Locating Stubs For Harmonic Suppression

Jim Brown K9YC

k9yc@arrl.net

Don’t Bother Taking Notes

- **A tutorial is already at k9yc.com/publish.htm**
- **These slides will be added when I’m finished with them**

Why Stubs?

- Power amps generate harmonics
  - 2nd harmonic typically -6 dBC
- Output stages filter the harmonics
  - In tube amps, transform impedance too
- Bandpass filter between rig and power amp can't filter power amp
- High power bandpass filter after the amp <u>does</u> filter power amp harmonics
- Stubs do too, and are a lot cheaper

Placement Along Line Matters

- Between stub and antenna
- Between stub and power amp
- Both must be satisfied for best results

How Stubs Kill Harmonics

- **A harmonic stub is a series resonant circuit**
- **Places a short across the line at the harmonic frequency**

Let’s Study Spacing to Antenna First

Why Spacing to Antenna Matters

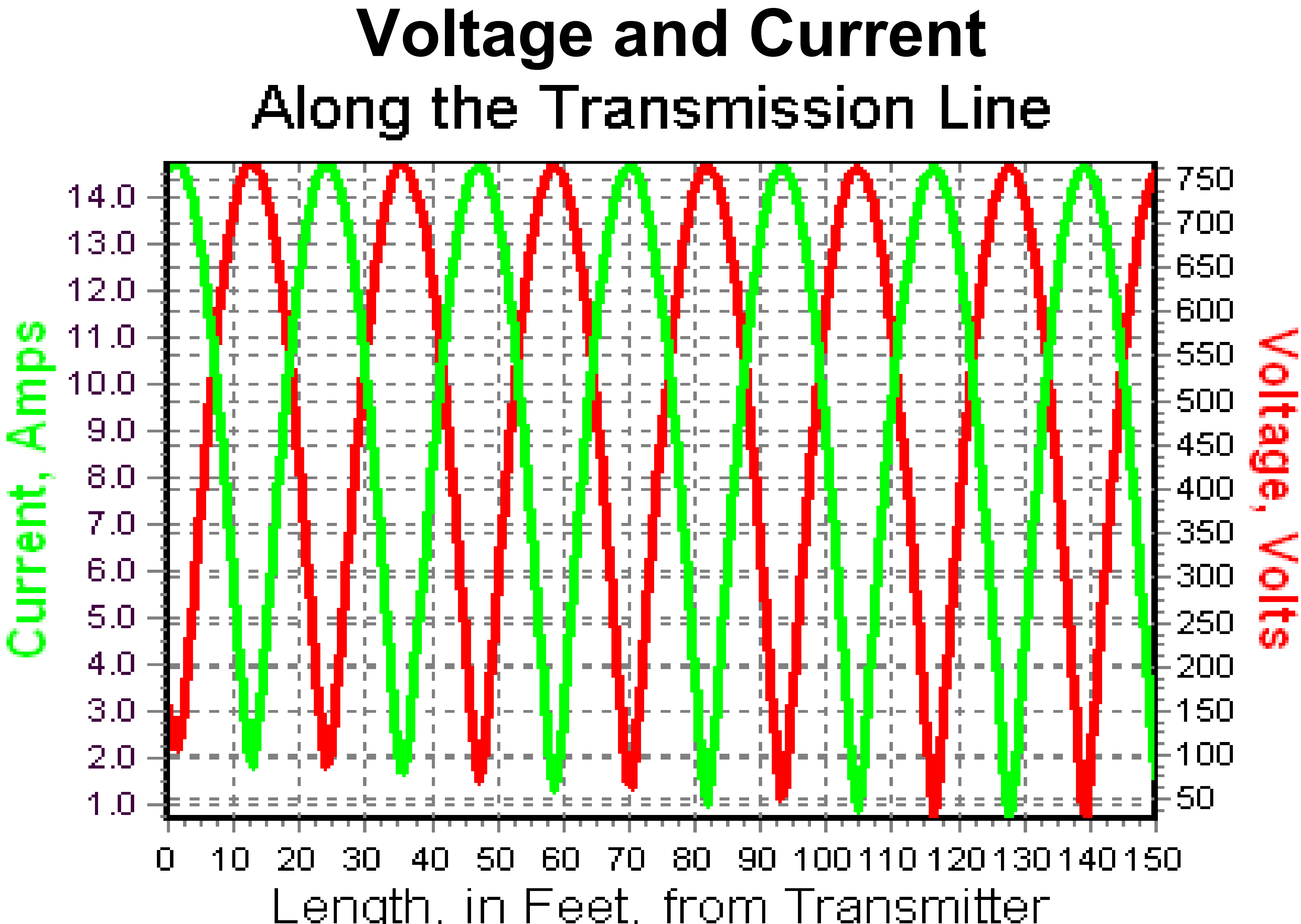
- **Most single-band resonant antennas have a high SWR on 2nd and 4th harmonics**
- **Impedance along the line will vary from very high to very low, repeating in half wave intervals**

Why Stub Placement Matters

- **A stub will be most effective at a <u>high</u> impedance point on the line (it's shorting out a high impedance)**
- **A stub won't do much at low impedance point on the line (it's in parallel with a very low impedance)**
- **Placement from the antenna doesn't matter if antenna is resonant on the harmonic you want to kill**

A 40M Dipole <u>on 20M</u> Fed By 150 ft RG8 with VF = 0.66

- **In the next slide**
  - **Plot by N6BV's TLW (Antenna Book) for Belden 8237**
  - **Red curve is voltage**
  - **Green curve is current**
- **High voltage means high impedance**
- **Peaks of red curve are high-Z points**



Voltage and Current
Along the Transmission Line
Current, Amps
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
Voltage, Volts
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Length, in Feet, from Transmitter

What Sets Location of Peaks?

- **The standing wave pattern on a line is established by the impedance match between the <u>load</u> and the line**
- **The <u>source</u> impedance has nothing to do with it**

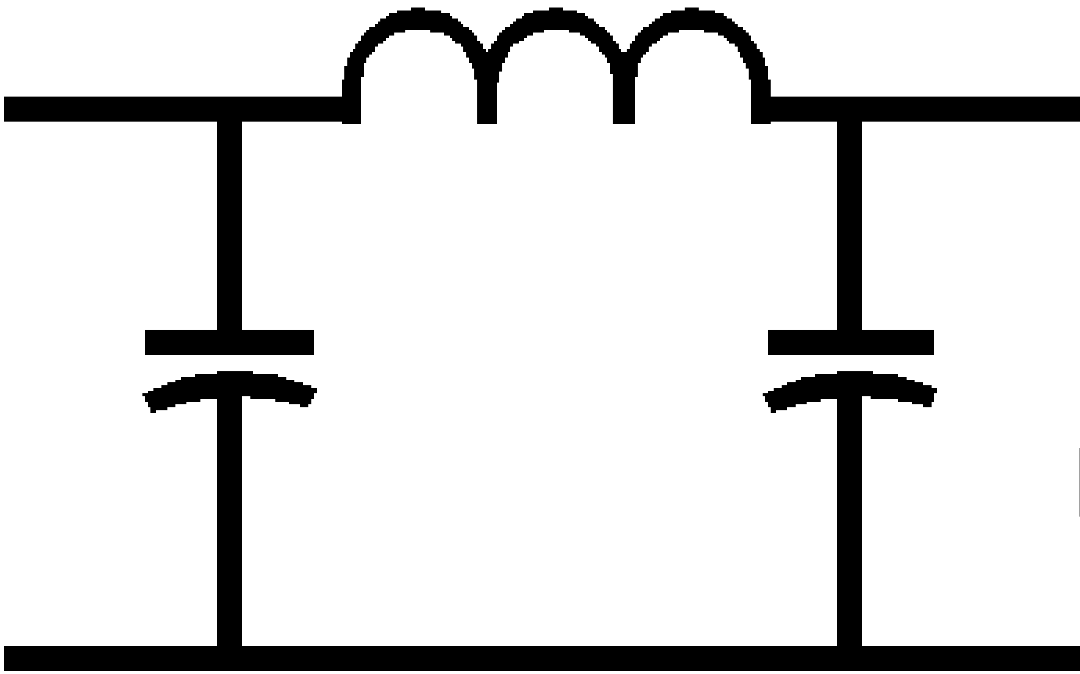
Stub Placement and Amplifiers

- **Amplifier output networks suppresses the 2nd harmonic (typically 30+ dB)**
- **A stub with "good" spacing to the power amp adds to that suppression**
- **A stub with "bad" spacing does <u>not</u> add much (if any) suppression**
- **"Good" and "bad" spacing depends on the output network**

Stub Placement and Amplifiers

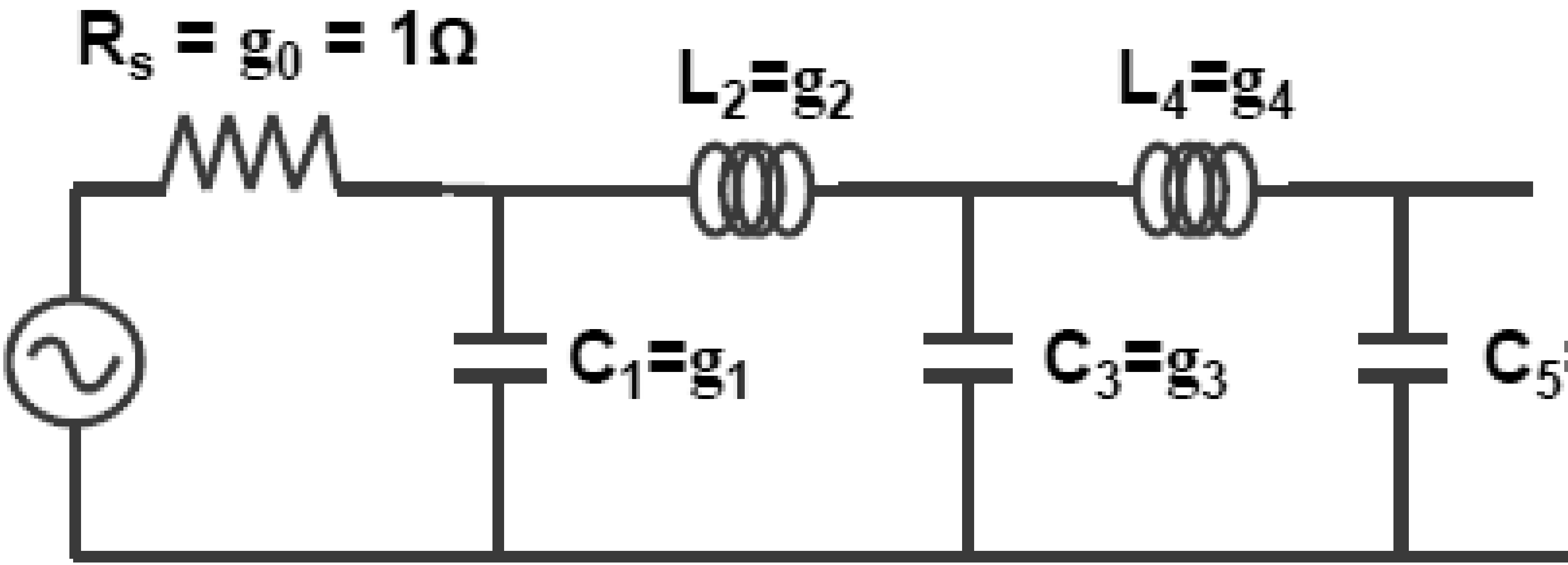
- Three common output networks
  - Pi
  - Pi-L
  - Elliptical

Pi Network



Output is
Low Z for
Harmonics

Typical Elliptical Filter Used in Solid State Amps

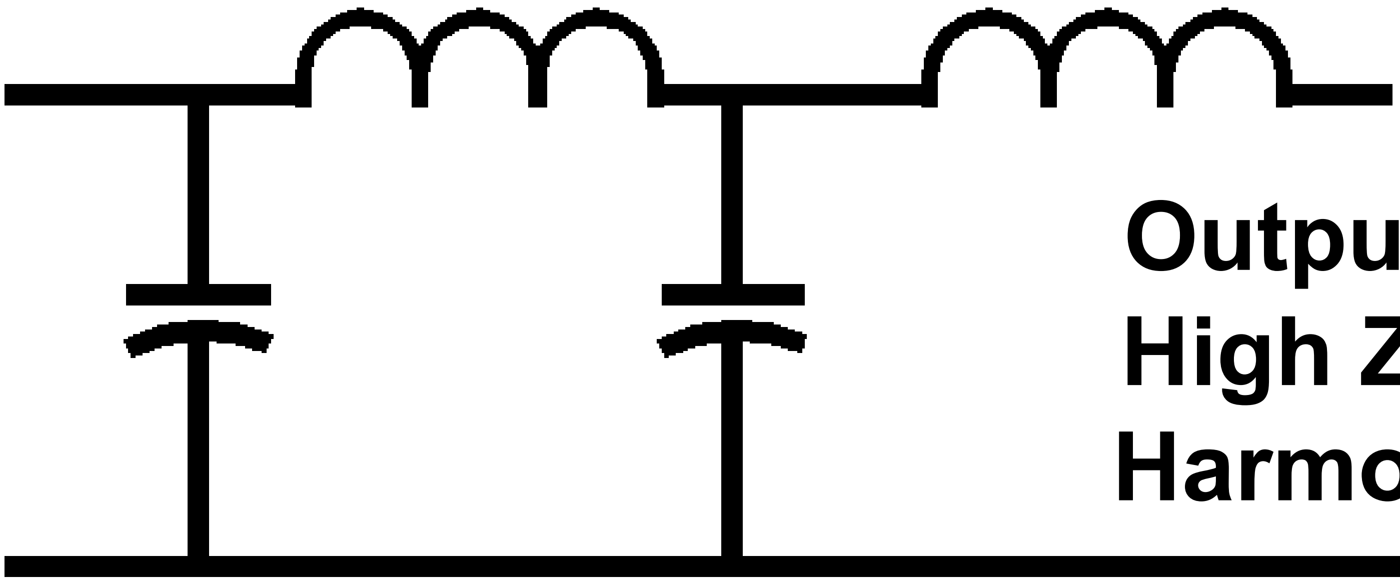


Output is Low Z for Harmonics

Pi and Elliptical Output Networks

- **The output capacitor makes the output impedance at the harmonic low**
- **Placing a stub directly at the amplifier output, or at some multiple of half-waves from the amplifier (at the harmonic frequency) won't do much**
- **A stub will be most effective at λ/4 from the amplifier, or at some odd multiple of λ/4, at the harmonic frequency**

Pi-L Network



Output is High Z for Harmonics

Stubs with Pi-L Output Network

- **A Pi-L network has a <u>high</u> output impedance at the harmonic**
- **A stub will be <u>most</u> effective directly at the amplifier output or some multiple of λ/2 from the amplifier (at the harmonic frequency)**
- **A stub will be <u>least</u> effective at λ/4 from the amplifier, or at some odd multiple of λ/4 (at the harmonic frequency)**

Amps with Pi or Elliptical Output

- Commander HF-1250, HF-2500
- Dentron Clipperton L, MLA-2500
- Drake L4, L7
- Heath SB-200, SB201, SB-220, SB-221
- Kenwood TL-922A
- Ten Tec Hercules II, Centurion
- Elecraft KPA500 (Elliptical)
- Most solid state amps (Elliptical)

Amps with Pi-L Output

- Acom 1000, 1010
- Alpha 374, 76, 77, 87, 87A, 89, 91B
- Ameritron AL800H
- QRO 2500DX
- Ten Tec Titan 425
- SPE 1K-FA

Amps with Pi-L on 160/80, Pi on Other Bands

- **Ameritron AL80, AL82, AL-1200**
- **Heath SB1000**

- **Additions to these amplifier listings are appreciated**

So – Stub Placement Criteria

- **At high impedance point along line from antenna**
  - **Placement may not matter much if antenna is near resonance at harmonic**
- **λ/4 or λ/2, or multiple of from power amp, depending on output network**
  - **Always matters**

How Much Does This Matter?

- **W2VJN started thinking about it when users of stubs he had built reported they weren't doing anything!**
- **I measured the difference in 2nd harmonic depending on coax length between stub and two amplifiers**
  - **RF voltage tap at output of power amp to spectrum analyzer**
  - **Ten Tec Titan 425 (Pi-L) 10 dB**
  - **Elecraft KPA500 (Elliptical) 12 dB**

How Much Does This Matter?

- SimSmith predicts 17 dB difference for a single shorted stub depending on placement from antenna
- That’s a total of 27-29 dB difference between ideal and worst case
- Best case for a single shorted RG-8 stub is about 33 dB
- All of this is for a 40M dipole

Process Overview

- In the shack, measure complex (R + jX) impedance of antenna at the harmonic
- Plug data into software to find one or more high Z point(s) along the line
- Break the line at one of those points, or add coax to get to the next one
- Add coax Tee and barrel, add stub
- Make the length of line from that point to the power amp “right” for that amp

Measuring Complex Impedance

- **Vector Impedance Analyzer**
  - **AIM 4170, 4300 ($500); UHF ($700), 120 ($2,700), SARK 110 ($400)**
- **Vector Network Analyzer**
  - **SDR Kits VNWA 3e (Not a kit) ~$575**
  - **AIM 2180 ($1,000), VNA UHF ($1,300)**
- **I strongly recommend the SDR Kits VNWA 3e**
  - **sdr-kits.net/VNWA3_Description.html**

VNWA 3e

- Runs in Windows, USB-powered
- 1 kHz – 1.3 GHz VNA, TDR and Spectrum Analyzer Functions

Design Software

- **N6BV's TLW (on Antenna Book CD)**
- **TLDetails by AC6LA (Windows, free) download at ac6la.com**
- **ZPlots by AC6LA (Excel spreadsheet, free) download ac6la.com**
  - **Excel only, <u>not</u> Open or Libre Office**
- **AE6TY's SimSmith (Smith chart, runs in JAVA, free) download at ae6ty.com**

Where Stubs Are Needed Most

- 80M CW
  - Harmonics on 40, 20 CW
- 40M CW / RTTY
  - Harmonics on 20, 15 CW / RTTY, 10M CW / RTTY / SSB
- 20M CW / RTTY / SSB
  - Harmonic on 10 CW / RTTY / SSB
- 75M, 40M SSB harmonics usually out of the harmonic band

What Stubs Can Not Fix

- **Harmonics generated outside our station in non-linear devices or circuits**
  - **Switch-mode power supplies**
  - **Antenna rotators**
  - **Rectifying junctions (corrosion, etc.)**
- **Fundamental is picked up on wiring connected to non-linear device**
- **Harmonics (and IMD) are re-radiated by the same wiring**

What Stubs Can <u>Not</u> Fix

- **These harmonics often have a "growl-like" sound, thanks to the presence of 60 Hz (Thanks W3LPL)**
- **Source can be in our home/shack or our neighbors**
- **Must be traced like any other RFI problem**
  - **Rotate TX antenna**
  - **Rotate RX antenna**
  - **Chase it with portable RX during TX**

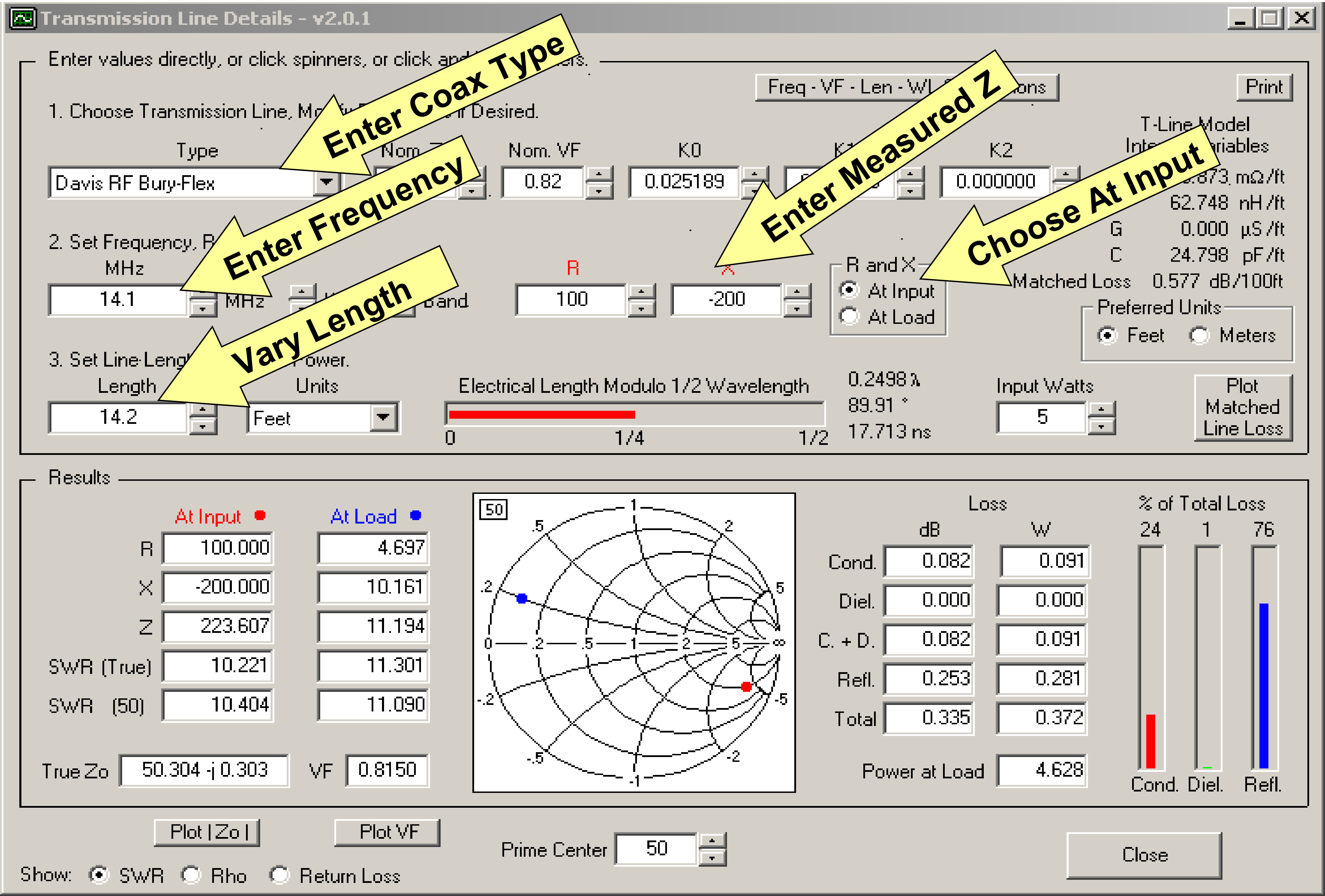
Killing Re-Radiated Harmonics

- Cannot be filtered in our station
- Must be killed at their source
  - Use chokes on wiring that acts as their antenna
  - Select chokes for TX frequency
  - Fix mechanical issues that set up the rectifying junctions

