EZNEC Pro/2+ v. 7.0.1 (64 bit calc. eng.)

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PA3A

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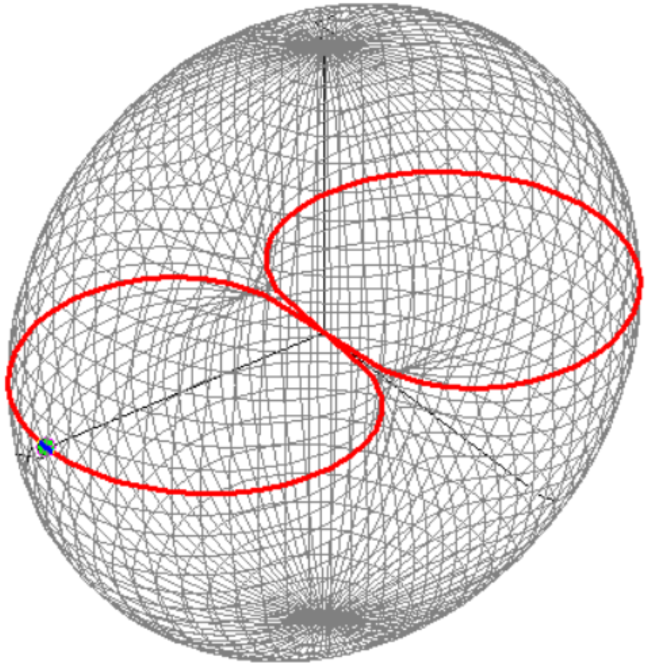
EZNEC (by Roy Lewallen W7EL)



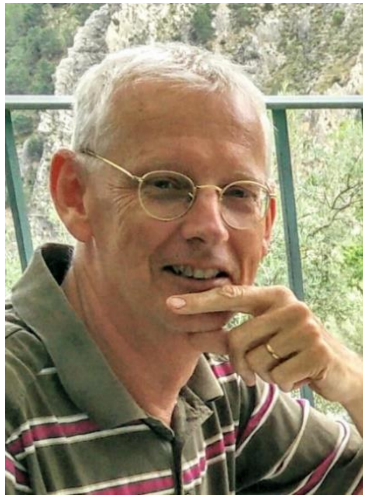
Experiences with EZNEC

(Formerly : ELNEC)

What can it do

Arie Kleingeld PA3A

User of Roy Lewallen’s software since 1995



Disclaimer:

- This presentation is **not**:
    - An EZNEC user training
    - Manual for EZNEC (That has many pages and is very thorough)
    - Theory of EM-fields or how NEC works
    - An antenna theory course
    - Comparison of different antenna software packages or simulation methods

- This is:
    - Introduction in modeling antennas, in this case with EZNEC
    - Demo of some EZNEC features
    - At the same time answers to some questions on antennas
    - Examples of constructed antennas and conclusions
    - Suitable to every hamradio operator that wants to experiment with antennas

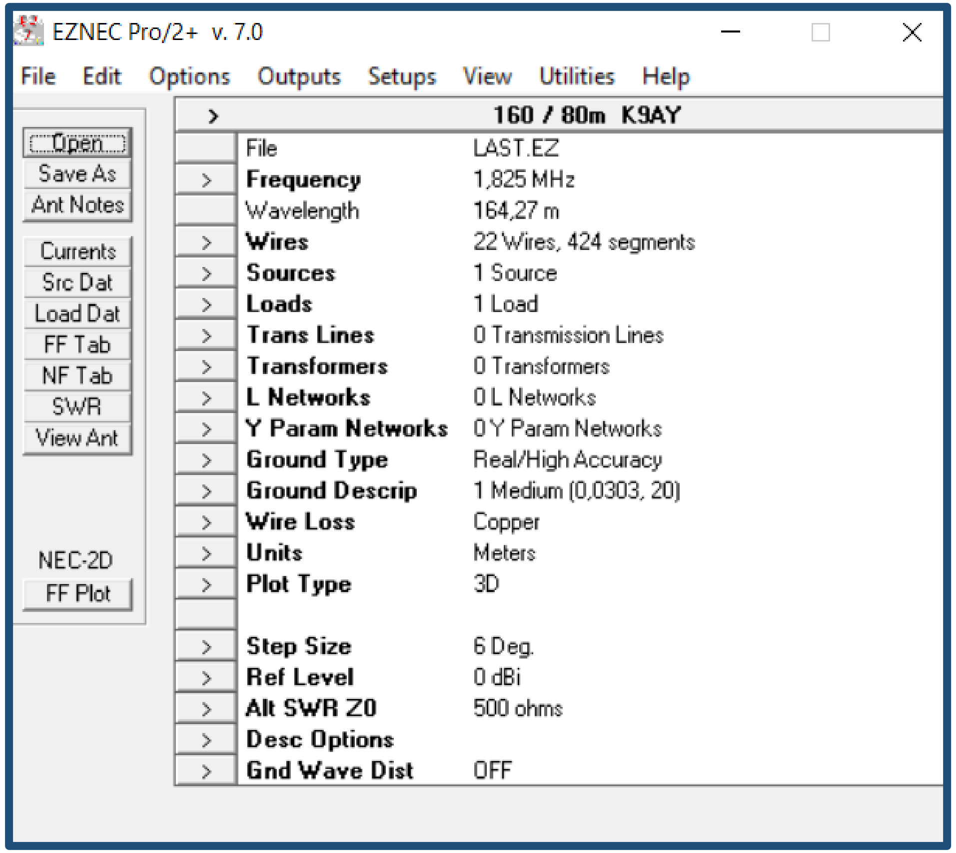
- **Over all:**
  If you keep the restrictions of NEC in mind,
  Then with EZNEC, you can learn a lot about antennas and their 'behaviour'

If you keep the restrictions of NEC in mind,

You can learn a lot about antennas and their ‘behaviour’

Contents

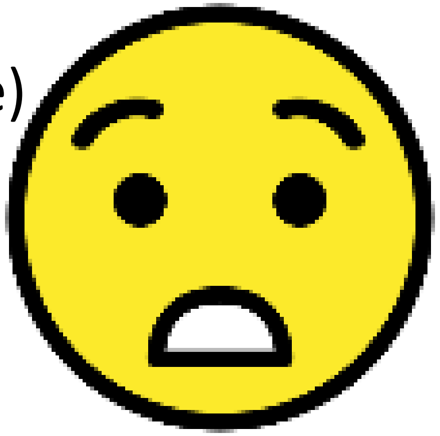
- Introduction NEC and EZNEC (Easy NEC)
- Couple of demo's
- A short break
- EZNEC features and possibilities
- At the same time: Checking some antenna statements* or assumptions with the help of EZNEC (it's impossible not to...)



* Statements that we can check with EZNEC

- Insulated wire or bare ware, does it make a difference?
- 80m NVIS antennas have be just above ground level (how low is that?)
- A vertical is <u>always</u> much better for DX than a dipole (low take-off angle)
- Influence by surroundings; if it’s there, then how much?
- Dipole antenna, center fed with coax and balun (common mode choke)

  Simulation with and without a choke
- …?



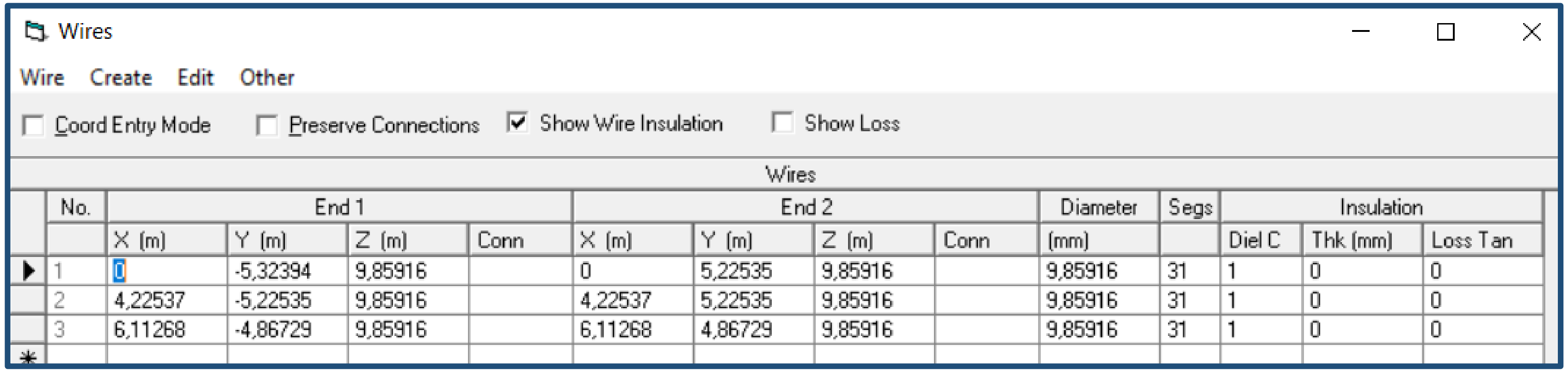
Introduction NEC: What is NEC

- NEC = Numerical Electromagnetics Code
- NEC-2 → Most used ***free*** application (core of EZNEC-7)
- NEC-3 → not used very much
- NEC-4 → used by professionals (licence fee in the order of $ 800+)
- NEC-5 → also a licence fee: $110
- MiniNEC → different code, already free for everyone for a very long time
- NEC-differences: we'll come back on that later

Software with NEC-2 e.g.:
- YO (Yagi Optimizer, from early days)
- 4NEC2 (free)
- EZNEC (fee: $100+)
- MMANA (free, uses MiniNEC)

Purpose: create proper user interface around NEC

(EZ)NEC

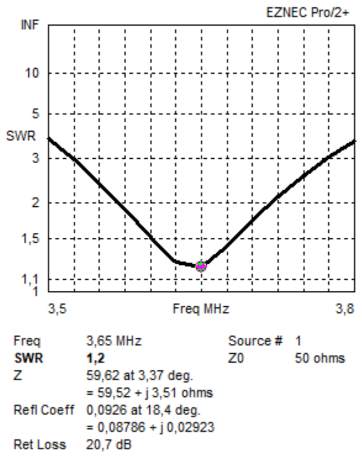


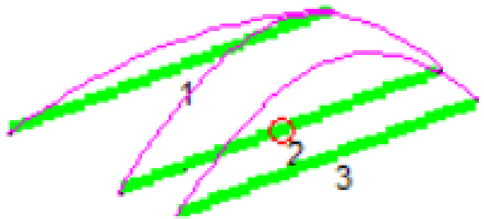
No.	End 1 X (m)	End 1 Y (m)	End 1 Z (m)	End 1 Conn	End 2 X (m)	End 2 Y (m)	End 2 Z (m)	End 2 Conn	Diameter (mm)	Segs	Insulation Diel C	Insulation Thk (mm)	Insulation Loss Tan
1	0	-5,32394	9,85916		0	5,22535	9,85916		9,85916	31	1	0	0
2	4,22537	-5,22535	9,85916		4,22537	5,22535	9,85916		9,85916	31	1	0	0
3	6,11268	-4,86729	9,85916		6,11268	4,86729	9,85916		9,85916	31	1	0	0

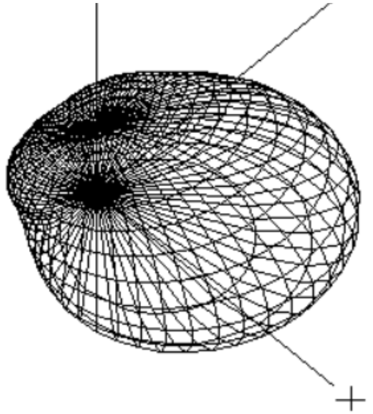
- Input:
  - **Wires:** Length, diameter and position (= coordinates)
  - **Source:** Where do we feed the antenna
  - **Loads:** Inductor, capacitance, resistor, and combinations
  - **Ground Type:** Ground, do we account for that or not
  - **Ground Descrip:** Properties of the ground (sand, seawater, etc.)
  - **Wire Loss:** Loss in the wires (copper, aluminium, etc.)
  - **Trans Lines:** Transmission lines
  - **L-network** and **Transformer**

  - Surroundings (towers, other antennas, raingutter, etc. → more **Wires**)

(EZ)NEC







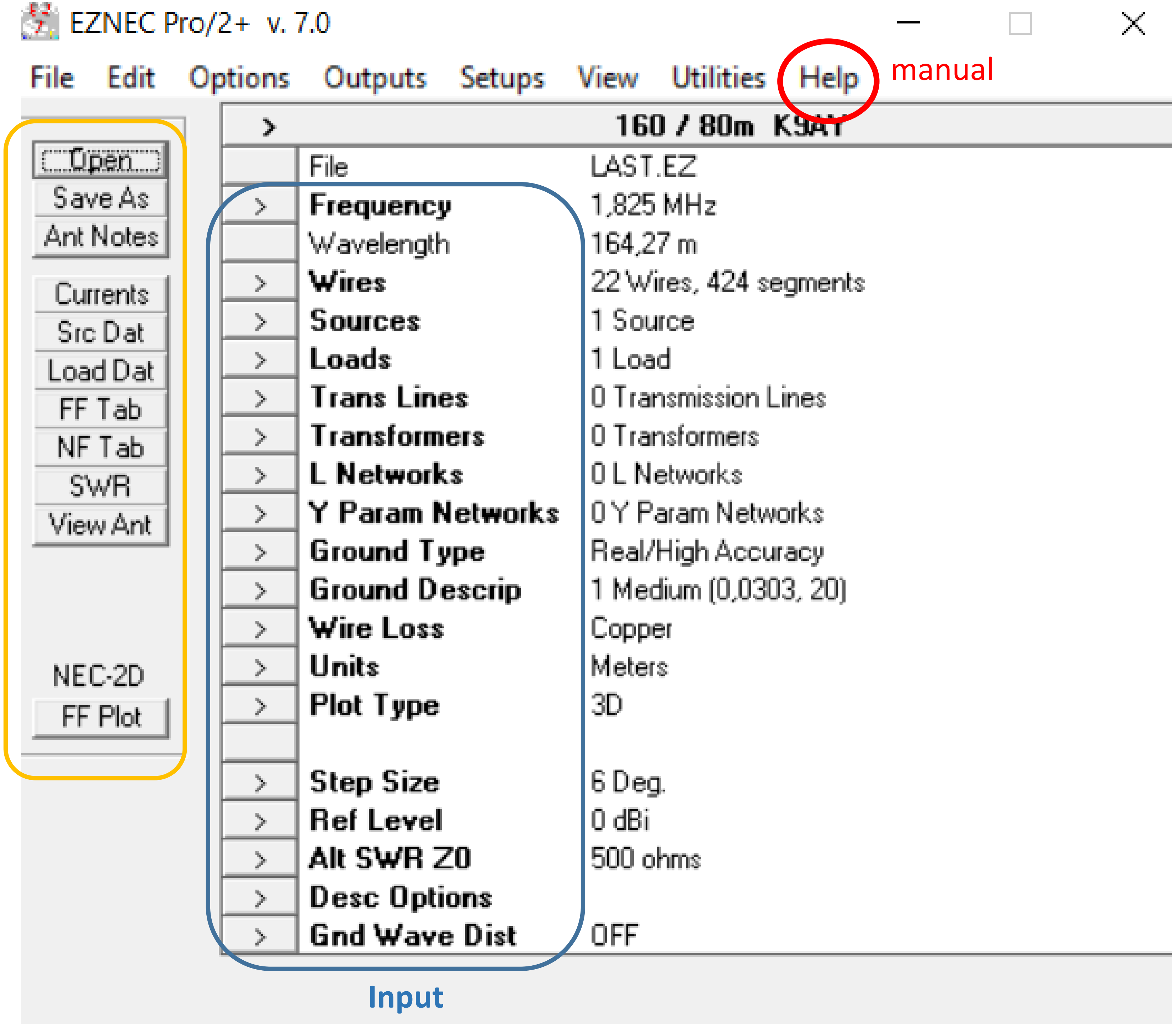
- Output:
  - **FF* Plot:** Radiation pattern (2D/3D), Gain, F/B ratio
  - **Src Data:** Feed impedance at the source
  - **SWR:** SWR-curve
  - **Average Gain (standard 0 dBi):** From this we can draw conclusions on loss in conductors, ground and loads
  - **Currents:** Current and phase in all conductors (each segment)
  - **NF Tab:** Fieldstrength near the antenna – so called Near Field

