

# **Locating Stubs For Harmonic Suppression**

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# **Don't Bother Taking Notes**

- **A tutorial is already at [k9yc.com/publish.htm](http://k9yc.com/publish.htm)**
- **These slides will be added when I'm finished with them**

# Why Stubs?

- **Power amps generate harmonics**
  - **2<sup>nd</sup> 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 does 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

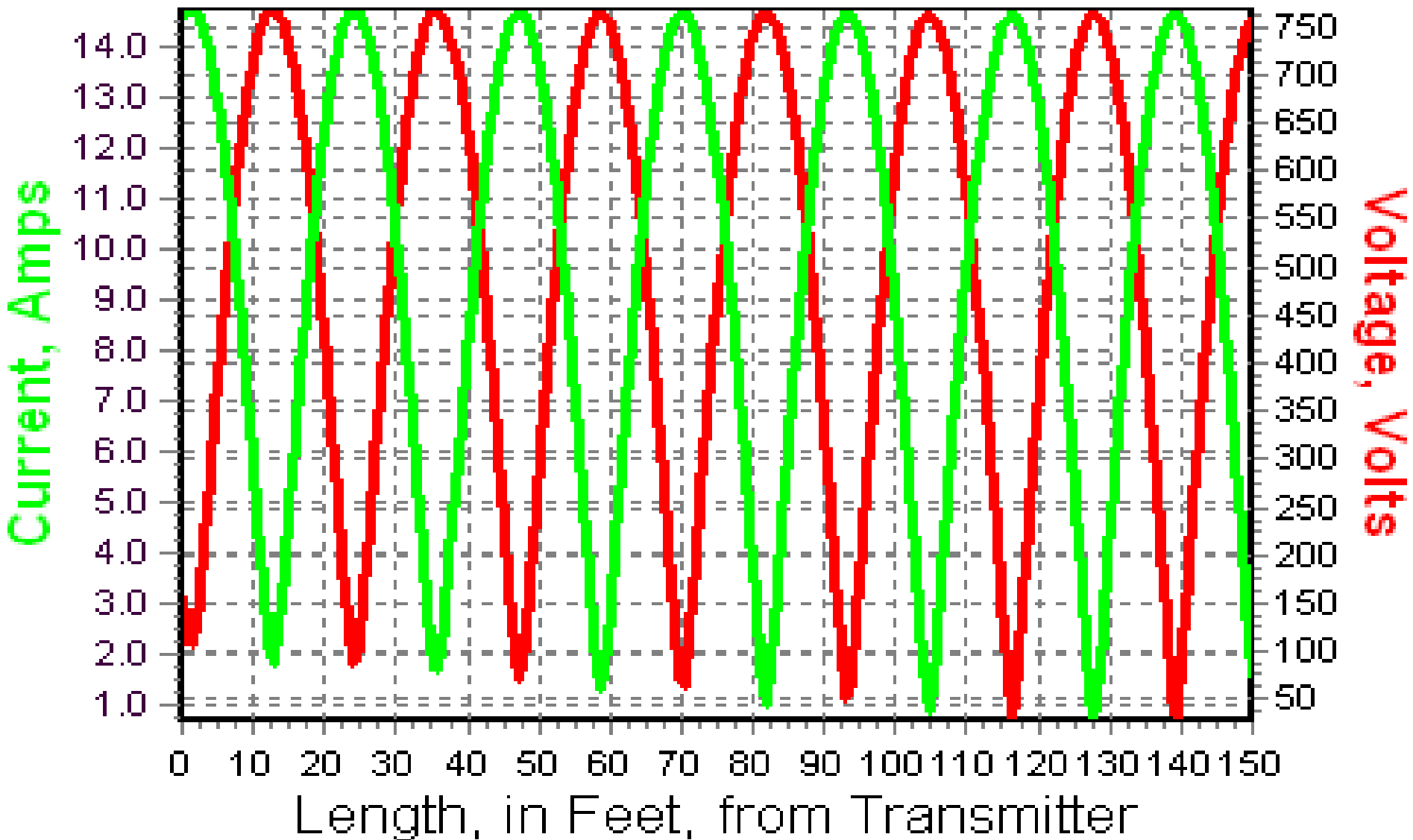
- **A stub will be most effective at a high impedance point on the line (it's shorting out a high impedance)**
- **A stub won't do much at low impedance point on the line (it's in parallel with a very low impedance)**
- **Placement from the antenna doesn't matter if antenna is resonant on the harmonic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



# **A 40M Dipole on 20M 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



# What Sets Location of Peaks?

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

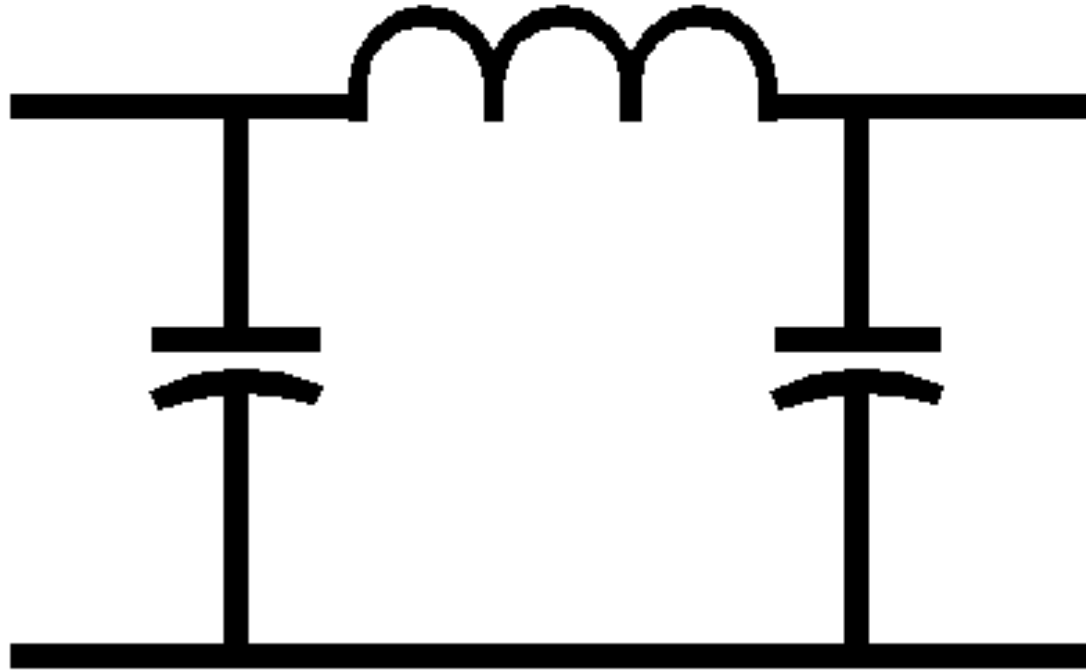
# Stub Placement and Amplifiers

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

# Stub Placement and Amplifiers

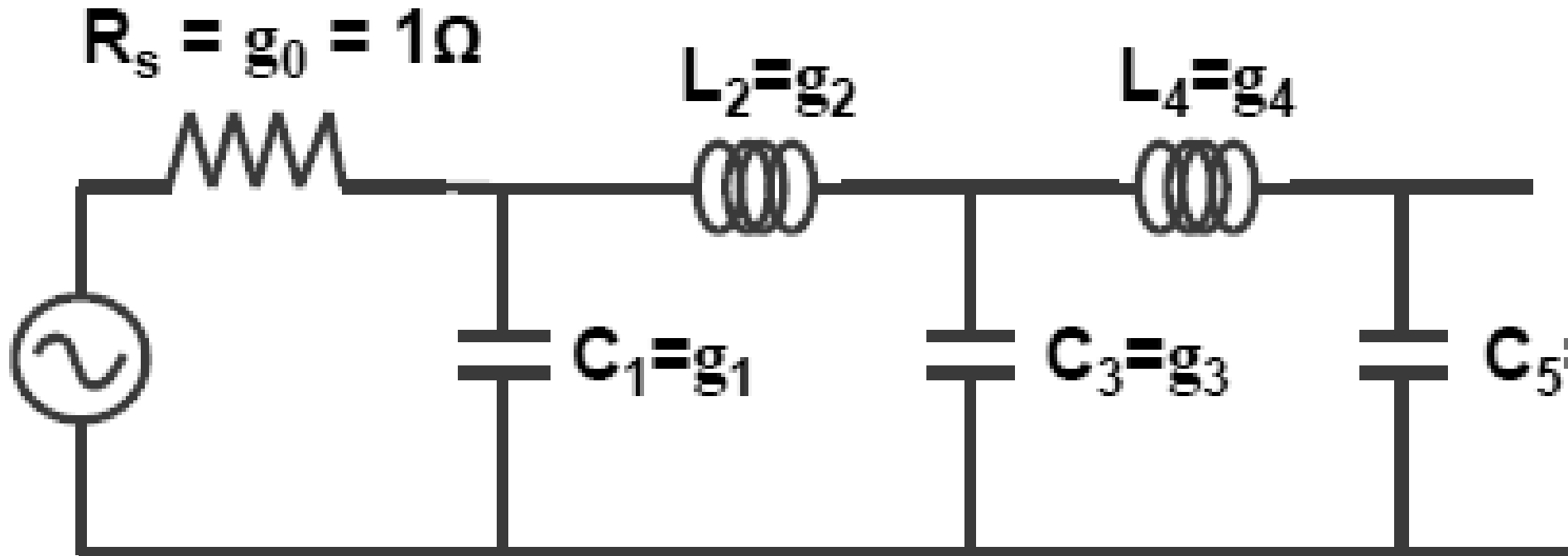
- **Three common output networks**
  - **Pi**
  - **Pi-L**
  - **Elliptical**

# Pi Network



**Output is  
Low Z for  
Harmonics**

# Typical Elliptical Filter Used in Solid State Amps



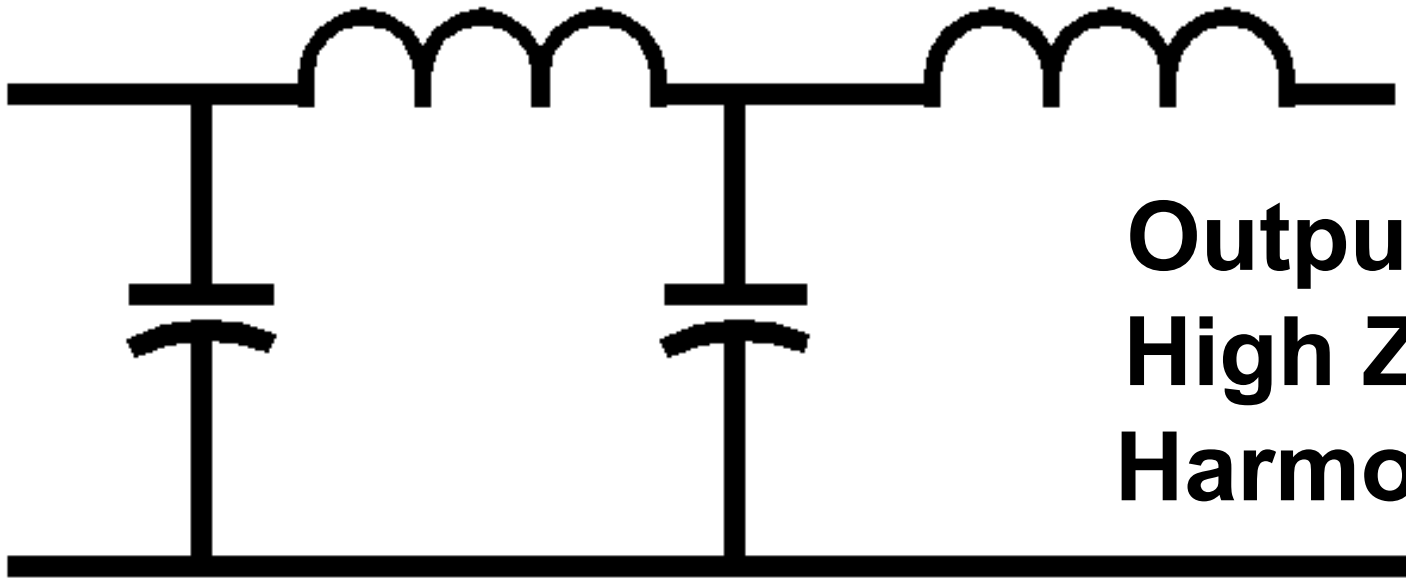
**Output is Low Z for Harmonics**

# 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  $\lambda/4$  from the amplifier, or at some odd multiple of  $\lambda/4$ , 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 high output impedance at the harmonic
- A stub will be most effective directly at the amplifier output or some multiple of  $\lambda/2$  from the amplifier (at the harmonic frequency)
- A stub will be least effective at  $\lambda/4$  from the amplifier, or at some odd multiple of  $\lambda/4$  (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**
- **$\lambda/4$  or  $\lambda/2$ , 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](http://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](http://ac6la.com)**
- **ZPlots by AC6LA (Excel spreadsheet, free) download [ac6la.com](http://ac6la.com)**
  - **Excel only, not Open or Libre Office**
- **AE6TY's SimSmith (Smith chart, runs in JAVA, free) download at [ae6ty.com](http://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 Not 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  $\lambda/2$  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 drag sliders.

1. Choose Transmission Line, Model, and Impedance Desired.

2. Set Frequency, Band, and Loss.

3. Set Line Length, Power, and Units.

**Enter Coax Type** (points to Type dropdown)

**Enter Frequency** (points to Frequency input)

**Vary Length** (points to Length input)

**Enter Measured Z** (points to R and X inputs)

**Choose At Input** (points to At Input radio button)

Print

Freq - VF - Len - Wavelength - Loss - Power - Units

Type: Davis RF Bury-Flex

Nom. VF: 0.82

K0: 0.025189

K1: 0.000000

K2: 0.000000

T-Line Model Variables

R: 100

X: -200

At Input (selected)

At Load

Matched Loss: 0.577 dB/100ft

Preferred Units: Feet (selected)

Meters

Electrical Length Modulo 1/2 Wavelength: 0.2498 λ

Input Watts: 5

Plot Matched Line Loss

Results

At Input (red dot) / At Load (blue dot)

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	% of Total Loss
	24	1	76
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	

Plot |Zo| Plot VF

Prime Center: 50

Show:  SWR  Rho  Return Loss

Close

# 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

**Transmission Line Details - v2.0.1**

Enter values directly, or click spinners, or click and hold.

1. Choose Transmission Line, Modify Parameters as desired.

Type	Nom. Zo	Nom. VF	K0	K1	K2
Davis RF Bury-Flex		0.82	0.025189	0.000000	0.000000

2. Set Frequency, R and X.

Frequency: 14.1 MHz

R and X:  At Input,  At Load

3. Set Line Length.

Length: 0 Feet

Electrical Length Modulo 1/2 Wavelength: 0 to 1/2

Input Watts: 5

Plot Matched Line Loss

T-Line Model Parameters:

- Series R: 0.000 mΩ/ft
- Series L: 62.748 nH/ft
- Shunt G: 0.000 μS/ft
- Shunt C: 24.798 pF/ft
- Matched Loss 1.#IND dB/100ft

Preferred Units:  Feet,  Meters

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**Results**

	At Input	At Load
R	100.000	100.000
X	200.000	200.000
Z	223.607	223.607
SWR (True)	10.474	10.474
SWR (50)	10.404	10.404
True Zo	50.304 - j 0.303	
VF	0.8150	

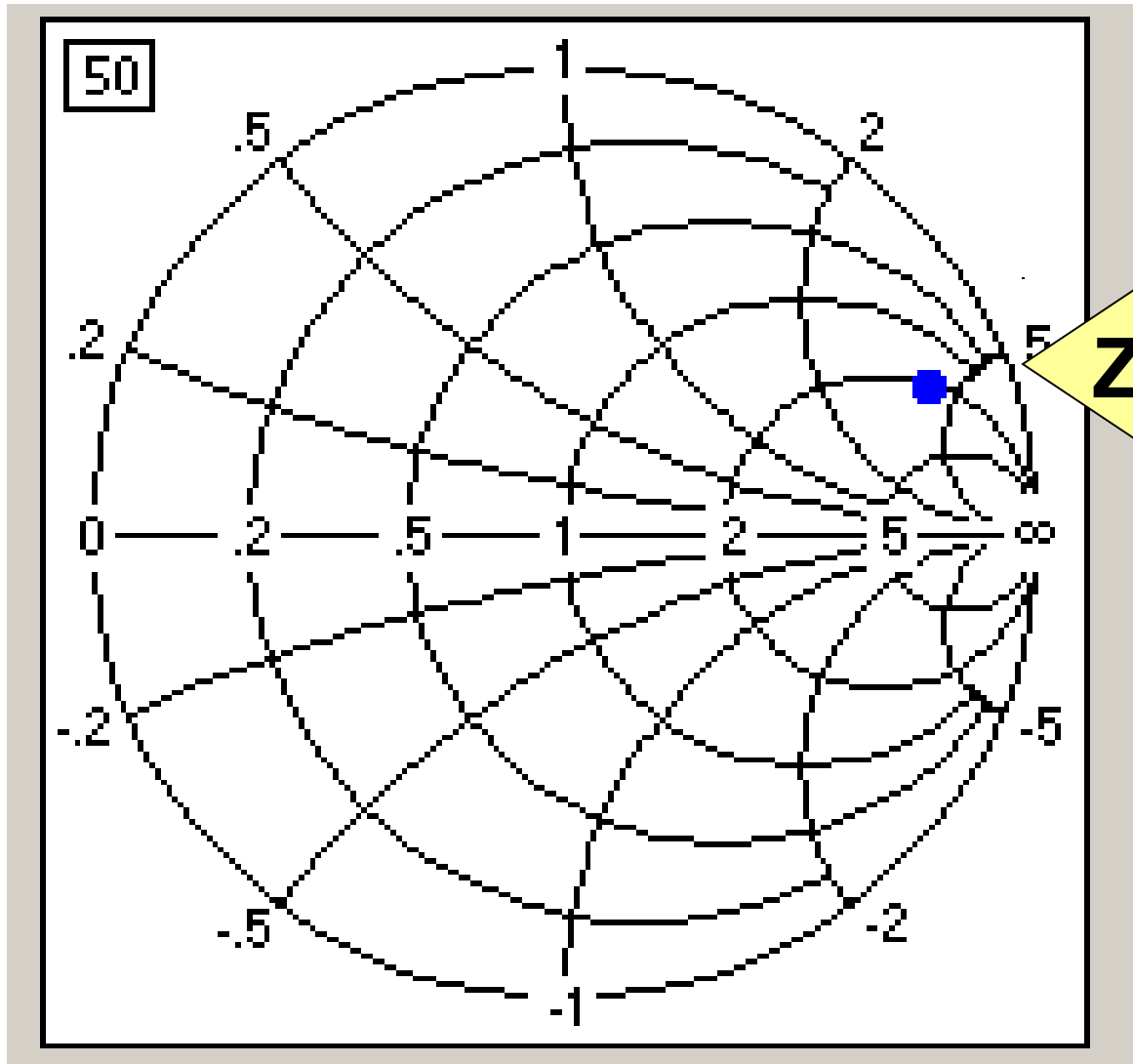
	Loss (dB)	W	% of Total Loss
Cond.	0.000	0.000	0
Diel.	0.000	0.000	0
C. + D.	0.000	0.000	0
Refl.	0.000	0.000	0
Total	0.000	0.000	
Power at Load	5.000		

Plot |Zo| Plot VF Prime Center 50

Show:  SWR  Rho  Return Loss

Close

# Smith Chart Display of Z Measure in Shack



**Z at Shack**

# Move Stub Toward Antenna

**Transmission Line Details - v2.0.1**

Enter values directly, or click spinners, or click and hold spinners.