A Typical Design Problem

- Stub for a 40M λ/2 Dipole to protect 20M
- Let’s use TLDetails first
  - Free, simple, runs in Windows
  - Best for single frequency measurement
- Later we’ll look at SimSmith
- First, measure the antenna Z at any convenient point
- Plug that data into the design software

TLDetails

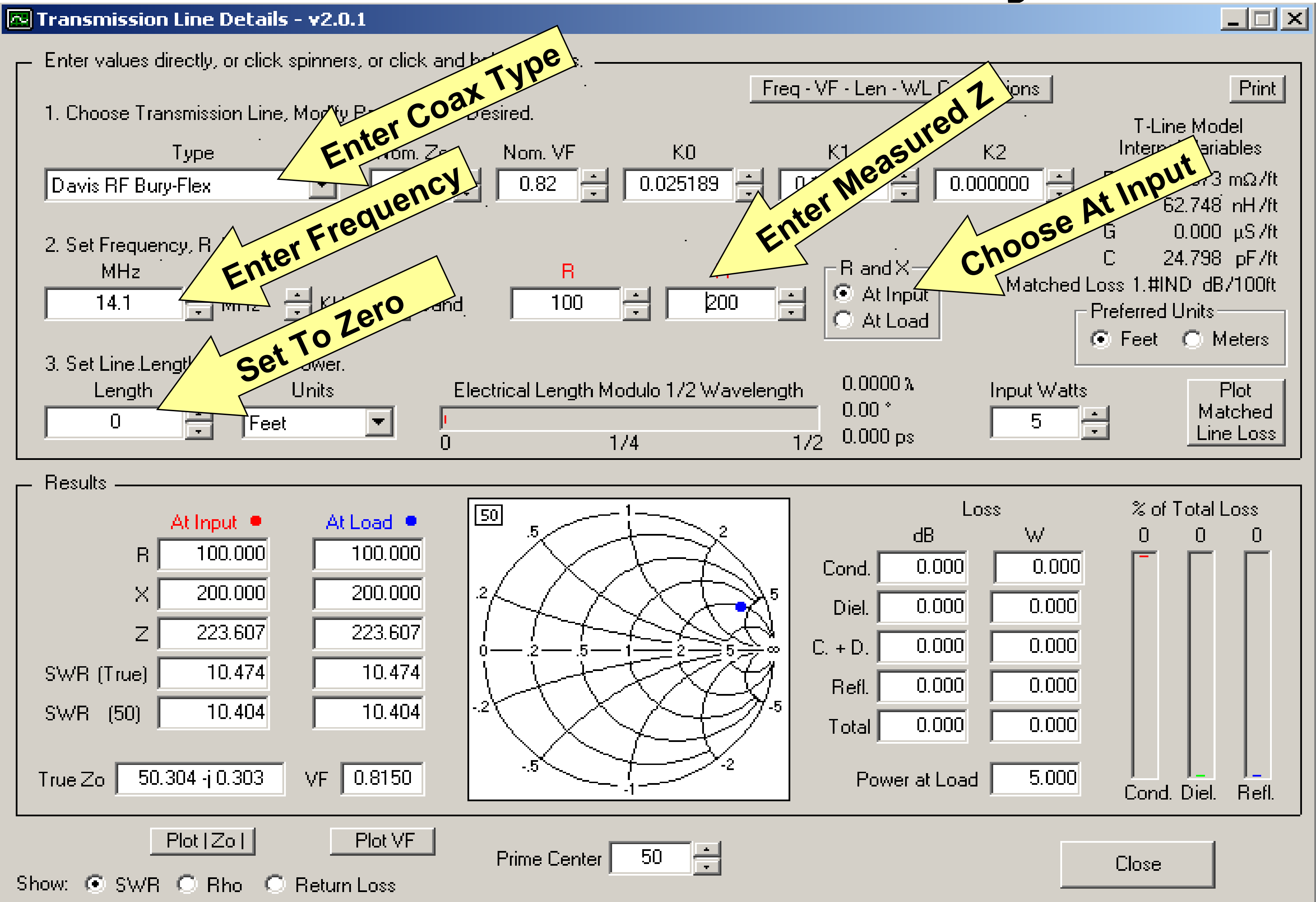


Transmission Line Details - v2.0.1
Enter values directly, or click spinners, or click and
Freq - VF - Len - WL
Print
1. Choose Transmission Line, Mo
if Desired.
Type
Davis RF Bury-Flex
Nom. VF
0.82
K0
0.025189
K2
0.000000
T-Line Model
62.748 nH /ft
G 0.000 µS /ft
C 24.798 pF /ft
Matched Loss 0.577 dB/100ft
2. Set Frequency, R
MHz
14.1
MHz
Band
R
100
X
-200
R and X
At Input
At Load
Preferred Units
Feet
Meters
3. Set Line Leng
Power.
Length
14.2
Units
Feet
Electrical Length Modulo 1/2 Wavelength
0
1/4
1/2
0.2498 λ
89.91 °
17.713 ns
Input Watts
5
Plot Matched Line Loss
Results
At Input
At Load
R 100.000 4.697
X -200.000 10.161
Z 223.607 11.194
SWR (True) 10.221 11.301
SWR (50) 10.404 11.090
True Zo 50.304 -j 0.303
VF 0.8150
50
Loss
dB
W
Cond. 0.082 0.091
Diel. 0.000 0.000
C. + D. 0.082 0.091
Refl. 0.253 0.281
Total 0.335 0.372
Power at Load 4.628
% of Total Loss
24 1 76
Cond. Diel. Refl.
Plot |Zo|
Plot VF
Prime Center
50
Close
Show: SWR Rho Return Loss
Enter Coax Type
Enter Frequency
Vary Length
Enter Measured Z
Choose At Input

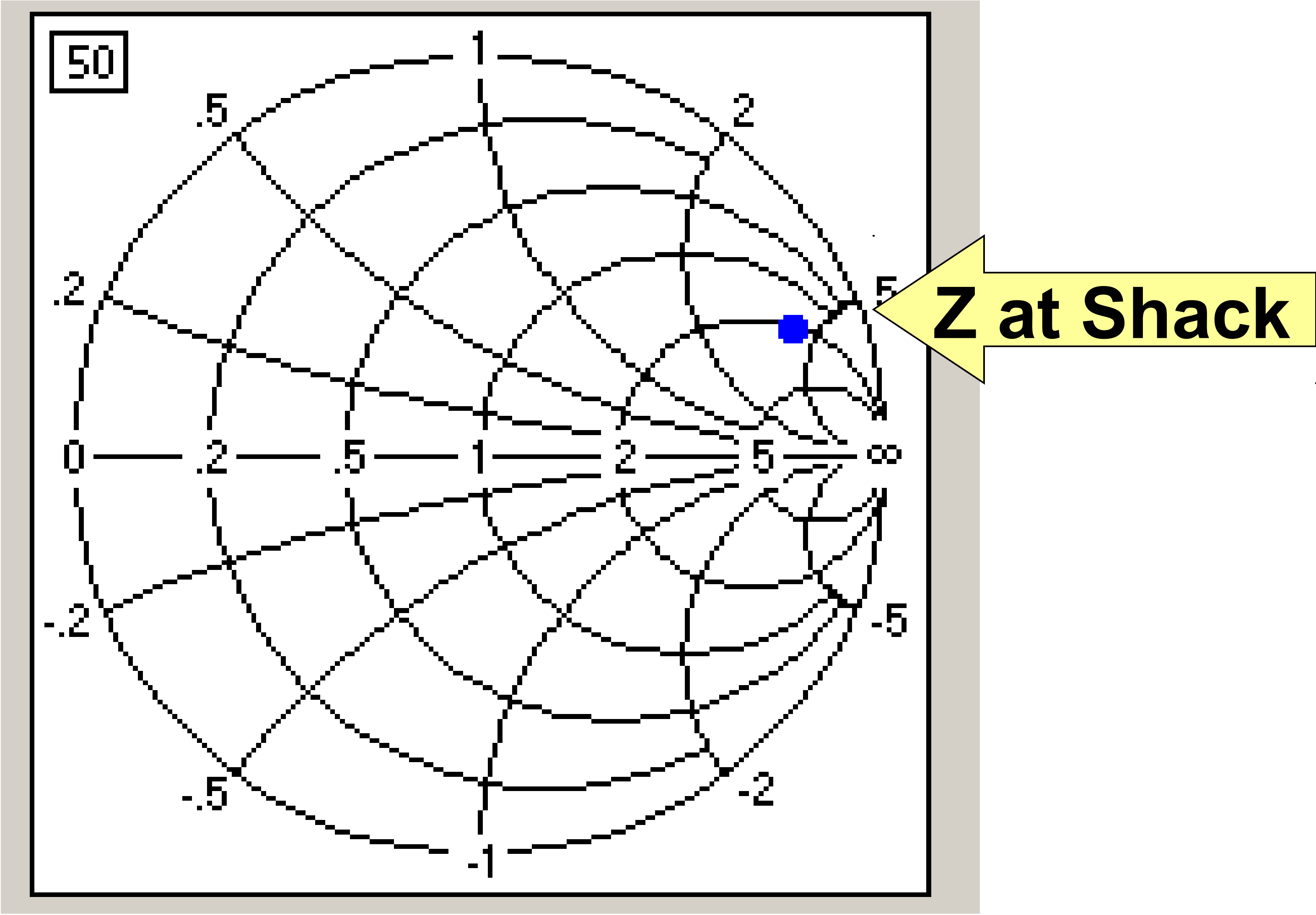
Using TLDetails

- **Set coax type feeding antenna (line 1)**
- **Enter harmonic frequency and measured Z (line 2), check "At Input"**
- **On line 3, set line length to 0, then use the spinners to increase the line length until the blue dot is at the right edge of the Smith chart**
- **Place the stub this distance from the measurement point toward the antenna**

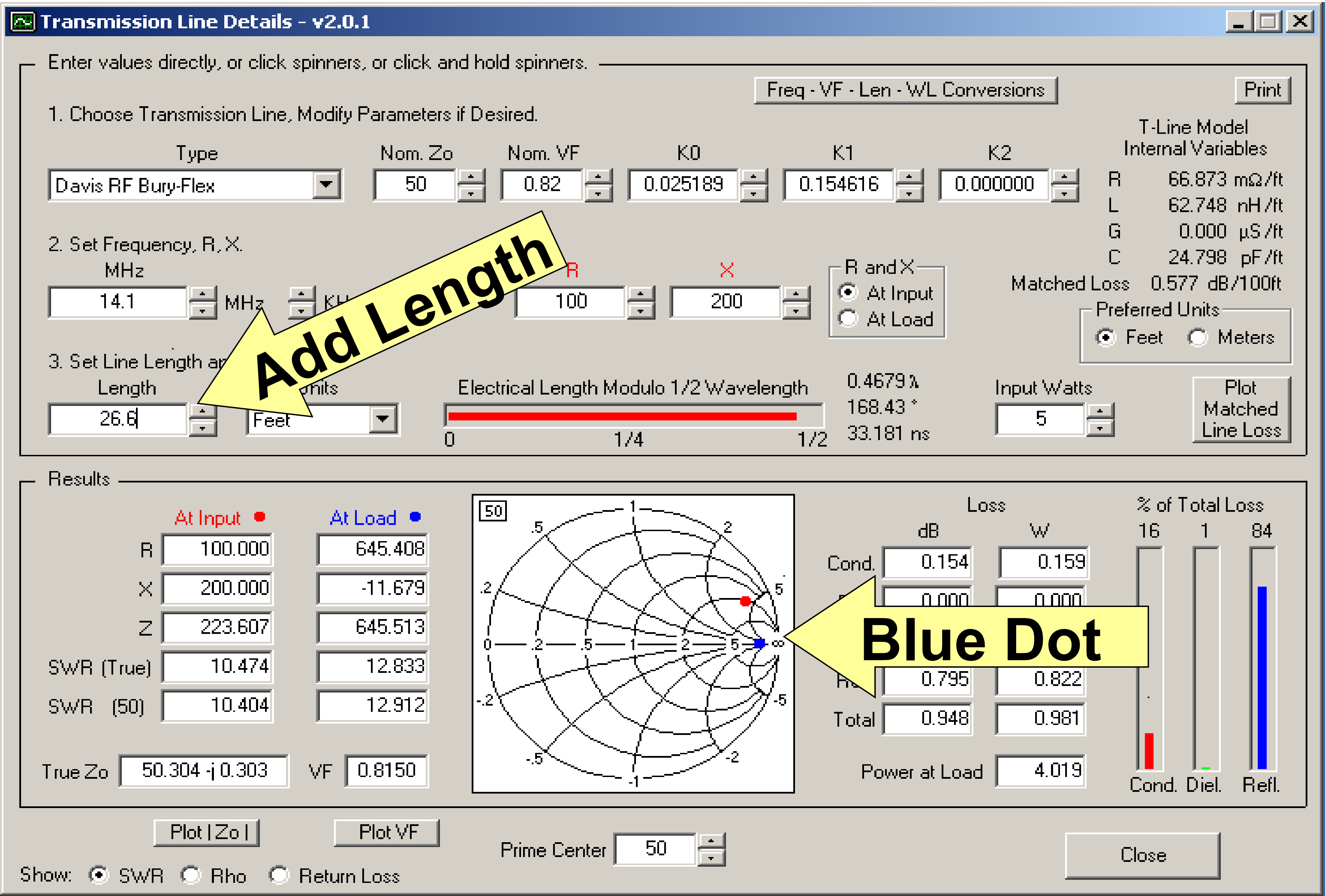
TLDetails – Data Entry



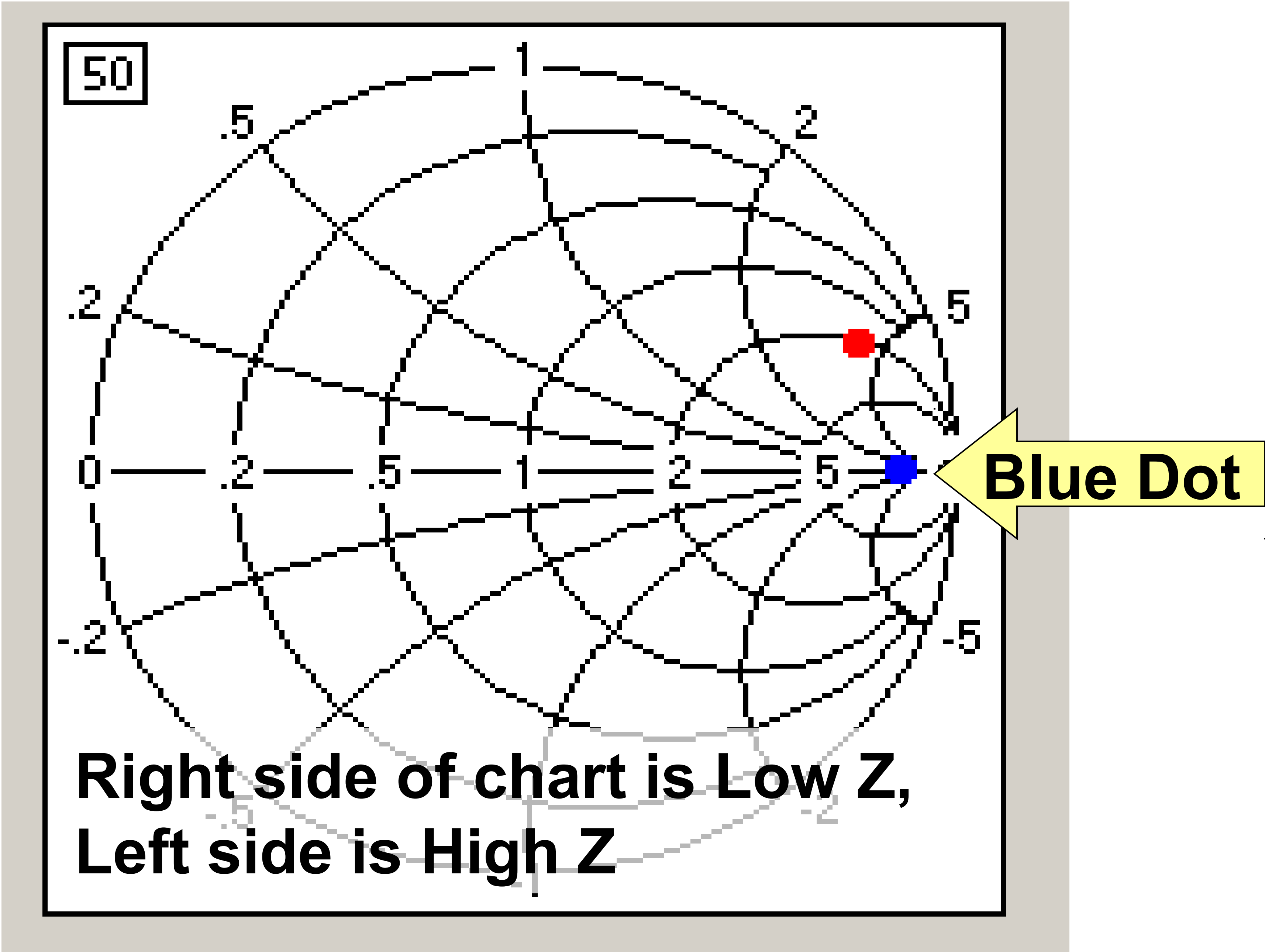
Smith Chart Display of Z Measure in Shack