* FF = Far Field

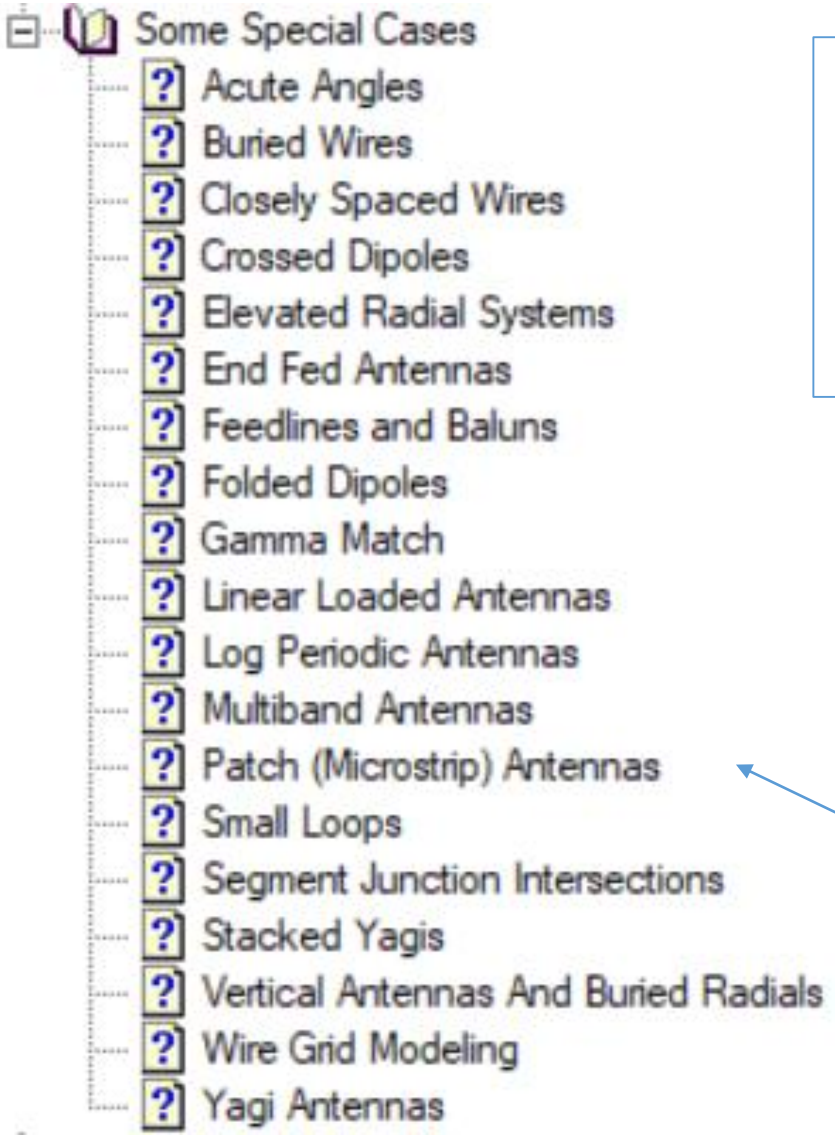
EZNEC ‘interface’ around NEC

‘Control Center’

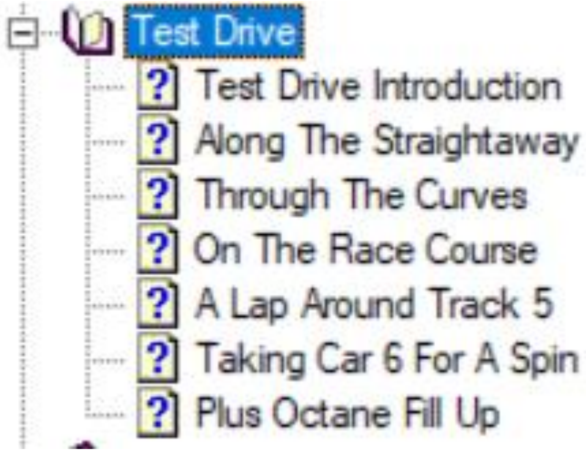
Commands



From the EZNEC-manual



- Learn the Basics for using EZNEC.
- **YOU HAVE TO DO THIS**



- Warnings for possible mistakes when simulating certain antennas
- Solutions to get the model behave as much as possible like in the real world
- Which NEC-engine (2, 4.2 or 5) is best suited for what purpose

Feature Availability vs Engine Choice
for EZNEC Pro/2+ and EZNEC Pro/4+

Feature	Calculating Engine: EZCalcD (NEC-2D)	EZCalc4D (NEC-4D)	External NEC-4.2	External NEC-5
Insulated wires	✓	✓	✓	
Buried wires		✓	✓	✓
Unconnected 1-seg wires with insertion objects	✓	✓	✓	
Split sources	✓	✓	✓	
Two ground media	✓	✓	✓	
Two ground media with MININEC ground	✓	✓		
Ground Wave calculation with MININEC ground	✓	✓		✓
Near Field calculation with MININEC ground	✓	✓		✓
Real/High Accuracy (GN2) ground	✓	✓	✓	
Real/Extended Accuracy (GN3) ground		✓	✓	✓

Notes:
1) Features not listed such as lossy transmission lines, L networks, and transformers are available with all engines.
2) The EZCalc4D engine is available only to existing EZNEC Pro/4 users.
3) External NEC-4.2 and/or NEC-5 engines must be purchased from LLNL.

AC6LA

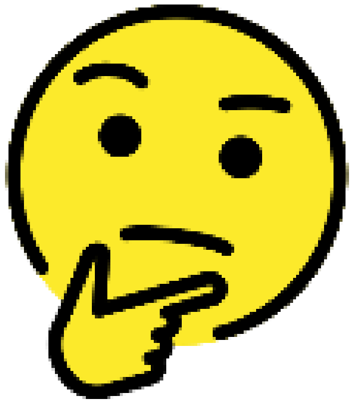
Different NEC versions & features

Source: EZNEC Manual

- NEC-2 for insulated wire
- NEC-5 for radials **in** the ground

MiniNEC comparison, see e.g. http://on5au.be/content/amod/amod56.html

The theory of NEC………



- Very specific, not easy
- Laws of Maxwell (EM-fields) are *only* the beginning…
- Numerical solutions instead of 'magic' or 'assumptions'

- Important for the radio amateur:
  - Wires are split up in so called **segments** (no limit in EZNEC-7)
    Each segment plays its part in the calculations for currents, EM-fields, loads, ground, etc.
  - EZNEC warns you if there are too many or too few segments in a wire

NEC: If you want to read something… (75 pages of formulas)

The portion of the i^{th} basis function on segment i is then

$$f_i^o(s) = A_i^o + B_i^o \sin k(s - s_i) + C_i^o \cos k(s - s_i) \tag{26}$$

$$|s - s_i| < \Delta_i/2 .$$

If $N^- \neq 0$ and $N^+ \neq 0$, end conditions are

$$\frac{\partial}{\partial s} f_i^o(s) \Big|_{s = s_i - \Delta_i/2} = a_i^- Q_i^- , \tag{27}$$

$$\frac{\partial}{\partial s} f_i^o(s) \Big|_{s = s_i + \Delta_i/2} = a_i^+ Q_i^+ . \tag{28}$$

If $N^- = 0$ and $N^+ \neq 0$, end conditions are

$$f_i^o(s_i - \Delta_i/2) = \frac{1}{k} X_i \frac{\partial}{\partial s} f_i^o(s) \Big|_{s = s_i - \Delta_i/2} \tag{29}$$

$$\frac{\partial}{\partial s} f_i^o(s) \Big|_{s = s_i + \Delta_i/2} = a_i^+ Q_i^+ . \tag{30}$$

$$G_\rho^V = C_1 \frac{\partial^2}{\partial\rho\partial z} k_1^2 V'_{22} + C_1 \frac{k_1^2 - k_2^2}{k_1^2 + k_2^2} \frac{\partial^2}{\partial\rho\partial z} G_{21} , \tag{136}$$

$$G_z^V = C_1\left(\frac{\partial^2}{\partial z^2} + k_2^2\right) k_1^2 V'_{22} + C_1 \frac{k_1^2 - k_2^2}{k_1^2 + k_2^2}\left(\frac{\partial^2}{\partial z^2} + k_2^2\right) G_{21} \tag{137}$$

$$G_\rho^H = C_1 \cos\phi \left(\frac{\partial^2}{\partial\rho^2} k_2^2 V'_{22} + k_2^2 U'_{22}\right) - C_1 \cos\phi \frac{k_1^2 - k_2^2}{k_1^2 + k_2^2}\left(\frac{\partial^2}{\partial\rho^2} + k_2^2\right) G_{21} , \tag{138}$$

$$G_\phi^H = -C_1 \sin\phi \left(\frac{1}{\rho}\frac{\partial}{\partial\rho} k_2^2 V'_{22} + k_2^2 U'_{22}\right) + C_1 \sin\phi \frac{k_1^2 - k_2^2}{k_1^2 + k_2^2}\left(\frac{1}{\rho}\frac{\partial}{\partial\rho} + k_2^2\right) G_{21} , \tag{139}$$

From: Burke & Poggio (Lawrence Livermore Laboratory)
Numerical Electromagnetics Code
Method of Moments
Part I

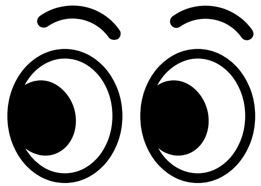
EZNEC - Wisdom

Wrong Model → Fairy Tale

(Garbage In → Garbage Out)

Although EZNEC warns you for *some* mistakes in the model.

Good to know



- EZNEC is not a design software package
  You yourself are the designer and EZNEC simulates what you designed
- You yourself are the optimizer also, or use AutoEZ with EZNEC
  (4NEC2 does have optimization tooling)
- ‘RTFM’
  This is critical for success

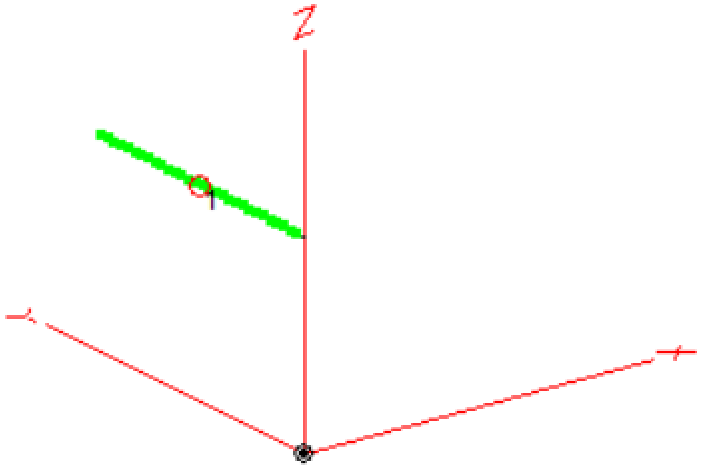
Let’s do some work: Simulations

- Dipole antenna
- Vertical GP
- Vertical with radials on the ground (**not** in the ground)

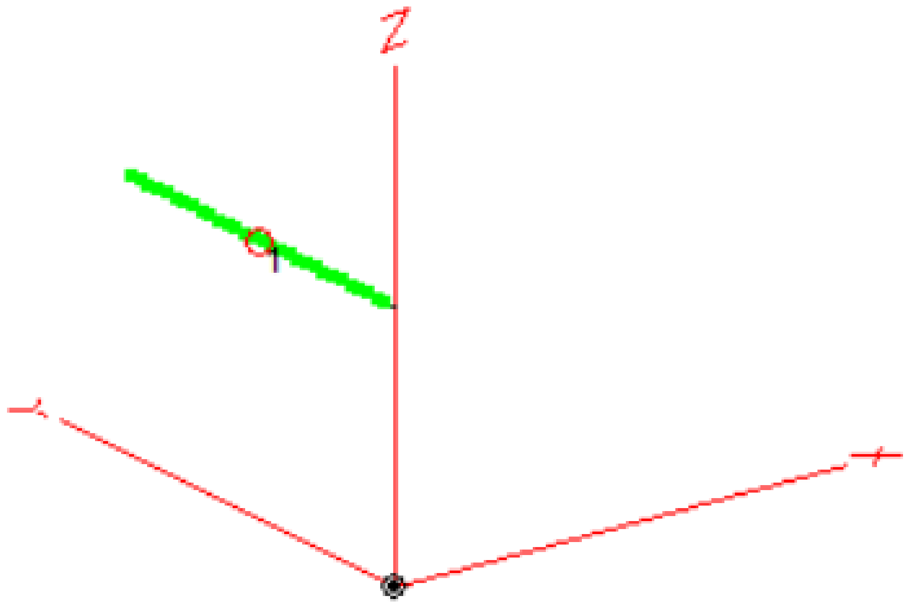
- Some variations:
  - Wire diameter
  - Insulated or bare wire
  - # segments (‘mini-dipoles’) in a wire
  - Height above the ground (NVIS?)