Freq - VF - Len - WL Conversions Print

1. Choose Transmission Line, Modify Parameters if Desired.

Type	Nom. Zo	Nom. VF	K0	K1	K2	T-Line Model Internal Variables		
Davis RF Bury-Flex	50	0.82	0.025189	0.154616	0.000000	R	66.873 mΩ/ft	
						L	62.748 nH/ft	
						G	0.000 μS/ft	
						C	24.798 pF/ft	
						Matched Loss	0.577 dB/100ft	

2. Set Frequency, R, X.

MHz: 14.1 MHz, KHz:

R: 100, X: 200

R and X:  
 At Input  
 At Load

3. Set Line Length and Length Units

Length: 26.6 Feet

Electrical Length Modulo 1/2 Wavelength: 0.4679λ, 168.43°, 33.181 ns

Input Watts: 5

Plot Matched Line Loss

**Add Length**

Results

	At Input	At Load
R	100.000	645.408
X	200.000	-11.679
Z	223.607	645.513
SWR (True)	10.474	12.833
SWR (50)	10.404	12.912

True Zo: 50.304 - j0.303, VF: 0.8150

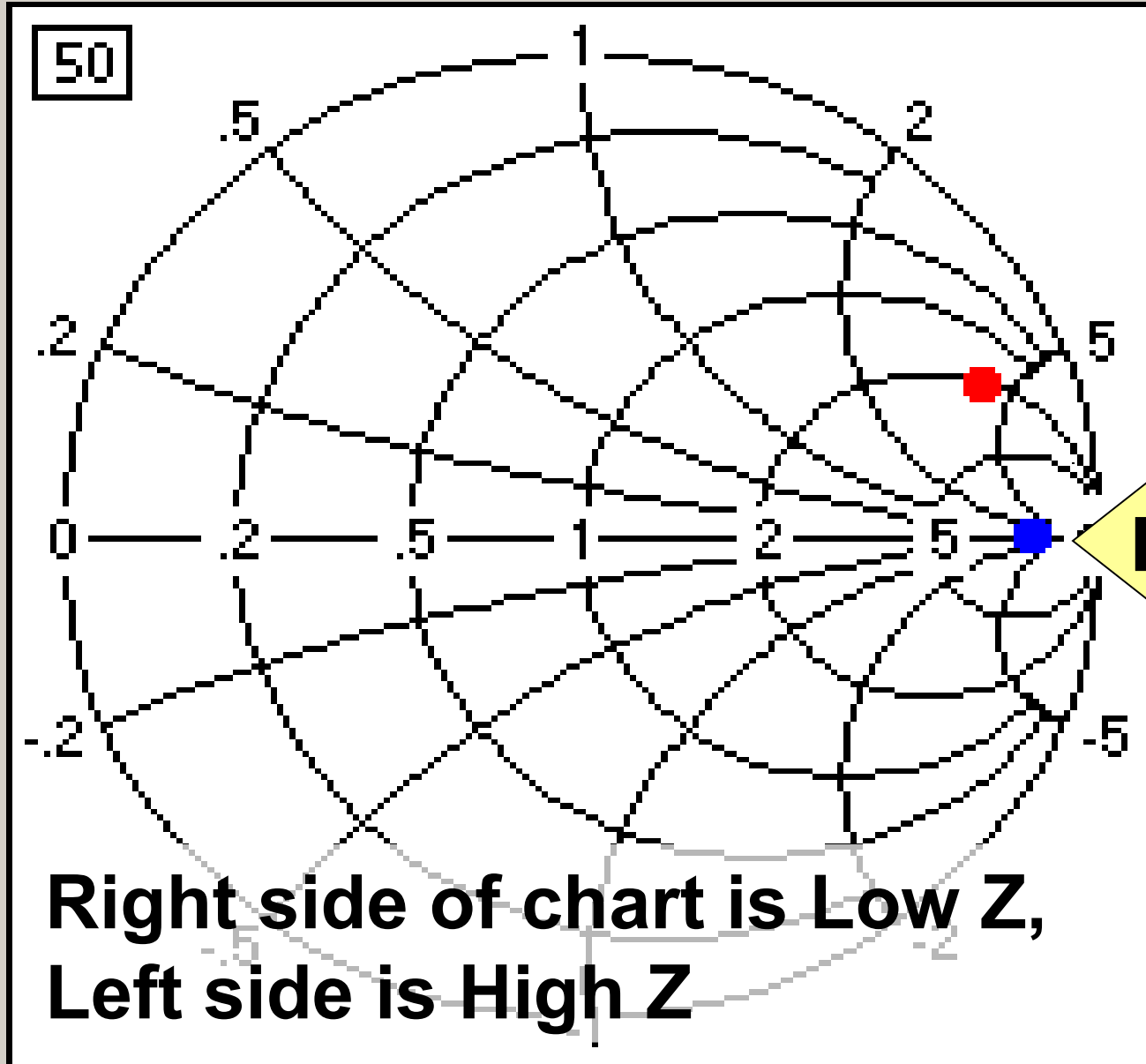
	Loss (dB)	W	% of Total Loss		
			16	1	84
Cond.	0.154	0.159			
Diel.	0.000	0.000			
Ref.	0.795	0.822			
Total	0.948	0.981			
Power at Load		4.019			

Plot |Zo| Plot VF Prime Center 50

Show:  SWR  Rho  Return Loss

Close

# Move Stub Toward Antenna



# 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**



Enter values directly, or click spinners, or click and hold

1. Choose Transmission Line, Modify Parameters

Type	Nom. VF	K0	K1	K2	T-Line Model Internal Variables	
Davis RF Bury-Flex	0.82	0.025189	0.154616	0.000000	R	66.873 mΩ/ft
					L	18 nH/ft
					C	200 pS/ft
					Loss	24.798 pF/ft
						0.577 dB/100ft

2. Set Frequency, R, X

MHz:  MHz  KHz  X  
 R and X:  At Input  At Load  
 Preferred Units:  Feet  Meters

3. Set Line Length and Velocity

Length:  Feet  
 Electrical Length Modulo 1/2 Wavelength:     
 Input Watts:

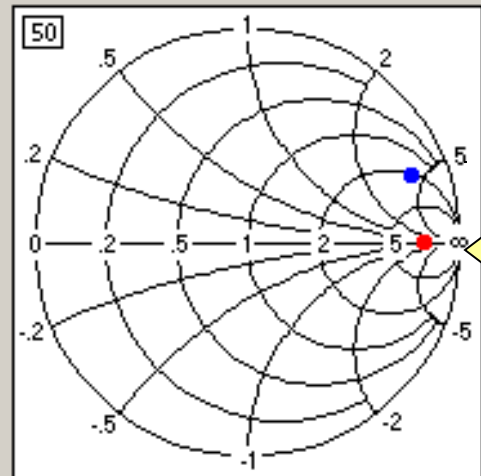
**Change if Needed**

**Coax to Add**

**At Load**

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 - j0.303	
VF	0.8150	



	Loss	% of Total Loss
	dB	W
Cond.	0.010	0.003
Diel.	0.000	0.000
Ref.	-0.008	0.000
Total	0.002	0.003
Power at Load	4.997	

**Red Dot**

Plot | Zo |

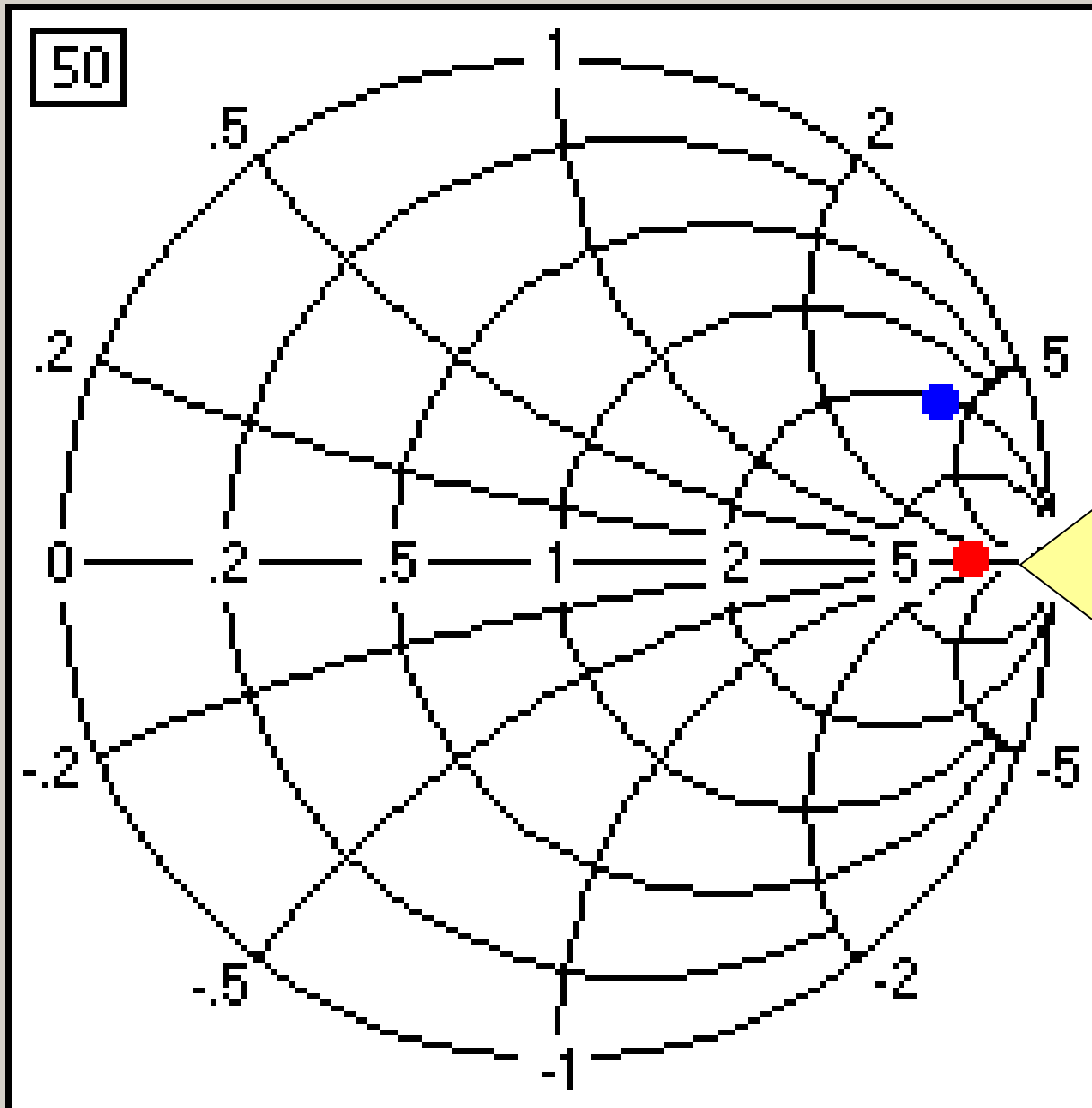
Plot VF

Prime Center

Close

Show:  SWR  Rho  Return Loss

# TLDetails



50

Red Dot

# **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  $\lambda/4$  toward the transmitter from the first stub (at the harmonic frequency)**
- **TLD can compute  $\lambda/4$  for your coax**
- **Set R and X = 0, At Load, vary length to put red dot at right edge of plot**

Enter values directly, or click spinners, or click and hold spinners

1. Choose Transmission Line, Mod

Type	Nom. Zo	Nom. VF	K0	K1	K2	T-Line Model
Davis RF Bury-Flex	50	0.82	0.025189		0.000000	Internal Variables

**Change if Needed**

**R=0, X=0**

**At Load**

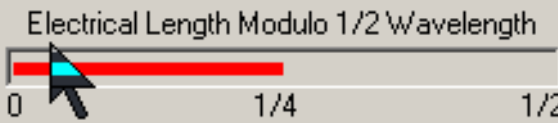
2. Set Frequency, R, X.

MHz:    
 R:    
 X:

**N/4 at 14 MHz**

3. Set Line Length

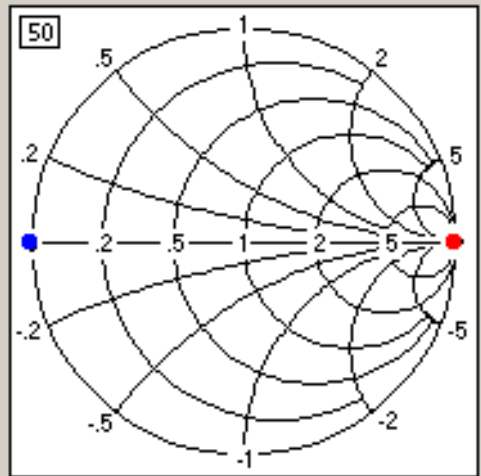
Length:    
 Units:



Input Watts:    
 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



**Red Dot**

	Loss		% of Total Loss		
	dB	W	1	1	100
Cond.	0.082	0.004			
Di.	0.000	0.000			
Ref.	116.692	4.996			
Total	116.774	5.000			
Power at Load		0.000			

True Zo:    
 VF:

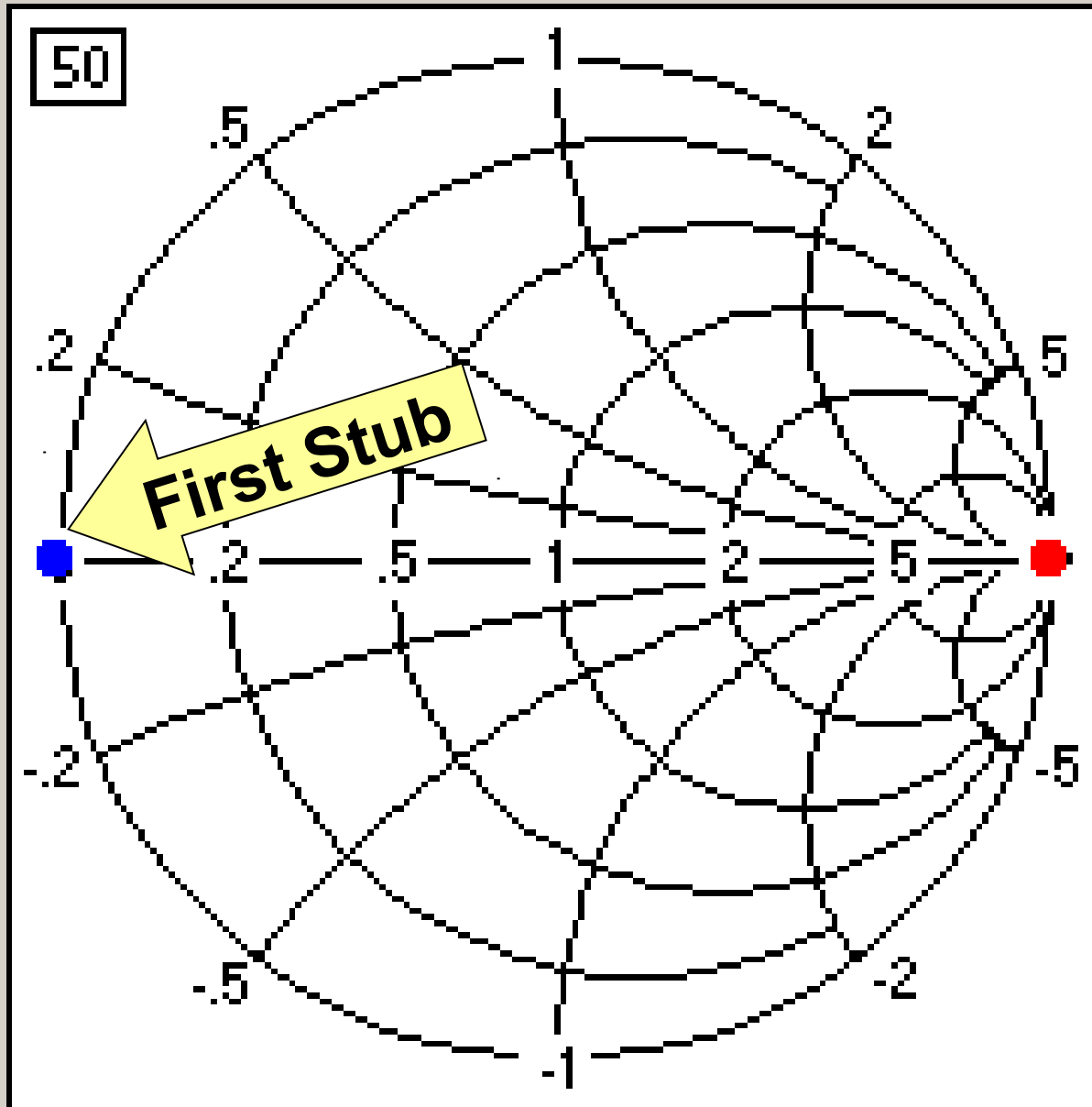
Plot |Zo|    
 Plot VF

Prime Center:

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

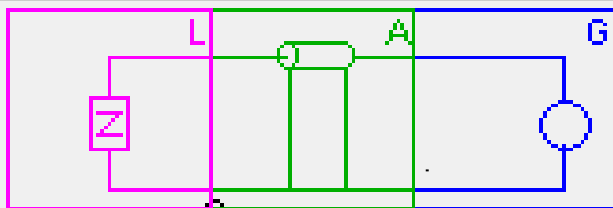
- Make a swept impedance measurement over the harmonic band
- Save data in Touchstone format (a plain text format with a header that defines the data format)
- Import data into SimSmith
  - Put the data file in the “Z block”

# 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

file savemages captures library standards references help



$R = 4.562K$      $R = 5.000$      $TK = 3.000$   
 $X = -1.542K$      $X = -7.674$      $Z = -102.9$   
 $-dBW = -10.52$      $-dBW = 0$   
 $V, R = 21.07, 4.97m$      $V, R = 4.000, 0.419$

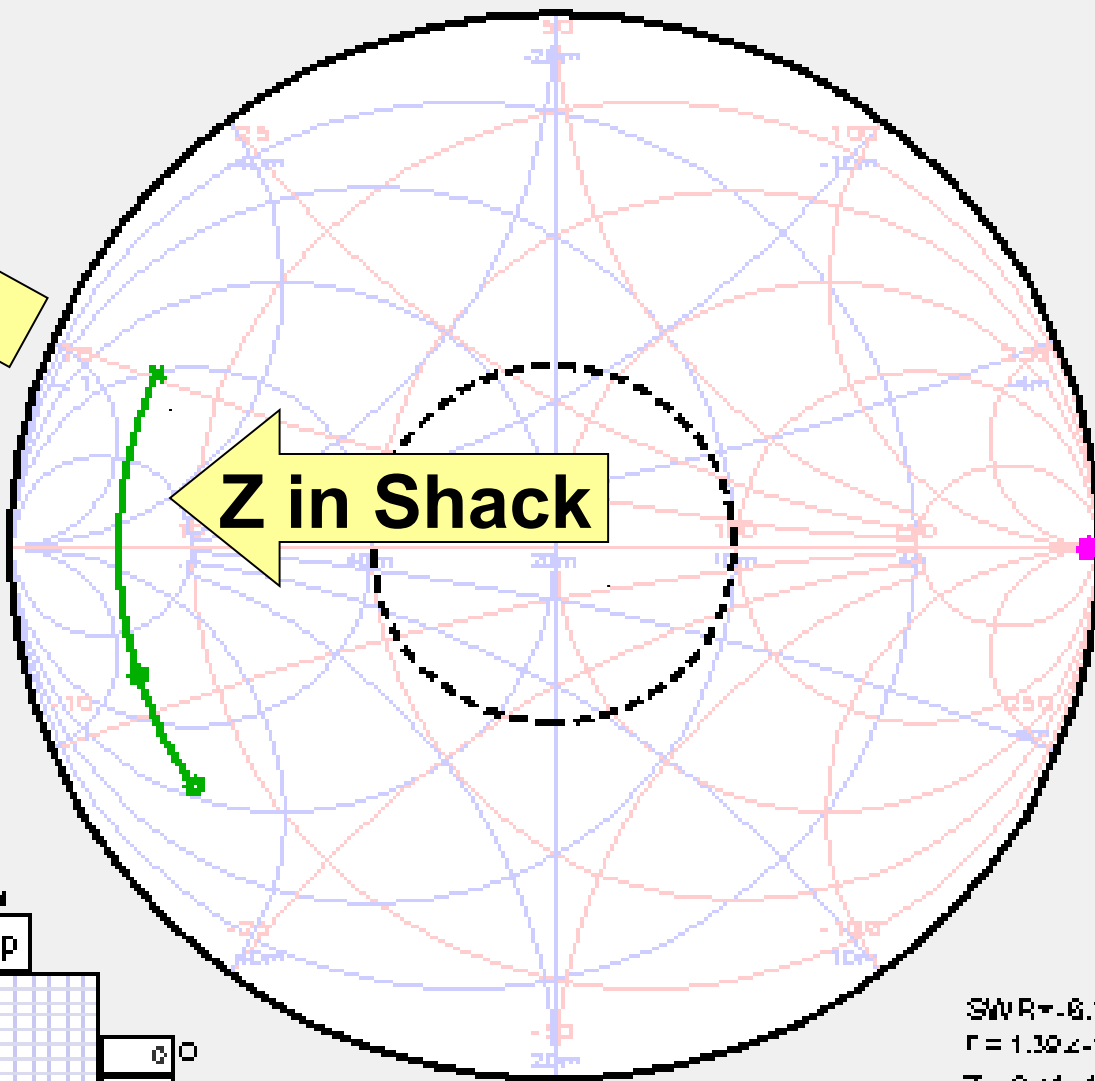
4.562K	ohms
-1.542K	ohms
resistor	type

1.181K	ohms
14.1	ohms
149.52	ohms
antenna	Model
30	freq
0	Zo
0	SWR
0	Plot

50	DB
SWR	Y
0	a
0	b
0	c
0	d
Plot	Plot

**Feedline**

**NEC Z @ 20M**



100	14	14.52
= 60 poles (unitless)		

type	mark	freq	id	name	unit
100	14	14.52	60 poles	unitless	r

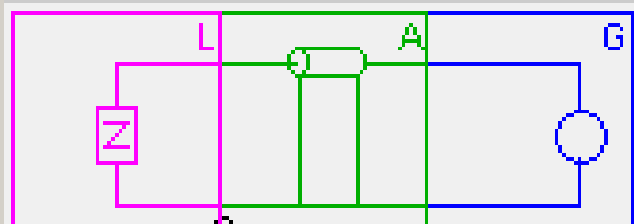

Showing

Sweep

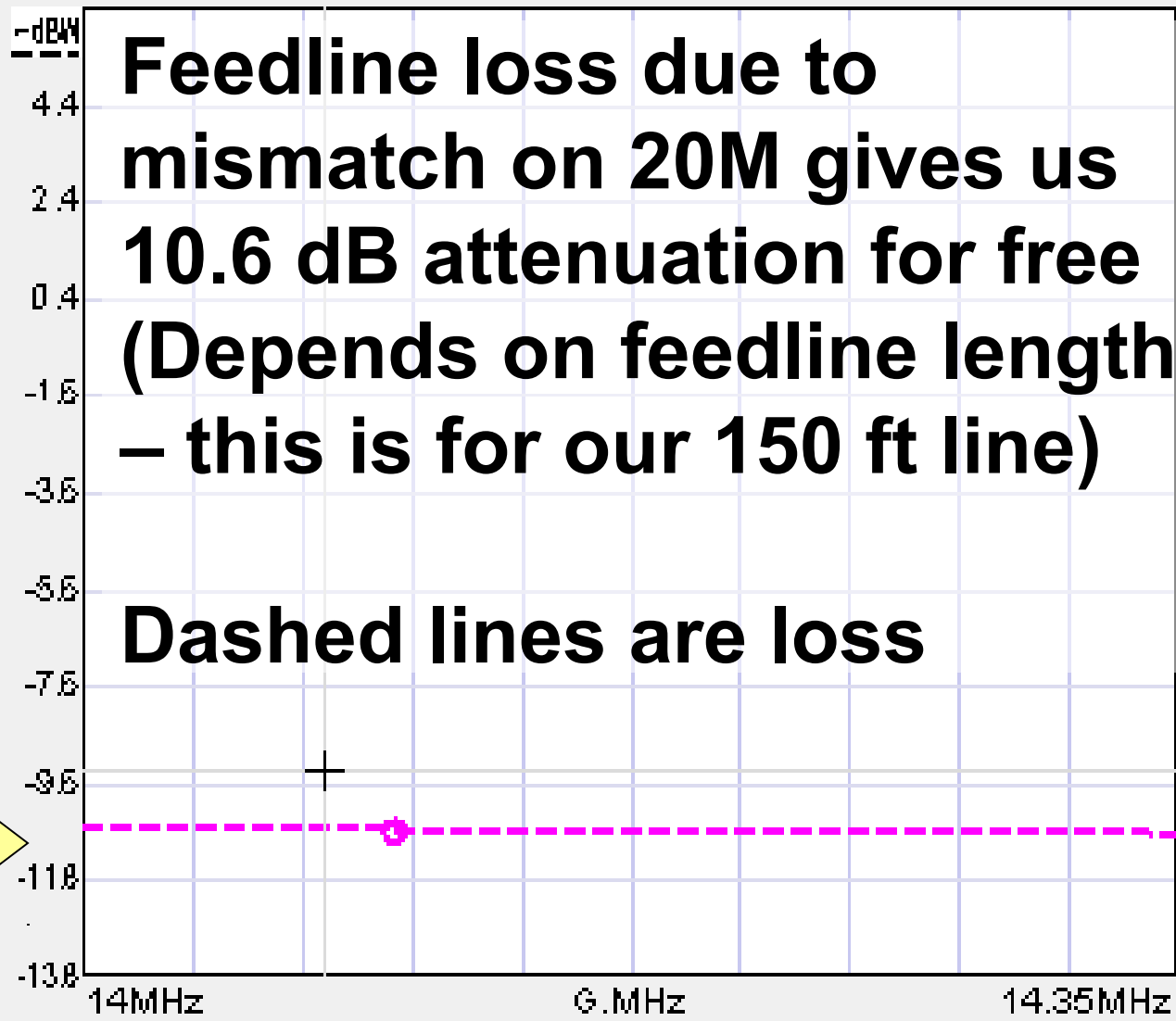
0 0  
2 SWR  
Mark

Plot L A G

$SWR = 6.154$   
 $\Gamma = 1.39 \angle -136$   
 $Z = 9.41 - j19.8$   
 $Y = -19.9m + j41.5m$



R = 4.500K	R = 5.000	SWR = 3.000
X = -1.540K	X = -7.674J	r = 0.37-102.9
-dBV = -10.59	-dBV = 0	
V <sub>1</sub> = 21.004.97m	V <sub>2</sub> = 4.000.0419	
4.500K ohms	1.000K -dB	14.1 MHz
-1.540K ohms	14.1 dB	50 Ohm
1000000.000	149.99	Switch
	imped	Vol
	0.0001	freq
	50	Zo
	0.5	1000
	10	Q/m
		Plot



**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)**

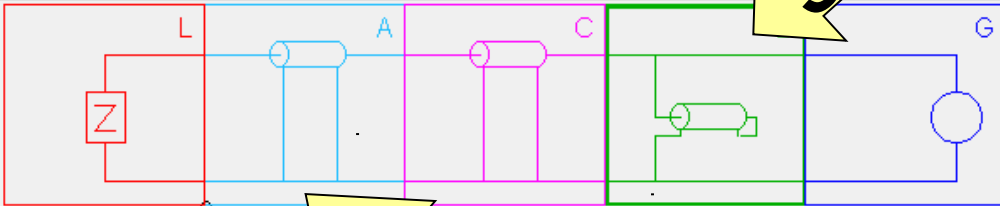
**Dashed lines are loss**

type	name	freq	id	freq	amp
in	100	14	14.95	6.0MHz	Y
=60ipole4um42>1			ch	14.1	F

**-10.6 dB**

# 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**



**Stub**

# $\lambda/4$ 40M Shorted Stub ( $\lambda/2$ on 20M)

R = 4.563K X = -1.549K ←dBW -38.14 V,A=0.884,183.5u	R = 1.161K X = 14.1 ←dBW -17.6 V,A=0.168,17.6u	R = 414.84 X = -9.1935 ←dBW -27.19 V,A=0.89,2.15m	R = 0.793 X ≈ 0 ←dBW ~0 V,A=0.11,1.121u	SWR = 63.06 $\Gamma = 0.97 \angle -180$
4.563K ohms	1.161K ~deg	12.1 @MHz	23.25 @MHz	14.1 MHz
-1.549K ohms	14.1 @MHz	149.98 ft	50 Zo	50 Zo
40DipoleHarm2.txt	simplified Mdl	simplified Mdl	simplified Mdl	Plots Plt
0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	
50 Zo	50 Zo	50 Zo	50 Zo	
0.5/100f	0.5/100f	0.5/100f	0.5/100f	
10 @frq	10 @frq	10 @frq	10 @frq	

**Feedline**

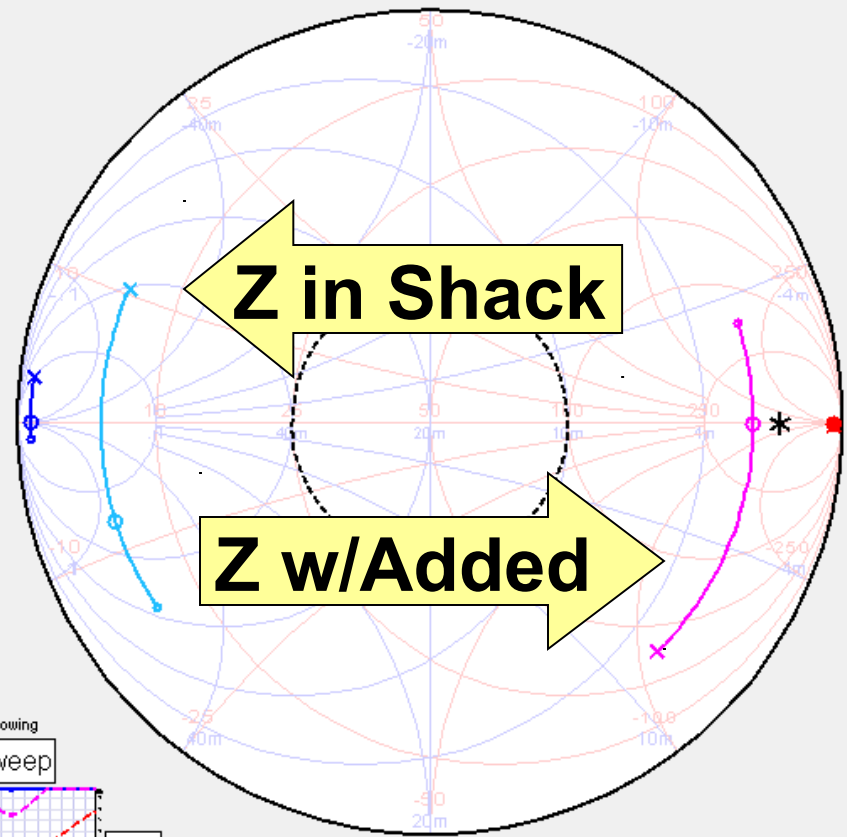
**Added**

Navigation buttons: <<< << < > >> >>>

undo: unDo reDo

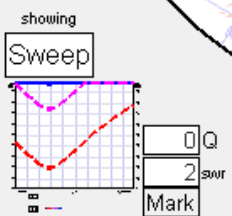
type	numPts	from	to	name	sweep
lin	100	g	11	G.MHz	n
		40DipoleHarm2.txt	clr	L.file	y

A grid of electrical symbols for simulation, including resistors, capacitors, inductors, and a trash can icon.

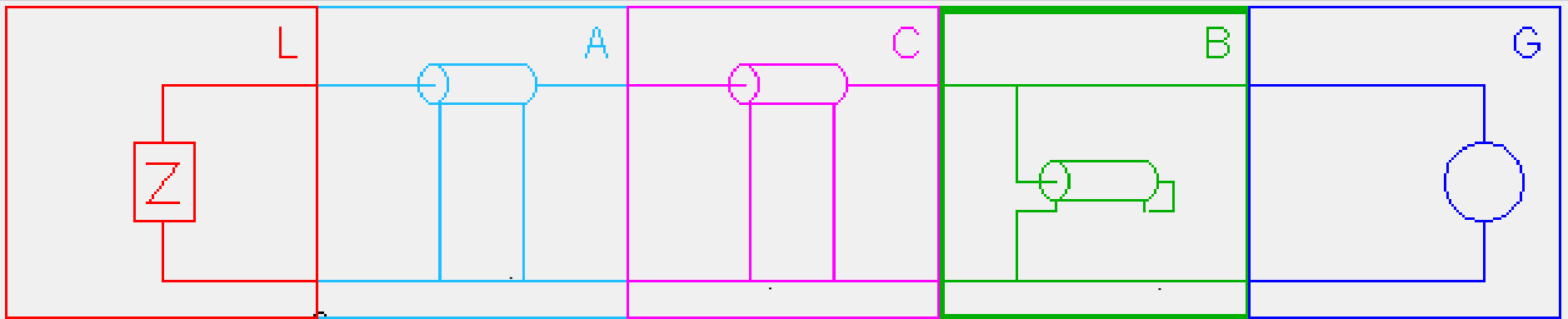


**Z in Shack**

**Z w/Added**



Plot L A C B G



R = 4.563K      F = 295      F = 414.84      R = 193      SWR = 63.06  
 X = -1.549K      X = 143      X = 1935      X = 0       $\Gamma = 0.97 \angle -180$   
 ←dBW -38.14      ←dBW -21.14      ←dBW -19.19      ←dBW -1.12  
 V,A=0.884,183.5u      V,A=0.168,17.6n      V,A=0.89,2.12n      V,A=0.89,1.12n

**Feedline**

**Added**

**Stub**

**Z-Block**

4.563K ohms	1.161K ~deg	2.938 ~deg	180 ~deg	14.1 MHz
-1.549K johms	14.1 @MHz	14.1 @MHz	14.1 @MHz	50 Zo
40DipoleHarm2.txt file	149.98 ft	12.781 ft	23.253 ft	xMtch V
simplified Mdl	simplified Mdl	simplified Mdl	simplified Mdl	0 a
0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0 b
50 Zo	50 Zo	50 Zo	50 Zo	0 c
0.5 /100f	0.5 /100f	0.5 /100f	0.5 /100f	0 d
10 @frq	10 @frq	10 @frq	10 @frq	Plots Plt

