Antenna modelling

A brief introduction to 4NEC2

For The Newport Amateur Radio Society

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Background

- 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:

Engines:

- 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:

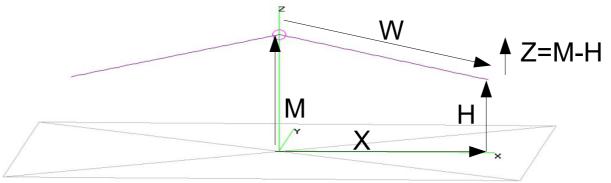
- + Add
- Subtract
- * Multiply
- / Divide
- ^ Raise to power

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) 'Feed point is 8cm wide SY F=0.08 'Wire is 1mm in diameter = 0.5mm radius SY R=0.0005 SY W=0.25*300/7.100 'Quarter wave length at 7.1MHz 'Vertical height of wire SY Z=M-H SY X=sqr(W² - Z²) 'Pythagoras: $W^2 = X^2 + Z^2 = X^2 = X^2 = X^2 = X = \sqrt{(W^2 - Z^2)}$ 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

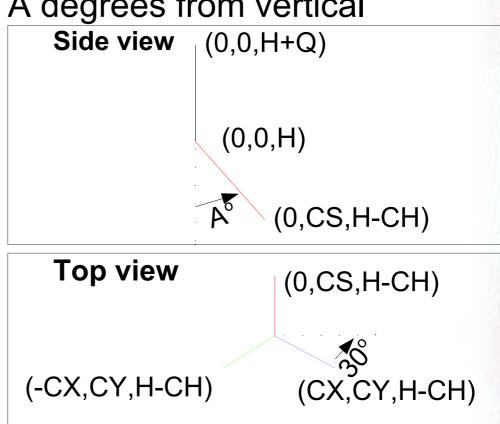
"NEC Editor (new)" example #1

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

🕼 v-2w1b-classic-40m.nec - 4nec2 Edit	- 🗆 ×	
File Cell Rows Selection Options		CW
Symbol/Variable with value or equation	🗆 Upd <u>Ins.</u> Del. 🛄	A CZ=M-H
Symbols Geometry Source/Load Fre	q./Ground Others Comment	
Symbols		
Nr Symbols and equations	comment	М ⊢Т)))))))))
1 M=8.0	Midpoint Height above ground	
2 H=5.0	Endpoint Height above ground	CX S
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		R
Get Clinch C Wave- Custom Fac	tor 1.0	
ienght		
Symbols Geometry Source/Load Fre	eq./Ground Others Comment	
Geometry (Scaling=Meters)	🔲 Use wire tapering	// Y/
Nr Type Tag Segs X1 Y1 Z1 X2 Y2 Z2 adi		X
	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	CONTRACTOR STREET
PROFESSION	Survey and S	

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

×

🔄 d	ipole-radials-2m.nec - 4nec2 Edit	- 🗆 ×
ile	Cell Rows Selection Options	
Symb	ol/Variable with value or equation	🗆 Upd Ins. Del. 🛄
1	Symbols Geometry Source/Load	Freq./Ground Others Comment
Syn	nbols	
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

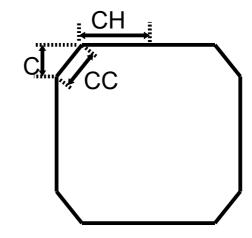
	Symbols		Geo	metry		Source/Lo	ad [Fre	eq./Ground	1	Others	Comment
Geo	ometry (Sca	ling=Meters)									🔲 Use wire tapering
Nr	Туре	Tag	Segs	×1	Y1	Z1	X2	Y2	Z2	Radius		comment
1	Wire	1	1	0	0	н	0	0	H+CF	B		Feed point
2	Wire	2	45	0	0	H+CF	0	0	H+CQ	B		Vertical
3	Wire	3	45	0	0	н	0	-CS	H-CH	B		Near radial
4	Wire	4	45	0	0	н	CX	CY	H-CH	B		Forward right radi
5	Wire	5	45	0	0	н	-CX	CY	H-CH	B		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: CC²=C²+C² so CC=sqr(2*C²)
- 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 elementsSY V=0.99'Radiating element length modifierSY C=0.02'Corner cutoff X/Y length (2cm)SY CC=sqr(2*C^2)'Corner cutoff diagonal lengthSY CL1=V*299.792458/145.0'Circumference DrivenSY CH1=(CL1-4*CC)/8'Half side lengthSY CL2=S*CL1'Circumference ReflectorSY CH2=(CL2-4*CC)/8'Half side lengthSY CL3=CL1/S'Circumference DirectorSY CH3=(CL3-4*CC)/8'Half side length



