

# Antenna modeling

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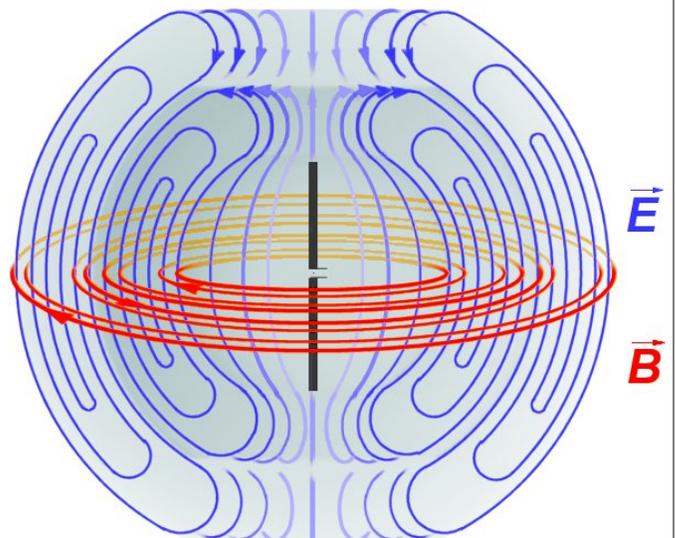
Eric Hansen, KB1VUN  
Twin State Radio Club, May 2018

## What does an antenna do?

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Transition from feedline to space

- Transmitter → Feedline current → Accelerating charges → EM radiation
- EM wave → Accelerating charges → Feedline current → Receiver



## Antenna modeling

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How will an antenna design perform?

- Radiation pattern (where the waves go, azimuth & elevation)
- Impedance (antenna as a load)
- SWR (how much of my power actually radiates)
- EM field intensity

“What if” analyses: How do changes in antenna design affect performance?

EM theory enables all of these to be calculated from the current flowing in the antenna. The hard part is calculating the current.

## Computing antenna currents

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EM theory (Maxwell, et al) gives equations for current on a thin straight wire in empty space.

EM theory gives principles for calculating current on an arbitrary conductor, in the vicinity of other conductors and dielectrics (ground, trees, vehicles, buildings), but no formulas.

Computational methods, based on EM theory, calculate antenna currents from the sources and the antenna geometry.



Wikipedia

## Numerical Electromagnetics Code (NEC)

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NEC-2: Lawrence Livermore Laboratory, 1981 <http://nec2.org>

Antenna is modeled as thin straight wires, divided into segments, coded on punch cards. Other cards describe sources and control the simulation

/2	5	10	15	20	30	40	50	60	70	80			
GW		NS		XW1		YW1	ZW1		XW2	YW2	ZW2		RAD
<i>element type</i> <i>GW=wire</i>	<i>#segments</i>		<i>(x,y,z) of end 1</i>		<i>(x,y,z) of end 2</i>								<i>wire radius</i>

## Numerical Electromagnetics Code (NEC)

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NEC-2: Widely available, two major limitations

- Can't do tapered elements
- Can't do wires on or under the ground

but these have workarounds that extend NEC's capability to Yagis, verticals, and Beverage antennas.

NEC-4: Newer, more accurate, more expensive

## Contemporary versions of NEC-2, for hams

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EZNEC, by W7EL (Windows, free & paid)	<a href="http://www.eznec.com">www.eznec.com</a>
4NEC2, by Arie Voors (Windows, free)	<a href="http://www.qsl.net/4nec2">www.qsl.net/4nec2</a>
MNOTA-GAL, by JE3HHT, DL2KQ, DL1PBD (Windows, free)	<a href="http://gal-ana.de/basicmm/en/">gal-ana.de/basicmm/en/</a>
CocoaNEC, by W7AY (MacOS, free)	<a href="http://www.w7ay.net">www.w7ay.net</a>

### Improvements:

- Better user interface: cards replaced by spreadsheet & menu options.
- Graphical outputs
- CocoaNEC also has a C-like programming language.
- CocoaNEC and 4NEC2 have optimization capabilities.