Move Stub Toward Antenna



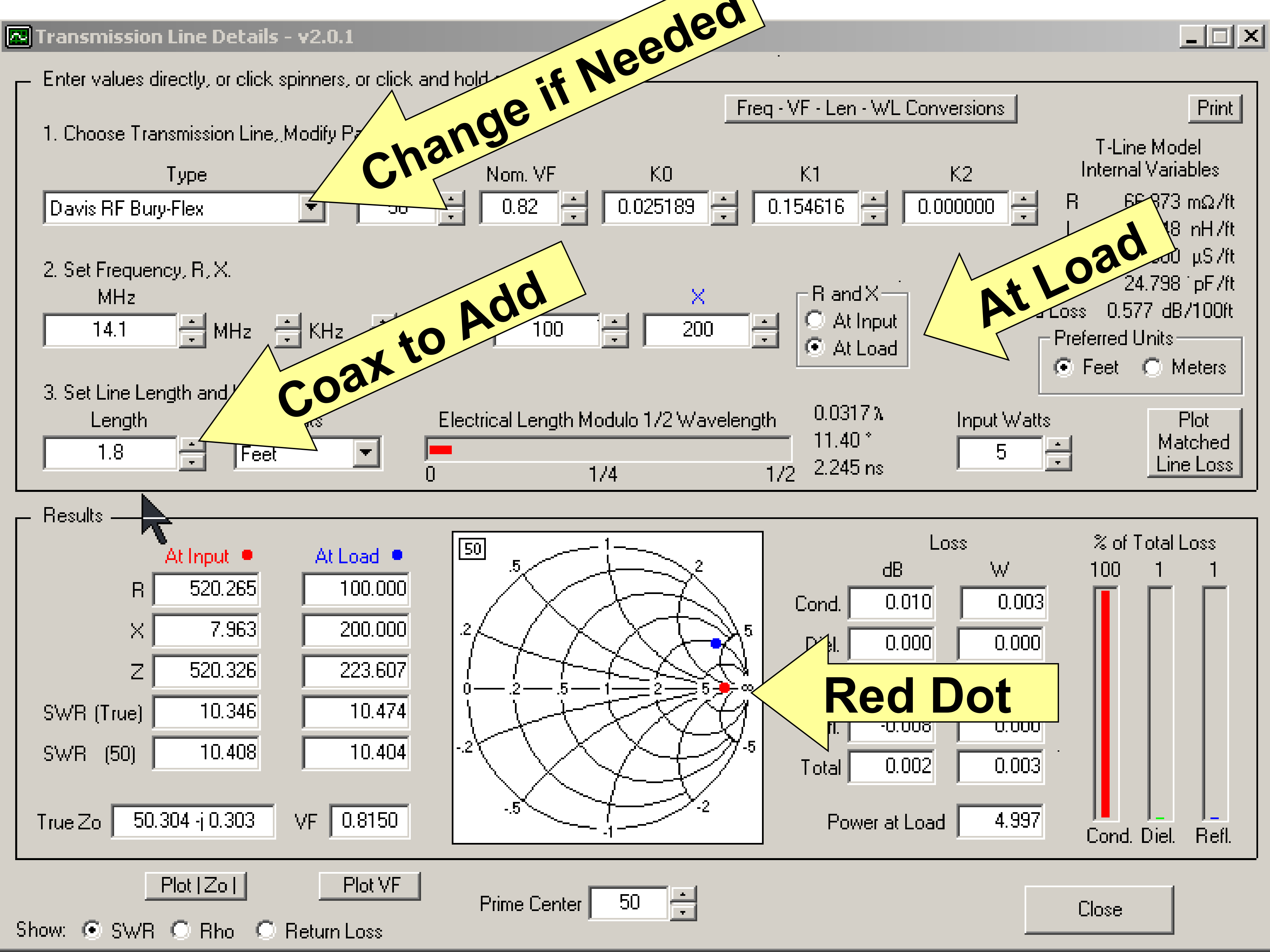
Move Stub Toward Antenna



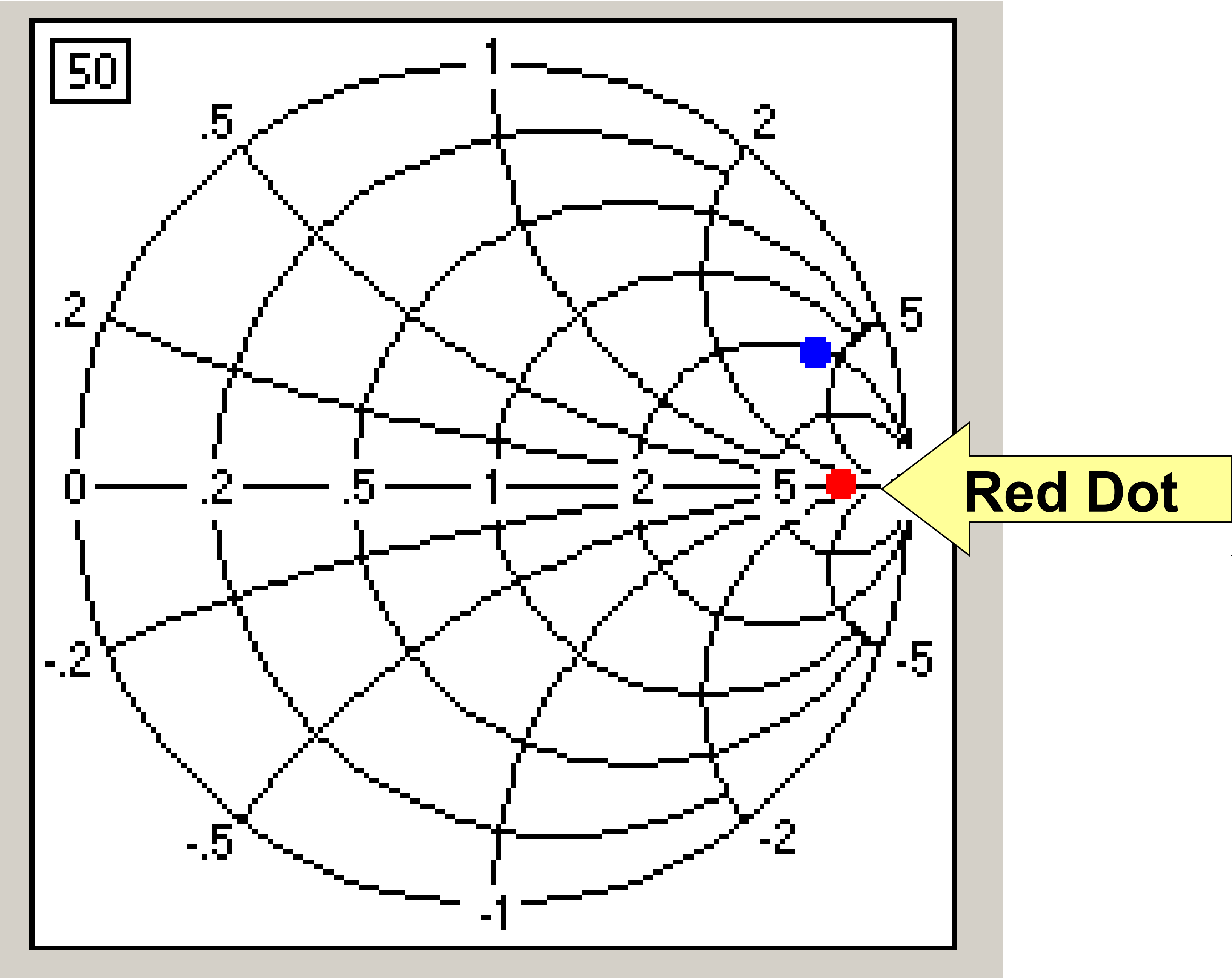
Right side of chart is Low Z, Left side is High Z

Using TLDetails

- **To add coax rather than cutting it, change line 2 to “At Load”**
- **Adjust line 3 to place the red dot at the right edge of the Smith chart**
- **Add this length of coax and place the stub**
- **If the added coax is a different type, choose it on line 1**


Transmission Line Details - v2.0.1
Enter values directly, or click spinners, or click and hold
Freq - VF - Len - WL Conversions
Print
1. Choose Transmission Line, Modify Pa
Type
Davis RF Bury-Flex
Nom. VF
0.82
K0
0.025189
K1
0.154616
K2
0.000000
T-Line Model
Internal Variables
24.798 pF/ft
0.577 dB/100ft
2. Set Frequency, R, X.
MHz
14.1
MHz
KHz
100
X
200
R and X
At Input
At Load
Preferred Units
Feet
Meters
3. Set Line Length and
Length
1.8
Feet
Electrical Length Modulo 1/2 Wavelength
0
1/4
1/2
0.0317 λ
11.40 °
2.245 ns
Input Watts
5
Plot Matched Line Loss
Results
At Input
At Load
R
520.265
100.000
X
7.963
200.000
Z
520.326
223.607
SWR (True)
10.346
10.474
SWR (50)
10.408
10.404
True Zo
50.304 -j 0.303
VF
0.8150
Loss
dB
W
Cond.
0.010
0.003
0.000
0.000
Total
0.002
0.003
Power at Load
4.997
% of Total Loss
100
1
1
Cond.
Diel.
Refl.
Plot | Zo |
Plot VF
Prime Center
50
Close
Show:
SWR
Rho
Return Loss
Change if Needed
Coax to Add
At Load
Red Dot

TLDetails

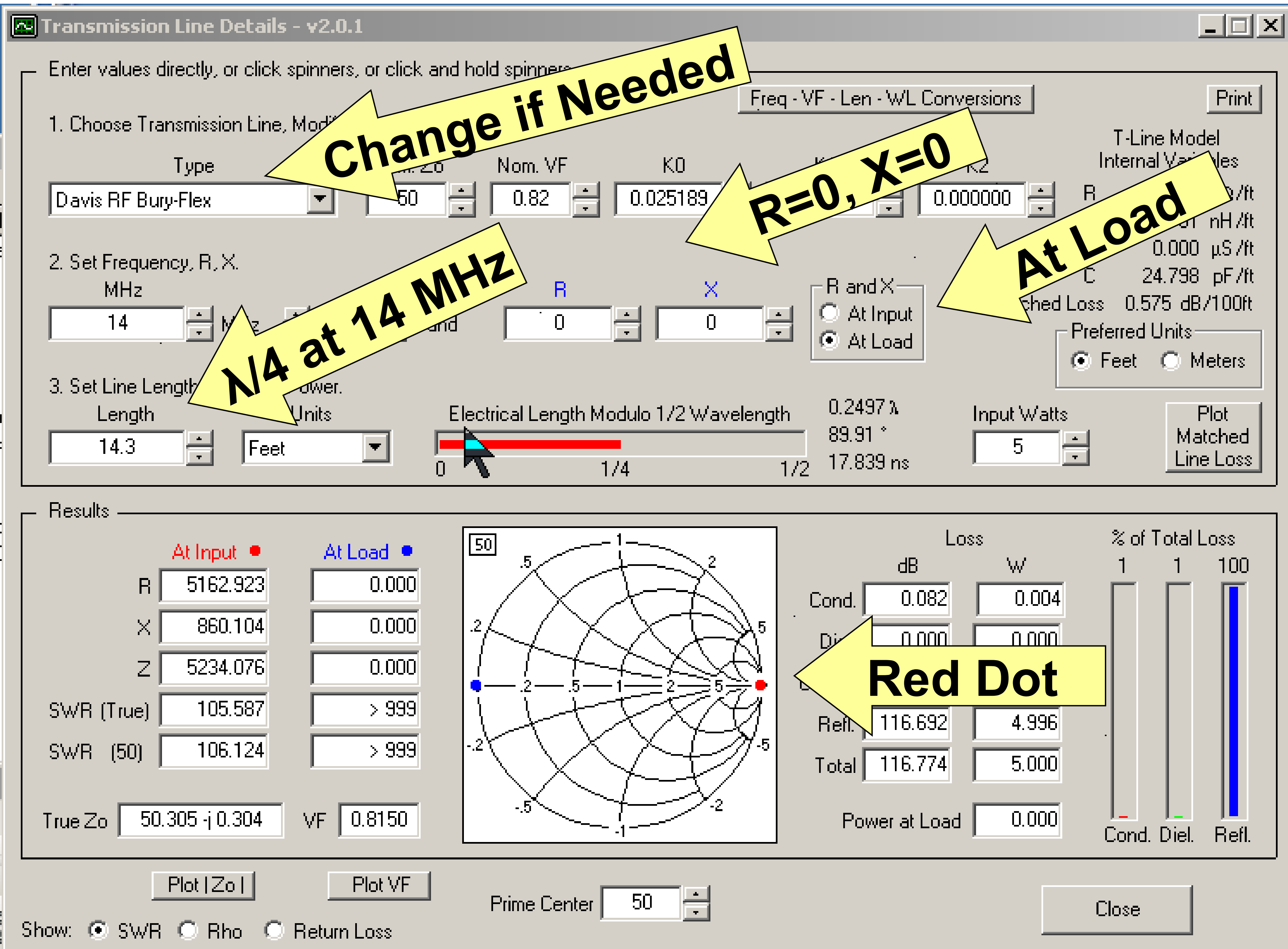


Close Can Be Good Enough

- **In this example, the measured Z is close enough to the maximum point that the stub could be placed at the measurement point**
- **It's easy to see this in SimSmith, where the model can predict the loss, and we can play "what ifs"**

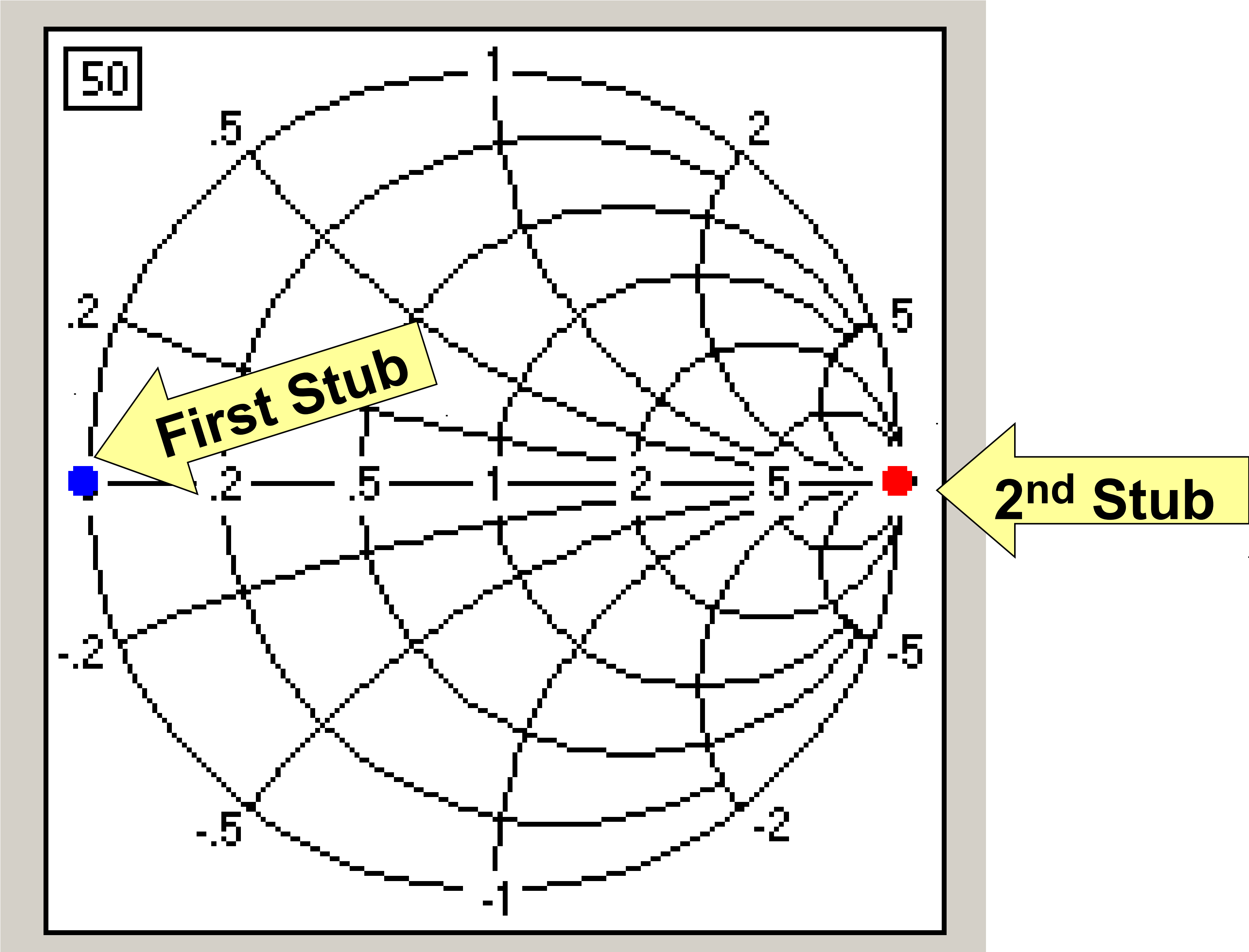
Adding a Second Stub

- A second stub increases suppression
- The first stub establishes a new voltage minimum on the line
- The next maximum will be λ/4 toward the transmitter from the first stub (at the harmonic frequency)
- TLD can compute λ/4 for your coax
- Set R and X = 0, At Load, vary length to put red dot at right edge of plot



Transmission Line Details - v2.0.1
Change if Needed
R=0, X=0
At Load
λ/4 at 14 MHz
Red Dot
Enter values directly, or click spinners, or click and hold spinners
Freq - VF - Len - WL Conversions
Print
1. Choose Transmission Line, Mod
Type
Davis RF Bury-Flex
50
Nom. VF
0.82
K0
0.025189
K2
0.000000
T-Line Model Internal Variables
2. Set Frequency, R, X.
MHz
14
R
0
X
0
R and X
At Input
At Load
0.000 µS /ft
C 24.798 pF /ft
0.575 dB/100ft
Preferred Units
Feet
Meters
3. Set Line Length
Length
14.3
Units
Feet
Electrical Length Modulo 1/2 Wavelength
0
1/4
1/2
0.2497 λ
89.91 °
17.839 ns
Input Watts
5
Plot Matched Line Loss
Results
At Input
At Load
R 5162.923 0.000
X 860.104 0.000
Z 5234.076 0.000
SWR (True) 105.587 > 999
SWR (50) 106.124 > 999
True Zo 50.305 -j 0.304
VF 0.8150
Loss
dB
W
Cond. 0.082 0.004
0.000 0.000
Refl. 116.692 4.996
Total 116.774 5.000
Power at Load 0.000
% of Total Loss
Cond. Diel. Refl.
Plot |Zo|
Plot VF
Prime Center 50
Close
Show: SWR Rho Return Loss

TLDetails



First Reason for Second Stub

- **Even if it's placement is poor, the first stub establishes a new voltage minimum on the line**
- **Even if the first stub is not optimally placed, the second stub will be**
- **This is a great application for portable setups where you may not have time to measure or tweak feedline length**

Second Reason for Second Stub

- **If antenna is resonant at the harmonic, Z doesn't change along line, so placement to the antenna for the first stub doesn't matter**
  - **The first stub is a short across 50 ohms, provides moderate suppression**
- **Because the first stub establishes a minimum on the line, we get full value from the second stub**
  - **Typically 30 dB for RG8**

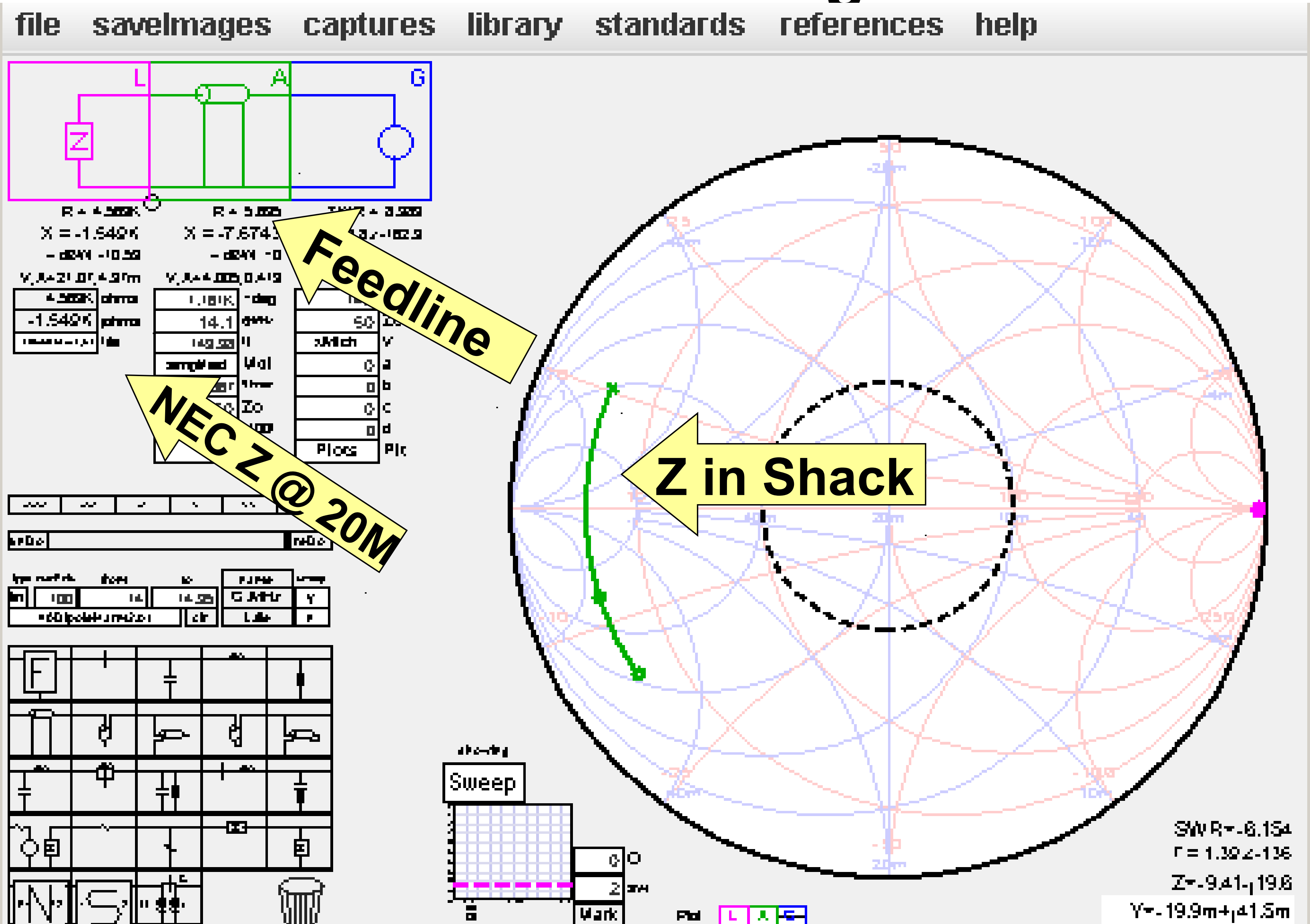
Getting Fancier With the Design

- **Make a <u>swept</u> impedance measurement over the harmonic band**
- **Save data in Touchstone format (a plain text format with a header that defines the data format)**
- **Import data into SimSmith**
  - **Put the data file in the "Z block"**

