

# NEC

Numerical Electromagnetic Code

# Objective Statement

- ▶ Develop understanding of NEC
- ▶ Apply NEC to current applications
- ▶ Successfully use NEC to design and simulate antenna systems
- ▶ Compare and contrast NEC results to analytical solutions
- ▶ Interpret NEC results for practical application

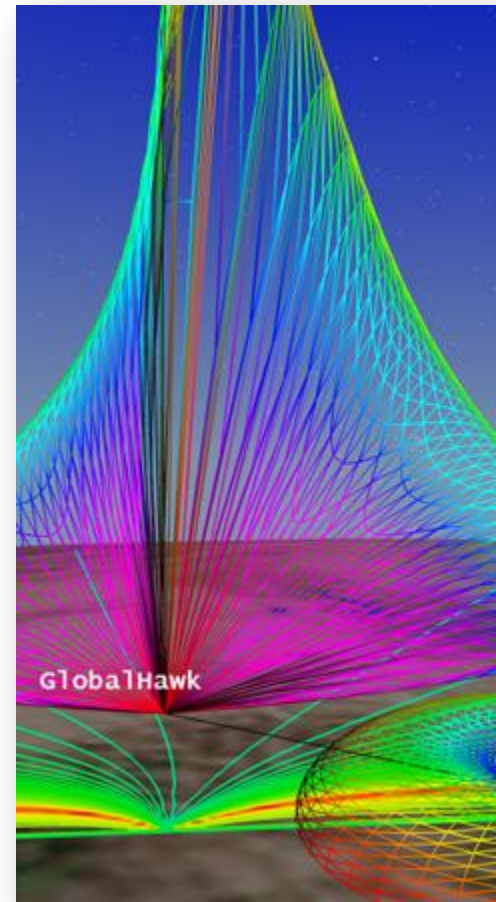


# NEC Overview



# Advantages

- ▶ Algorithm for antenna modeling
- ▶ Publicly available
- ▶ No theoretical limit
- ▶ Wide application
  - Very large arrays
  - Detailed modeling of very small antenna systems



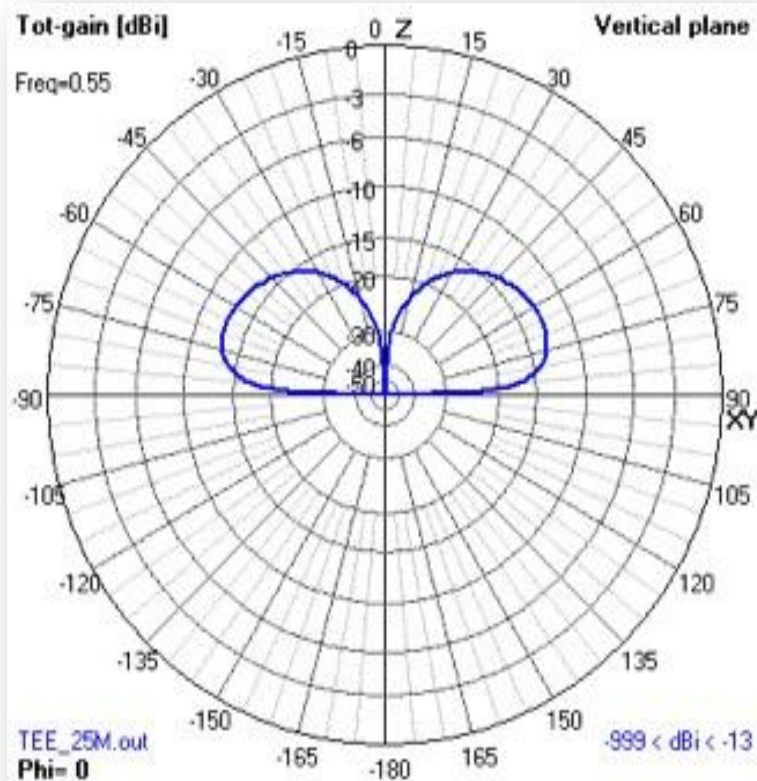
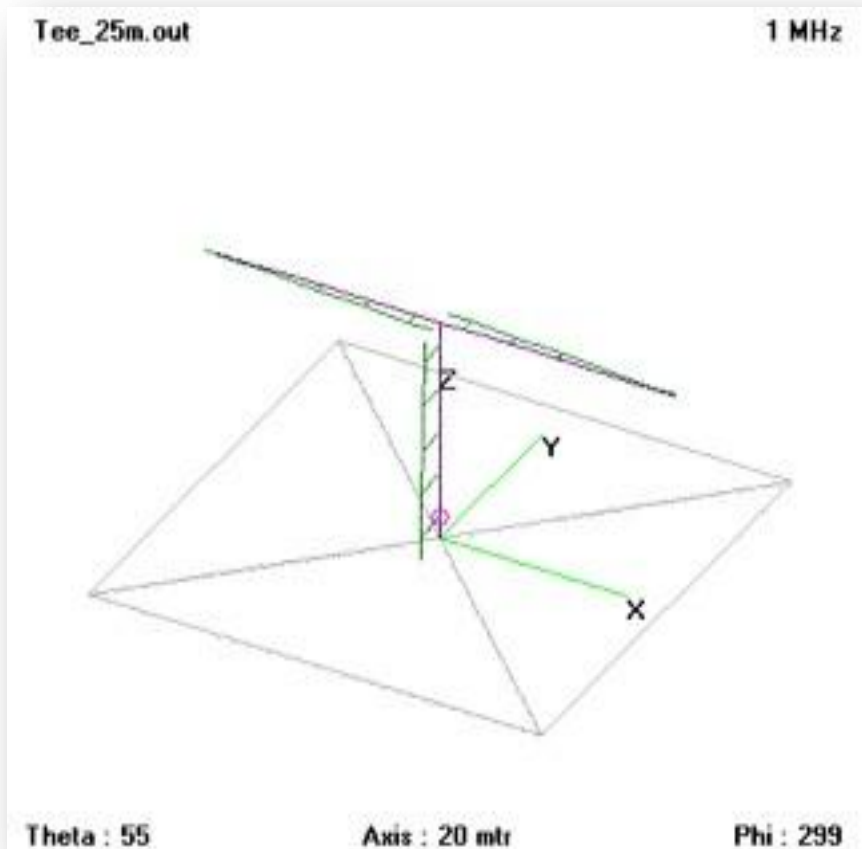
# Disadvantages

- ▶ Computing time increases as number of wire segments  $N$  is increased
- ▶ Decreasing the number of wire segments  $N$  below guideline may cause computed feed-point impedance to be incorrect
- ▶ Guideline = More than 10 segments per  $\lambda/2$



$N > 10$   
per  $\lambda/2$

# Tee Antenna Example



# User Interface

The screenshot displays a software interface with a toolbar at the top containing icons for file operations, 3D modeling, and simulation. The main area is divided into several sections:

- Parameters Table:** A table of simulation parameters with input fields and units.
 

|               |                         |                |                 |     |
|---------------|-------------------------|----------------|-----------------|-----|
| Filename      | Monopole_25m_perfect.ou | Frequency      | 1.65            | Mhz |
|               |                         | Wavelength     | 181.7           | mtr |
| Voltage       | 2012 + j 0 V            | Current        | 0.05 + j 3.45 A |     |
| Impedance     | 8.39 - j 583            | Series comp.   | 56.22           | uH  |
| Parallel form | 4.e4 // - j 583         | Parallel comp. | 56.23           | uH  |
| S.W.R. 50     | 816                     | Input power    | 100             | W   |
| Efficiency    | 100                     | Structure loss | 0               | W   |
| Radiat-eff.   | 99.99                   | Network loss   | 0               | W   |
| RDF [dB]      | 4.88                    | Radiat-power   | 100             | W   |
- Environment:** A text box containing the message: "GROUND PLANE SPECIFIED. WHERE WIRE ENDS TOUCH GROUND, CURRENT WILL BE INTERPOLATED TO IMAG PERFECT GROUND".
- Comment:** A text box containing: "Example 1 : Dipole in free space", "See GetStarted.txt", and "\*.Out loading-time=0.156".
- Simulation Settings:** A table of calculation parameters.
 

|                  |       |             |     |            |     |             |     |            |   |
|------------------|-------|-------------|-----|------------|-----|-------------|-----|------------|---|
| Seg's/patches    | 50    | Theta start | -90 | Theta stop | 90  | Theta count | 91  | Theta step | 2 |
| Pattern lines    | 16471 | Phi start   | 0   | Phi stop   | 360 | Phi count   | 181 | Phi step   | 2 |
| Freq/Eval steps  | 1     |             |     |            |     |             |     |            |   |
| Calculation time | 0.813 |             |     |            |     |             |     |            | s |