## Where to read about using NEC-2 (mostly EZNEC)

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ARRL Antenna Handbook, Chapter 8

Steve Nichols G0KYA, “An Introduction to Antenna Modeling”

<http://www.arrl.org/shop/An-Introduction-to-Antenna-Modeling/>

Four articles by L.B. Cebik in QST, Nov 2000 – Feb 2001

[http://wireless.ictp.it/school\\_2005/download/nec2/nec\\_part1.pdf](http://wireless.ictp.it/school_2005/download/nec2/nec_part1.pdf) ... [nec\\_part4.pdf](#)

Greg Ordy W8WWV, “How to Start Modeling Antennas Using EZNEC”

[http://www.arrl.org/files/file/Antenna Modeling for Beginners Supplemental Files/EZNEC Modeling Tutorial by W8WWV.pdf](http://www.arrl.org/files/file/Antenna%20Modeling%20for%20Beginners%20Supplemental%20Files/EZNEC%20Modeling%20Tutorial%20by%20W8WWV.pdf)

Steve Stearns K6OIK, “Antenna Modeling for Radio Amateurs”

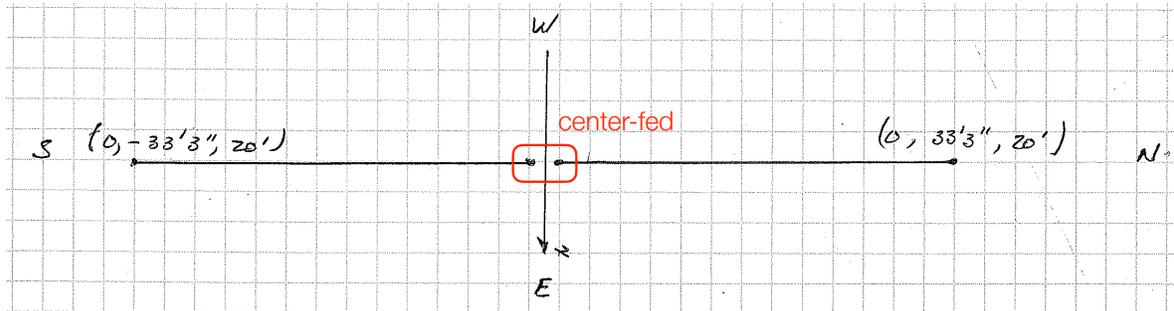
<http://www.fars.k6ya.org/docs/>

[K6OIK,\\_Antenna\\_Modeling\\_for\\_Radio\\_Amateurs,\\_ARRL\\_Pacificon,\\_Oct\\_2017.pdf](#)

NEC-2 Manual, Part III: User’s Guide, <http://www.nec2.org>

## Simple example: 40m dipole

Good to sketch it out first, get (x,y,z) coordinates of endpoints of wires.



## Simple example: 40m dipole

Transfer antenna elements to spreadsheet (CocoaNEC)

Rule of thumb:  
≥10 segments per  
half-wavelength  
(should be odd)

Dipole40m-flattop

Edit: \_\_\_\_\_

#	x	y	z	x	y	z	radius	segments	transform	*
1	0 ft	-33' 3.0"	20 ft	0 ft	33' 3.0"	20 ft	0.032 in	22		

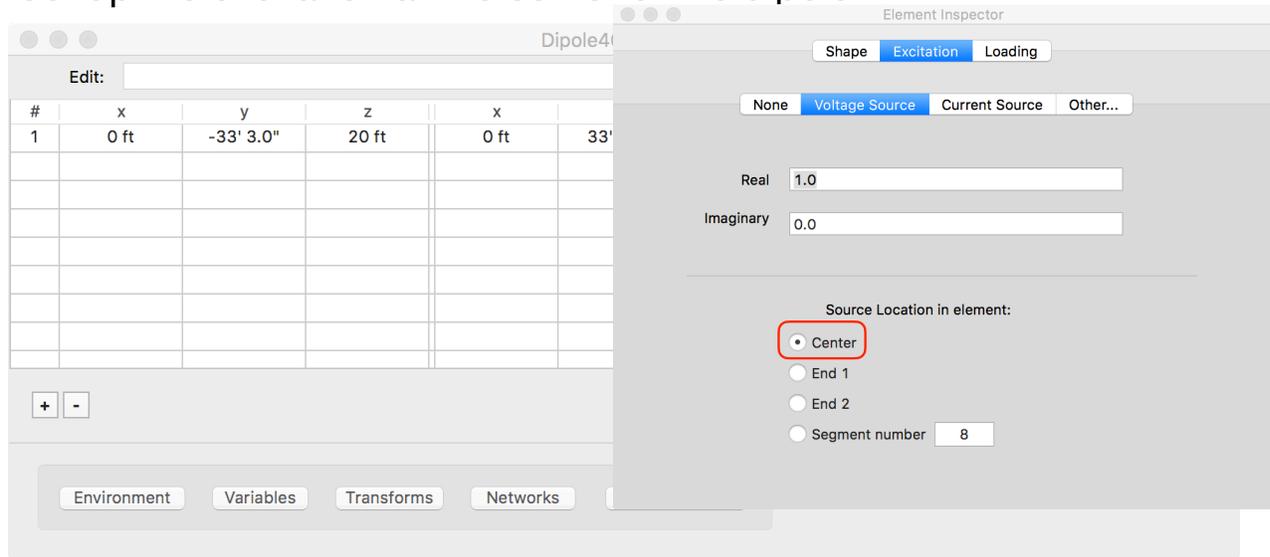
In the model, dipole is one long wire, not two (software inserts the source).  
For an inverted-VEE or sagging dipole, use two wires and a third, short wire in the center for the feedpoint.

