# Using Sim Smith to Improve Antenna Matching

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# The Objectives

- Eliminate antenna tuners
- Improve match to our rigs
- Minimize losses
- Improve operating efficiency
- Prepare for automatic switching

# I wanted to replace these tuners that I also had to tune

# With this switching that I can automate with band decoders

# The Tools

- **NEC Design Software**
- **Vector Network Analyzer**
  ***or***
- **Vector Impedance Analyzer**
- **Sim Smith Design Software**

# The Process

- **Measure an existing antenna**

  **or:**

- **Export antenna design from NEC**
- **Import data into Sim Smith, use it to design matching networks**
  - **Stubs**
  - **Matching sections**
  - **Capacitors, inductors, transformers**

# About Analyzers

- **<u>Vector</u> Analyzer – includes phase**
  - **Needed for any design work**
- **Vector <u>Impedance</u> Analyzer (VIA)**
  - **Single Port**
  - **Measures impedance (R + jX)**
  - **Time Delay Reflectrometry (TDR)**
    - **Line length, cable quality, splices**
    - **Works even w/antenna connected**

# About Analyzers

- Vector Network Analyzer (VNA)
  - Two port analysis
  - Measures impedance, TDR, and
  - Measures response through a network or system
    - Coax loss, velocity factor
    - Bandpass filter response
    - Coupling between antennas
    - Gain (loss) of networks and systems

# <u>Single Port</u> Vector Analyzers

- AIM 4170 $545, 180 MHz
- AIM UHF  $900 1 GHz
- Power AIM (Broadcasters) ($3K)

# Two-Port Vector Network Analyzers

- TenTec TAPR – 100 MHz discontinued, works up to 120 MHz
- AIM VNA-2180 – 180 MHz $1,500
- N2PK – 60 MHz

  M0WWA builds to order w/options
- DG8SAQ VNWA 3E – 1.3GHz $750
  - Sold by SDR kits in the UK
  - Cost includes shipping to US

# Low Cost Vector Analyzers

- All use a Windows computer to process and display data
- All couple data via USB port
- All come with free software
- All come with calibration set
- DG8SAQ powers from USB port
- All others need DC power
- All export data in standard formats

# My Choice – DG8SAQ VNWA 3E

- Self powered from USB port, easiest to set up in the field
- Full specs to 500 MHz, reduced dynamic range to 1.3 GHz
- Active Yahoo user group support
- Ongoing development of software, firmware, hardware by DG8SAQ

# The DG8SAQ VNWA 3E

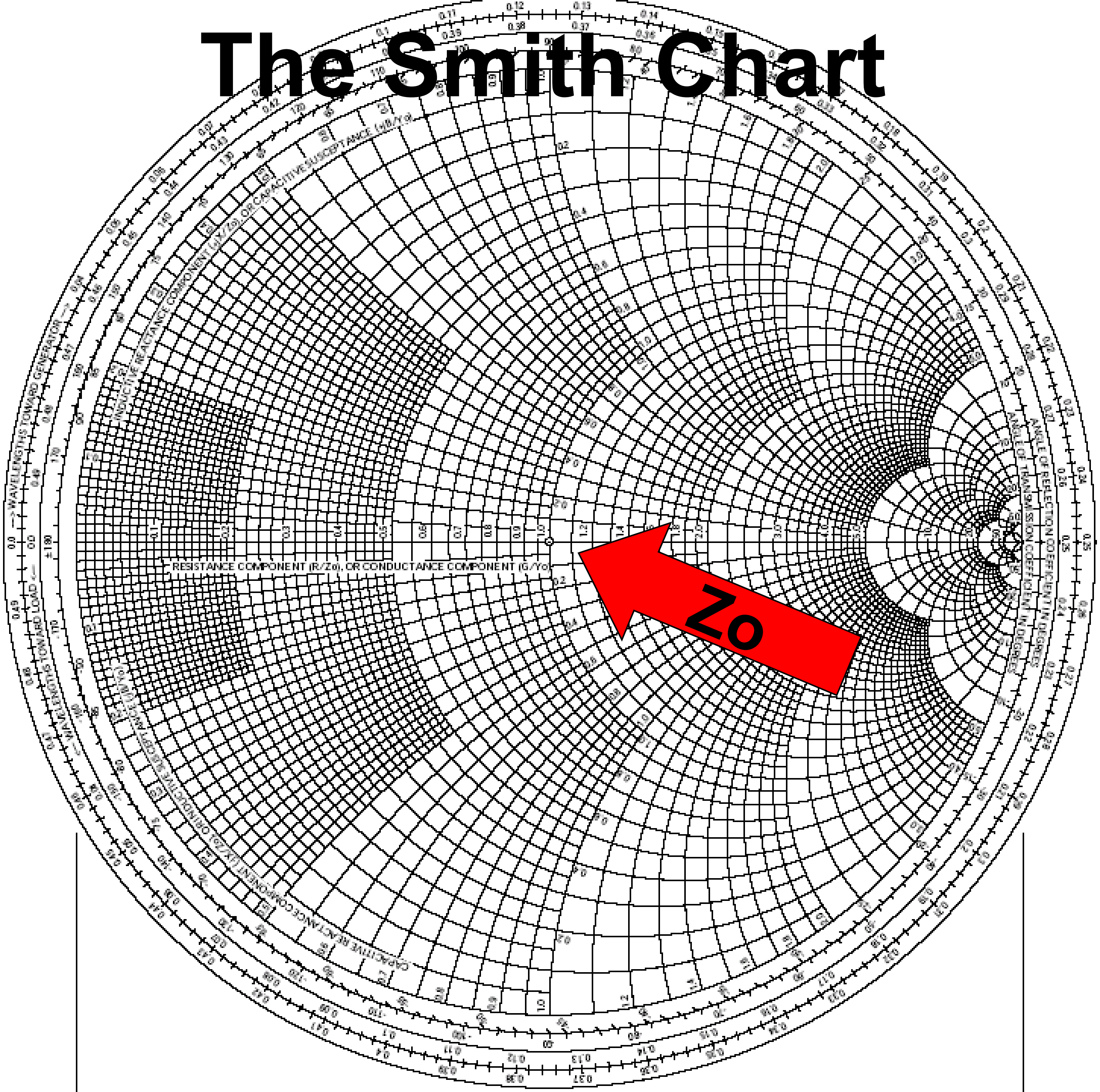
# About the Smith Chart

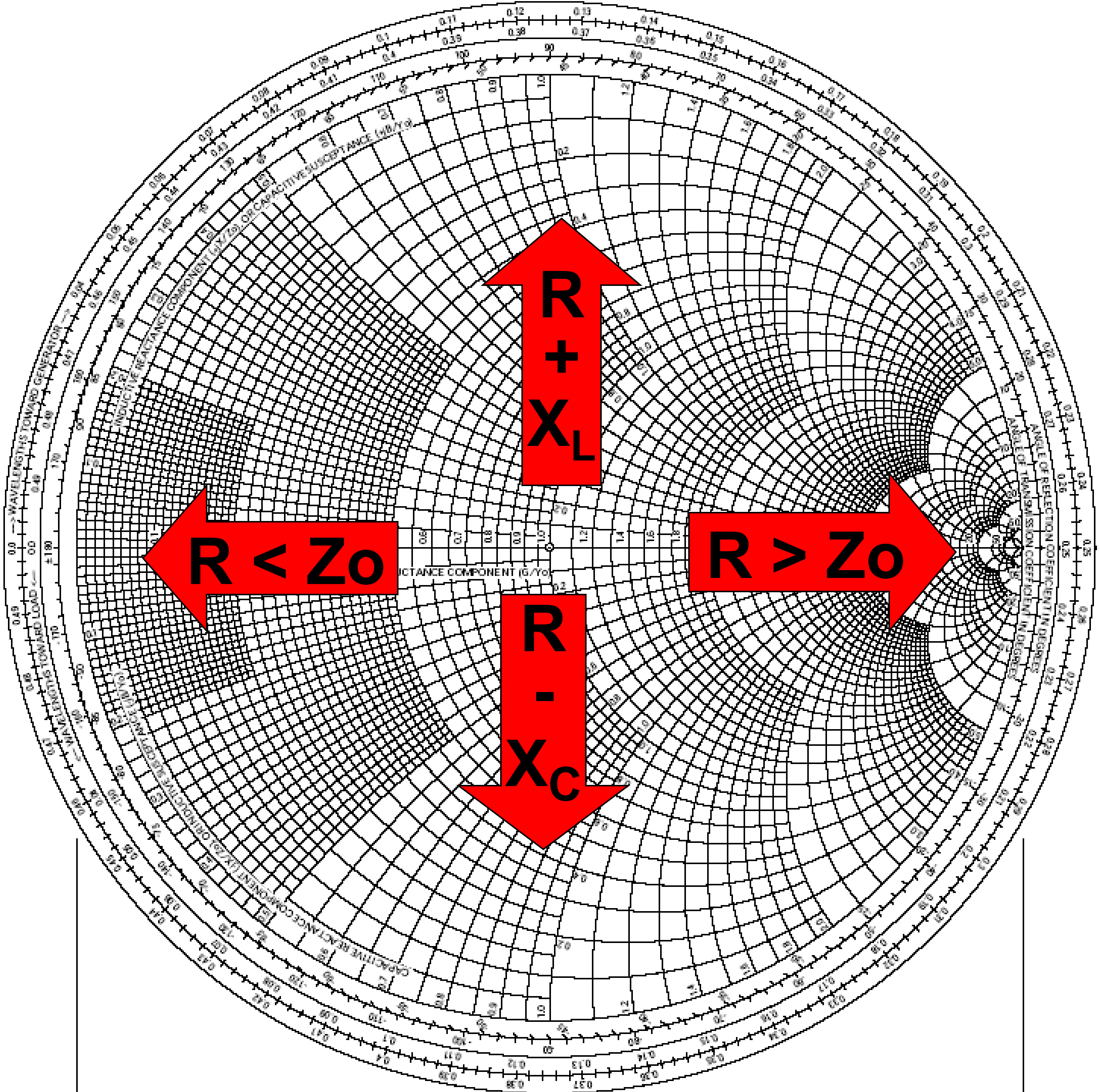
- **Developed by Phillip Smith in 1939**
- **A method of plotting R + jX data that allows graphical computations involving transmission lines**
- **Allows a “way of looking” at a problem that, with experience, suggests solutions**
- **A great *learning* tool**

# About the Smith Chart

- **Impedances plotted on the chart are "normalized" to Zo**
- ***Normalized*** **means every data point is divided by the same value, in this case, Zo**