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

efai	ult straight I	ine wire	-elem	ent							Upo	<u>Ins.</u>	<u>D</u> el.	Ø
	Symbols) – I	Geomet	ry	Sour	ce/Load	Υ	Freq./Ground	Ŷ	Others	- Y	Com	ment
Geo	ometry (Scaling=	Mete	rs)								Г	Use wire	taperi
Nr	Туре	Tag	iegs	×1	Y1	Z1	×2	Y2	Z2	Radius	con	ment		
1	Wire	1	9	-CH1	0	H-(CH1+CC)	CH1	0	H-(CH1+CC)	B	Bot	om elemer	nt	
2	Wire	2	1	CH1	0	H-(CH1+CC)	CH1+CC	0	H-CH1	B	Bot	om right cl	hamfer	
3	Wire	3	9	CH1+CC	0	H-CH1	CH1+CC	0	H+CH1-CC	B	Rig	nt side		
4	Wire	4	1	CH1+CC	0	H+CH1-CC	CH1	0	H+CH1	B	Тор	right char	nfer	
5	Wire	5	9	CH1	0	H+CH1	-CH1	0	H+CH1	B	Тор	element		
6	Wire	6	1	-CH1	0	H+CH1	-(CH1+CC)	0	H+CH1-CC	B	Тор	left cham	fer	
7	Wire	7	9	(CH1+CC)	0	H+CH1-CC	-(CH1+CC)	0	H-CH1	B	Left	side		
8	Wire	8	1	(CH1+CC)	0	H-CH1	-CH1	0	H-(CH1+CC)	B	Bot	om left ch	amfer	

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

	ult straigh	ht line wire	-elem	nent							Upd <u>Ins.</u> <u>D</u> el.
	Symbo	ols)	Geomet	ry	Sour	ce/Load) — (Freq./Ground		Others Co
Geo	ometry	(Scaling=	Mete	ers)		50. 					🔲 Use v
Nr	Туре	Tag	iegs	×1	Y1	Z1	X2	Y2	Z2	Radius	comment
9	Wire	21	9		L	H-(CH2+CC)	CH2	L	H-(CH2+CC)	B	Bottom element
10	Wire	22	1	CH2	L	H-(CH2+CC)	CH2+CC	L	H-CH2	B	Bottom right chamfer
11	Wire	23	9	CH2+CC	Ľ	H-CH2	CH2+CC	L	H+CH2-CC	B	Right side
12	Wire	24	1	CH2+CC	L	H+CH2-CC	CH2	L	H+CH2	B	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	B	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)	B	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	B	Bottom right chamfer
19	Wire	33	9	CH3+CC	D	H-CH3	CH3+CC	D	H+CH3-CC	B	Right side
20	Wire	34	1	CH3+CC	D	H+CH3-CC	CH3	D	H+CH3	B	Top right chamfer
21	Wire	35	9	CH3	D	H+CH3	-CH3	D	H+CH3	B	Top element
22	Wire	36	1	-CH3	D	H+CH3	-(CH3+CC)	D	H+CH3-CC	B	Top left chamfer
23	Wire	37	9	(CH3+CC)	D	H+CH3-CC	-(CH3+CC)	D	H-CH3	B	Left side
24	Wire	38	1	(CH3+CC)	D	H-CH3	-CH3	D	H-(CH3+CC)	B	Bottom left chamfer

HTT I

Analysing a 3ele Cubical Quad #1

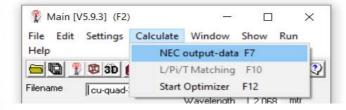
1: Launch 4nec2



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

1	Vain [\	/5.9.3] (F2))				\times
File	Edit	Settings	Calculate	Window	Show	Run	
	Open	4nec2 in/o	ut file				
	Save (Output file	as				