+ -      Display: English - mixed      Show Cards

Environment   Variables   Transforms   Networks   Output Control      Run

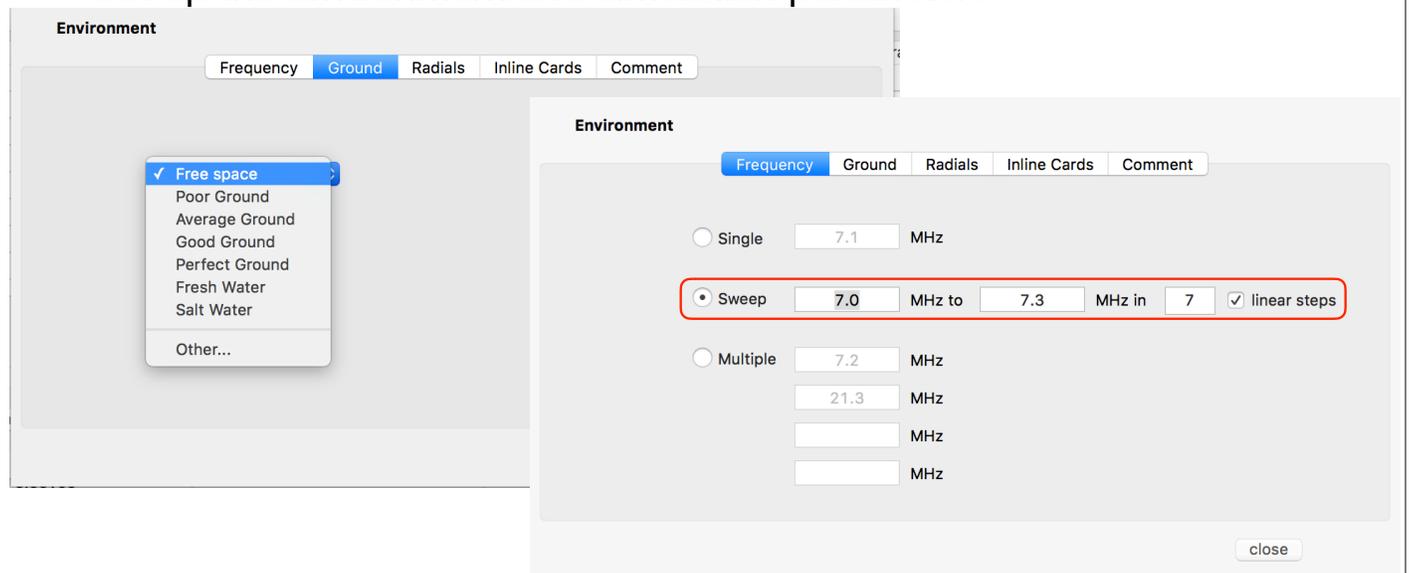
# Simple example: 40m dipole in space

Set up the excitation at the center of the dipole



# Simple example: 40m dipole in space

Set up the environment and simulation parameters



# Simple example: 40m dipole in space

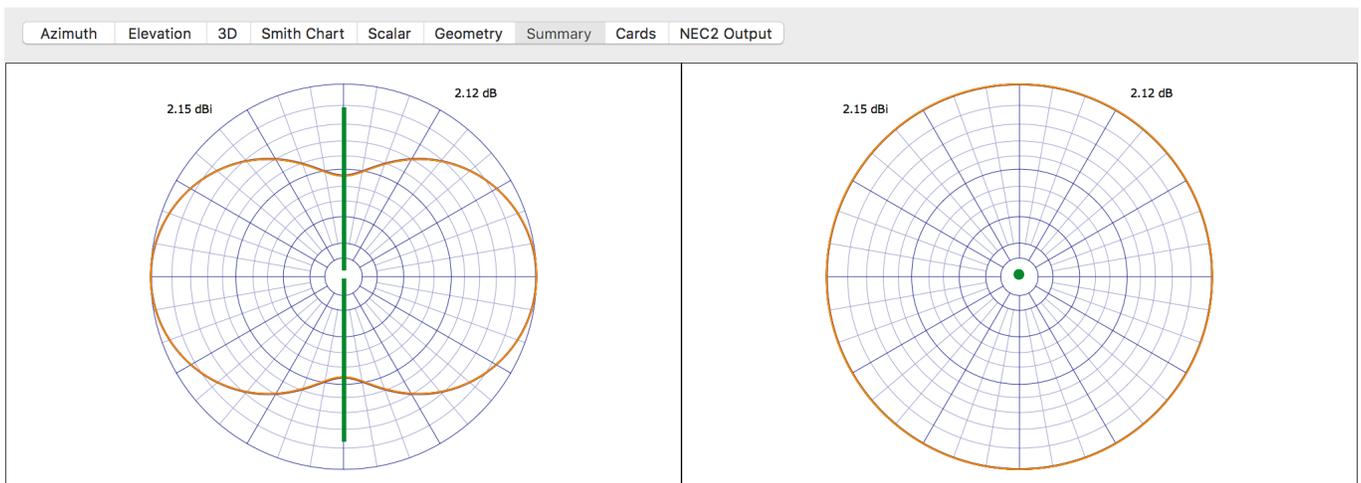
This is the card deck that results (“assembly language”)

```

CM COCOANEC 2.0 2018-05-12 07:40 2018-05-12 07:40 comments
CE -----
GW 1 23 0.000000 -10.1346 6.096000 0.000000 10.13460 6.096000 8.14E-04 wire
GE 1 end geometry (ground plane present)
FR 0 1 0 0 7.000000 0.000000 frequency (7 MHz)
GN 1 0 0 ground (free space)
EX 0 1 8 1 1.000000 0.000000 excitation (voltage source)
XQ execute
RP 0 1 360 1000 70.00000 0.000 0.000 1.000 5.000E+03
RP 0 360 1 1000 -90.000 0.000000 1.000 0.000 5.000E+03 radiation pattern
RP 0 91 120 1001 0.000 0.000 2.000 3.000 5.000E+03 request
XQ