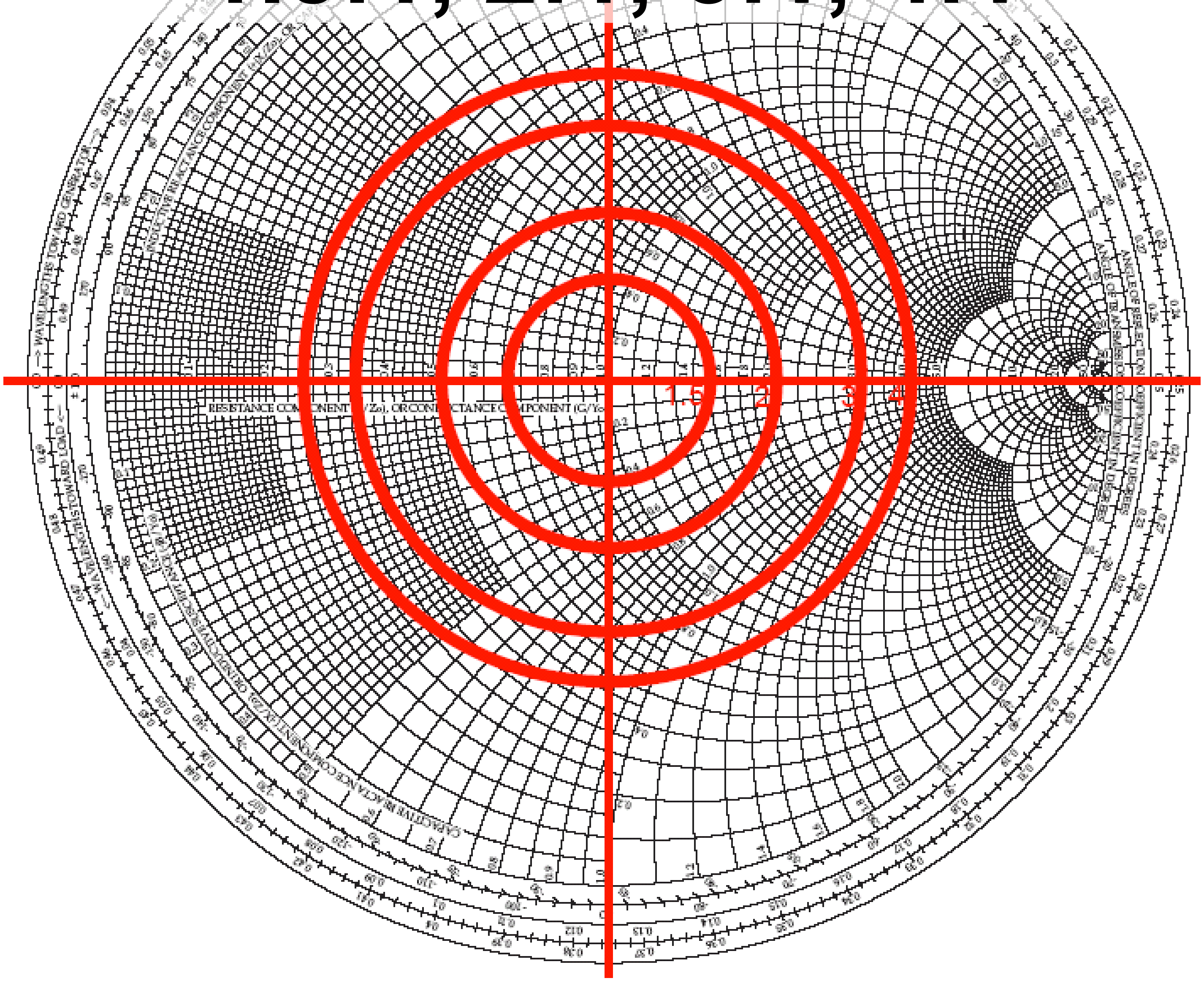
# The Smith Chart



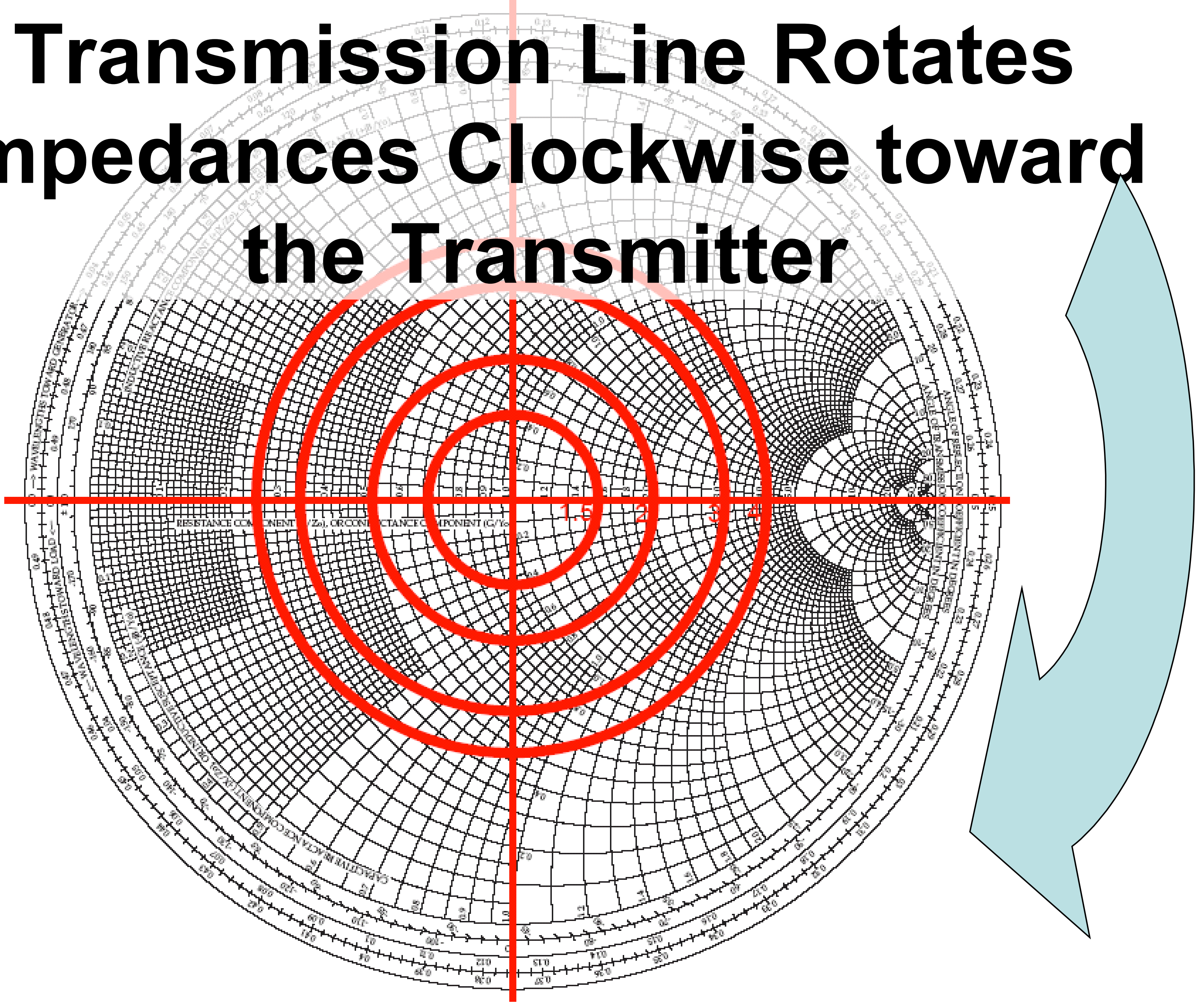

R + $X_L$
R < Zo
R > Zo
R - $X_C$

# Constant SWR Circles

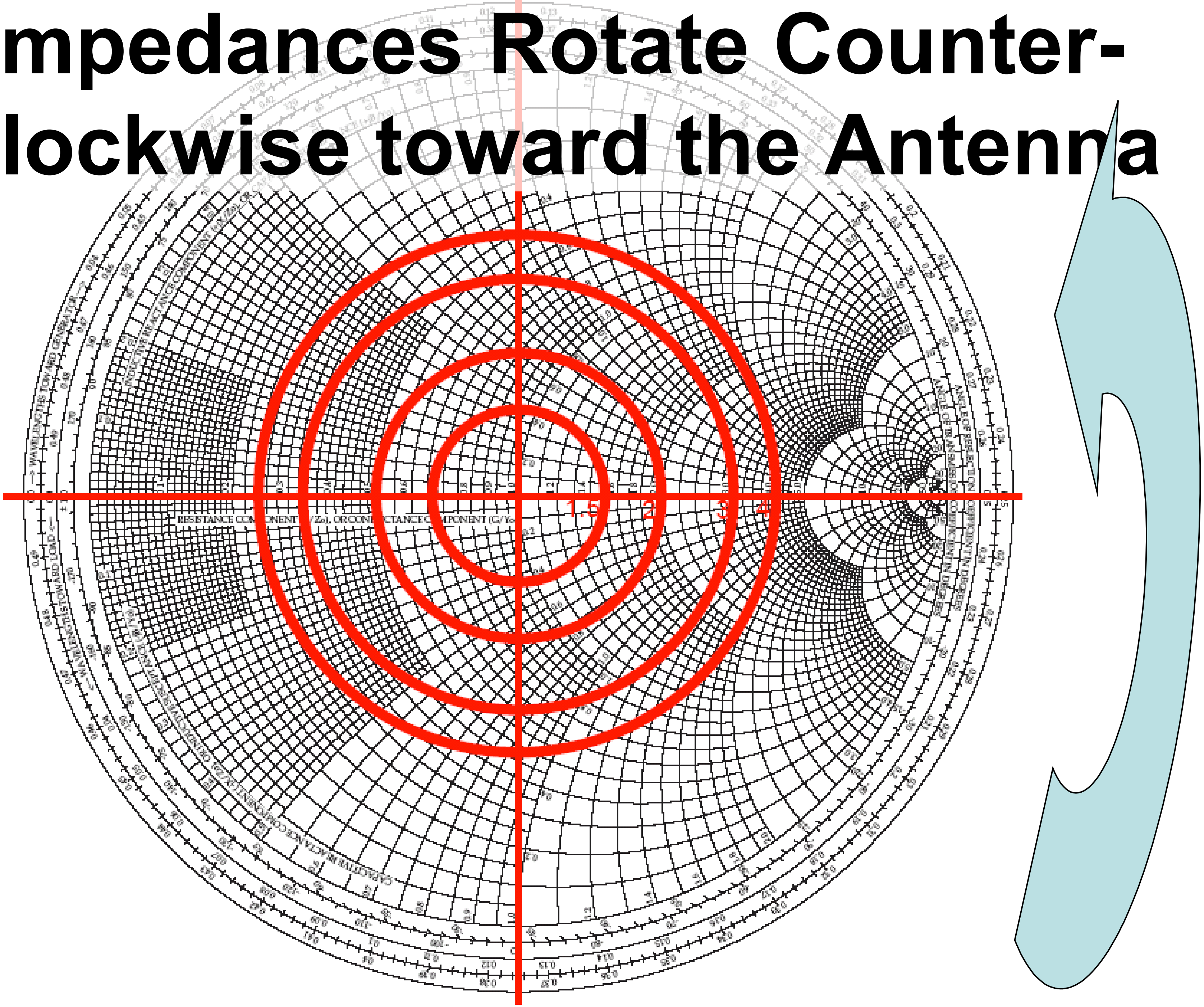
