Antenna modelling

A brief introduction to 4NEC2

For
The Newport Amateur Radio Society

By
Roger – GW6HRU

Background

- Engines:
  - NEC = Numerical Electro-magnetics Code
  - Written in FORTRAN in the 1970s at Lawrence Livermore National Laboratory
  - The code to NEC2 (version 2) was publicly released in the 1980s and is still widely used (probably because it's free!). NEC5 can be licensed for $120!
  - MiniNEC2/3 (version 3=1986) are an open source re-write of the NEC2 engine, with some limitations, but also with some newer features
- Programs:
  - 4NEC2 is a (free) Windows program that adds a graphics UI and full variable parser to the NEC2 engine (can use NEC4, and with tweaking NEC5).
  - EZNEC is a (now free) windows program with nicer graphical views, but only straight elements, no variables, and limited resizing options
  - MMANA is a (basic=free/advanced=paid for) program using the MiniNEC3 engine, with a nice graphical editor, but limited expressions.
  - CocoaNEC is a Mac application, similar to EZNEC

Main NEC (and MiniNEC) limitations

- Wires are split into segments, the segments should be:
  - 1/1000th to 1/20th of a wavelength long (more segments = slower run time)
  - Longer than their diameter (greater than 2x diameter preferred)
- Segment intersections should:
  - Have lengths within 5:1 (3:1 preferred) of their neighbours
  - Not overlap more than 1/3 of the neighbouring segments (acute angle limits)
- Feedpoints will be a single segment (so at least 1/1000th of a wavelength long)
- Parallel wires must have similar (sometimes very similar) segmentation
- Wires near ground (Note: NEC2 only, fixed in the paid for NEC4 and NEC5)
  - All wires should be least two diameters above ground
  - Wires cannot touch ground

The good news: Many errors are really warnings, often the results are “close enough” for a starting point.

Other simulation problems

- Auto segmentation options:
  - Don't always give good results (checks still fail)
  - Can generate lots of segments (2x segments=4x time!)
- Modelling capacitors and inductors/traps, is difficult/limited:
  - Have to define a segment, then apply modifiers
  - Really only supports LCR in series or LCR in parallel
- Modelling helix, arcs and cylinders is extremely complex
  - Their definition puts them at (0,0,0)
  - Need to be moved/rotated in 3D space to where they should be
  - (Not supported by EZNEC)

NEC file commands

The NEC/MiniNEC engines are driven by a file of commands, one per line:

CM	Comment Line
EX	Excitation (feedpoint) *
FR	Frequency
GA	Wire Arc Specification *
GD	Additional Ground Parameter
GH	Helix/Spiral Specification *
GM	Move/Copy segment(s) *
GN	Ground Parameters
GR	Generate Cylindrical Structure *
GS	Scale Structure Dimensions (default is meters)
GW	Wire Specification
LD	Loading
SM	Multiple Patch Surface *
SP	Surface Patch *
SY	Set variable **

' Rest of line ignored (per line comment)

* = Not supported by EZNEC ** = 4NEC2 extension

What does 4NEC2 offer?

- Editing:
  - Simple graphical editor
  - Old/New Line based editors with syntax checking entry
  - Notepad for full edits (best for copy+paste)
- Metric (meters) or imperial (feet or inches) input and display
- Allows: variables, calculations, and expressions
- Supports: Arc, helix, cylinder, and move/repeat NEC commands
- 3D viewer for antenna design
- Simple SWR sweeps, Smith charts (up to 256 frequency steps)
- Near field and Far field plots in 2D and 3D
- Multi-pass optimizer to tune SWR/gain/other

Why use variables? (4NEC2 only)

- Variables allow:
  - A common place to define things like:
    height, frequency, wavelengths, offsets, diameters, etc.
  - Calculations/expressions avoid pre-calculated “magic” values
  - Allows parameter based designs
  - The optimizer can automatically adjust variables to improve SWR/FB-Gain/Gain...
- The graphical editors don't allow for this!
- !! Maths alert !!
  - Is basically algebra!
  - Often involves basic trigonometry (Sin/Cos/Pythagoras)!

Variables and expressions (4nec2 only)

The SY command defines variables:

SY name=expression 'Syntax

Expressions can also be used instead of values:
Operators:

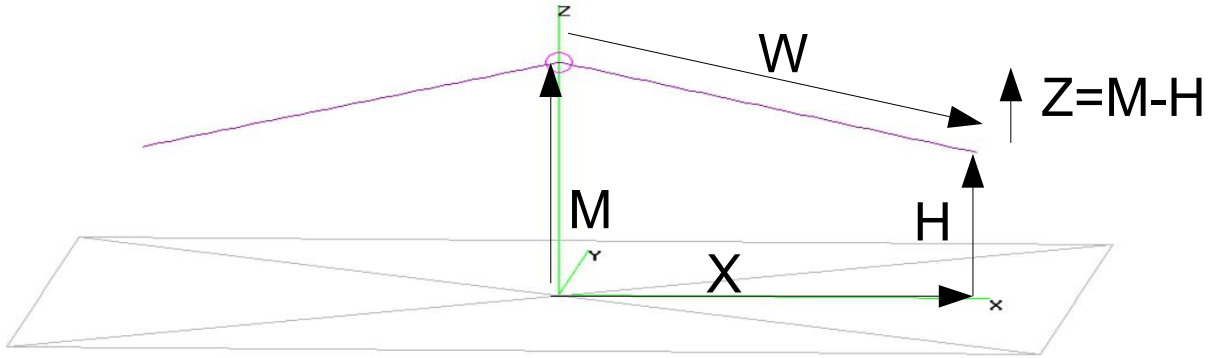
+ Add
- Subtract
* Multiply
/ Divide
^ Raise to power

Functions:

sin(angle)	'Sine of angle in degrees
cos(angle)	'Cosine of angle in degrees
tan(angle)	'Tangent of angle in degrees
atn(val)	'Arc tangent, returns angle in degrees
sqr(val)	'Square root
exp(val)	'Exponent (e^val)
log(val)	'Base e logarithm
log10(val)	'Base 10 logarithm
abs(val)	'Absolute value (maps -ve or +ve to +ve)
sgn(val)	'Return -1,0,+1 depending on sign of value
int(val)	'Rounds to nearest integer
mod(val,div)	'Modulo arithmetic (remainder after division)