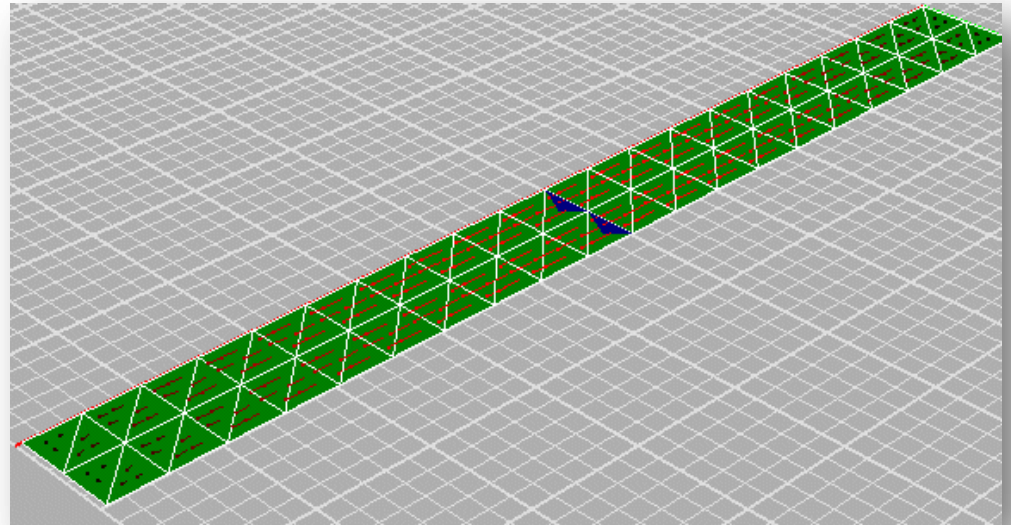
# How NEC Works





# Method of Moments

- ▶ Model constructed of thin, perfectly conducting wires
  - Plane = 2D intersecting grid of wires
  - Volume = 3D intersecting grid of wires
  - Loss = Lumped impedance resistance in each segment
- ▶ Add source (voltage or current) to a conducting segment
- ▶ Calculations in free space or ground plane vicinity
- ▶ Abbreviated MoM

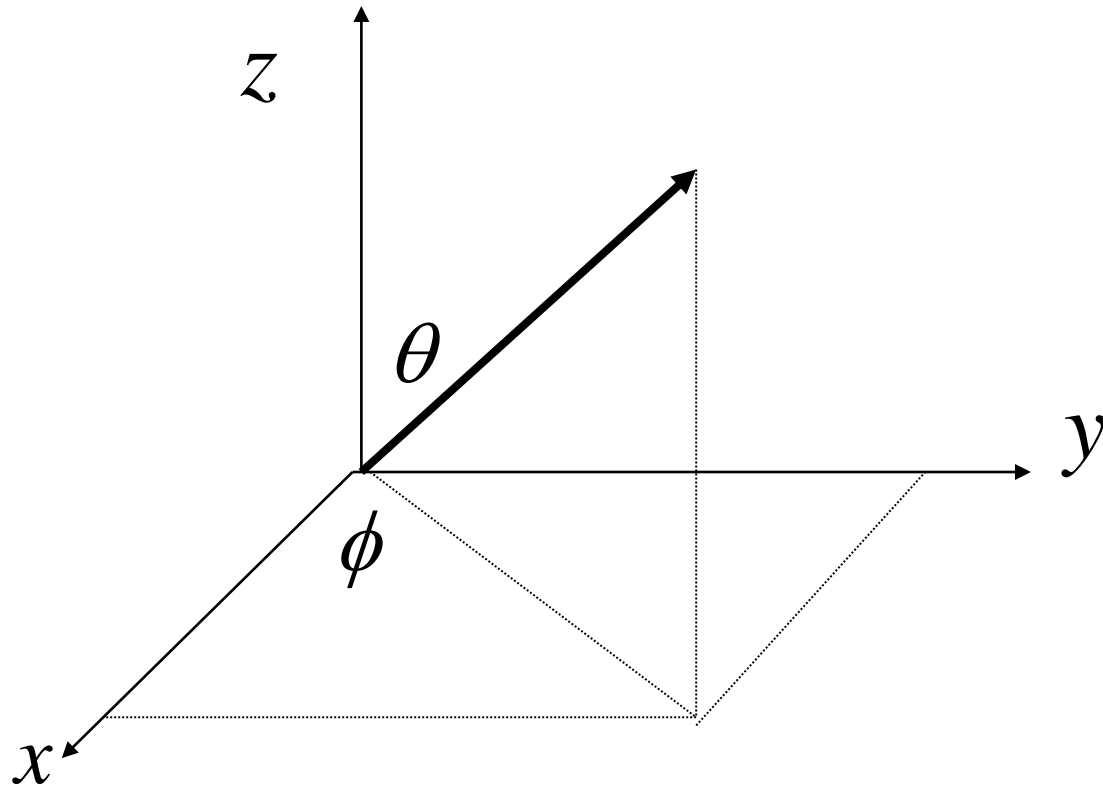


# Method of Moments Calculations

- ▶ Impedance matrix  $Z$  is built
- ▶ Linear system  $V=ZI$  solved
  - Currents  $I$  later used to recover the surface current distribution
  - Source impedance of defined sources also calculated
- ▶ From this first step, the three following procedures may be solved independently:
  - Exact surface current distribution
  - Near fields (E and M)
    - Also wave impedance ( $Z=E/H$ ) provided in this process
  - Far fields (E and M)
    - Gain, directivity, and other parameters also provided in this process



# NEC Coordinate System



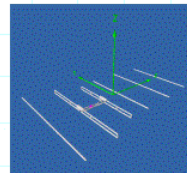
The  $x$ - $y$  plane ( $z = 0$ ) is where the ground plane is located, if used.



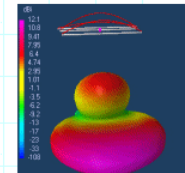
# Using 4NEC2 – A Tutorial



# Download 4NEC2



## 4nec2



*NEC based antenna modeler and optimizer*

*by Arie Voors*

4nec2 is a completely free Nec2, Nec4 and windows based tool for creating, viewing, optimizing and checking 2D and 3D style antenna geometry structures and generate, display and/or compare near/far-field radiation patterns for both the starting and experienced antenna modeler.

When running frequency sweeps, linear or logarithmic style SWR, Gain, F/B-ratio and impedance line-charts are produced. With the included Optimizer and Sweeper one is able to optimize antenna- and/or other environment-variables for Gain, resonance, SWR, efficiency and/or F/B, F/R-ratio. With the sweeper one is able to graphically display the effect of changing one or more of these variables for a specified range of values/frequencies.

For the starting modeler a graphically based 3D geometry-editor is included which requires no additional NEC knowledge while still enabling you to create and visualize and compare current-distribution, far/near-field patterns and Gain/SWR charts. More experienced modelers can use the gradient style and/or the genetic algorithm based optimizers to improve their designs.

To list some of its features or see some screenshots, click the appropriate links below on the left. To download and try the software click upmost two links below on the right (setup.exe) or the third link for a single zip containing all separate files.

NOTE: When experiencing problems running 4nec2, please consult the 'List known bugs' page on this website for latest news.

### Information

[List features](#)  
[View screenshots](#)  
[Show release notes](#)  
[List known bugs](#)  
[FAQ](#)

[4NEC2 Tutorials](#)

[Links and other stuff](#)

### Downloads

\* [Latest 4nec2 version](#) (5.8.4)  
\* [4nec2 files as a ZIP \(no install\)](#) (5.8.4)

[\(4\)Nec2 support files](#)

[Gnuplot 2D/3D plotting](#)  
[ItsHF propagation prediction](#)

[HAM magazine article in Dutch](#)