# 1.5:1, 2:1, 3:1, 4:1



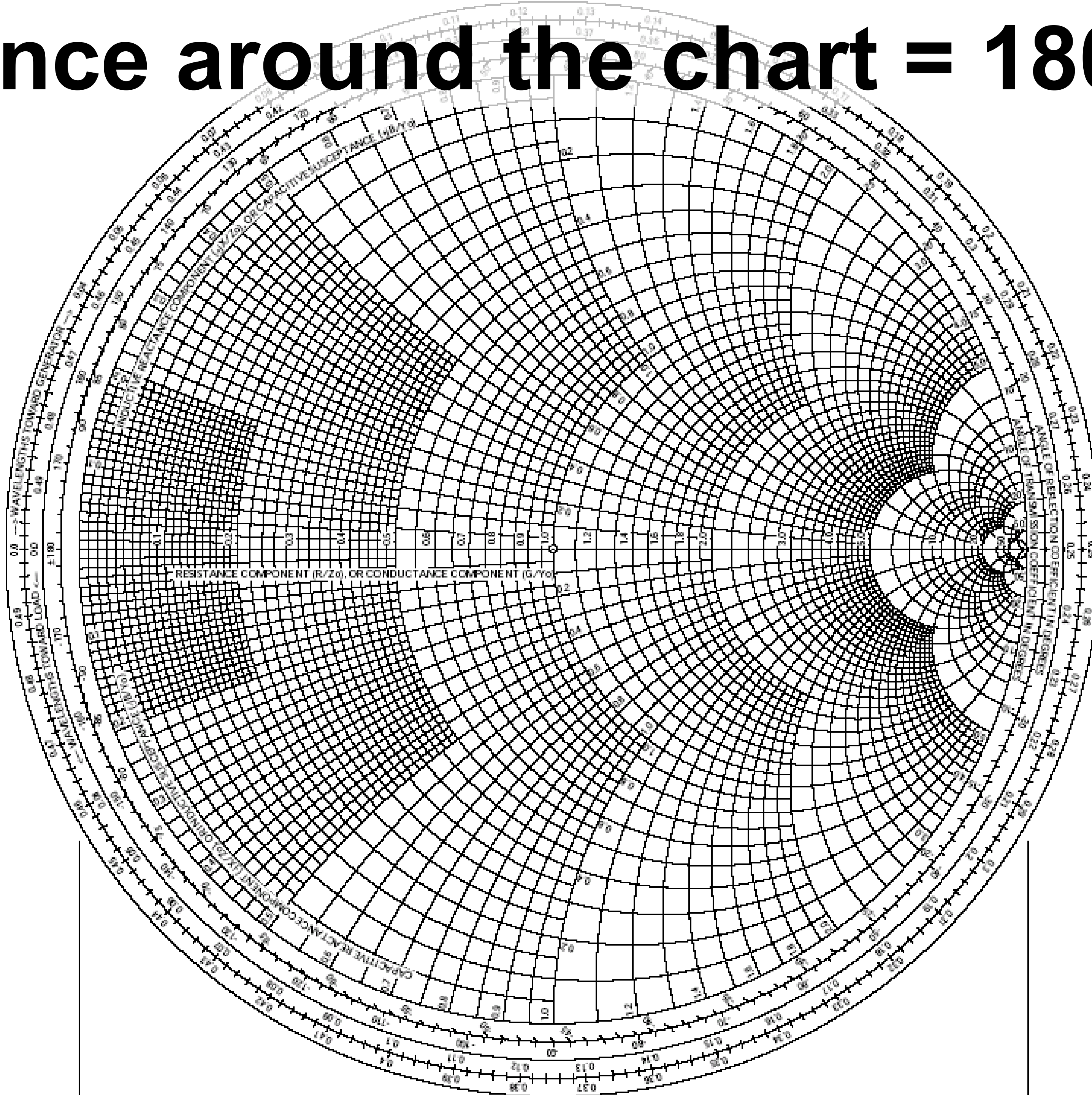
# Transmission Line Rotates Impedances Clockwise toward the Transmitter



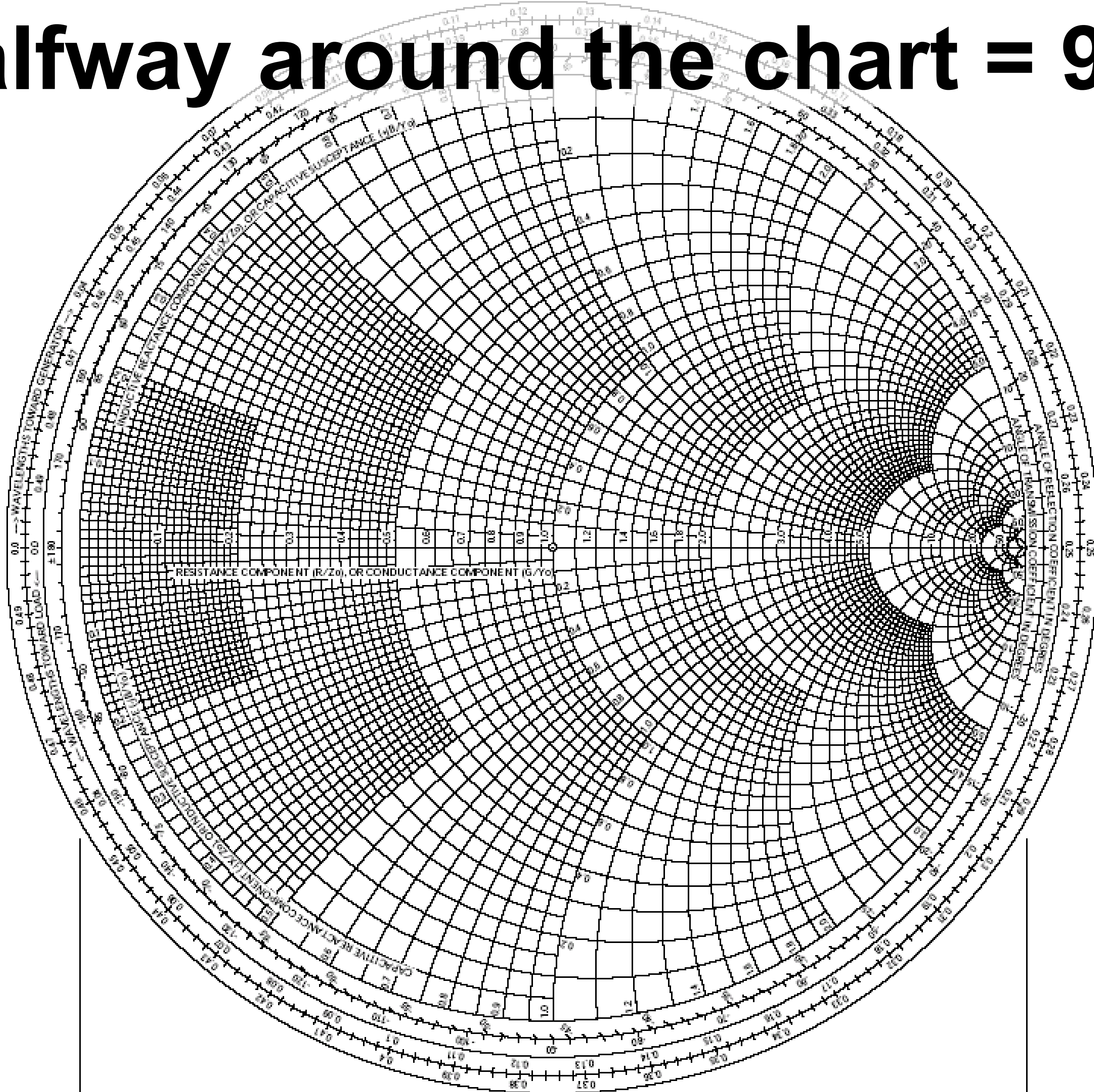
# Impedances Rotate Counter-Clockwise toward the Antenna