Notes on variable names:
Case insensitive (“load” and “LoAd” are the same)
Must start with a letter, can contain a-z,A-Z,0-9,_
Must not be a predefined symbol or token
Max of 64 names available

Simple inverted V - example



Straight wires use X,Y,Z start, and X,Y,Z end coordinates, so we need to calculate X

```
SY M=8.0                 'Midpoint height (in meters)
SY H=5.0                 'Endpoint height (in meters)
SY F=0.08                'Feed point is 8cm wide
SY R=0.0005              'Wire is 1mm in diameter = 0.5mm radius
SY W=0.25*300/7.100      'Quarter wave length at 7.1MHz
SY Z=M-H                 'Vertical height of wire
SY X=sqr(W^2 - Z^2)      'Pythagoras: W ²=X²+Z² => X²=W ² - Z² => X=√(W ² - Z²)
'    Tag Segs X   Y Z   X    Y Z  Radius
GW 99   1   -F/2  0 M  F/2 0 M R  'Feed point is at top of middle pole, F/2 left, F/2 right
GW 10   45 -F/2 0  M  -X  0 H R  'Left span, from feed point at M to -X at H
GW 11   45  F/2 0  M  X   0 H R  'Right span, from feed point at M to X at H
```

“NEC Editor (new)” example #1

From the previous page, we can enter the following into the editor

v-2w1b-classic-40m.nec - 4nec2 Edit

File Cell Rows Selection Options

Symbol/Variable with value or equation Upd Ins. Del.

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

Symbols

Nr	Symbols and equations	comment
1	M=8.0	Midpoint Height above ground
2	H=5.0	Endpoint Height above ground
3	F=0.08	Feedpoint size
4	R=0.0005	Wire radius
5	V=0.9635	Wire velocity (also adjusts for nearness to ground)
6	CW=V*0.25*299.792458/7.100	1/4 Wavelength (length of each wire)
7	CZ=M-H	Vertical span of each wire
8	CX=sqr((CW*CW)-(CZ*CZ))	Horizontal span of each wire

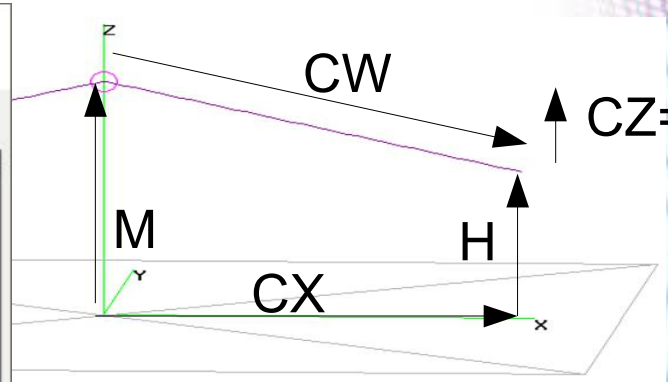
Scaling

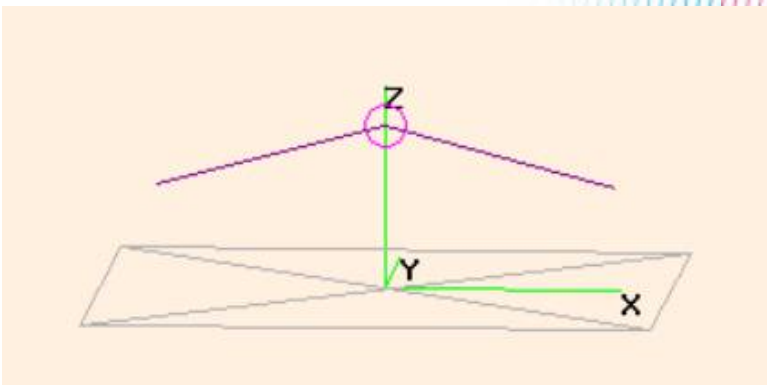
Meters Feet Inch Wave-lenght Custom Factor 1.0

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

Geometry (Scaling=Meters) Use wire tapering

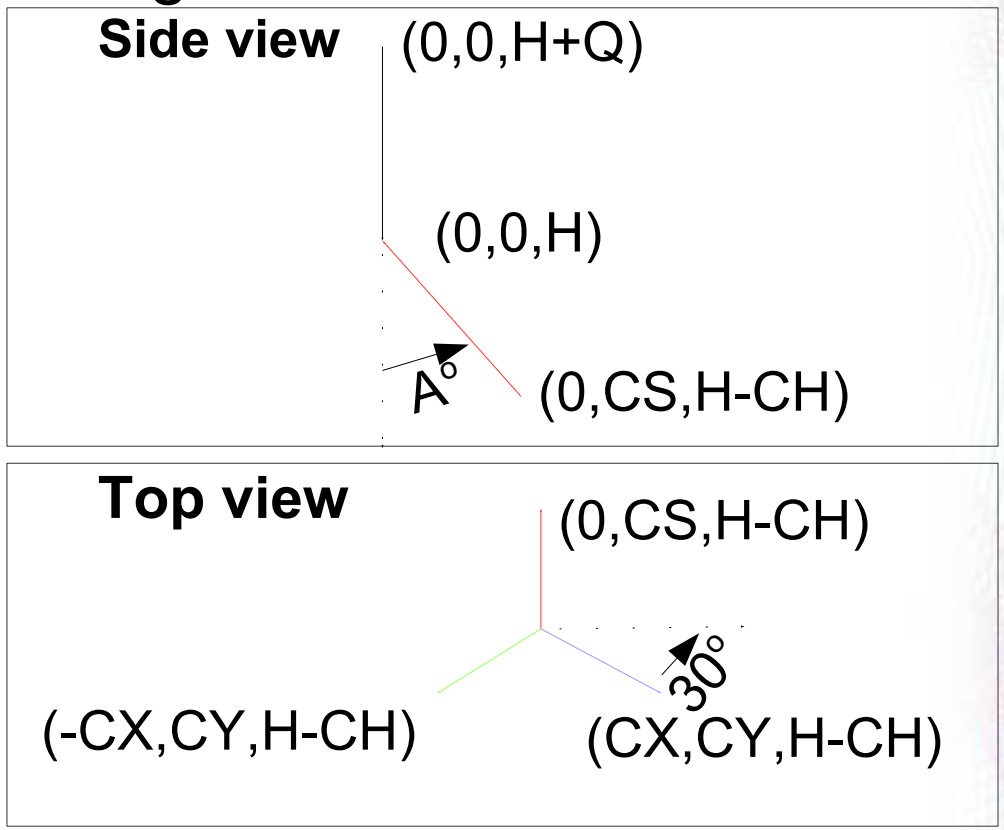
Nr	Type	Tag	Segs	X1	Y1	Z1	X2	Y2	Z2	adius				comment
1	Wire	99	1	-F/2	0	M	F/2	0	M	R				Feed point is at top of middle pole, 1/2 left
2	Wire	10	45	-F/2	0	M	-CX	0	H	R				Left span, from feed point to -CX at H
3	Wire	11	45	F/2	0	M	CX	0	H	R				Right span, from feed point to CX at H