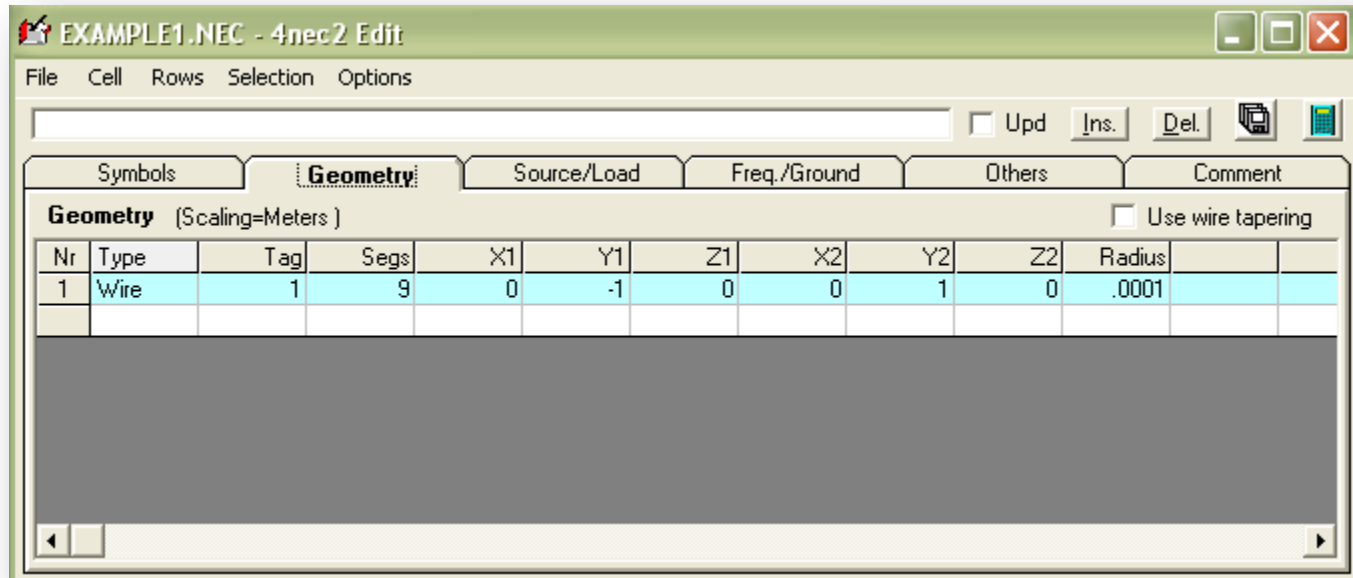
# Main Interface and Geometry Window

The image displays two windows from the NEC software interface. The 'Main [V5.8.4] (F2)' window on the left contains a menu bar (File, Edit, Settings, Calculate, Window, Show, Run, Help) and a toolbar. Below the toolbar are input fields for 'Filename' (EXAMPLE1.NEC), 'Frequency' (300 Mhz), and 'Wavelength' (0.999 mtr). There are also fields for 'Voltage', 'Current', 'Impedance', 'Series comp.', 'Parallel form', 'Parallel comp.', 'S.W.R.50', 'Input power', 'Efficiency', 'Structure loss', 'Radiat-eff.', 'Network loss', 'RDF [dB]' (2.14), and 'Radiat-power'. An 'Environment' section is set to 'Free space', and checkboxes for 'Loads' and 'Polar' are present. A 'Comment' field contains the text: 'Example 1 : Dipole in free space' and 'See GetStarted.txt'. At the bottom, there are fields for 'Seg's/patches' (9), 'Pattern lines', 'Freq/Eval steps' (1), and 'Calculation time'.

The 'Geometry (F3)' window on the right shows the title 'EXAMPLE1.NEC' and '300 MHz'. It features a menu bar (Show, View, Validate, Currents, Far-field, Near-field, Wire, Plot) and a 3D coordinate system with X, Y, and Z axes. A dipole antenna is represented by two small circles on the X-axis. At the bottom of the window, the following parameters are displayed: 'Theta : 80', 'Axis : 1 mtr', and 'Phi : 280'.



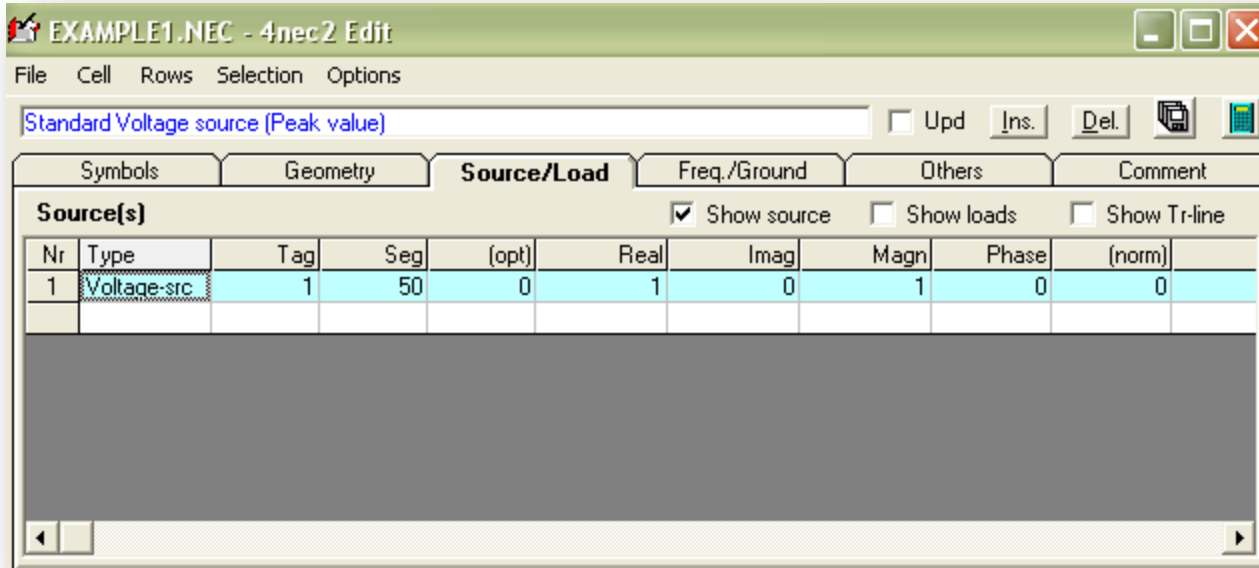
# NEC Editor – Geometry



- ▶ Ctrl+F4
- ▶ Wire dimensions
- ▶ Voltage sources
- ▶ Wire segments



# NEC Editor – Source/Load

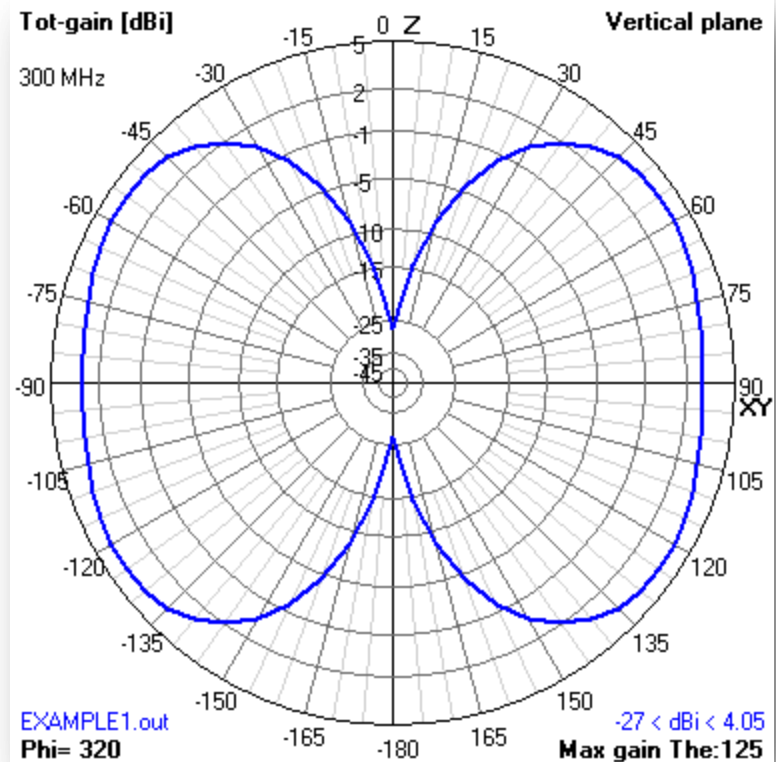
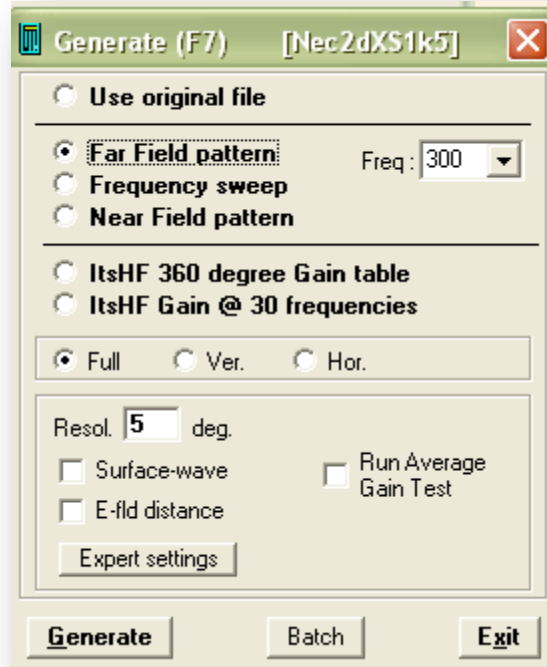