# Once around the chart = 180°



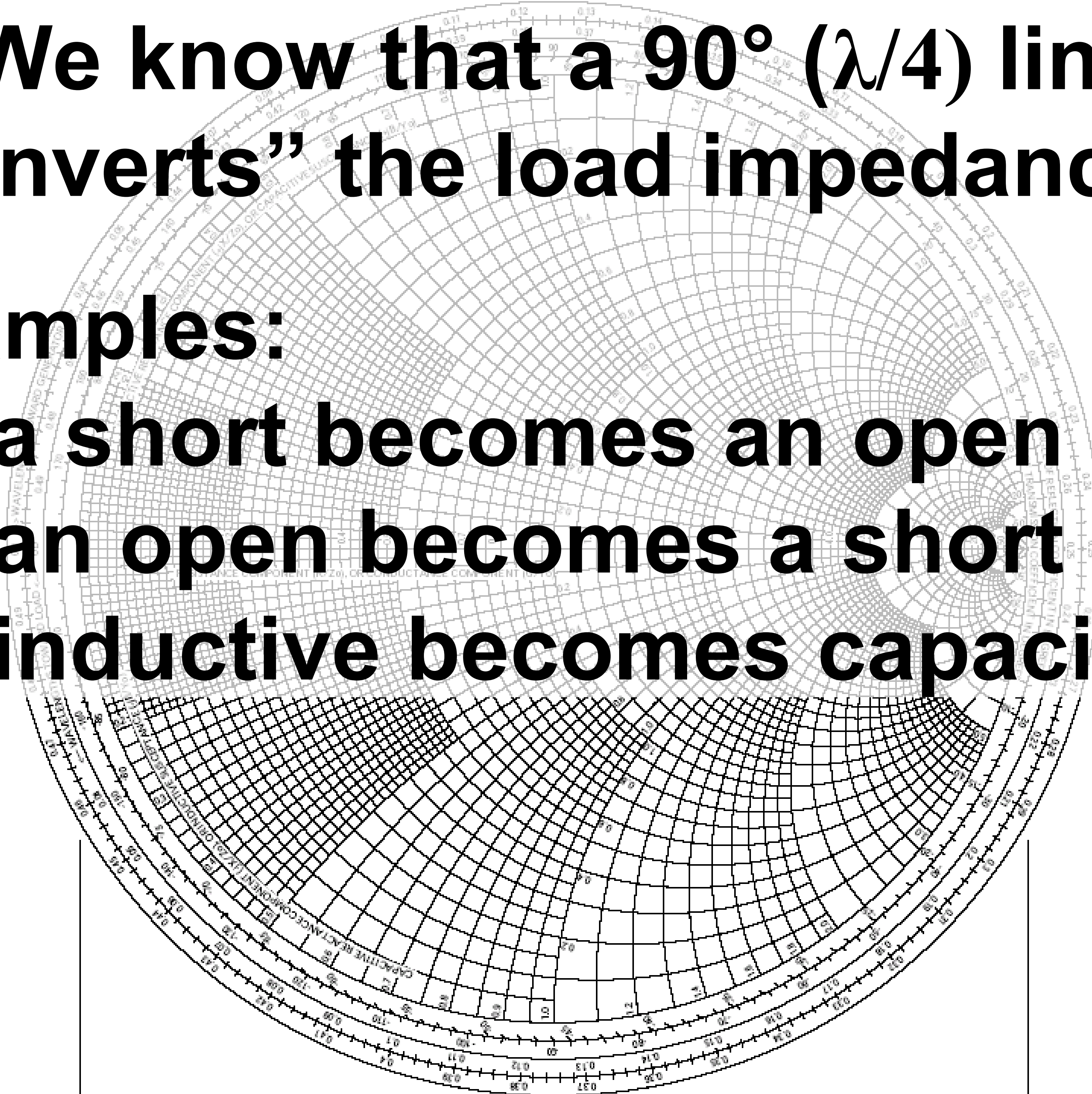
# Halfway around the chart = 90°

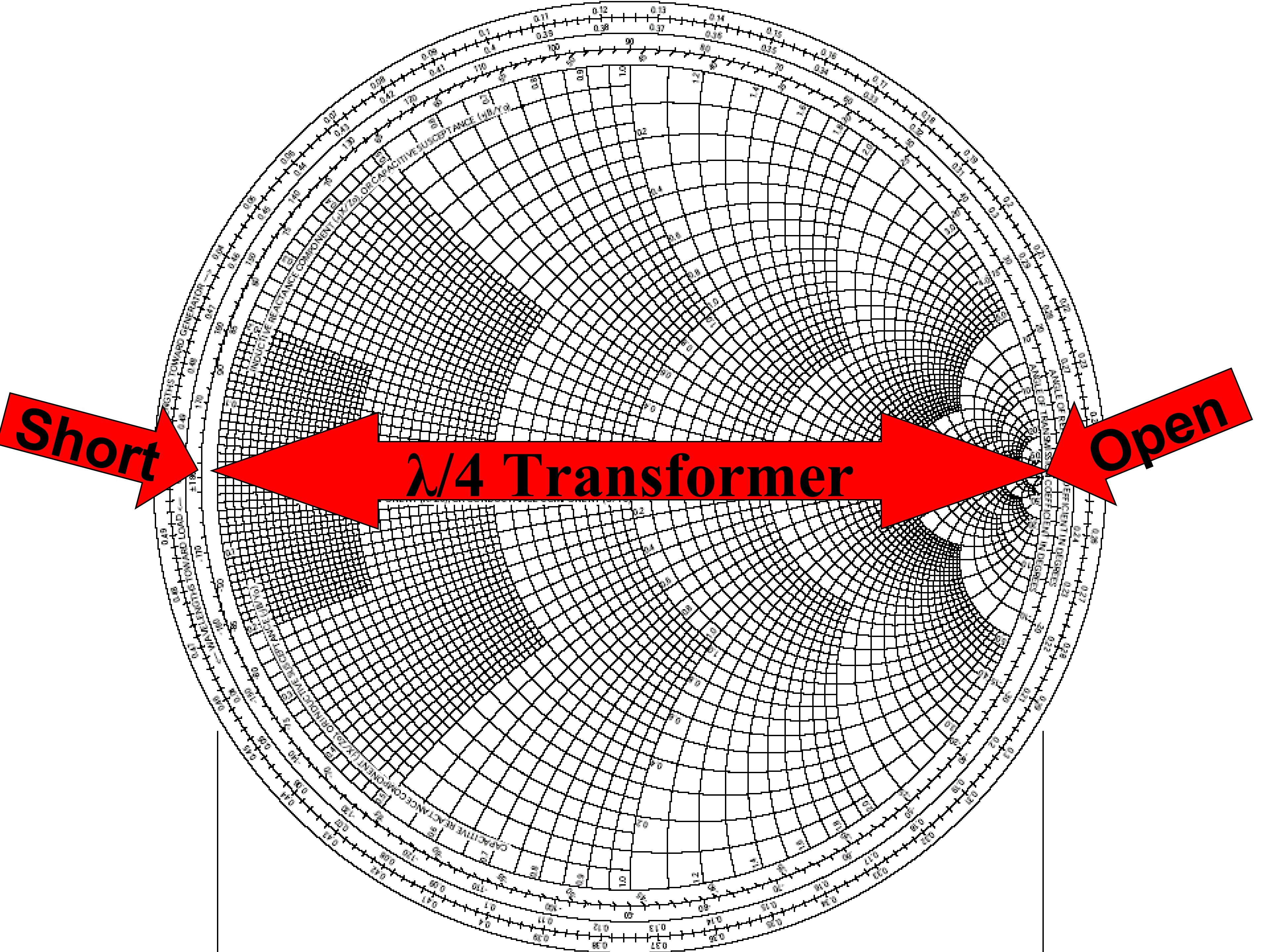


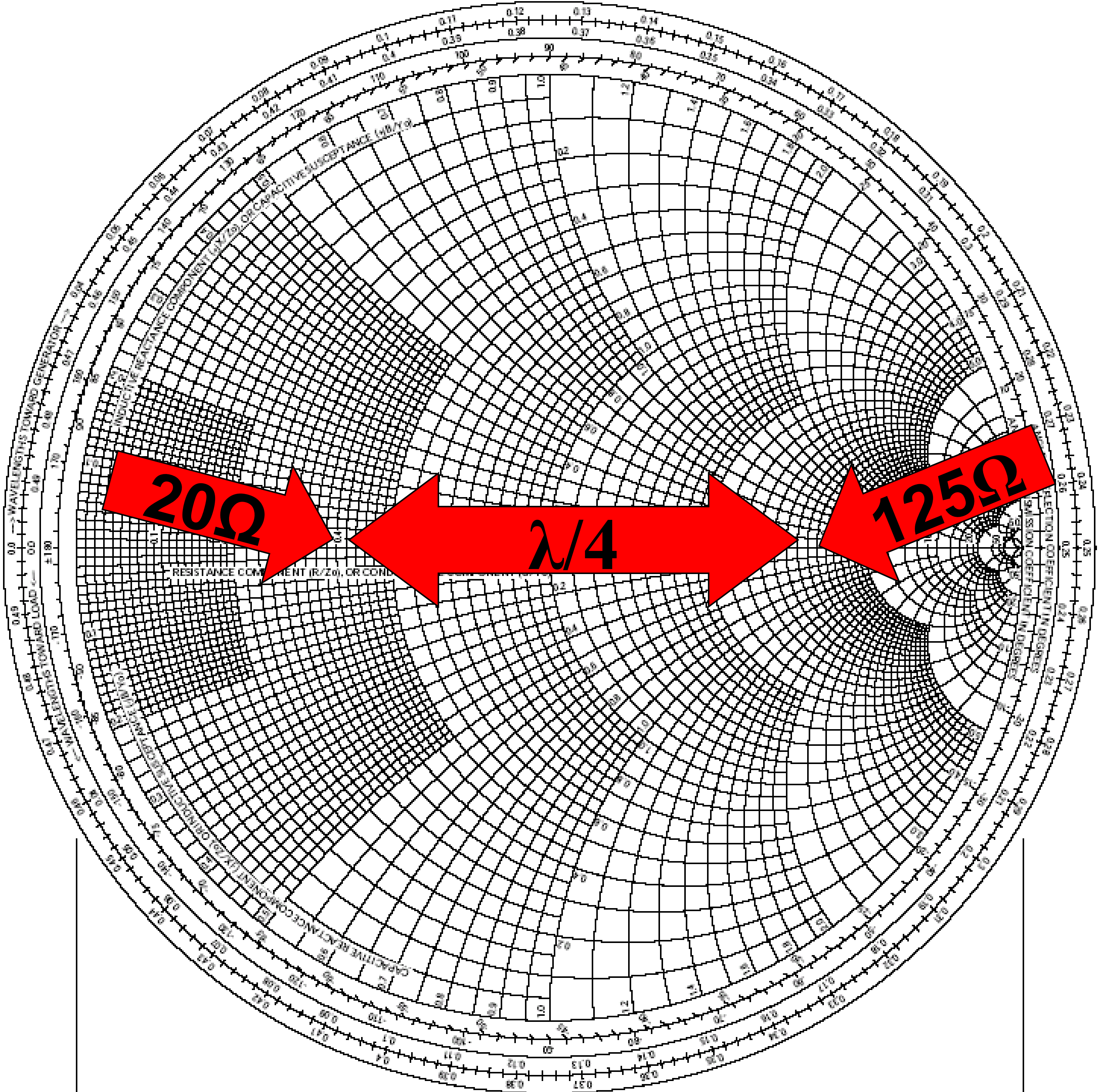
# We know that a 90° (λ/4) line "inverts" the load impedance

**Examples:**

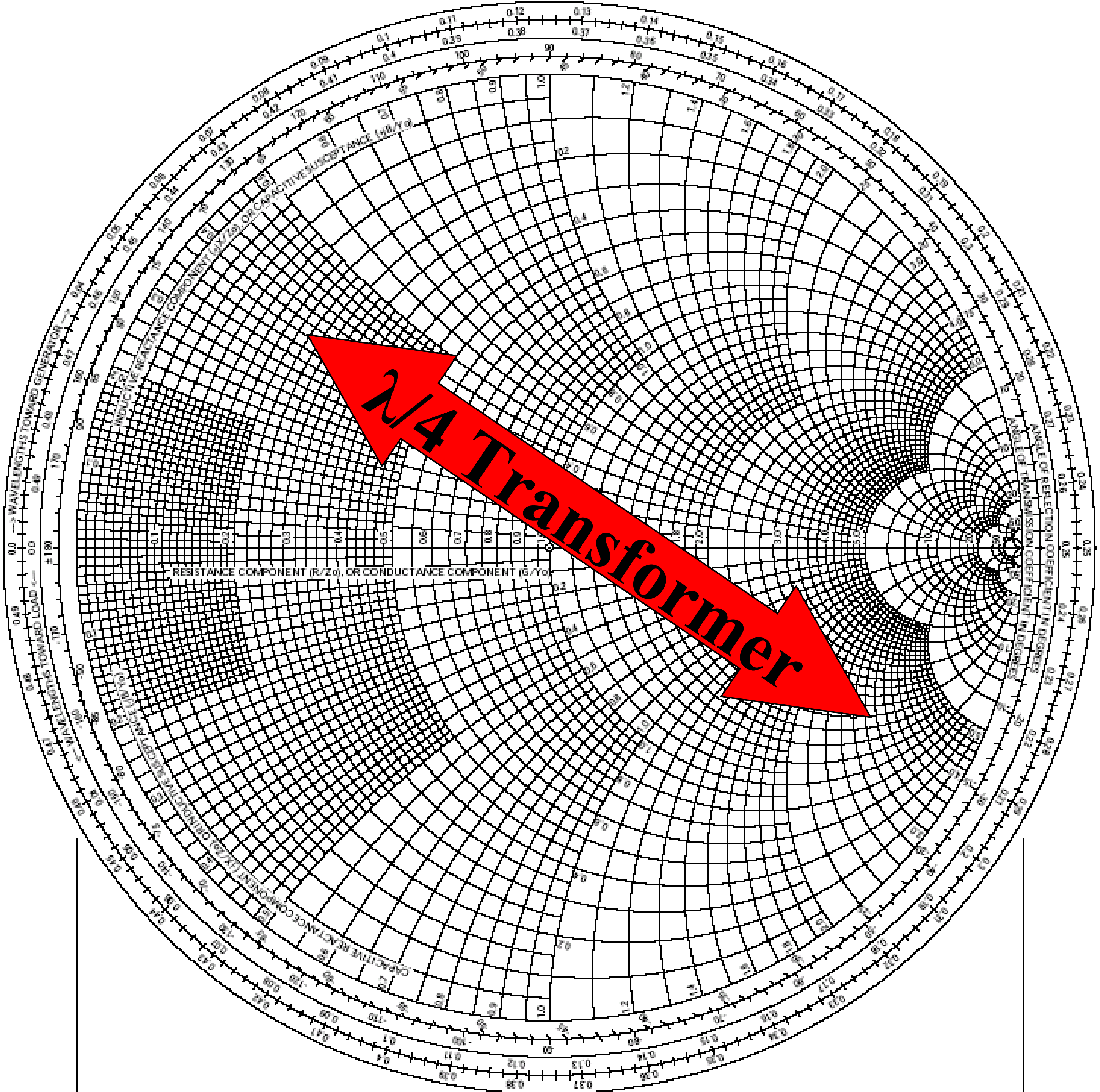
- a short becomes an open
- an open becomes a short
- inductive becomes capacitive