Example: Vertical dipole + radials

- 3 equally spaced radials at A degrees from vertical
- Height above ground is H
- Q=1/4 wavelength
- Some trigonometry:
  - CS=Q*sin(A)
  - CH=Q*cos(A)
  - CX=CS*cos(30)
  - CY=CS*sin(30)



“NEC Editor (new)” example #2

From the previous page, we can enter the following into the editor

dipole-radials-2m.nec - 4nec2 Edit

File Cell Rows Selection Options

Symbol/Variable with value or equation Upd Ins. Del.

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

Symbols

Nr	Symbols and equations	comment
1	F=145.0	Freq
2	V=0.93	Velocity
3	H=7	Height above ground
4	R=0.001	Wire radius
5	A=30	Radial angle from vertical
6	CQ=V*0.25*299.792458/F	Quarter wave length
7	CF=CQ/200	Feed point size
8	CS=sin(A)*CQ	Sideways offset from centre line
9	CH=cos(A)*CQ	Height offset from midpoint
10	CX=cos(30)*CS	X offset for diagonal radials
11	CY=sin(30)*CS	Y offset for diagonal radials

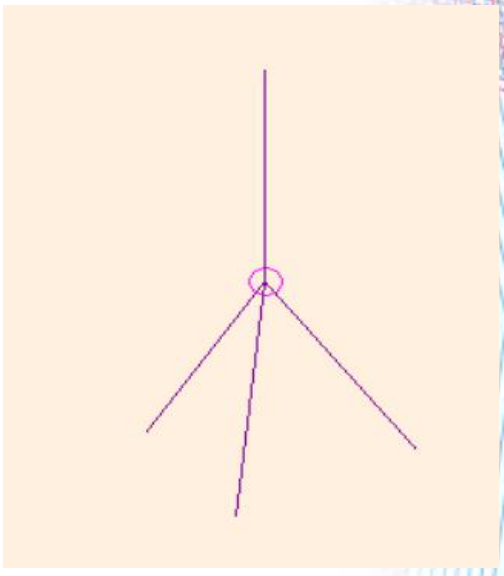
Scaling

Meters Feet Inch Wave-lenght Custom Factor 1.0

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

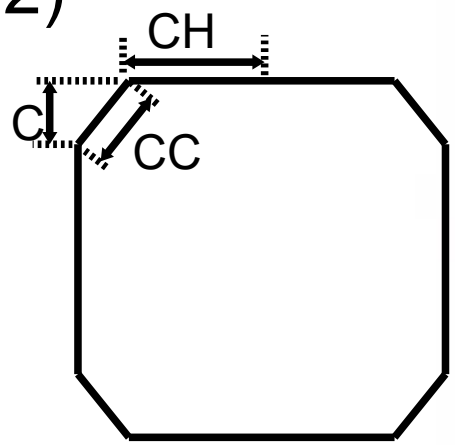
Geometry (Scaling=Meters) Use wire tapering

Nr	Type	Tag	Segs	X1	Y1	Z1	X2	Y2	Z2	Radius	comment
1	Wire	1	1	0	0	H	0	0	H+CF	R	Feed point
2	Wire	2	45	0	0	H+CF	0	0	H+CQ	R	Vertical
3	Wire	3	45	0	0	H	0	-CS	H-CH	R	Near radial
4	Wire	4	45	0	0	H	CX	CY	H-CH	R	Forward right radial
5	Wire	5	45	0	0	H	-CX	CY	H-CH	R	Forward left radial



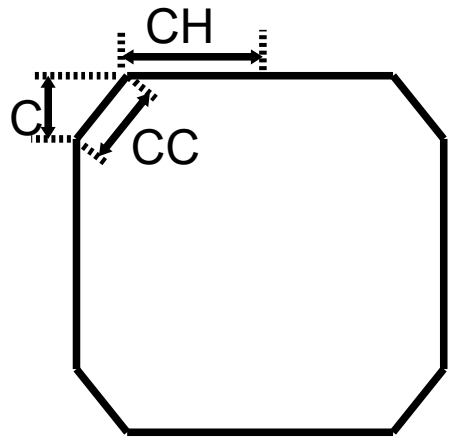
Example: 3ele Cubical Quad #1

- Each element is a square with curved corners
- We approximate the curve with a 45 degree angle
- Driven element is about 1 wavelength long
- Reflector is a bit bigger, Director is a bit smaller
- Corner length: $CC^2=C^2+C^2$ so CC=sqr(2*C^2)
- If CL is the circumference
- Total of 4 sides = CL - 4*CC
- Half of one side is CH=(CL - 4*CC)/8



Example: 3ele Cubical Quad #2

```
SY S=1.05                    'Scale between elements
SY V=0.99                    'Radiating element length modifier
SY C=0.02                    'Corner cutoff X/Y length (2cm)
SY CC=sqr(2*C^2)             'Corner cutoff diagonal length
SY CL1=V*299.792458/145.0    'Circumference Driven
SY CH1=(CL1-4*CC)/8          'Half side length
SY CL2=S*CL1                 'Circumference Reflector
SY CH2=(CL2-4*CC)/8          'Half side length
SY CL3=CL1/S                 'Circumference Director
SY CH3=(CL3-4*CC)/8          'Half side length
```



This gives the following entries for the driven element (at Y=0)

cu-quad-3el-2m-fb.nec - 4nec2 Edit

File Cell Rows Selection Options

Default straight line wire-element Upd Ins. Del.