- ▶ Ctrl+F4
- ▶ Wire dimensions
- ▶ Voltage sources
- ▶ Wire segments





# Generate Radiation Pattern



# Practical Application: The Parallel and Colinear Dipole Problem

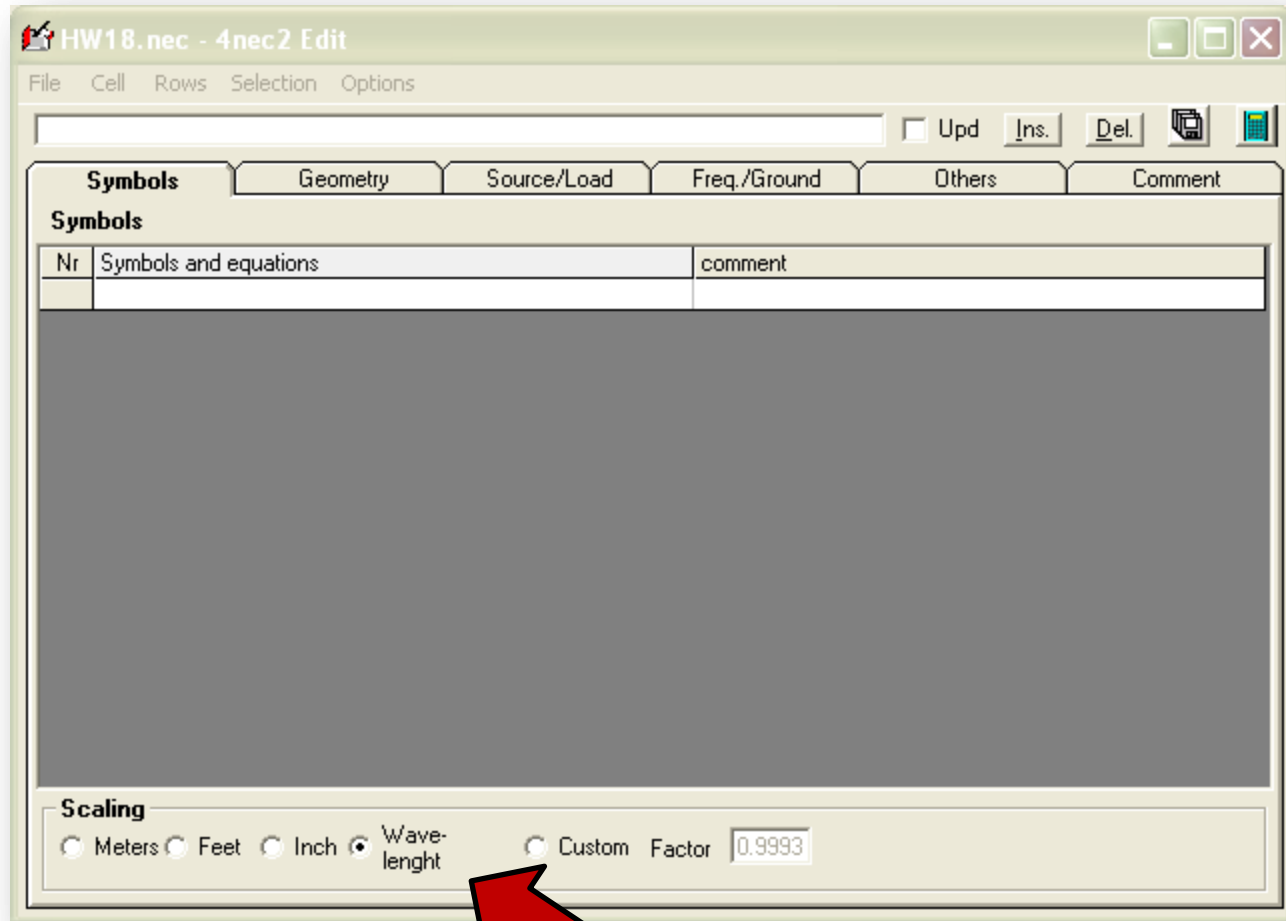


# Dipole Application

- ▶ Side-by-side parallel dipole antennas
  - $L = 0.4781 \lambda$  (nominal half-wave dipoles)
  - Inter-element distance  $d/\lambda = 0.40$
  - Progressive phase difference  $a = -144^\circ$
  
- ▶ Colinear dipole antennas
  - $L = 0.4781 \lambda$
  - End-to-end separation  $s = 0.40 \lambda$
  - All antennas fed in phase  $a = -144^\circ$



# Open Geometry Editor



Define dimensions in terms of wavelengths



# Program Antenna Dimensions

HW18.nec - 4nec2 Edit

File Cell Rows Selection Options

Upd Ins. Del. [Icons]

Symbols **Geometry** Source/Load Freq./Ground Others Comment

Geometry (Scaling=Wave-length)  Use wire tapering

| Nr | Tag | Segs | X1   | Y1 | Z1 | X2   | Y2 | Z2     | Radius |  |  |
|----|-----|------|------|----|----|------|----|--------|--------|--|--|
| 1  | 1   | 99   | 0    | 0  | 0  | 0    | 0  | 0.4781 | .0001  |  |  |
| 2  | 2   | 99   | -0.4 | 0  | 0  | -0.4 | 0  | 0.4781 | .0001  |  |  |
| 3  | 3   | 99   | 0.4  | 0  | 0  | 0.4  | 0  | 0.4781 | .0001  |  |  |

Assign a tag to each antenna

Provide enough segments for good resolution

Define beginning and end points of each antenna



# Program Source Parameters

HW18.nec - 4nec2 Edit

File Cell Rows Selection Options

Standard Current source (Peak value)  Upd  Ins.  Del

| Symbols   |             | Geometry |     | Source/Load |          | Freq./Ground |      | Others |        | Comment |
|---|-------------|----------|-----|-------------|----------|--------------|------|--------|--------|---------|
| Source(s)   |             |          |     |             |          |              |      |        |        |         |
| <input checked="" type="checkbox"/> Show source <input type="checkbox"/> Show loads <input type="checkbox"/> Show Tr-line |             |          |     |             |          |              |      |        |        |         |
| Nr  | Type        | Tag      | Seg | (opt)       | Real     | Imag         | Magn | Phase  | (norm) |         |
| 1   | Current-src | 1        | 50  | 00          | 1        | 0            | 1    | 0      |        |         |
| 2   | Current-src | 2        | 50  | 00          | -0.80902 | -0.58779     | 1    | -144   |        |         |
| 3   | Current-src | 3        | 50  | 00          | -0.80902 | 0.587785     | 1    | 144    |        |         |

Select source type

Dipole sources should be located on middle segment

Assign magnitude and phase



# Program Simulation Frequency

Save and run simulation

The screenshot shows the '4nec2 Edit' software window with the 'Freq./Ground' tab selected. The interface is divided into several sections:

- Frequency:** Includes input fields for 'Frequency' (300 Mhz), 'Nr steps' (10), and 'Stepsize' (100). There is a 'Sweep' checkbox.
- Environment:** Features a dropdown menu for 'Ground / Free-space' set to 'Free-space' and a checkbox for 'Connect wire(s) for Z=0 to ground'.
- Main ground:** Contains dropdowns for 'Ground type', 'Conductivity', and 'Dielectric constant', along with checkboxes for 'Use ground-screen' and 'Use second ground'.
- Ground screen:** Includes input fields for 'Nr of radials', 'Radial length' (mtr), and 'Wire radius' (mm).
- Second ground:** Features a dropdown for 'Ground type', input fields for 'Conductivity', 'Dielectric constant', 'Distance' (mtr), and 'Depth' (mtr), and radio buttons for 'Circular boundary' and 'Perpendicular to Y-axis'.

Red arrows point to the 'Save' icon in the top right, the 'Frequency' input field, the 'Ground / Free-space' dropdown, and the 'Perpendicular to Y-axis' radio button.