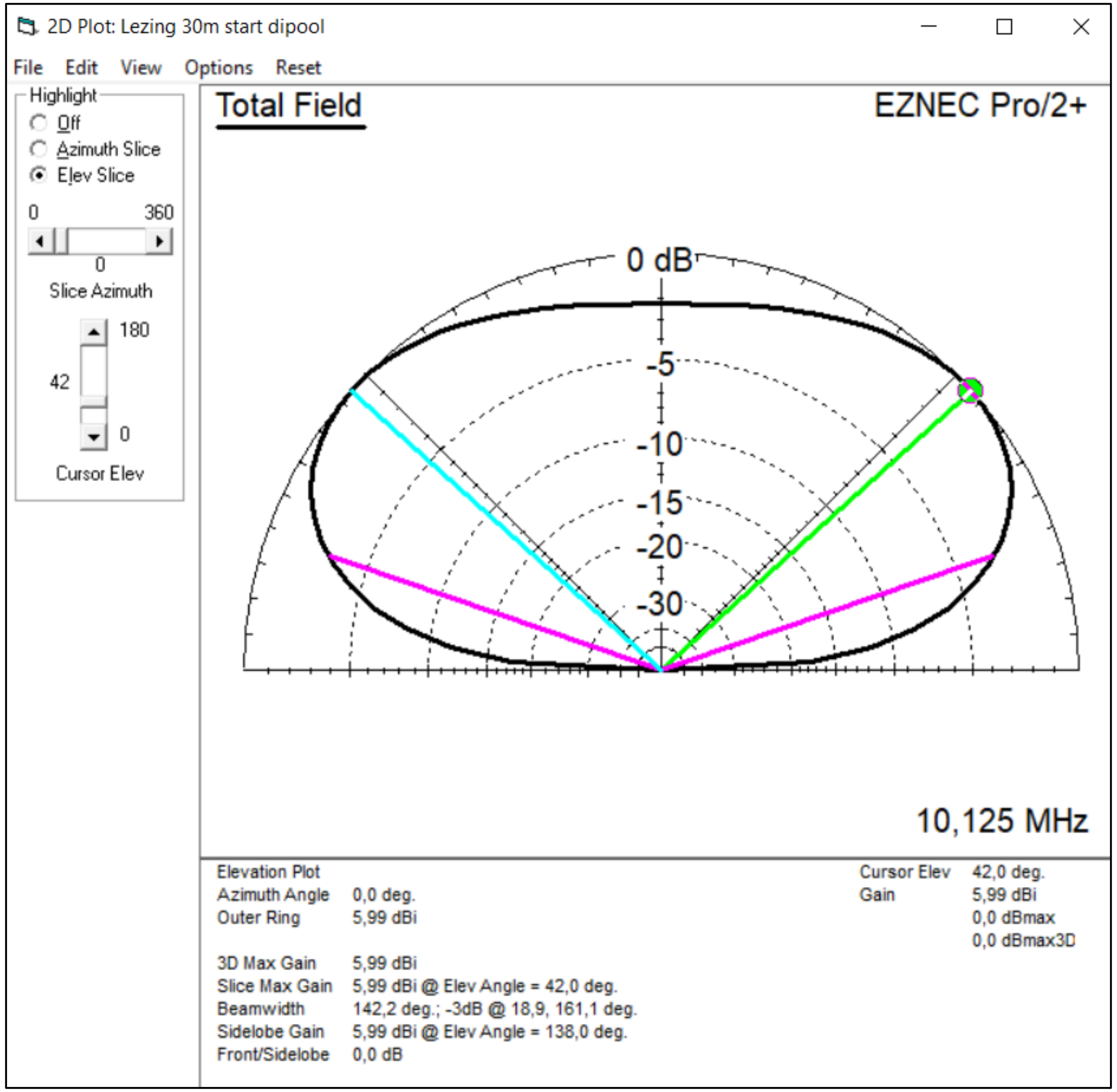
Demo Dipole Antenna

- Build a dipole for 30m (start with the file: Bydipole.ez)
- How about the SWR
- Tune the dipole to lowest SWR on the 30m frequency
- Save the radiation pattern

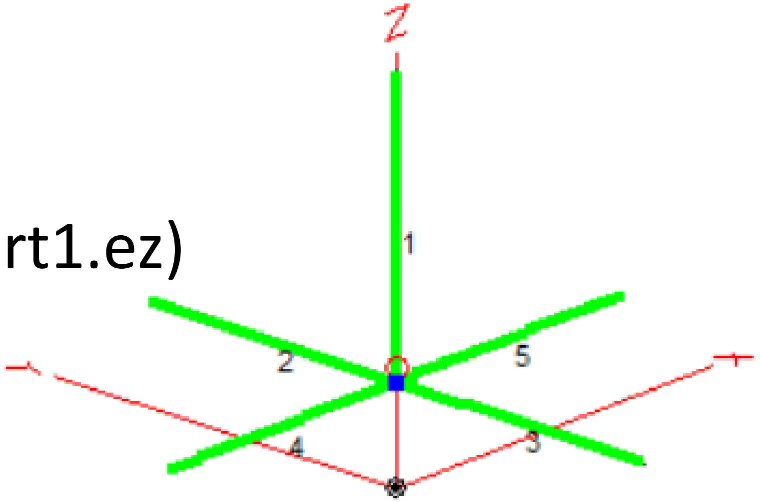


30m dipole antenne, h = 10m





Demo Verticals

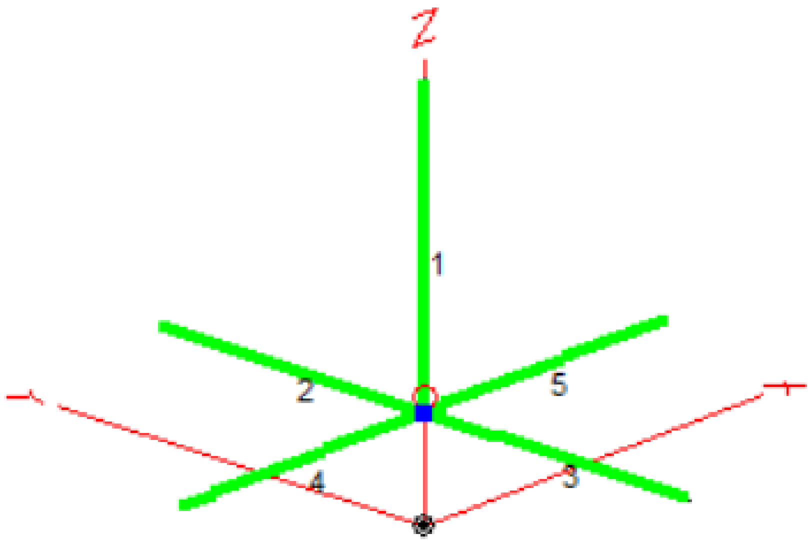


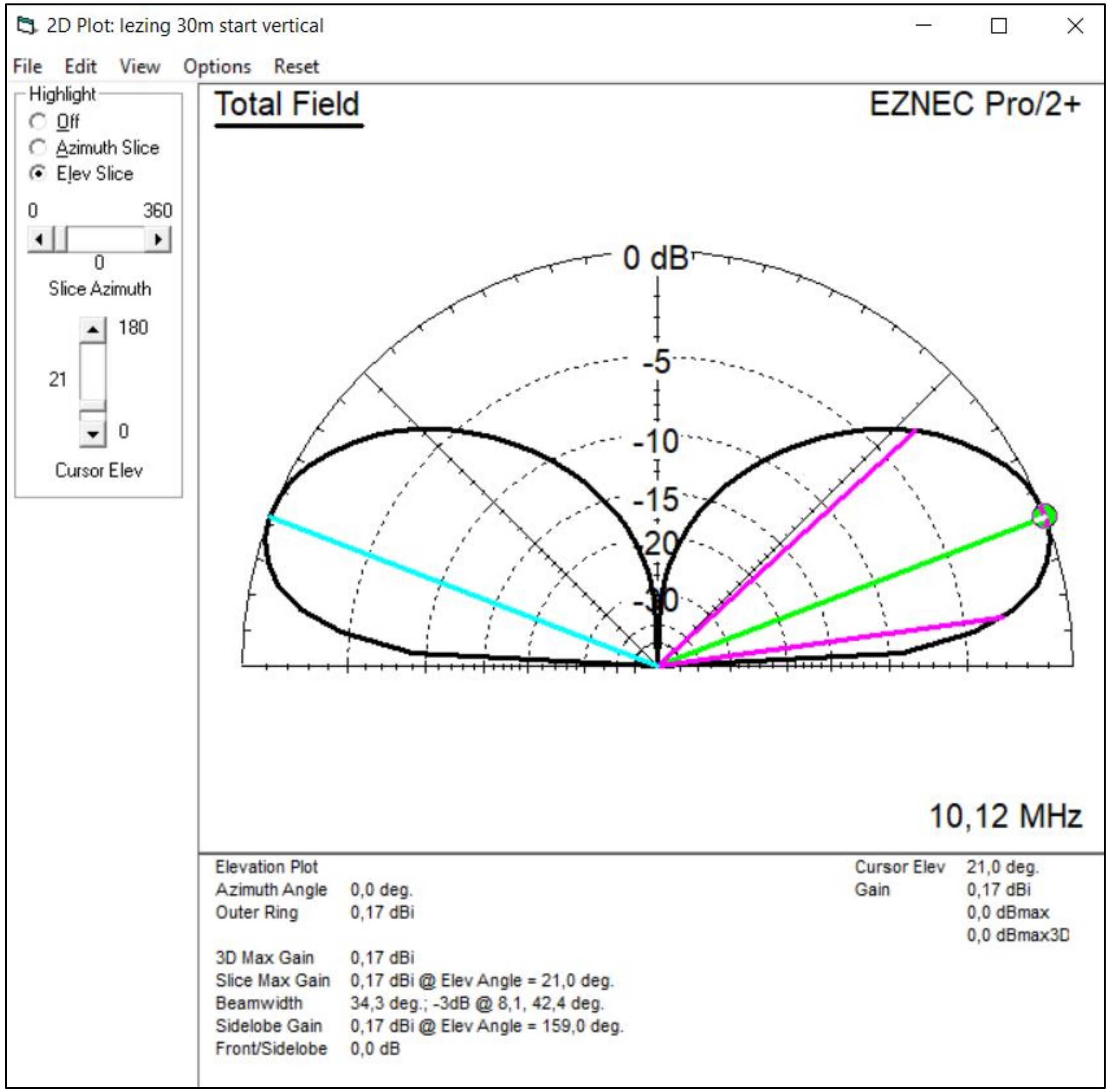
- Build a GP for 30m with 4 radials (Start with : vert1.ez)
- Tune it to right frequency
- Save the radiation pattern

- Build a 30m vertical with 20 radials on the ground
- Tune it to right frequency
- Save the radiation pattern

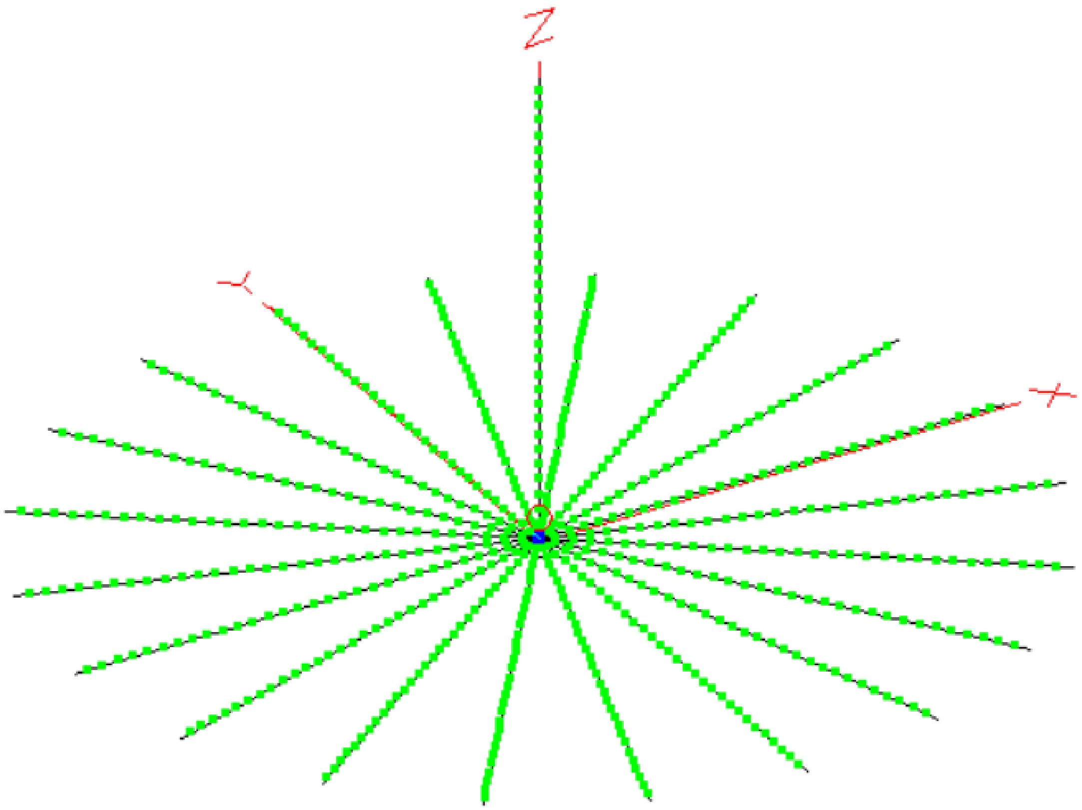
- Compare the radiation pattern of the ‘normal’ vertical to the GP-version
- Compare the two verticals to the 30m dipole, we just made