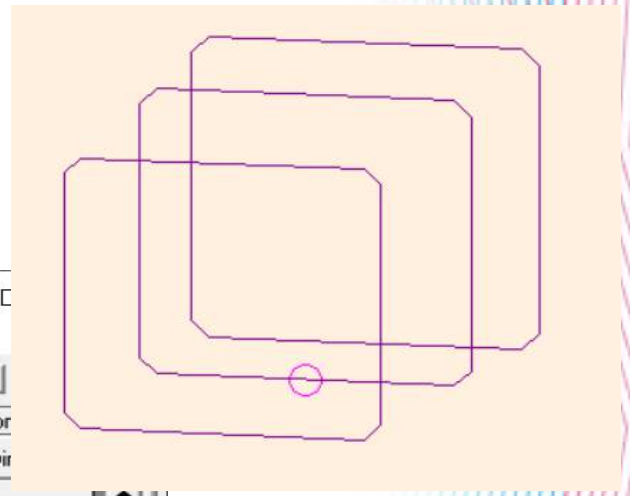
Symbols | **Geometry** | Source/Load | Freq./Ground | Others | Comment

Geometry (Scaling=Meters) Use wire tapering

Nr	Type	Tag	iegs	X1	Y1	Z1	X2	Y2	Z2	Radius	comment
1	Wire	1	9	-CH1	0	H-(CH1+CC)	CH1	0	H-(CH1+CC)	R	Bottom element
2	Wire	2	1	CH1	0	H-(CH1+CC)	CH1+CC	0	H-CH1	R	Bottom right chamfer
3	Wire	3	9	CH1+CC	0	H-CH1	CH1+CC	0	H+CH1-CC	R	Right side
4	Wire	4	1	CH1+CC	0	H+CH1-CC	CH1	0	H+CH1	R	Top right chamfer
5	Wire	5	9	CH1	0	H+CH1	-CH1	0	H+CH1	R	Top element
6	Wire	6	1	-CH1	0	H+CH1	-(CH1+CC)	0	H+CH1-CC	R	Top left chamfer
7	Wire	7	9	-(CH1+CC)	0	H+CH1-CC	-(CH1+CC)	0	H-CH1	R	Left side
8	Wire	8	1	-(CH1+CC)	0	H-CH1	-CH1	0	H-(CH1+CC)	R	Bottom left chamfer

Example: 3ele Cubical Quad #3

Uses Y offsets for the Director and reflector
SY M= 1.05 'Max boom length
SY L= -0.45 'Distance between Driven (at Y=0) and reflector
SY D= M+L 'Distance between Driven (at Y=0) and director



cu-quad-3el-2m-fb.nec - 4nec2 Edit

File Cell Rows Selection Options

Default straight line wire-element Upd Ins. Del.

Symbols | **Geometry** | Source/Load | Freq./Ground | Others | Cor

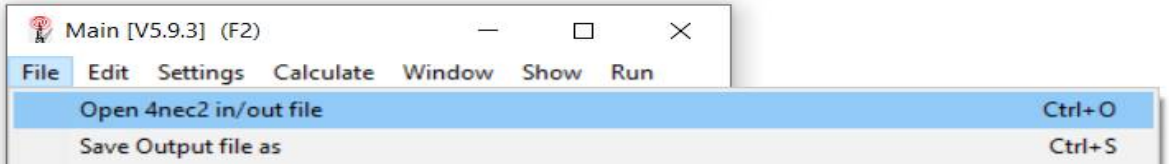
Geometry (Scaling=Meters) Use wi

Nr	Type	Tag	egs	X1	Y1	Z1	X2	Y2	Z2	Radius	comment
9	Wire	21	9	-CH2	L	H-(CH2+CC)	CH2	L	H-(CH2+CC)	R	Bottom element
10	Wire	22	1	CH2	L	H-(CH2+CC)	CH2+CC	L	H-CH2	R	Bottom right chamfer
11	Wire	23	9	CH2+CC	L	H-CH2	CH2+CC	L	H+CH2-CC	R	Right side
12	Wire	24	1	CH2+CC	L	H+CH2-CC	CH2	L	H+CH2	R	Top right chamfer
13	Wire	25	9	CH2	L	H+CH2	-CH2	L	H+CH2	R	Top element
14	Wire	26	1	-CH2	L	H+CH2	-(CH2+CC)	L	H+CH2-CC	R	Top left chamfer
15	Wire	27	9	-(CH2+CC)	L	H+CH2-CC	-(CH2+CC)	L	H-CH2	R	Left side
16	Wire	28	1	-(CH2+CC)	L	H-CH2	-CH2	L	H-(CH2+CC)	R	Bottom left chamfer
17	Wire	31	9	-CH3	D	H-(CH3+CC)	CH3	D	H-(CH3+CC)	R	Bottom element
18	Wire	32	1	CH3	D	H-(CH3+CC)	CH3+CC	D	H-CH3	R	Bottom right chamfer
19	Wire	33	9	CH3+CC	D	H-CH3	CH3+CC	D	H+CH3-CC	R	Right side
20	Wire	34	1	CH3+CC	D	H+CH3-CC	CH3	D	H+CH3	R	Top right chamfer
21	Wire	35	9	CH3	D	H+CH3	-CH3	D	H+CH3	R	Top element
22	Wire	36	1	-CH3	D	H+CH3	-(CH3+CC)	D	H+CH3-CC	R	Top left chamfer
23	Wire	37	9	-(CH3+CC)	D	H+CH3-CC	-(CH3+CC)	D	H-CH3	R	Left side
24	Wire	38	1	-(CH3+CC)	D	H-CH3	-CH3	D	H-(CH3+CC)	R	Bottom left chamfer