Specify frequency

Choose ground or free-space

Now we are simulating in free-space, but ground environment can also be used



# Generate Results

- ▶ Full, Vertical, or Horizontal Plane
- ▶ Select Full for 3D
- ▶ Frequency sweep and near field also possible





# Parameters

Select "Loads" to see  
input impedance at  
each source segment



Main [V5.8.4] (F2)

File Edit Settings Calculate Window Show Run Help

Filename: HW18.out      Frequency: 300 Mhz  
Wavelength: 0.999 mtr

Voltage: 46.6 + j 33.4 V      Current: 0.73 - j 0 A

Impedance: 63.4 + j 45.4      Series comp.: 11.68 pF  
Parallel form: 96 // j 134      Parallel comp.: 3.96 pF

S.W.R.50: 2.27      Input power: 100 W  
Efficiency: 100 %      Structure loss: 0 W  
Radiat-eff.: %      Network loss: -0 W  
RDF [dB]: 6.32      Radiat-power: 100 W

Excitation/Load data       Loads       Polar

| Type        | Tag | Seg | Impedance     | Voltage       | Pwr  | SWR  |
|-------------|-----|-----|---------------|---------------|------|------|
| EX 6: I-src | 1   | 50  | 63.4 + j 45.4 | 46.6 + j 33.4 | 34.2 | 2.27 |
| EX 6: I-src | 2   | 50  | 95.3 + j 37.6 | -40 - j 63.5  | 51.4 | 2.29 |
| EX 6: I-src | 3   | 50  | 26.8 + j 1.48 | -17 + j 10.7  | 14.5 | 1.87 |

Seg's/patches: 300      start stop count step  
Pattern lines: 0      Theta: -180 180 73 5  
Freq/Eval steps: 1      Phi: 0 360 73 5  
Calculation time: 0.266 s

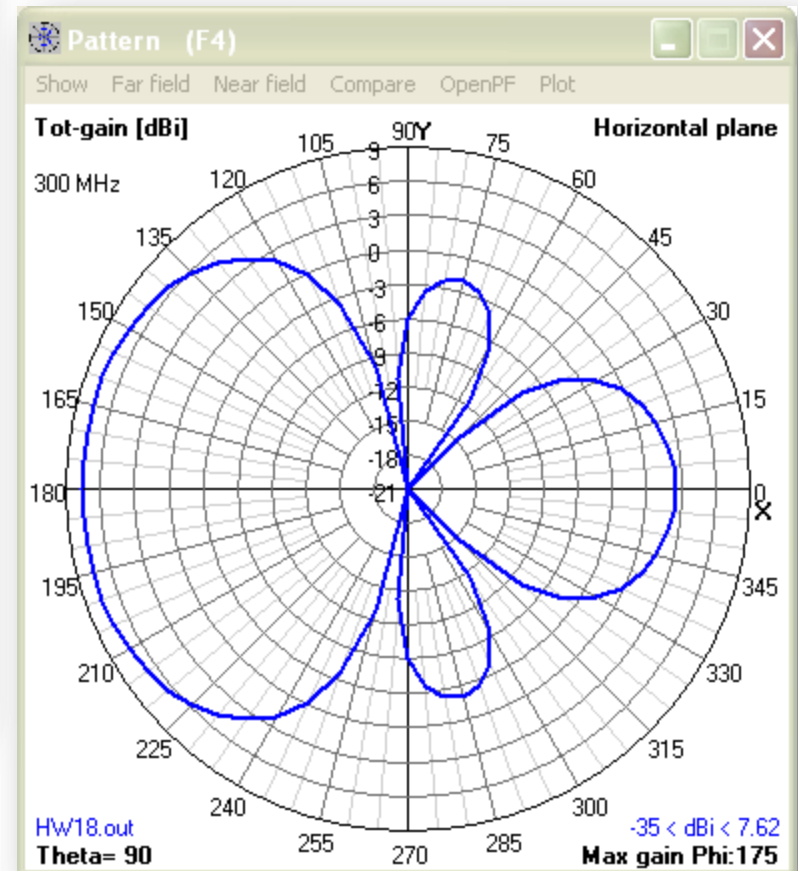
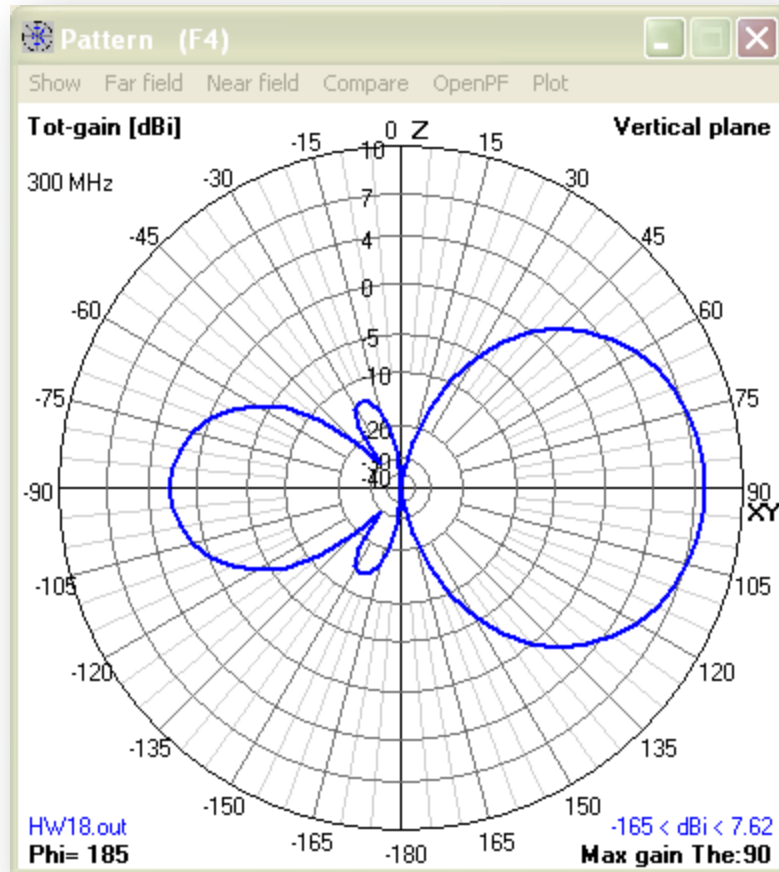


# Input Impedance

- ▶ In simulation, source impedance *will* vary depending on parameters such as wire radius, frequency, etc.
- ▶ Be sure to use parameters assigned to homework problems in order to obtain correct results