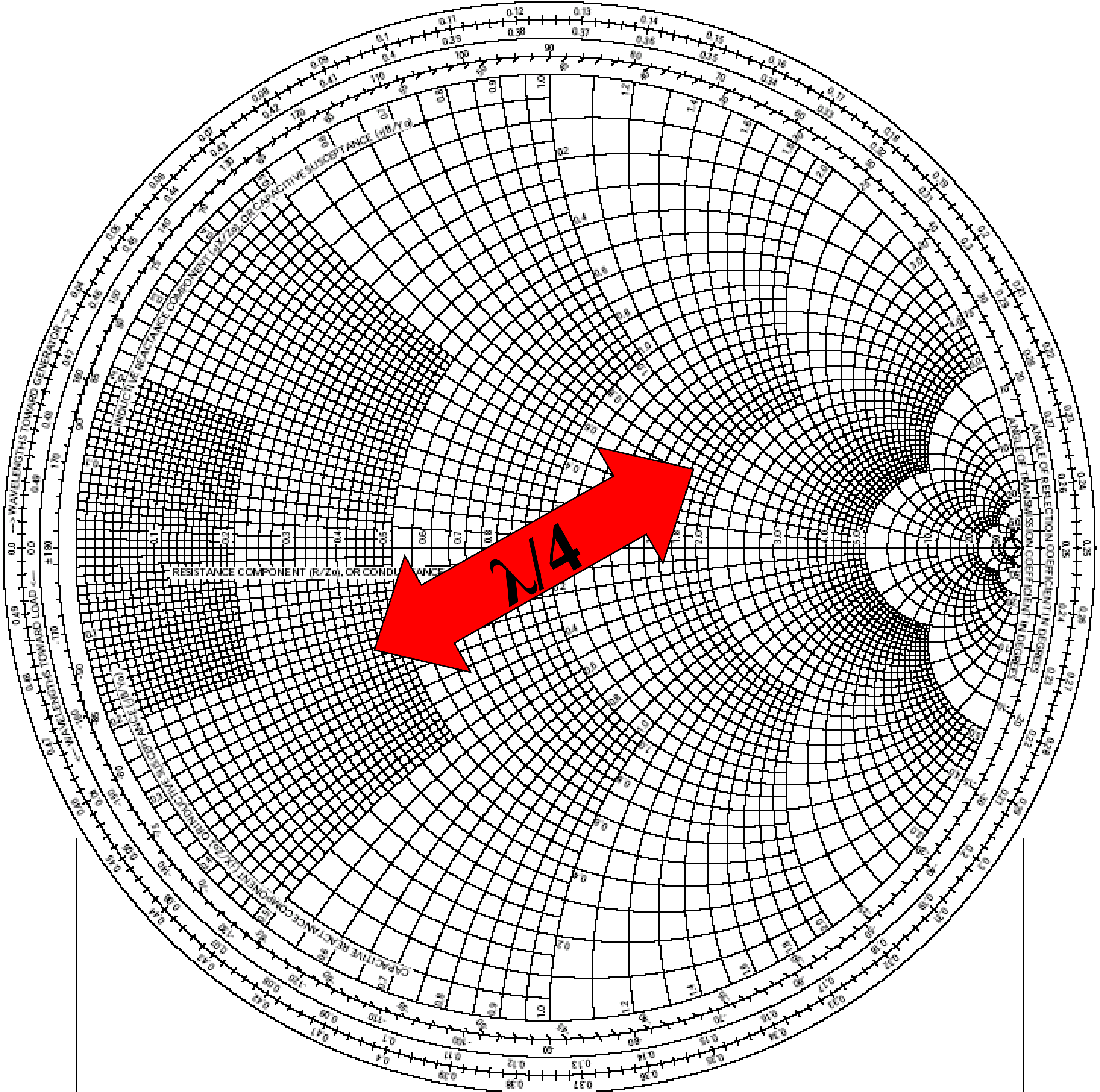



Short
λ/4 Transformer
Open



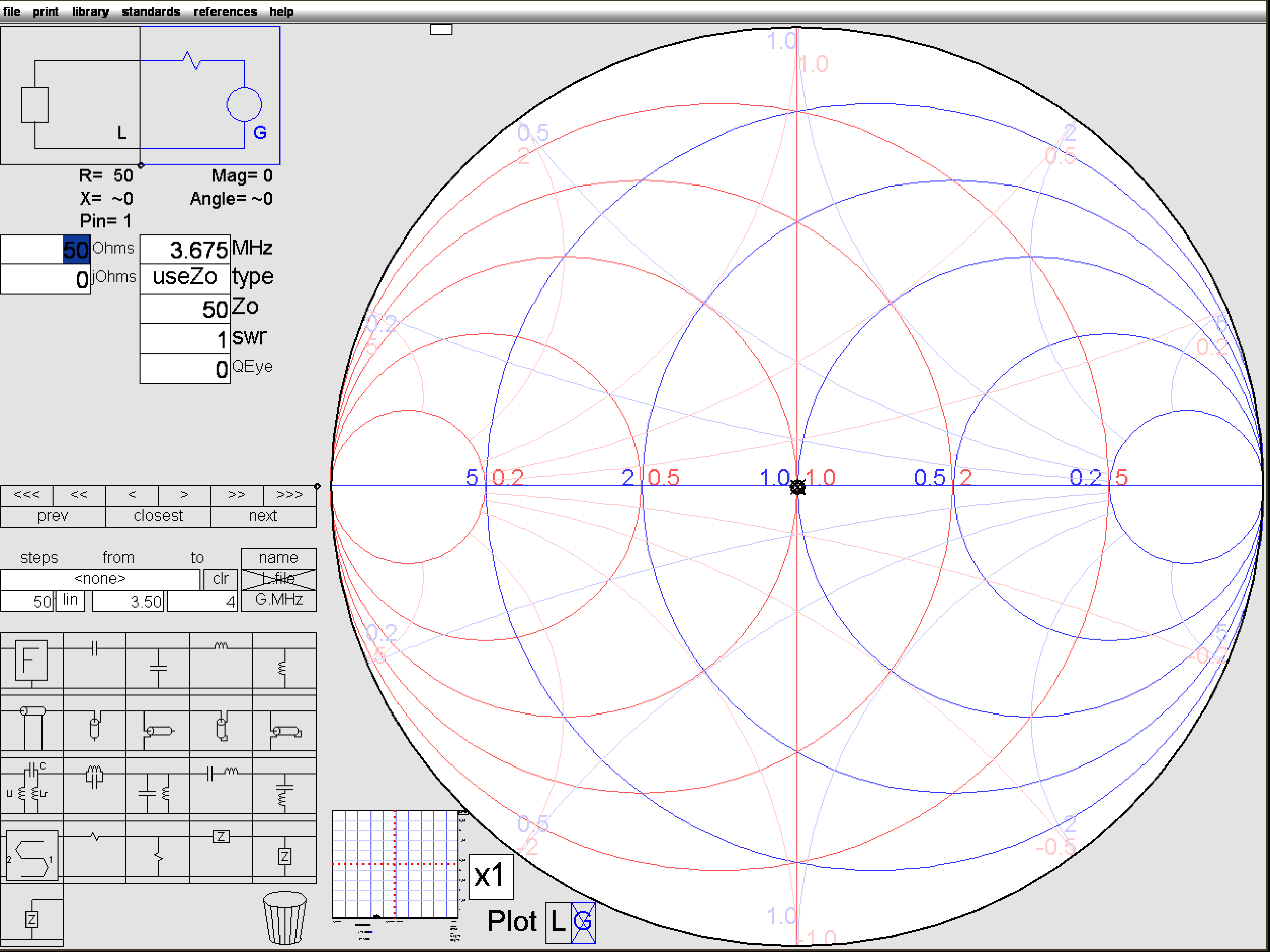
20Ω
λ/4
125Ω


λ/4 Transformer
RESISTANCE COMPONENT (R/Zo), OR CONDUCTANCE COMPONENT (G/Yo)
—> WAVELENGTHS TOWARD GENERATOR —>
<— WAVELENGTHS TOWARD LOAD <—
ANGLE OF REFLECTION COEFFICIENT IN DEGREES
ANGLE OF TRANSMISSION COEFFICIENT IN DEGREES

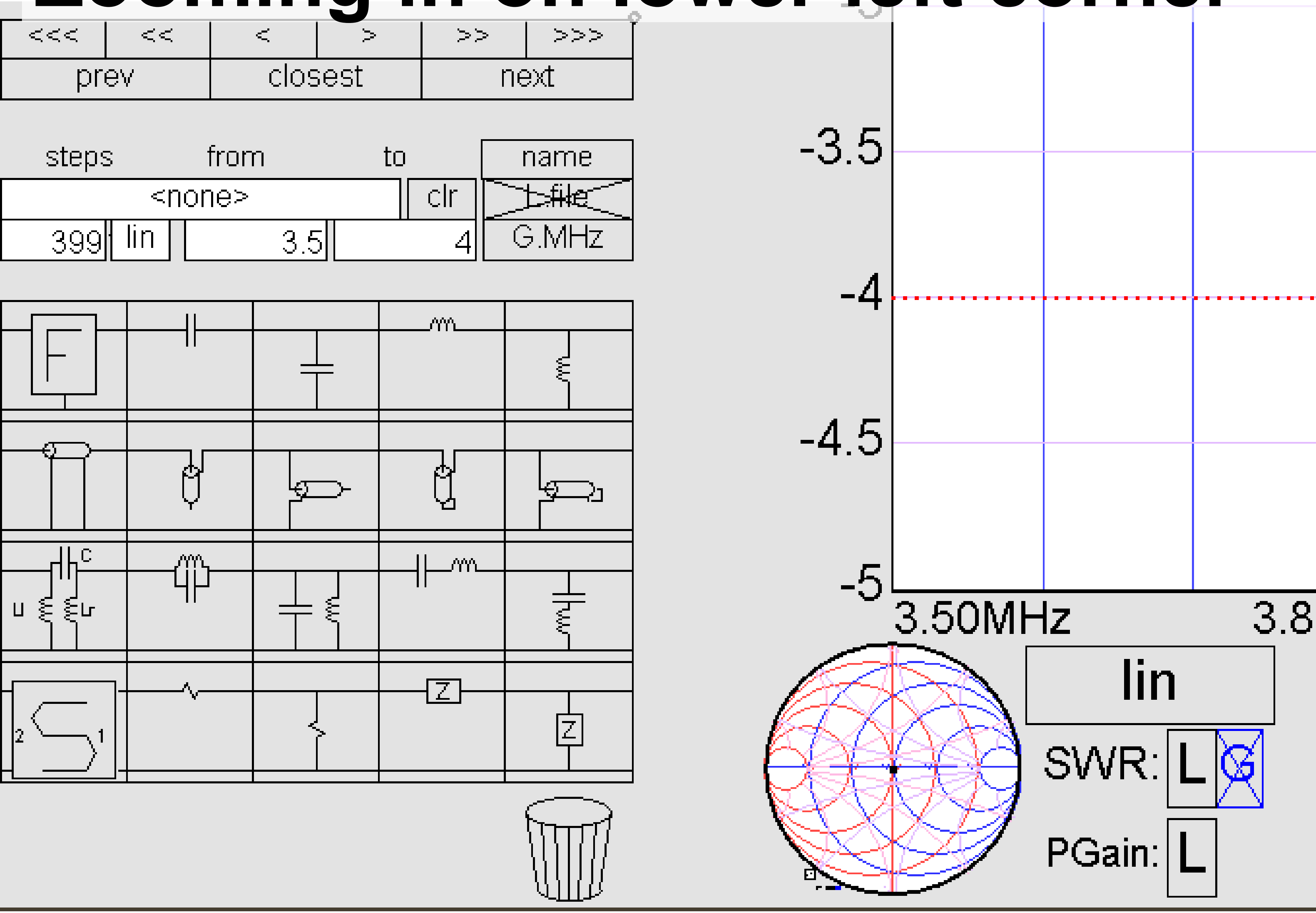

λ/4
RESISTANCE COMPONENT (R/Zo), OR CONDUCTANCE
INDUCTIVE REACTANCE COMPONENT (+jX/Zo), OR CAPACITIVE SUSCEPTANCE (+jB/Yo)
CAPACITIVE REACTANCE COMPONENT
ANGLE OF REFLECTION COEFFICIENT IN DEGREES
ANGLE OF TRANSMISSION COEFFICIENT IN DEGREES
—> WAVELENGTHS TOWARD GENERATOR —>
<— WAVELENGTHS TOWARD LOAD <—