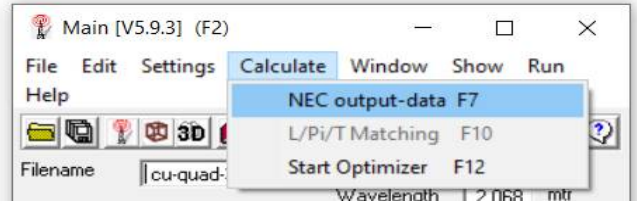
Analysing a 3ele Cubical Quad #1

1: Launch 4nec2

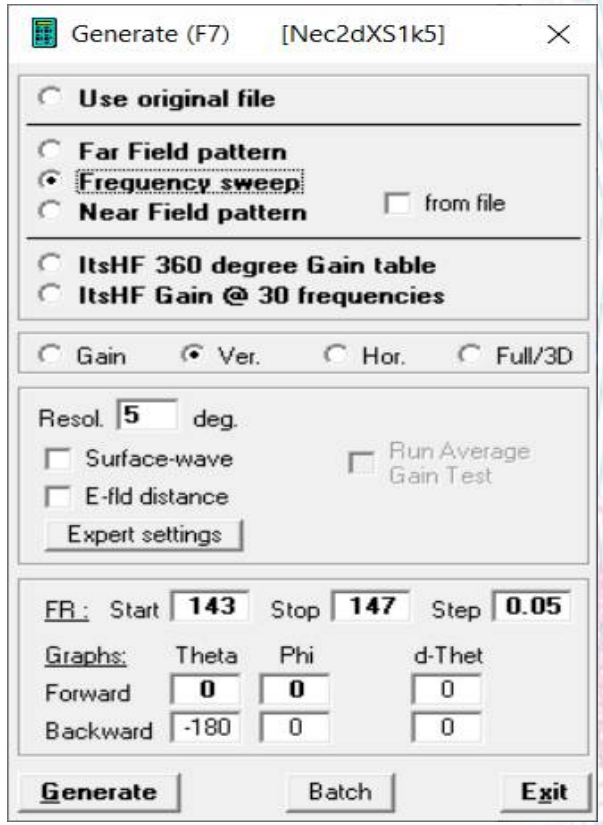
2: Select - Open/select file (cu-quad-3el-2m-fb.nec)