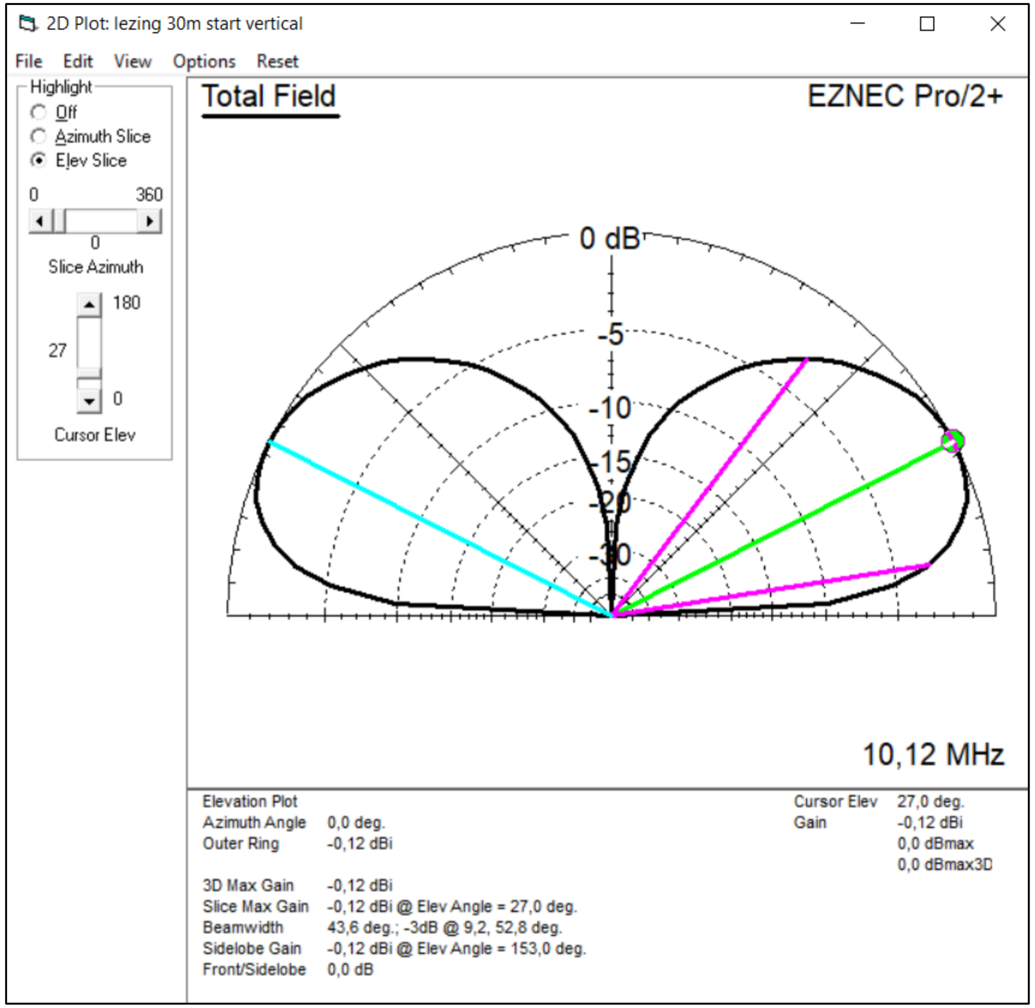
Vertical with 4 horizontal (elevated) radials



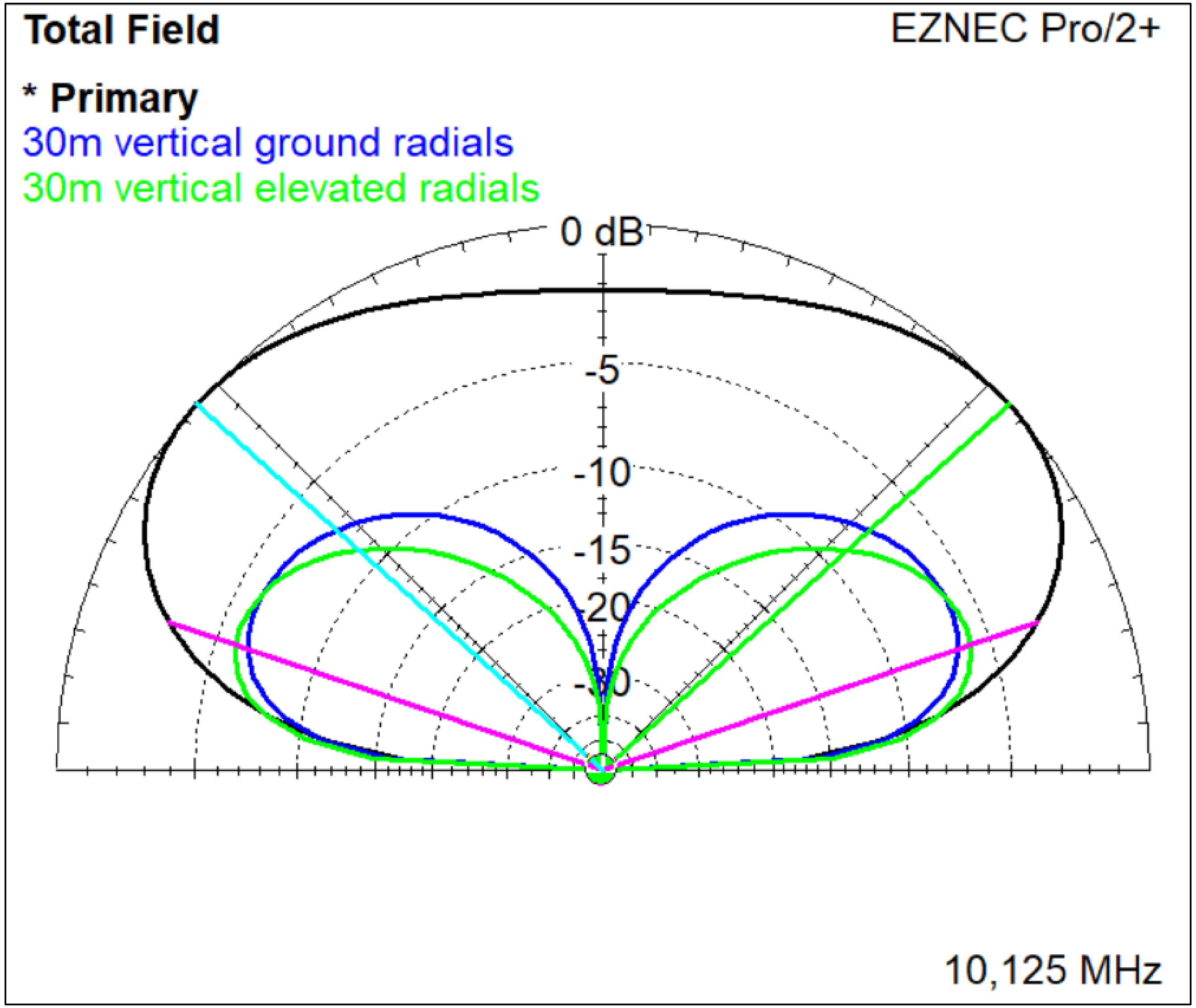


30m vertical with radials on the ground



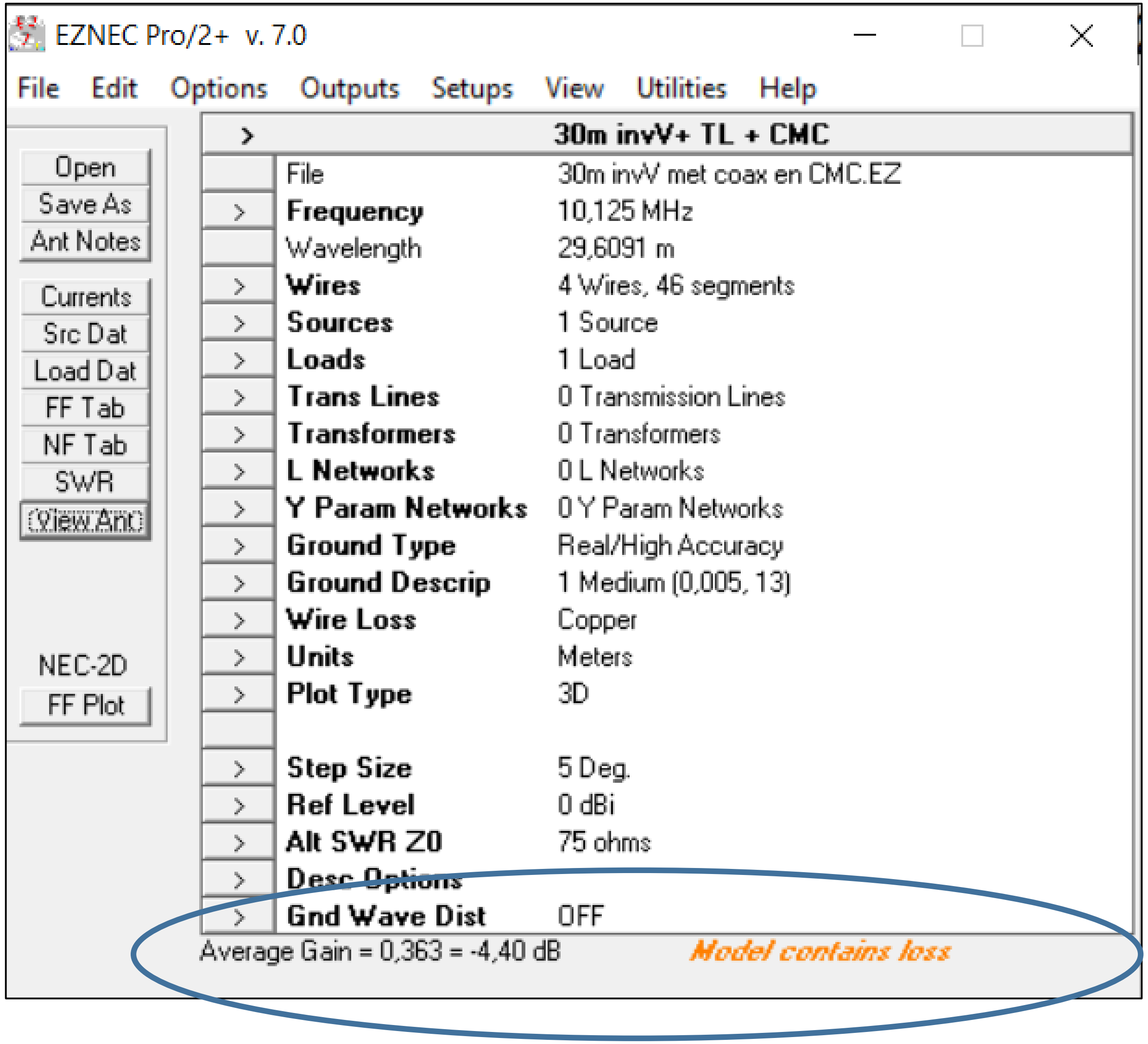


Dipole antenna ('primary') compared to the two verticals

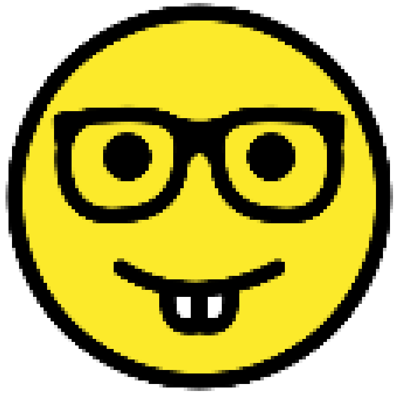


The FF 3D plot and the Average Gain

- Check the model with a 3D plot. EZNEC then reports the **'Average Gain'.**
  That 'Average Gain', simulated with the antenna **in free space or with perfect ground, and zero wire loss**, has to be very near unity =1 .
  If not, then the model is not entirely correct. This can happen e.g. if the segmentation of the wires is not correct or the source is not placed correctly.
- If the requirement Average Gain = 1 is met, loss in the antenna system can be predicted as demonstrated in the Dipole vs Verticals example.
- A tip:
  Try simulating a T2FD antenne in free space, zero wire loss, and zero load resistance and check the Average Gain. Then do the same with a load resistor of 800 ohm or so.
  The average gain will give a nice indication of the loss in the loading resistor. Ofcourse this can be done with real ground also.
  Also nice to use is the Currents-table where you can look up the current in the segments next to the resistor. i^2R will then give an indication of the loss also.



After the break: Typical situations to play with:



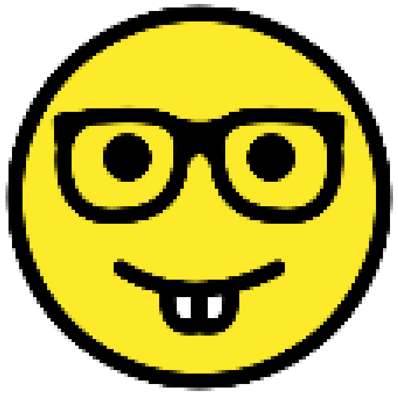
- Split source and normal source (when to use)
- What’s the effect of the number of segments in a wire
- Radiating feedline (coax with and without choke/balun)
    - What happens to the SWR
    - What happens to the radiation pattern
- Insulated antenna wire
- What is a good height above ground for an 80m NVIS antenna

Real world example:

- 160m vertical influencing a receiving antenna on 160m (e.g. a K9AY-loop)

A short break…

Typical situations to play with:



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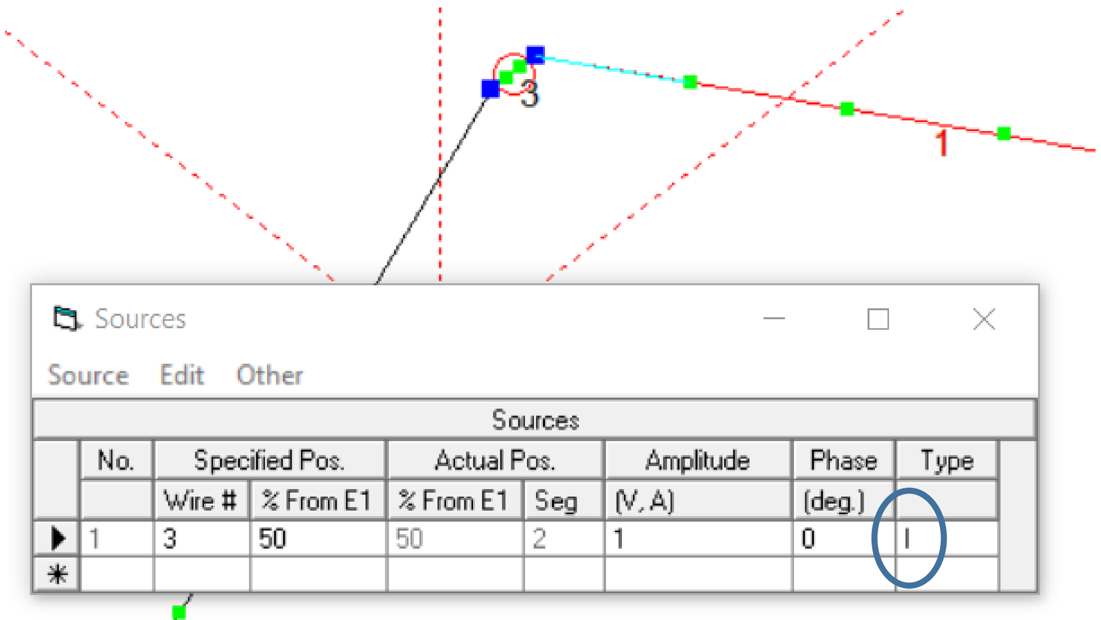
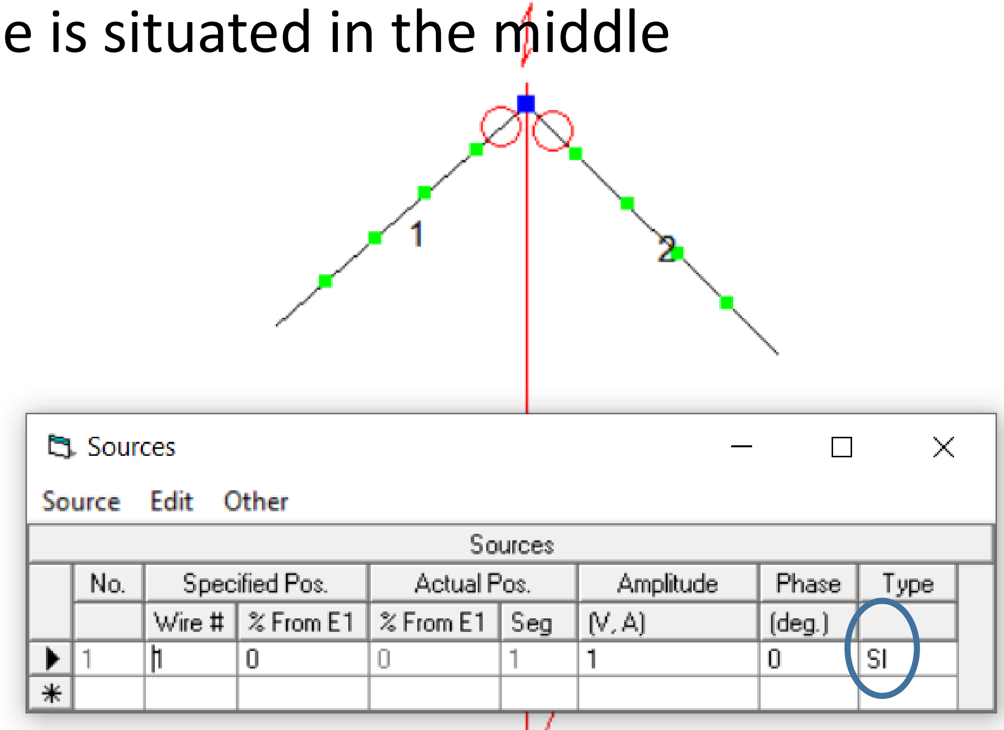
= source