3: Select - Calculate / NEC output-data



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

Ctrl+O Ctrl+S

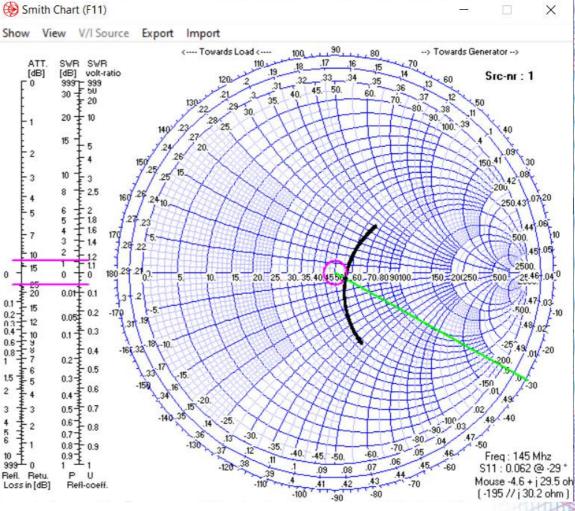
Generate (F7)	[Nec2dXS1k5	
O Use original fi	le	
 Far Field patter Frequency sw Near Field patter 	еер	rom file
⊂ ItsHF 360 deg ⊂ ItsHF Gain @	pree Gain table 30 frequencie	
⊂ Gain	r. C Hor.	C Full/3D
Resol. 5 deg.	Bui	Accesses
E-fld distance	E Gair	Average Test
Expert settings		
FR : Start 143	Stop 147	Step 0.05
Graphs: Theta	Phi d-	Thet
Forward 0		0
Backward -180	0	0

Analysing a 3ele Cubical Quad #2

Refl.

Show View V/I Source Export Import From the Sweep we get: SVR SVB. dB1 volt-ratio 999 30 /Gain/SWR/Impedance (F5) 20 Show View V/I source Plot cu-quad-3el-2m-fb.out SWR (50 ohm) 10 8 6 3 2 - 1.1 180.29.21 143 143.5 144.5 145 145.5 146 146.5 144 147 0.01 0.1 20 Refl coef [dB] (50 ohm) 0.05 -15 0.4 0.1 -20 0.6 -25 0.8 -30 -35 1.5 -40 2 -45 -50 3 0.5 - 0.7 143.5 144 144.5 145 145.5 146 146.5 143

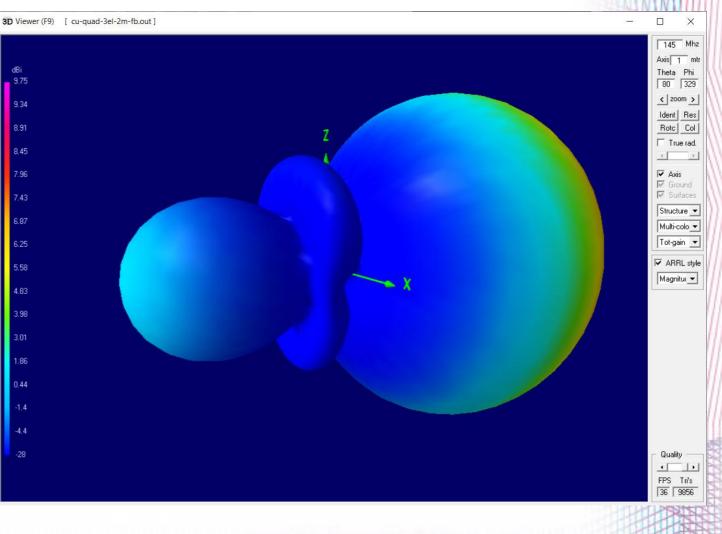
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Analysing a 3ele Cubical Quad #3

Using "Far Field"
 Set "Freq"
 Click "Generate"
 Window/3D-viewer

Generate (F7) [Nec	2dXS1k5] ×
Use original file	
 Far Field pattern Frequency sweep Near Field pattern 	Freq : 145 💌
○ ItsHF 360 degree Ga ○ ItsHF Gain @ 30 fre	
Resol. 5 deg. Surface-wave	Run Average Gain Test
E-fld distance	



Optimizing a 3ele Cubical Quad #1

1: Calculate/Start Optimizer

💱 Main [V5.9.3] (F2)	6				×
File Edit Settings	Calculate	Window	Show	Run	
Help	NEC	output-data	a F7		
😑 🕼 🦹 🕸 3D (L/Pi/	T Matching	F10		?
Filename cu-quad-	Start	Optimizer	F12		

2: Set SWR 60%,Gain 35%,F/B 5% 3: Select variables: M & L 4: Click "Start"