FR 0 1 0 0 7.050000 0.000000 frequency (7.05 MHz)
GN 1 0 0
EX 0 1 8 1 1.000000 0.000000
(etc)

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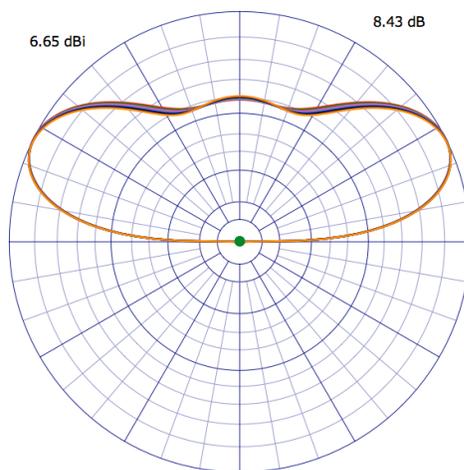
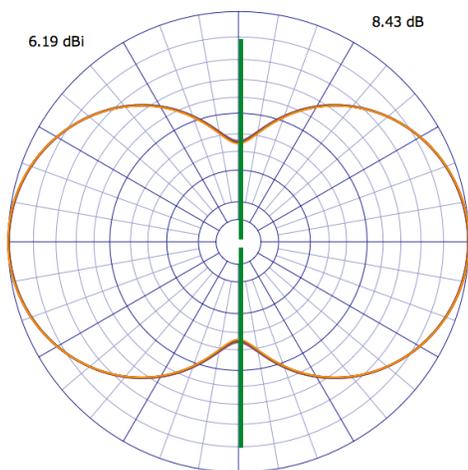
# Radiation pattern. Free space.



In free space, antenna height (z) is effectively ignored.

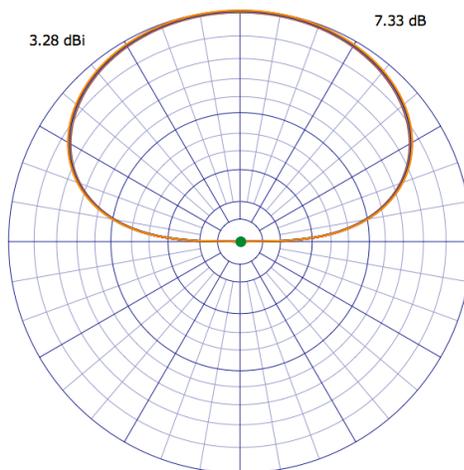
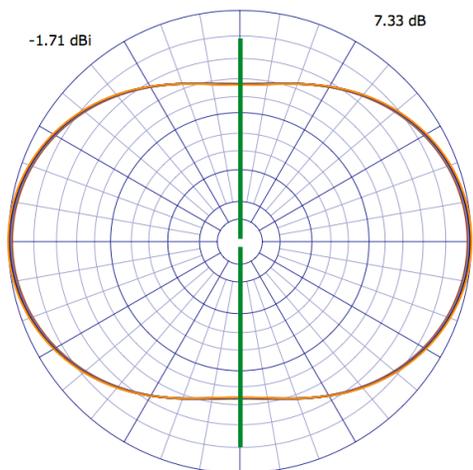
## Behavior over poor ground. Height 66.5 feet.

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## Behavior over poor ground. Height 20 feet.

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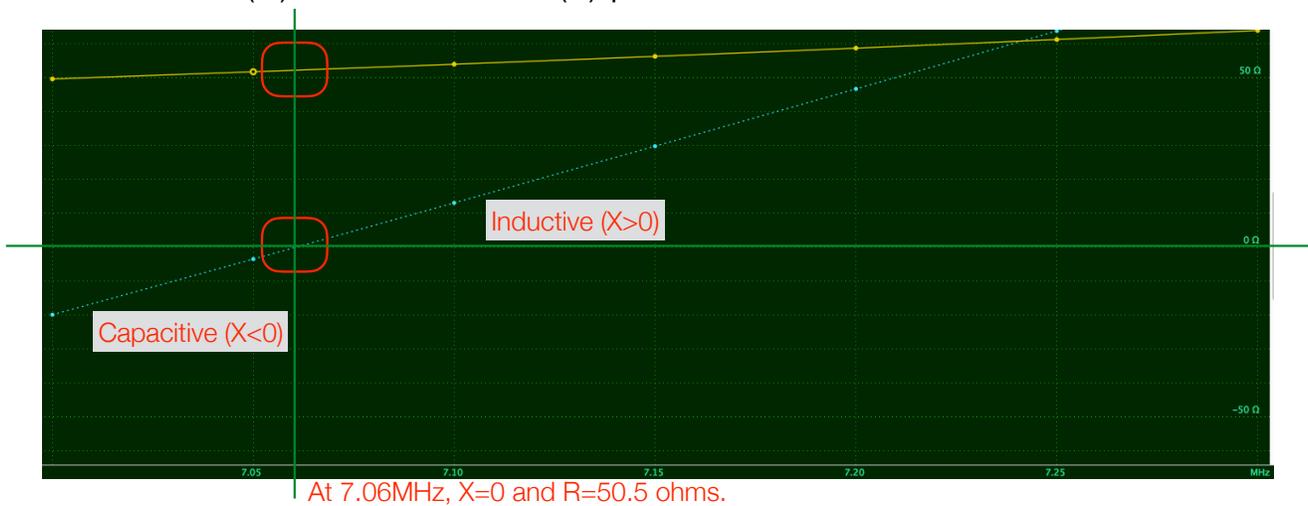


# SWR vs frequency. Free space.



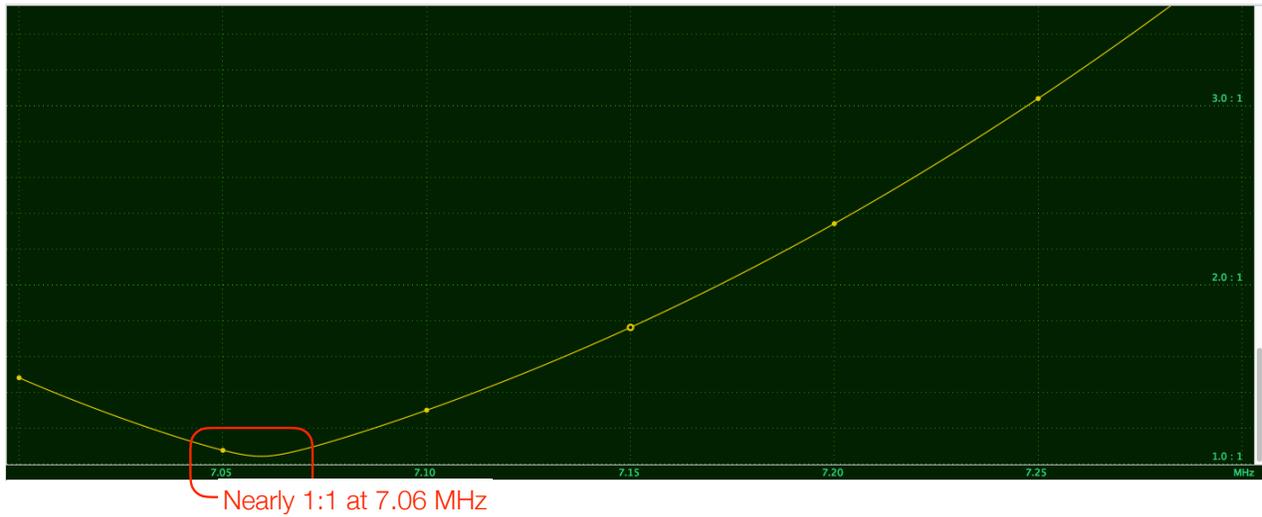
# Behavior over perfect ground. Height 20 feet.

Resistance (R) and reactance (X) plot



# Behavior over perfect ground. Height 20 feet.

Standing wave ratio



# Behavior over poor ground. Height 20 feet.

Standing wave ratio



Frequency: 7.125 MHz  
Z = 89.2 - j5.2 Ω  
|Z| = 89.3 Ω  