3: Select - Calculate / NEC output-data

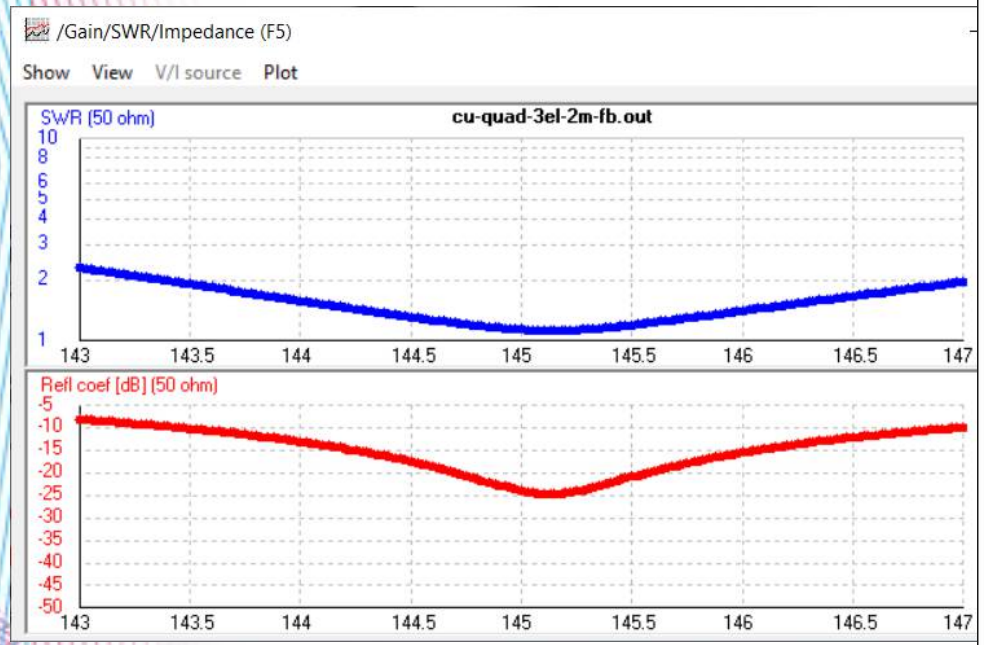


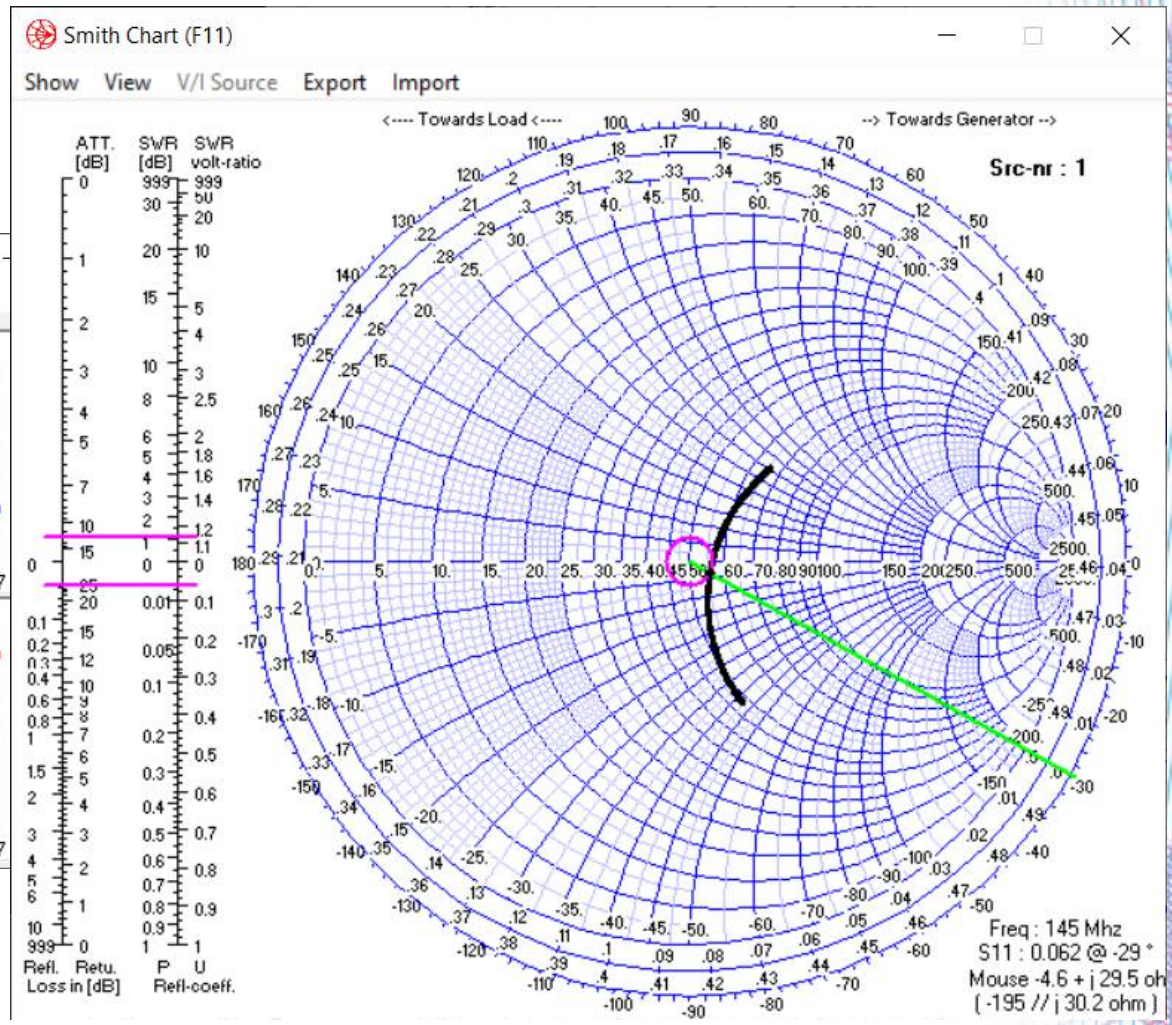
4: Select “Frequency Sweep”
5. Set the “FR:” Start/Stop/Step values
6: Click “Generate”



Analysing a 3ele Cubical Quad #2

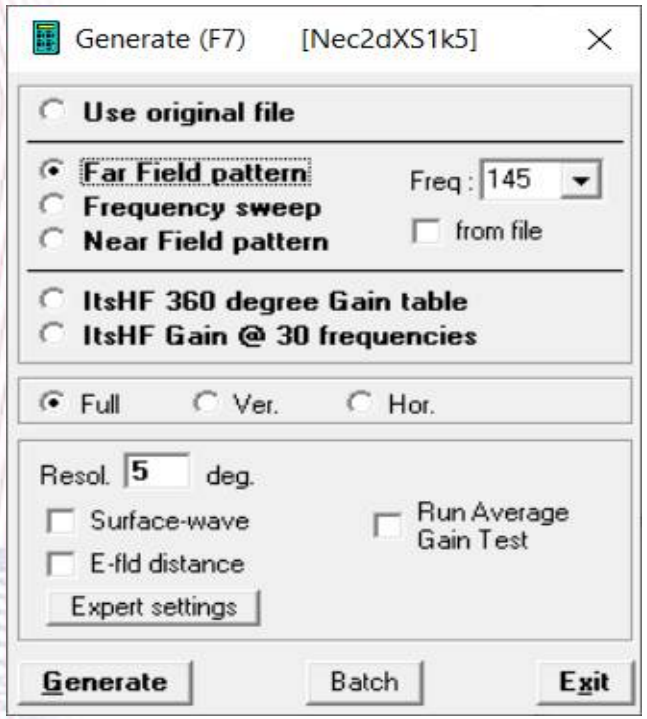
From the Sweep we get:

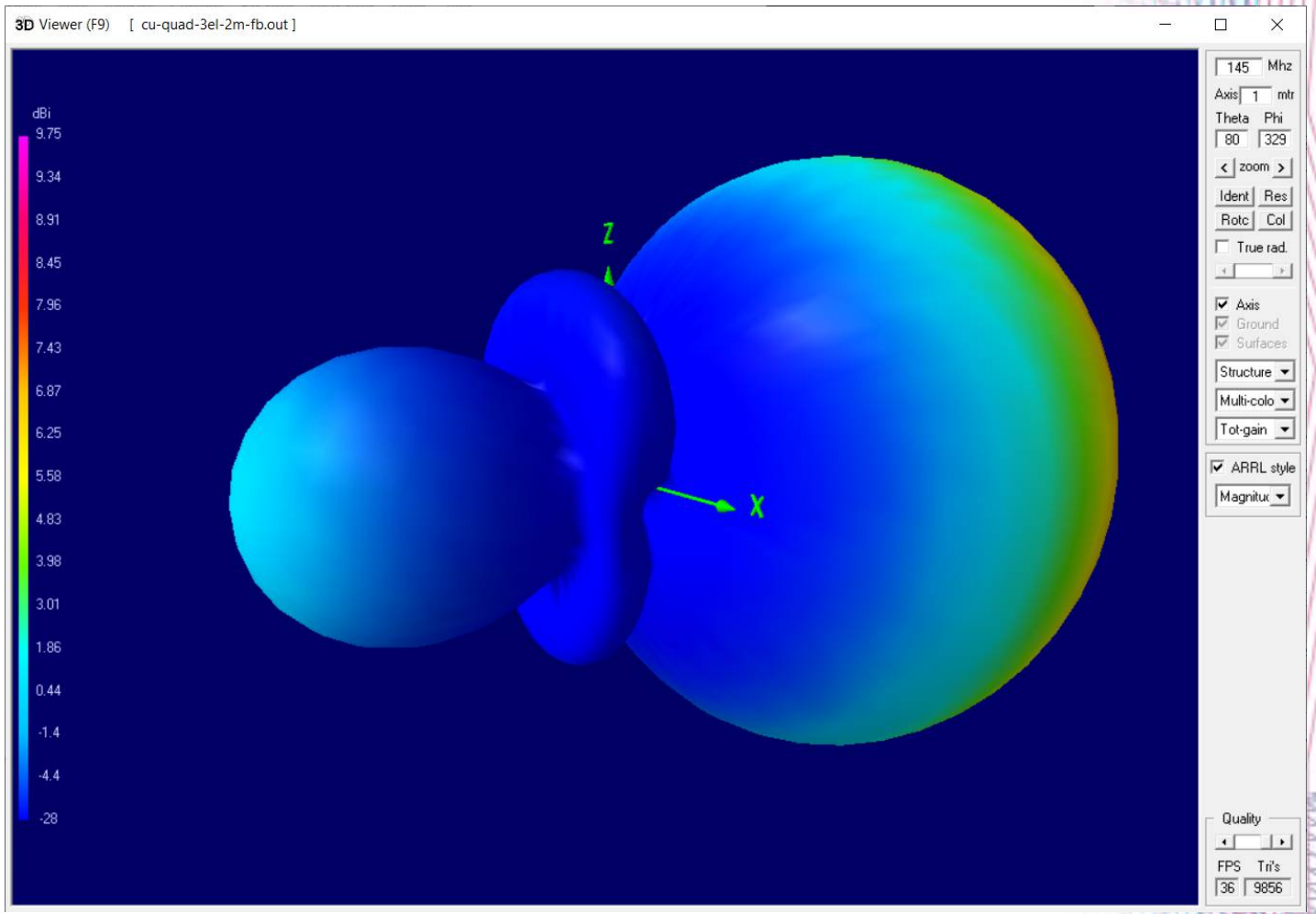




Analysing a 3ele Cubical Quad #3

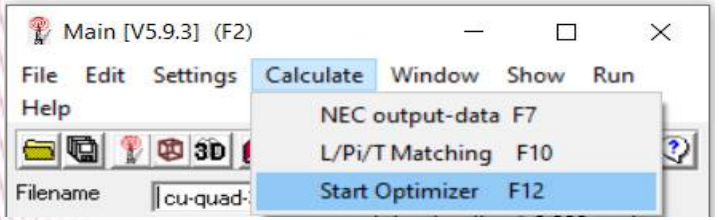
1: Using “Far Field”
2: Set “Freq”
3: Click “Generate”
4: Window/3D-viewer





