End Fed Half Wave MultiBand Antennas

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What motivated this presentation

- I got into a long running debate about EFHW on QRZ.com Antenna Forum
- It has been going on for months...
- The key issues:
  - Need for a “counterPoise”
  - Coax is the other half of the antenna
  - Effects of Current on the coax

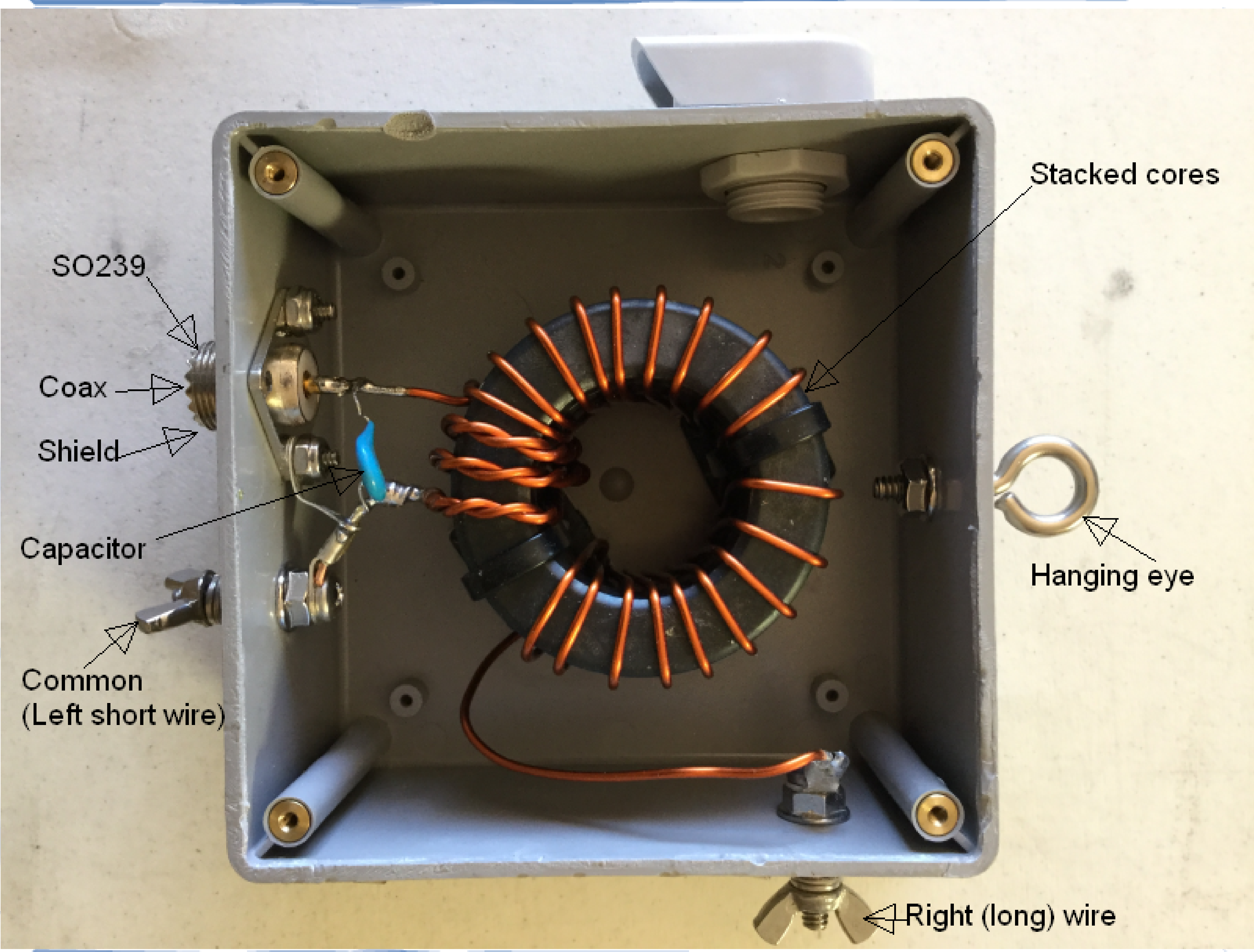
What is an **E**nd **F**ed **H**alf **W**ave Antenna?

- Let's call it a "**EFHW**"
- Works on a similar principle to a Zepp and J-Pole
- ~0.5 Wave-Length wire on lowest band (130ft on 80m, 67ft on 40m)
- Fed from one end using a transformer in a box

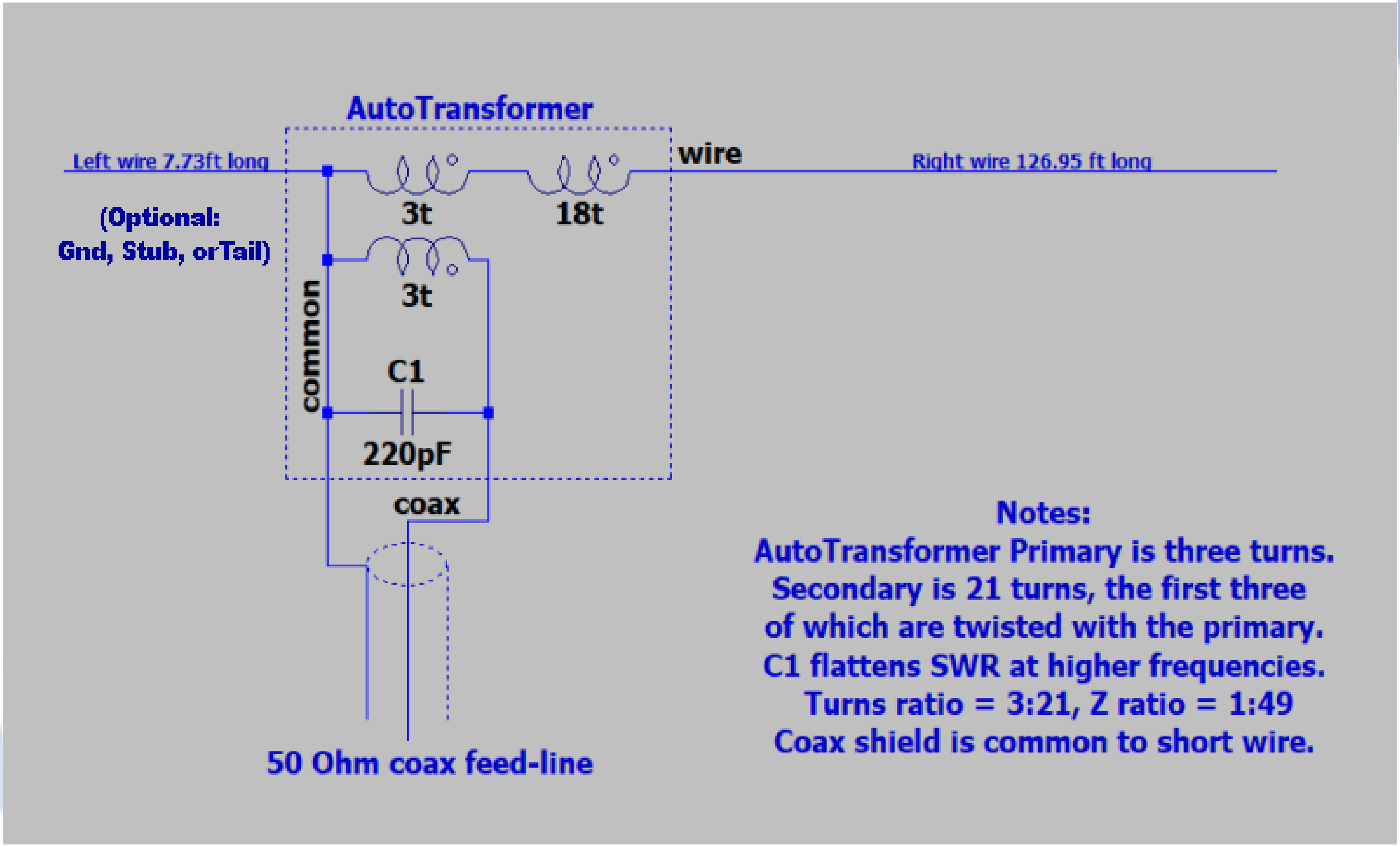
What is an **E**nd **F**ed **H**alf **W**ave Antenna?

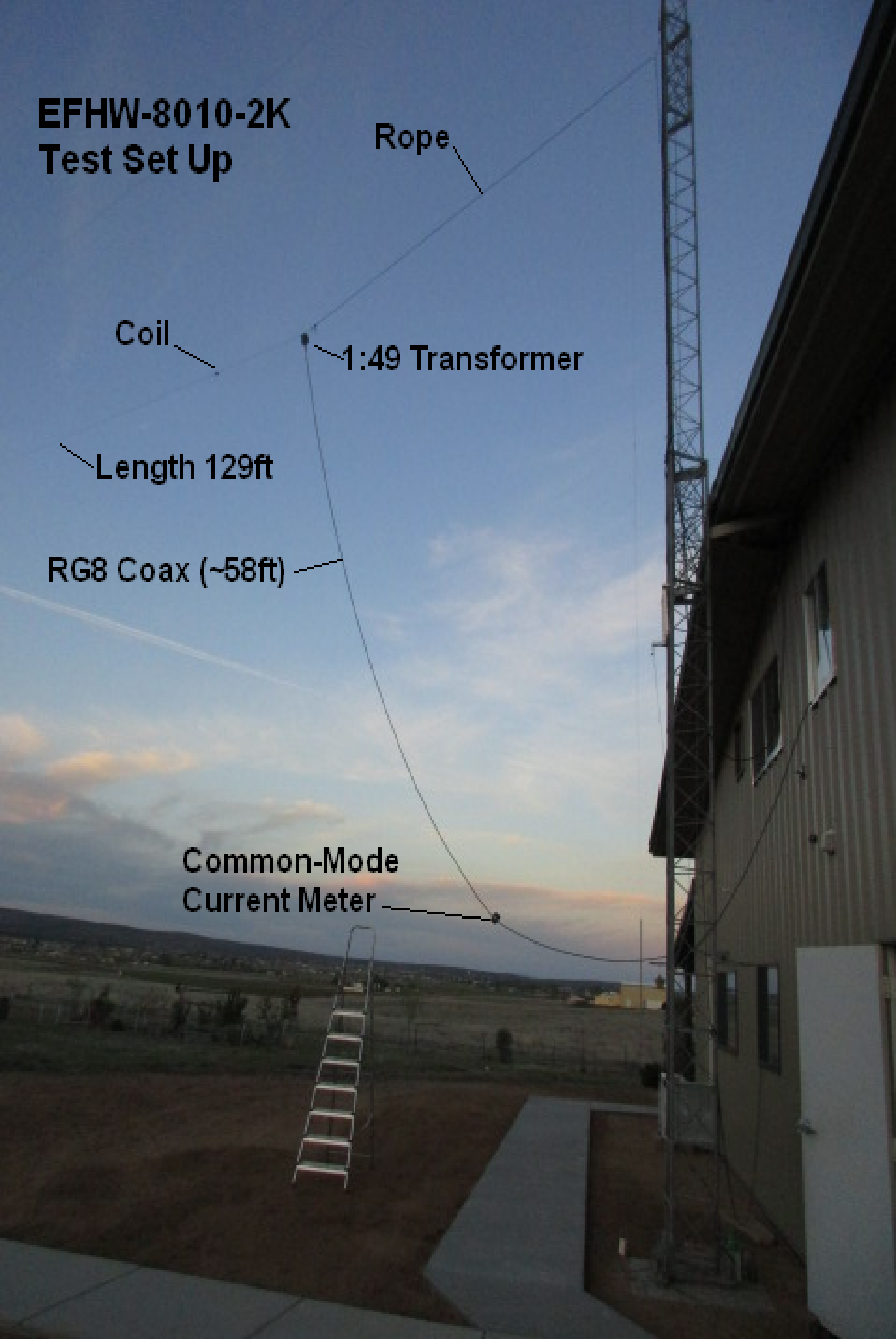
- Transformer is a 1:49 or 1:64 UnUn (not 1:4 or 1:9 used on random wire antennas)
- 50 Ohm Coax from transformer to station
- Multi-Band (works on all harmonics)
- Deploy it horizontal, sloping, inverted-L, inverted-V
- Commercial example: MyAntennas EFHW-8010-2K
- Pass it around (I want it back!)


129 ft of wire
Transformer
Multiband
End-Fed Half Wave
Antenna-EFHW
80/40/30/20/17/15/12/10m
EFHW-8010-2K
Maximum Power: 2kW I.C.A.S
MyAntennas.com
Designed by E73M, Made in USA
Compensating Coil
Coax
Tail


Stacked cores
SO239
Coax
Shield
Capacitor
Hanging eye
Common
(Left short wire)
Right (long) wire