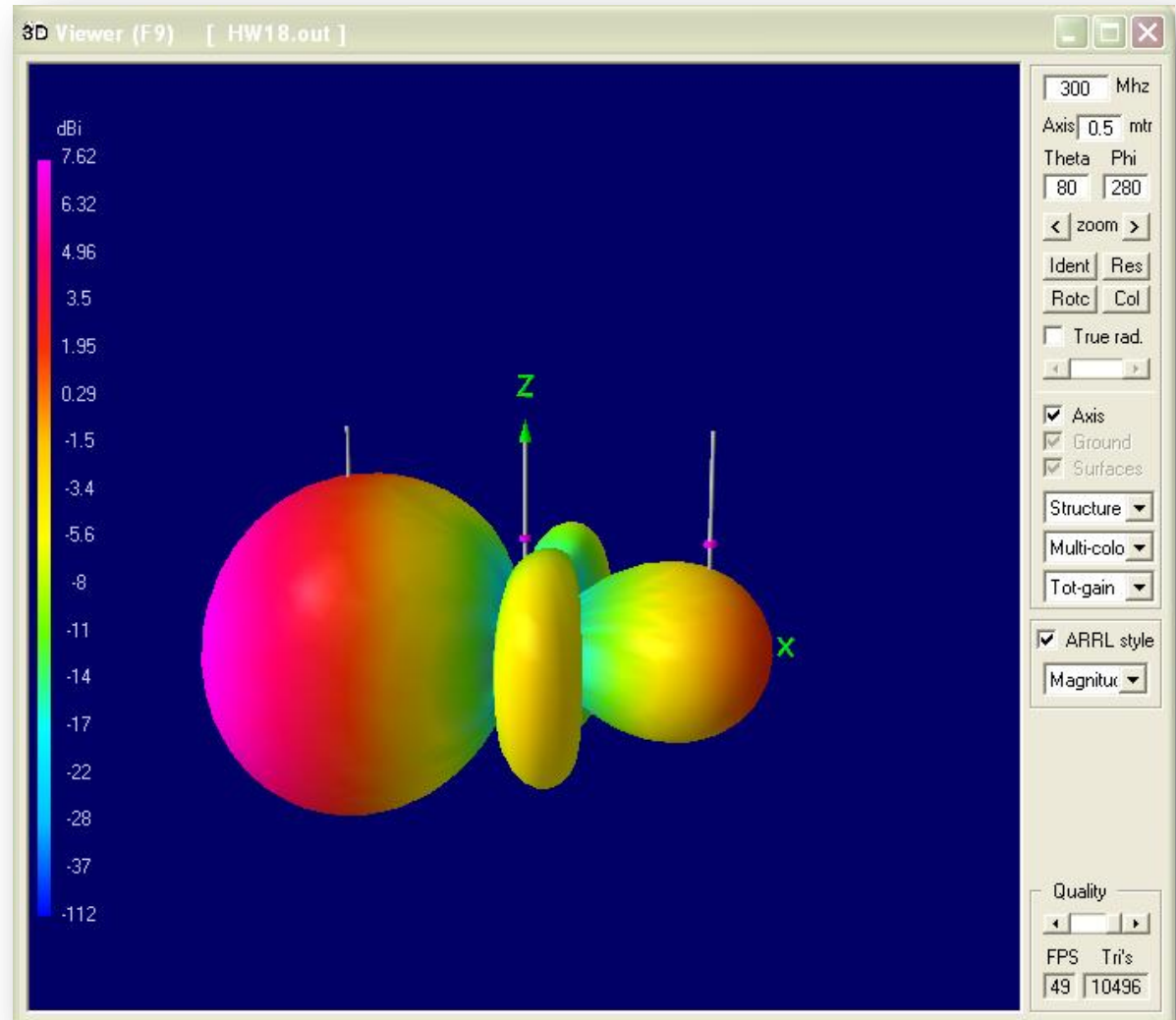


# Radiation Patterns



# 3D Viewer

- ▶ Run far field simulation
- ▶ Hit F9 for 3D



# Practical Application: The Yagi-Uda Antenna Problem



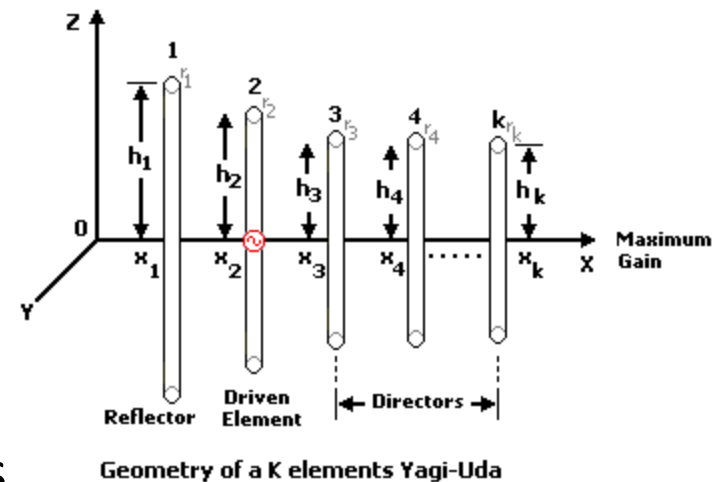
# Yagi-Uda Application

## ▶ Five-element Yagi-Uda antenna design

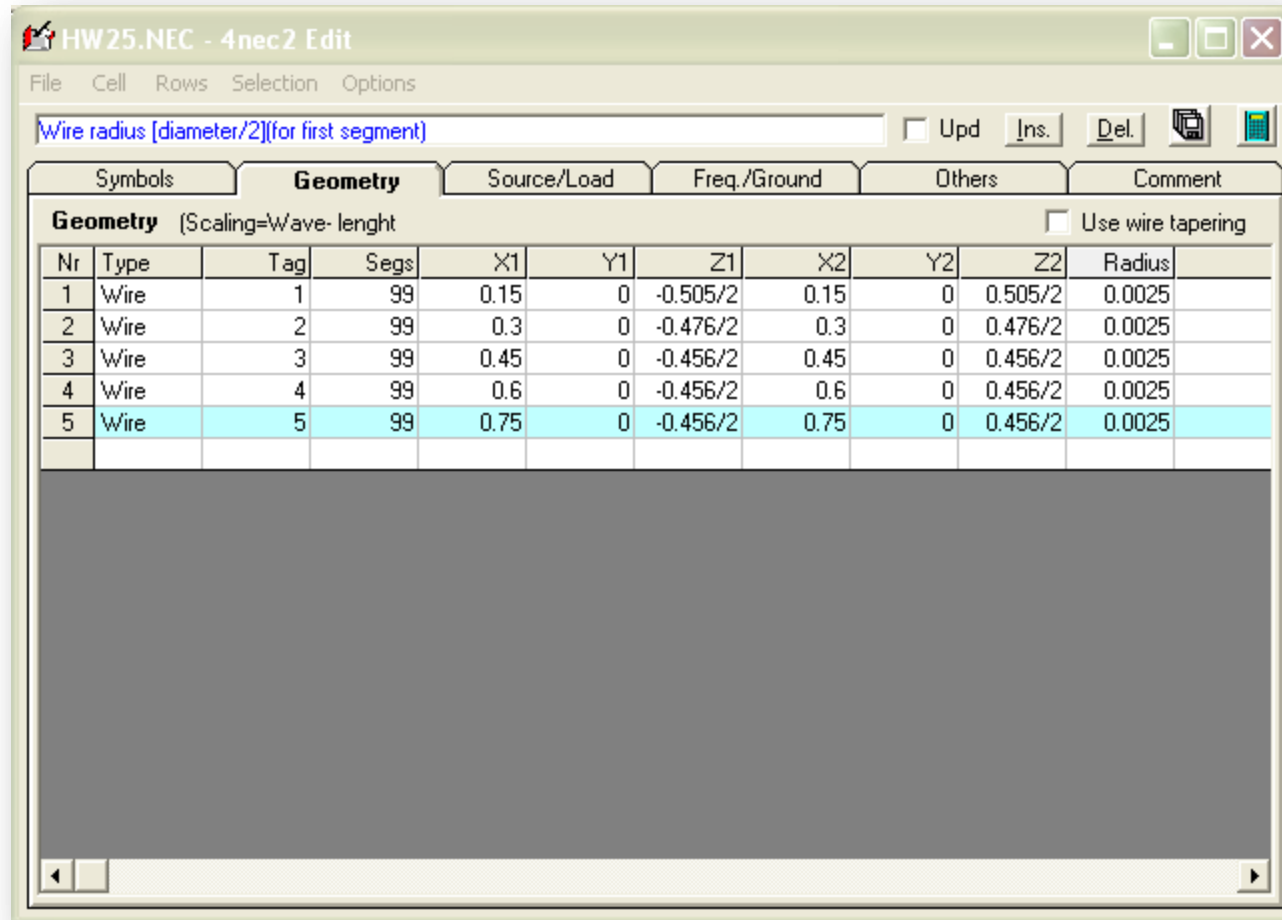
- Spacing =  $0.15\lambda$
- Reflector length =  $0.505\lambda$
- Driver length =  $0.476\lambda$
- Three directors of length =  $0.456\lambda$

## ▶ Verify: Are these correct?

- Gain = 10.0 dB
- Front-to-back ratio = 13.1 dB
- Input impedance =  $9.6 + j13.0$  ohms
- For H-plane ( $\theta = 90^\circ$  xy plane)
  - Half-power beam width HPBW =  $76^\circ$
  - Side-lobe level SLL = -8.9 dB





# Program Element Dimensions



The screenshot shows the 'HW25.NEC - 4nec2 Edit' window. The menu bar includes 'File', 'Cell', 'Rows', 'Selection', and 'Options'. The toolbar contains buttons for 'Upd', 'Ins.', 'Del.', and a copy icon. The 'Geometry' tab is active, showing a table with columns: Nr, Type, Tag, Segs, X1, Y1, Z1, X2, Y2, Z2, and Radius. The table contains five rows of wire element data. The fifth row is highlighted in light blue. Below the table is a large grey area for visualization. The status bar at the bottom shows a scroll bar.

File Cell Rows Selection Options

Wire radius [diameter/2][for first segment]  Upd  Ins.  Del.  