# $\lambda/4$ 40M Shorted Stub ( $\lambda/2$ on 20M)

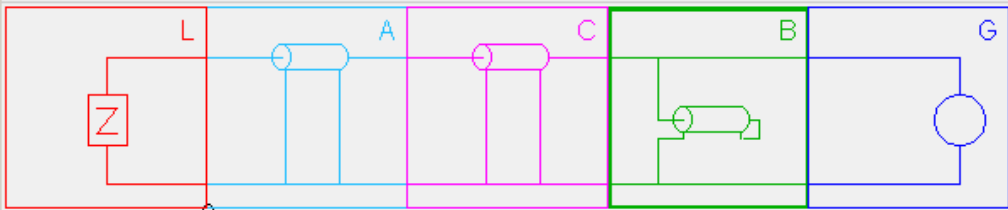
# Example Problem

- **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**



# $\lambda/4$ 40M Shorted Stub ( $\lambda/2$ on 20M)

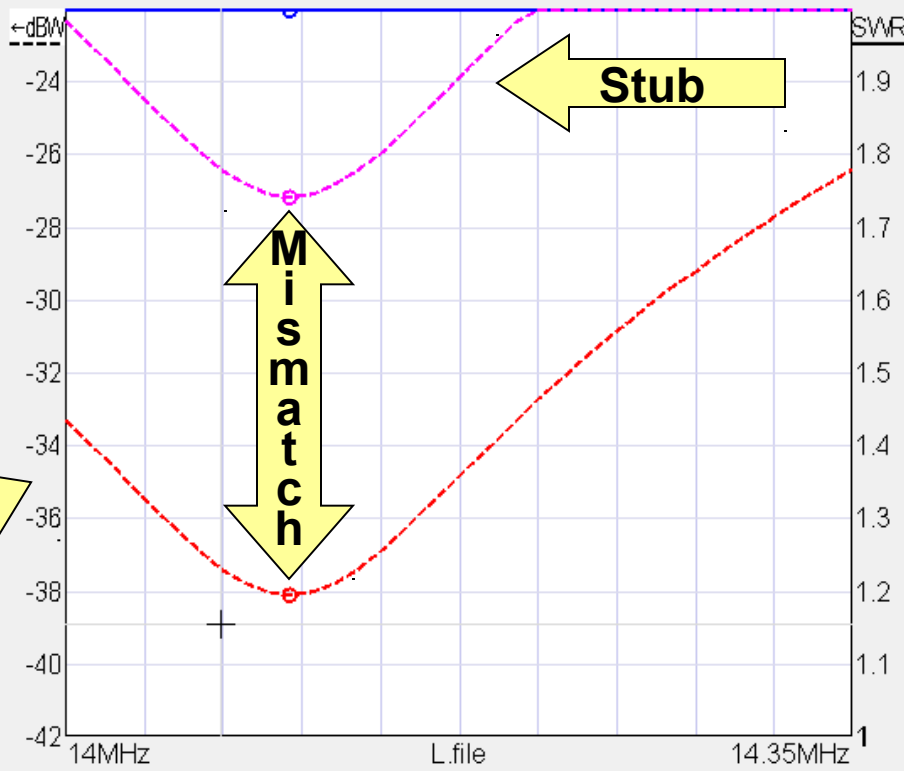
R = 4.563K X = -1.549K  $\leftarrow$ dBW -38.14 V<sub>A</sub>=0.884,183.5u  
 R = 5.695 X = -7.6743  $\leftarrow$ dBW -27.54 V<sub>A</sub>=0.168,17.6m  
 R = 414.84 X = -9.1935  $\leftarrow$ dBW -27.19 V<sub>A</sub>=0.89,2.15m  
 R = 0.793 X  $\approx$  0  $\leftarrow$ dBW  $\sim$ 0 V<sub>A</sub>=0.89,1.121  
 SWR = 63.06  $\Gamma$  = 0.97  $\angle$ -180

4.563K ohms	1.161K ~deg	98.938 ~deg	180 ~deg	14.1 MHz
-1.549K johms	14.1 @MHz	14.1 @MHz	14.1 @MHz	50 Zo
40DipoleHarm2.txt file	149.98 ft	12.781 ft	23.253 ft	xMch V
simplified Mdl	simplified Mdl	simplified Mdl	simplified Mdl	0 a
0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0 b
50 Zo	50 Zo	50 Zo	50 Zo	0 c
0.5/100f	0.5/100f	0.5/100f	0.5/100f	0 d
10 @frq	10 @frq	10 @frq	10 @frq	Plots Plt

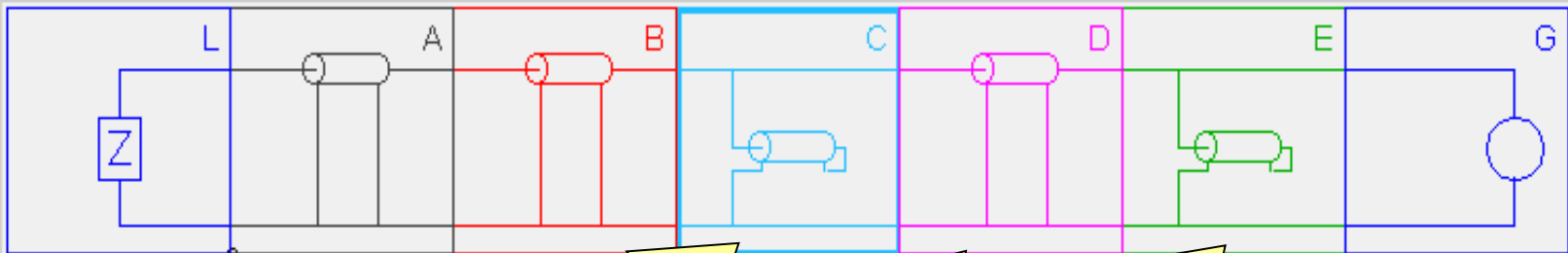
Navigation: <<< << < > >> >>>  
 unDo reDo

type	numPnts	from	to	name	sweep
lin	100	g	11	G.MHz	n
		40DipoleHarm2.txt	clr	L.file	y

**Antenna**



Pwr: L A C B  
 Mark SWR: L A C B G



Section	Impedance	SWR	Gamma
L	R = 4.563K X = -1.549K ←dBW -71.14		
A	R = 5.7105 X = -8.1672 ←dBW -60.55		
B	R = 41 X = 1 ←dBW -31.5		
C	R = 0.8017 X = 0.77 ←dBW -23.5		
D	R = 1.461K X = -963.67 ←dBW -31.5		
E	R = 0.7942 X ≈ 0 ←dBW ~0		
G	SWR = 62.96 Γ = 0.97 ∠-180		

Section	Length (ft)	Angle	SWR	Gamma
A	149.98	1.16K ~deg	180	14.1 MHz
B	12.83	1.315 ~deg	14.1	50 Zo
C	1.37	1.1 ~deg	23.253	xMtch V
D	1.527	1.1 ~deg	0.667	0 a
E	23.253	180 ~deg	0.6667	0 b

**1st Stub**

**λ/4 on 20M**

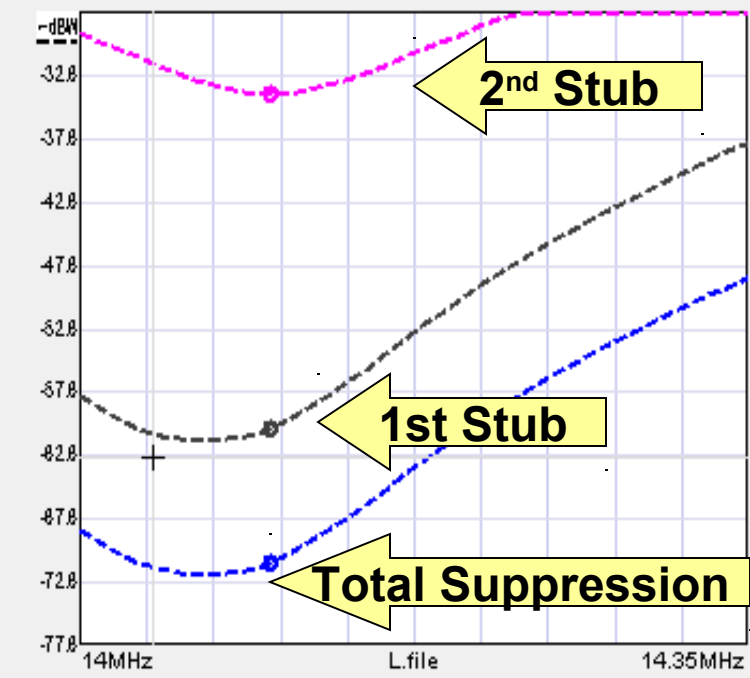
**2nd Stub**

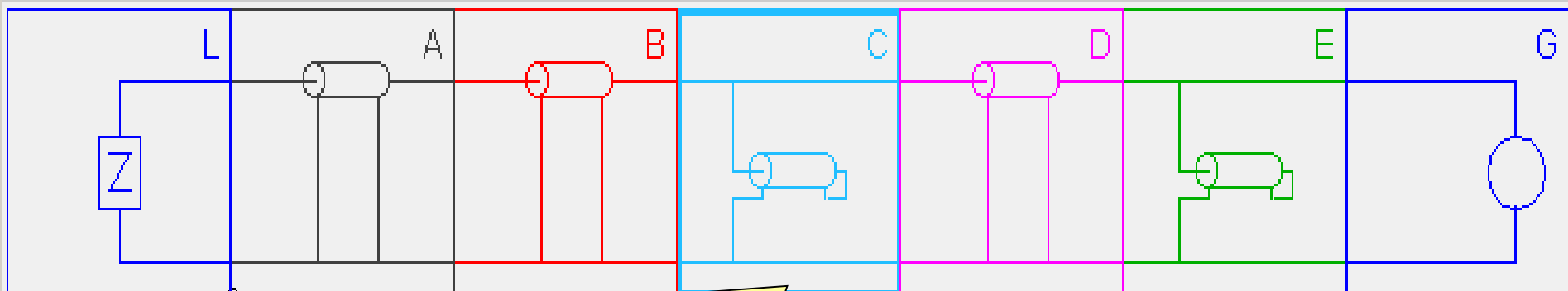
Navigation: <<< << < > >> >>>

undo redo

type	num	freq	from	to	name	sweep
lin	100		7	7.3	G.MHz	n
			40DipoleHarm2.txt	clr	L.file	y

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





R = 4.563K

R = 5.7105

R = 414.9

R = 0.8017

R = 1.461K

R = 0.7942

SWR = 62.96

X = -1.549K

X = -8.1672

X = 1.534

X = 0.77

X = -963.6

X ≈ 0

Γ = 0.97 ∠ -180

+dBW -71.14

+dBW -60.55

+dBW

+dBW

+dBW

+dBW ~0

V,A=19.8m,4.1u

V,A=3.91m,392.8u

V,A=1.48u

V,A=1.78m

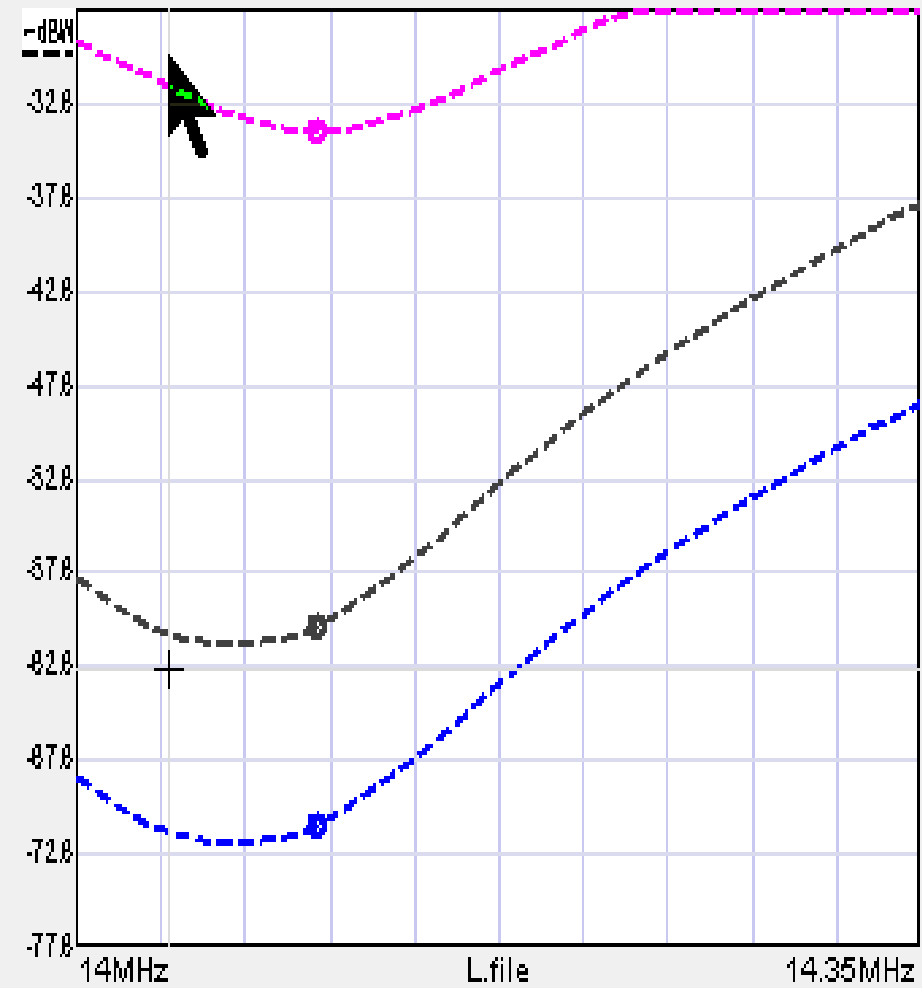
V,A=0.3u

V,A=0.891,1.122

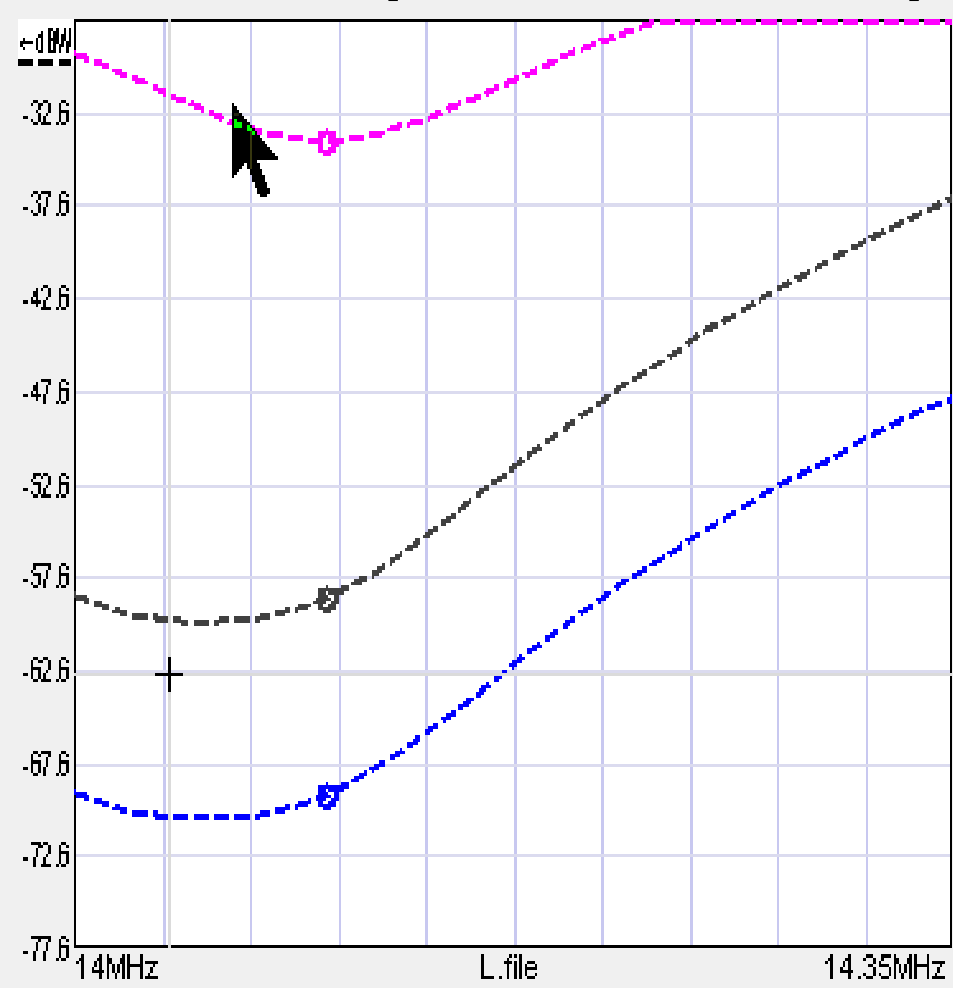
4.563K ohms	1.16K ~deg	99.515 ~deg	14.1 ~deg	90 ~deg	180 ~deg	14.1 MHz
-1.549K ohms	14.1 @MHz	14.1 @MHz	14.1 @MHz	14.1 @MHz	14.1 @MHz	50 Zo
400poleHamZ.ccr file	149.98 ft	12.83 ft	23.37 ft	11.627 ft	23.253 ft	xMtch V
simplified Mdl	simplified Mdl	simplified Mdl	simplified Mdl	simplified Mdl	simplified Mdl	0 a
.667 VFnom	0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0 b
50 Zo	50 Zo	50 Zo	50 Zo	50 Zo	50 Zo	0 c
.5 /100f	0.5 /100f	0.5 /100f	0.5 /100f	0.5 /100f	0.5 /100f	0 d
10 @frq	10 @frq	10 @frq	10 @frq	10 @frq	10 @frq	Plots Plt