1:49 Transformer schematic

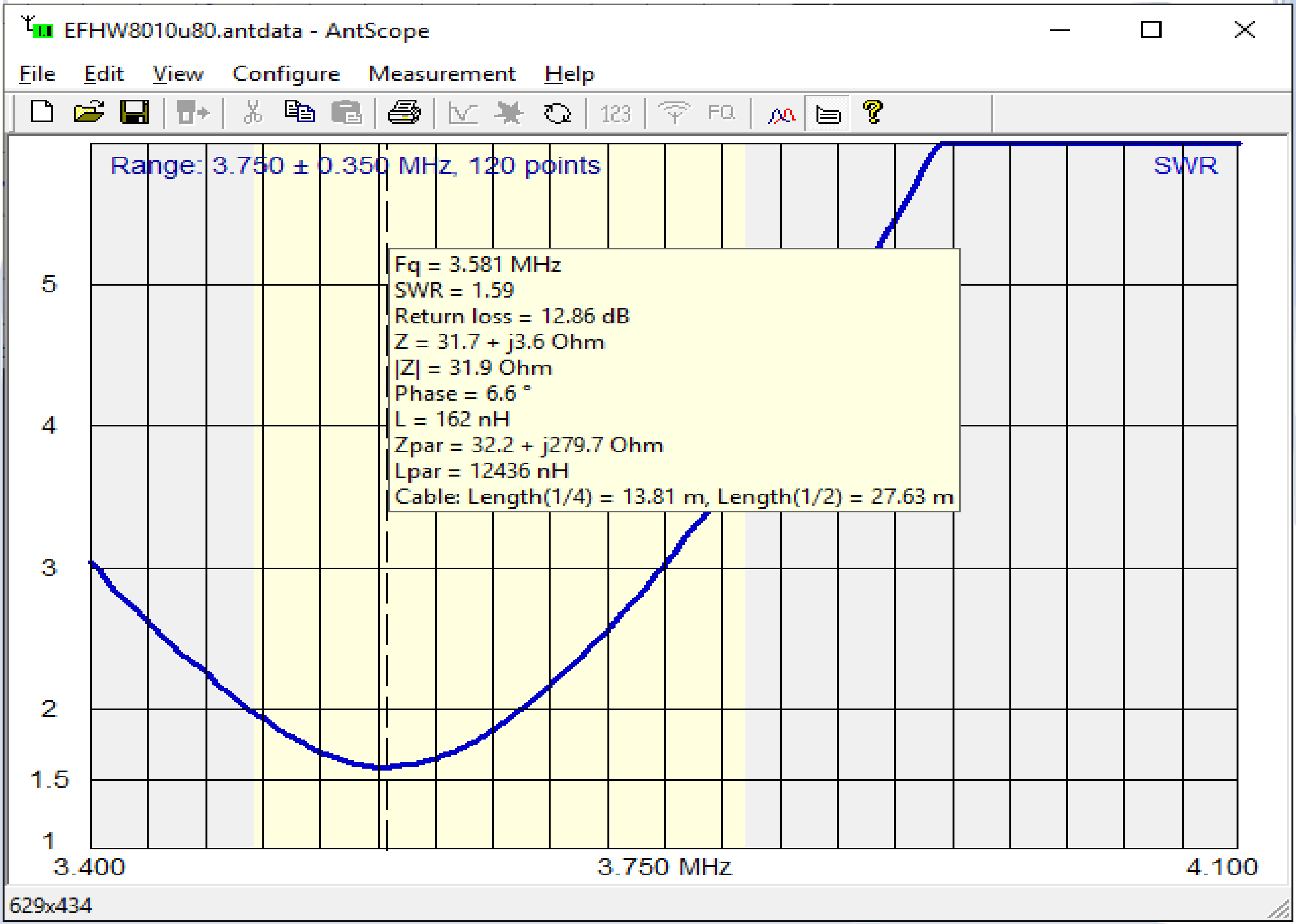




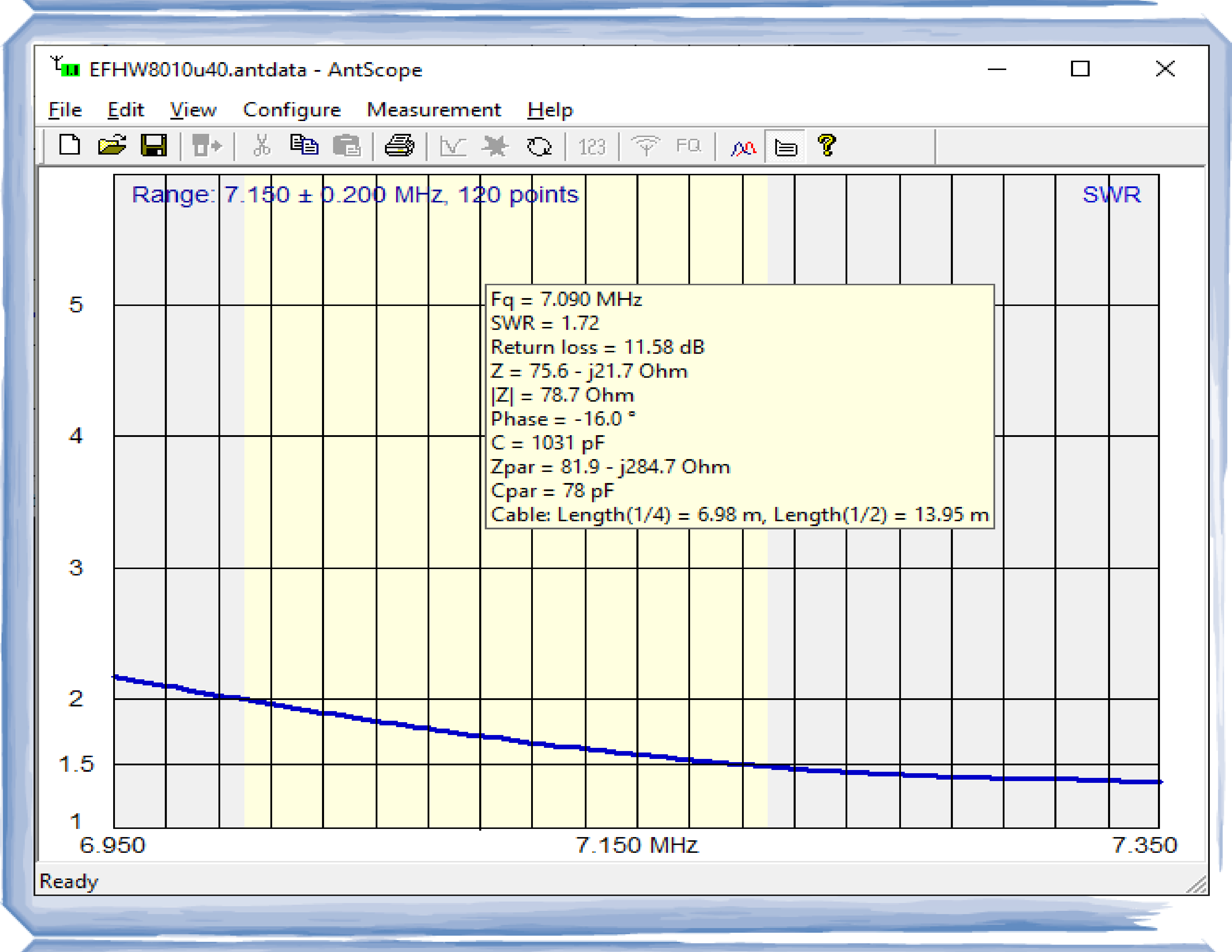
- My test set-up for the 8010
- Mostly Horizontal
- ~35ft Above Ground
- Tried Variable Coax length
- Grounded only at IC7300
- Optional external grounds
- CM current measurement

Actual SWR measurements

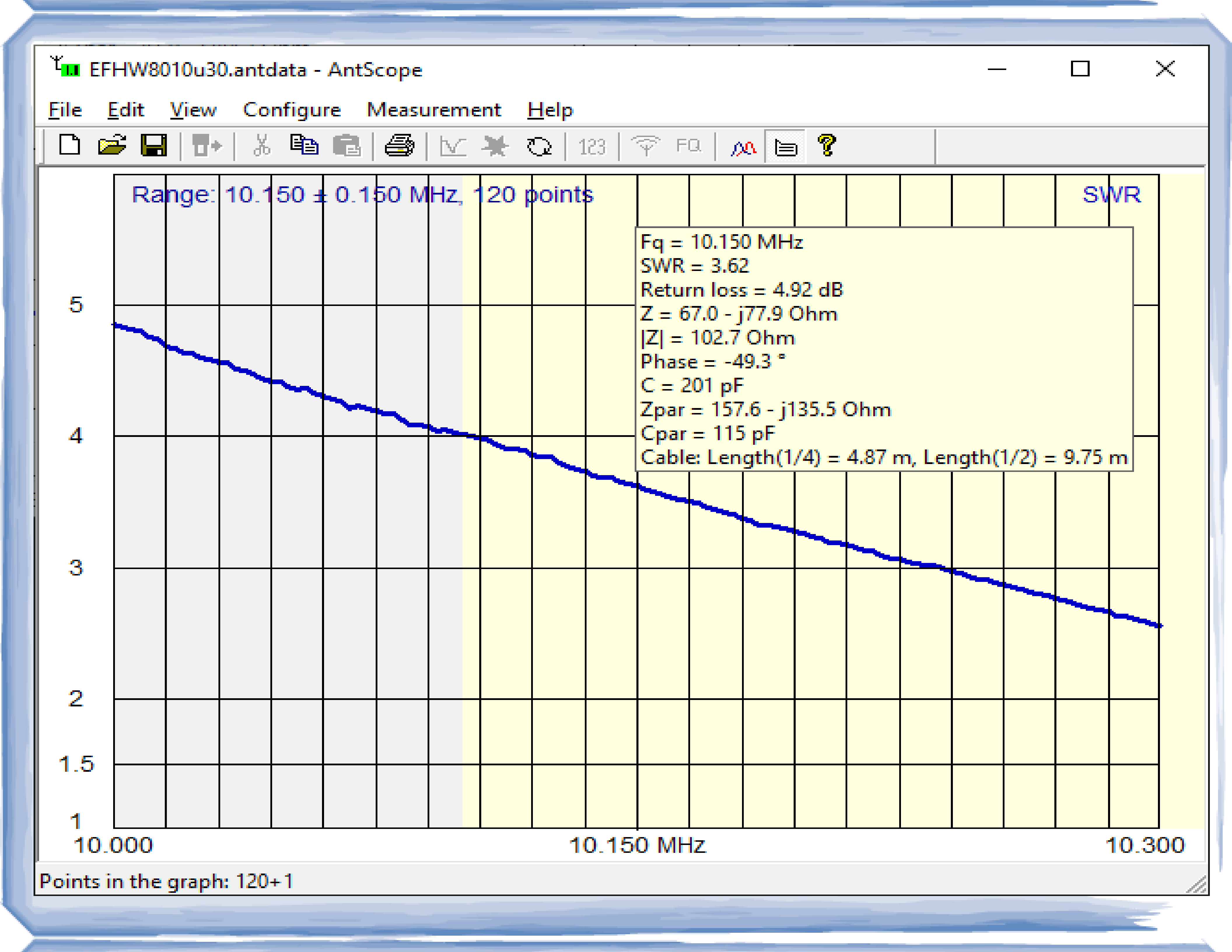
- Started with 58ft of foam RG8 (benign)
- No ground connection except at IC7300
  - On purpose to see if any RF “problems”
  - No CMC
- Measured SWR using RigExpert AA-600
- Actual Plots for 80m to 10m follow:

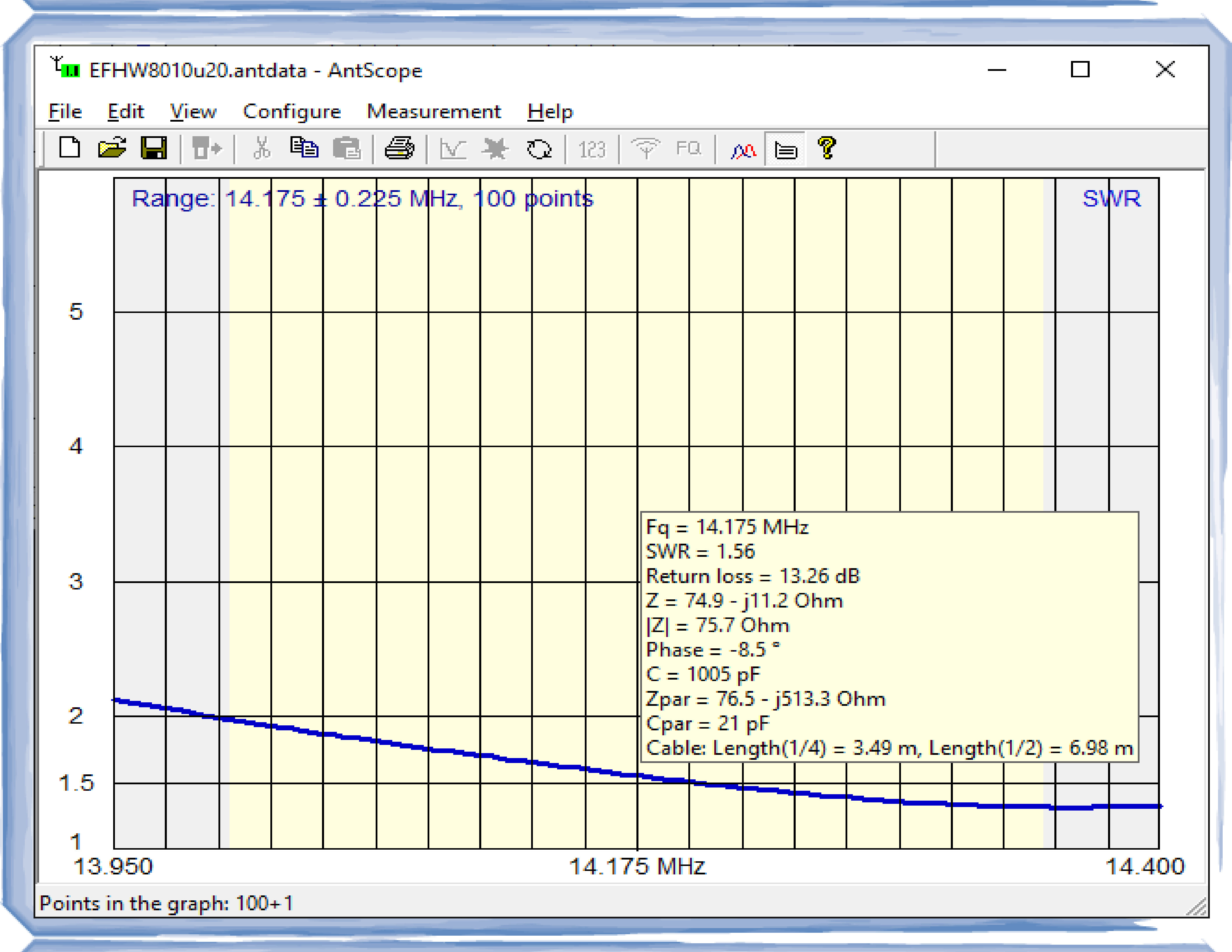


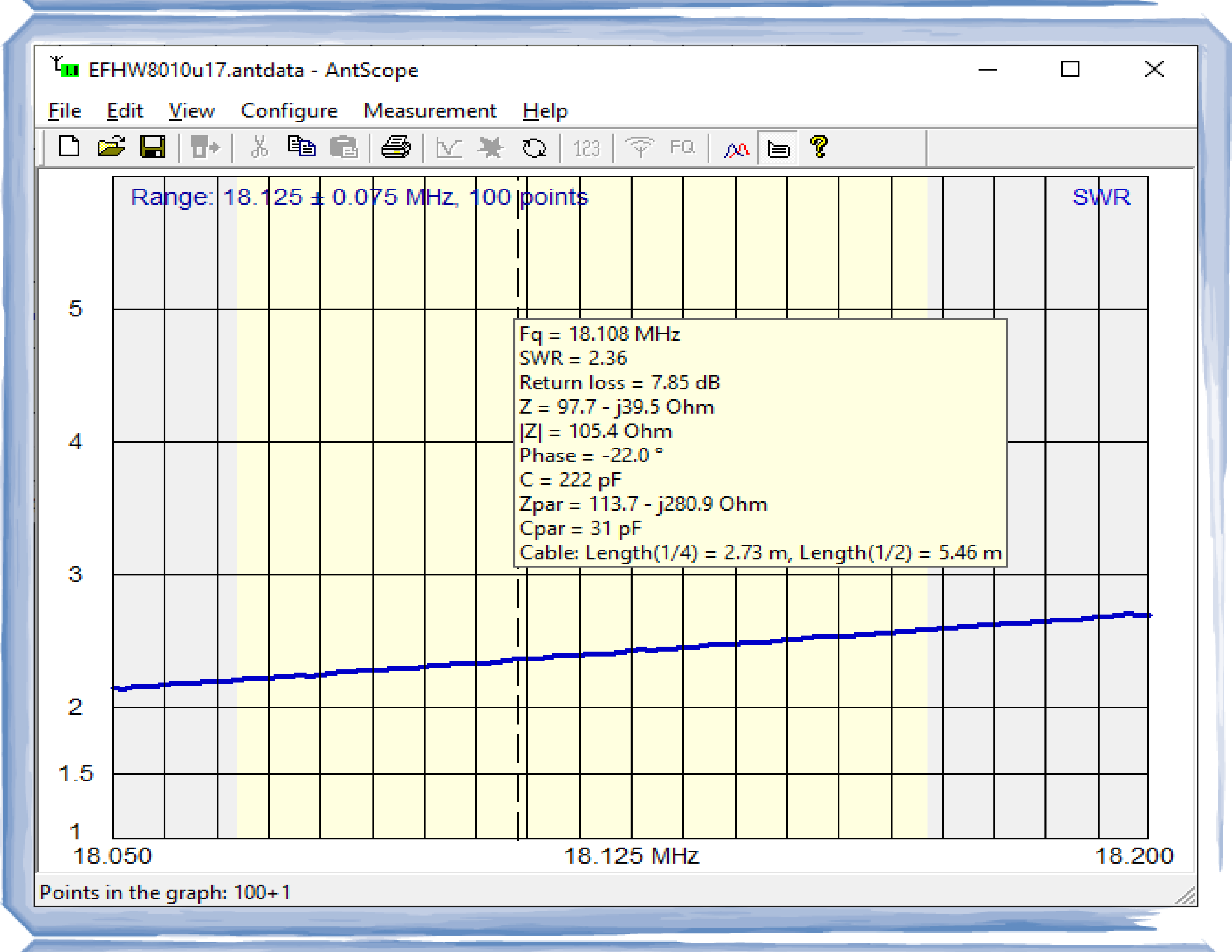
EFHW8010u80.antdata - AntScope
File Edit View Configure Measurement Help
Range: 3.750 ± 0.350 MHz, 120 points
SWR
Fq = 3.581 MHz
SWR = 1.59
Return loss = 12.86 dB
Z = 31.7 + j3.6 Ohm
|Z| = 31.9 Ohm
Phase = 6.6 °
L = 162 nH
Zpar = 32.2 + j279.7 Ohm
Lpar = 12436 nH
Cable: Length(1/4) = 13.81 m, Length(1/2) = 27.63 m
5
4
3
2
1.5
1
3.400
3.750 MHz
4.100
629x434