Symbols **Geometry** Source/Load Freq./Ground Others Comment

**Geometry** (Scaling=Wave-length)  Use wire tapering

| Nr | Type | Tag | Segs | X1   | Y1 | Z1       | X2   | Y2 | Z2      | Radius |
|----|------|-----|------|------|----|----------|------|----|---------|--------|
| 1  | Wire | 1   | 99   | 0.15 | 0  | -0.505/2 | 0.15 | 0  | 0.505/2 | 0.0025 |
| 2  | Wire | 2   | 99   | 0.3  | 0  | -0.476/2 | 0.3  | 0  | 0.476/2 | 0.0025 |
| 3  | Wire | 3   | 99   | 0.45 | 0  | -0.456/2 | 0.45 | 0  | 0.456/2 | 0.0025 |
| 4  | Wire | 4   | 99   | 0.6  | 0  | -0.456/2 | 0.6  | 0  | 0.456/2 | 0.0025 |
| 5  | Wire | 5   | 99   | 0.75 | 0  | -0.456/2 | 0.75 | 0  | 0.456/2 | 0.0025 |



# Program Source Parameters

The screenshot shows a software window titled "HW25.NEC - 4nec2 Edit". The window has a menu bar with "File", "Cell", "Rows", "Selection", and "Options". Below the menu bar is a text input field containing "Standard Current source (Peak value)". To the right of this field are buttons for "Upd", "Ins.", and "Del.", along with icons for a folder and a document. Below the input field are several tabs: "Symbols", "Geometry", "Source/Load", "Freq./Ground", "Others", and "Comment". The "Source/Load" tab is active. Under this tab, there are checkboxes for "Show source" (checked), "Show loads", and "Show Tr-line". Below these checkboxes is a table with the following data:

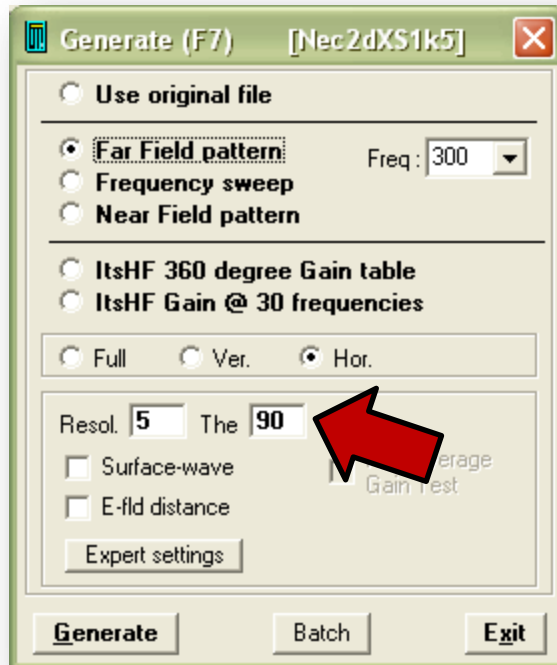
| Nr | Type        | Tag | Seg | (opt) | Real | Imag | Magn | Phase | (norm) |
|----|-------------|-----|-----|-------|------|------|------|-------|--------|
| 1  | Current-src | 2   | 50  | 0     | 1    | 0    | 1    | 0     | 0      |

The table is followed by a large grey rectangular area, likely a workspace for editing or visualization. At the bottom of the window, there are navigation arrows.





# Generate Results



Main [V5.8.4] (F2)

File Edit Settings Calculate Window Show Run Help

Filename HW25.out Frequency 300 Mhz  
Wavelength 0.999 mtr

Voltage 30 + j 96.3 V Current 3.33 + j 0 A

Impedance 9.03 + j 28.9 Series comp. 18.33 pF  
Parallel form 102 // j 31.8 Parallel comp. 16.71 pF

S.W.R.50 7.44 Input power 100 W  
Efficiency 100 % Structure loss 0 W  
Radiat-eff. % Network loss -0 W  
RDF [dB] 9.39 Radiat-power 100 W

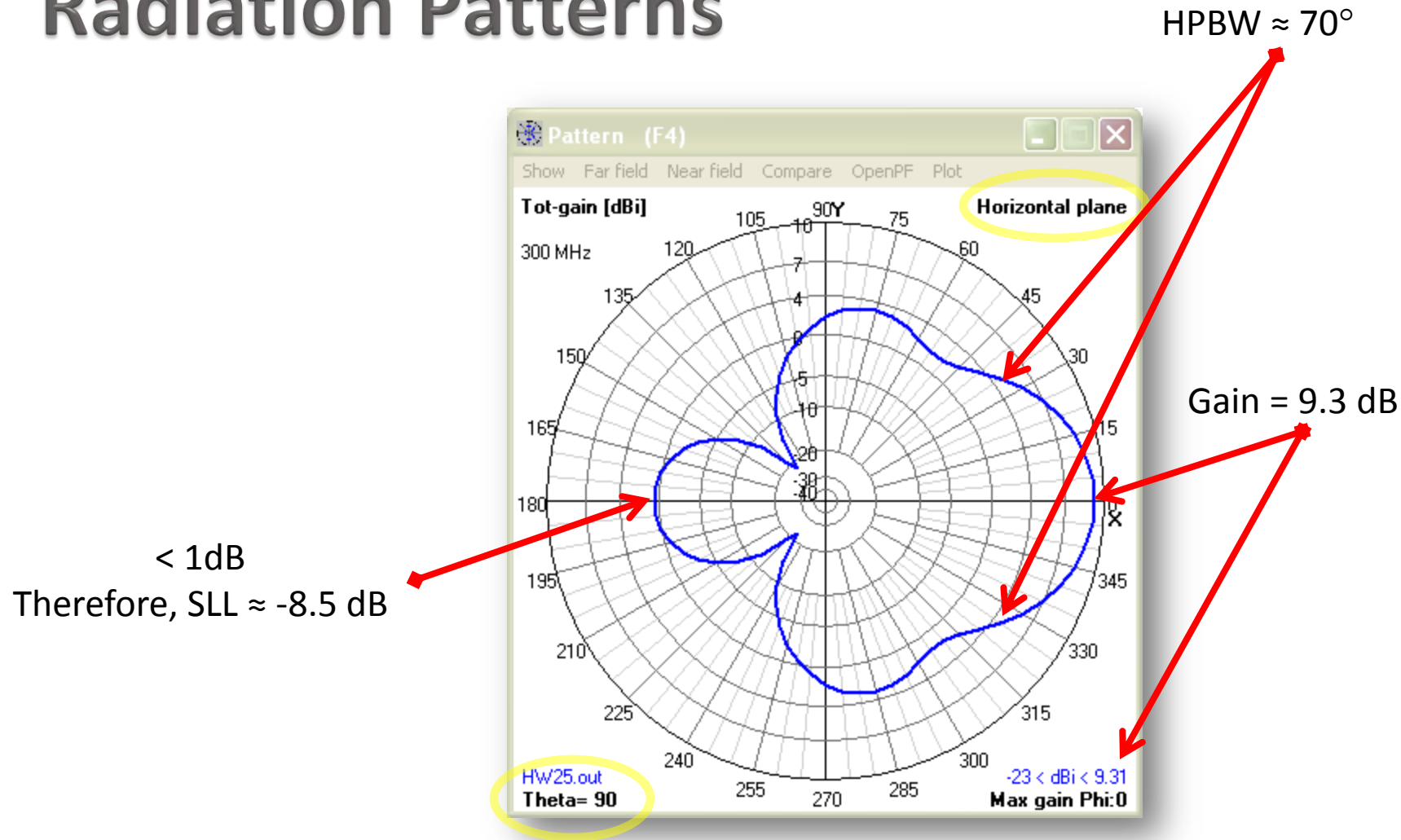
Excitation/Load data  Loads  Polar

| Type        | Tag | Seg | Impedance     | Voltage     | Pwr | SWR  |
|-------------|-----|-----|---------------|-------------|-----|------|
| EX 6: l-src | 2   | 50  | 9.03 + j 28.9 | 30 + j 96.3 | 100 | 7.44 |