VSWR 1.79 : 1  
Return loss = 10.9 dB

# Another example: 6m wire Moxon

Input antenna elements into spreadsheet

Moxon6wire-built

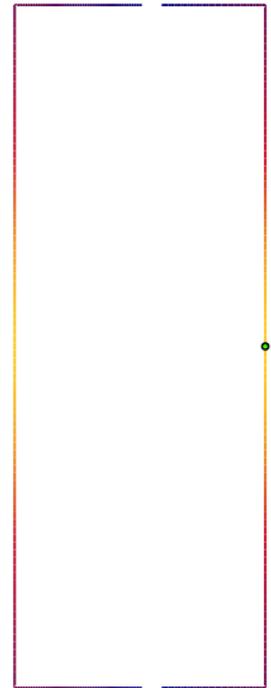
driven element

#	x	y	z	x	y	z	radius	segments	transform	*
1	-1.0795	0.3946	3.9624	1.0795	0.3946	3.9624	0.8128 mm	89		
2	-1.0795	0.3946	3.9624	-1.0795	0.0688	3.9624	0.8128 mm	32		
3	1.0795	0.3946	3.9624	1.0795	0.0688	3.9624	0.8128 mm	32		
4	-1.0795	5.3975 mm	3.9624	-1.0795	-0.3946	3.9624	0.8128 mm	48		
5	-1.0795	-0.3946	3.9624	1.0795	-0.3946	3.9624	0.8128 mm	89		
6	1.0795	-0.3946	3.9624	1.0795	5.3975 mm	3.9624	0.8128 mm	48		

reflector

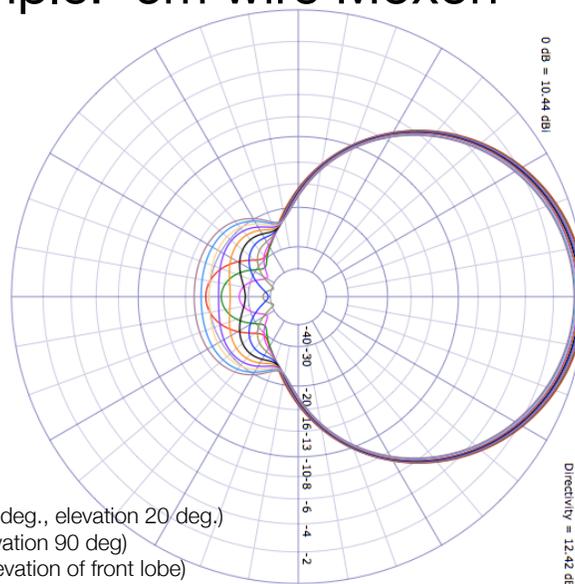
Display: Metric Show Cards

Environment Variables Transforms Networks Output Control Run

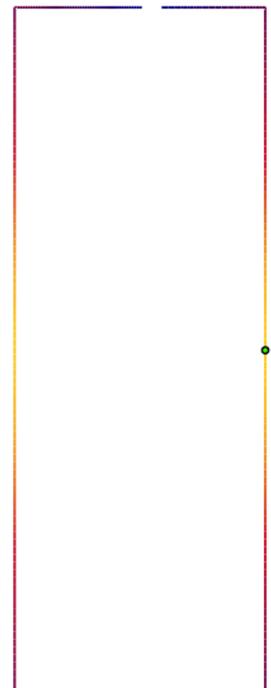


# Another example: 6m wire Moxon

Radiation pattern



Directivity: 12.42 dB  
 Max gain: 10.44 dBi (azimuth 89 deg., elevation 20 deg.)  
 Front-to-back ratio: 9.12 dB (elevation 90 deg)  
 Front-to-back ratio: 17.39 dB (elevation of front lobe)  