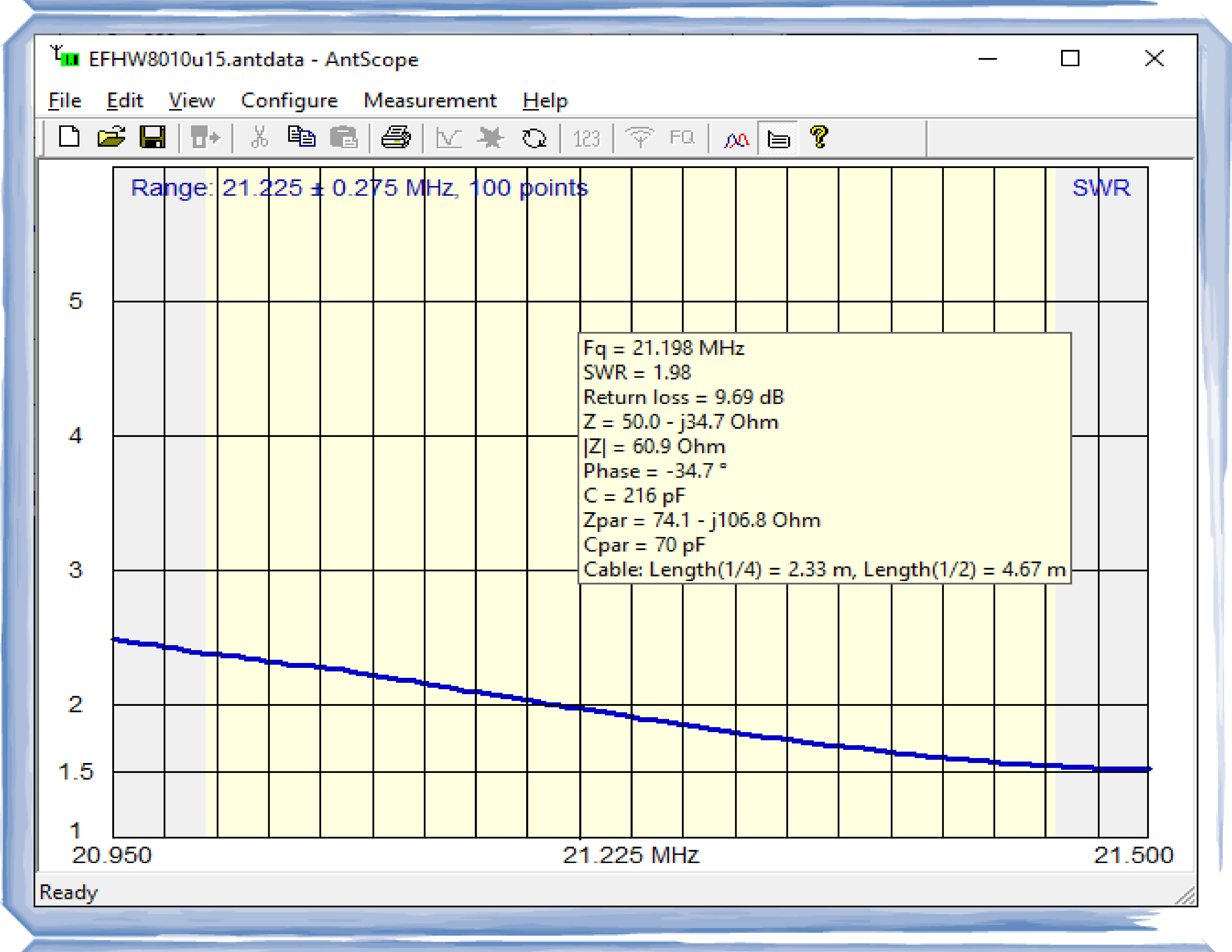


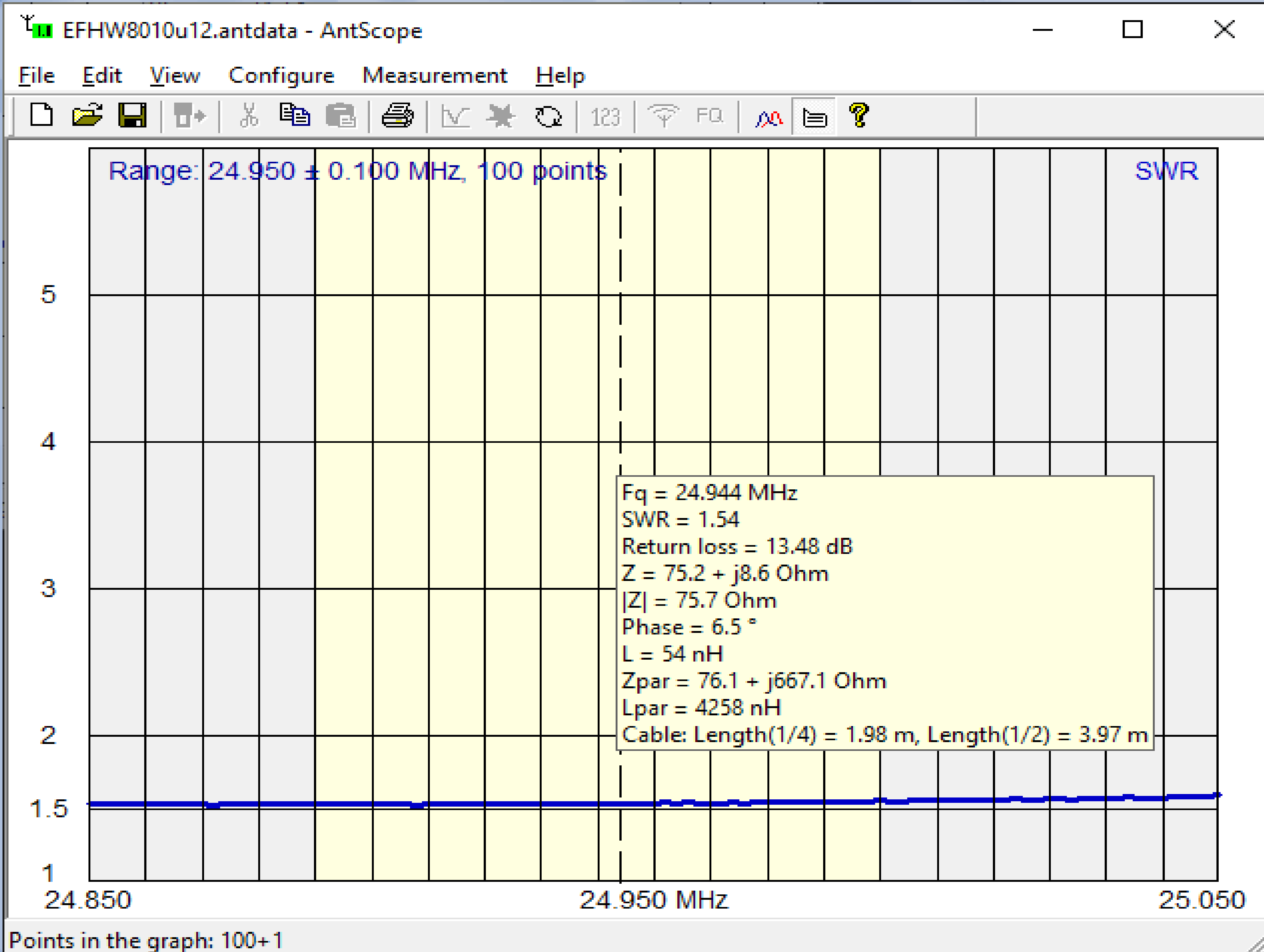
EFHW8010u40.antdata - AntScope
File Edit View Configure Measurement Help
Range: 7.150 ± 0.200 MHz, 120 points
SWR
Fq = 7.090 MHz
SWR = 1.72
Return loss = 11.58 dB
Z = 75.6 - j21.7 Ohm
|Z| = 78.7 Ohm
Phase = -16.0 °
C = 1031 pF
Zpar = 81.9 - j284.7 Ohm
Cpar = 78 pF
Cable: Length(1/4) = 6.98 m, Length(1/2) = 13.95 m
5
4
3
2
1.5
1
6.950
7.150 MHz
7.350
Ready

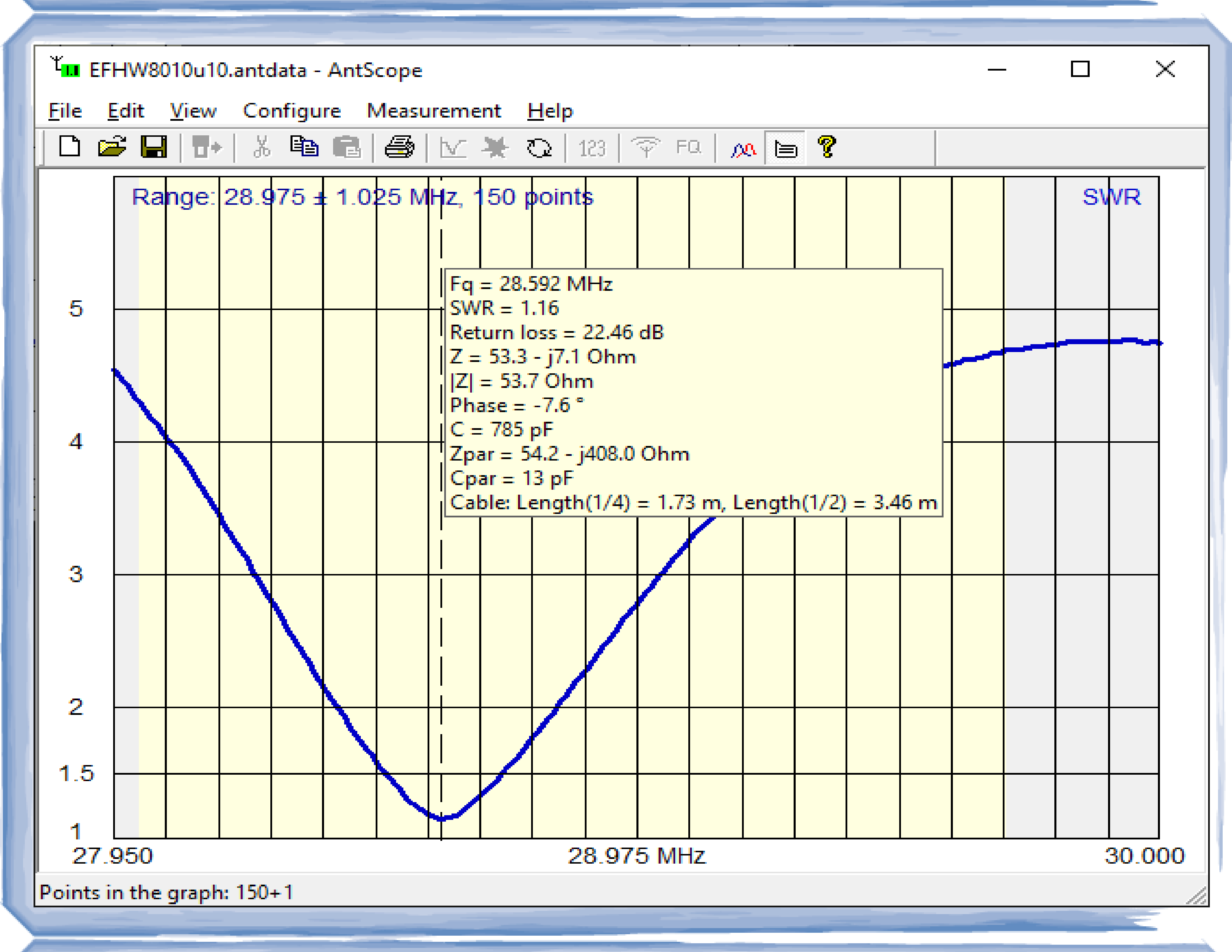

EFHW8010u30.antdata - AntScope
File Edit View Configure Measurement Help
Range: 10.150 ± 0.150 MHz, 120 points
SWR
Fq = 10.150 MHz
SWR = 3.62
Return loss = 4.92 dB
Z = 67.0 - j77.9 Ohm
|Z| = 102.7 Ohm
Phase = -49.3 °
C = 201 pF
Zpar = 157.6 - j135.5 Ohm
Cpar = 115 pF
Cable: Length(1/4) = 4.87 m, Length(1/2) = 9.75 m
5
4
3
2
1.5
1
10.000
10.150 MHz
10.300
Points in the graph: 120+1


EFHW8010u20.antdata - AntScope
File Edit View Configure Measurement Help
Range: 14.175 ± 0.225 MHz, 100 points
SWR
5
4
3
2
1.5
1
13.950
14.175 MHz
14.400
Fq = 14.175 MHz
SWR = 1.56
Return loss = 13.26 dB
Z = 74.9 - j11.2 Ohm
|Z| = 75.7 Ohm
Phase = -8.5 °
C = 1005 pF
Zpar = 76.5 - j513.3 Ohm
Cpar = 21 pF
Cable: Length(1/4) = 3.49 m, Length(1/2) = 6.98 m
Points in the graph: 100+1