# This Talk is About Sim Smith

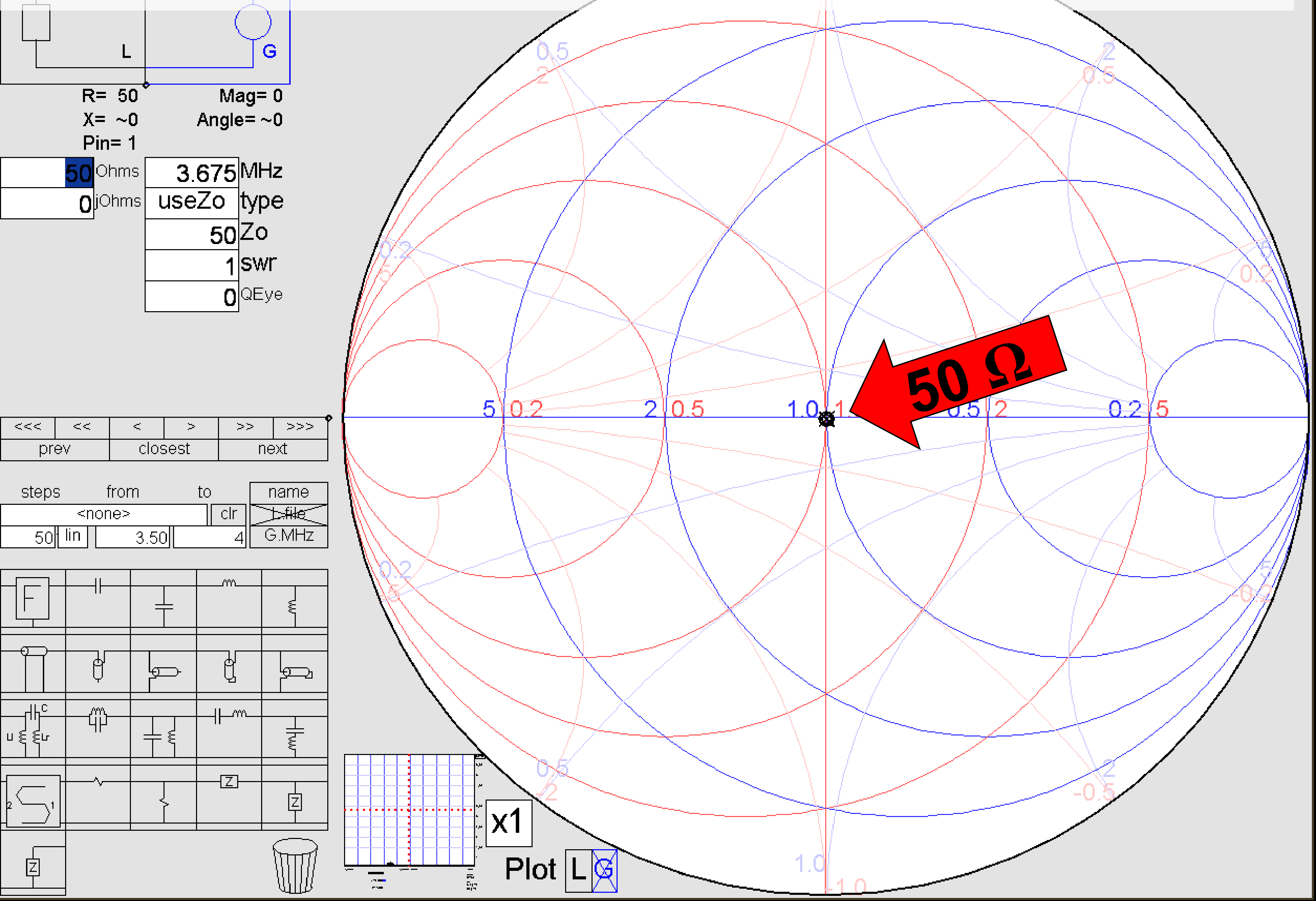
- Software that graphs transmission line problems and solves them
- We plug in our circuit, Sim Smith does all the math, graphs the result
- Sim Smith makes it easy
- It's like NEC for transmission lines
- Runs in Java
- Let's look at Sim Smith


file print library standards references help
L
G
R= 50
X= ~0
Pin= 1
Mag= 0
Angle= ~0
50 Ohms
0 jOhms
3.675 MHz
useZo type
50 Zo
1 swr
0 QEye
<<< << < > >> >>>
prev closest next
steps from to name
<none> clr
file
50 lin 3.50 4 G.MHz
x1
Plot L G
1.0
0.5
0.2
2
5