Same Example Problem

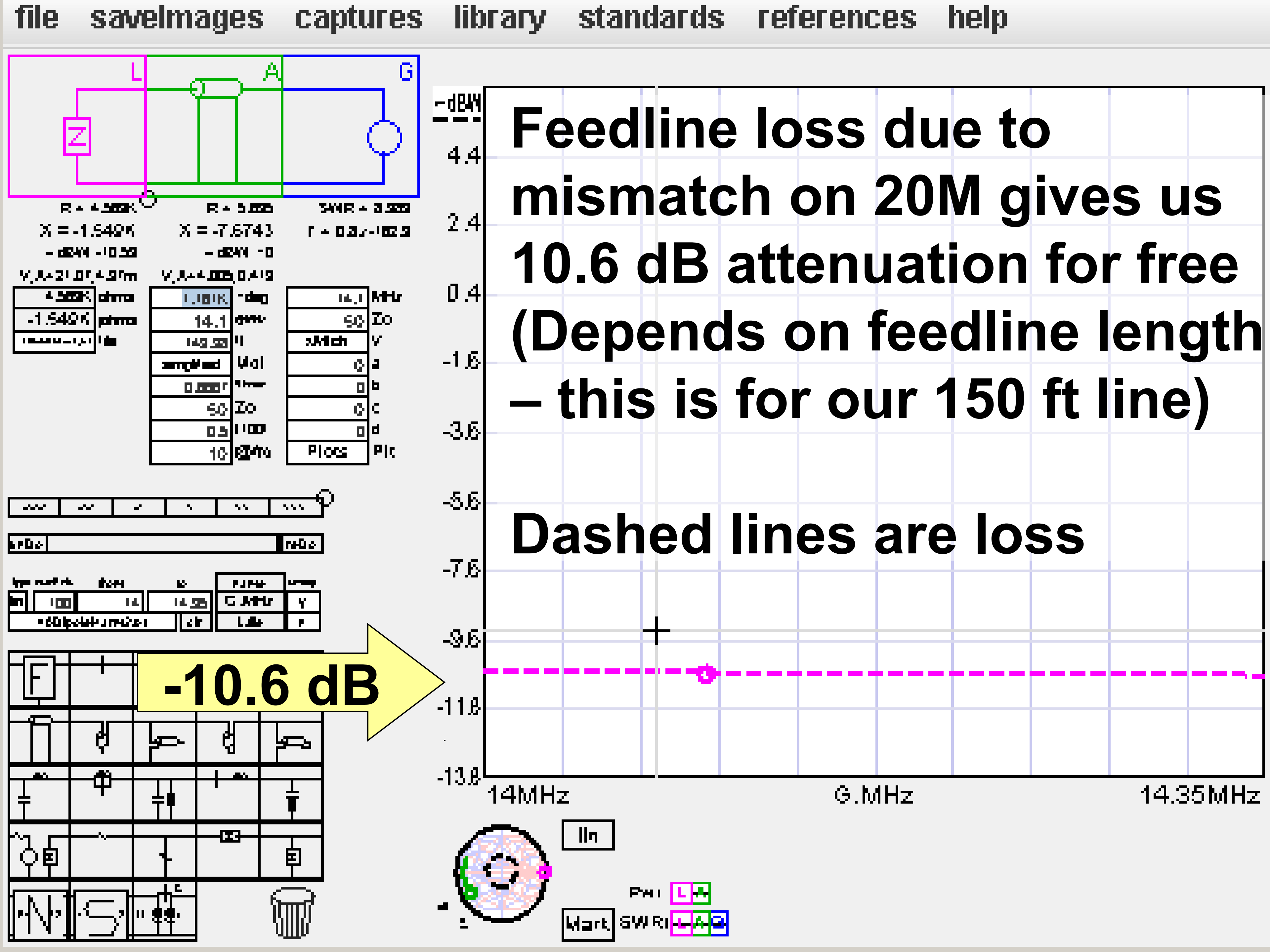
- **I've imported the impedance of a 40M dipole on its 2nd harmonic and put it in the Z block (last block at the left)**
  - **This is the 20M SWR data from NEC**
  - **Plain text file is LASTZ.TXT, and is in Touchstone format**
- **I added 150 ft of feedline (2nd block) to simulate a typical station**
  - **The Cyan curve shows Z in the shack (what we would measure)**

SimSmith – Entering Data



Feedline loss due to mismatch on 20M gives us 10.6 dB attenuation for free (Depends on feedline length – this is for our 150 ft line)

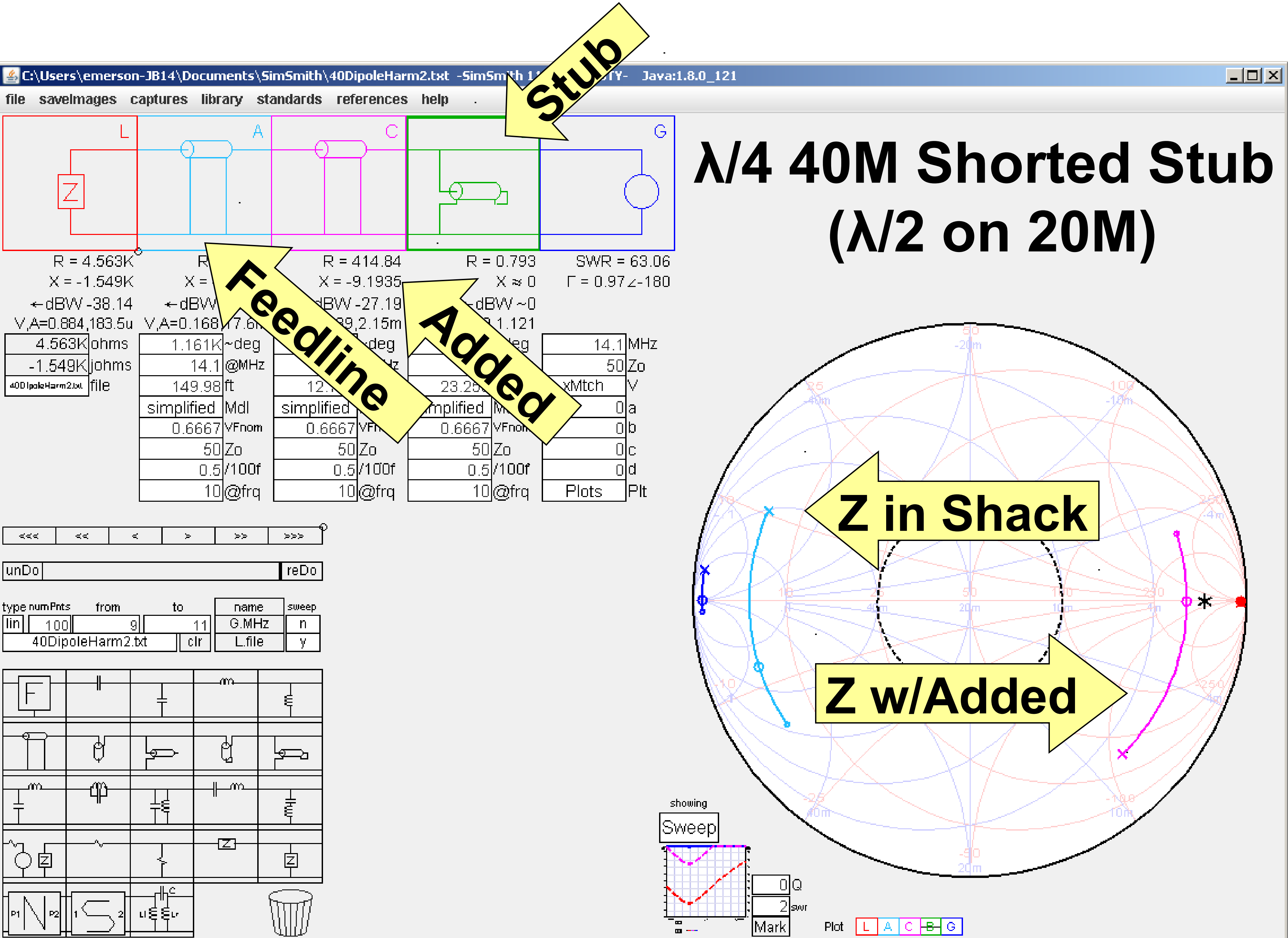
Dashed lines are loss

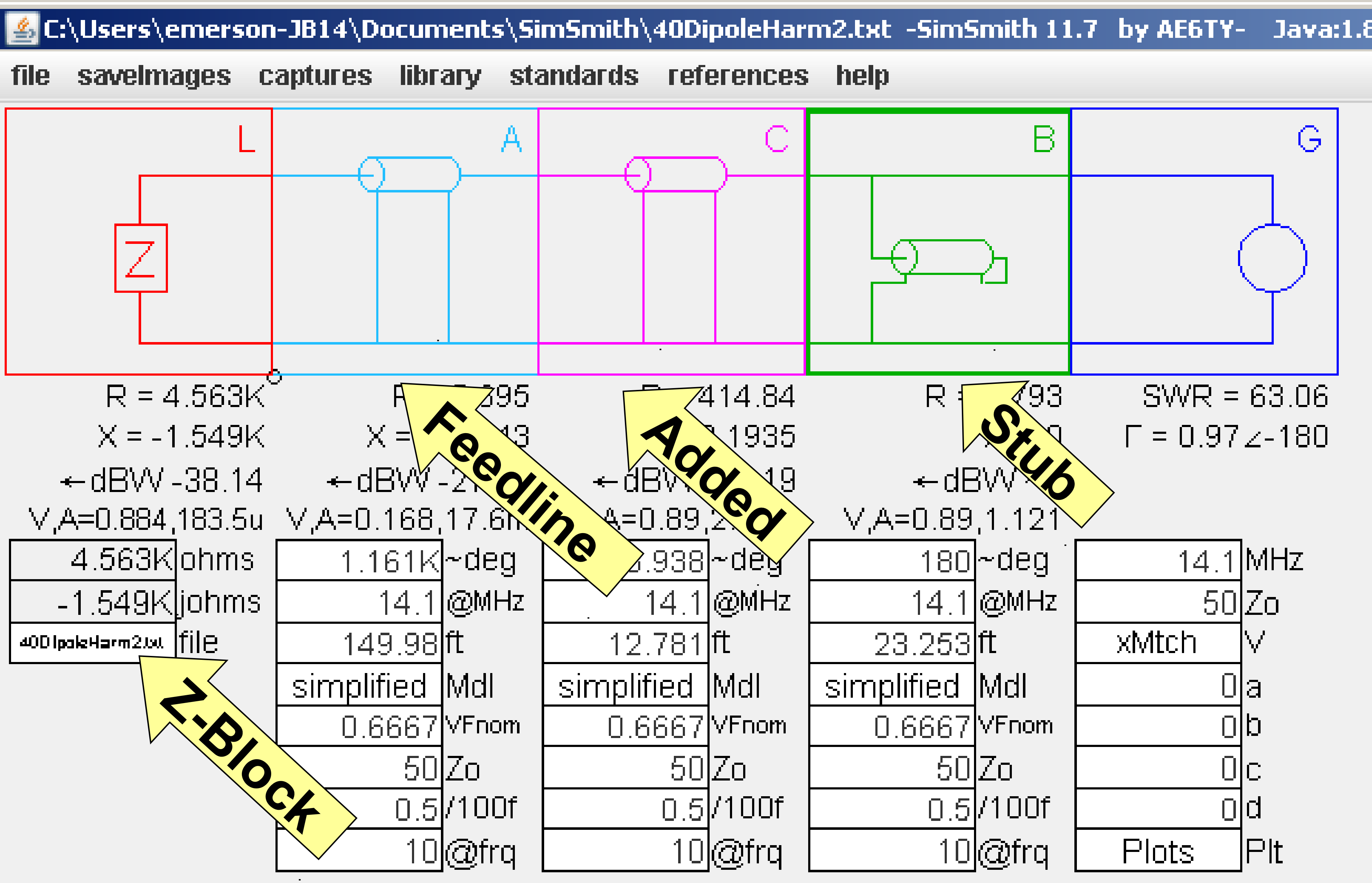


Example Problem

- Set the frequency of the generator to where you want maximum attenuation
  - This frequency will show as a dot on each curve on the Smith chart
- Add a second feedline block
  - Set VF and loss, or choose a coax type from the dropdown list
- Vary the length of this feedline so that the dot on the chart for this block is on the horizontal axis on the right of center

λ/4 40M Shorted Stub (λ/2 on 20M)





λ/4 40M Shorted Stub (λ/2 on 20M)

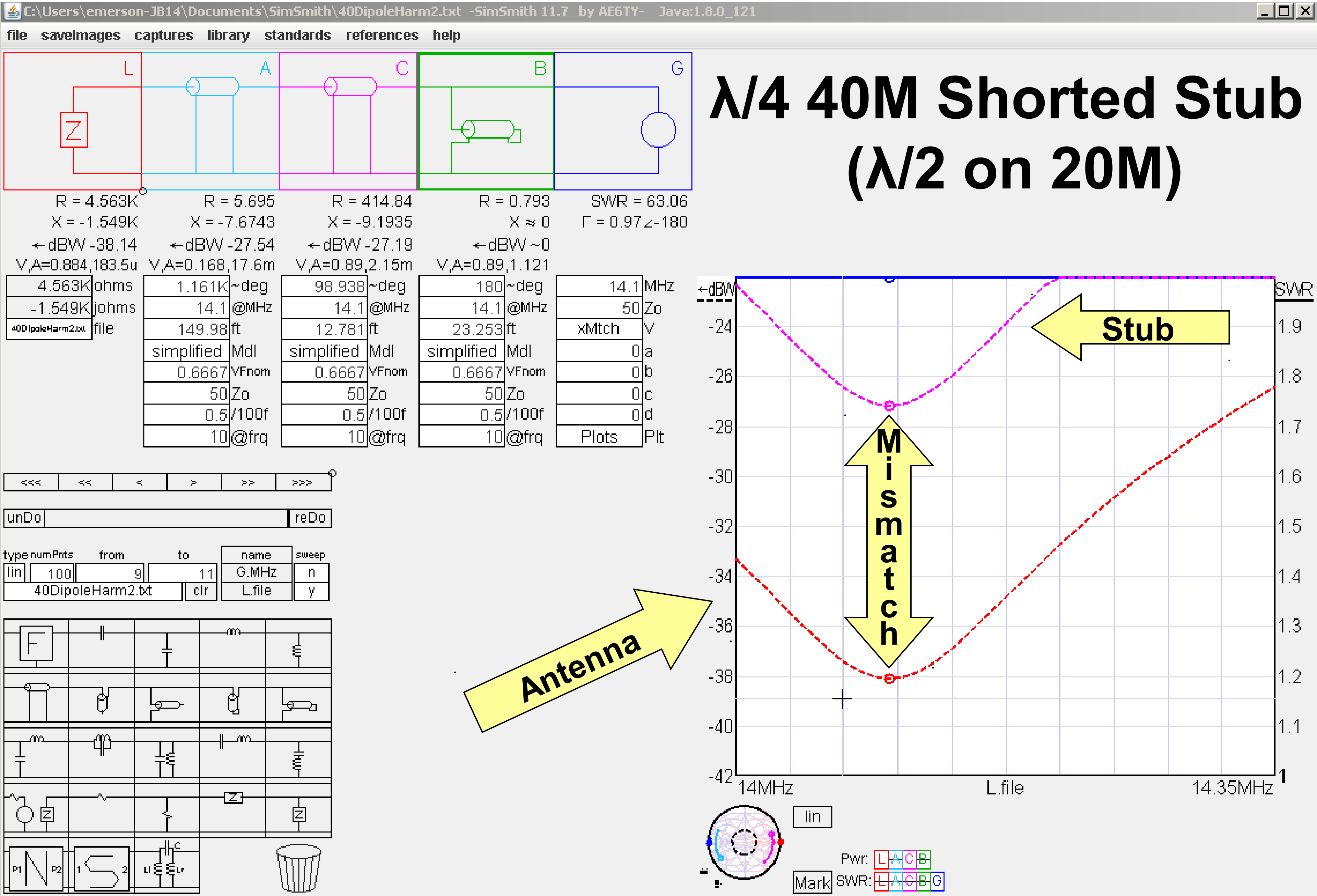
Example Problem

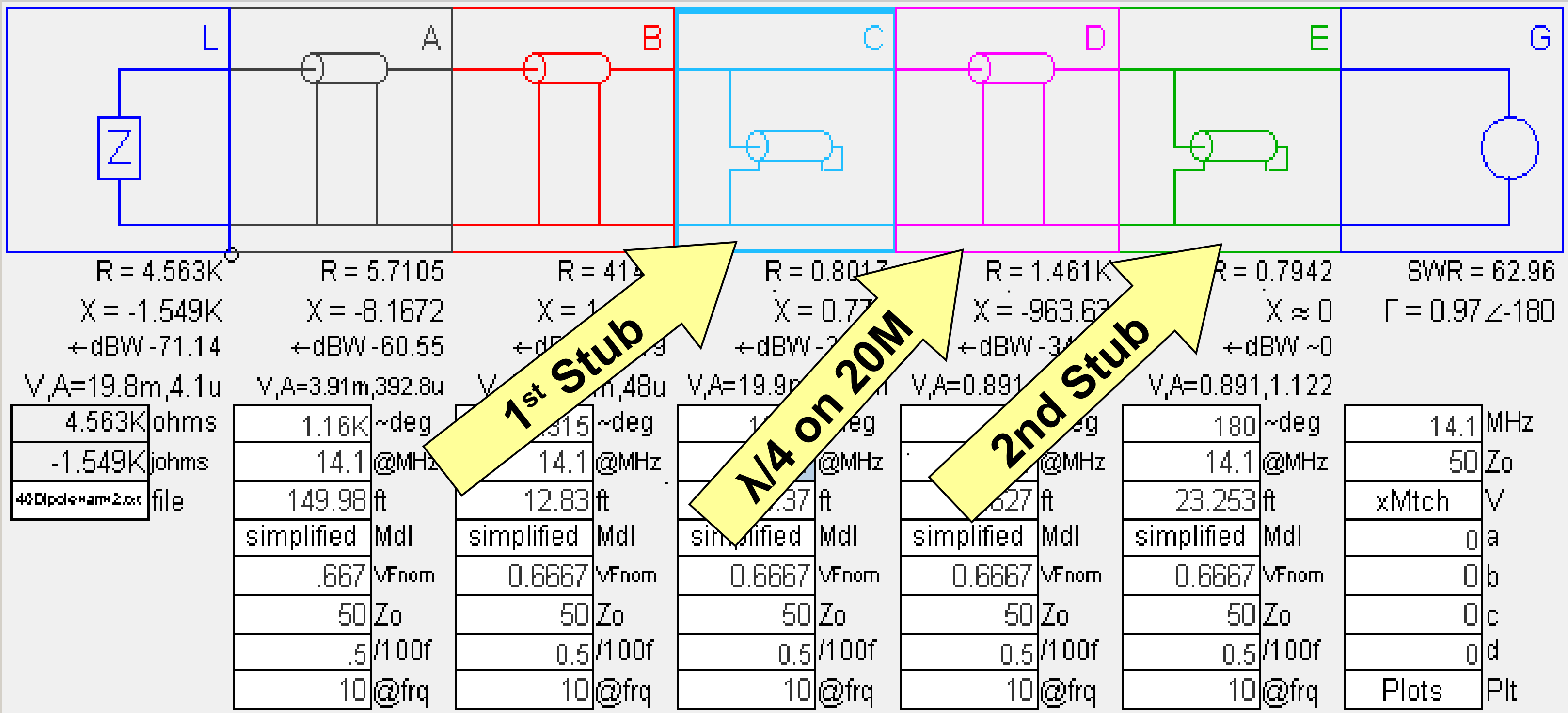
- **Vary the length of the added feedline so that the dot on the chart for this block is on the horizontal axis on the right of center**
  - **Positive length adds coax before the stub**
  - **Negative length subtracts coax (that is, cut the coax and add the stub)**

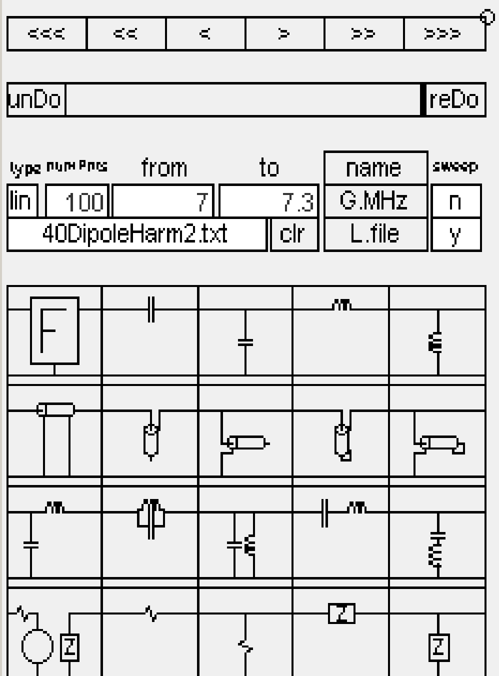
Example Problem

- **Switch to the attenuation/SWR display**
- **Choose to display loss at the antenna**
- **Adjust the left axis scale so that the curve is on the graph and with a good scale**
- **Tweak the length of the added (or subtracted) feedline and the length of the stub for best attenuation where you want it**

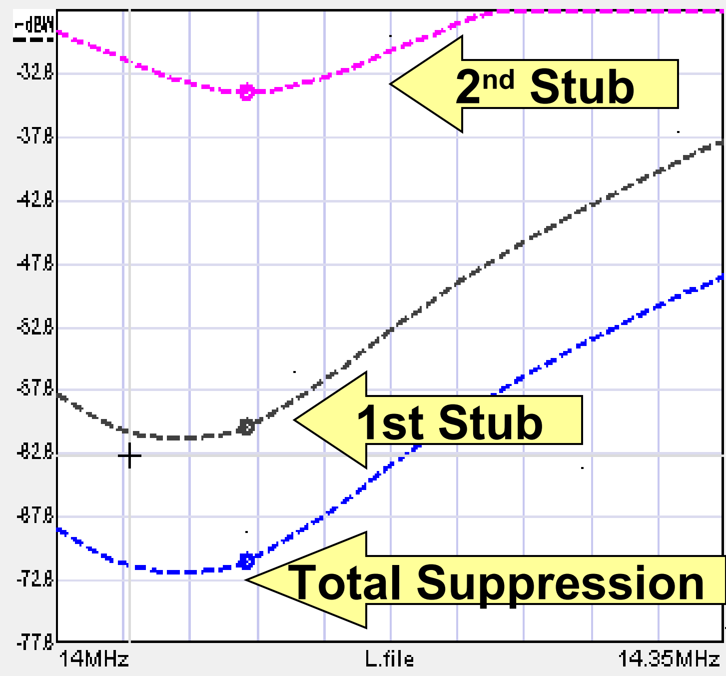
λ/4 40M Shorted Stub (λ/2 on 20M)

