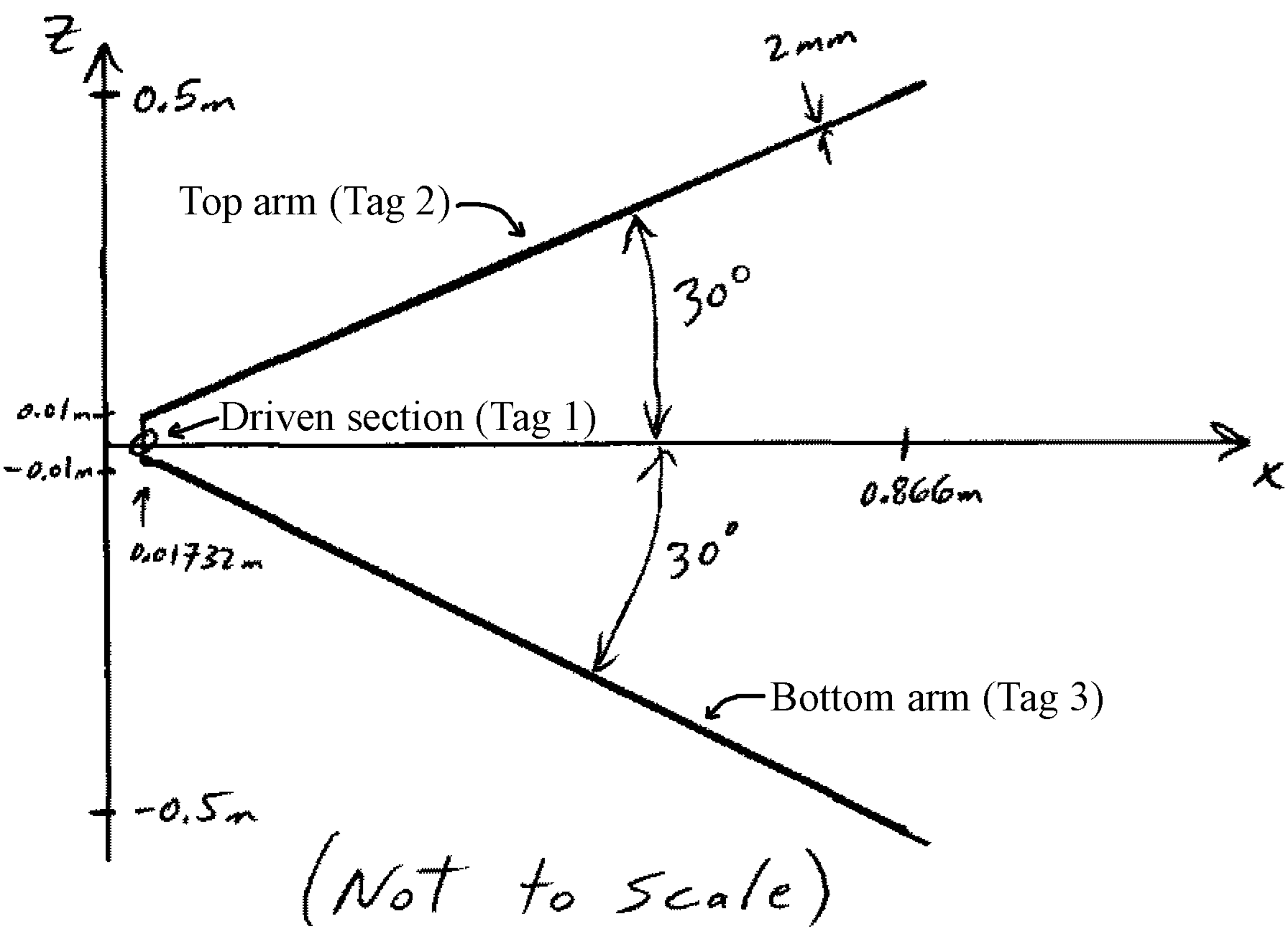
4) execute (i.e., run on the f: drive server) the program by typing:

   nec2dxs1K5.exe <enter>,

5) enter the input filename when prompted (e.g., vee_dipole.txt <enter>),
6) enter the output filename when prompted (e.g., vee_dipole.dat <enter>),
7) wait for NEC-2 program to finish.