Optimizing a 3ele Cubical Quad #1

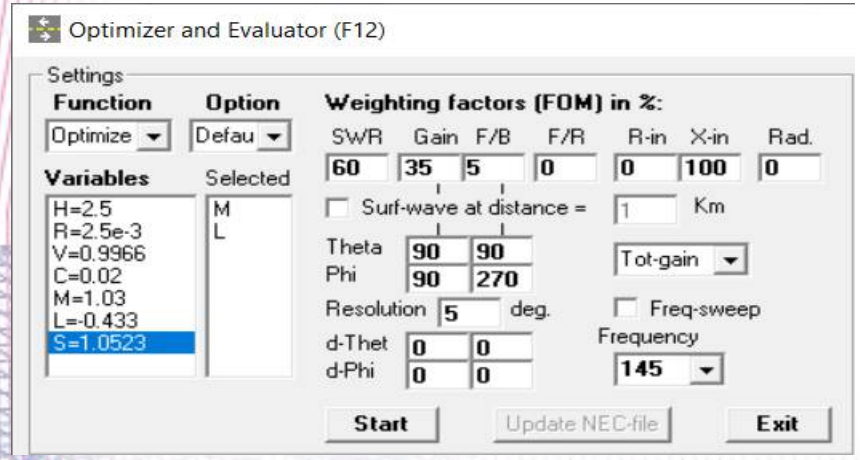
1: Calculate/Start Optimizer



2: Set SWR 60%,Gain 35%,F/B 5%

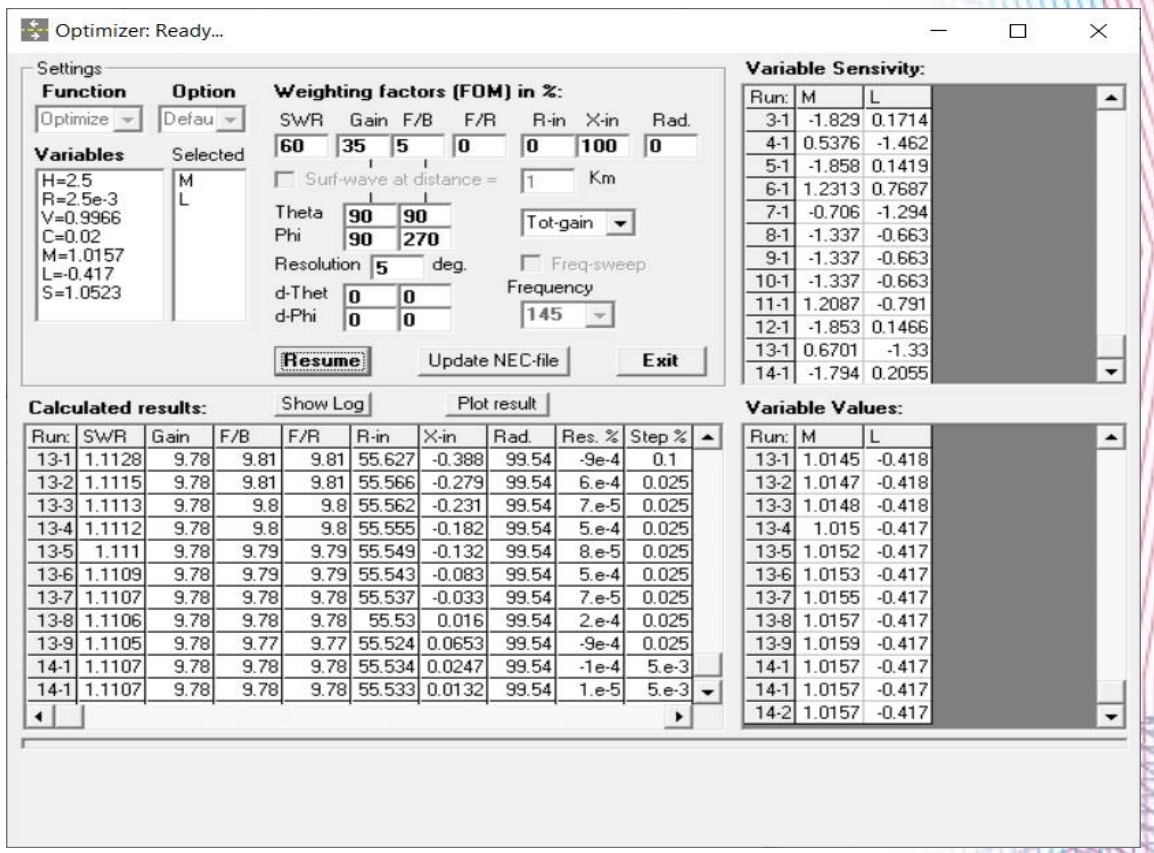
3: Select variables: M & L

4: Click “Start”



5: Click “Resume” a few times

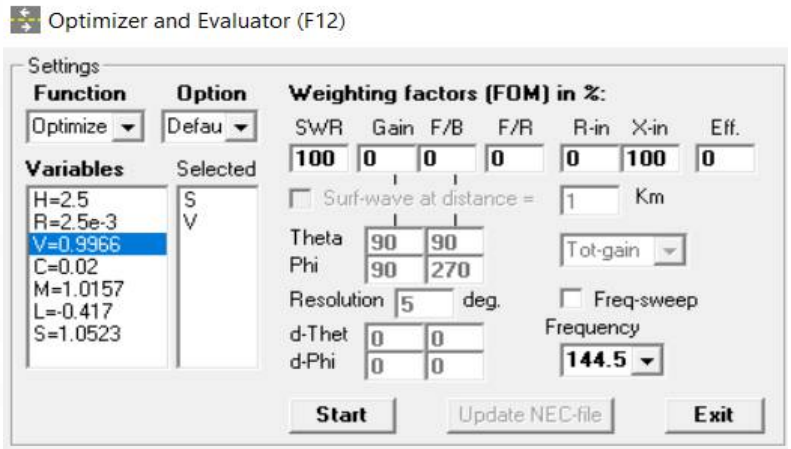
6: Click “Update NEC-file”

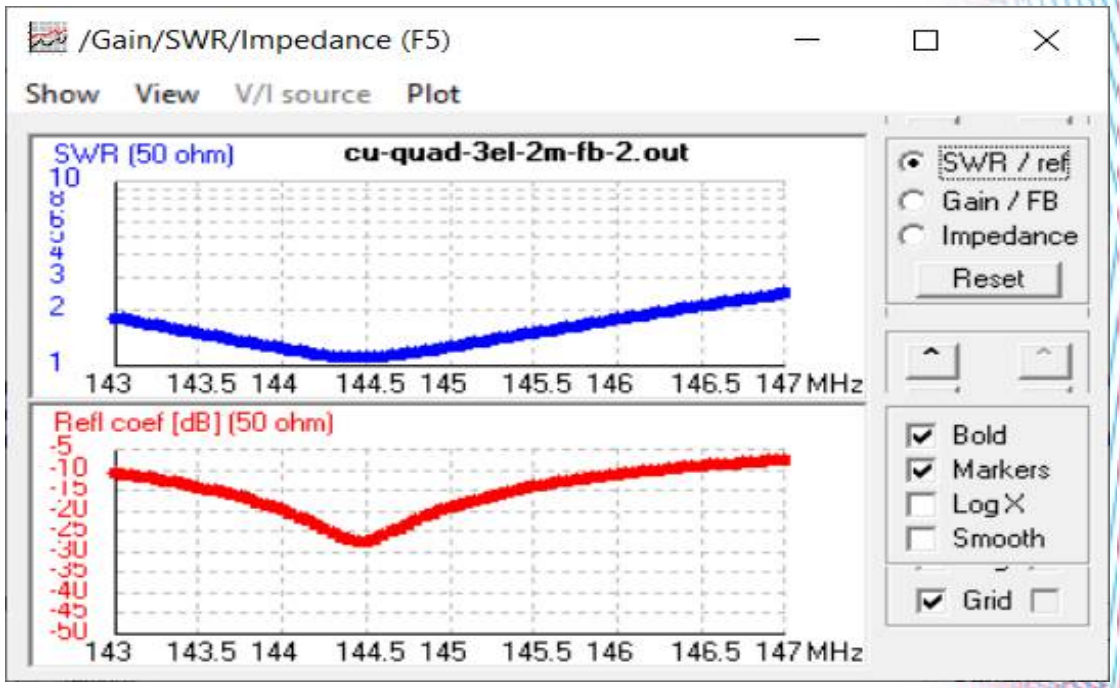


Optimizing a 3ele Cubical Quad #2

1: Set SWR 100, Freq to 144.5
2: Select variables: S & V
4: Click “Start”
5: Click “Resume” a few times

6: Click “Update NEC-file”
7: Calculate/Frequency Sweep





Useful links:

- My simple design tutorial:

  http://www.fareham.org/rw8-nec2-designing.shtml

- My example .NEC files (100+ so far):

  http://www.fareham.org/rw7-4nec2.shtml

- 4NEC2 download link:

  https://www.qsl.net/4nec2/

- NEC2 file command document:

  https://www.nec2.org/other/nec2prt3.pdf

- NEC5 license link: (Lawrence Livermore National Laboratory)

  https://ipo.llnl.gov/technologies/software/nec-v50-numerical-electromagnetic-code

Questions ?

(+ Live Demo if we have time!)