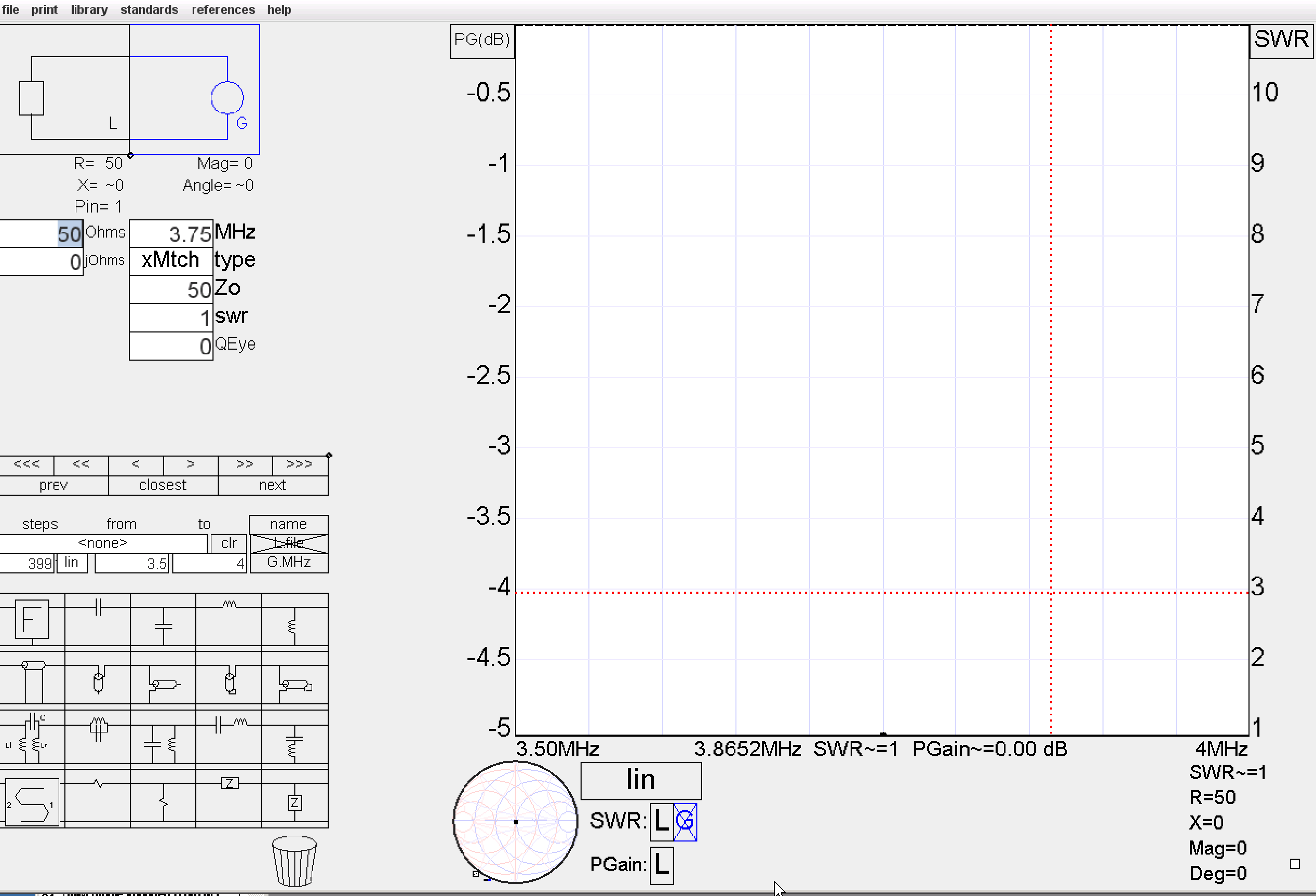
# Zooming in on lower left corner



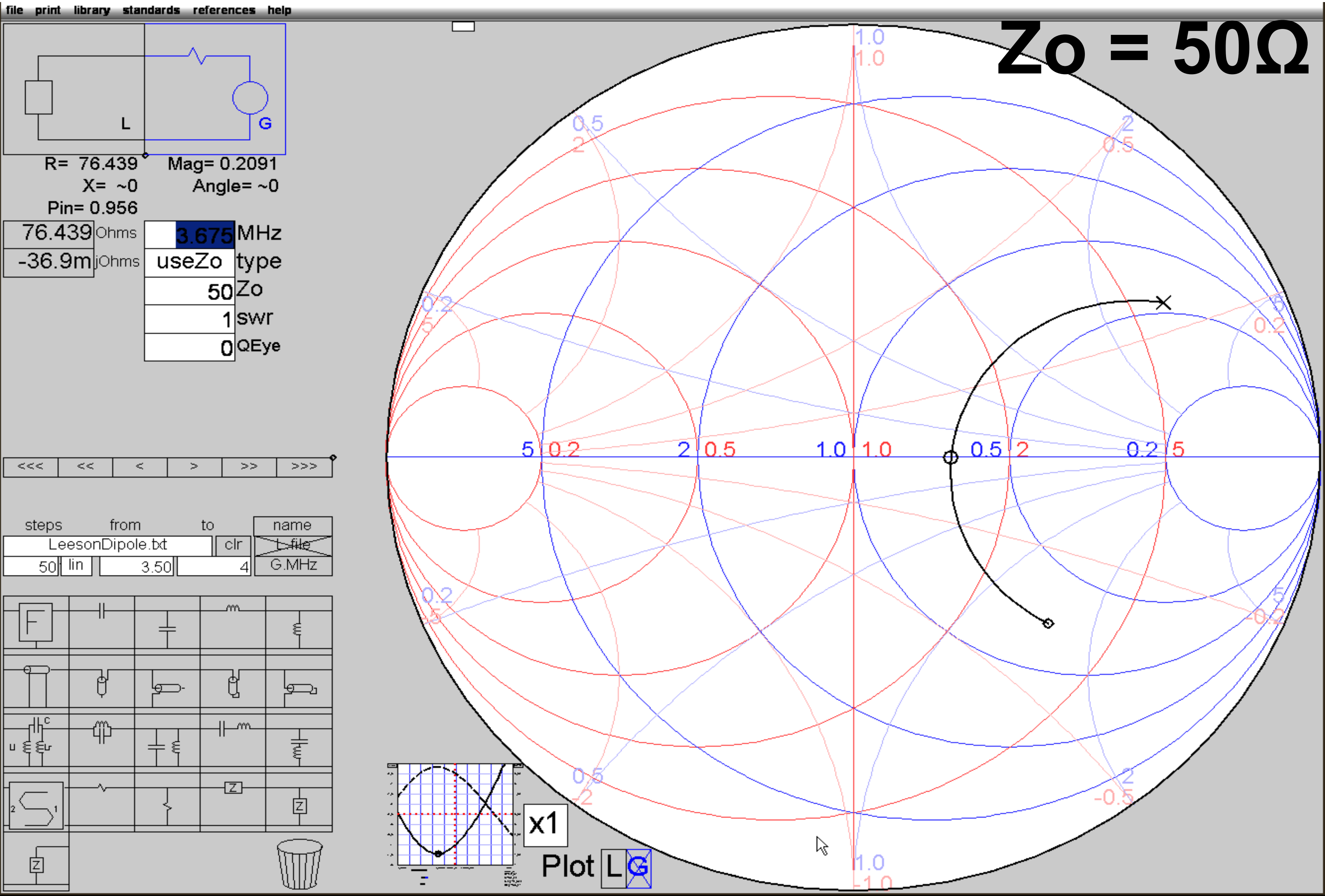
# 50Ω Plots at the Center



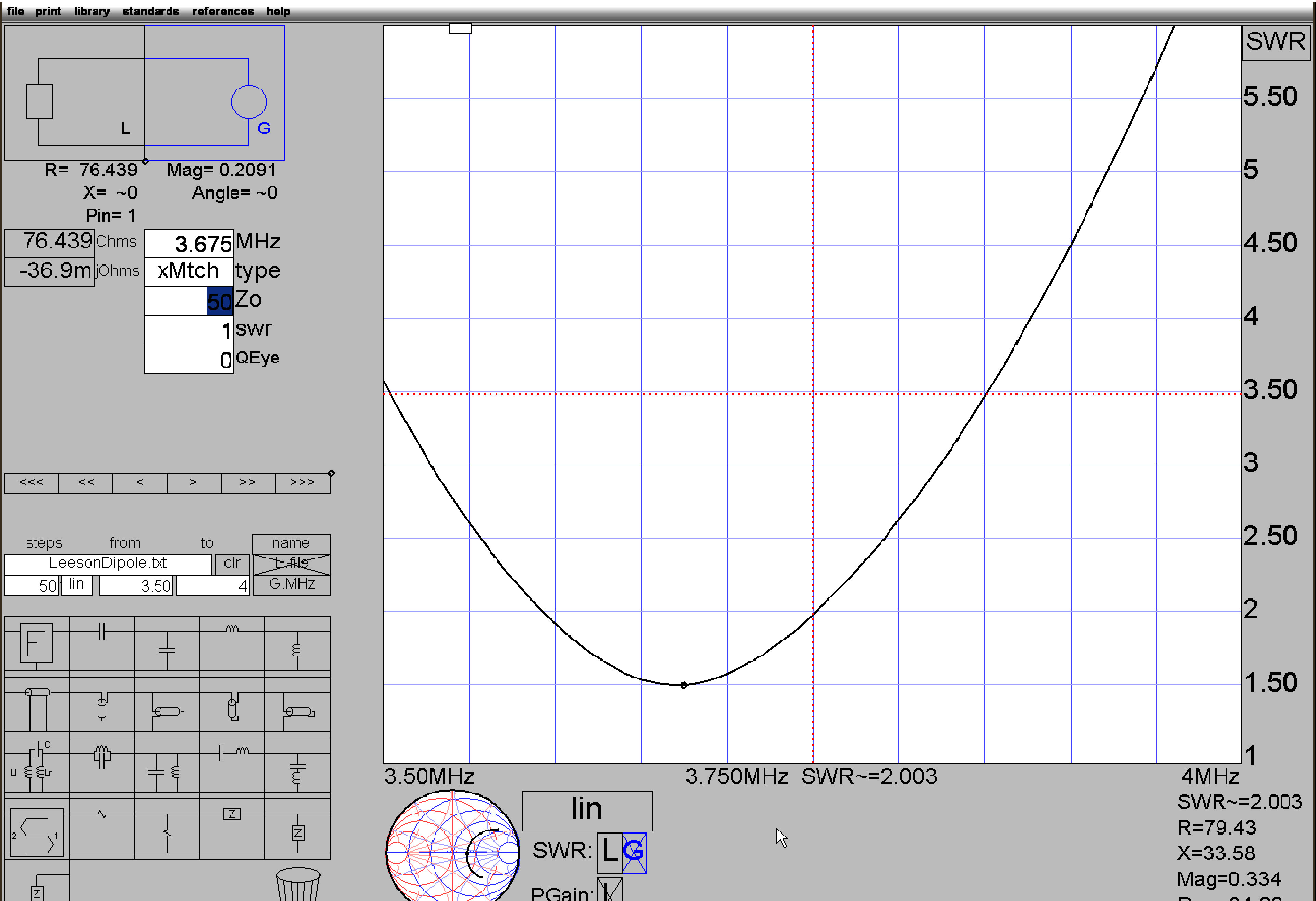
# SWR and Loss View of a Model

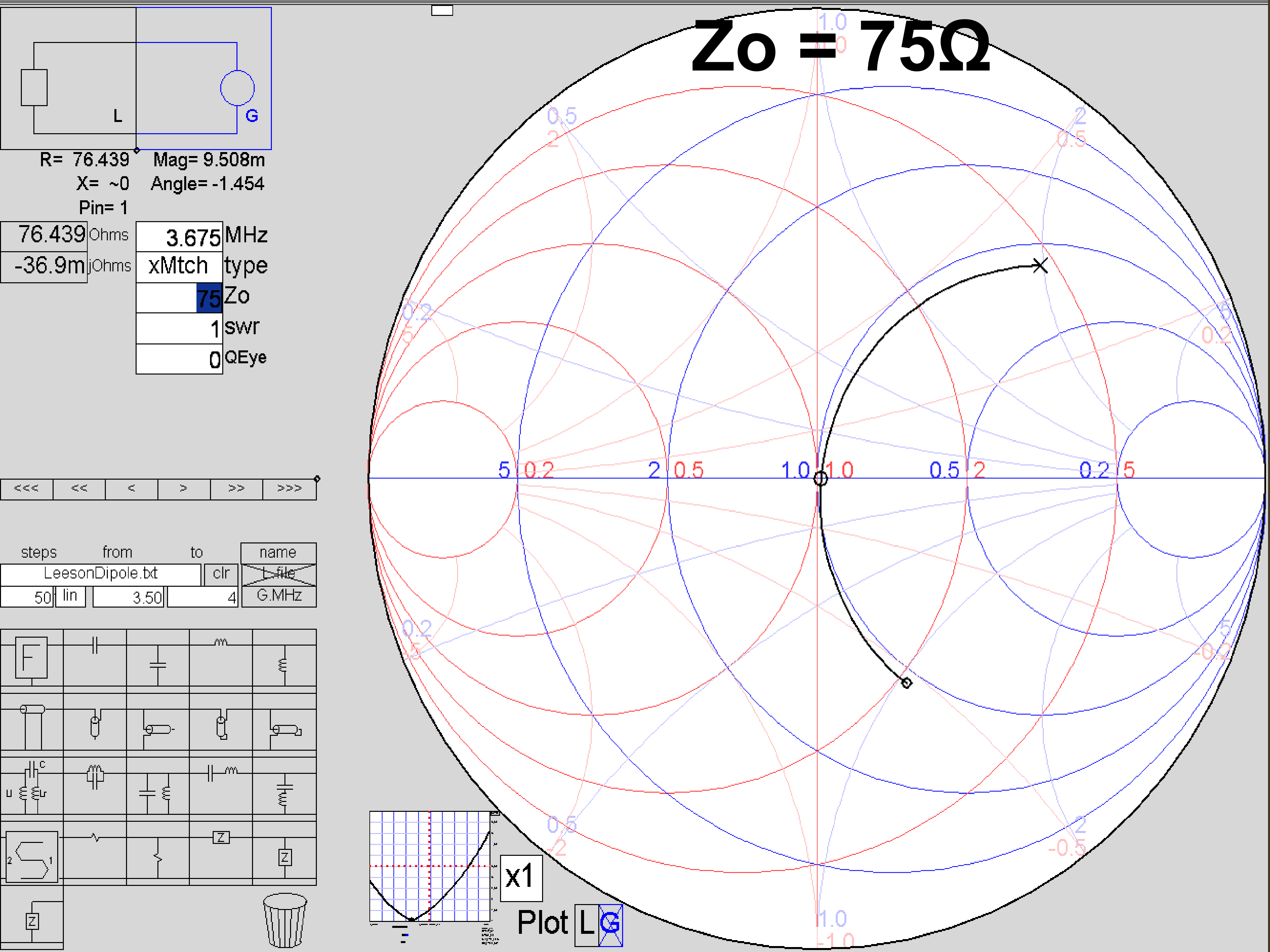


# 80M Dipole Imported From NEC, Zo = 50Ω



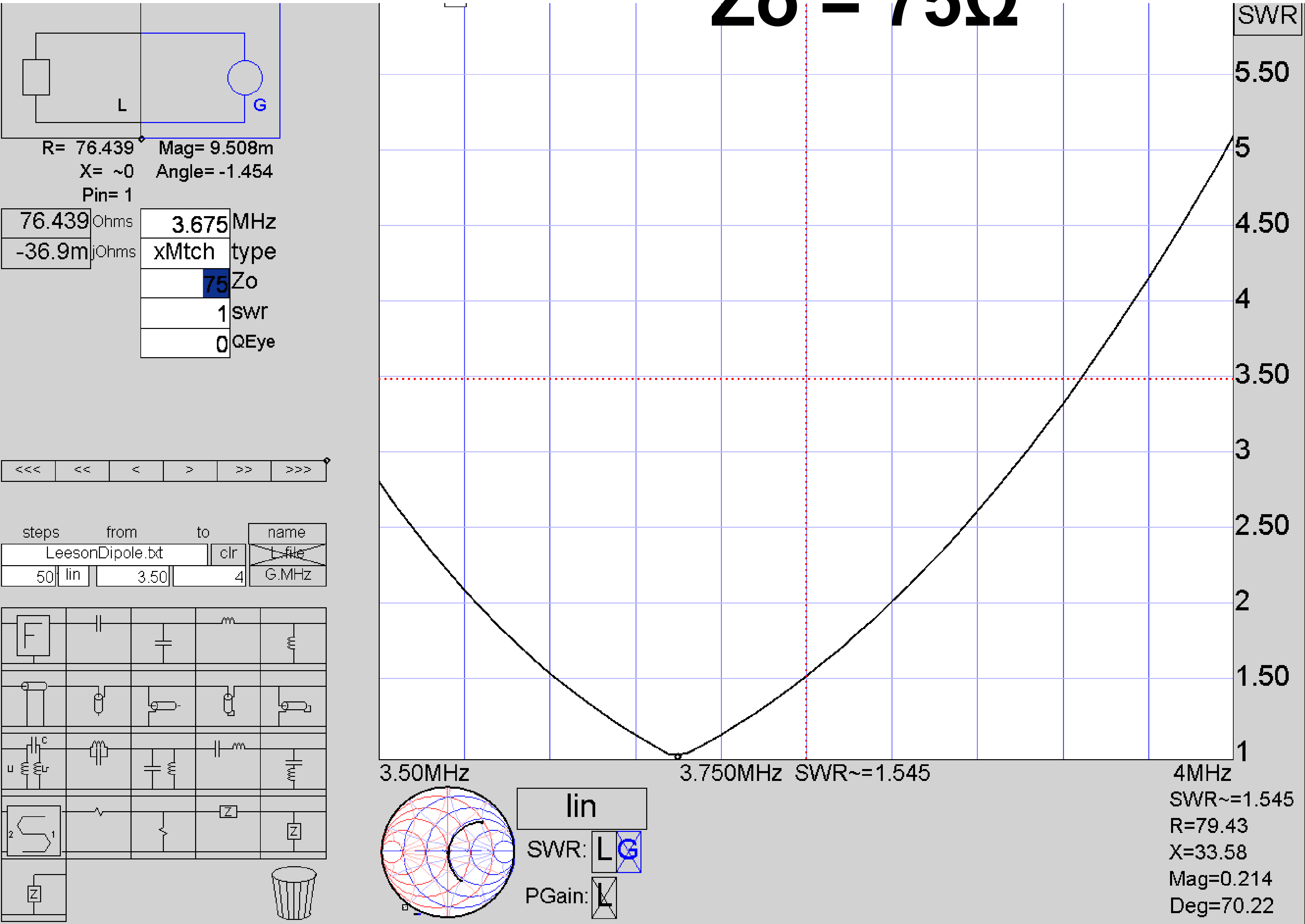
# SWR View Zo = 50Ω





Zo = 75Ω
L
G
R= 76.439
Mag= 9.508m
X= ~0
Angle= -1.454
Pin= 1
76.439 Ohms
-36.9m jOhms
3.675 MHz
xMtch type
75 Zo
1 swr
0 QEye
<<< << < > >> >>>
steps from to name