Input file- vee_dipole.txt

```
CM  PEC VEE-DIPOLE ANTENNA.
CM  THIS FILE IS USED TO DETERMINE THE RADIATION PATTERN
CM  AT 450 MHz FOR A 60 deg PEC VEE-DIPOLE THAT IS DRIVEN
CM  AT THE CENTER. DIMENSIONS ARE: radius a=1mm, arm length h ~ 1 m,
CM  SEGMENT LENGTH = h/150.  DRIVEN SEGMENT IS #2.
CE
GW 1     3 0.01732 0.0 -0.01 0.01732 0.0 0.01 0.001  ! Driven section (Tag 1)
GW 2 150 0.01732 0.0  0.01 0.866    0.0   0.5  0.001   ! Top arm (Tag 2)
GW 3 150 0.01732 0.0 -0.01 0.866    0.0  -0.5  0.001   ! Bottom arm (Tag 3)
GE 0           ! No ground plane
FR 0 1 0 0 450.0 0.0   ! 450 MHz input
EX 0 1 2 0 1.0 0.0       ! 1V input at segment 2 of tag 1
PT -1          ! Do NOT print currents
RP 0 36 1 0000 0.0 0.0 5.0 0.0   ! 0 to 175 deg in theta w/ 5 deg steps
EN
```



Output file- vee_dipole.dat

```
1
                                 ********************************************

                                    NUMERICAL ELECTROMAGNETICS CODE (NEC-2D)

                                 ********************************************

                                     - - - - COMMENTS - - - -

                          PEC VEE-DIPOLE ANTENNA.
                          THIS FILE IS USED TO DETERMINE THE RADIATION PATTERN
                          AT 450 MHz FOR A 60 deg PEC VEE-DIPOLE THAT IS DRIVEN
                          AT THE CENTER. DIMENSIONS ARE: radius a=1mm, arm length h ~ 1 m,
                          SEGMENT LENGTH=h/150.  DRIVEN SEGMENT IS #2.

                                 - - - STRUCTURE SPECIFICATION - - -

                                     COORDINATES MUST BE INPUT IN
                                     METERS OR BE SCALED TO METERS
                                     BEFORE STRUCTURE INPUT IS ENDED


 WIRE                                                                           NO. OF    FIRST  LAST     TAG
 NO.       X1         Y1         Z1          X2         Y2         Z2      RADIUS   SEG.      SEG.  SEG.     NO.
 1     0.01732    0.00000   -0.01000     0.01732    0.00000    0.01000    0.00100     3          1     3       1
 2     0.01732    0.00000    0.01000     0.86600    0.00000    0.50000    0.00100   150          4   153       2
 3     0.01732    0.00000   -0.01000     0.86600    0.00000   -0.50000    0.00100   150        154   303       3

   TOTAL SEGMENTS USED=  303     NO. SEG. IN A SYMMETRIC CELL=  303     SYMMETRY FLAG=  0


         - MULTIPLE WIRE JUNCTIONS -
 JUNCTION    SEGMENTS  (- FOR END 1, + FOR END 2)
  NONE

                                 - - - - SEGMENTATION DATA - - - -

                                        COORDINATES IN METERS

                         I+ AND I- INDICATE THE SEGMENTS BEFORE AND AFTER I


  SEG.   COORDINATES OF SEG. CENTER     SEG.    ORIENTATION ANGLES    WIRE    CONNECTION DATA   TAG
  NO.       X         Y         Z      LENGTH     ALPHA      BETA    RADIUS    I-    I    I+    NO.
    1   0.01732   0.00000  -0.00667   0.00667   90.00000   0.00000   0.00100  -154    1    2      1
    2   0.01732   0.00000   0.00000   0.00667   90.00000   0.00000   0.00100     1    2    3      1
    3   0.01732   0.00000   0.00667   0.00667   90.00000   0.00000   0.00100     2    3    4      1
    4   0.02015   0.00000   0.01163   0.00653   30.00073   0.00000   0.00100     3    4    5      2
    5   0.02581   0.00000   0.01490   0.00653   30.00073   0.00000   0.00100     4    5    6      2
    6   0.03146   0.00000   0.01817   0.00653   30.00073   0.00000   0.00100     5    6    7      2
    7   0.03712   0.00000   0.02143   0.00653   30.00073   0.00000   0.00100     6    7    8      2
<snip>
   150   0.84620   0.00000   0.48857   0.00653   30.00073   0.00000   0.00100   149  150  151      2
   151   0.85186   0.00000   0.49183   0.00653   30.00073   0.00000   0.00100   150  151  152      2
   152   0.85751   0.00000   0.49510   0.00653   30.00073   0.00000   0.00100   151  152  153      2
   153   0.86317   0.00000   0.49837   0.00653   30.00073   0.00000   0.00100   152  153    0      2
   154   0.02015   0.00000  -0.01163   0.00653  -30.00073   0.00000   0.00100    -1  154  155      3
   155   0.02581   0.00000  -0.01490   0.00653  -30.00073   0.00000   0.00100   154  155  156      3
   156   0.03146   0.00000  -0.01817   0.00653  -30.00073   0.00000   0.00100   155  156  157      3
   157   0.03712   0.00000  -0.02143   0.00653  -30.00073   0.00000   0.00100   156  157  158      3
<snip>
   300   0.84620   0.00000  -0.48857   0.00653  -30.00073   0.00000   0.00100   299  300  301      3
   301   0.85186   0.00000  -0.49183   0.00653  -30.00073   0.00000   0.00100   300  301  302      3
   302   0.85751   0.00000  -0.49510   0.00653  -30.00073   0.00000   0.00100   301  302  303      3
   303   0.86317   0.00000  -0.49837   0.00653  -30.00073   0.00000   0.00100   302  303    0      3


 ***** DATA CARD NO.  1   FR   0     1     0     0  4.50000E+02  0.0   0.0   0.0   0.0   0.0
 ***** DATA CARD NO.  2   EX   0     1     2     0  1.00000E+00  0.0   0.0   0.0   0.0   0.0
 ***** DATA CARD NO.  3   PT  -1     0     0     0  0.0   0.0   0.0   0.0   0.0   0.0
 ***** DATA CARD NO.  4   RP   0    36     1     0  0.0   0.0   5.00000E+00  0.0   0.0   0.0
```