EFHW8010u17.antdata - AntScope
File Edit View Configure Measurement Help
Range: 18.125 ± 0.075 MHz, 100 points
SWR
5
4
3
2
1.5
1
18.050
18.125 MHz
18.200
Fq = 18.108 MHz
SWR = 2.36
Return loss = 7.85 dB
Z = 97.7 - j39.5 Ohm
|Z| = 105.4 Ohm
Phase = -22.0 °
C = 222 pF
Zpar = 113.7 - j280.9 Ohm
Cpar = 31 pF
Cable: Length(1/4) = 2.73 m, Length(1/2) = 5.46 m
Points in the graph: 100+1


EFHW8010u15.antdata - AntScope
File Edit View Configure Measurement Help
123
FQ
Range: 21.225 ± 0.275 MHz, 100 points
SWR
5
4
3
2
1.5
1
20.950
21.225 MHz
21.500
Fq = 21.198 MHz
SWR = 1.98
Return loss = 9.69 dB
Z = 50.0 - j34.7 Ohm
|Z| = 60.9 Ohm
Phase = -34.7 °
C = 216 pF
Zpar = 74.1 - j106.8 Ohm
Cpar = 70 pF
Cable: Length(1/4) = 2.33 m, Length(1/2) = 4.67 m
Ready


EFHW8010u12.antdata - AntScope
File Edit View Configure Measurement Help
Range: 24.950 ± 0.100 MHz, 100 points
SWR
5
4
3
2
1.5
1
24.850
24.950 MHz
25.050
Fq = 24.944 MHz
SWR = 1.54
Return loss = 13.48 dB
Z = 75.2 + j8.6 Ohm
|Z| = 75.7 Ohm
Phase = 6.5 °
L = 54 nH
Zpar = 76.1 + j667.1 Ohm
Lpar = 4258 nH
Cable: Length(1/4) = 1.98 m, Length(1/2) = 3.97 m
Points in the graph: 100+1


EFHW8010u10.antdata - AntScope
File
Edit
View
Configure
Measurement
Help
Range: 28.975 ± 1.025 MHz, 150 points
SWR
Fq = 28.592 MHz
SWR = 1.16
Return loss = 22.46 dB
Z = 53.3 - j7.1 Ohm
|Z| = 53.7 Ohm
Phase = -7.6 °
C = 785 pF
Zpar = 54.2 - j408.0 Ohm
Cpar = 13 pF
Cable: Length(1/4) = 1.73 m, Length(1/2) = 3.46 m
5
4
3
2
1.5
1
27.950
28.975 MHz
30.000
Points in the graph: 150+1

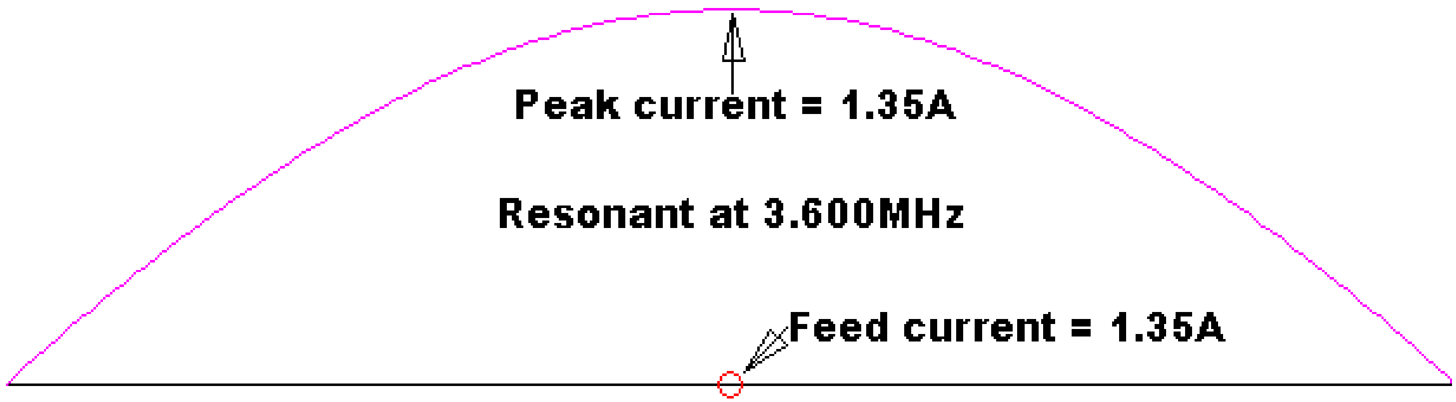
Summary of SWR measurements

- 3.5 to 3.82Mhz: IC7300's internal 1:3 tuner
- 80m band: external manual tuner (Palstar)
- 40m band: no tuner needed
- 30m band: external tuner
- 20m band: no tuner
- 15m band: no tuner
- 17m band: internal 1:3 tuner
- 12m band: no tuner
- 10m band: internal tuner

Modeling the EFHW

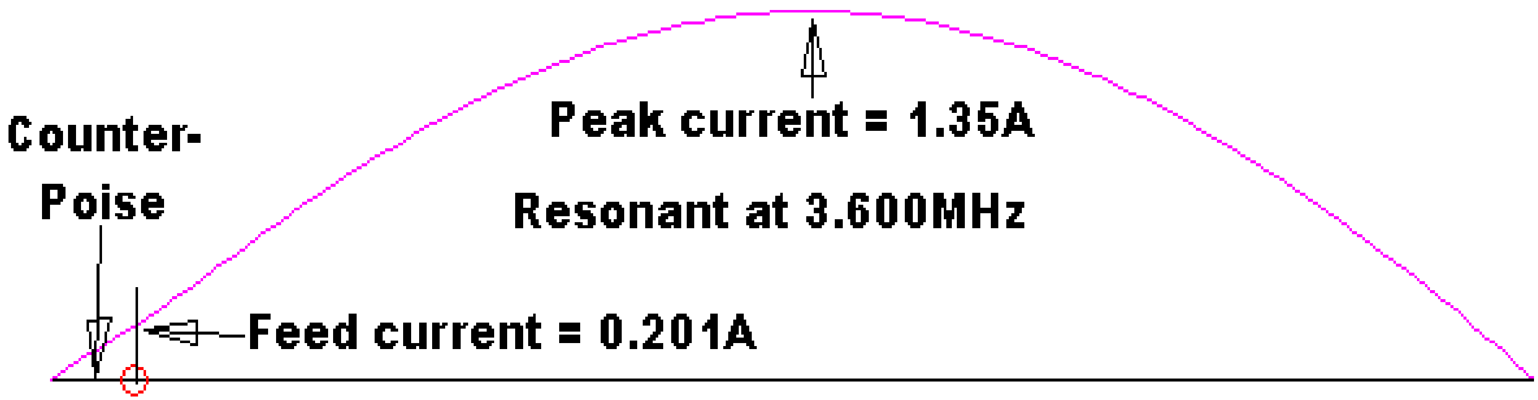
- Using NEC to learn how it works
- Compare it to Center-Fed Dipole
- Show feed-point impedences
- Overlay current distributions
- Overlay SWR plots
- Overlay Patterns
- Show CM effects

Prototype Center-Fed Dipole

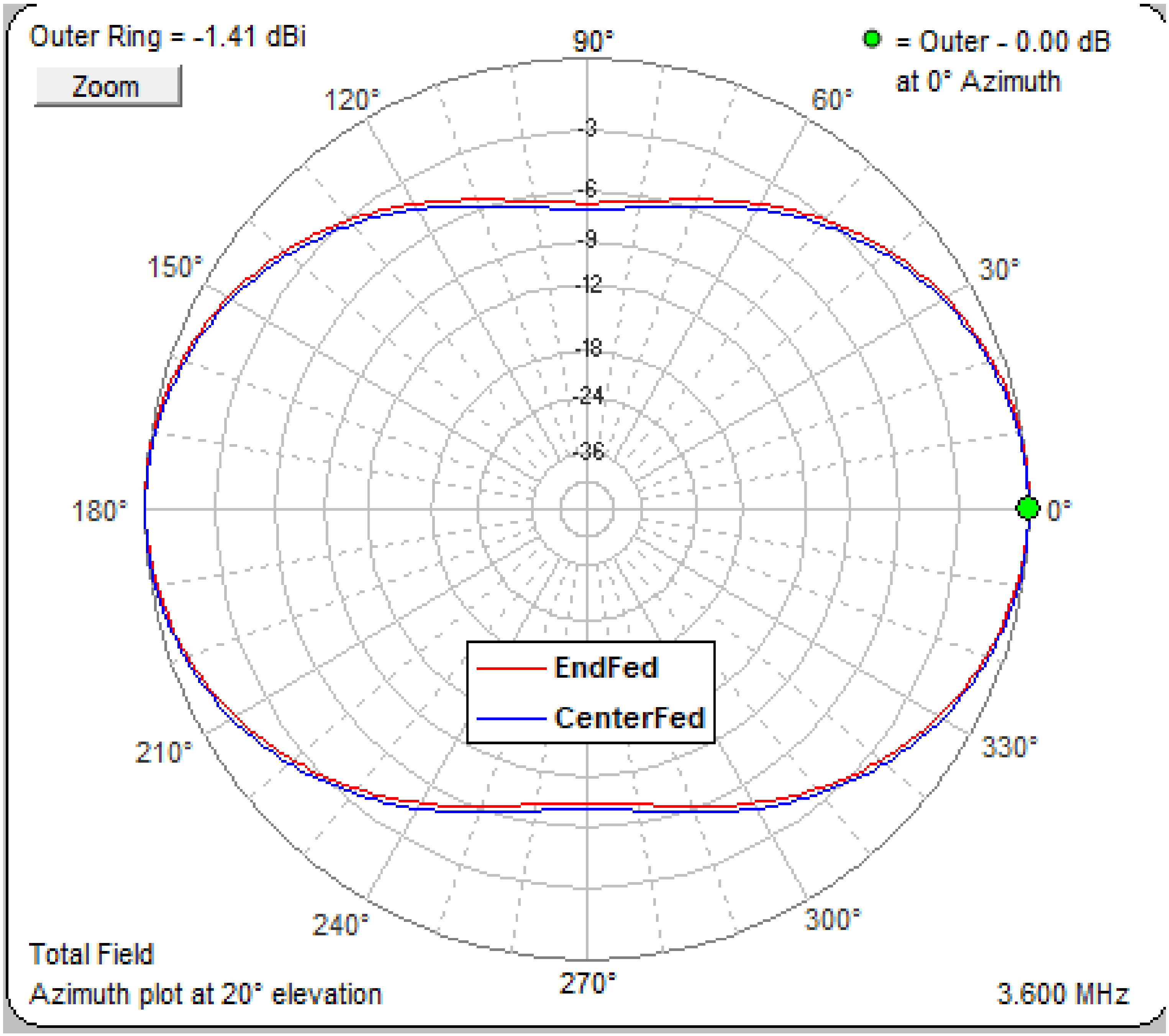


Wire Length = 131.25ft, Z = 54.6 - j0.6 Ohms, Swr50 = 1.094
Height = 35ft, average dirt

Prototype End-Fed Antenna

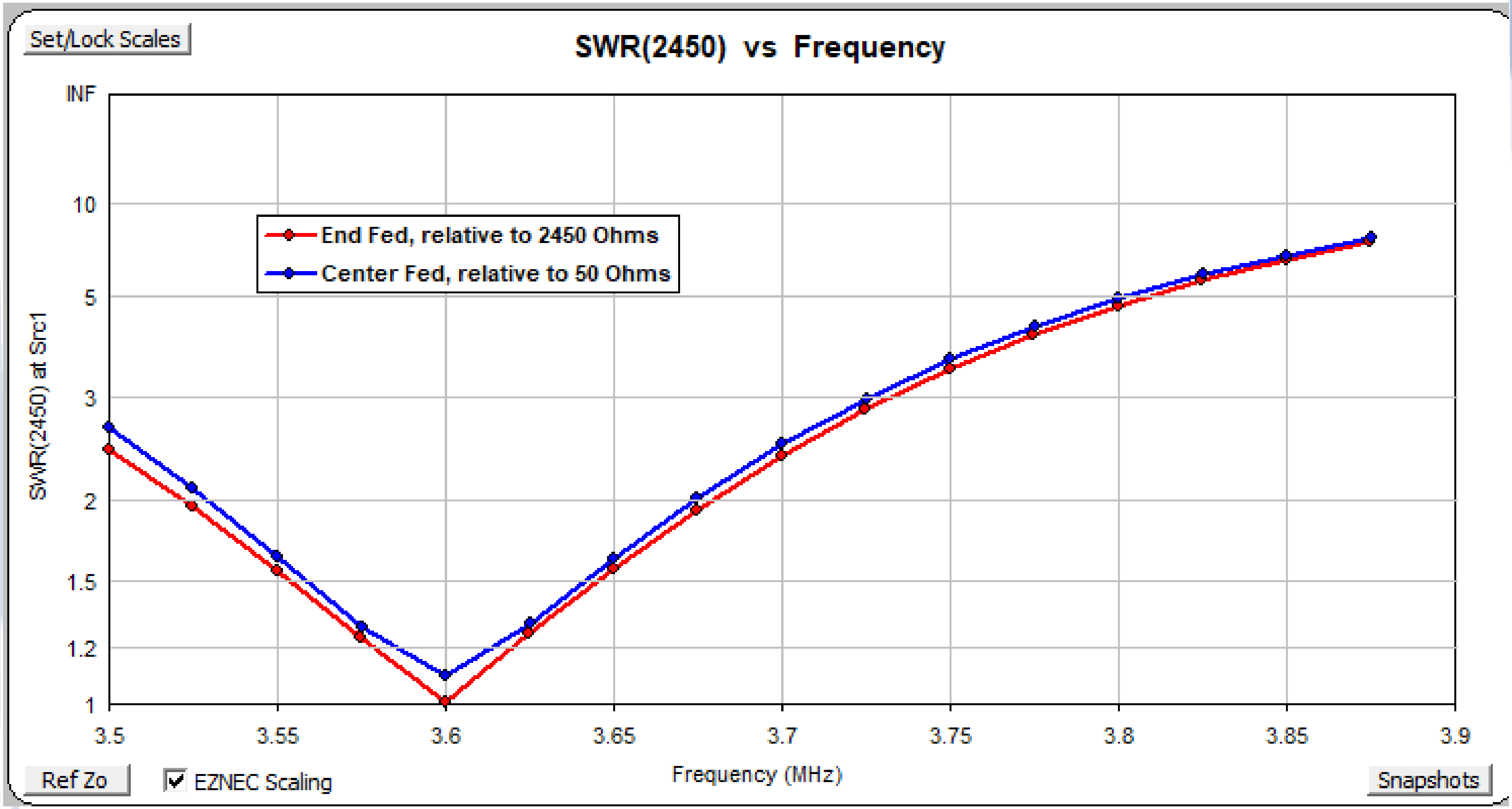


Feed-Point 5.7% from end, Wire Length=134.6ft
Z=2469 - j11.8, Swr2450=1.009



Outer Ring = -1.41 dBi
Zoom
= Outer - 0.00 dB
at 0° Azimuth
90°
120°
60°
150°
30°
180°
0°
210°
330°
240°
300°
270°
-3
-6
-9
-12
-18
-24
-36
EndFed
CenterFed
Total Field
Azimuth plot at 20° elevation
3.600 MHz