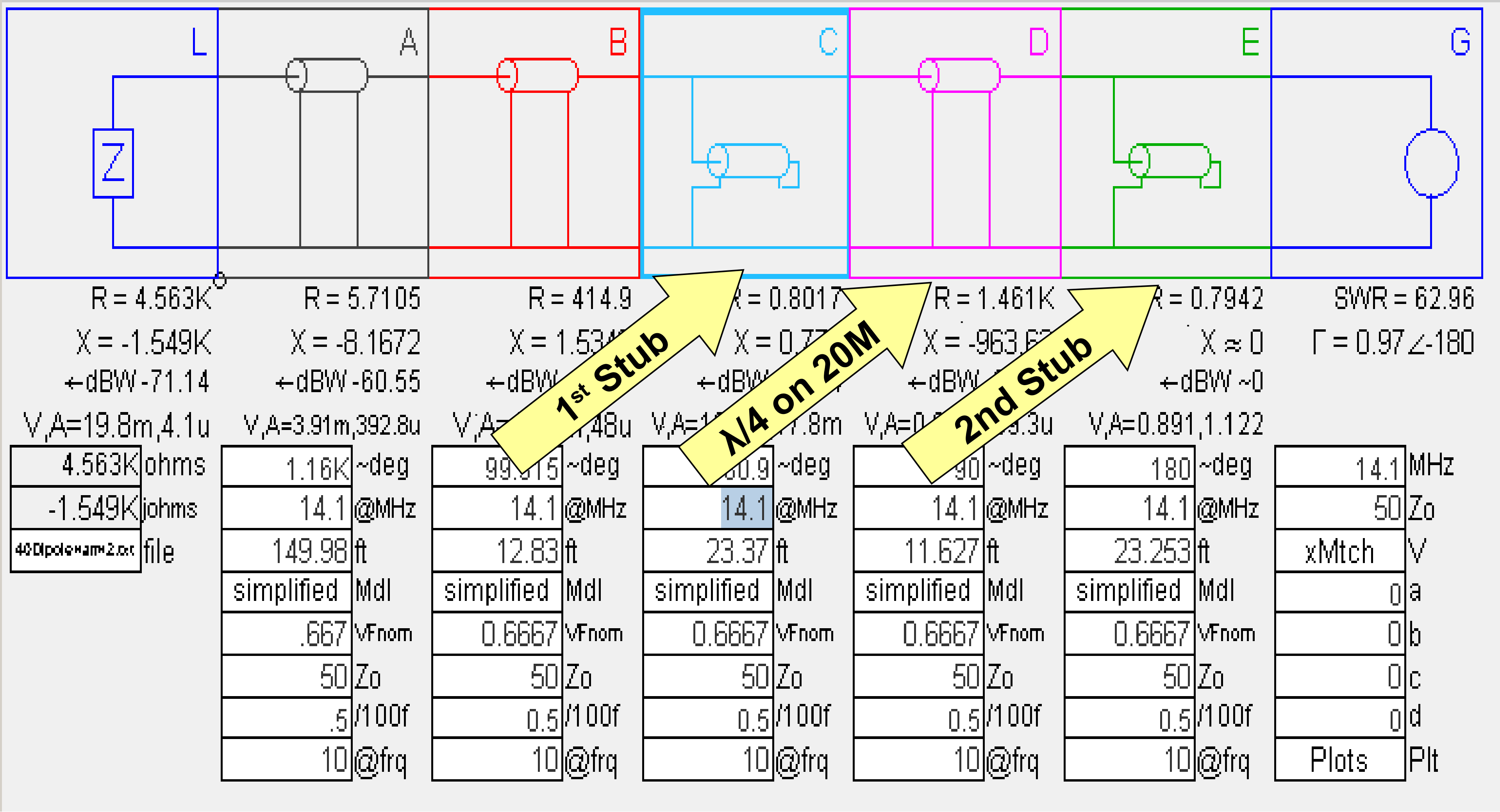






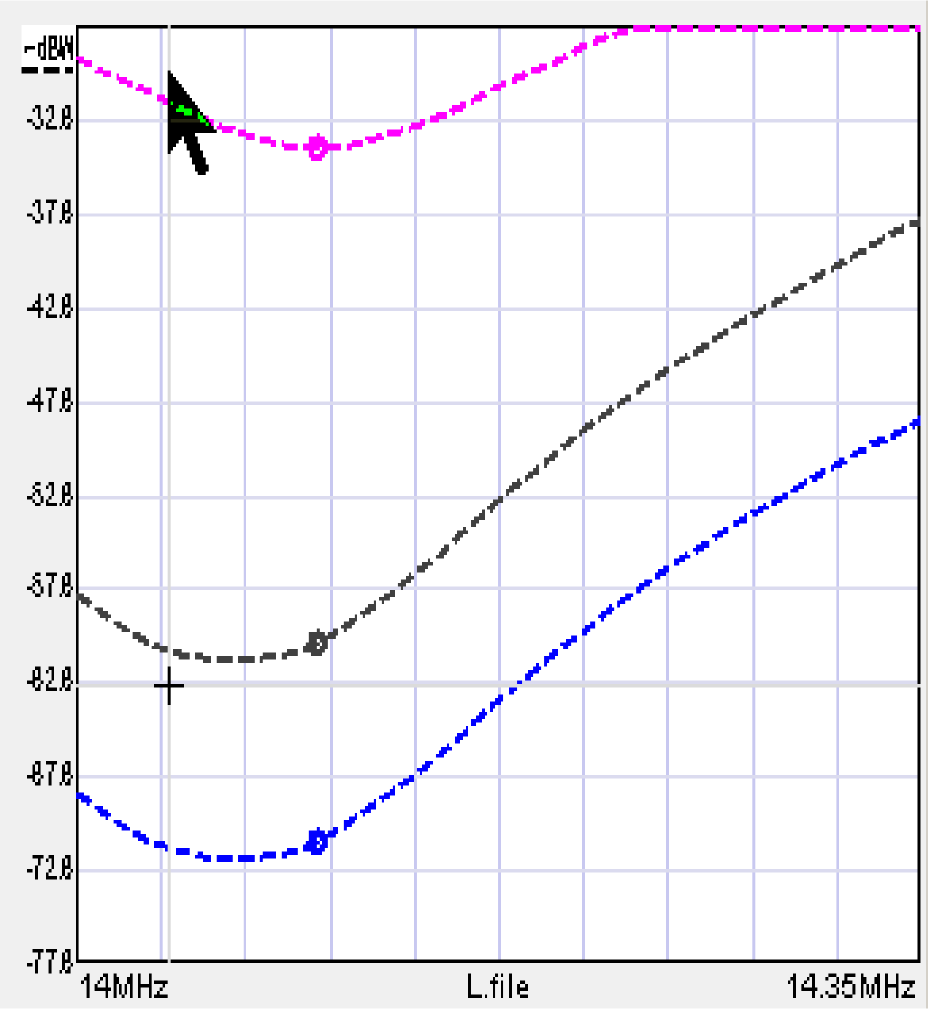
Two λ/4 40M Shorted Stubs (λ/2 on 20M)



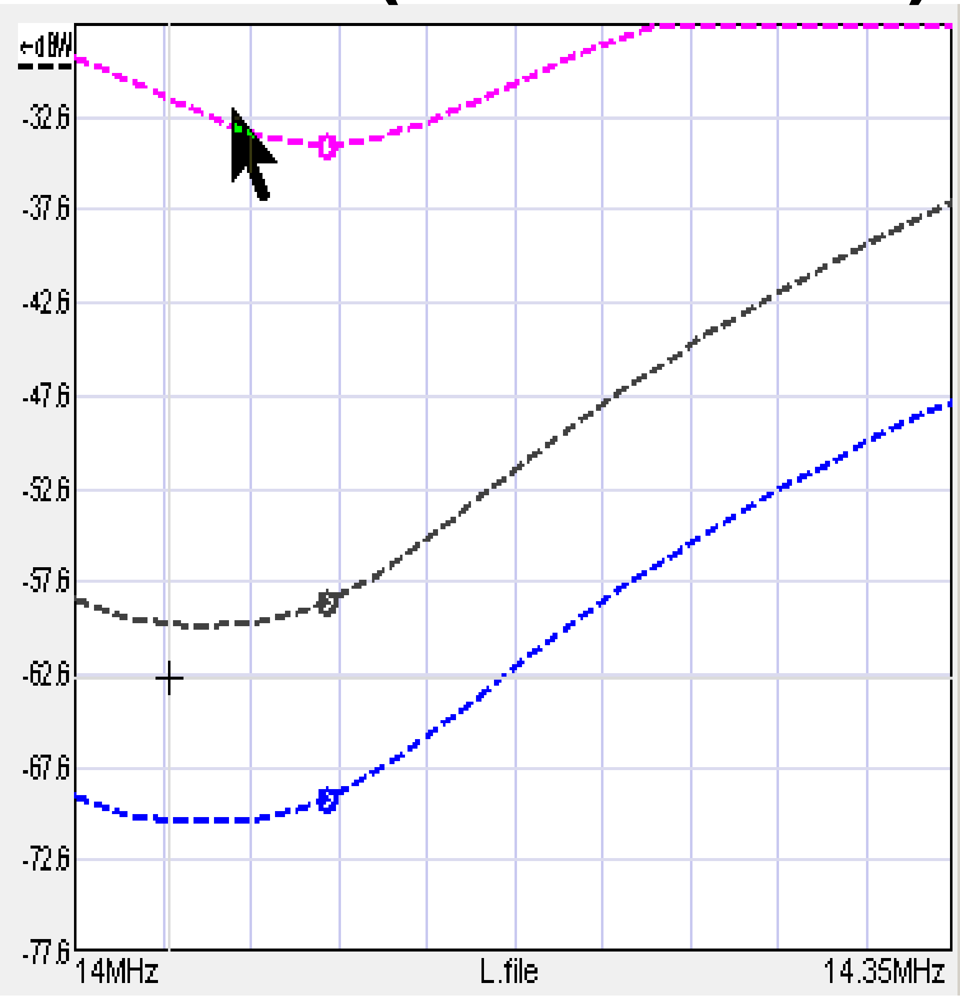


Two λ/4 40M Shorted Stubs
(λ/2 on 20M)

Two λ/4 40M Shorted Stubs (λ/2 on 20M)



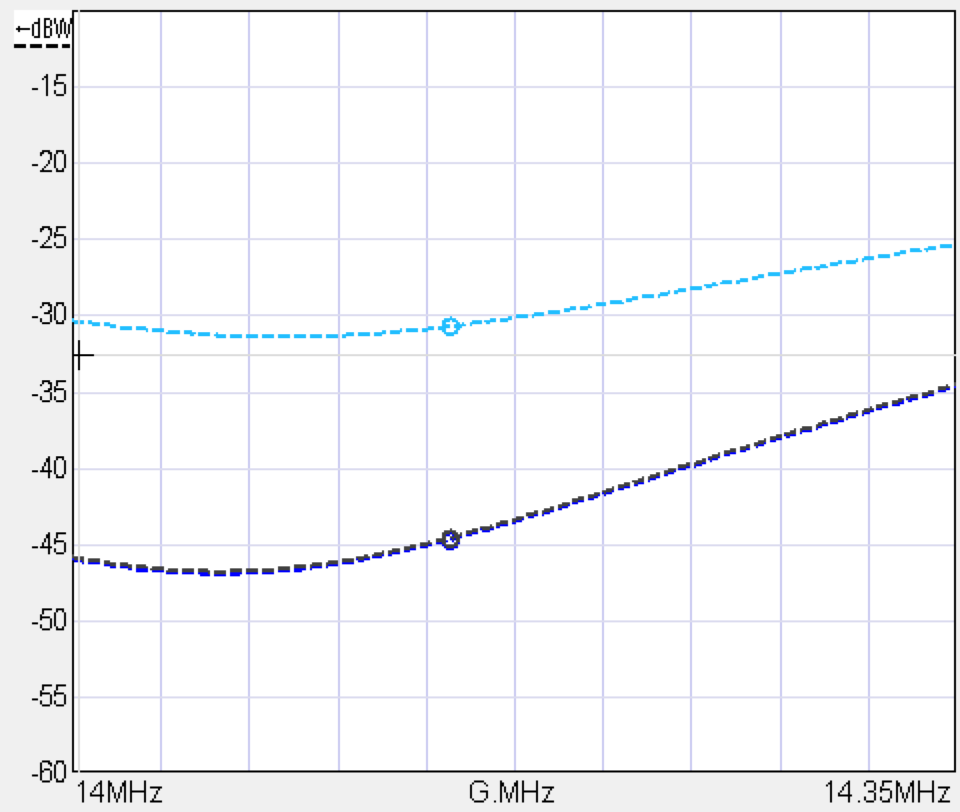
Both Stubs 14.1 MHz



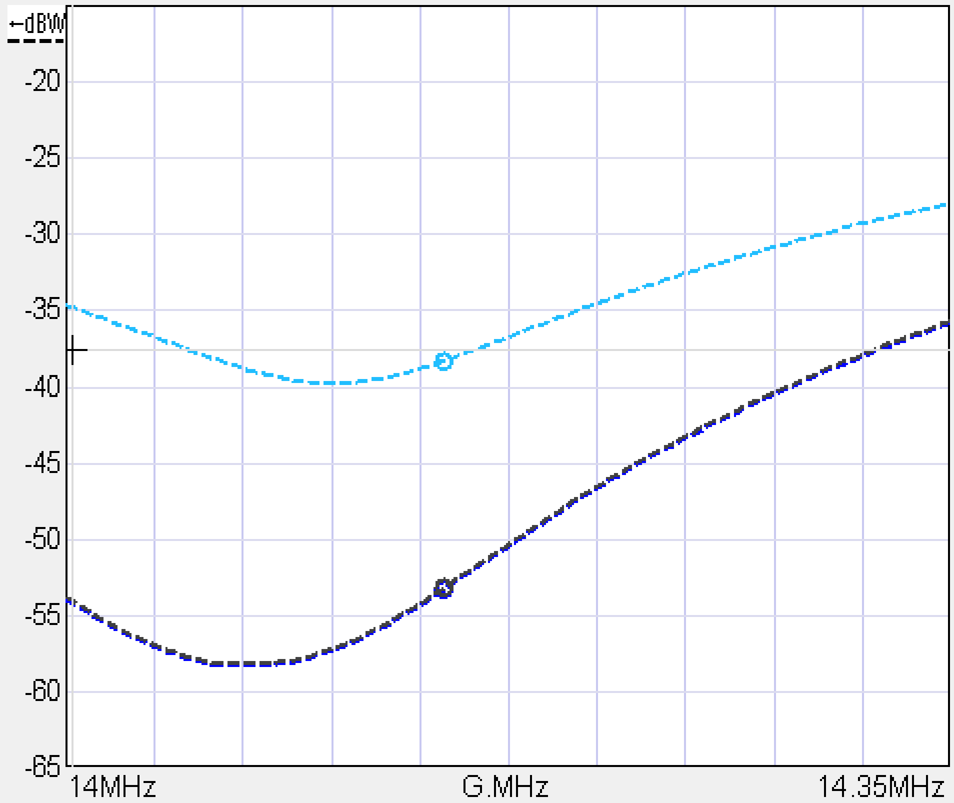
Stagger-Tuned
14.072, 14.1 MHz

If Antenna Is Resonant On Harmonic

- **Impedance is nearly constant along the line, so placement from antenna doesn't matter**
- **Placement from amplifier <u>does</u> matter**
- **No harmonic suppression from line loss due to mismatch at harmonic, so less total suppression**