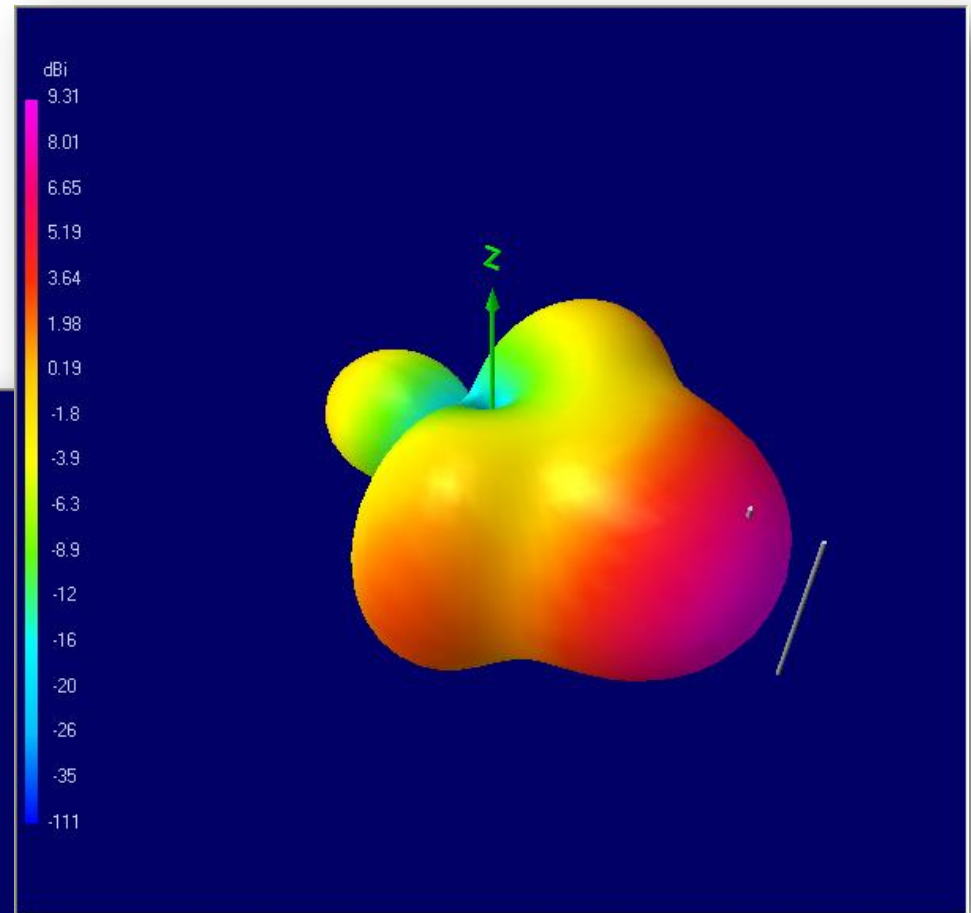
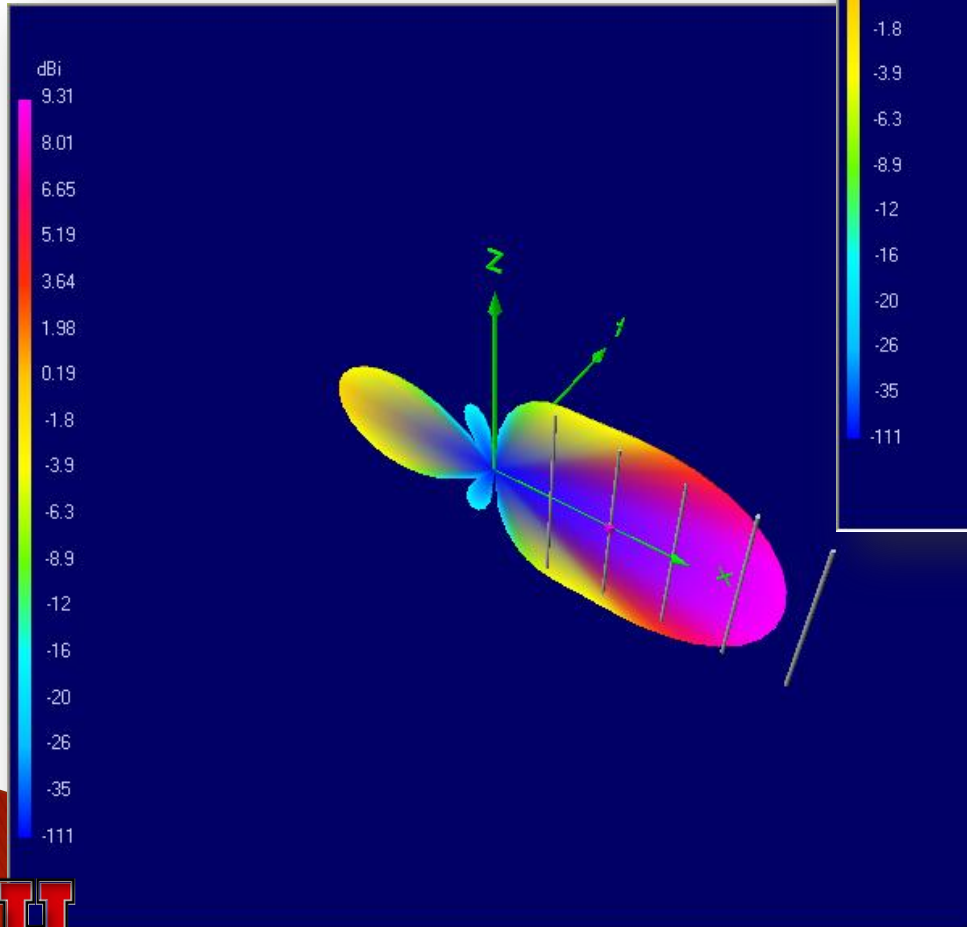
Seg's/patches 496 start stop count step  
Pattern lines 73 Theta 90 90 1 0  
Freq/Eval steps 1 Phi 0 360 73 5  
Calculation time 0.891 s



# Radiation Patterns



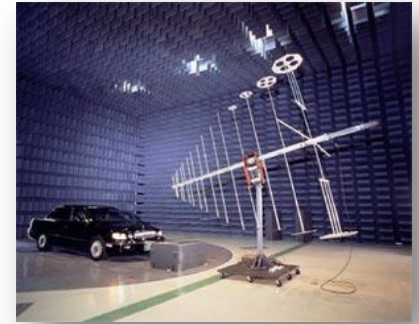
# 3D View



# More Practical Application: The Antenna Array Problem



# Array Application Problems



- ▶ 4-element array stretched along x-axis
  - Ordinary end fire array ( $\alpha = -\beta d = -2p \times 0.40 = -144^\circ$ )
  - Increased directivity end-fire array
- ▶ Inter-element spacing  $d/\lambda = 0.40$
- ▶ Half-wave dipoles
- ▶ Simulate in the xy plane ( $\theta = 90^\circ$ )
  - Radiation pattern
  - Beam width between first nulls
  - Half-power beam width
  - Directivity
  - Levels of first side lobes in dB below principal lobe



# How Would You Solve This Problem?

- ▶ Program array dimensions for both cases
- ▶ Run simulation for  $\theta = 90^\circ$  in xy plane
- ▶ Obtain data from radiation pattern results
  - Directivity from angle of maximum radiation

$$D = \max \left( \frac{\text{Radiated power density } (\theta, \phi)}{\text{Total radiated power} / (4\pi)} \right)$$

- ▶ Put data in table for comparison
- ▶ Refer to this and other tutorials on the website



# Evaluations

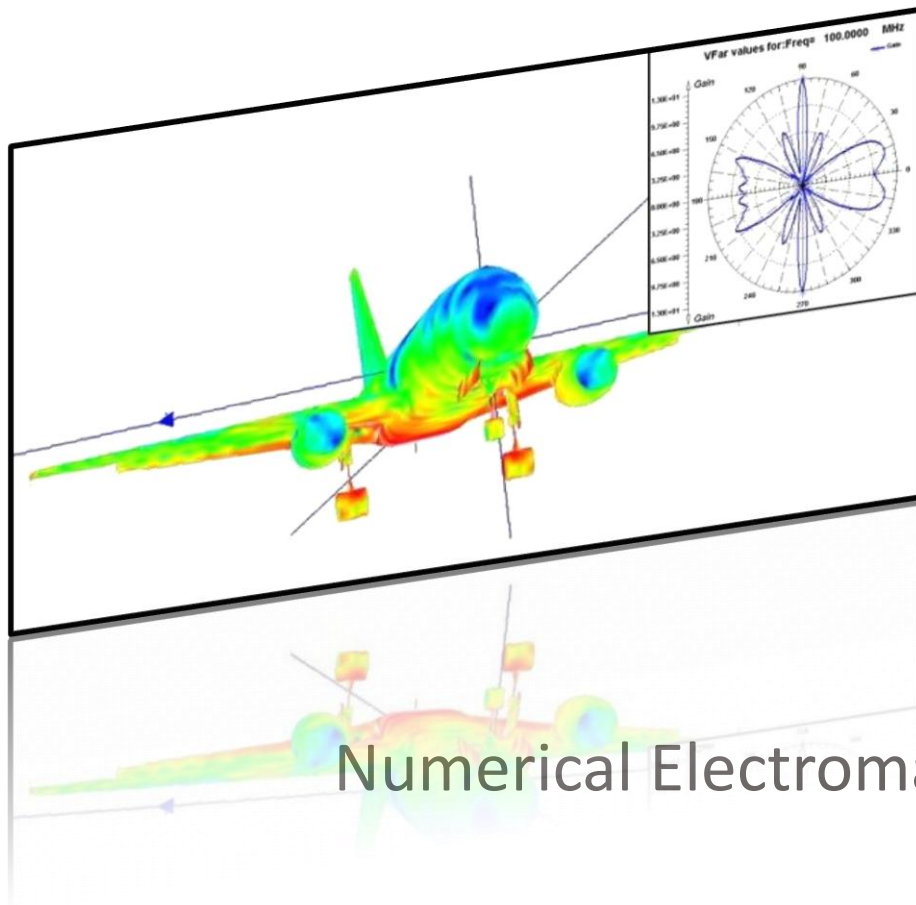


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# Thank You

## Numerical Electromagnetic Code (NEC) Lecture