 Front-to-rear ratio: 7.49 dB  
 Average Gain: 0.6388 (1.946 dB)



## What else can be modeled?

- Coaxial cables
- LC matching networks, traps, loading coils
- Radials for vertical antennas

## One more example: 20m vertical, using EZNEC

The screenshot shows the EZNEC software interface. The 'Wires' table is visible, with the 'Conn' column highlighted in red for wires 2 through 5. The table data is as follows:

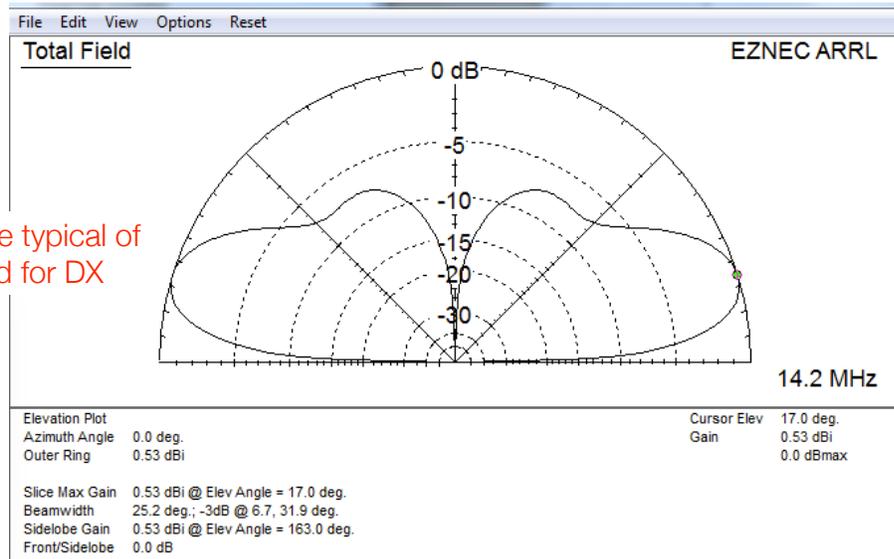
No.	End 1			Conn	End 2			Diameter (in)	Segs	Insulation	
	X (ft)	Y (ft)	Z (ft)		X (ft)	Y (ft)	Z (ft)			Diel C	Thk (in)
1	0	0	15	W2E1	0	0	32.229	#14	11	1	0
2	0	0	15	W3E1	0	17.479	15	#14	11	1	0
3	0	0	15	W4E1	-17.479	0	15	#14	11	1	0
4	0	0	15	W5E1	0	-17.479	15	#14	11	1	0
5	0	0	15	W1E1	17.479	0	15	#14	11	1	0

Below the table, there is a 3D coordinate system with X, Y, and Z axes. A vertical wire (wire 1) is shown along the Z-axis from 0 to 15 feet. Four radial wires (wires 2, 3, 4, and 5) are shown extending from the top of the vertical wire to the ground plane (Z=0) at various angles. The EZNEC ARRL logo is visible in the top right corner of the software window.