## Two $\lambda/4$ 40M Shorted Stubs ( $\lambda/2$ on 20M)

# Two $\lambda/4$ 40M Shorted Stubs ( $\lambda/2$ on 20M)



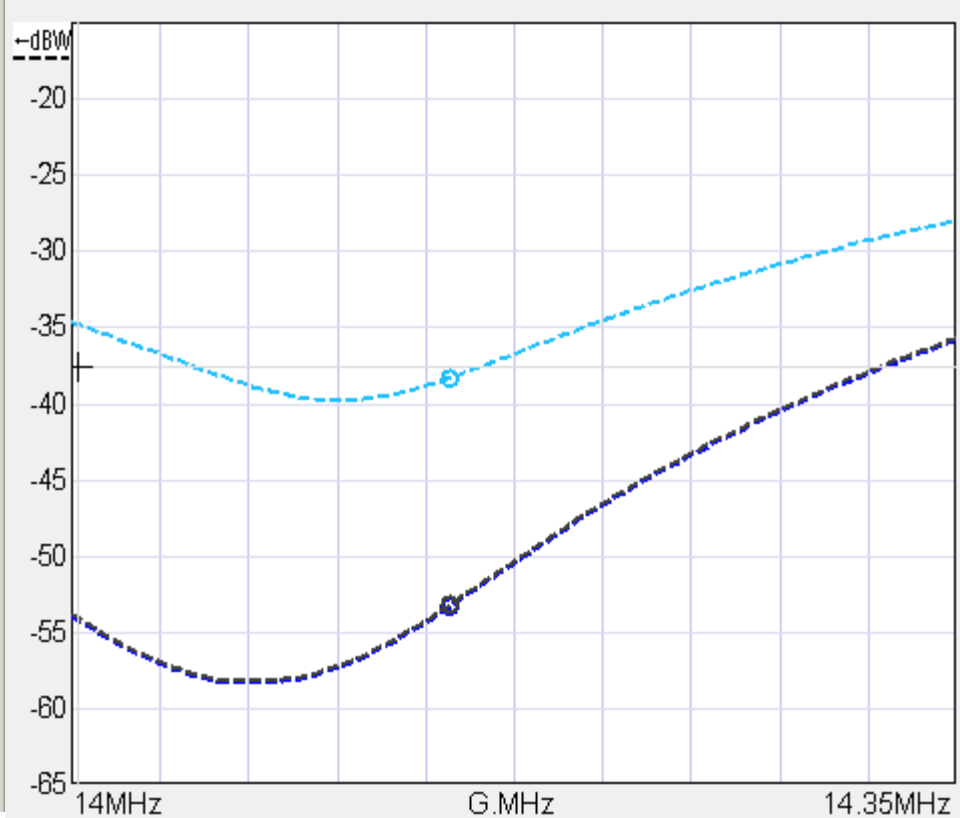
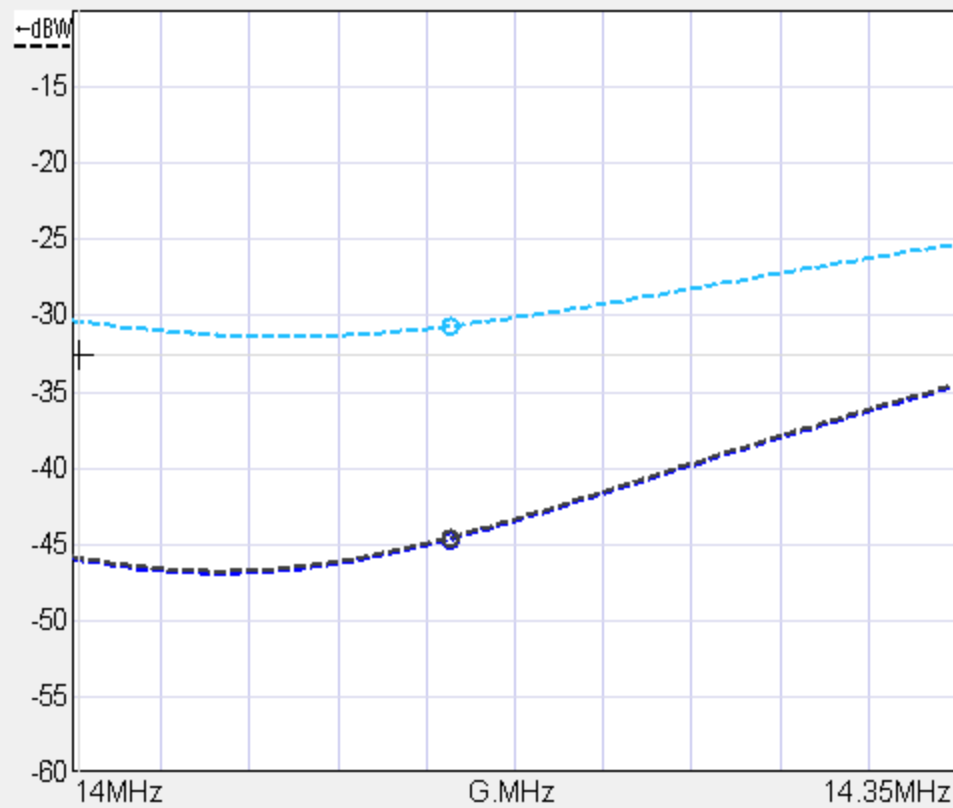
**Both Stubs 14.1 MHz**



**Stagger-Tuned  
14.072, 14.1 MHz**

# **If Antenna Is Resonant On Harmonic**

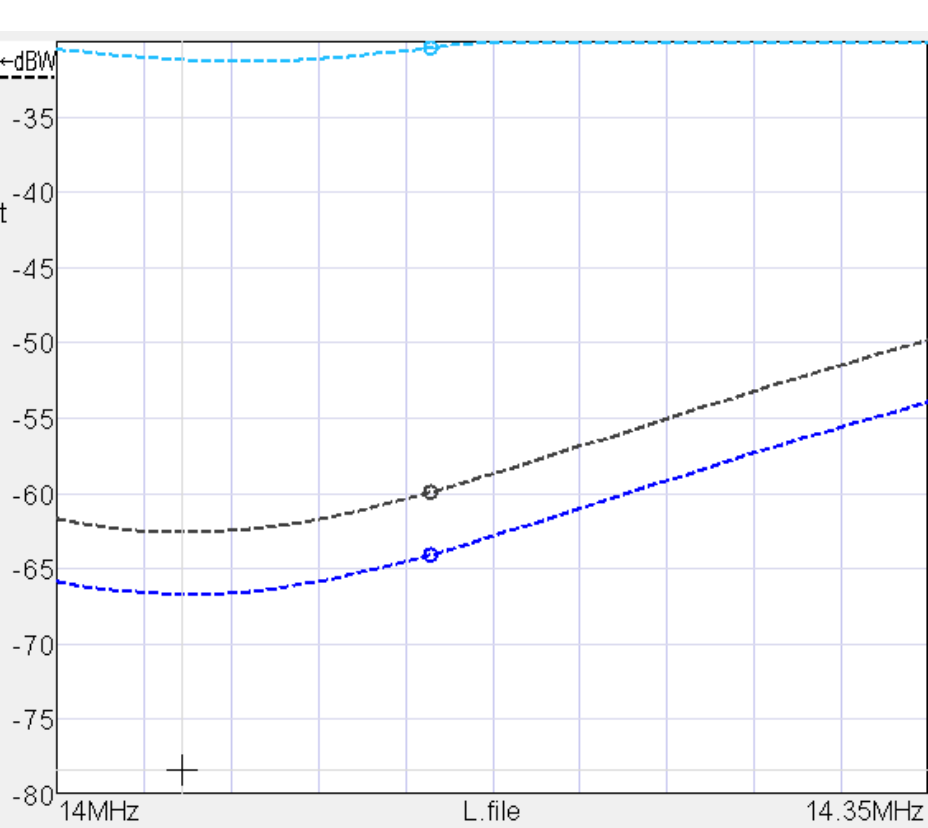
- Impedance is nearly constant along the line, so placement from antenna doesn't matter**
- Placement from amplifier does matter**
- No harmonic suppression from line loss due to mismatch at harmonic, so less total suppression**



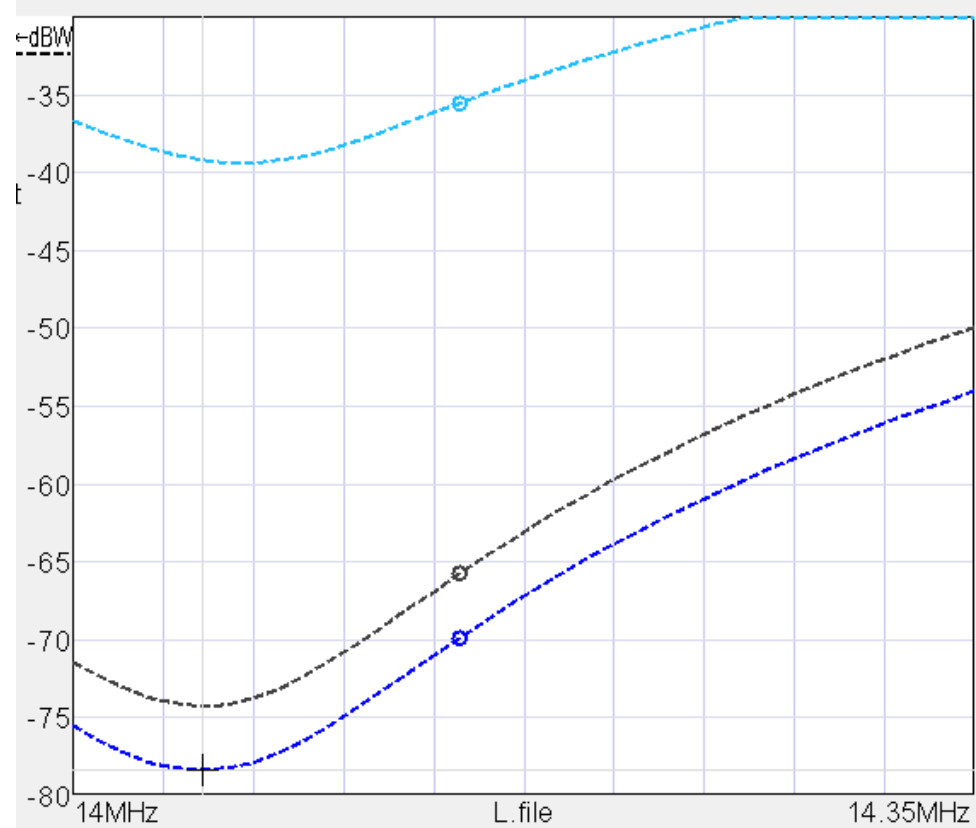
**Two RG8X Stubs**

**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**

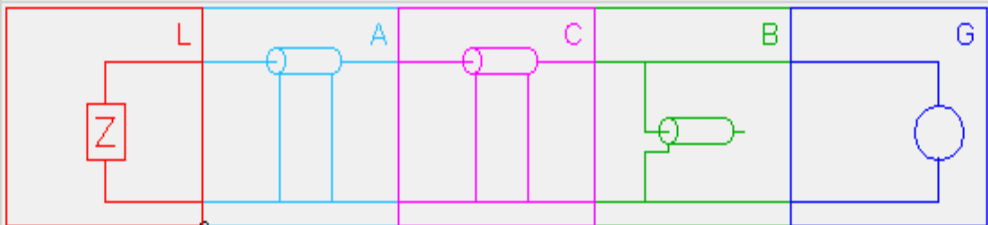


# An Even Better Stub Design

- $\lambda/4$  open 20M stub is  $\lambda/8$  on 40M
- Because it's half as long, resistance is half as much, so greater attenuation
- $\lambda/8$  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  $\lambda/4$  stub**
- It's twice as many stubs, so it's more complex (more coax Tees and barrels)**



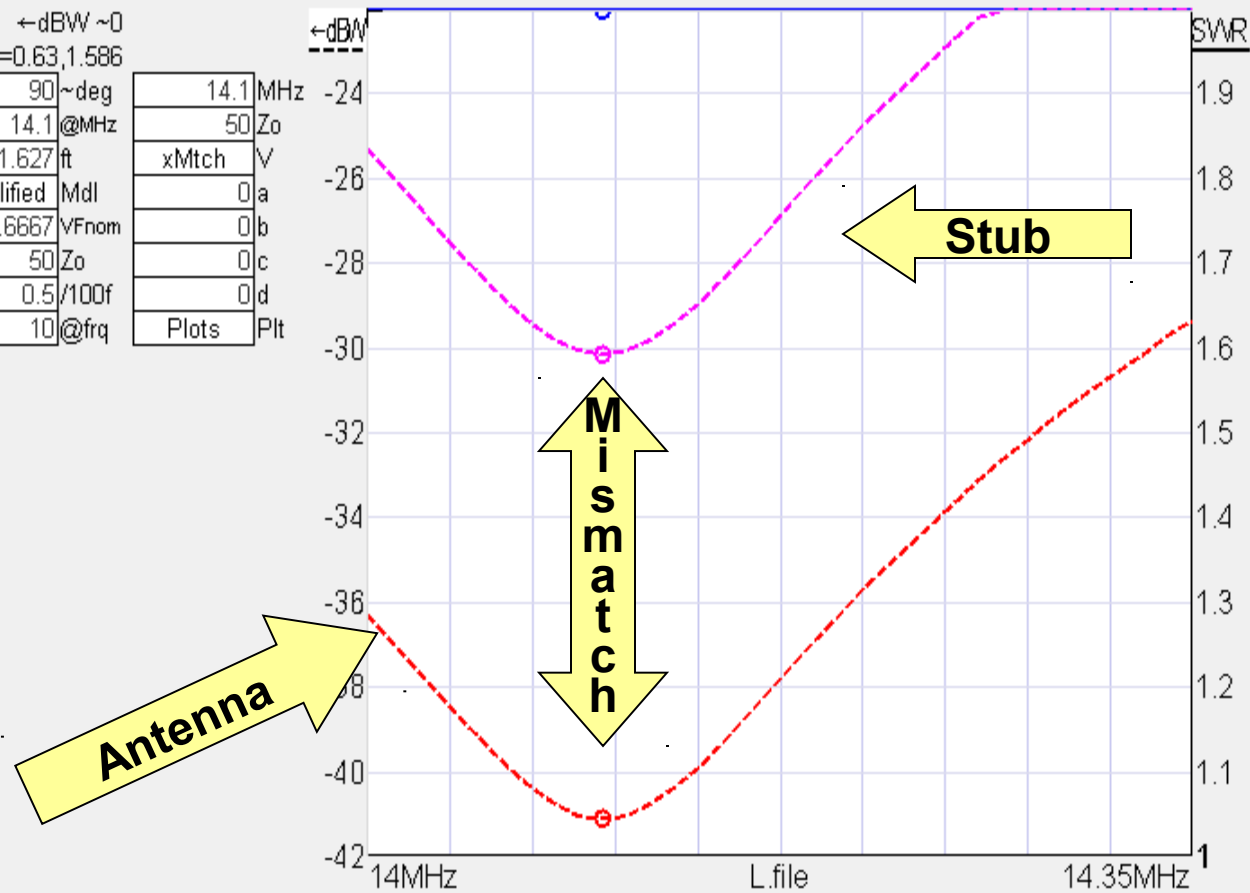
R = 4.563K	R = 5.695	R = 414.84	R = 0.3969	SWR = 126
X = -1.549K	X = -7.6743	X = -9.1935	X ≈ 0	Γ = 0.98∠-180
←dBW -41.14	←dBW -30.55	←dBW -30.19	←dBW ~0	
V,A=0.625,129.8u	V,A=0.119,12.4m	V,A=0.63,1.52m	V,A=0.63,1.586	
4.563K ohms	1.161K ~deg	98.938 ~deg	90 ~deg	14.1 MHz
-1.549K ohms	14.1 @MHz	14.1 @MHz	14.1 @MHz	50 Zo
40DipoleHarm2.txt file	149.98 ft	12.781 ft	11.627 ft	xMlch V
simplified Mdl	simplified Mdl	simplified Mdl	simplified Mdl	0 a
0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0 b
50 Zo	50 Zo	50 Zo	50 Zo	0 c
0.5/100f	0.5/100f	0.5/100f	0.5/100f	0 d
10 @frq	10 @frq	10 @frq	10 @frq	Plots Plt

Navigation buttons: <<< << < > >> >>>

undo redo

type	num Pnts	from	to	name	sweep
lin	100	g	11	G.MHz	n
		40DipoleHarm2.txt	clr	L.file	y