Settings Function	Option	Weighting factors (FOM) in %:	_
Optimize 💌	Defau 👻		Rac 0
Variables	Selected		
H=2.5	M	Surf-wave at distance = 1 Km	
R=2.5e-3	L	Theta lon lon	
V=0.9966 C=0.02		I ot-gain V	
M=1.03		130 1270	
L=-0.433		Resolution 5 deg. Freq-sweep	
S=1.0523		d-Thet 0 0 Frequency	
		d-Phi 0 0 145 ▼	

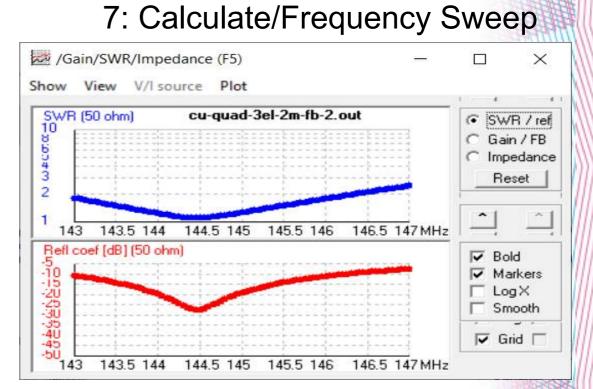
5: Click "Resume" a few times6: Click "Update NEC-file"

Fun	ction	Opti	on \	√eighti	ng fact	ors (FO	M) in %	:			Bun: 1	vi	L		
Opti	mize 👻	Defau	7	SWR	Gain F	/B F/F	R R-i	n X-in	Rad.	1	3-1	-1.829	0.1714		
Varia	ables	Selec	ted [60 3	5 5	. 0	0	100	0				-1.462		
H=2	.5	M	r	Surf-v	vave at o	distance	= 1	Km					0.1419		
	.5e-3	L		heta 🖡		1	_		-				-1.294		
V=0 C=0	.9966				90 9 90 2	70	Tot	gain 💌	·]			-1.337			
	.0157						-					-1.337	and the second second		
	.417			Resolutio	1-	deg.		req-swe	ер			-1.337			
S=1	.0523				0 0		Frequ				11-1		and the second second		
-			0	J-Phi	0 0		145	ō 🔻					0.1466		
			Г	Resum		Undate	NEC-file	1	Exit	11	13-1	0.6701	-1.33		
			L	nesuiii	e	Opuate	INEC-IIIE	<u> </u>	Exit		14-1	-1.794	0.2055		
Calcu	ulated r	esults:		Show Lo	g	Plot	t result				Variab	le Va	lues:		
Run:	SWR	Gain	F/B	F/R	B-in	X-in	Rad.	Res. %	Step %	-	Bun: I	M	L		
	1.1128	9.78	9.81		55.627	-0.388		-9e-4	0.1				-0.418		
13-2		9.78	9.81		55.566			6.e-4	0.025		13-2		and the second se		
	1.1113	9.78	9.8		55.562	-0.231	99.54	7.e-5	0.025	4	13-3		1.1.0.0.00.0000		
	1.1112	9.78	9.8		55.555			5.e-4	0.025	4		1.015	and the second se		
13-5		9.78	9.79		55.549			8.e-5	0.025	4	13-5				
	1.1109	9.78	9.79		55.543			5.e-4	0.025	4	13-6				
	1.1107	9.78	9.78		55.537			7.e-5	0.025		13-7				
	1.1106	9.78	9.78	9.78				2.e-4	0.025	4	13-8		and the second se		
	1.1105	9.78	9.77			0.0653		-9e-4	0.025		13-9				
	1.1107	9.78	9.78			0.0247		-1e-4	5.e-3			1.0157	and the second se		
	1.1107	9.78	9.78	9.78	00.033	0.0132	99.54	1.e-5	5.e-3	-	and the second se	1.0157	-0.417		
•	1								•		14.2	1.0157	-0.417		

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

Optimize 👻	Defau 👻	SWR	Gain	F/B	F/R	R-in	X-in	Eff.
√ariables	Selected	100	0	0	0	0	100	0
H=2.5 R=2.5e-3 /=0.9966 C=0.02 M=1.0157 L=-0.417 S=1.0523	S V	☐ Su Theta Phi Resolu d-Thet d-Phi	15	90 270	eg.	Tot-g	eq-swee	4



6: Click "Update NEC-file"

Optimizer and Evaluator (F12)

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!)