Split source, normal source

- A feedpoint (source) wherever you want it to be
- In an inverted Vee (2 wires at an angle) you can:
  - Split the source (‘split source’ or SI for a split current source)
  - Add an extra wire where the current source is situated in the middle





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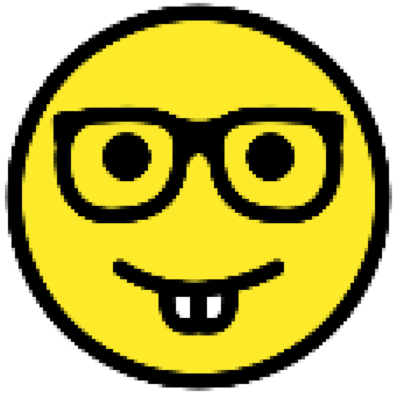
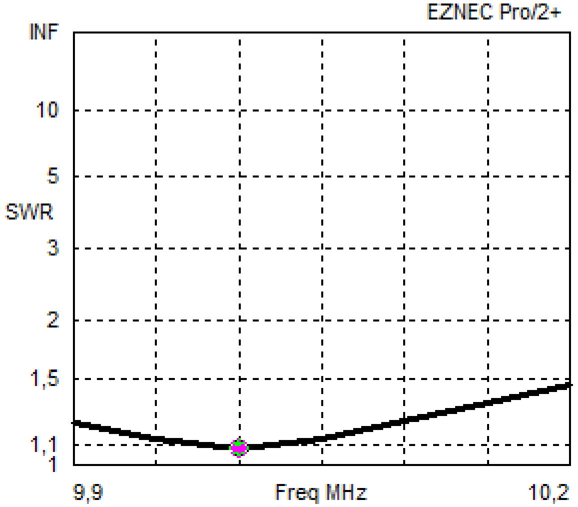


Real world example:

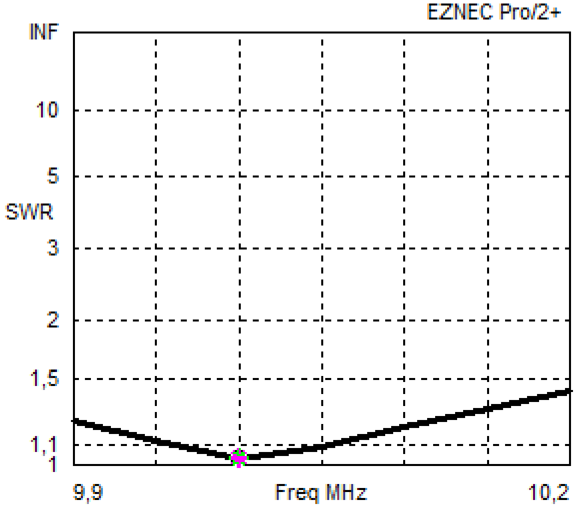
- 160m vertical influencing a receiving antenna on 160m (e.g. a K9AY-loop)

Riadials (4) of a 30m GP en #segments

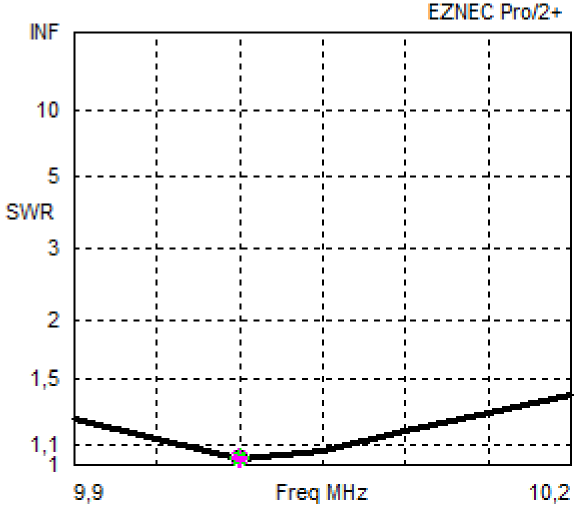
30m GP, f=10.12M	R	X
31+ 4x 10	55,4	+j11,4
31+ 4x 31	52,6	+j10,4
31+ 4 x tapered	51	+j9,6



Freq 10 MHz Source # 1
SWR **1,078** Z0 50 ohms
Z 53,89 at -0,2 deg.
= 53,89 - j 0,1923 ohms
Refl Coeff 0,03751 at -2,72 deg.
= 0,03747 - j 0,001782
Ret Loss 28,5 dB



Freq 10 MHz Source # 1
SWR **1,029** Z0 50 ohms
Z 51,22 at -0,85 deg.
= 51,21 - j 0,7599 ohms
Refl Coeff 0,01413 at -31,68 deg.
= 0,01202 - j 0,007417
Ret Loss 37,0 dB



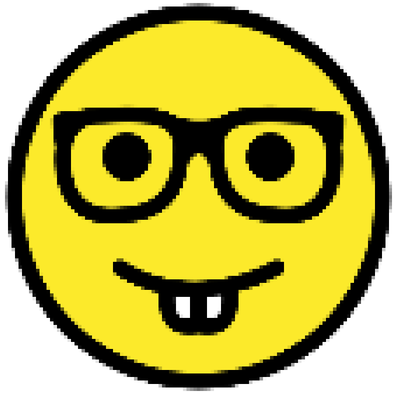
Freq 10 MHz Source # 1
SWR **1,026** Z0 50 ohms
Z 49,65 at -1,4 deg.
= 49,64 - j 1,211 ohms
Refl Coeff 0,01269 at -106,07 deg.
= -0,003513 - j 0,0122
Ret Loss 37,9 dB

Segments:
vertical 31
Radials 4 x 10

Segments:
Vertical 31
Radials 4 x 31

Segments:
Vertical 31
Radials 4 x 10 ‘tapered’

Typical situations to play with:



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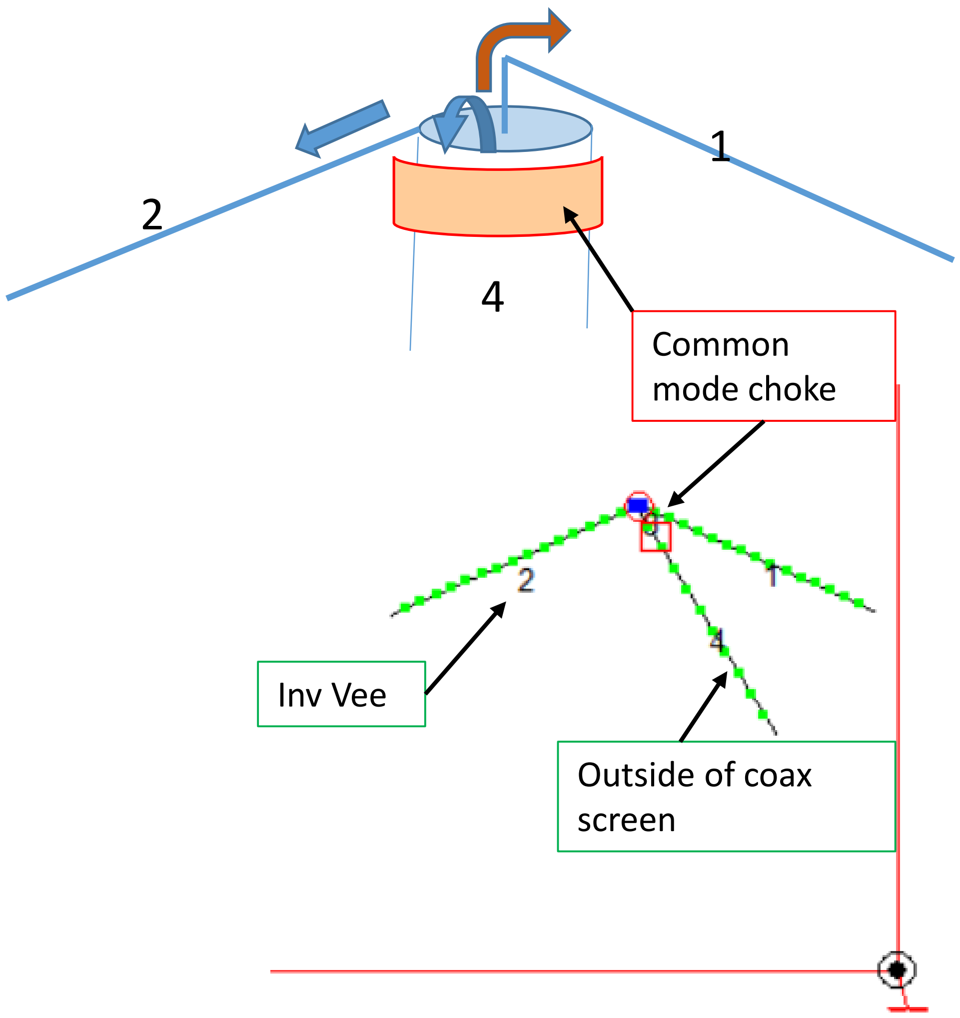
Dipole antenna coax fed (extra)

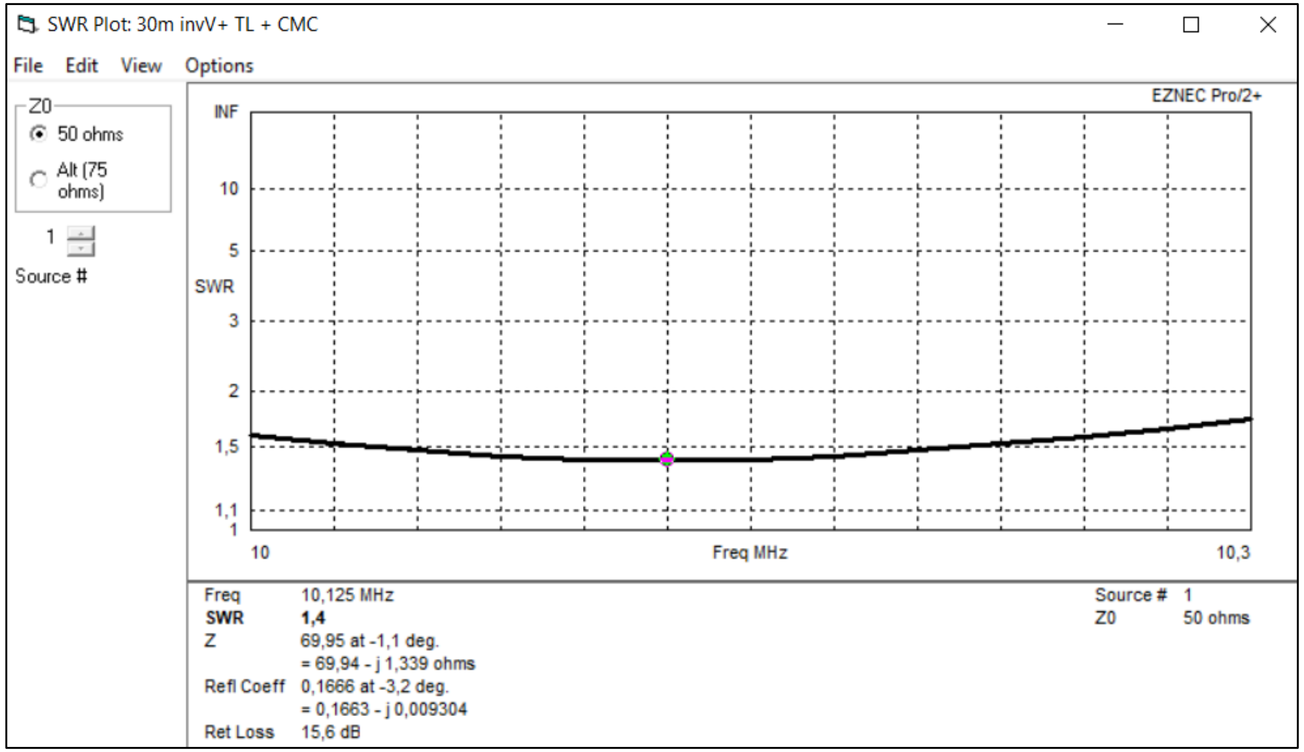


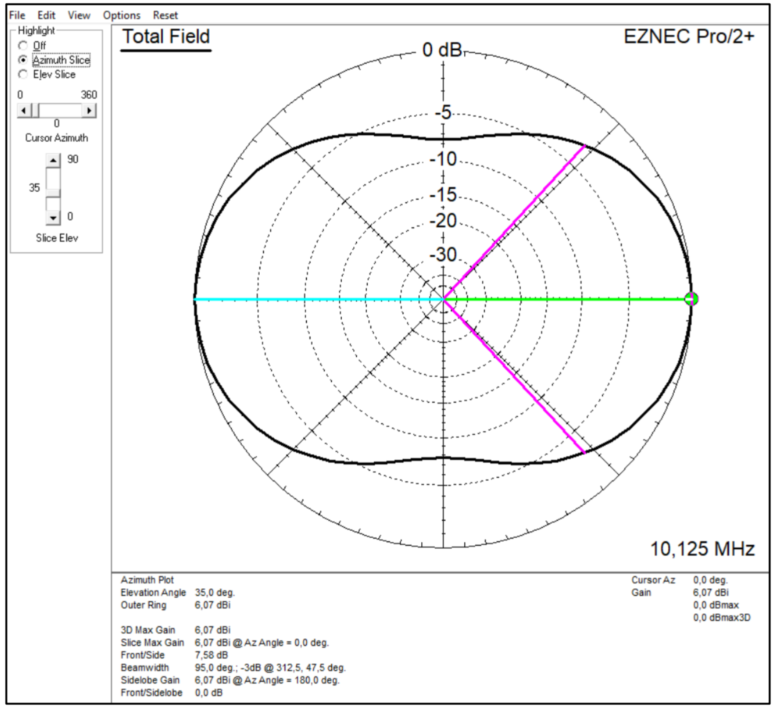
- Coax currents:
  - Current on center conductor
  - Screen (inside) current split
    - Antenna wire
    - Outside coax screen without a CMC
- Simulation:
  - Extra wire (wire 4) connected to one of the dipole wires (in this case wire 2). This extra wire simulates the outside of the coax shield. Try varying the impedance of the choke, say 1+j1 to 100 + j1000 or so
  - Calculate the FF plot (in 3D)
  - Calculate the Src Dat and SWR curve