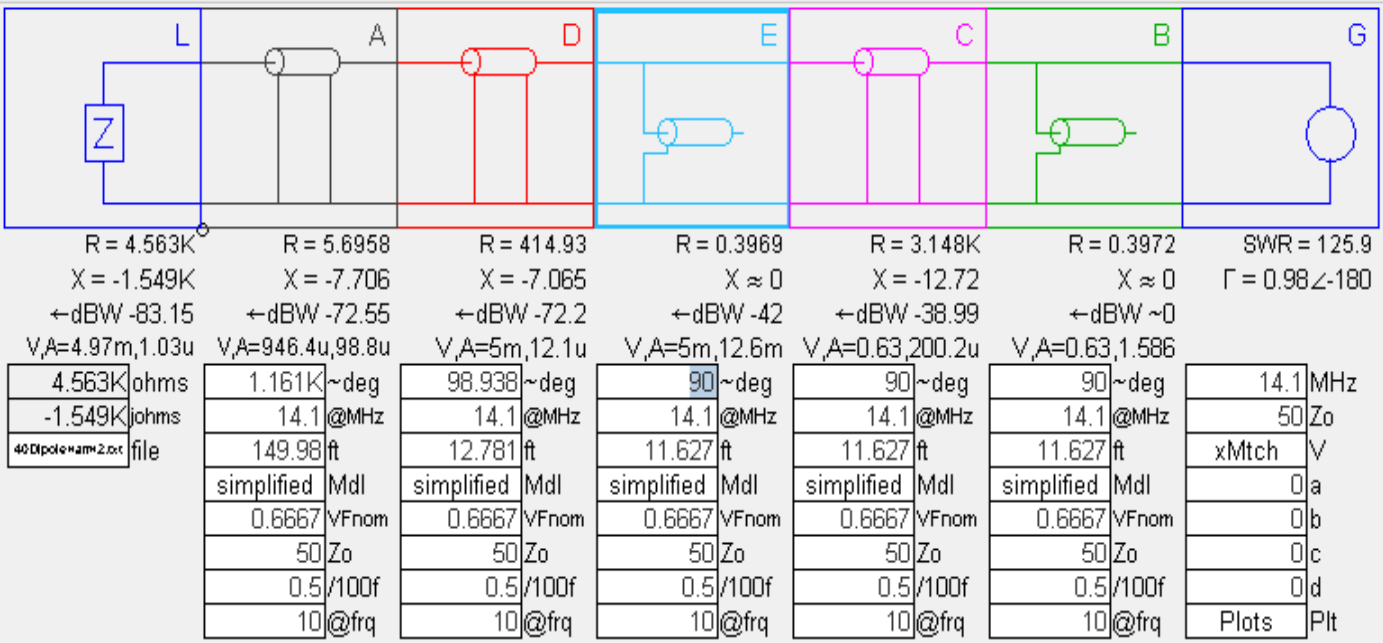
# λ/8 40M Open Stub (λ/4 on 20M)



lin

SWR=126.5  
Γ = 0.98∠-178.7  
Z=0.4-j0.56  
14 MHz Y=0.85+j1.19

Mark SWR: LACB  
LACBG

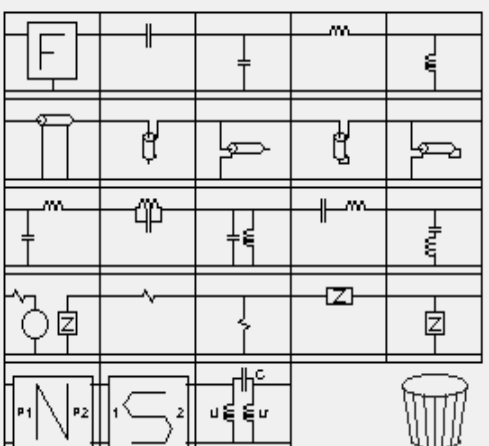


# Two $\lambda/8$ 40M Open Stubs

Navigation buttons: <<< << < > >> >>>

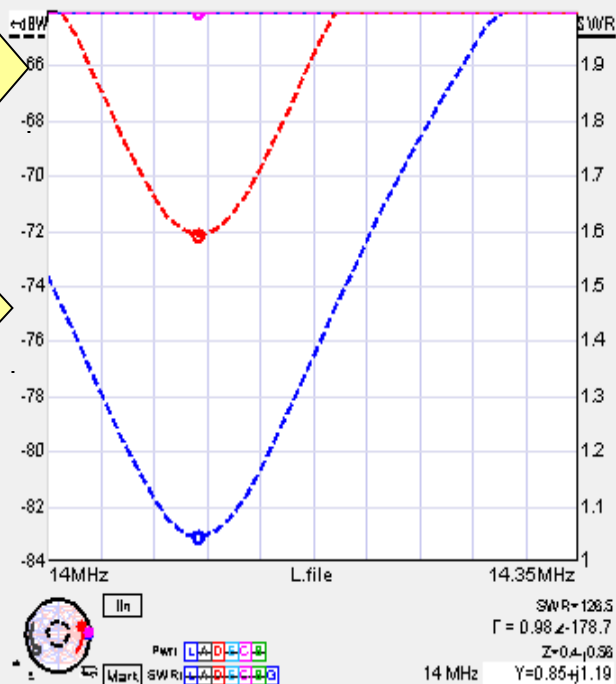
unDo reDo

type	numPts	from	to	name	sweep
lin	100	g	11	G.MHz	n
		40DipoleHarm2.txt	clr	L.file	y

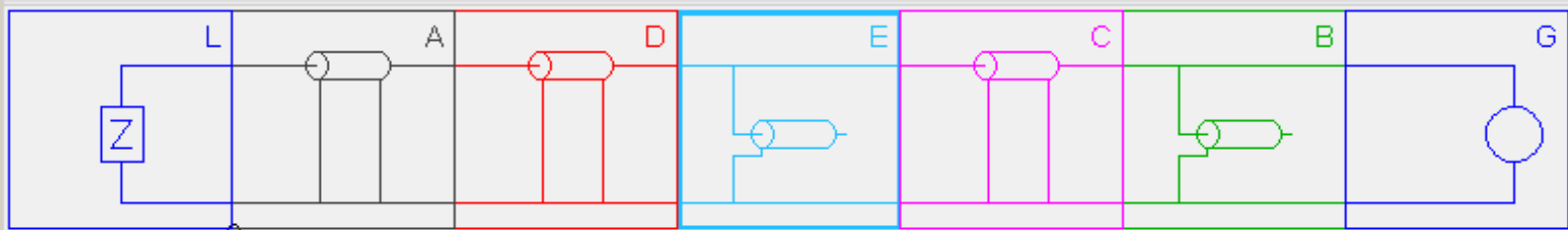


Stubs

Antenna



SWR=126.5  
 $\Gamma = 0.98 \angle -178.7$   
 $Z = 0.4 - j0.98$   
 14 MHz Y=0.85+j1.19



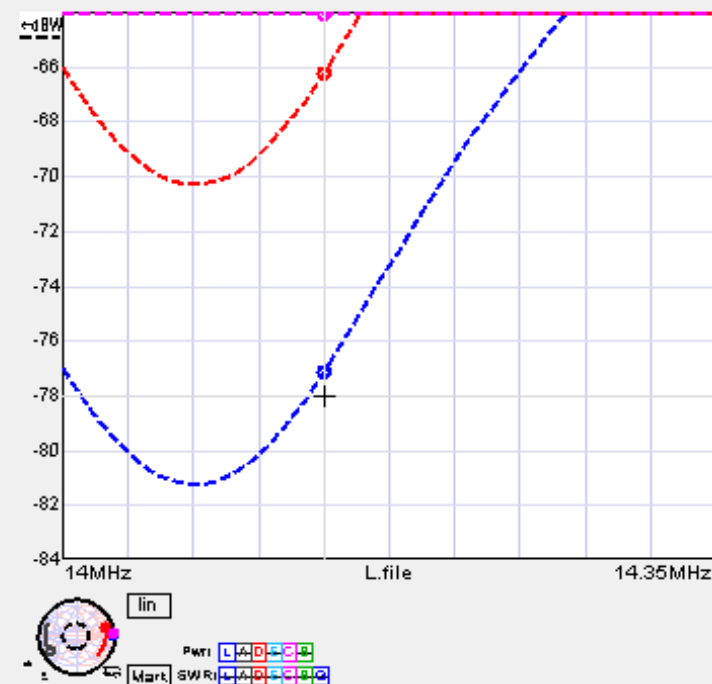
L	A	D	E	C	B	G
R = 4.435K	R = 5.6331	R = 323.12	R = 0.4031	R = 1.545K	R = 0.3985	SWR = 125.5
X = -1.7K	X = -4.8014	X = -171.04	X = 0.5794	X = -1.571K	X = 0.1932	$\Gamma = 0.98 \angle 179.6$
$\leftarrow$ dBW -77.19	$\leftarrow$ dBW -66.59	$\leftarrow$ dBW -66.25	$\leftarrow$ dBW -41.01	$\leftarrow$ dBW -38.05	$\leftarrow$ dBW ~0	
V,A=9.85m,2.07u	V,A=1.46m,197.3u	V,A=9.9m,27.1u	V,A=9.9m,14m	V,A=0.702,318.3u	V,A=0.702,1.584	
4.435K ohms	1.161K ~deg	98.938 ~deg	90 ~deg	90 ~deg	90 ~deg	14.14 MHz
-1.7K ohms	14.1 @MHz	14.1 @MHz	14.036 @MHz	14.1 @MHz	14.105 @MHz	50 Zo
40DipoleHarm2.txt file	149.98 ft	12.781 ft	11.68 ft	11.627 ft	11.623 ft	xMtch V
simplified Mdl	simplified Mdl	simplified Mdl	simplified Mdl	simplified Mdl	simplified Mdl	0 a
0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0.6667 VFnom	0 b
50 Zo	50 Zo	50 Zo	50 Zo	50 Zo	50 Zo	0 c
0.5 /100f	0.5 /100f	0.5 /100f	0.5 /100f	0.5 /100f	0.5 /100f	0 d
10 @frq	10 @frq	10 @frq	10 @frq	10 @frq	10 @frq	Plots Plt

Navigation: <<< << < > >> >>>

undo: [ ] redo: [ ]

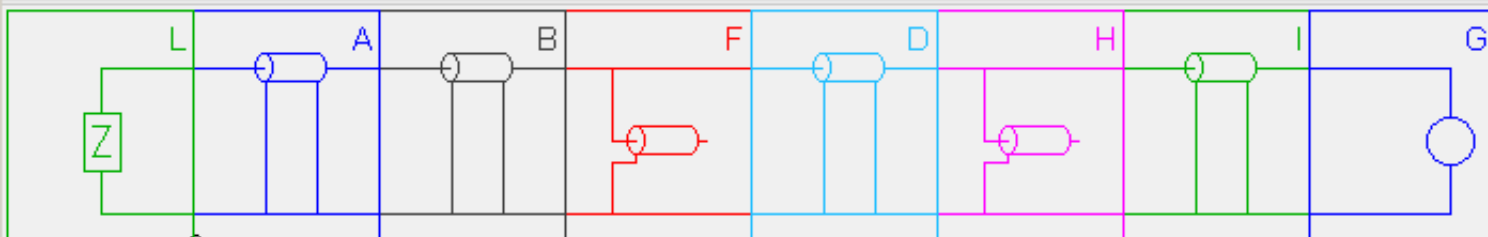
type	num Pnts	from	to	name	sweep
lin	100	9	11	G.MHz	n
		40DipoleHarm2.txt	clr	L.file	y

# Stubs Stagger- Tuned For Broader Suppression



lin [ ] Mark [ ]

Pwr1 [ ] SWR [ ]



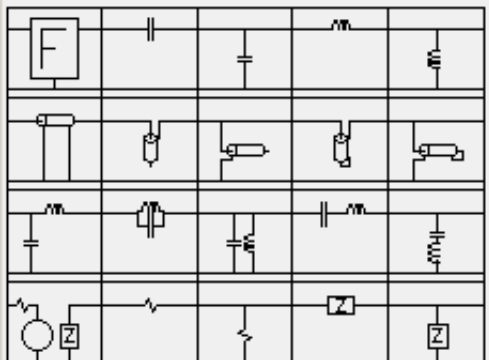
R = 45.857 X = -9.8141 ←dBW -0.975 V,A=6.19,0.132	R = 41.532 X = 0.7811 ←dBW -0.327 V,A=6.207,0.149	R = 51.954 X = 8.9337 ←dBW -0.269 V,A=7.091,0.135	R = 29.598 X = -26.417 ←dBW -0.243 V,A=7.091,0.142	R = 22.475 X = 6.7506 ←dBW -0.147 V,A=4.867,0.207	R = 23.592 X = -4.4631 ←dBW -0.135 V,A=4.867,97.3m	R = 100.84 X = 17.355 ←dBW ~0 V,A=10.19,99.6m	SWR = 2.095 Γ = 0.35 ∠12.3
45.857 ohms -9.8141 ohms file	1.16K ~deg 14.1 @MHz 149.92 ft simplified Mdl .667 VFnom 50 Zo .5 /100f 10 @frq	99.315 ~deg 14.1 @MHz 12.83 ft simplified Mdl 0.6667 VFnom 50 Zo 0.5 /100f 10 @frq	90 ~deg 14.1 @MHz 11.627 ft simplified Mdl 0.6667 VFnom 50 Zo 0.5 /100f 10 @frq	90 ~deg 14.1 @MHz 11.627 ft simplified Mdl 0.6667 VFnom 50 Zo 0.5 /100f 10 @frq	90.002 ~deg 14.1 @MHz 11.627 ft simplified Mdl 0.6667 VFnom 50 Zo 0.5 /100f 10 @frq	90 ~deg 7.05 @MHz 23.253 ft simplified Mdl 0.6667 VFnom 50 Zo 0.5 /100f 10 @frq	7.05 MHz 50 Zo xMtch V 0 a 0 b 0 c 0 d Plots Plt

← 40M

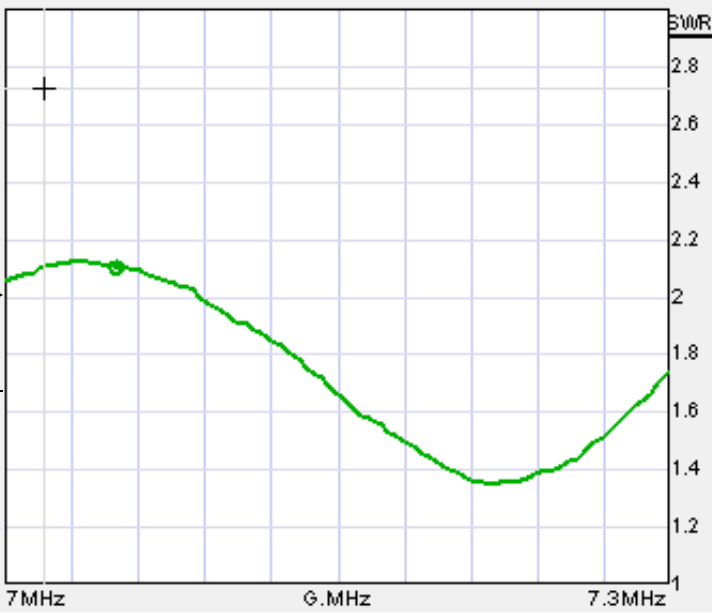
<<< << < > >> >>>

undo redo

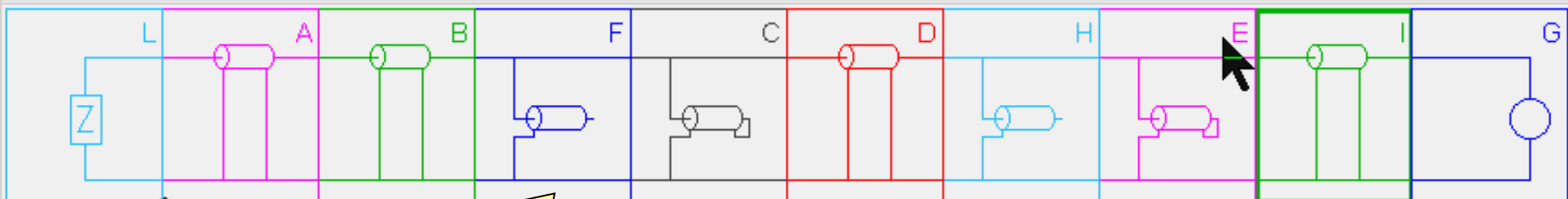
type	num	freq	from	to	name	sweep
lin	100	7	7.3	G.MHz	y	
	400lpole_SR_Fundamental.s1p	clr		L.file	n	



2:1 Match to Amp →



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



R = 45.857 X = -9.8141 ←dBW -1.052 V,A=6.135,0.131	R = 41.532 X = 0.7811 ←dBW -0.404 V,A=6.153,0.148	R = 51.954 X = 8.9337 ←dBW -0.207 V,A=7.028,0.142	29.598 -26.417 ←dBW -0.32 V,A=7.028,0.142	R = 52.279 X = 1.204 ←dBW -0.248 V,A=7.028,0.142	R = 41.378 X = 1.5719 ←dBW -0.201 V,A=7.012,0.142	R = 3.781 X = 25.543 ←dBW -0.177 V,A=7.012,0.142	R = 47.926 X = 4.965 ←dBW ~0 V,A=7.12,0.123	R = 49.723 X = 7.8622 ←dBW ~0 V,A=7.139,0.142	SWR = 1.171 Γ = 78.6m ∠87.5
45.857 ohms -9.8141 ohms file	1.16K ~deg 14.1 @MHz 149.92 ft simplified Mdl .667 VFnom 50 Zo .5 /100f 10 @frq	99 ~deg 14.1 @MHz 113.3 ft simplified Mdl .6667 VFnom 50 Zo .5 /100f 10 @frq	90 ~deg 14.1 @MHz 12.89 ft simplified Mdl .667 VFnom 50 Zo .5 /100f 10 @frq	90 ~deg 12.89 @MHz 12.89 ft simplified Mdl .667 VFnom 50 Zo .5 /100f 10 @frq	90 ~deg 14.1 @MHz 11.33 ft simplified Mdl .6667 VFnom 50 Zo .5 /100f 10 @frq	90.002 ~deg 13.011 @MHz 12.6 ft simplified Mdl .667 VFnom 50 Zo .5 /100f 10 @frq	90 ~deg 13.011 @MHz 23.253 ft simplified Mdl .6667 VFnom 50 Zo .5 /100f 10 @frq	90 ~deg 7.05 @MHz 23.253 ft simplified Mdl .6667 VFnom 50 Zo .5 /100f 10 @frq	7.05 MHz 50 Zo xMtch V 0 a 0 b 0 c 0 d Plots Plt

**1st Stub**

**Shorted Stub**

**λ/4 on 20M**

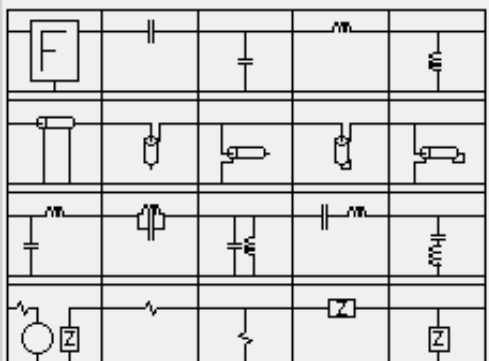
**2nd Stub**

**Shorted Stub**

<<< << < > >> >>>

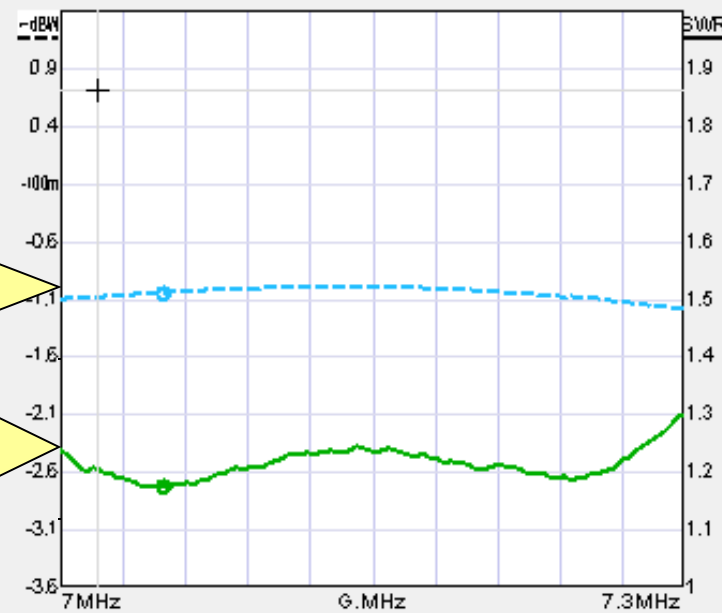
undo redo

type	num Pnts	from	to	name	sweep
lin	100	7	7.3	G.MHz	y
400lpole_SR_Fundamental.s1p		clr		L.file	n