\- - - - - - FREQUENCY - - - - - -

FREQUENCY= 4.5000E+02 MHZ
WAVELENGTH= 6.6622E-01 METERS

APPROXIMATE INTEGRATION EMPLOYED FOR SEGMENTS MORE THAN 1.000 WAVELENGTHS APART

\- - - STRUCTURE IMPEDANCE LOADING - - -

THIS STRUCTURE IS NOT LOADED

\- - - ANTENNA ENVIRONMENT - - -

FREE SPACE

\- - - MATRIX TIMING - - -

FILL= 0.495 SEC., FACTOR= 0.934 SEC.

\- - - ANTENNA INPUT PARAMETERS - - -

TAG	SEG.	VOLTAGE (VOLTS)		CURRENT (AMPS)		IMPEDANCE (OHMS)		ADMITTANCE (MHOS)		POWER
NO.	NO.	REAL	IMAG.	REAL	IMAG.	REAL	IMAG.	REAL	IMAG.	(WATTS)
1	2	1.00000E+00	0.0	5.59042E-04	6.62088E-04	7.44508E+02	-8.81739E+02	5.59042E-04	6.62088E-04	2.79521E-04

\- - - POWER BUDGET - - -

INPUT POWER = 2.7952E-04 WATTS
RADIATED POWER= 2.7952E-04 WATTS
STRUCTURE LOSS= 0.0000E+00 WATTS
NETWORK LOSS = 0.0000E+00 WATTS
EFFICIENCY = 100.00 PERCENT