SWR of EF vs CF



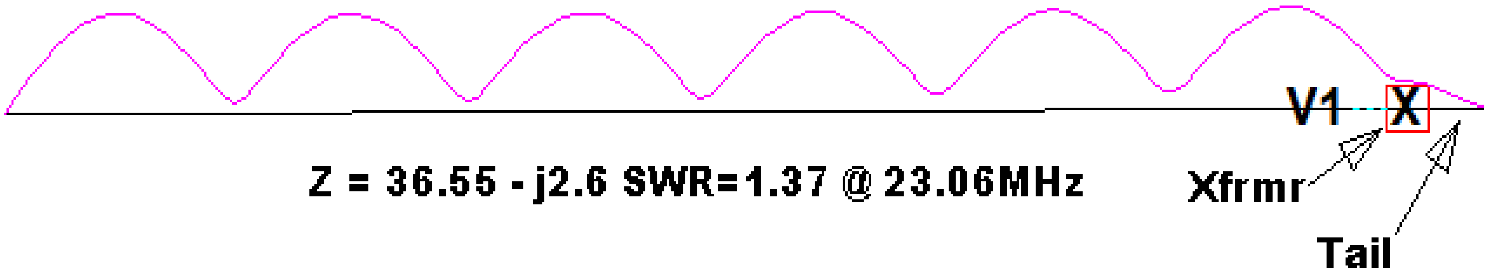
Takeaways from CF/EF simulations

- Current distribution almost identical on fundamental band
- 3.6 MHz Azimuth Patterns identical
- Tail (counterpoise) is a required part
- EF tail is tiny, only 7.7ft out of 134.6ft
- Ratio is for 2450 Ohm (1:49 transformer)
- Tail current is only 15% of peak in wire
- Not a big stretch to cut off tail

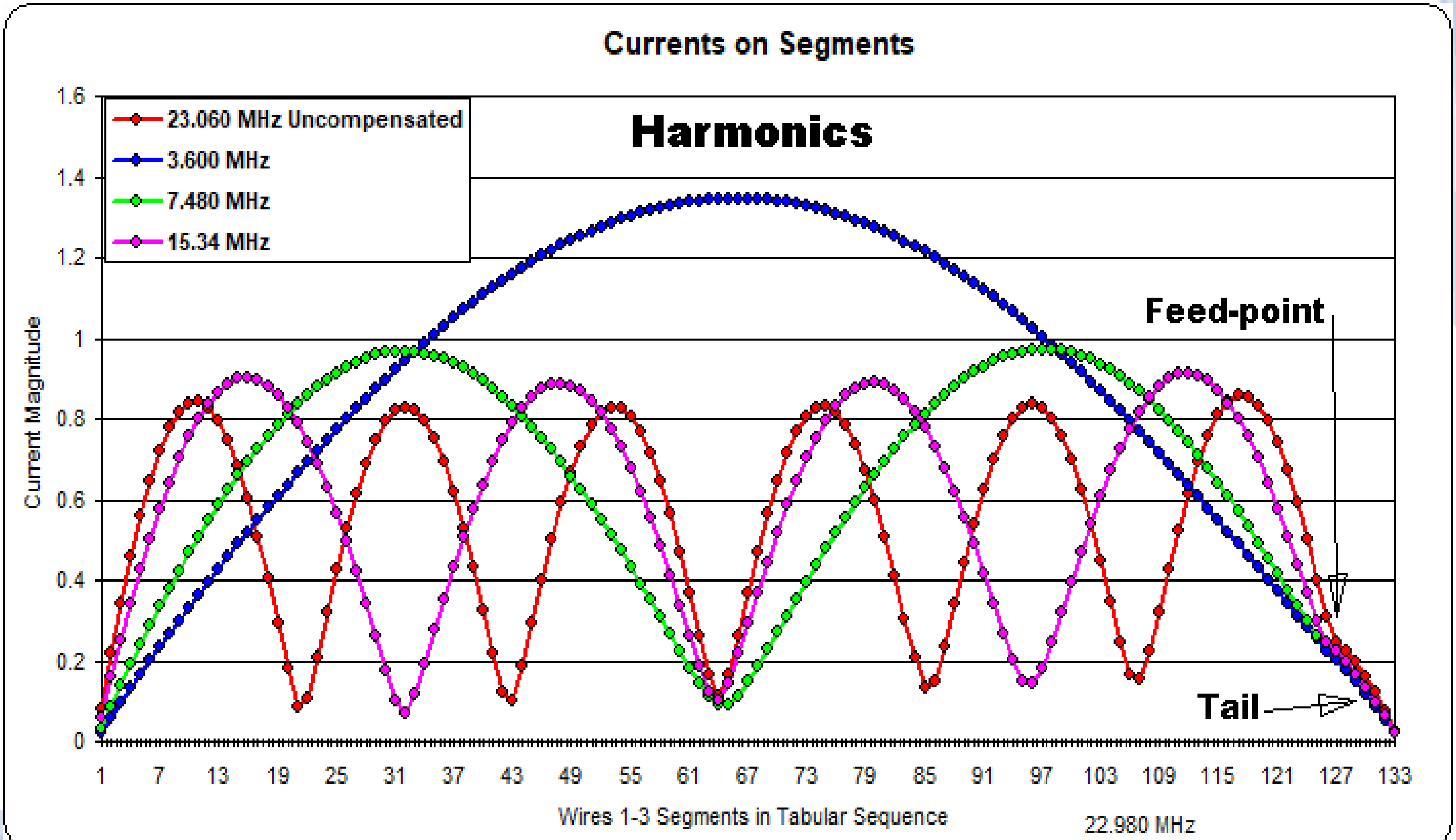
EFHW as a multi-band antenna

- EF resonates on **all harmonics,**
- Resonance not exact integer multiples
- Requires Compensation coil, about 6ft from transformer
- Aligns the SWR dips on harmonics
- Coil makes it “longer”
- Show simulation
- Show Patterns

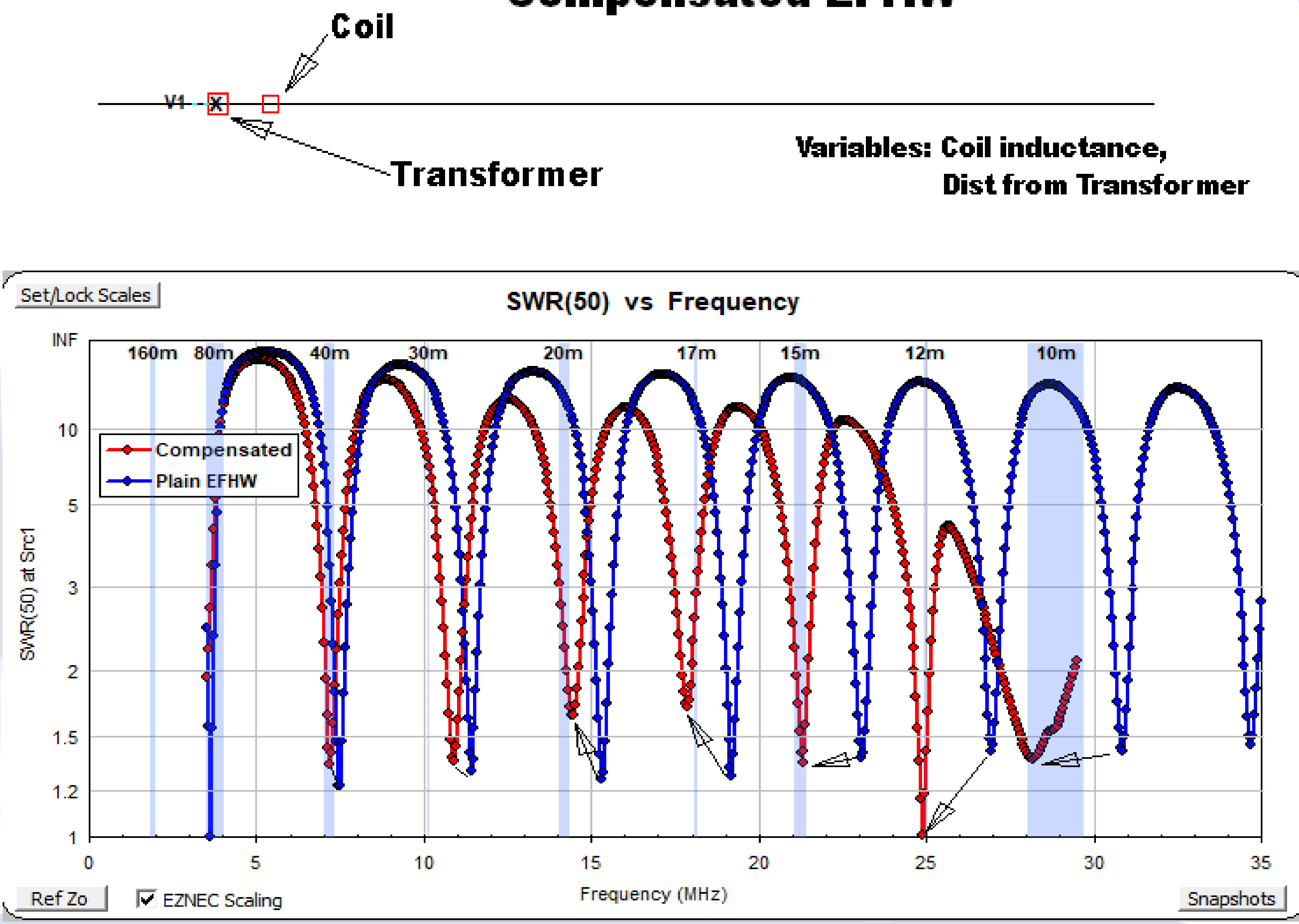
3.6 MHz EFHW on its sixth harmonic



Z = 36.55 - j2.6 SWR=1.37 @ 23.06MHz



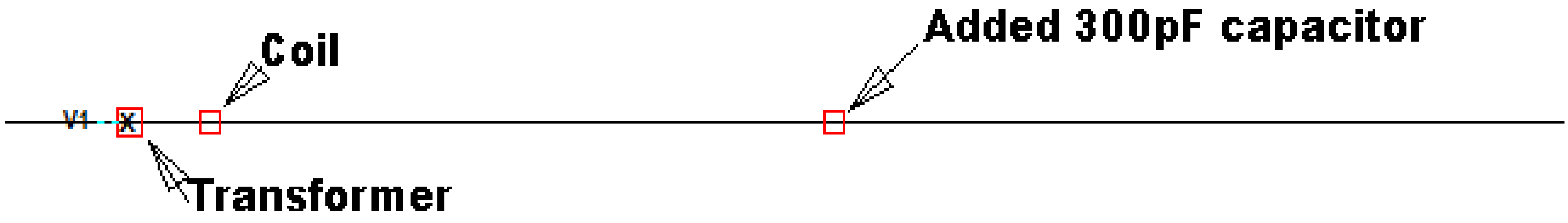
Compensated EFHW

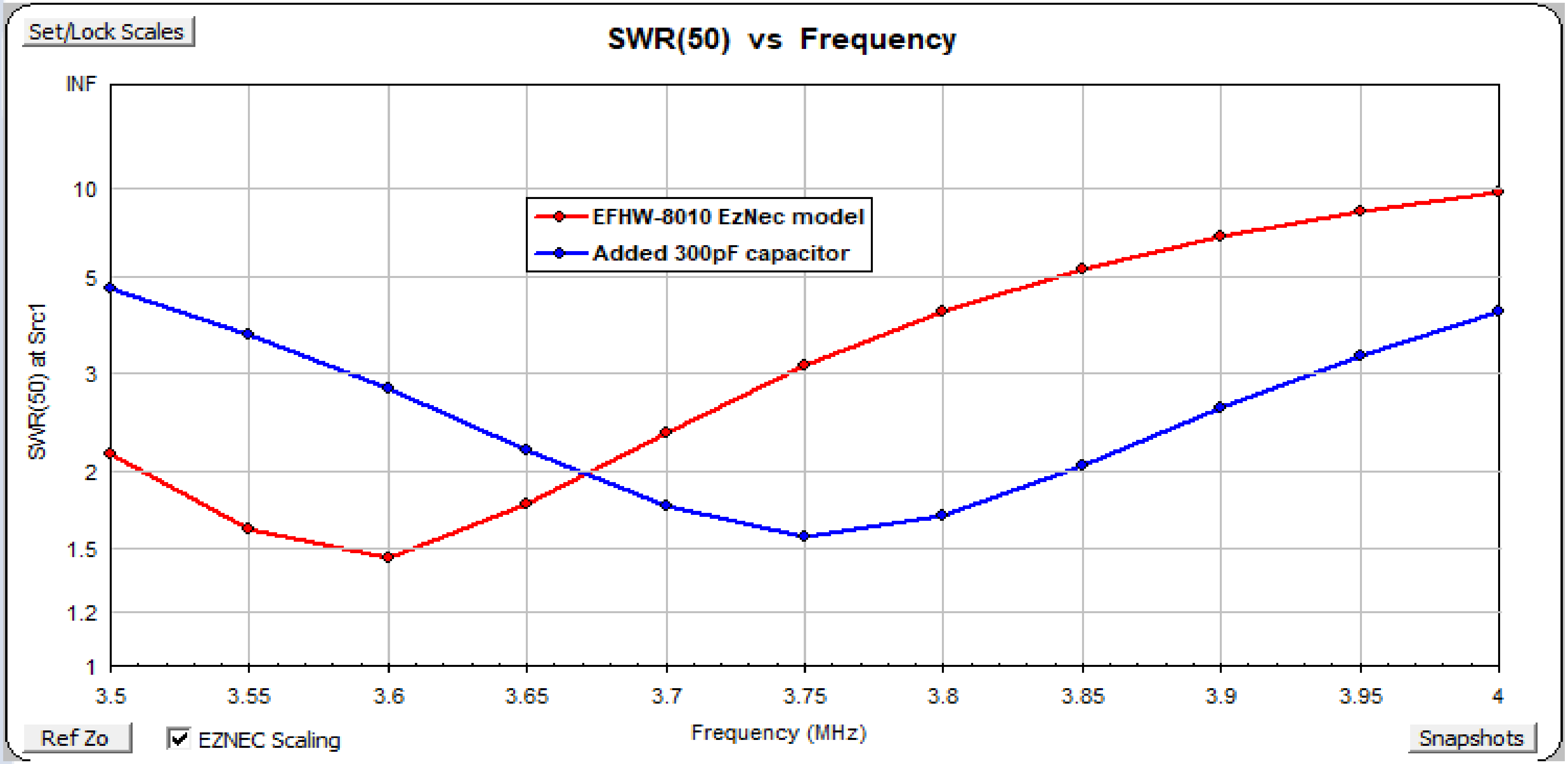


Move the first SWR null to 75m

- The EFHW-8010 has the lowest SWR at ~3.58MHz
- Not good if your interest is 75m
- There is a new EFHW-7510-2K model
- Adds a 300pF capacitor to center of the long wire.
- How does that work?