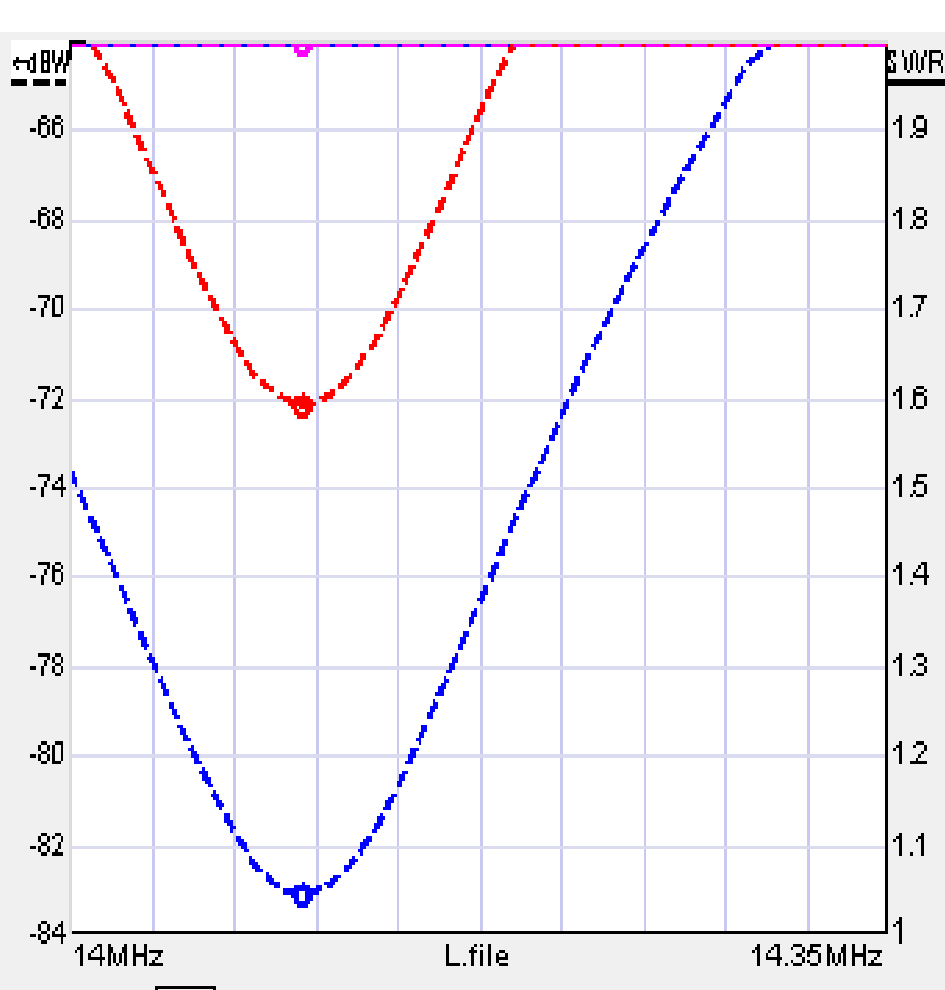


**1 dB Loss To Antenna**

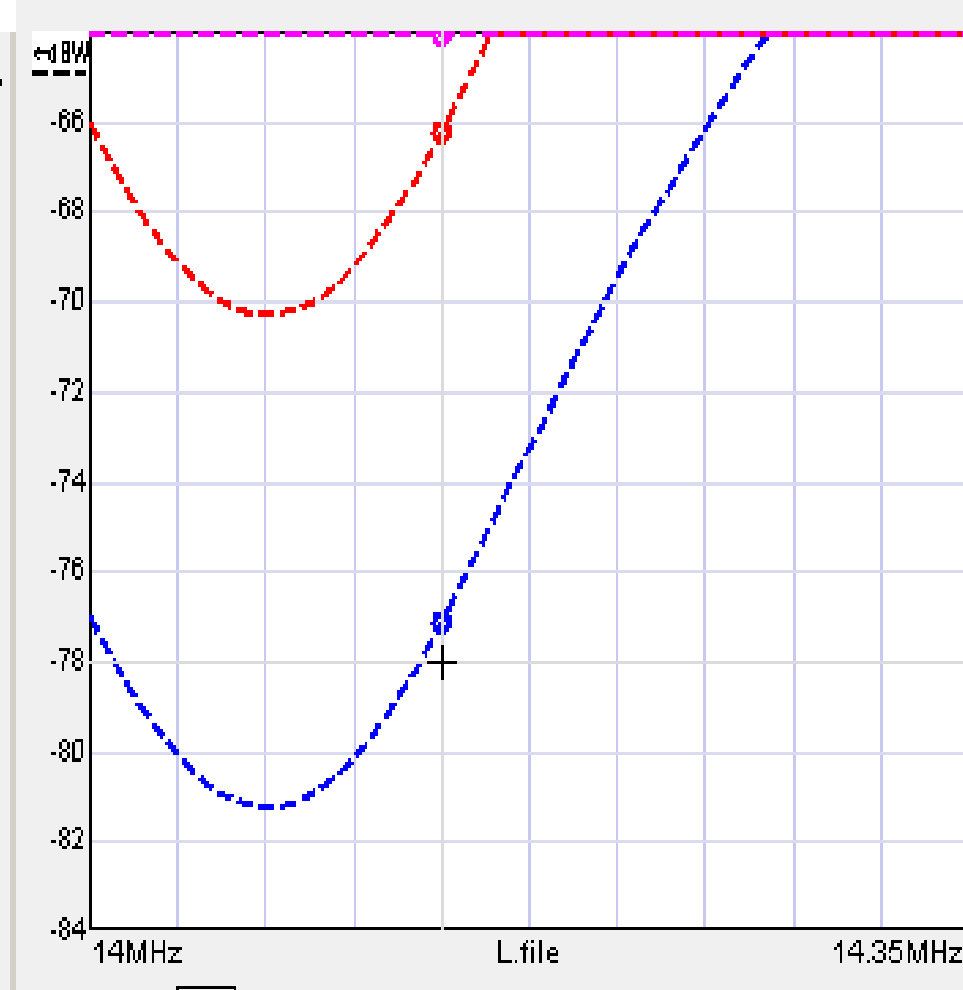
**1.25:1 VSWR**



# Shorted Stubs Added For 40M Match



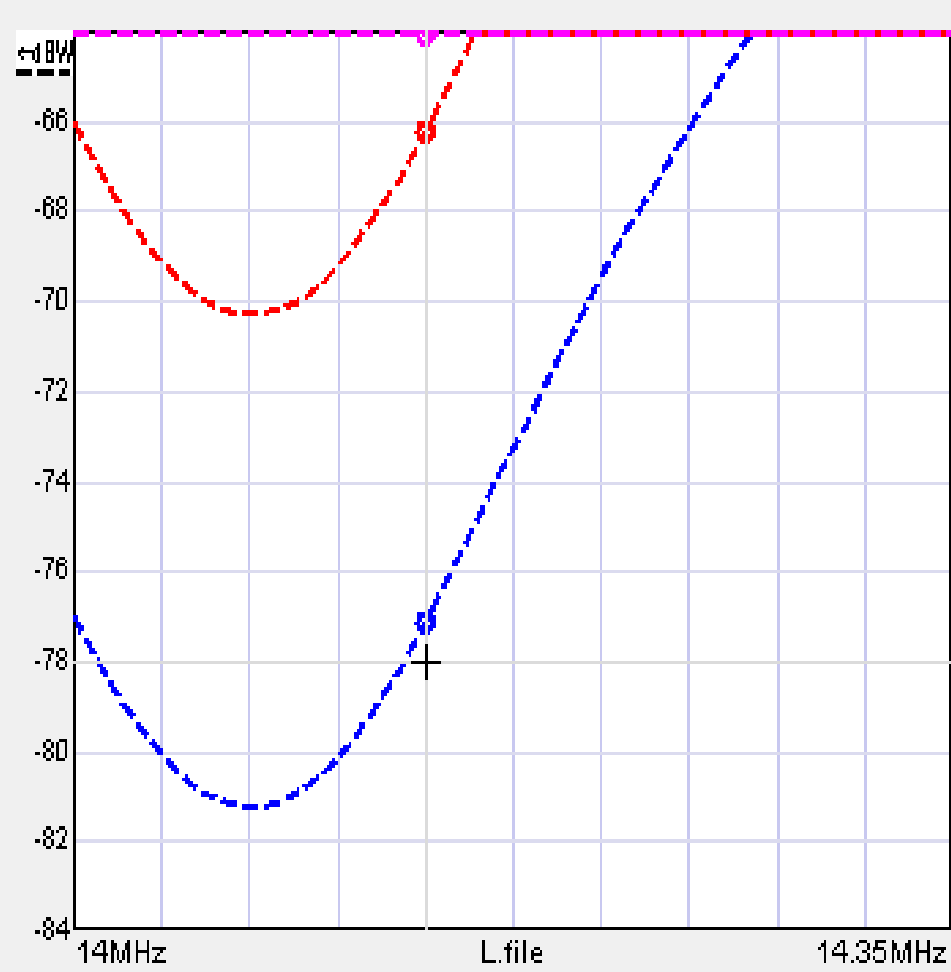
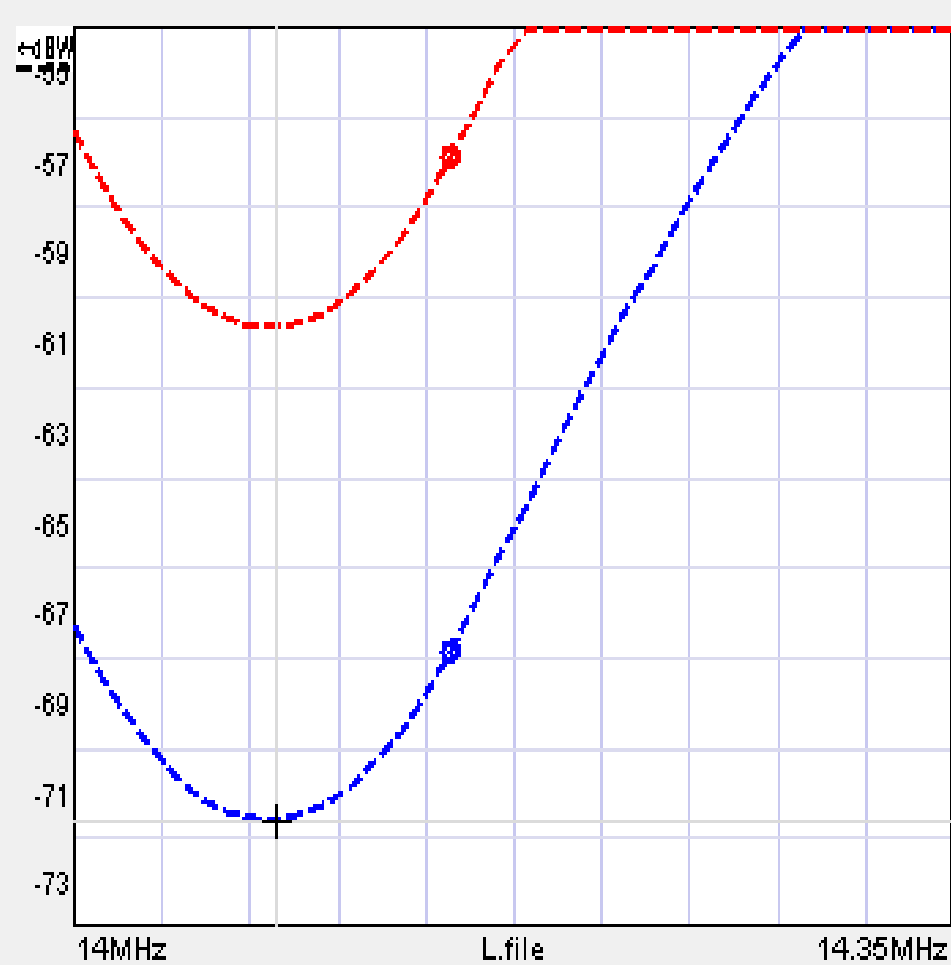
**Tuned to 14.1 MHz**



**Stagger-Tuned**

**Two  $\lambda/4$  20M ( $\lambda/8$  40M) Open Stubs  
Optimized for CW and RTTY**





**$\lambda/4$  40M Stubs**  
**67 dB Attenuation**  
**14 – 14.15 MHz**

**$\lambda/8$  40M Stubs**  
**77 dB Attenuation**  
**14 – 14.15 MHz**

# Mismatch With $\lambda/8$ 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**

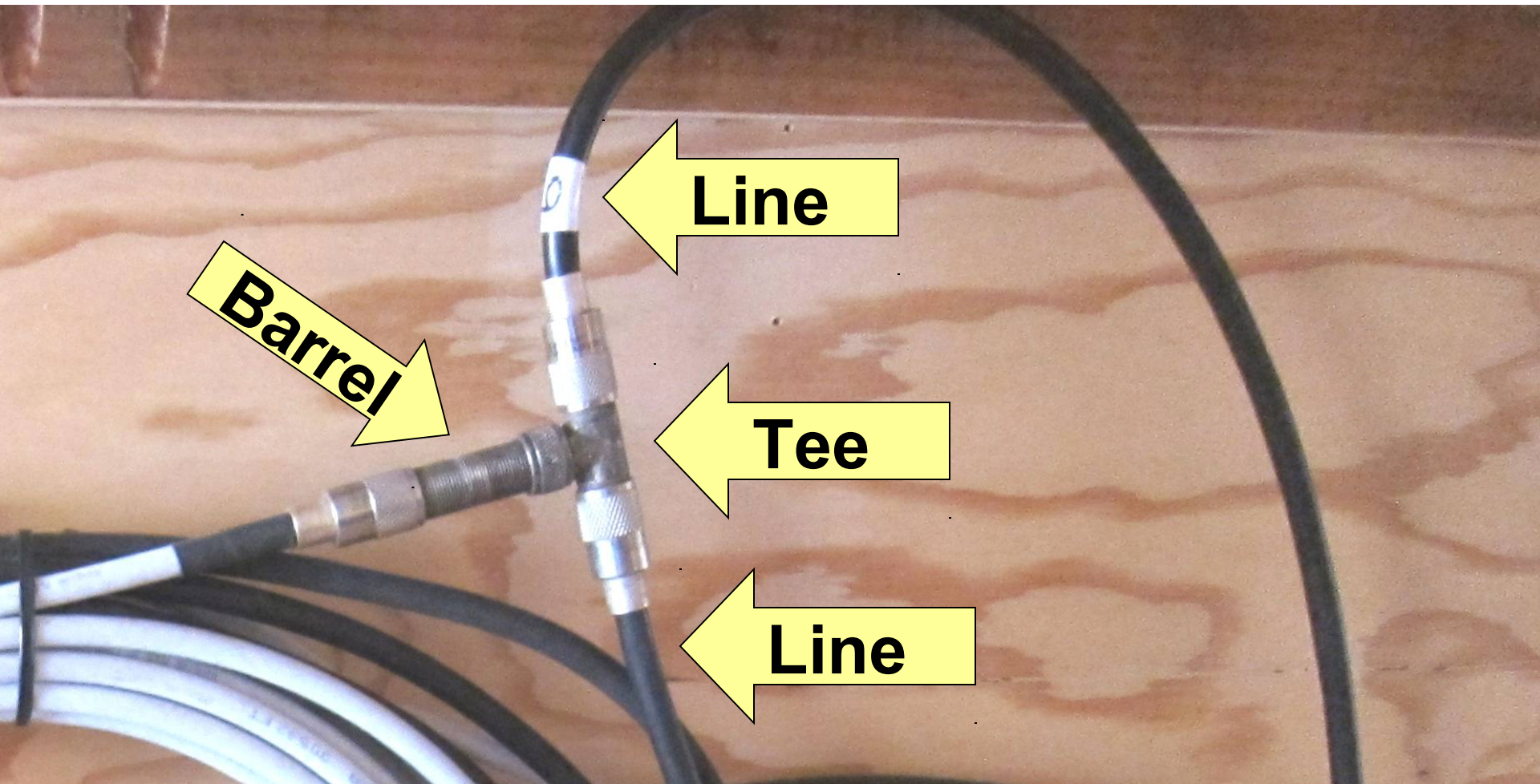
# Making Stubs

- **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**

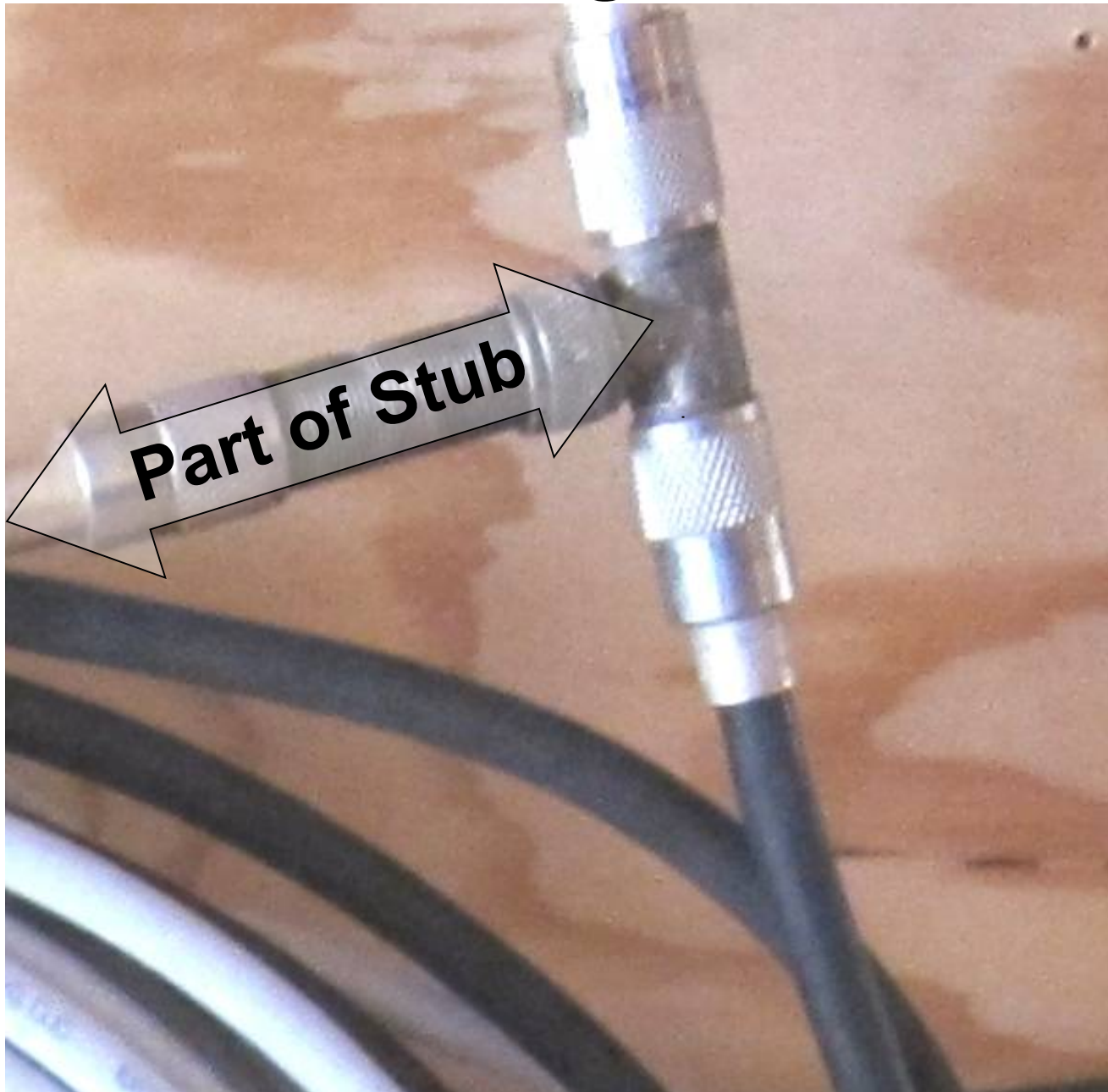
# Making Stubs

- **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  $\lambda/4$  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  $\lambda/2$  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