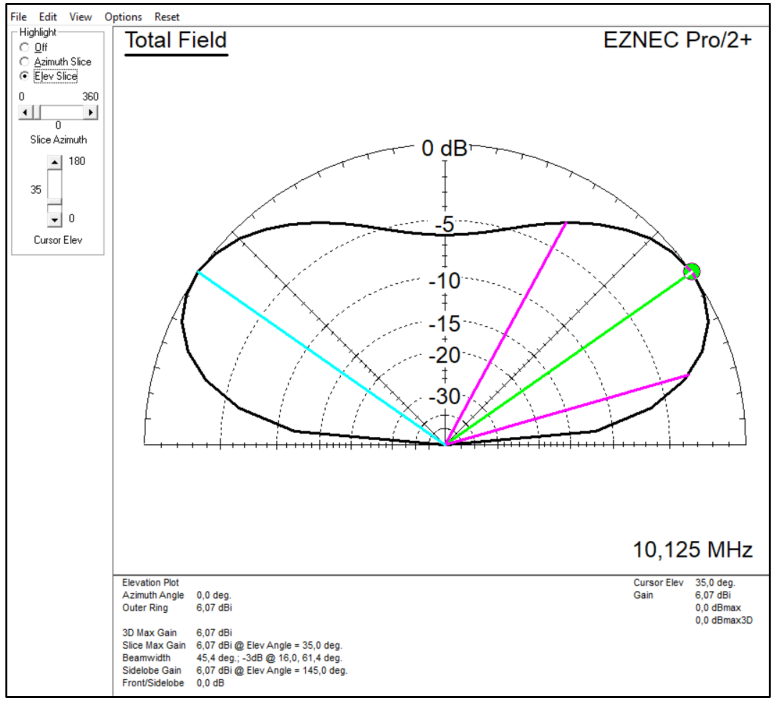
30m Inv Vee with balun / common mode shoke

CMC Z = 20 + j 1000
so R = 20 ohm and X_L = 1000 ohm
Settings: via Loads-window of EZNEC

The usual graphs of an Inverted Vee dipole





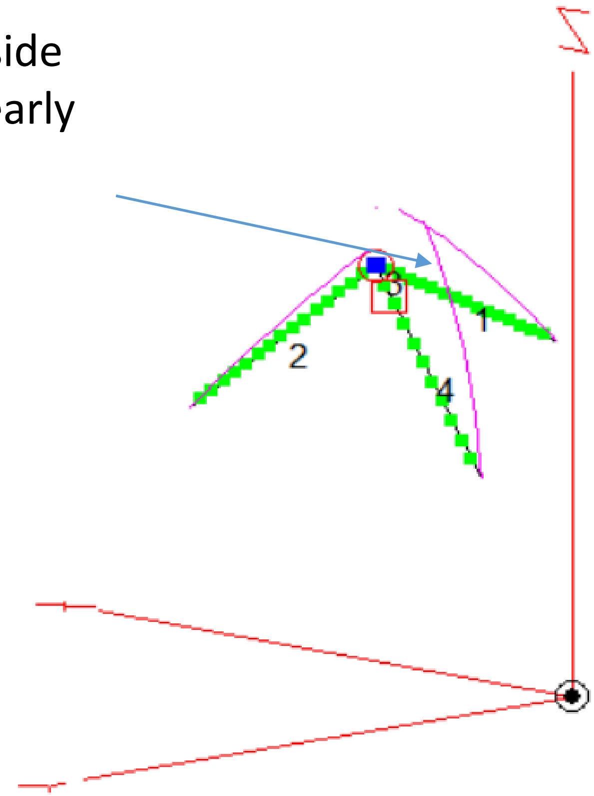


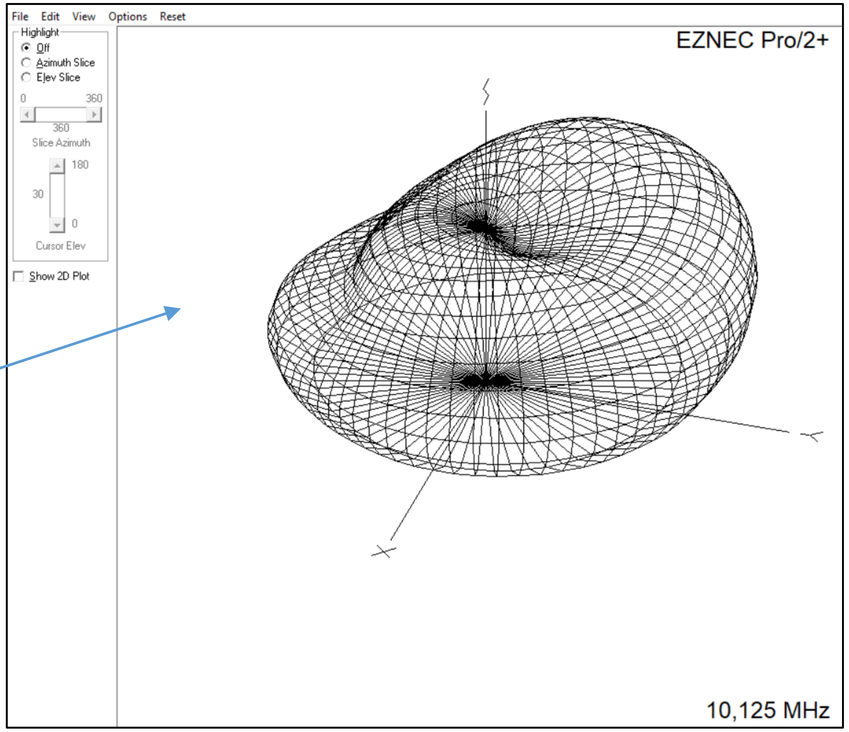
30m Inv Vee **without** CMC

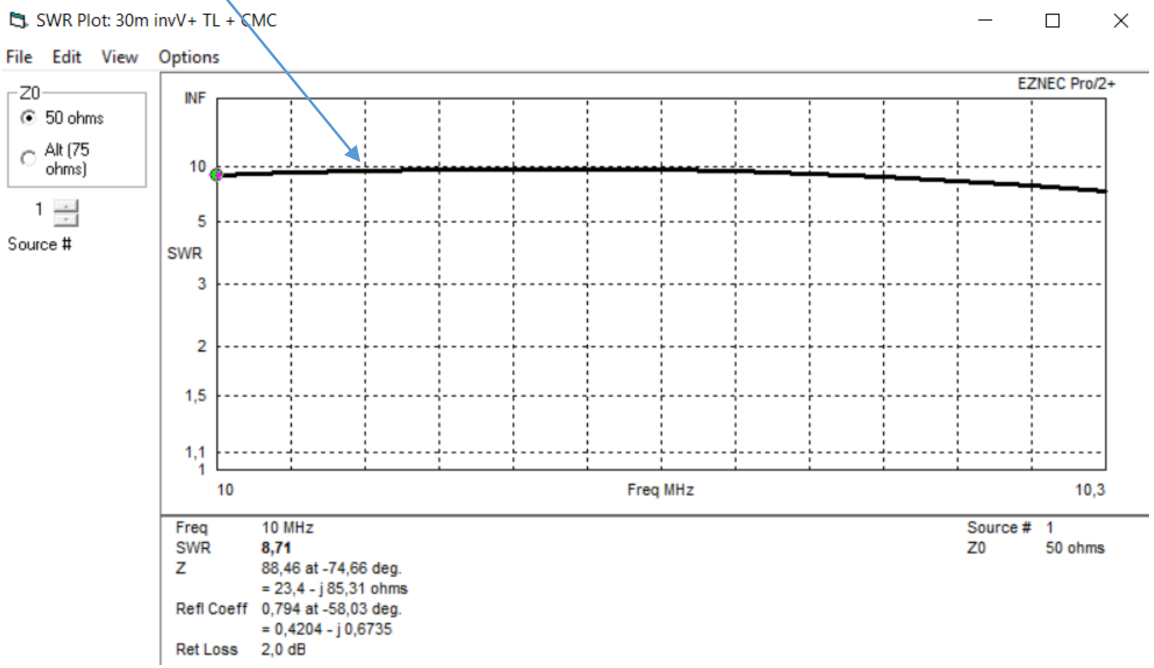
CMC $Z = 1 + j\,1$
$R = 1$ ohm and $X_L = 1$ ohm

The radiation pattern and SWR curve changed

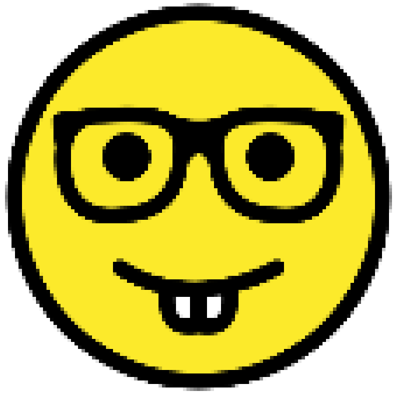
The current on the outside screen of the coax is clearly visible (wire 4).
The coax feedline is a radiating part of the antenna now.







Typical situations to play with:



- Split source and normal source (when to use)
- What's the effect of the number of segments in a wire
- Radiating feedline (coax with and without choke/balun)
    - What happens to the SWR
    - What happens to the radiation pattern
- Insulated antenna wire
- What is a good height above ground for an 80m NVIS antenna

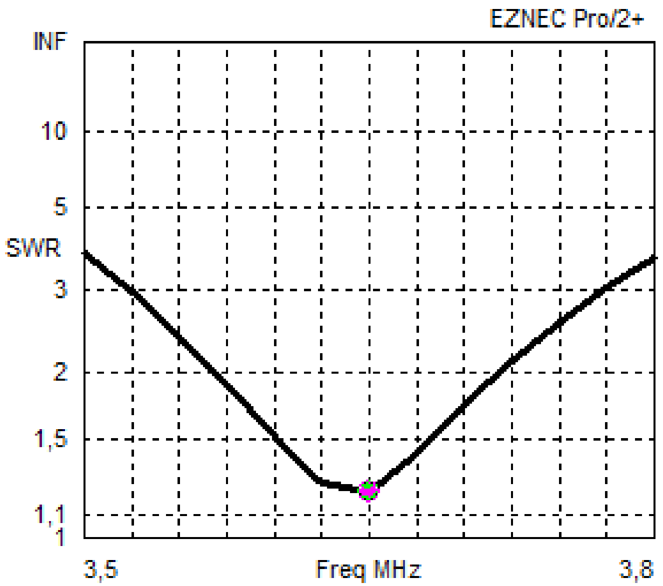
Real world example:

- 160m vertical influencing a receiving antenna on 160m (e.g. a K9AY-loop)

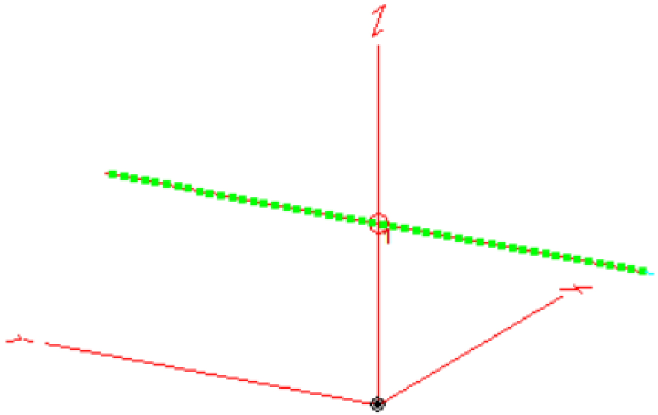
80m dipole, 12m above normal ground

Copper wire – 2,5 mm²

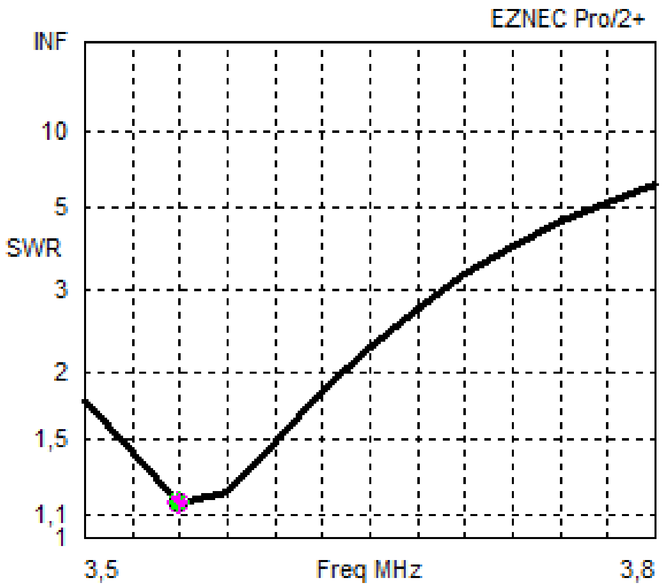
Left: bare copper wire — **Right: PVC insulation - 0,75mm**



Freq	3,65 MHz	Source #	1
SWR	**1,2**	Z0	50 ohms
Z	59,62 at 3,37 deg.		
	= 59,52 + j 3,51 ohms		
Refl Coeff	0,0926 at 18,4 deg.		
	= 0,08786 + j 0,02923		
Ret Loss	20,7 dB		