Evolution of EFHW-7510 antenna



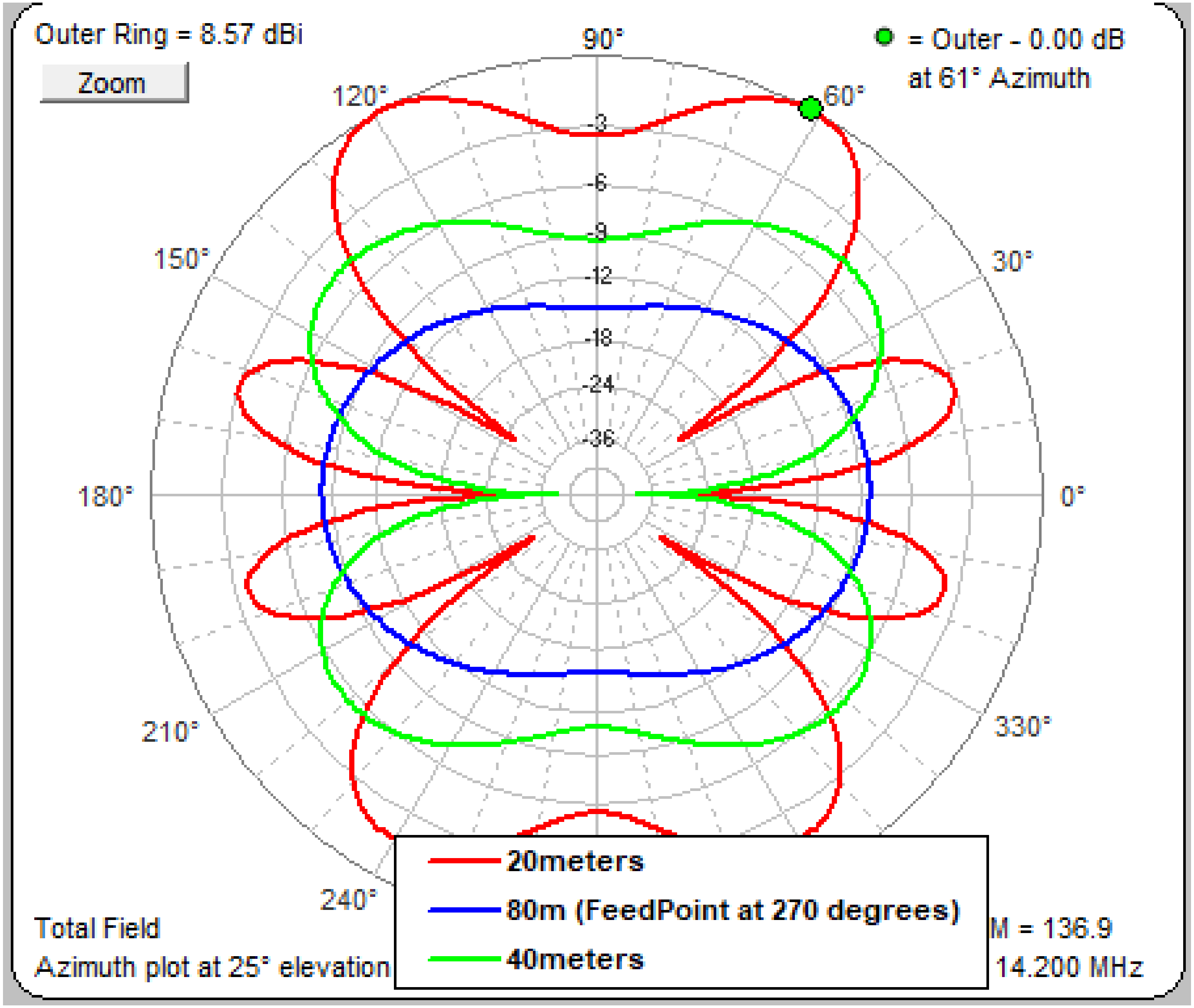


Compensation capacitor

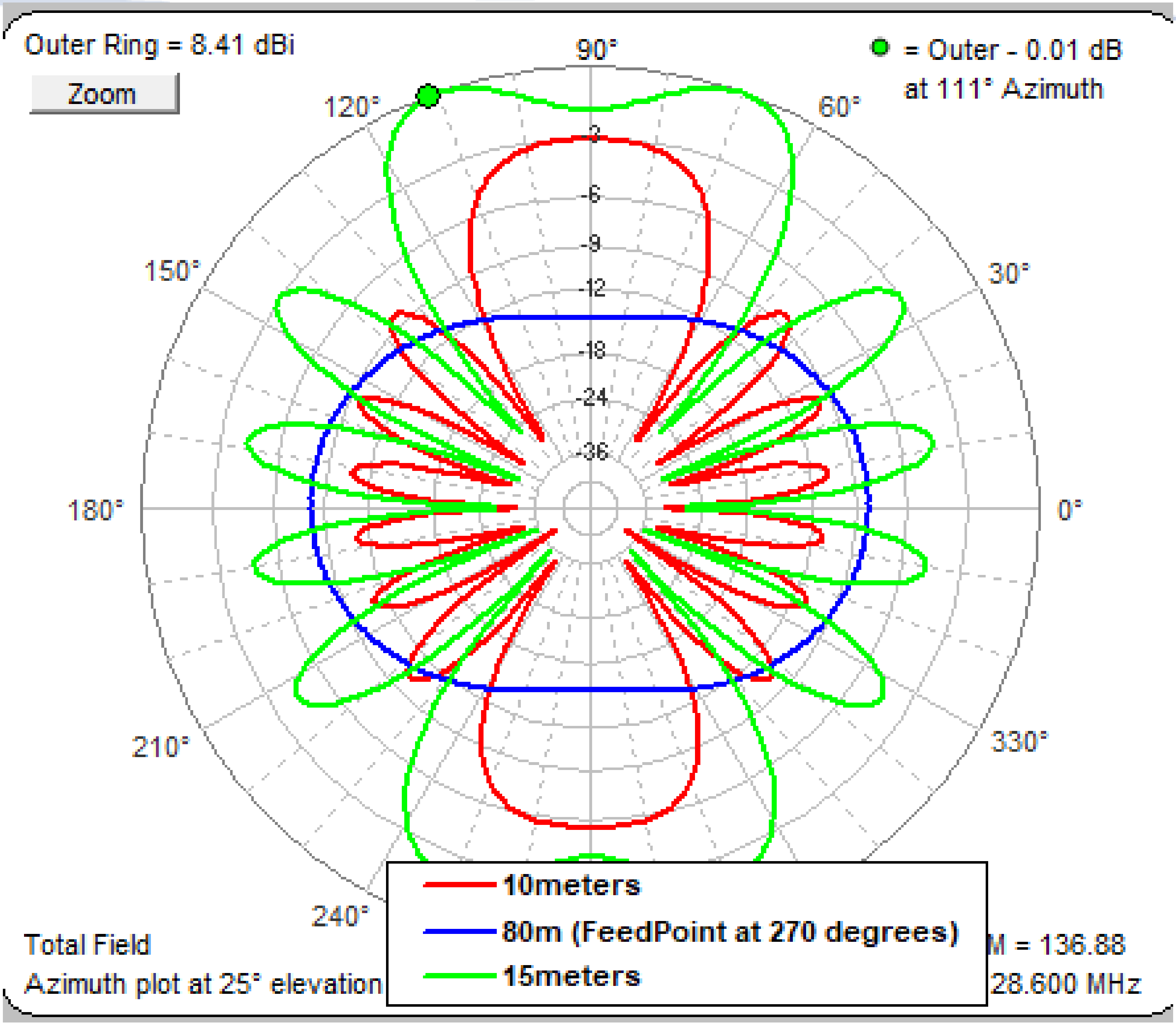
- 80m: current is max at center of long wire
- 40m: current is min at center of long wire
- Capacitive reactance makes antenna shorter only on 80m
- not on 40m on up
- Capacitor becomes a short on higher bands
- Position juggled with compensation coil.

Azimuth Patterns

- Identical to dipole on fundamental
- On Higher Harmonics:
  - "lobes"
  - Some Gain
  - Deep Nulls
- Might need two antennas?
- Look at what the simulator predicts:
- Observed



Outer Ring = 8.57 dBi
Zoom
= Outer - 0.00 dB
at 61° Azimuth
90°
120°
60°
150°
30°
180°
0°
210°
330°
240°
-3
-6
-9
-12
-18
-24
-36
20meters
80m (FeedPoint at 270 degrees)
40meters
Total Field
Azimuth plot at 25° elevation
M = 136.9
14.200 MHz

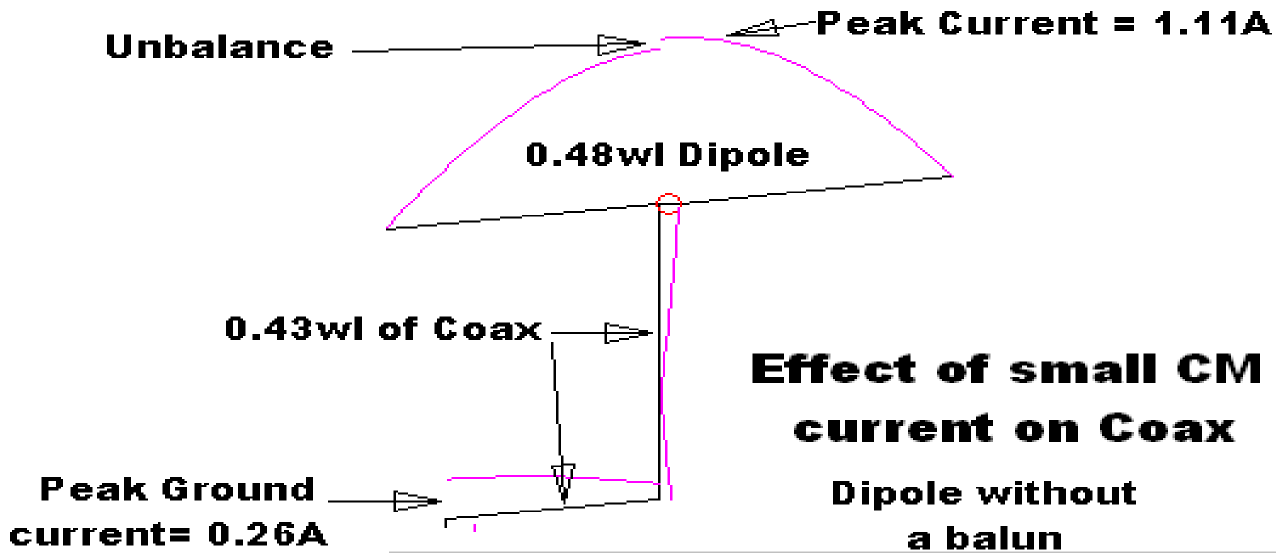

Outer Ring = 8.41 dBi
Zoom
90°
= Outer - 0.01 dB
at 111° Azimuth
120°
60°
150°
30°
180°
0°
210°
330°
240°
-3
-6
-9
-12
-18
-24
-36
10meters
80m (FeedPoint at 270 degrees)
15meters
Total Field
Azimuth plot at 25° elevation
M = 136.88
28.600 MHz

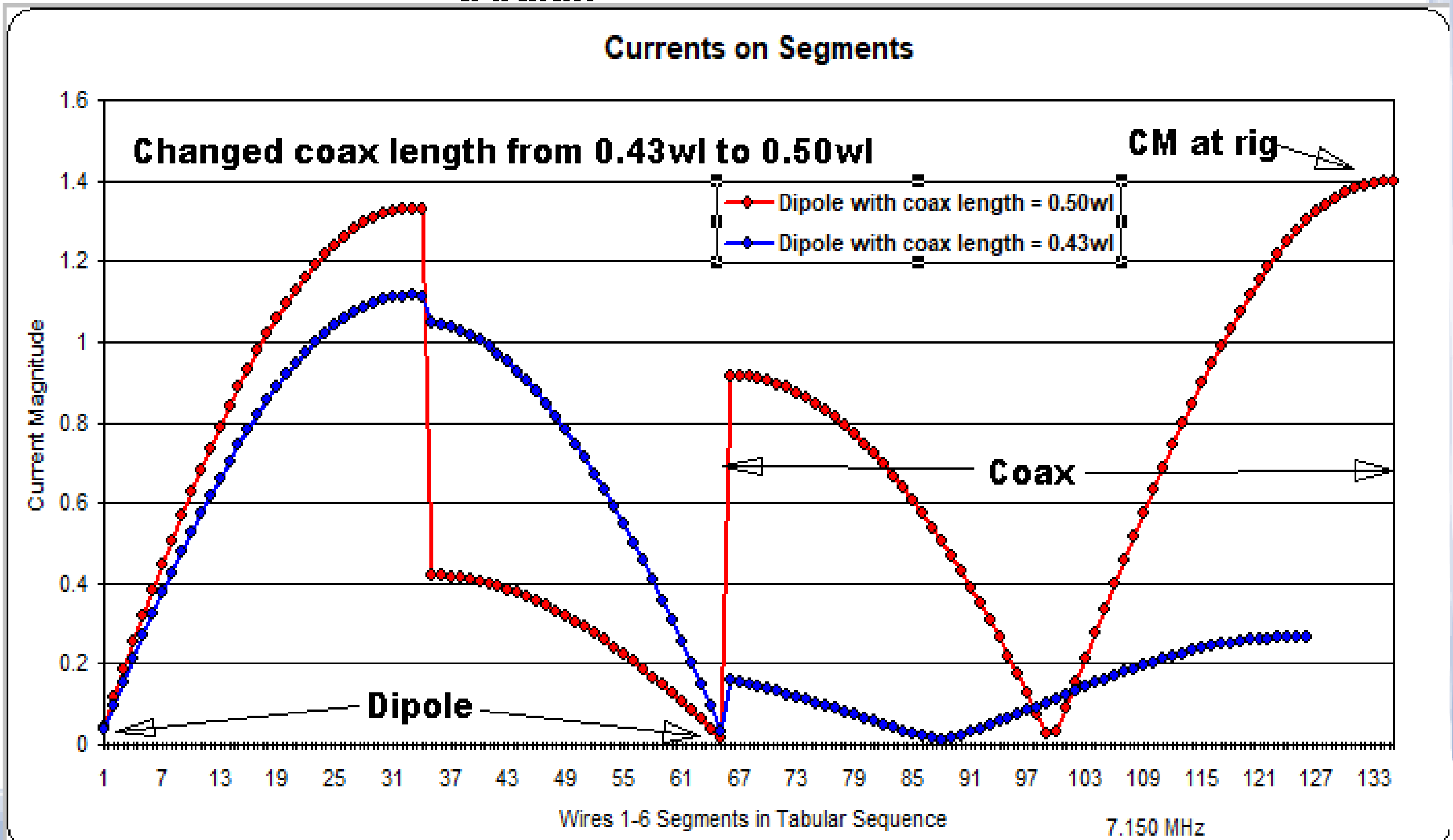
Coax is really three conductors

- Two are Center-to-Inside-of-Shield
  - Called Differential (TEM) Mode of coax
  - Carries power to antenna.
  - Fields completely cancel inside coax
- Third conductor is the outside of Shield
  - Acts as a real wire in the near-field
  - Modifies the pattern/SWR
  - Follows the coax back to the shack
- Called Common Mode (**CM)** on coax