40M Dipole



80M Inv Vee

**C3SS**

**40M Dipole**

**Colorado River in SE Utah**



# How Well Do They Work?

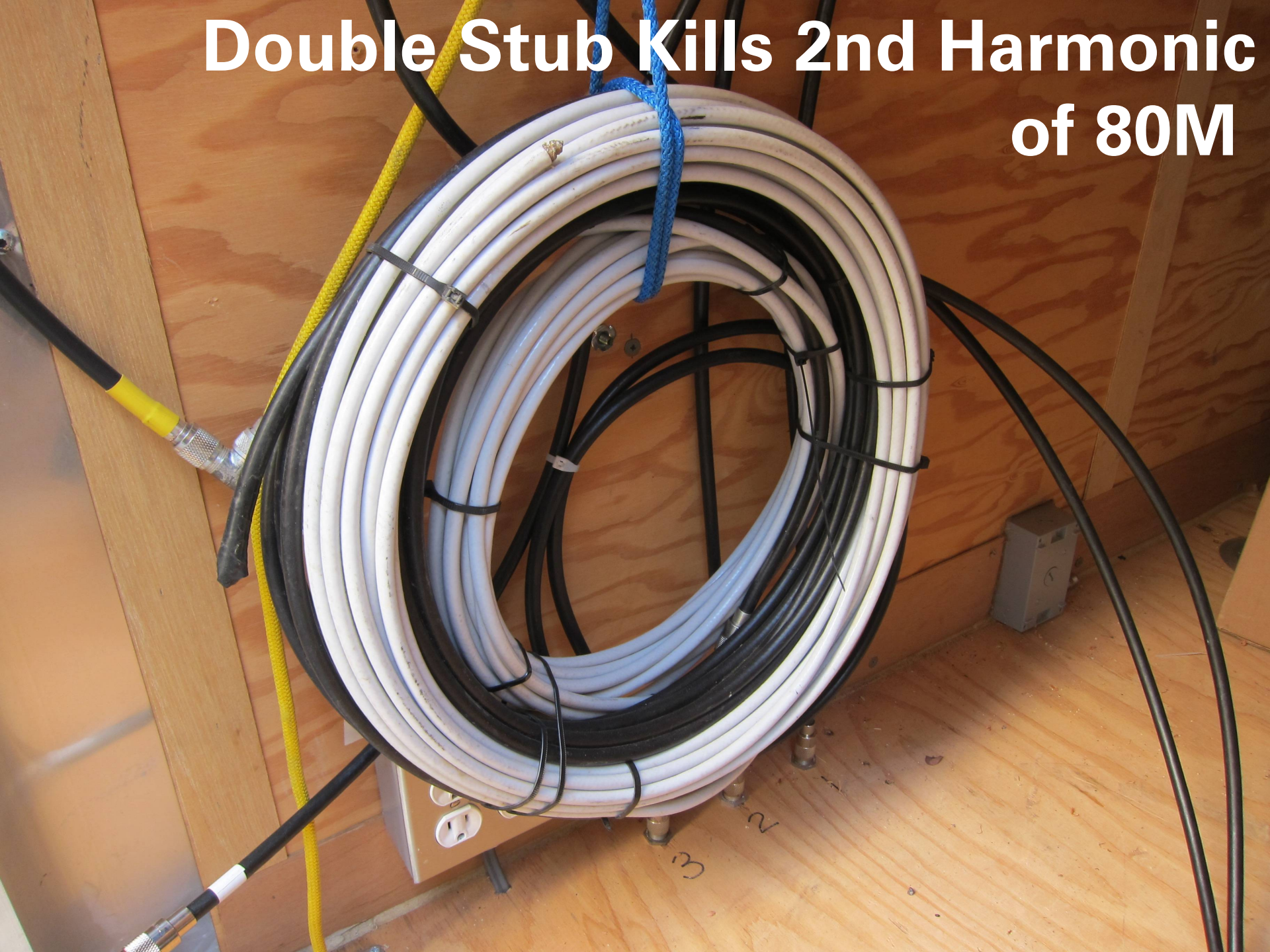
- **During the day, no 80M dipole, C3SS (for 20M) is rigged a few feet below 40M dipole**
- **Stubs allow us to run 600W with no problems with crossband QRM**
- **Three contests so far**
  - **7QP 2016, five setups in 7 NV counties**
  - **CQP 2016, two setups in 2 CA counties**
  - **7QP 2017, three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

# Double Stub Kills 2nd Harmonic of 40M



40M CW  
Double Stub  
To Kill  
20M Harm  
DONOT  
Take  
Apart

# Double Stub Kills 2nd Harmonic of 80M





# 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**

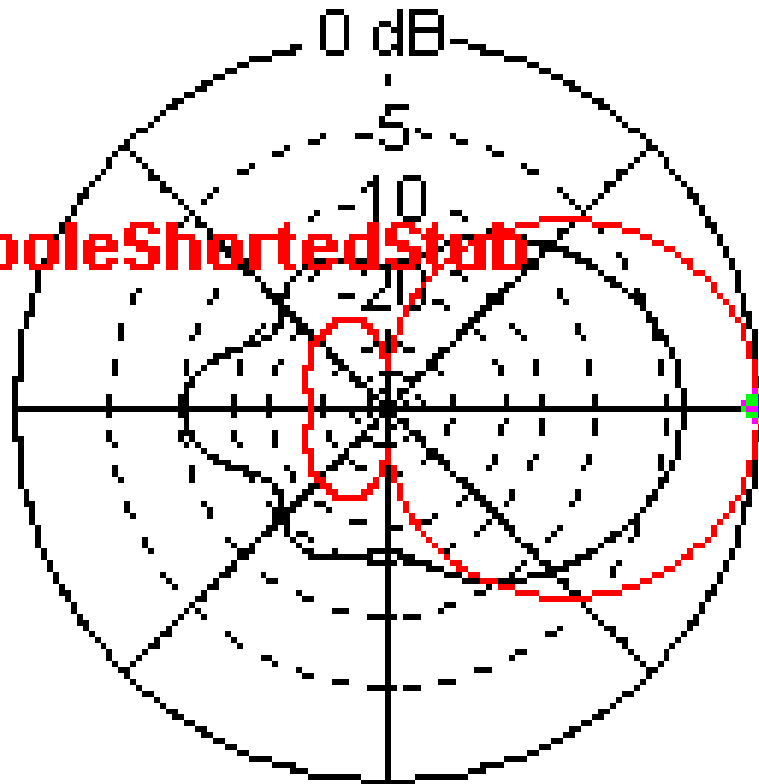
# Black Curve Shows Interference

Total Field

EZNEC Pro/2

Primary

\* 20MYagi-40MDipoleShortedStub



14.2 MHz

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

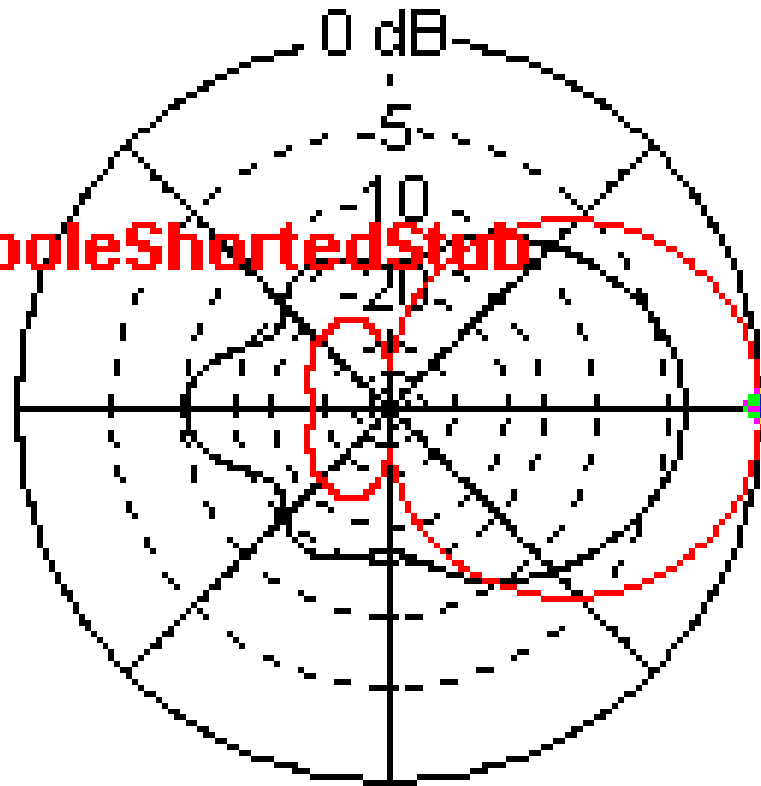
# Red Curve Is With Stub On the Dipole

Total Field

EZNEC Pro/2

Primary

\* 20MYagi-40MDipoleShortedStub



14.2 MHz

Azimuth Plot

Cursor Az

0.0 deg.

Elevation Angle 0.0 deg.

Gain

12.93 dBi

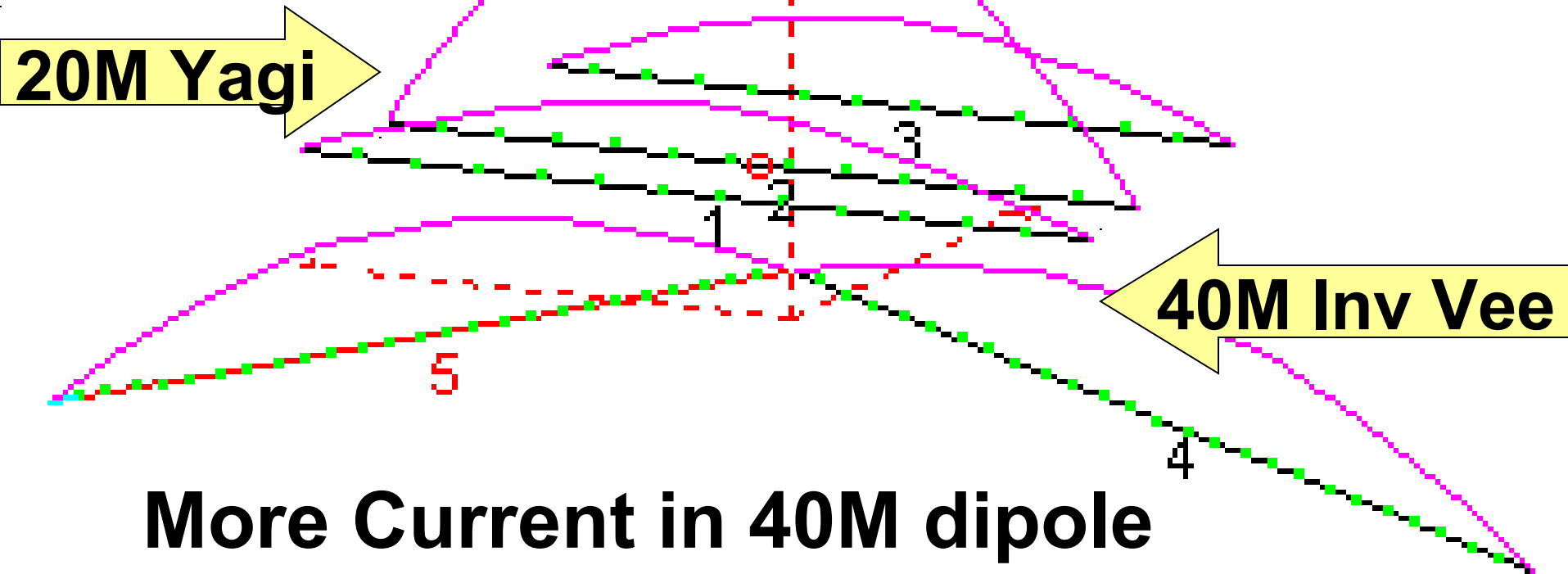
Outer Ring 12.93 dBi

0.0 dBmax

3.94 dBPrTrc

# Currents With Dipole Feedpoint Open

EZNEC Pro/2

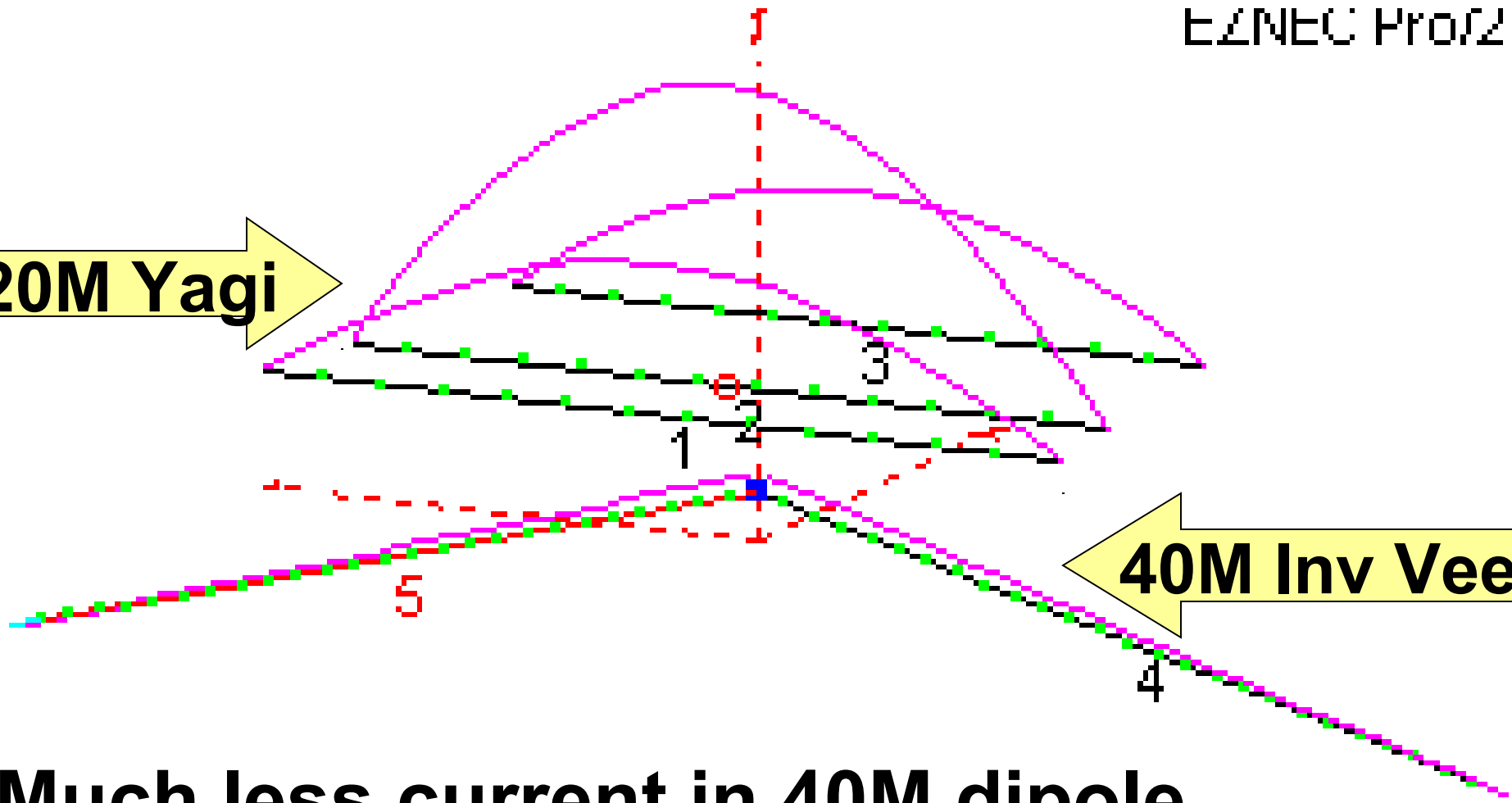


**More Current in 40M dipole  
than in parastic Yagi elements**

# Currents With Dipole Feedpoint Shorted

EZNEC Pro/2

20M Yagi



40M Inv Vee

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  $n \lambda/2$  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,  $\lambda/4$  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 2<sup>nd</sup> harmonic band**

# In Summary

- **Gurgly, growly sounding harmonics are usually not 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**

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