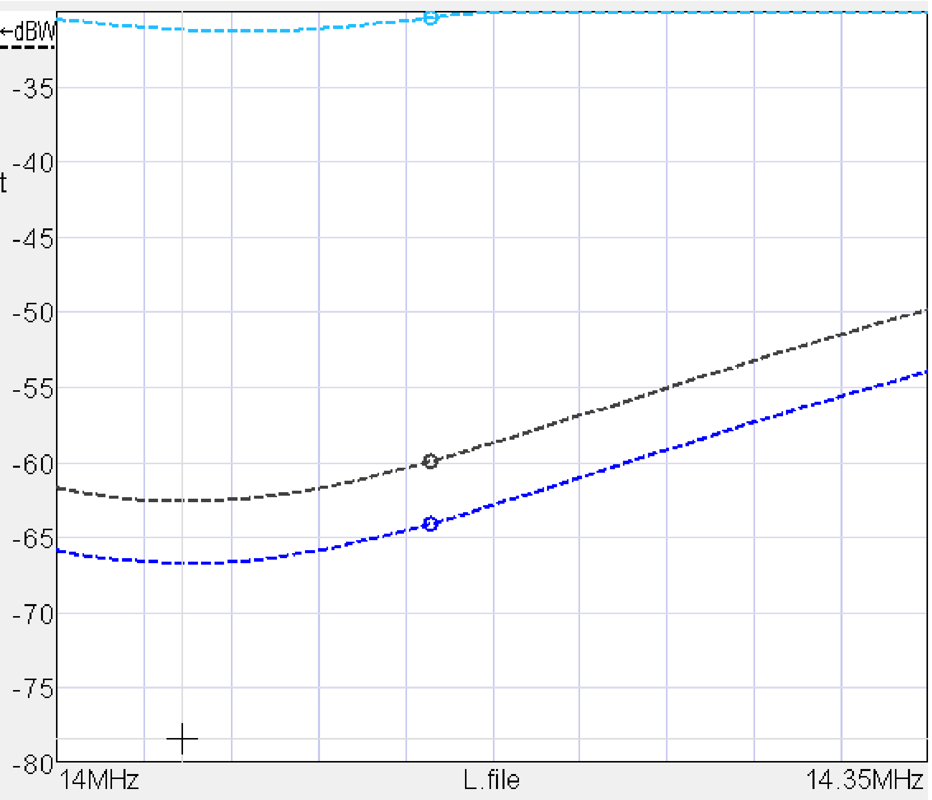


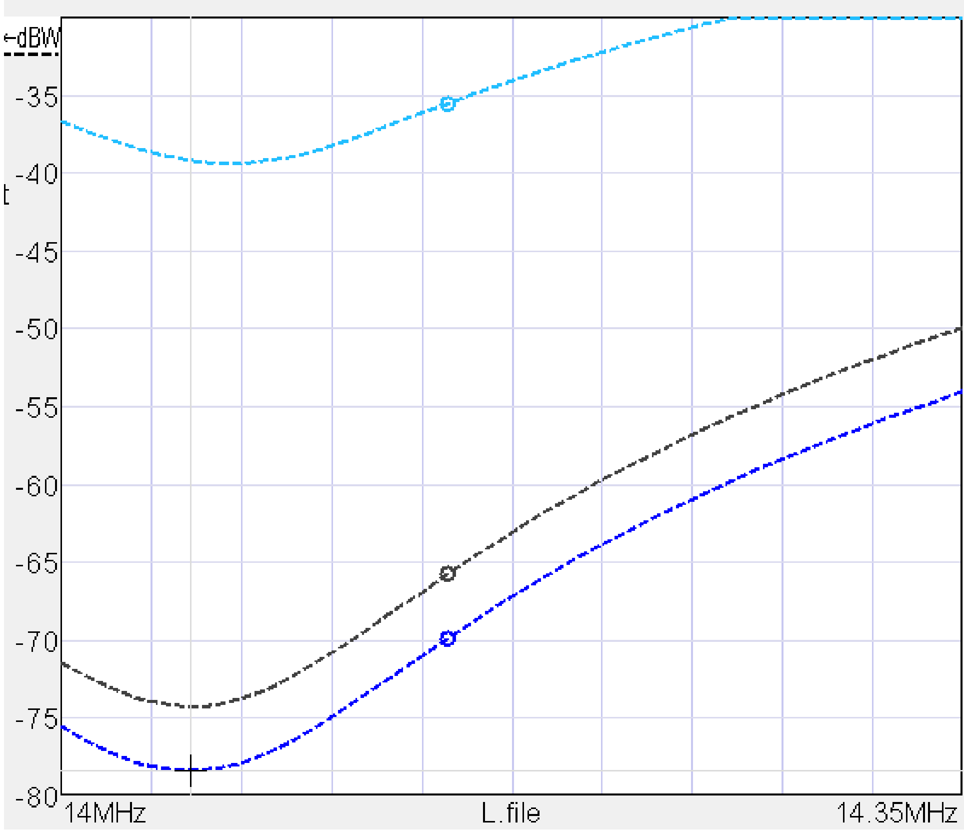
Two RG8X Stubs



Two RG8 Stubs

When the antenna is resonant at the harmonic frequency





RG8X on 40M Dipole **RG8 on 40M Dipole**

Smaller coax for stubs yields less suppression but greater bandwidth

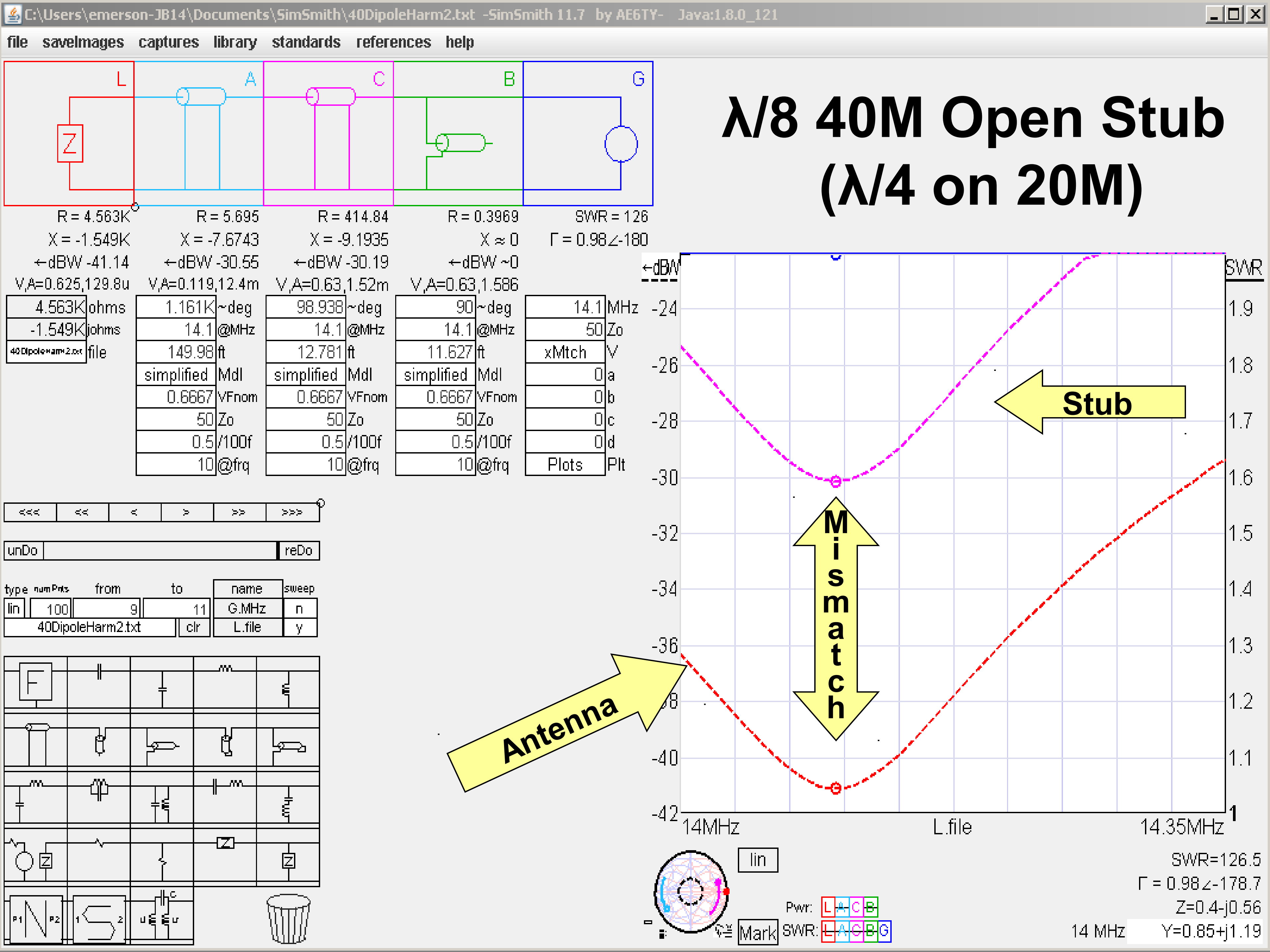
An Even Better Stub Design

- λ/4 open 20M stub is λ/8 on 40M
- Because it's half as long, resistance is half as much, so greater attenuation
- λ/8 on 40M adds mismatch loss
- Corrected by adding a shorted stub of equal length at the same point
- So – at each stub location, there are two stubs, one open, one shorted

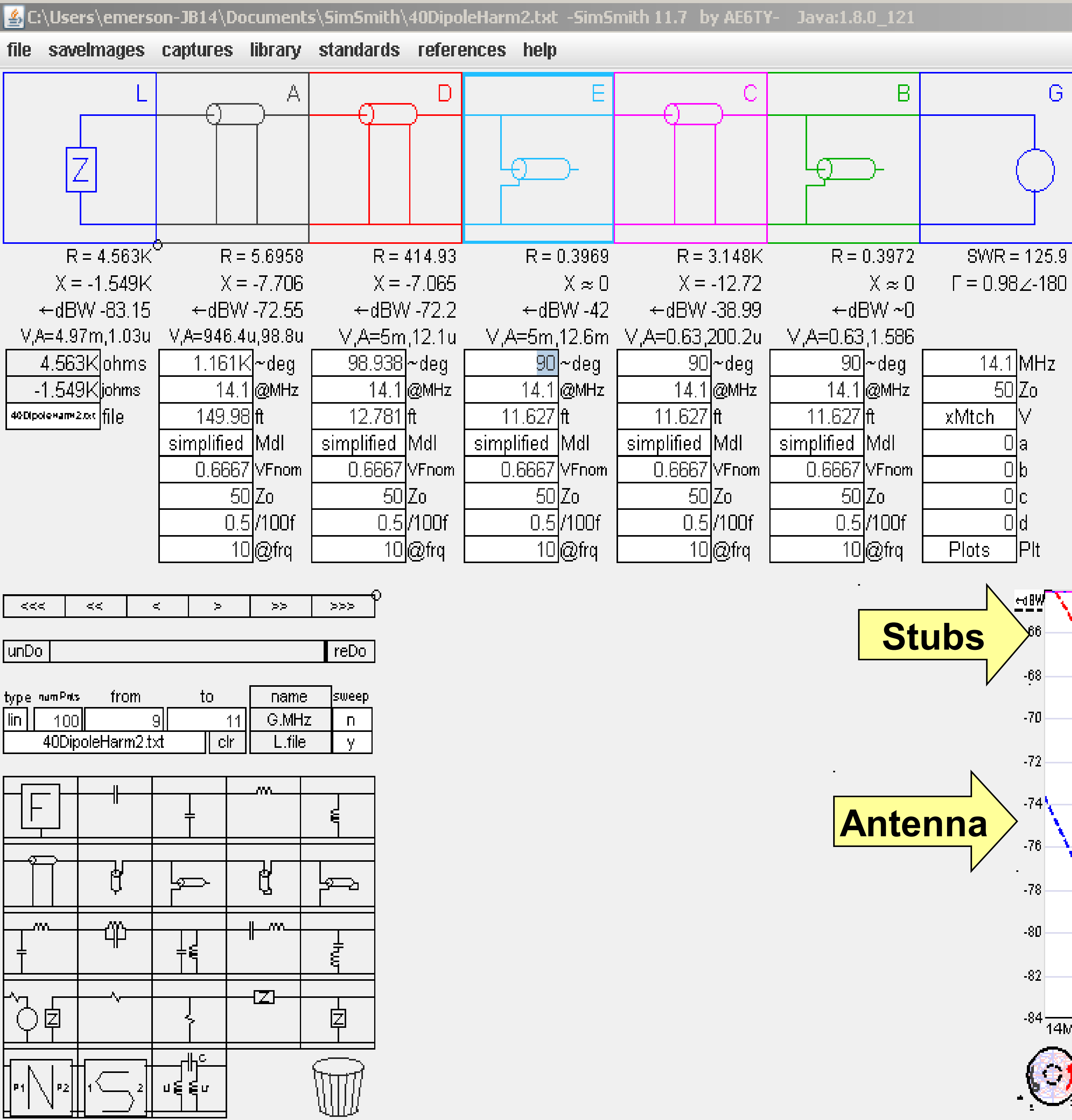
An Even Better Stub Design

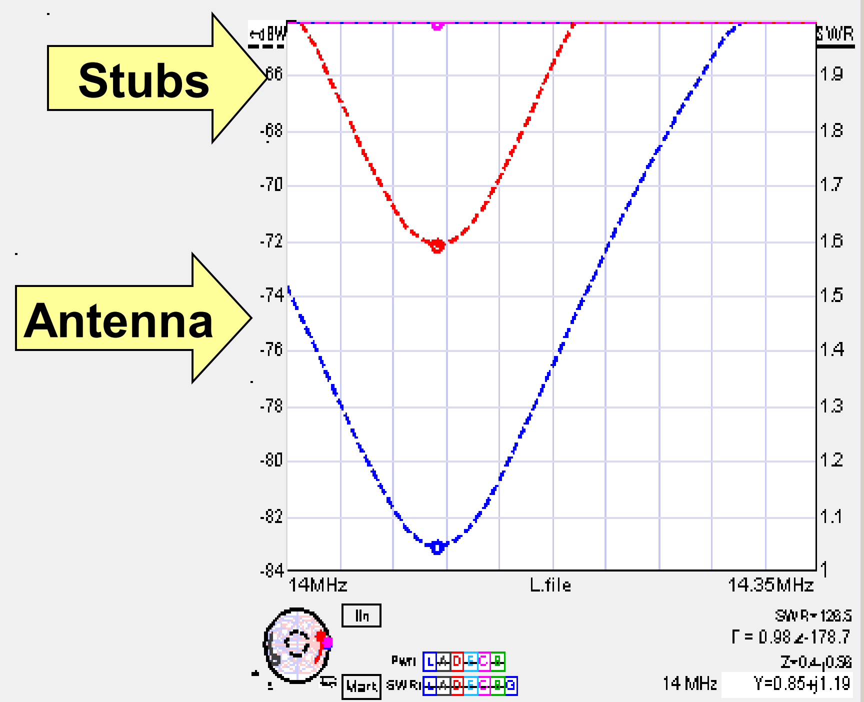
- **Uses the same amount of coax as shorted 40M λ/4 stub**
- **It's twice as many stubs, so it's more complex (more coax Tees and barrels)**

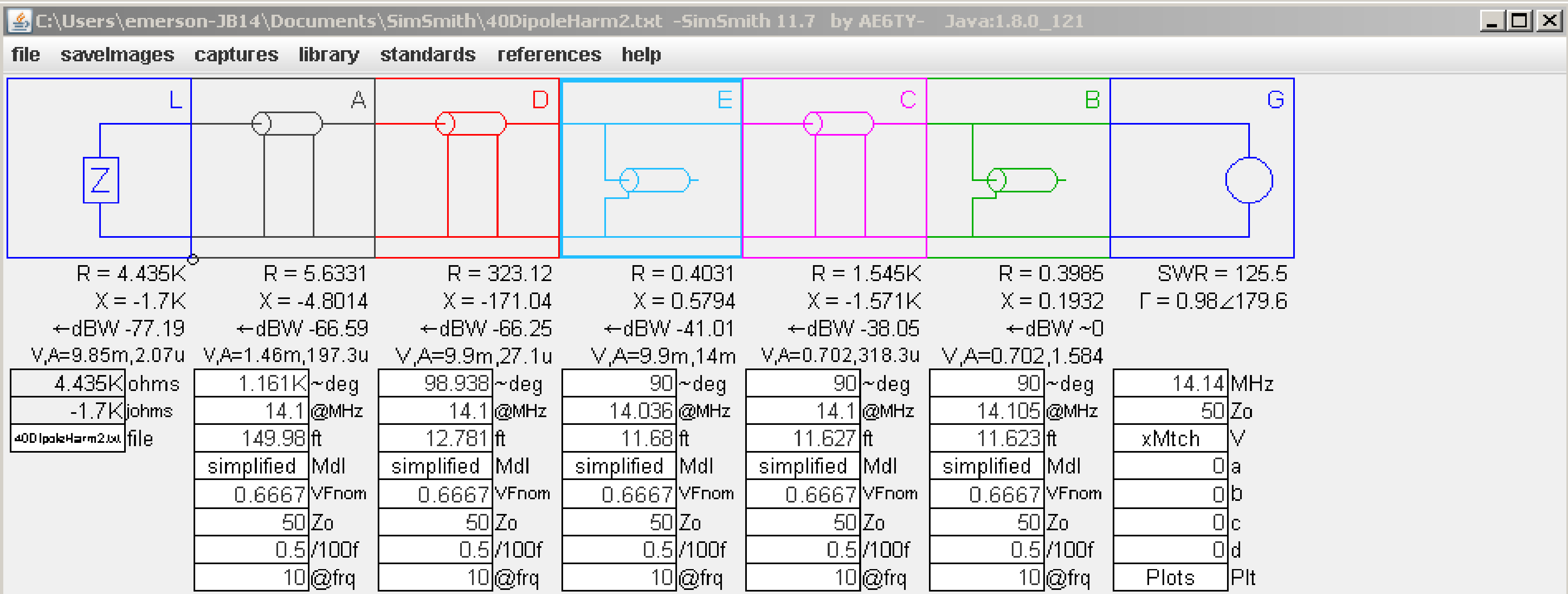
λ/8 40M Open Stub (λ/4 on 20M)

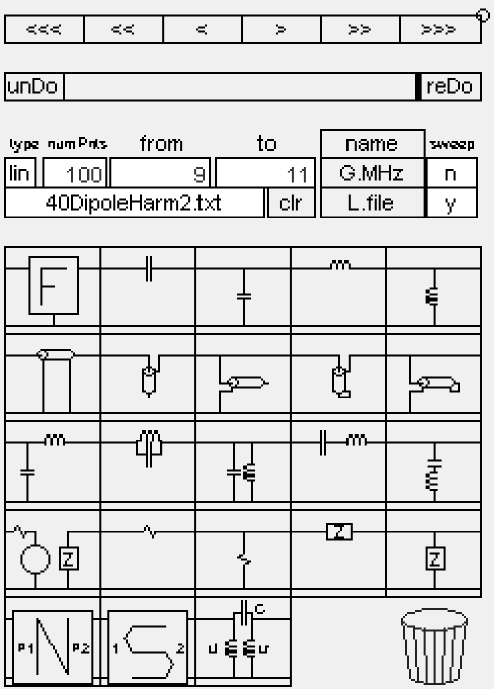


Two λ/8 40M Open Stubs

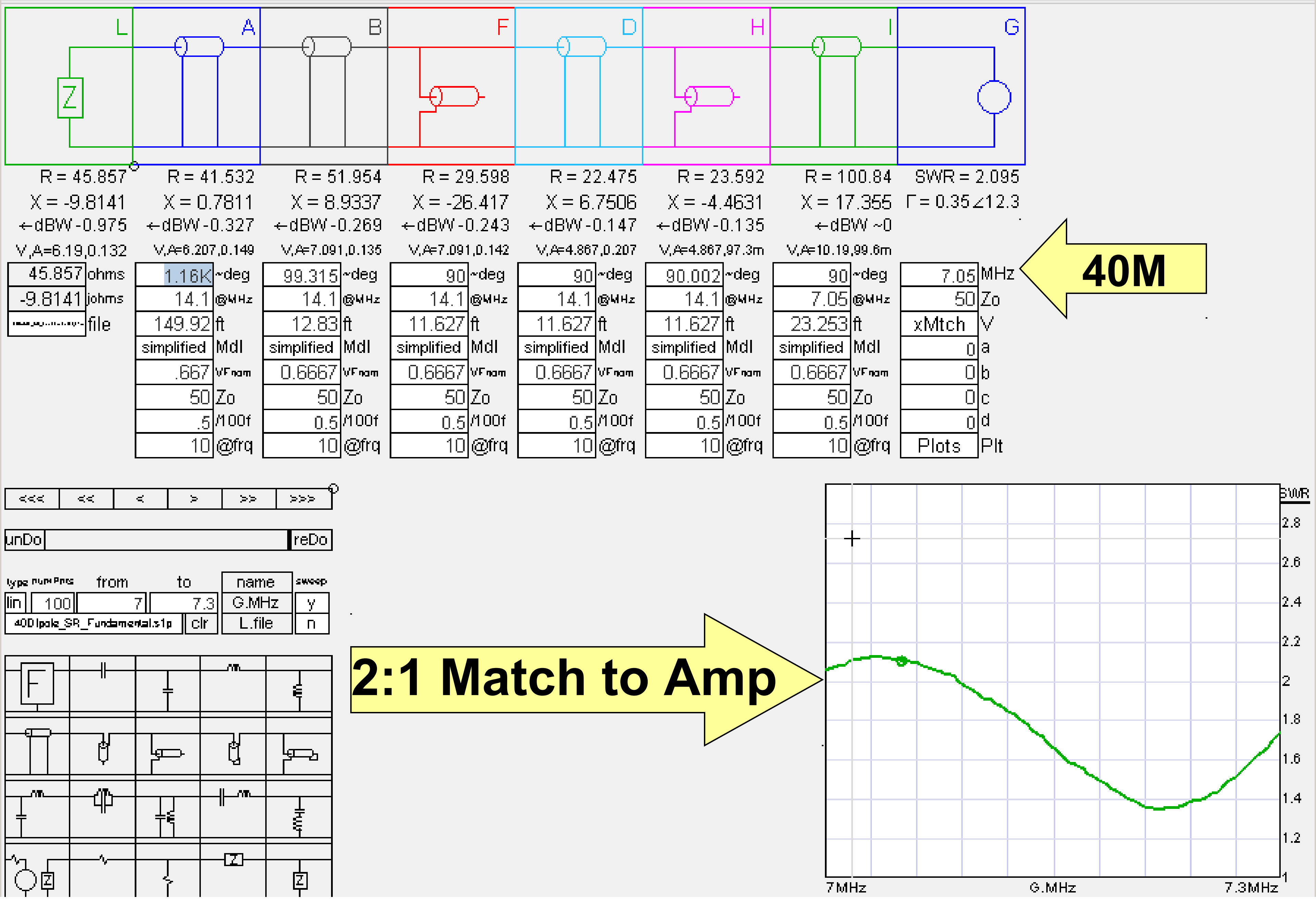




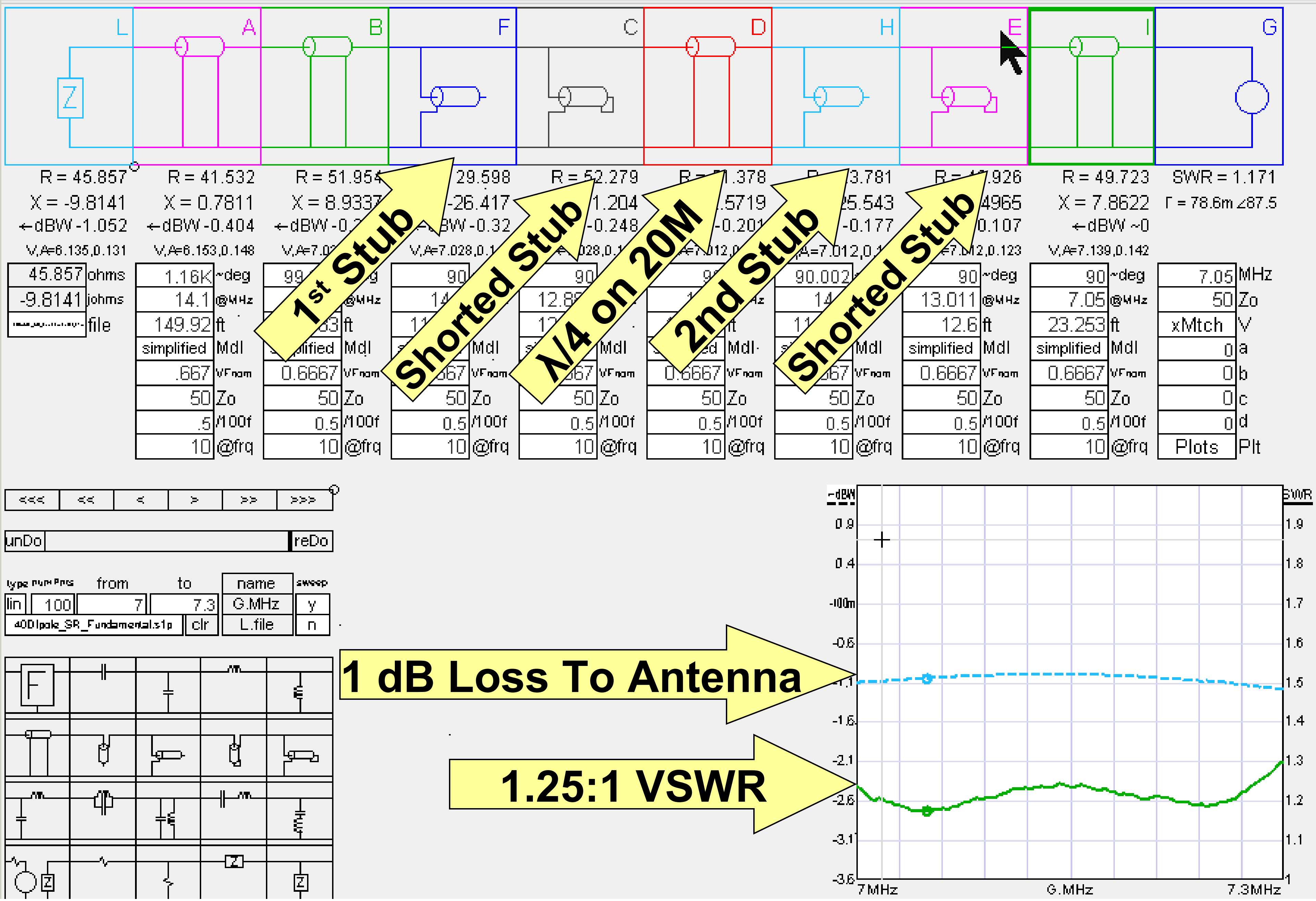




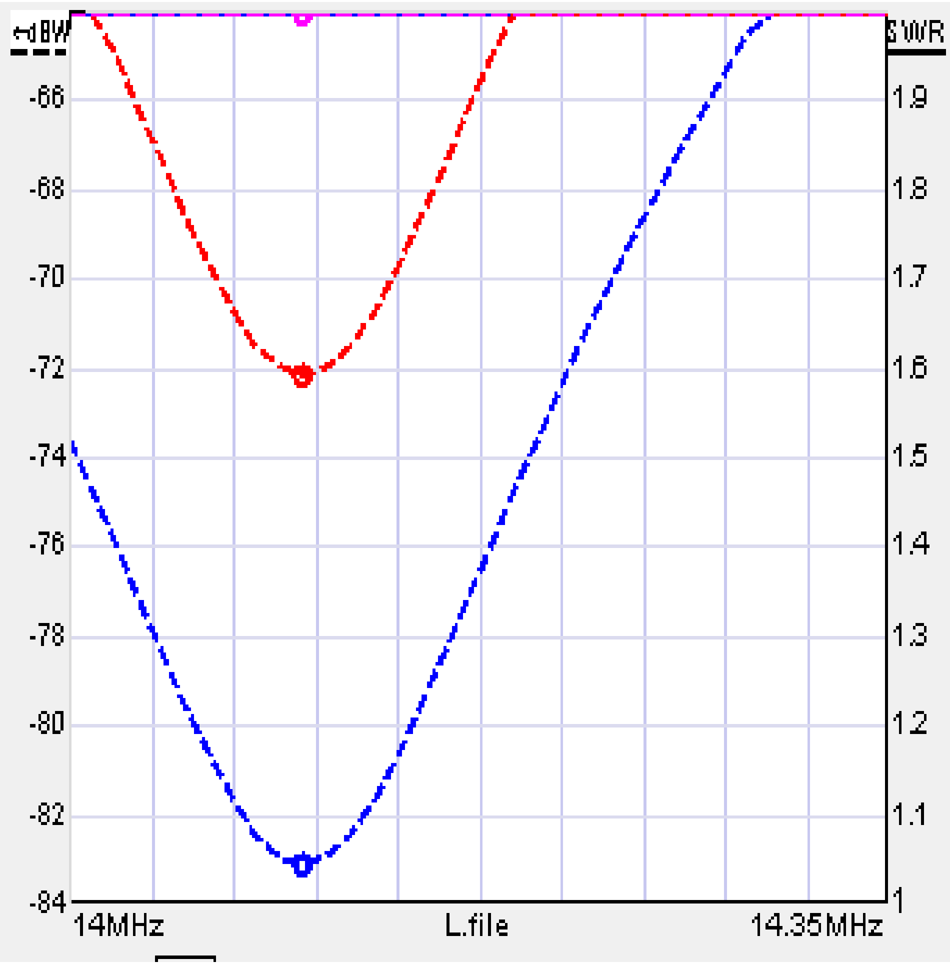
Stubs Stagger-Tuned For Broader Suppression