\- - - RADIATION PATTERNS - - -

- - ANGLES - -		- POWER GAINS -			- - - POLARIZATION - - -			- - - E(THETA) - -		- - E(PHI) --	
THETA DEGREES	PHI DEGREES	MAJOR DB	MINOR DB	TOTAL DB	AXIAL RATIO	TILT DEG.	SENSE	MAGNITUDE VOLTS/M	PHASE DEGREES	MAG. VOLTS/M	PHASE DEG
0.00	0.00	-1.12	-999.99	-1.12	0.00000	0.00	LINEAR	1.13765E-01	110.80	0.0	0.00
5.00	0.00	0.49	-999.99	0.49	0.00000	0.00	LINEAR	1.36929E-01	153.26	0.0	0.00
10.00	0.00	1.93	-999.99	1.93	0.00000	0.00	LINEAR	1.61666E-01	-171.69	0.0	0.00
15.00	0.00	2.75	-999.99	2.75	0.00000	0.00	LINEAR	1.77750E-01	-141.47	0.0	0.00
20.00	0.00	2.83	-999.99	2.83	0.00000	0.00	LINEAR	1.79277E-01	-114.31	0.0	0.00
25.00	0.00	2.07	-999.99	2.07	0.00000	0.00	LINEAR	1.64322E-01	-89.54	0.0	0.00
30.00	0.00	0.35	-999.99	0.35	0.00000	0.00	LINEAR	1.34782E-01	-67.47	0.0	0.00
35.00	0.00	-2.57	-999.99	-2.57	0.00000	0.00	LINEAR	9.63305E-02	-50.13	0.0	0.00
40.00	0.00	-6.78	-999.99	-6.78	0.00000	0.00	LINEAR	5.92935E-02	-44.79	0.0	0.00
45.00	0.00	-9.57	-999.99	-9.57	0.00000	0.00	LINEAR	4.30343E-02	-63.82	0.0	0.00
50.00	0.00	-7.42	-999.99	-7.42	0.00000	0.00	LINEAR	5.50776E-02	-73.03	0.0	0.00
55.00	0.00	-5.03	-999.99	-5.03	0.00000	0.00	LINEAR	7.25510E-02	-56.34	0.0	0.00
60.00	0.00	-3.07	-999.99	-3.07	0.00000	0.00	LINEAR	9.09021E-02	-27.74	0.0	0.00
65.00	0.00	-0.80	-999.99	-0.80	0.00000	0.00	LINEAR	1.18070E-01	3.18	0.0	0.00
70.00	0.00	1.72	-999.99	1.72	0.00000	0.00	LINEAR	1.57822E-01	29.10	0.0	0.00
75.00	0.00	3.97	-999.99	3.97	0.00000	0.00	LINEAR	2.04427E-01	47.86	0.0	0.00
80.00	0.00	5.64	-999.99	5.64	0.00000	0.00	LINEAR	2.47787E-01	60.28	0.0	0.00
85.00	0.00	6.65	-999.99	6.65	0.00000	0.00	LINEAR	2.78274E-01	67.34	0.0	0.00
90.00	0.00	6.98	-999.99	6.98	0.00000	0.00	LINEAR	2.89227E-01	69.64	0.0	0.00
95.00	0.00	6.65	-999.99	6.65	0.00000	0.00	LINEAR	2.78274E-01	67.34	0.0	0.00
100.00	0.00	5.64	-999.99	5.64	0.00000	0.00	LINEAR	2.47787E-01	60.28	0.0	0.00
105.00	0.00	3.97	-999.99	3.97	0.00000	0.00	LINEAR	2.04427E-01	47.86	0.0	0.00
110.00	0.00	1.72	-999.99	1.72	0.00000	0.00	LINEAR	1.57822E-01	29.10	0.0	0.00
115.00	0.00	-0.80	-999.99	-0.80	0.00000	0.00	LINEAR	1.18070E-01	3.18	0.0	0.00
120.00	0.00	-3.07	-999.99	-3.07	0.00000	0.00	LINEAR	9.09021E-02	-27.74	0.0	0.00
125.00	0.00	-5.03	-999.99	-5.03	0.00000	0.00	LINEAR	7.25510E-02	-56.34	0.0	0.00
130.00	0.00	-7.42	-999.99	-7.42	0.00000	0.00	LINEAR	5.50776E-02	-73.03	0.0	0.00
135.00	0.00	-9.57	-999.99	-9.57	0.00000	0.00	LINEAR	4.30343E-02	-63.82	0.0	0.00
140.00	0.00	-6.78	-999.99	-6.78	0.00000	0.00	LINEAR	5.92935E-02	-44.79	0.0	0.00
145.00	0.00	-2.57	-999.99	-2.57	0.00000	0.00	LINEAR	9.63305E-02	-50.13	0.0	0.00
150.00	0.00	0.35	-999.99	0.35	0.00000	0.00	LINEAR	1.34782E-01	-67.47	0.0	0.00
155.00	0.00	2.07	-999.99	2.07	0.00000	0.00	LINEAR	1.64322E-01	-89.54	0.0	0.00
160.00	0.00	2.83	-999.99	2.83	0.00000	0.00	LINEAR	1.79277E-01	-114.31	0.0	0.00
165.00	0.00	2.75	-999.99	2.75	0.00000	0.00	LINEAR	1.77750E-01	-141.47	0.0	0.00
170.00	0.00	1.93	-999.99	1.93	0.00000	0.00	LINEAR	1.61666E-01	-171.69	0.0	0.00
175.00	0.00	0.49	-999.99	0.49	0.00000	0.00	LINEAR	1.36929E-01	153.26	0.0	0.00

***** DATA CARD NO. 5 EN 0 0 0 0 0.0 0.0 0.0 0.0 0.0 0.0

RUN TIME = 1.538