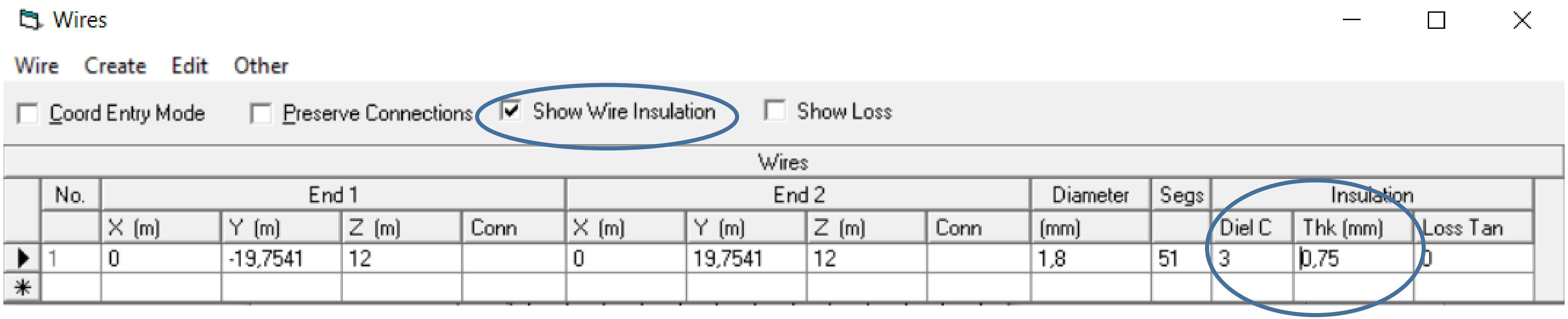


With insulation:
- 100kHz lower
- ≈ - 3,5 %



Freq	3,55 MHz	Source #	1
SWR	**1,15**	Z0	50 ohms
Z	55,54 at -5,1 deg.		
	= 55,32 - j 4,941 ohms		
Refl Coeff	0,06889 at -40,18 deg.		
	= 0,05263 - j 0,04444		
Ret Loss	23,2 dB		

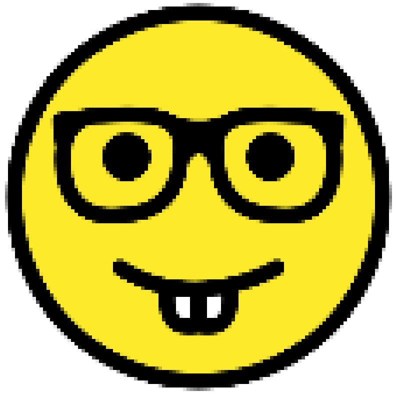
Data 80m dipoole



Length dipole: 39,5m
Height: 12m
Ground: Average ground
Copper wire with PVC insulation: $\varepsilon_r = 3$
(Copper wire losses are switched on in the main menu)

Typical situations to play with:

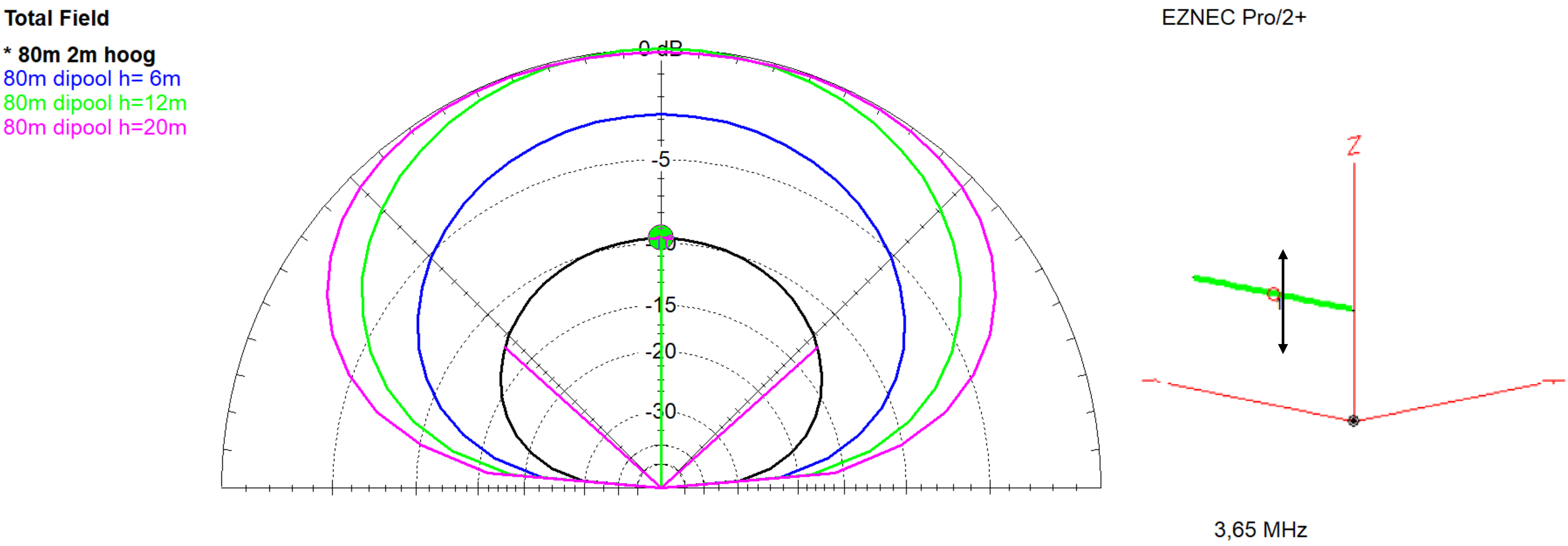
- Split source and normal source (when to use)
- What's the effect of the number of segments in a wire
- Radiating feedline (coax with and without choke/balun)
    - What happens to the SWR
    - What happens to the radiation pattern
- Insulated antenna wire
- What is a good height above ground for an 80m NVIS antenna



Real world example:

- 160m vertical influencing a receiving antenna on 160m (e.g. a K9AY-loop)

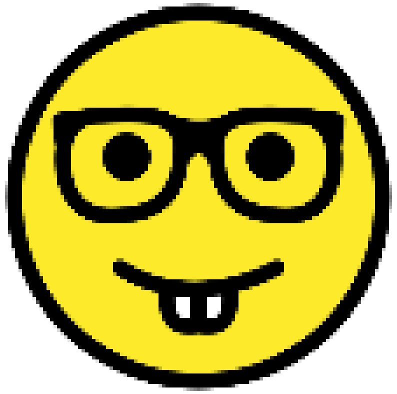
The same 80m dipole at different heights
How high for a good NVIS?



Remark: 80m NVIS antenna at height 6m
An extra reflector at 1m delivers about 2 dB extra gain straight up

Typical situations to play with:

- Split source and normal source (when to use)
- What's the effect of the number of segments in a wire
- Radiating feedline (coax with and without choke/balun)
  - What happens to the SWR
  - What happens to the radiation pattern
- Insulated antenna wire
- What is a good height above ground for an 80m NVIS antenna



Real world example:

- 160m vertical influencing a receiving antenna on 160m (e.g. a K9AY-loop)

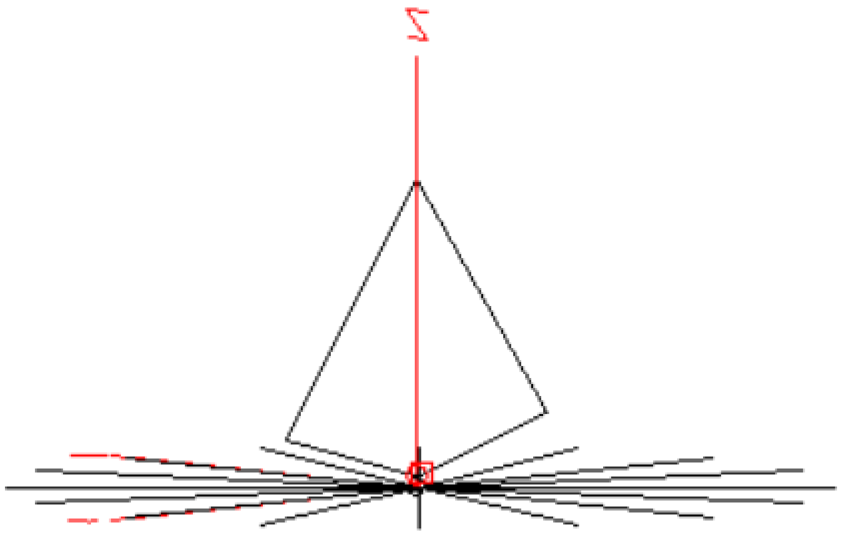
TN2MS DXpedition
Republic of the Congo

- RX: K9AY loop
- TX: 160m vertical

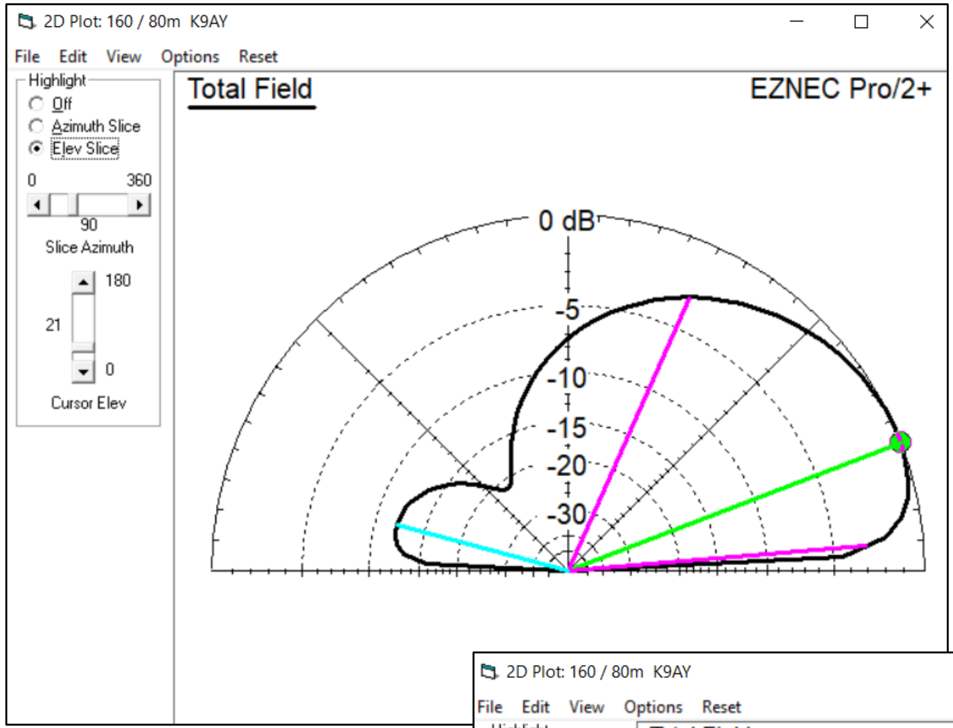
The (receive)antenna (K9AY) and surroundings

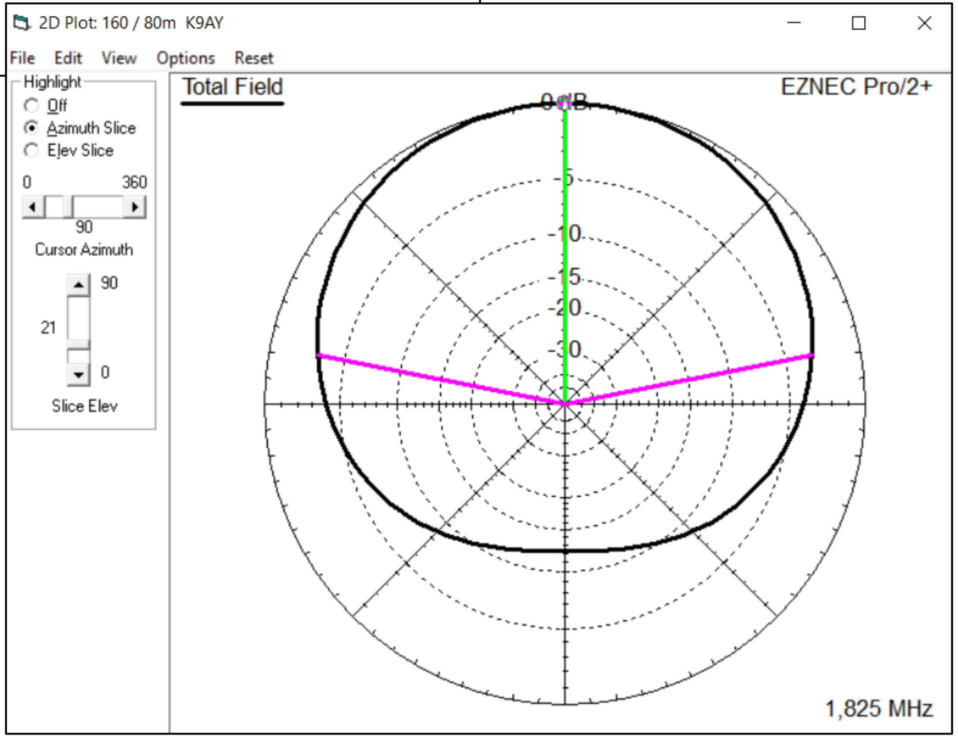
- Comparing the receiving pattern of a K9AY loop for 160m:
  - Without any obstacles (as a starting point)
  - With a 160m vertical in the receive direction e.g.
    - At 60m distance
    - At 120m distance
    - At 60m distance, at ‘the back’ of the K9AY

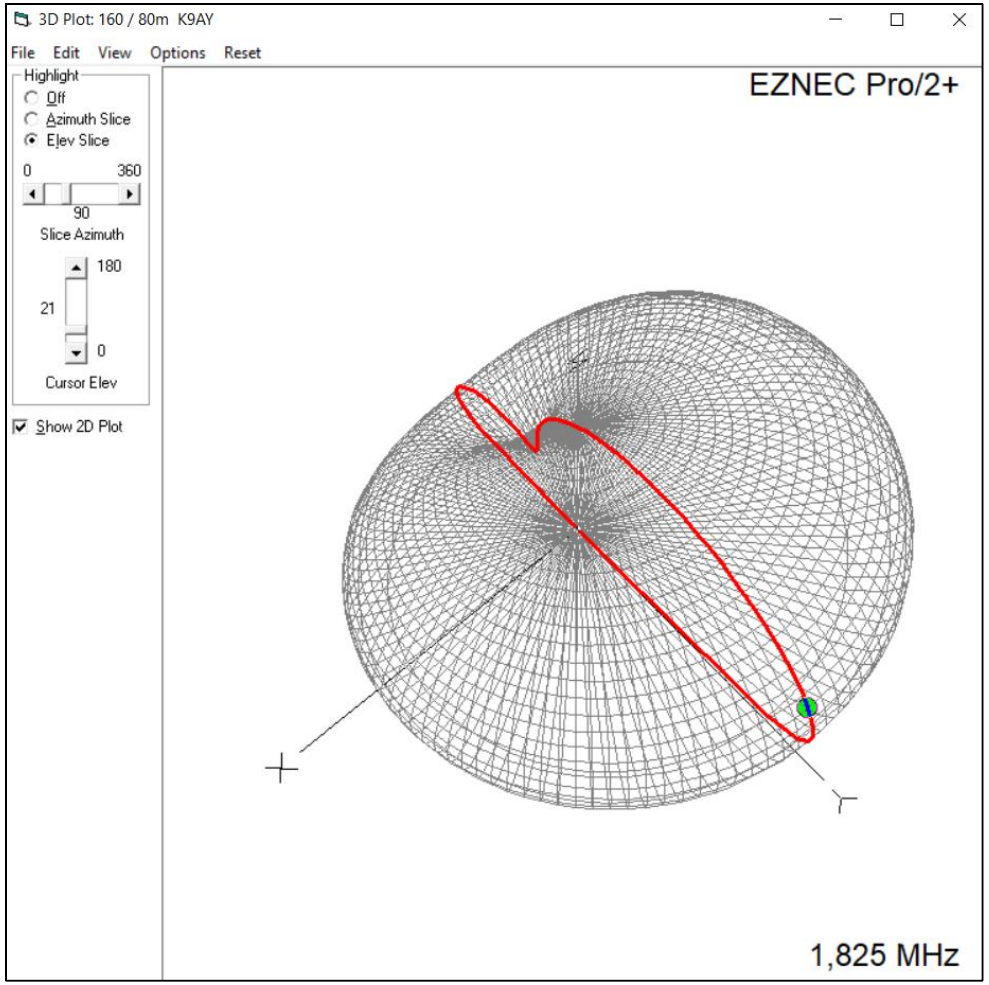
    - What can we do about this?