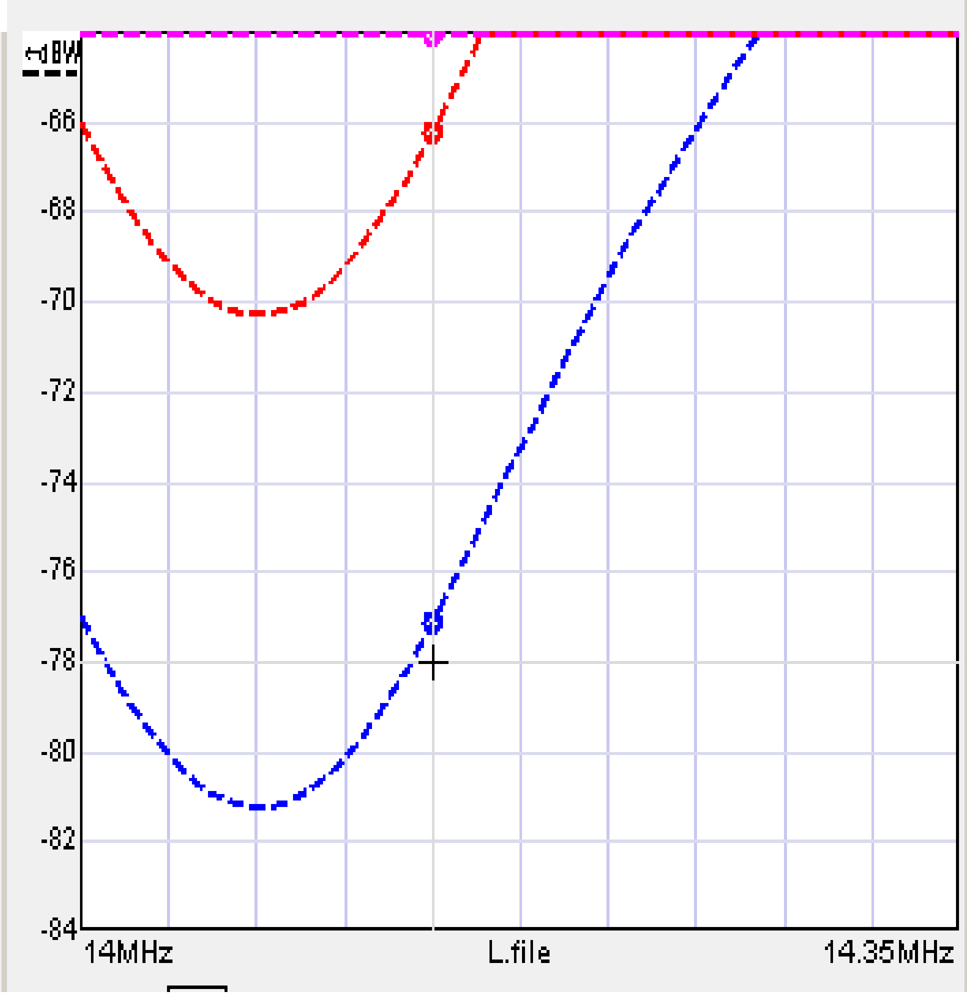


Two λ/8 40M Open Stubs, no shorted stubs



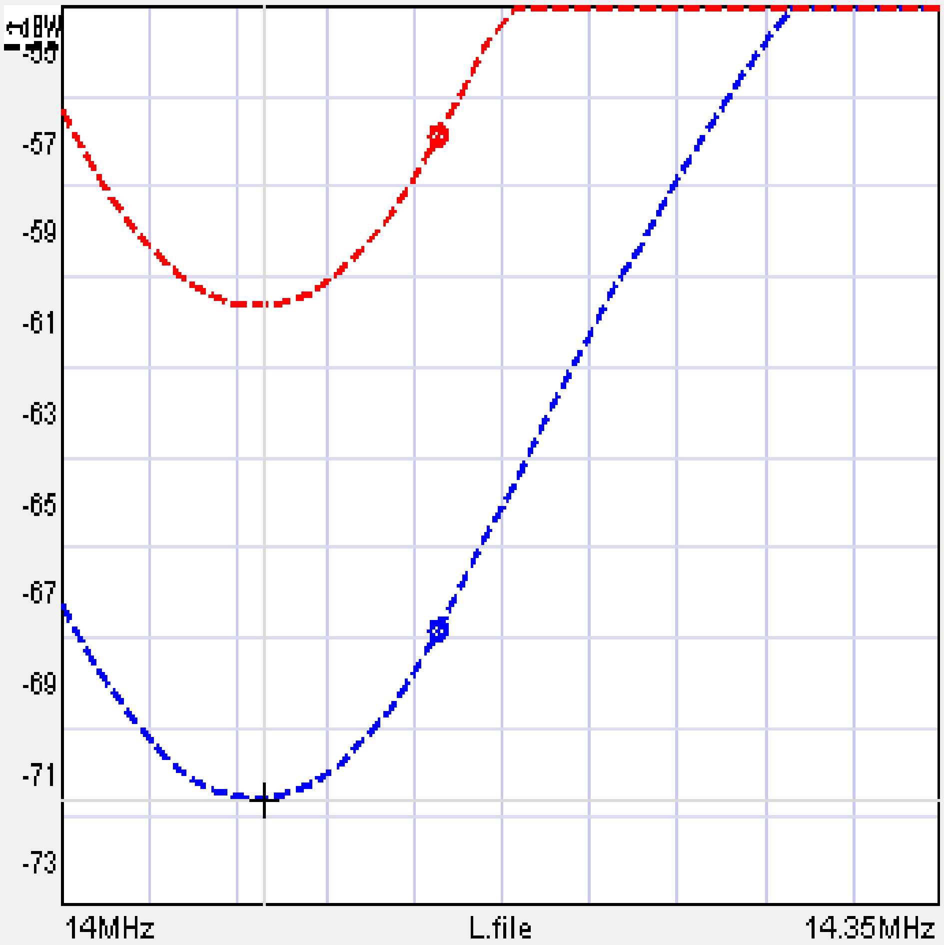
Shorted Stubs Added For 40M Match



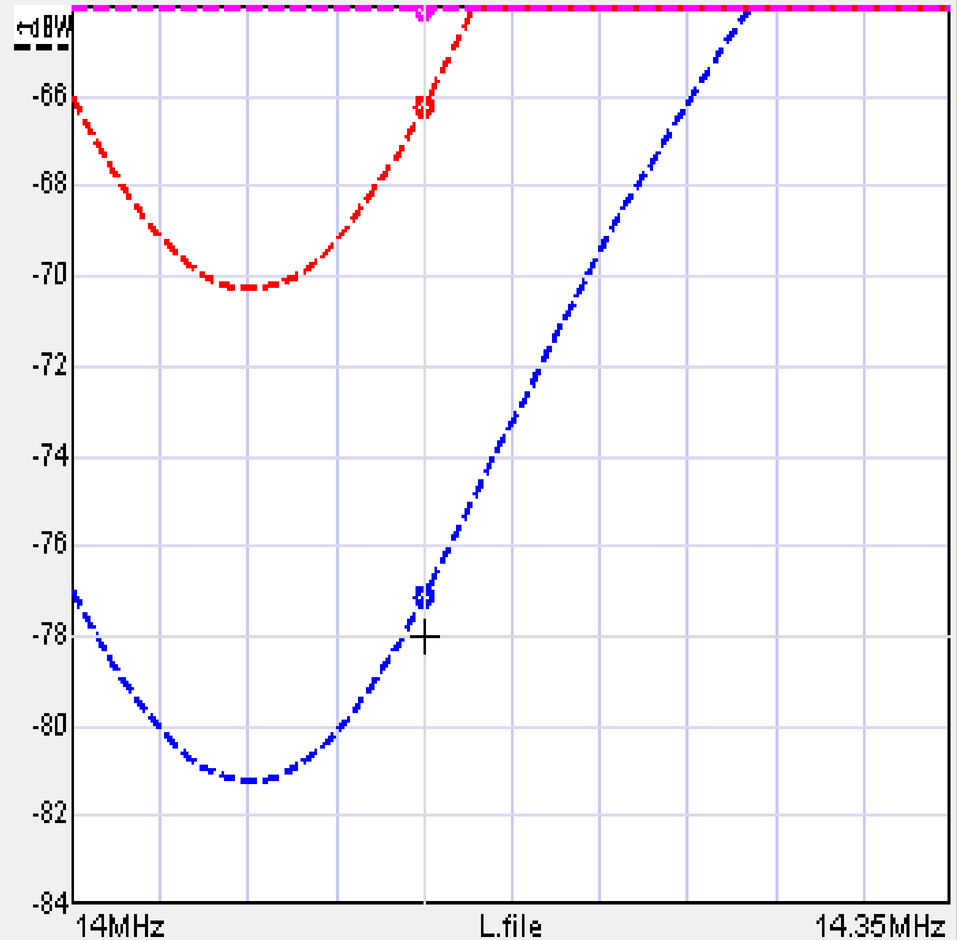


Tuned to 14.1 MHz **Stagger-Tuned**

Two λ/4 20M (λ/8 40M) Open Stubs Optimized for CW and RTTY



λ/4 40M Stubs
67 dB Attenuation
14 – 14.15 MHz



λ/8 40M Stubs
77 dB Attenuation
14 – 14.15 MHz

Mismatch With λ/8 Stubs

- If stubs are close to power amp (within 50 ft or so), mismatch loss is too small to matter
  - Mismatch loss only happens between power amp and stubs
- Auto-tune power amps may not be happy with near 2:1 mismatch
- Tuner required for solid state amps

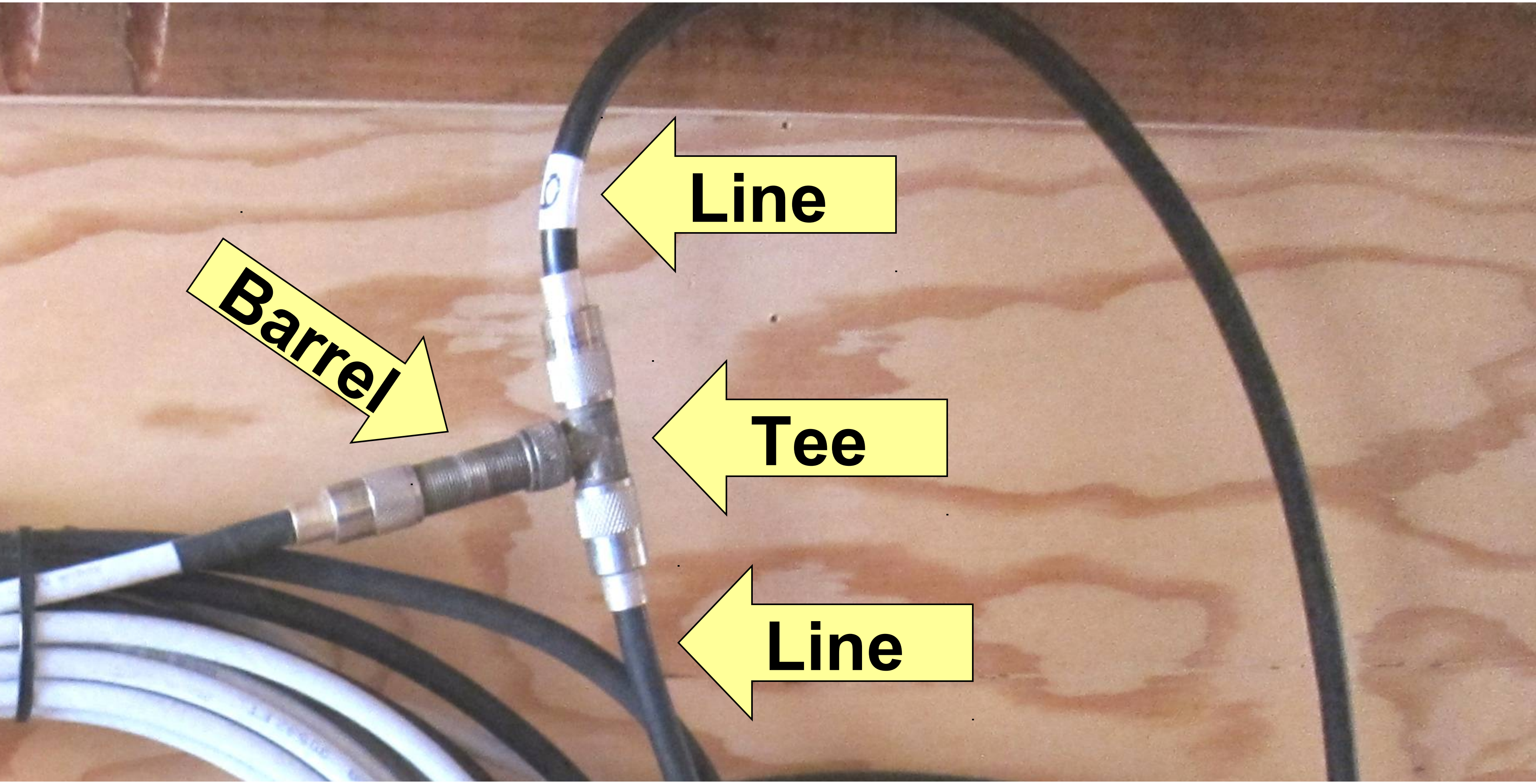
Making Stubs

- Use coax with low RF resistance
  - Larger center conductor
  - Beefy copper shield
- Foam dielectric stubs must be longer
  - VF is 25% higher
  - Lower loss/ft, but 25% longer
  - OK, but no advantage over solid dielectric
- Add to line using Tee and barrel

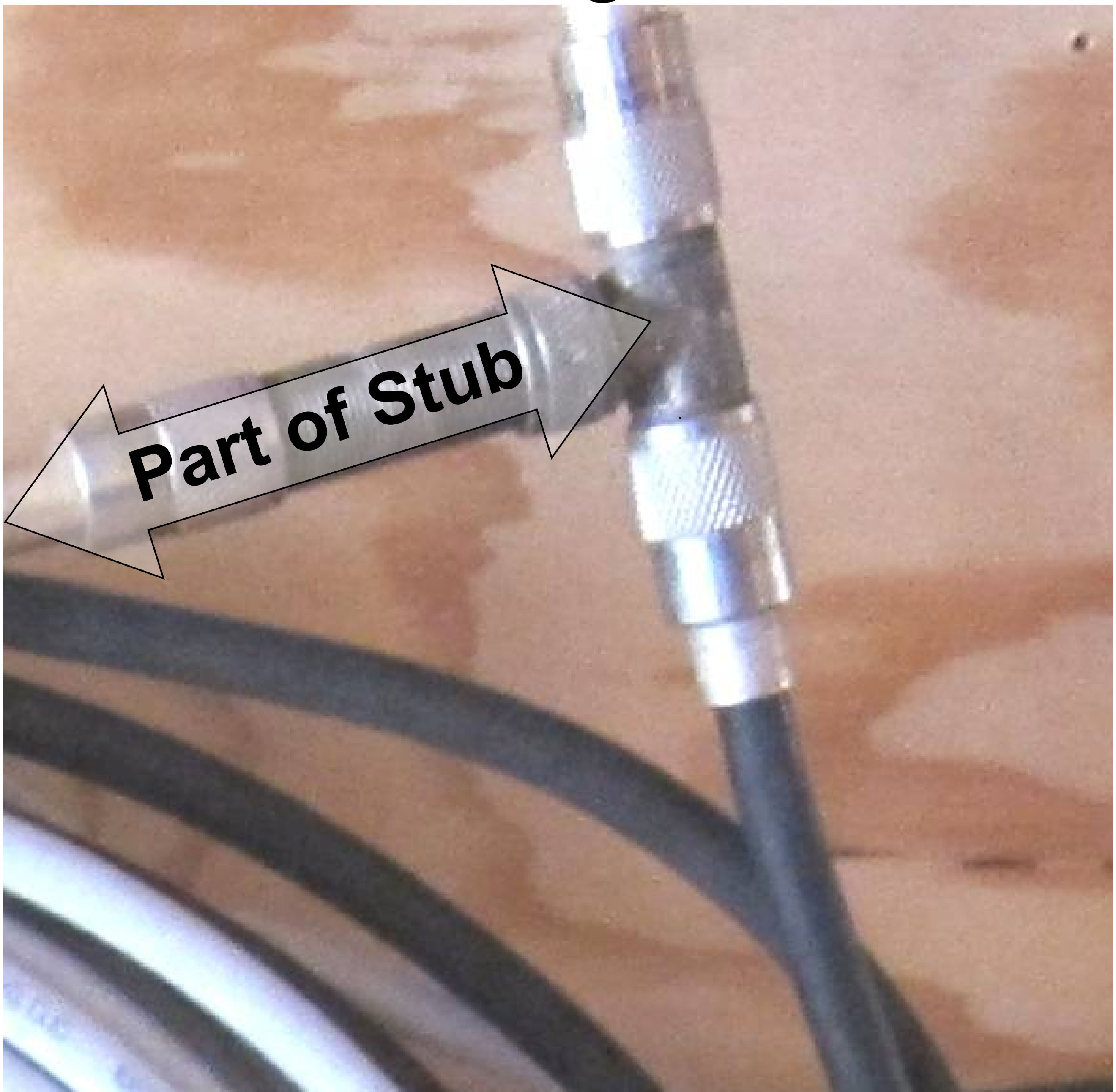
Making Stubs

- **Cut it long and trim it to length at the frequency of the null (VF varies with frequency)**
- **The effective stub length in your test setup should be the same as when it will be inline with the antenna**
  - **If your test setup has a female UHF (SO-239) connector, plug the stub onto one side of a Tee, plug the Tee into the test set**

Connecting a Stub



Connecting a Stub



Connecting Two Stubs at Same Point

Dissipation and Loss – Fundamental

- With 1,500 W output on 40M and λ/4 20M RG-8X stubs:
  - The shorted stubs each burn 50 W
  - The open stubs each burn 15 W
  - Total loss in stubs on 40M is 0.46 dB
- With RG8 stubs:
  - The shorted stubs each burn 27.5 W
  - The open stubs each burn 7.5 W
  - Total loss in stubs on 40M is 0.2 dB

Dissipation and Loss – Fundamental

- **With 1,500 W output on 40M and λ/2 20M shorted stubs:**
  - **RG-8X stubs each burn 35 W**
  - **RG-8 stubs each burn 18 W**
- **Total loss in two stubs is:**
  - **0.2 dB in RG-8X stubs**
  - **0.1 dB in RG-8 stubs**

Dissipation – Harmonic Power

- The stub nearest the transmitter is optimally placed, it dissipates almost all of the second harmonic power
- If the second harmonic is only 30dB below the 1,500W carrier (pretty poor) that's 1.5W
- There's almost no harmonic power left after the first stub

How Well Do They Work?