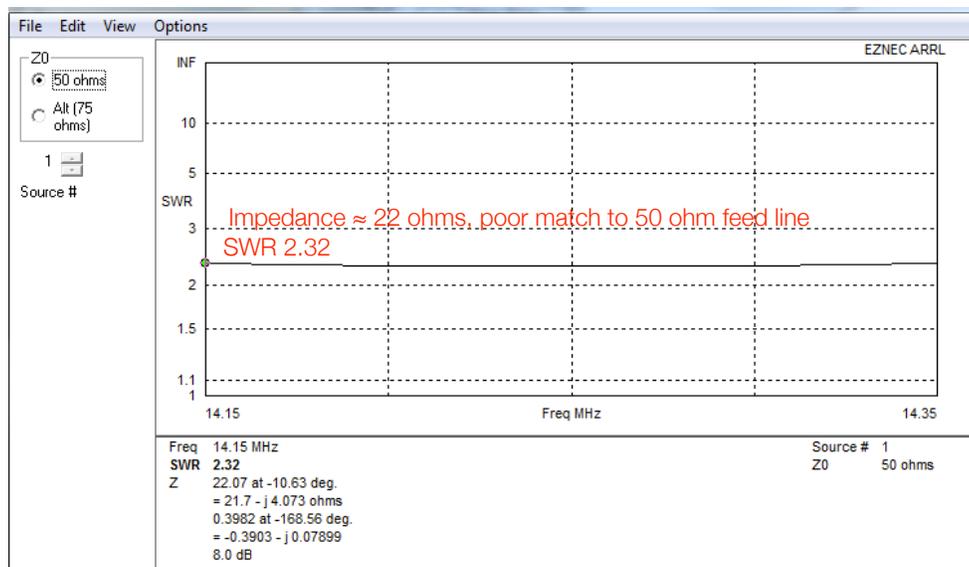
Specify connections explicitly (e.g., Wire 2 End 1)

# 20m vertical, elevation pattern

Low takeoff angle typical of verticals, good for DX



# 20m vertical, SWR



# 20m vertical, bend radials toward ground

**Wires**

No.	End 1			Conn	End 2			Conn	Diameter (in)	Segs	Insulation	
	X (ft)	Y (ft)	Z (ft)		X (ft)	Y (ft)	Z (ft)				Diel C	Thk (in)
1	0	0	15	W2E1	0	0	31.729		#14	11	1	0
2	0	0	15	W3E1	0	14.318	4.97446		#14	11	1	0
3	0	0	15	W4E1	-14.318	0	4.97446					
4	0	0	15	W5E1	0	-14.318	4.97446					
5	0	0	15	W1E1	14.318	0	4.97446					

Context Menu:

- Connect End to...
- Change Coord by...
- Change Length by...
- Change Length to...
- Multiply Length by...
- Divide Length by...
- Elevation Rotate End...**
- Azimuth Rotate End...

Move Image:

X: [Left Arrow] [Right Arrow]

Y: [Left Arrow] [Right Arrow]

Z: [Left Arrow] [Right Arrow]