Effect of small CM current on Coax

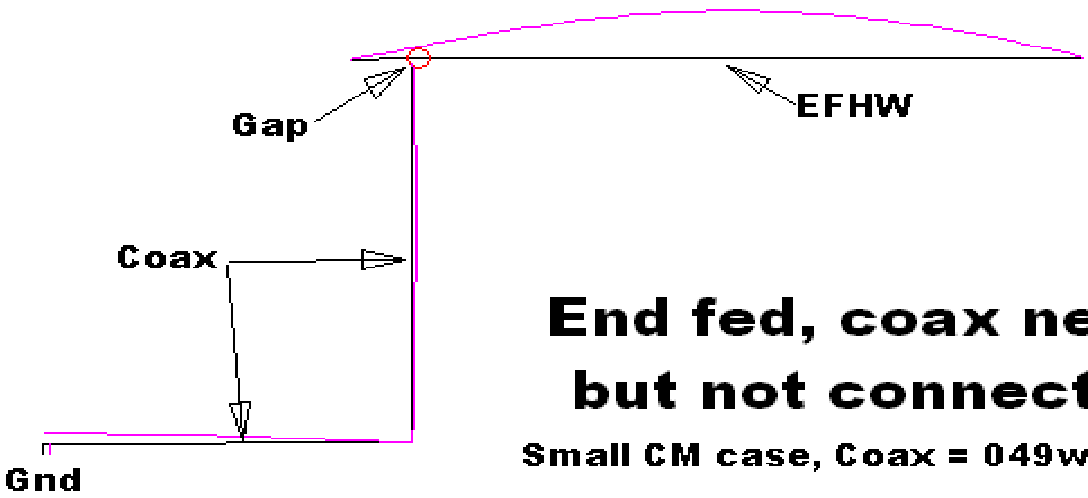
Dipole without a balun

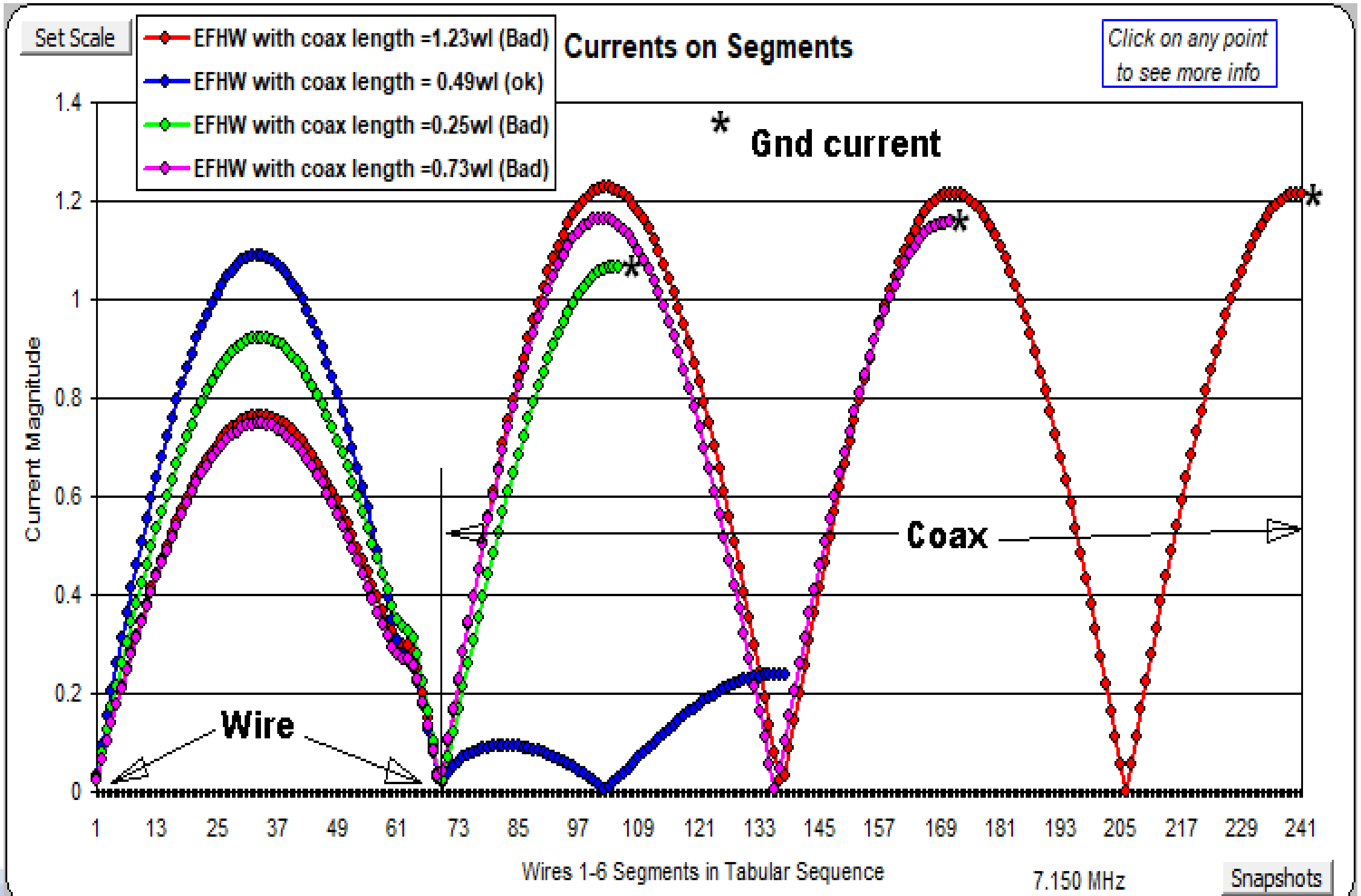


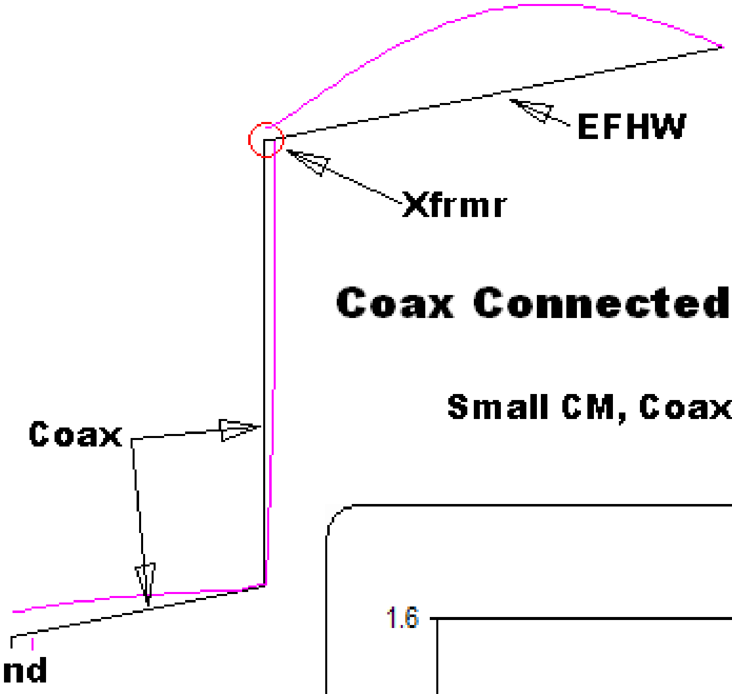


End fed, coax near, but not connected

Small CM case, Coax = 049wl

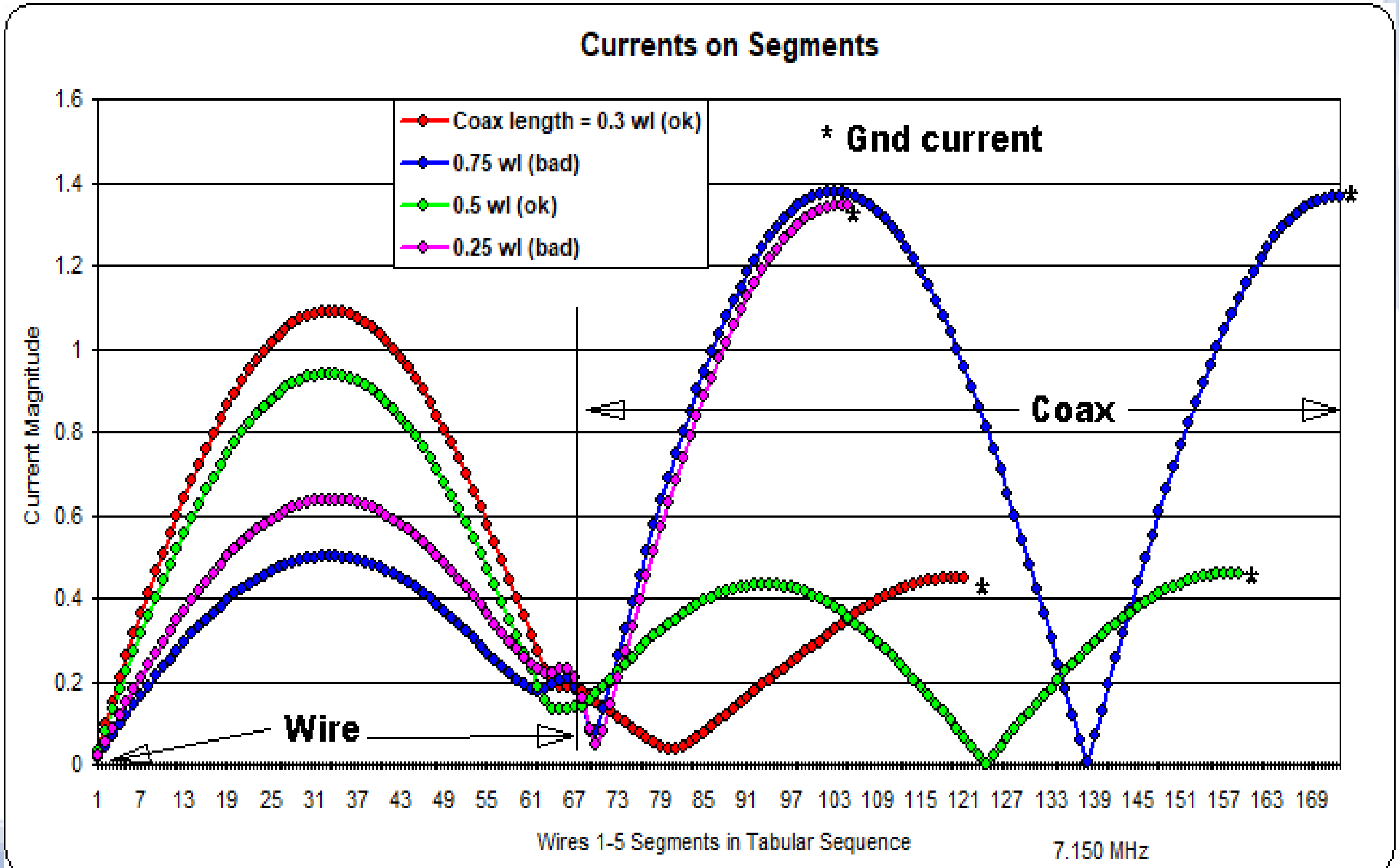






Coax Connected to Transformer

Small CM, Coax = 0.49wl



Vary coax length on EFHW

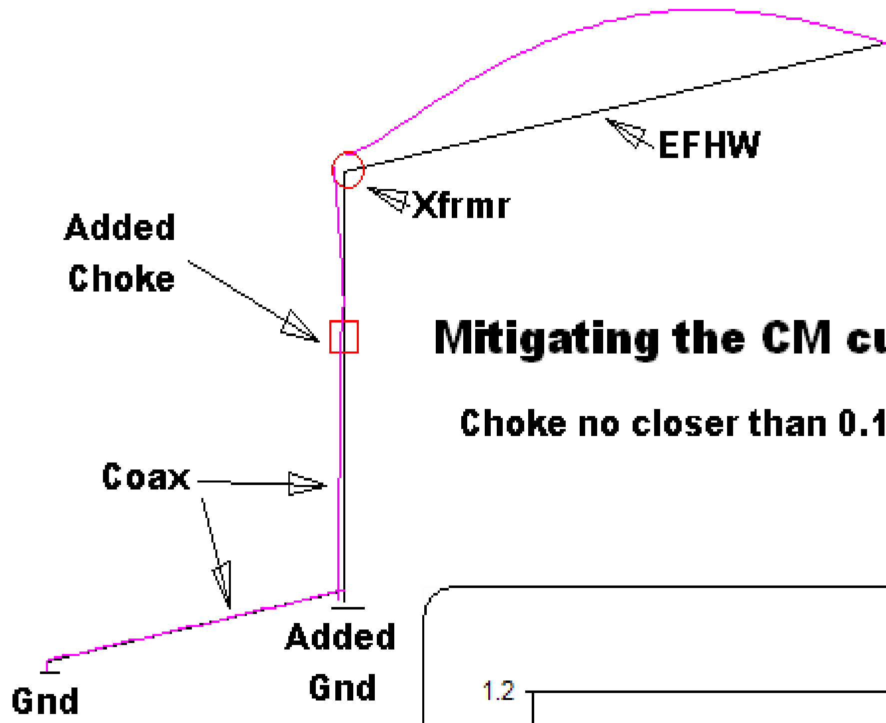
- 80m EFHW (coax only)
- Coax grounded
- No CMC
- Vary coax from 45ft (0.16wl) to 265ft (0.97wl)
- Watch the movie:

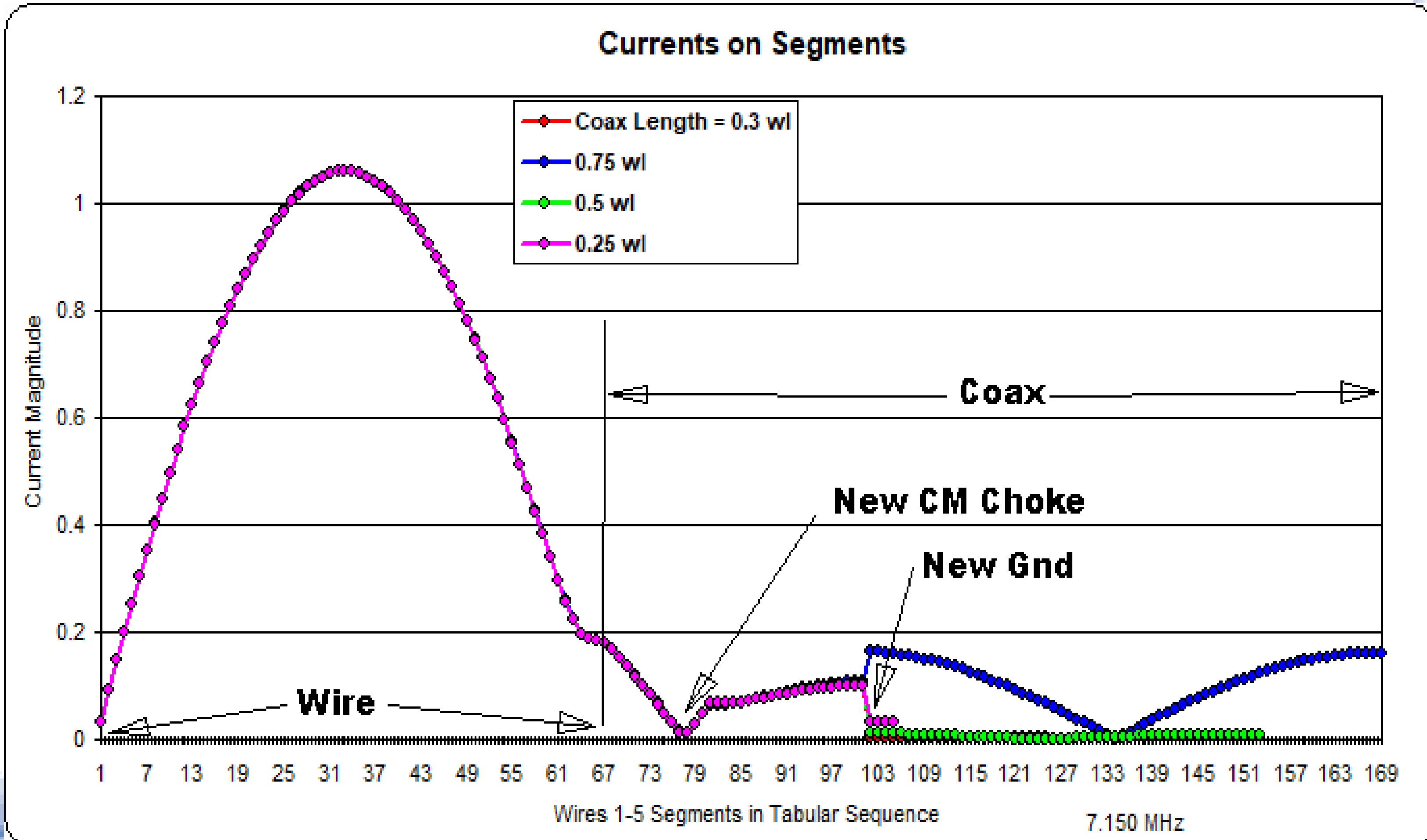
Now let's fix it

- Mitigation
  - Common Mode Choke (see example)
  - Ground near transformer.

Mitigating the CM current

Choke no closer than 0.1wl





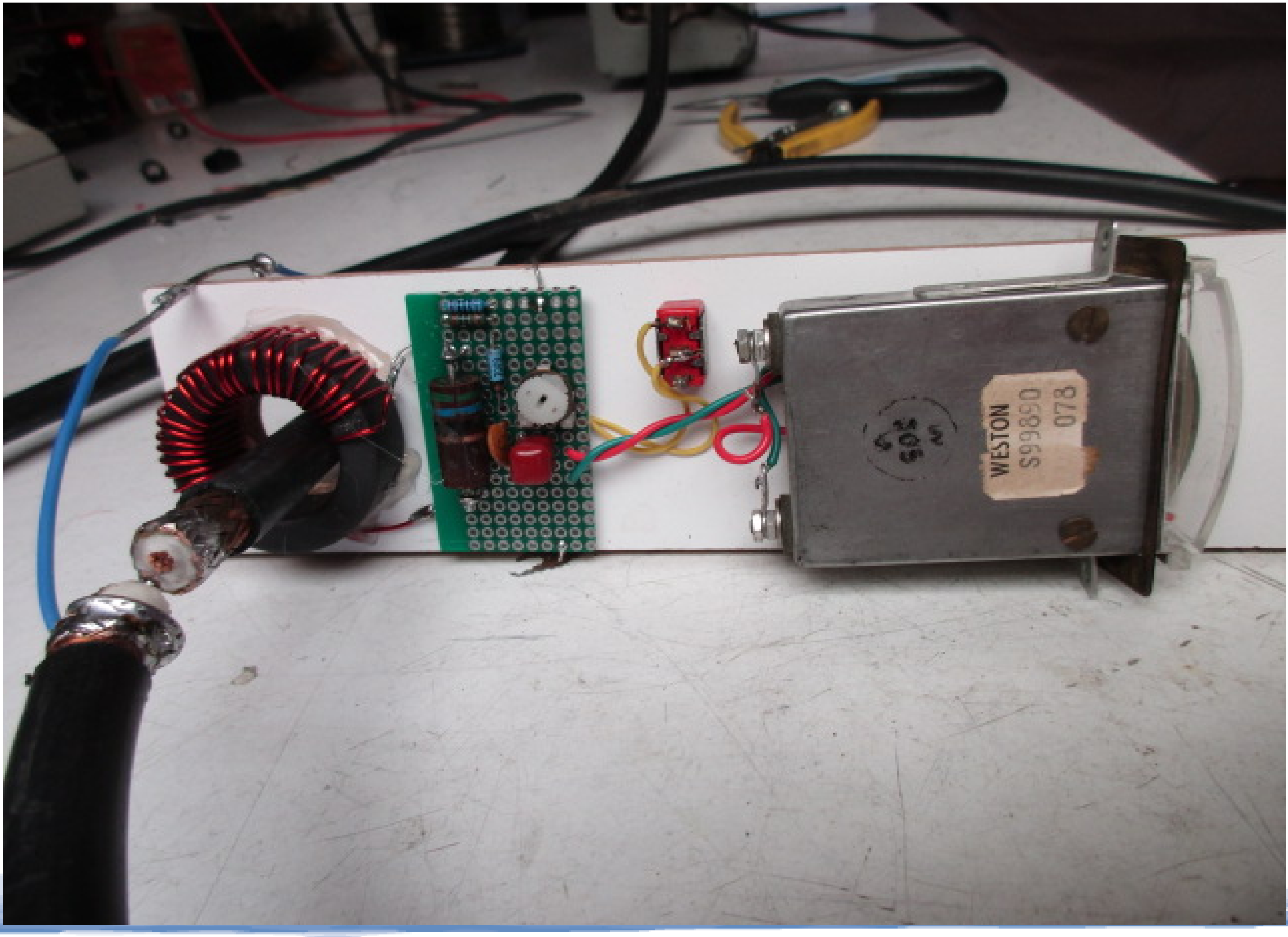
What simulation shows about coax shield

- CM Current on coax shield comes from:
  - Mutual coupling between EF wire and coax, especially if coax-to-ground path becomes resonant (dominant effect
  - Transformer secondary current (small effect)
- When Standing-Wave forms on coax shield
  - Radiates and distorts pattern
  - Changes feed-point Z and SWR
  - Conducts RF < into shack
  - Conducts noise > to receiver front-end

CM on coax during testing

- I used the EFHW-8010 test set up shown
- 100W to antenna, Max wire current ~1.4A
- I used a CM current meter I built (0.6A f.s.)
- Tried w/wo CM choke, Ground at window
- Tried various coax lengths to find resonances
- Tried all bands where no tuner needed
- Highest CM sometimes outside (Standing W)

Current Transformer/Detector for measuring CM current on coax



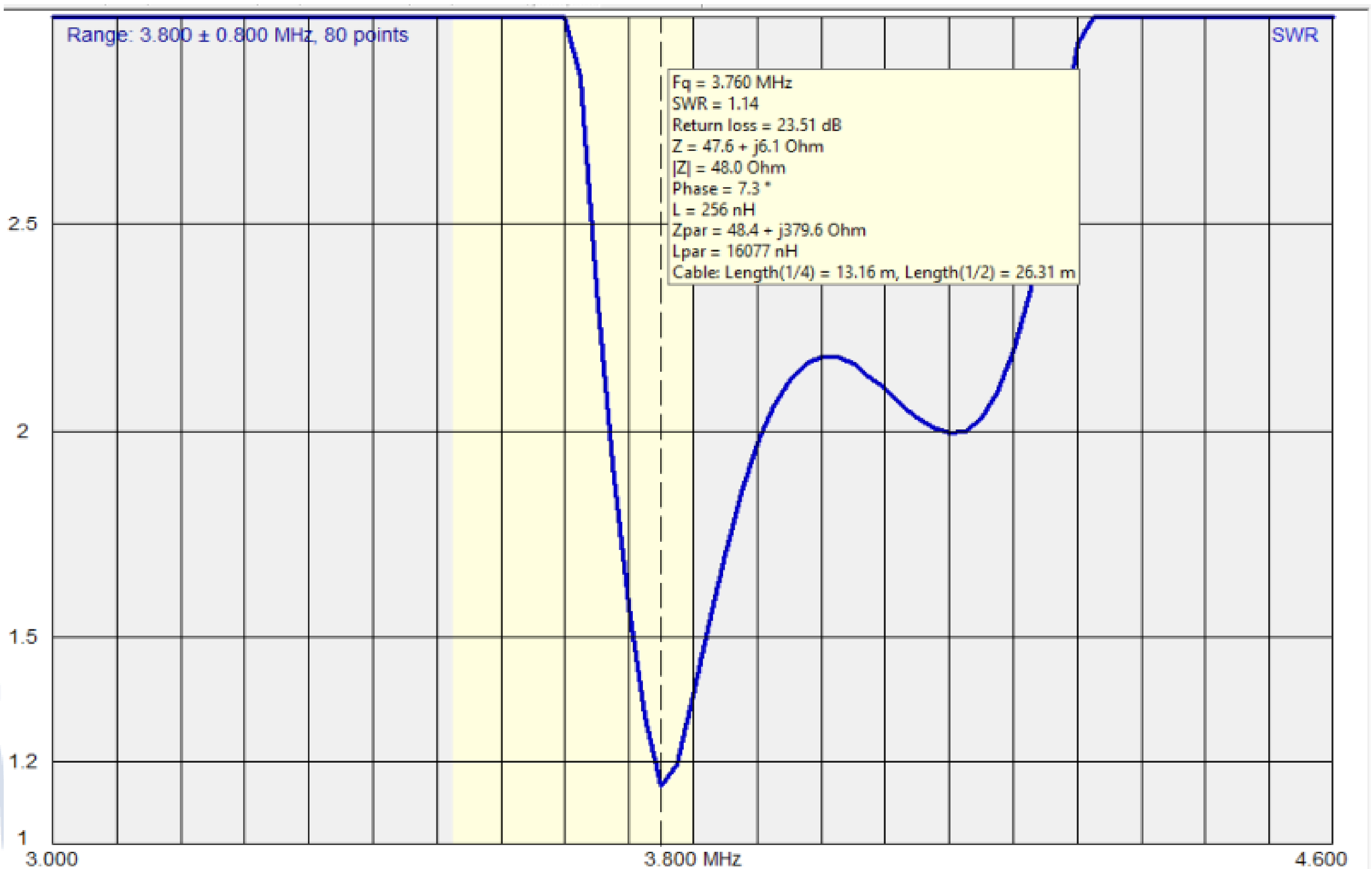
Measured CM at rig end (circled values cause "buzz" in computer speakers

coax Len=	40.8	55.6	69.02	80.1	102.8	115.1	162.3
frequency	mA	mA	mA	mA	mA	mA	mA
3.500	116	64	240	104	499	65	70
3.600	79	61	116	42	338	61	60
7.000	585	178	240	412	264	178	77
7.150	240	129	215	215	190	129	55
7.300	141	129	314	129	166	129	60
14.000	573	240	190	116	45	48	0
14.100	511	240		92	43	44	0
14.200	437	190	166	79	42	41	0
14.300	363	153	116	67	40	0	0
14.350	289	141	104	67	0	0	0
21.000	215	598	227	129	0	0	0
21.100	166	536	203	116	0	0	0
21.200	141	511	166	92	0	0	0
21.300	104	412	141	67	0	0	0
21.400	42	289	116	42	0	0	0
28.300	166	141	42	0	0	0	0
28.500	104	116	18	0	0	0	0
28.700	129	166	55	0	0	0	0

Finding the Coax “monopole” resonance on 80m

- Added coax in 2ft steps
- 0.25wl resonance in coax shield at 66ft
- CM meter pinned at 100W (0.6A = f.s.)
- Had to reduce power to ~10W
- Can see the coax resonance in SWR plot:

Coax resonance shows in 80m SWR plot



Grounding coax shield at Entry Panel

- Shunts CM current to earth
- Eliminates it inside shack (verified)
- Changes the path length (for better/worse)
- CM might still be high between entry panel and the transformer to:
  - Distort pattern
  - Pick up noise
  - Change SWR

Adding Common Mode Choke

- CMC = 10 to 17t of small coax on FT240-31
- Analogy: break resonance in guy wire
- Placement (recall simulation)
  - No closer than ~0.1 lowest-band wl to Xfrmr
  - Optimum location on one band may not be optimum on others
  - Locate where coax turns corner below antenna.
- May not need; if CM, then experiment.

Grounding coax/transformer

- Add second earth ground to coax shield under antenna
- Low-mounted transformer (invertedV or L), use Gnd wingnut on box?
- Horizontal/Sloper EFHW fed from tower case study, have some inconsistency between simulation and measurement of actual ant.

Home-building

- Certainly do-able
- Just wire, toroids, capacitor, coax, insulator, box and hardware
- Web is full of resources, some of it bad
- Steve Ellington's videos on YouTube
- FT140-43 toroid for QRP
- Use two or three stacked FT-240-43 for 100W to QRO.

Conclusions: Advantages

- Useful antenna for multi-band operation
- Lots of bands with no-tuner or tuner built-in rig
- Fed from one end sometimes more convenient
- Simple to deploy Horiz, Sloped, V or L
- Useful for limited space, RV, SOTA, FD
- Home-brewable

Conclusions: Disadvantages

- Patterns with deep nulls on certain headings
- Common-mode can be problematic
  - RF in the shack
  - Noise coupled to coax in the shack
- I would:
  - Plan for CM Choke (added cost)
  - Plan for a ground rod

So, to summarize my take on the debate as far as it has come:

1. There is no such thing as an End Fed Half Wave (EFHW) antenna.
2. There is such a thing as an Extremely Off Center Fed (EOCF) Antenna, which is what we have been discussing.
3. An isolated EOCF antenna requires at least a minimal (0.05wl) counterpoise to work.
4. The current into the counter poise is small compared to the peak current in the active part of the antenna (~20%).
5. The counterpoise can be a 0.05 to 0.4 wl wire without affecting SWR hardly at all.
6. If a coax feeds a three-terminal auto-transformer, the coax shield can be the counterpoise, and the short wire is redundant.
7. The current on the coax shield can be choked, as long as the choke is no closer than 0.05wl to the transformer.
8. The current on the coax shield can be shunted into the earth with a ground rod.
9. In certain installations, you might have to do both 7 and 8 to prevent RF getting into things in the shack.