- We run multi-two for CQP and 7QP in W6GJB’s contesting trailer
- Each station is a K3, P3, KPA500, KAT500
- 40 and 20 CW during the day
- 80 and 40 CW at night
- Some SSB when CW gets slow

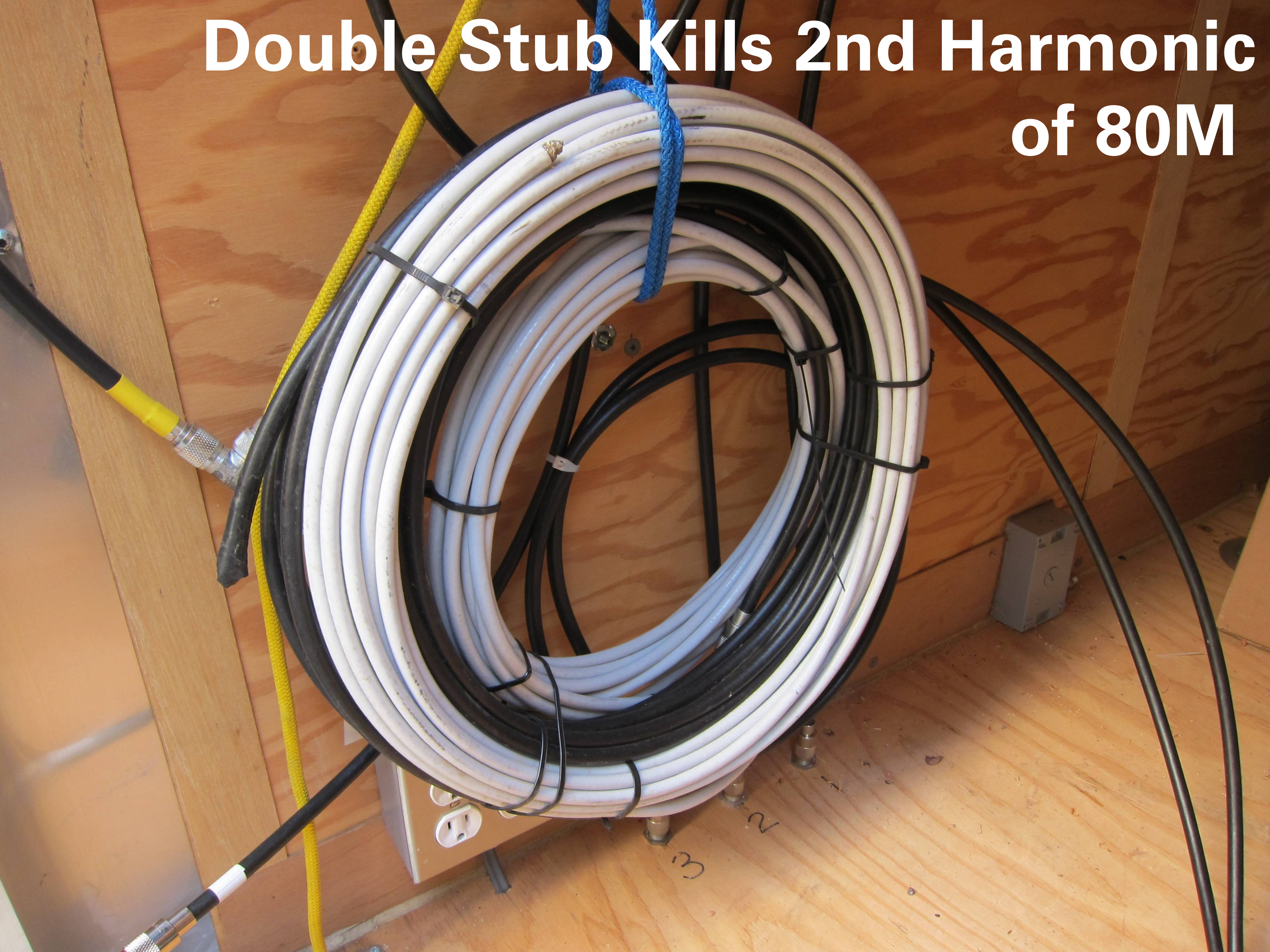
7QP and CQP Antennas Both Choked at Feedpoint


C3SS
40M Dipole
Colorado
River
Colorado River in SE Utah

How Well Do They Work?

- During the day, no 80M dipole, C3SS (for 20M) is rigged a few feet below 40M dipole
- Stubs allow us to run 600W with no problems with crossband QRM
- Three contests so far
  - 7QP 2016, five setups in 7 NV counties
  - CQP 2016, two setups in 2 CA counties
  - 7QP 2017, three setups in 5 UT counties

Double Stub Kills 2nd Harmonic of 40M


Double Stub Kills 2nd Harmonic
of 80M
2
3

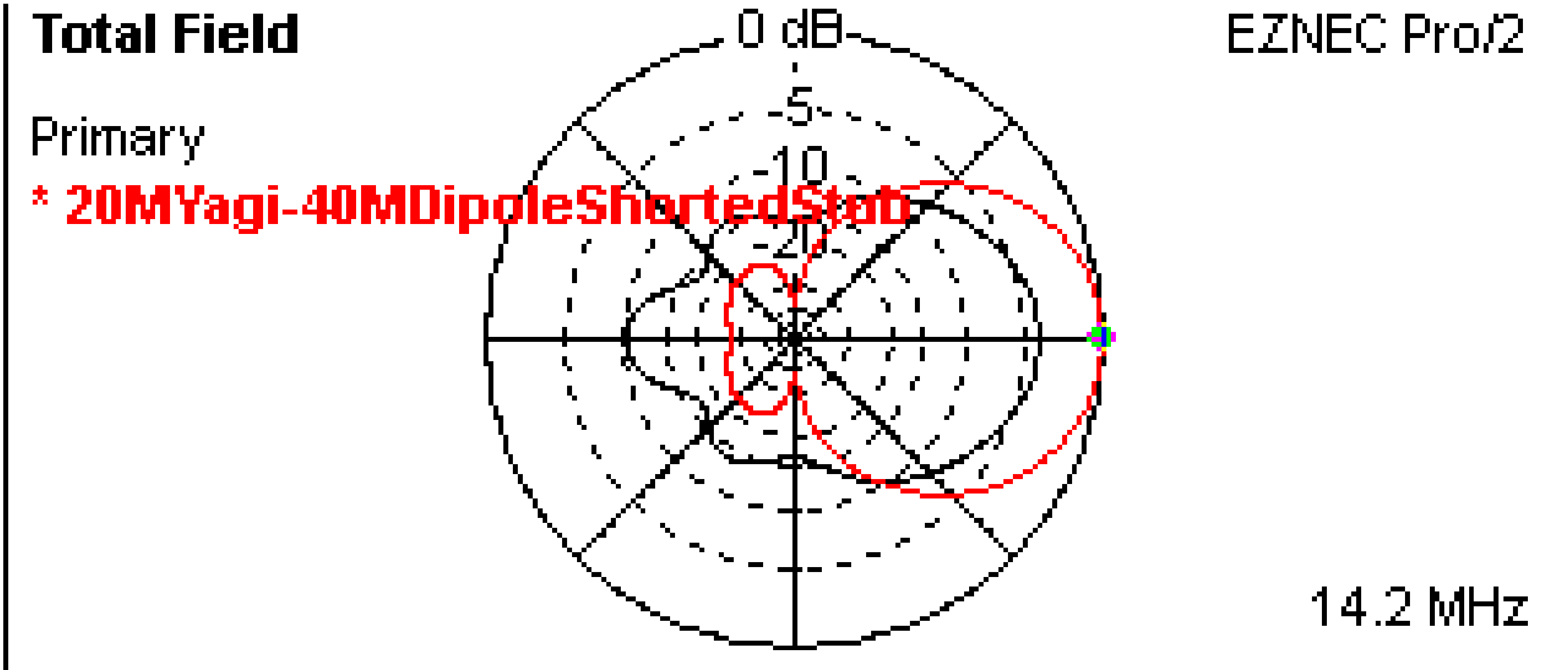
How Well Do They Work?

- CQP set up the second day in Colusa Co on access road next to I-5, we did have birdies on 20 from 40
- Rectification and re-radiation from something nearby caused QRM on 20 from 40 (harmonic sounds “growly”)

There's Another Benefit

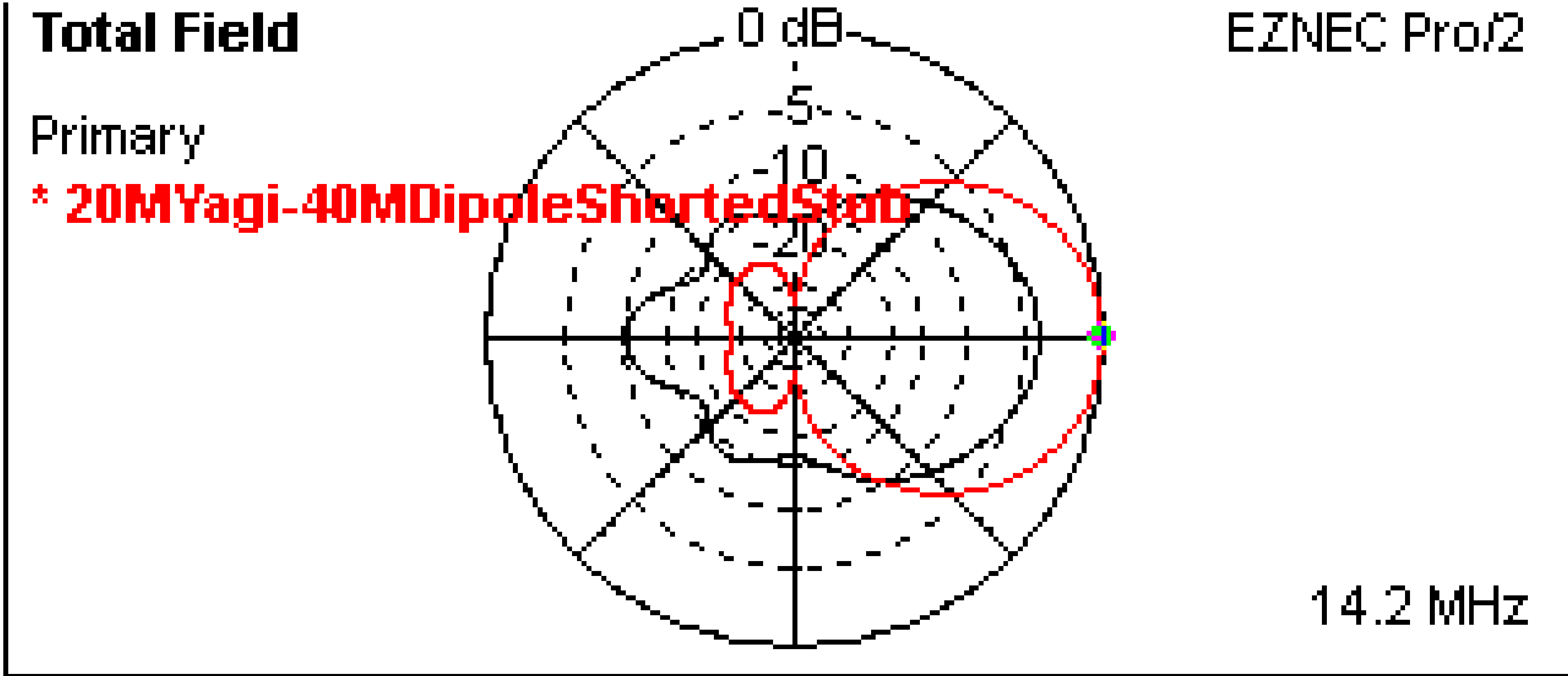
- **A resonant dipole close to an antenna operating on its harmonic can interfere with the pattern of the higher frequency antenna**
  - **40M dipole interferes with 20M**
  - **80M dipole interferes with 40M**
- **Following plots are from NEC model**

Black Curve Shows Interference



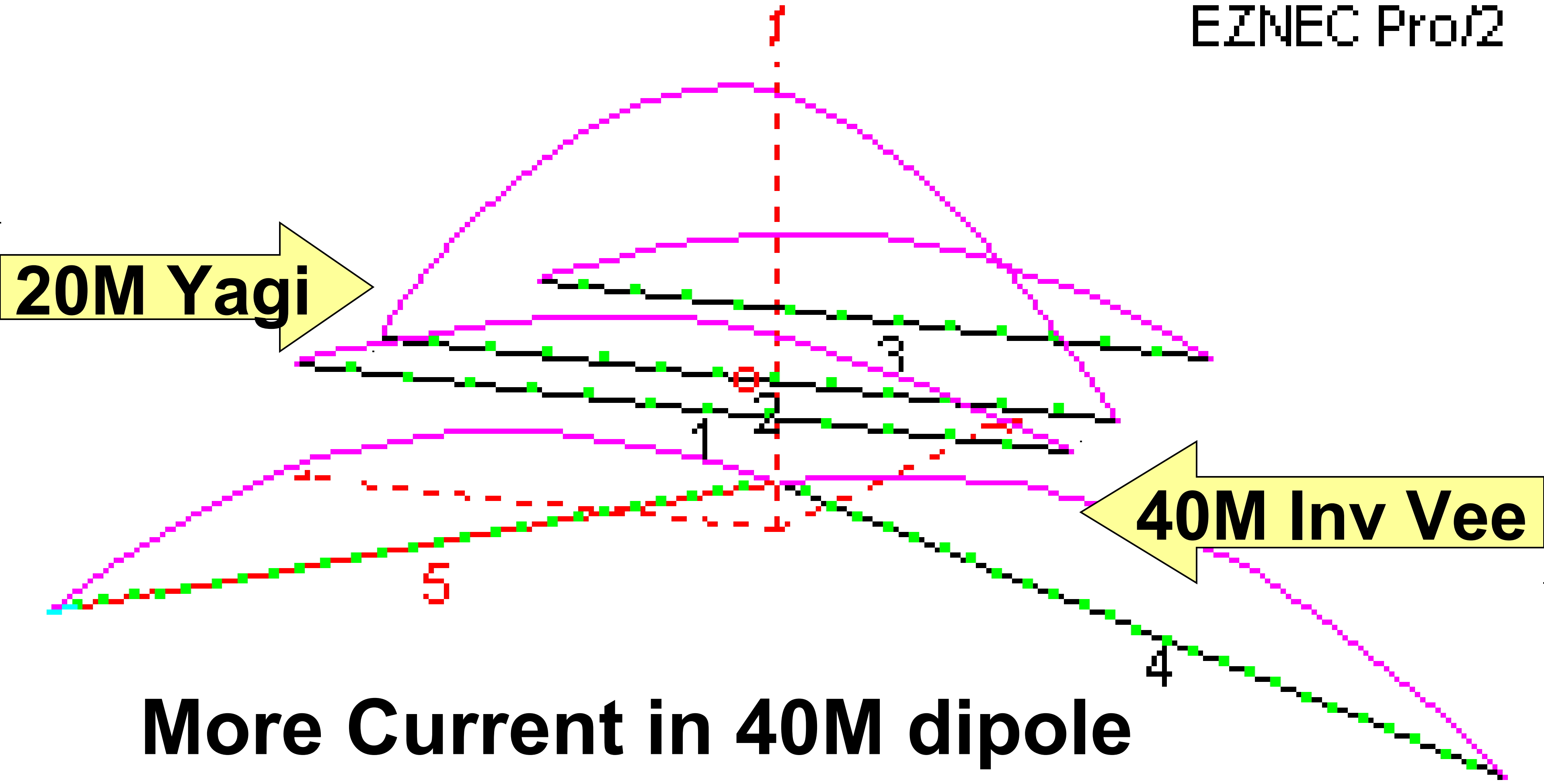
Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	12.93 dBi
Outer Ring	12.93 dBi		0.0 dBmax
			3.94 dBPrTrc

Red Curve Is With Stub On the Dipole



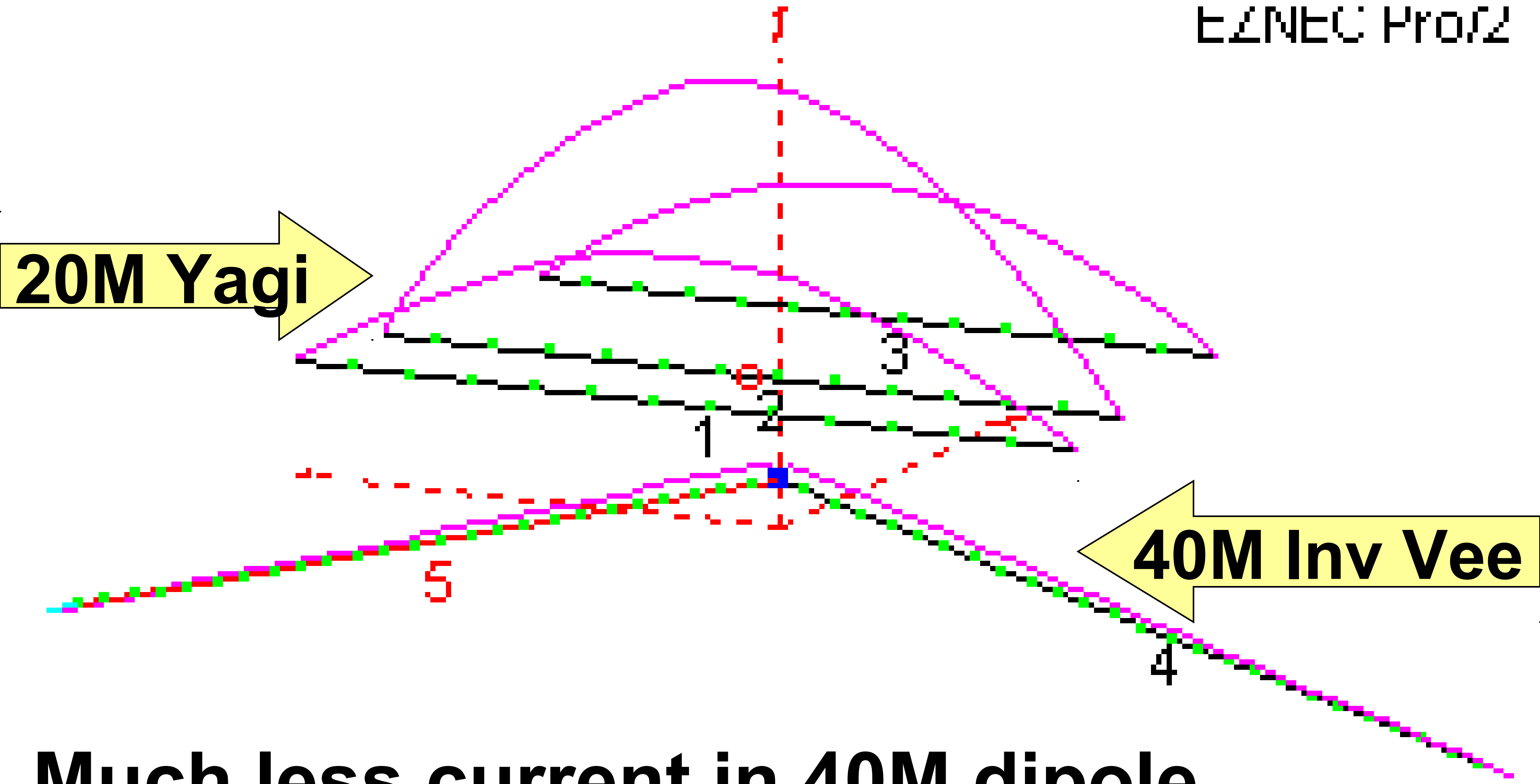
Azimuth Plot		Cursor Az	0.0 deg.
Elevation Angle	0.0 deg.	Gain	12.93 dBi
Outer Ring	12.93 dBi		0.0 dBmax
			3.94 dBPrTrc

Currents With Dipole Feedpoint Open



More Current in 40M dipole than in parastic Yagi elements

Currents With Dipole Feedpoint Shorted



Much less current in 40M dipole

The Bonus – A Free Lunch!

- **Shorting feedpoint of 40M dipole also kills interference with Yagi pattern**
- **The stub, and the stub placement, that works for harmonic suppression provides that short circuit**
  - **The stub closest to the antenna is n λ/2 down the line at 20M**
  - **It works for any 2:1 harmonically related where the lower frequency antenna is resonant on a single band**

In Summary

- **A shorted quarter wave stub at the transmitter frequency, some whole number of half waves from a resonant antenna**
  - **Is optimally located to kill the amplifier's second harmonic AND**
  - **Minimizes interaction between that antenna and a nearby antenna on the harmonic frequency**

In Summary

- At the harmonic frequency, a stub for harmonic suppression should be
  - A whole number of half waves at the from amps with Pi-L output networks
  - An odd number of quarter waves from amps with Pi and Elliptical output networks

In Summary

- **An additional 30 dB of harmonic suppression is provided by adding a second stub, λ/4 at the harmonic frequency closer to the amplifier**

In Summary

- **If the TX antenna is resonant at the harmonic being suppressed, placement with respect to the antenna doesn't affect suppression, but it CAN prevent interaction with an antenna on the 2nd harmonic band**

In Summary

- **Gurgly, growly sounding harmonics are usually <u>not</u> generated in our rigs, they are the result of reception, rectification, and re-radiation by non-linear devices on wiring connected to those devices**
- **This trash can only be suppressed at their source (the non-linear device) by a ferrite choke, tuned to the TX fundamental, on that wiring**

Locating Stubs For Harmonic Suppression

Jim Brown K9YC

k9yc@arrl.net