Reset

Center Ant Image

EZNEC ARRL

# 20m vertical, bend radials toward ground

**Total Field**

EZNEC ARRL

14.2 MHz

Elevation Plot: 0.0 deg  
Azimuth Angle: 0.0 deg  
Outer Ring: 0.62 dBi

Cursor Elev: 19.0 deg  
Gain: 0.62 dBi  
0.0 dBmax

Slice Max Gain: 0.62 dBi @ Elev Angle = 19.0 deg  
Beamwidth: 28.9 deg, -3dB @ 7.3, 36.2 deg  
Sidelobe Gain: 0.62 dBi @ Elev Angle = 161.0 deg  
Front/Sidelobe: 0.0 dB

**SWR**

EZNEC ARRL

Excellent match to 50 ohms

14.15 Freq MHz 14.35

Source # 1  
Z 50 ohms

Freq 14.15 MHz  
SWR 1.006  
Z 51.9 at -4.18 deg  
= 51.76 - j3.785 ohms

## Summary

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- NEC-2 software is effective for modeling wire-like antennas, including antennas made from tubing, like Yagis.
- Several NEC-based applications are available for Windows and MacOS platforms.
- Can predict radiation patterns, impedance, SWR, and in some cases, optimize designs.
- A variety of print tutorials and references make it easy to get started.