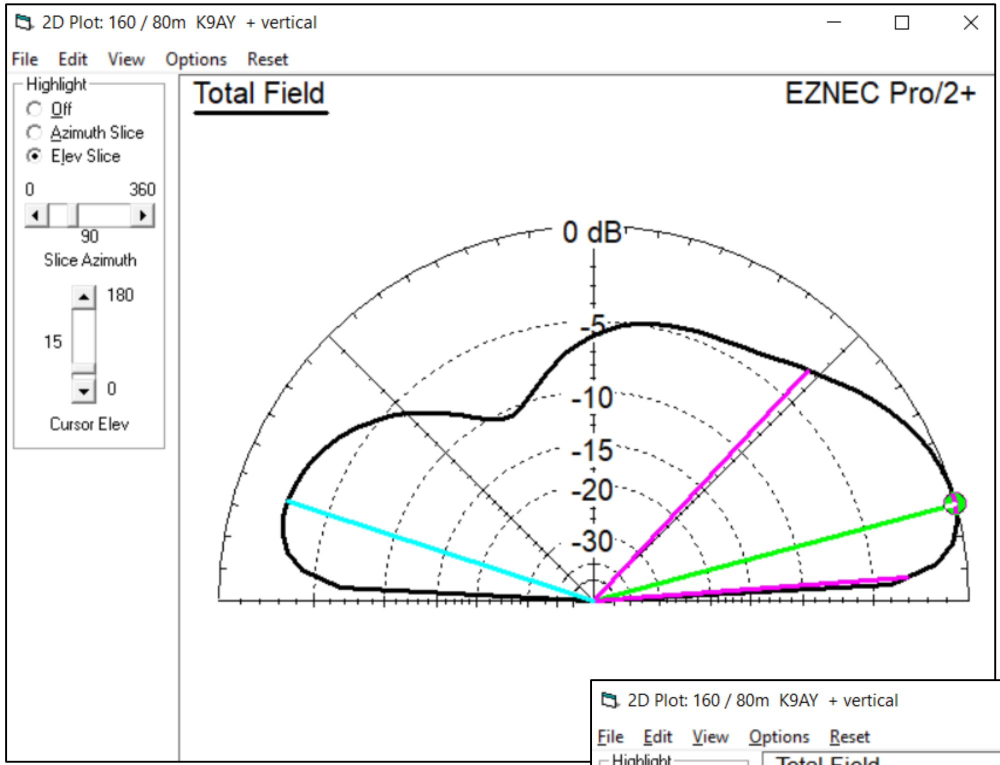
160m K9AY loop

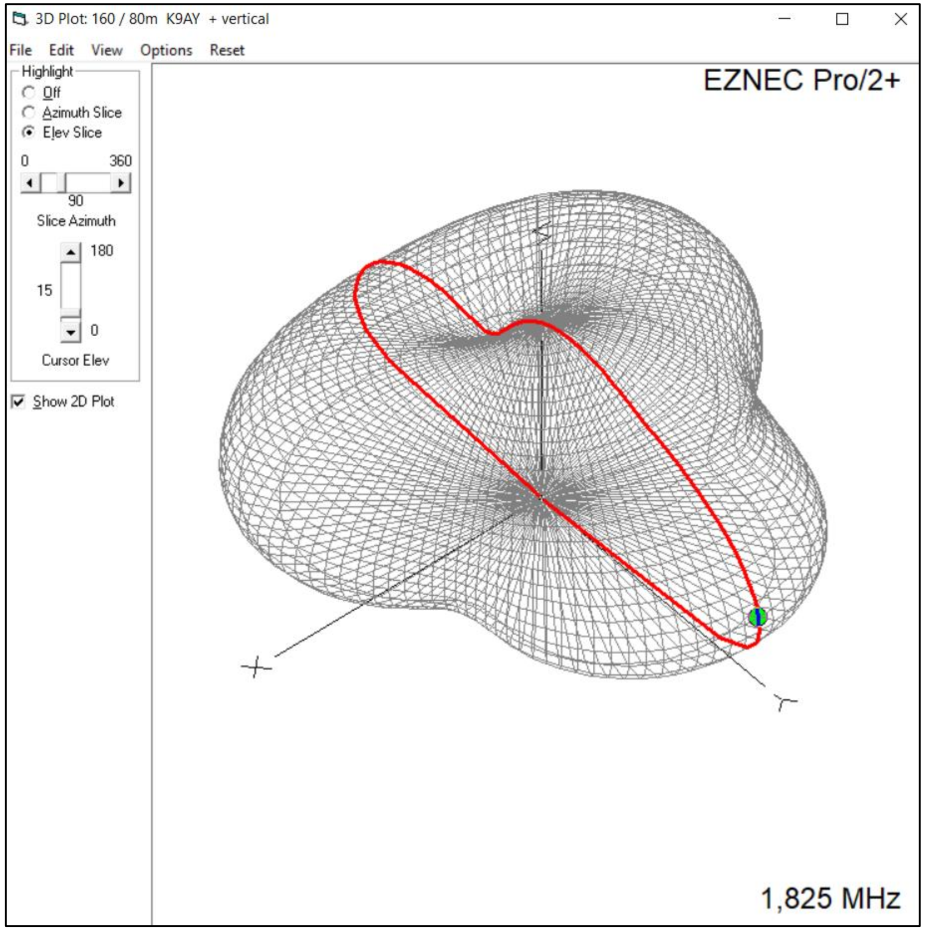


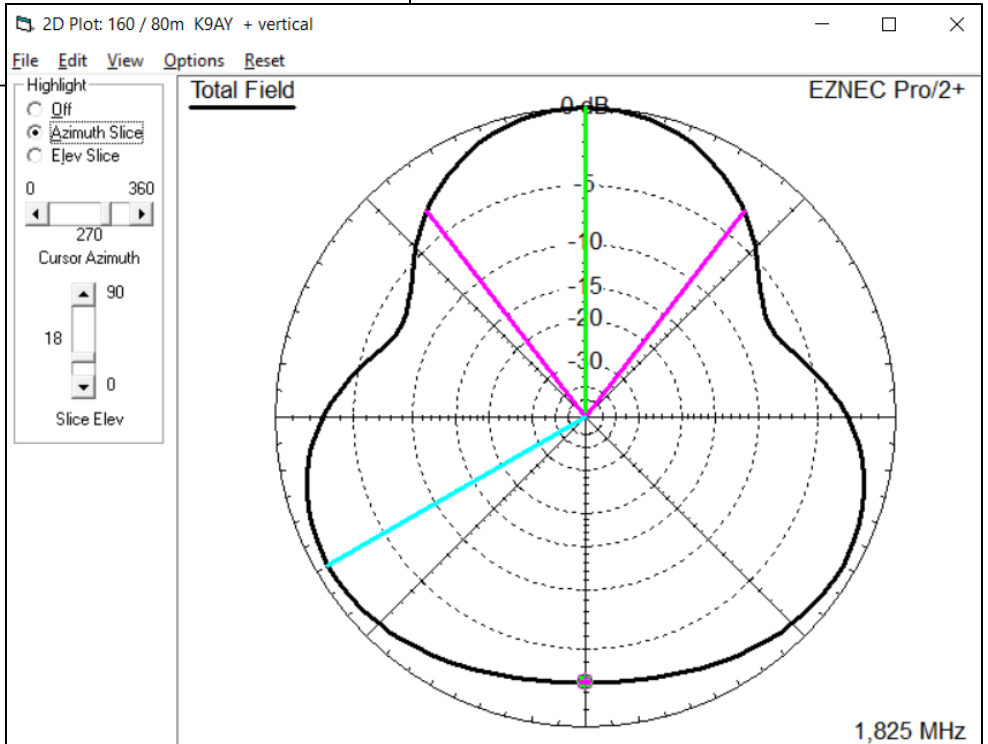




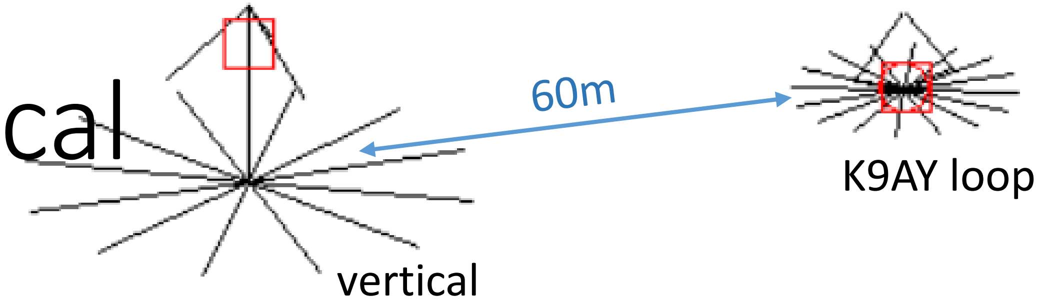
160m K9AY loop + ¼ golf vertical,
at 60m distance (direction of receive)







Simulations K9AY and vertical



Concluding:

- The vertical (a quarter wave radiator) has a lot (!) of influence if in the direction of receive (distance 60m)
- Same for 120m distance

- Very little influence if the vertical is at ‘the back’ of the K9AY-loop

- Very little influence if the vertical is detuned during K9AY reception

Most important

Read the manual

Feed Impedance

- You want:
  - To know the feed impedance of the antenna
  - A reliable SWR simulation
- Pay attention to:
  - Source in the middle of an inverted-Vee antenna (easy simulation)
  - Source impedance in an End-Fed wire (random LW or a HWEF) is a tricky simulation. See manual.
  - Radials under a vertical

Radiation diagram

- You want:
  - A realistic radiation pattern
  - Expected performance to become reality
- Pay attention to:
  - Surroundings like metal objects, other antennas
  - Groundtype
  - Radiating coax (!?!)
  - One dB is one dB?
    dBi, dBd, dB compared to another antenna

Remark: Check the model with a 3D plot. EZNEC reports **'Average Gain'.**
'Average Gain', antenna simulated in free space/ perfect grond, zero loss, should be =1 or 0 dBi .
If not, the model is not entirely correct. Problem might be in the segment lengths of wires, wire diameters or location of the source. See also in the manual.

Some rules of thumb for EZNEC calculations

(see the EZNEC-manual and the ‘Nice Reads’ page)

- **Segment length:**
  - 0,001 – 0,05 wavelength so e.g.
    Half wave dipole antenna: min 10 – max 500 segments (31 segments works ok)
  - Segment at least 8x longer than wire diameter
  - Segments may not overlap or cross in the same plane
  - Where wires connect, use about the same segment length in those wires

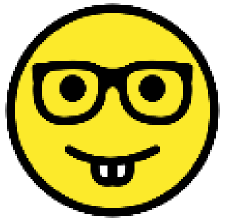
- **Wire diameter**:
  - Diameter max 1/30 wavelength
  - Tapering (stepped diameter) makes NEC2 less accurate. EZNEC has a correcting algorithm
  - Radials ON the ground in EZNEC (=NEC2), so not IN the ground, minimum 2x the wirediameter above groundlevel (EZNEC)
  - Where wires are connected, use the same wire diameter for them if possible

Antenna geometry check: reports from EZNEC

- Source 1: Segment connects to multiple wires
  - The source is in the last segment of a wire where more wires connect.
  - Solution: Move the source one segment away.
    Remark: segment length must be short otherwise you will move the source to much (physically).
  - Same can happen when connecting transmission lines
  - This fault is usually not critical
- The description does not contain any sources. It must include at least one
  - This is clear. Solution: add a source
- Wire x segment too short. L= … etc
  - Too many segments in a wire (segment length compared to wavelength)
  - Solution: reduce number of segments
- Wire x segment too long. L= … etc
  - Too few segments in the wire (segment length compared to wavelength)
  - Solution: increase number of segments
- Wire x and y intersect at other than a segment junction or end
  - Wires x en y cross, touching each other
  - Wires may not touch unless wire-end connections
  - Solution: move a wire

EZNEC

- Just do it
- Learn from the results
- You will know if someone tells you a tale about an antenna or an untrue myth (you can check it or might have simulated that one before)
- Design and build a dipole antenna or a GP and see the difference or likeness between EZNEC simulation and practice.

Nice reads: 

- https://eznec.com/
- http://on5au.be/content/amod/amod56.html
- https://en.wikipedia.org/wiki/Numerical_Electromagnetics_Code
- https://www.arrl.org/files/file/Technology/tis/info/pdf/9102018.pdf
- http://www.w8io.com/mininec.htm

- Emoji’s: https://emojiterra.com/ (OpenMoji)

More info on pa3a.nl, EZNEC page

Contains examples of simple and not so simple antennas (e.g. a 4-square) that really have been constructed and used

https://pa3a.nl/antenna-design-with-eznec/