LeesonDipole.txt
clr
L file
50 lin 3.50 4
G.MHz
x1
Plot L G

# Zo = 75Ω


L
G
R= 76.439
X= ~0
Pin= 1
Mag= 9.508m
Angle= -1.454
76.439 Ohms
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xMtch type
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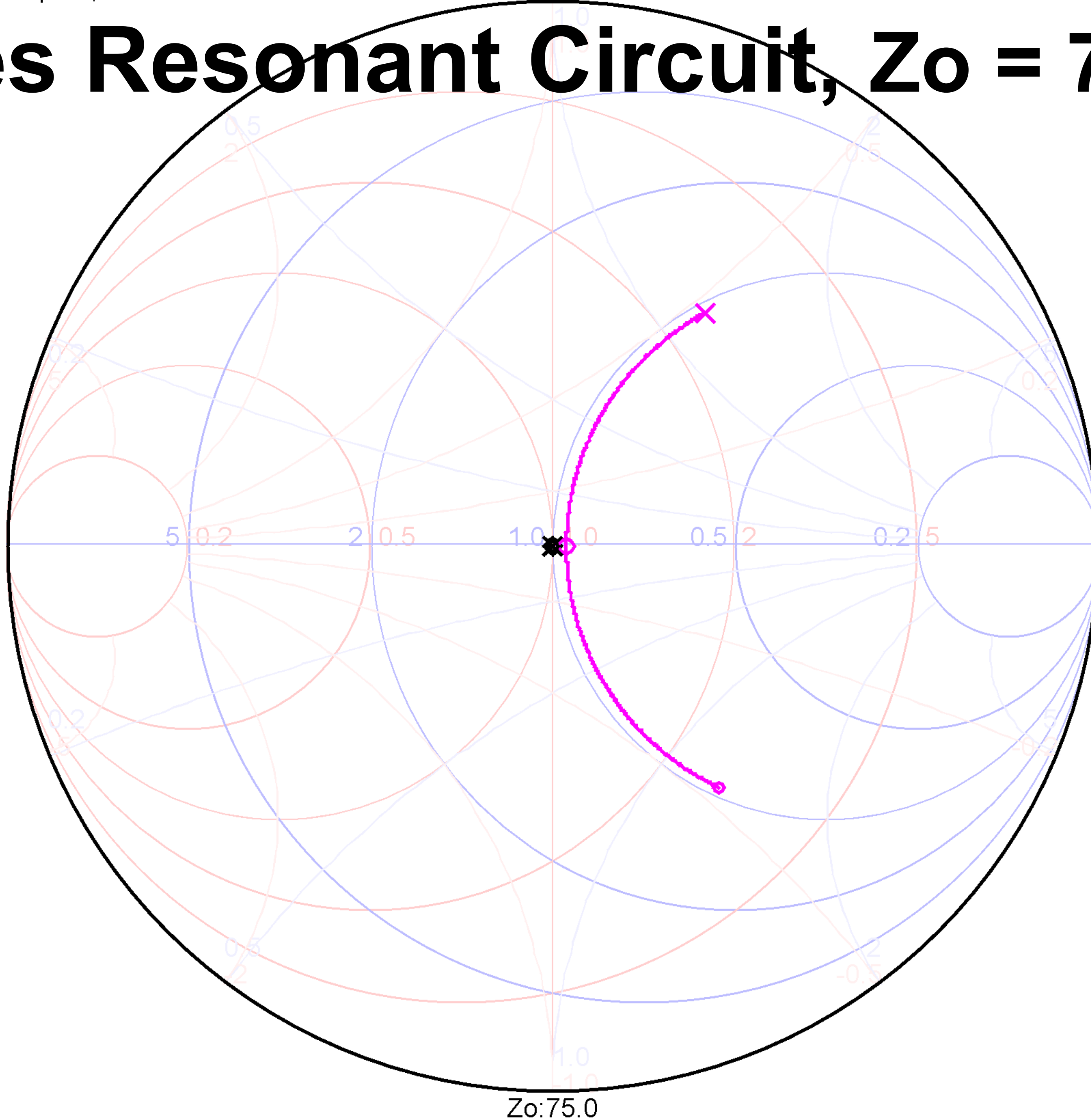
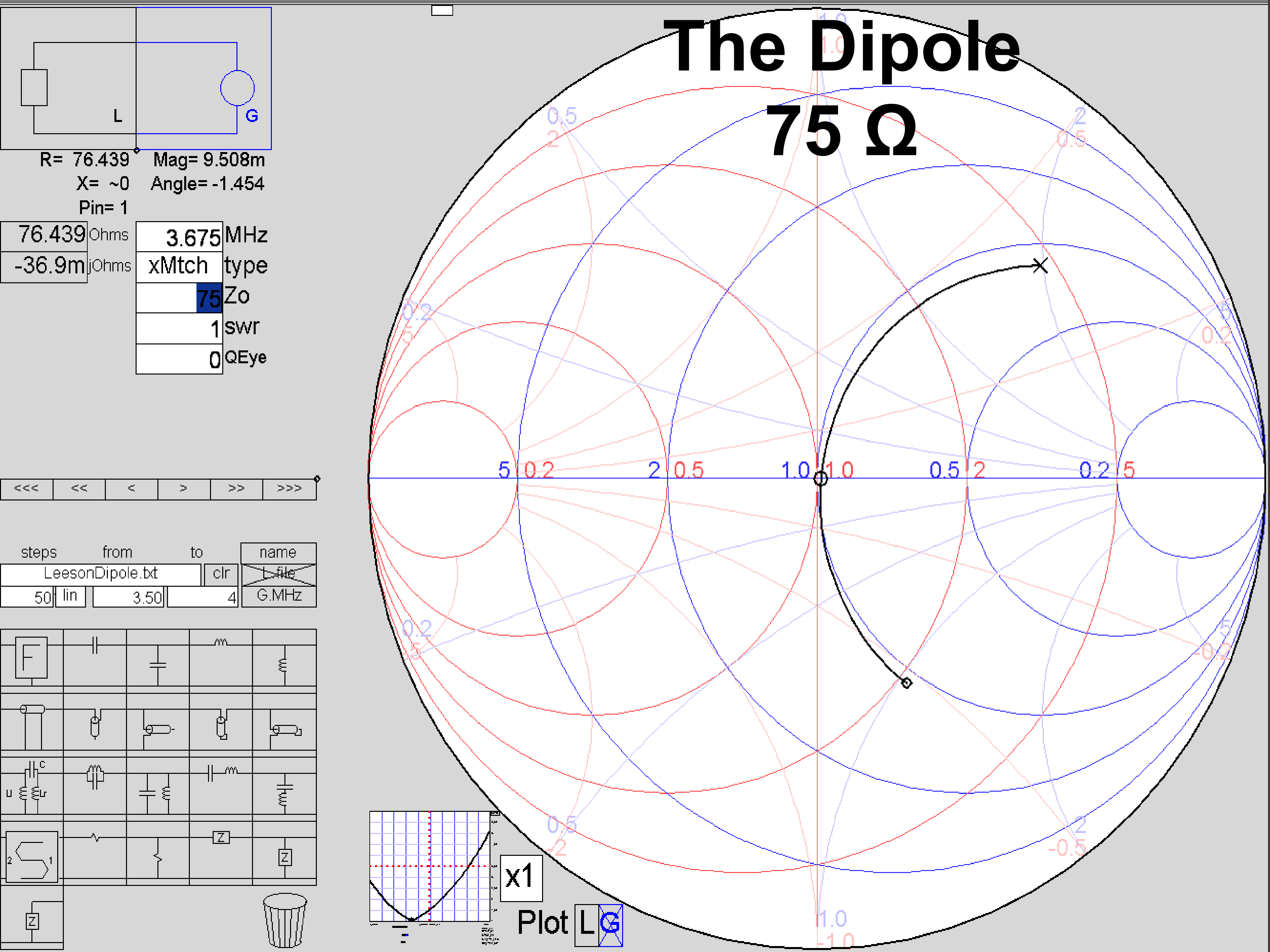
1 swr
0 QEye
steps
from
to
name
LeesonDipole.txt
clr
L file
50
lin
3.50
4
G.MHz
SWR
5.50
5
4.50
4
3.50
3
2.50
2
1.50
1
3.50MHz
3.750MHz SWR~=1.545
4MHz
lin
SWR:
PGain:
SWR~=1.545
R=79.43
X=33.58
Mag=0.214
Deg=70.22

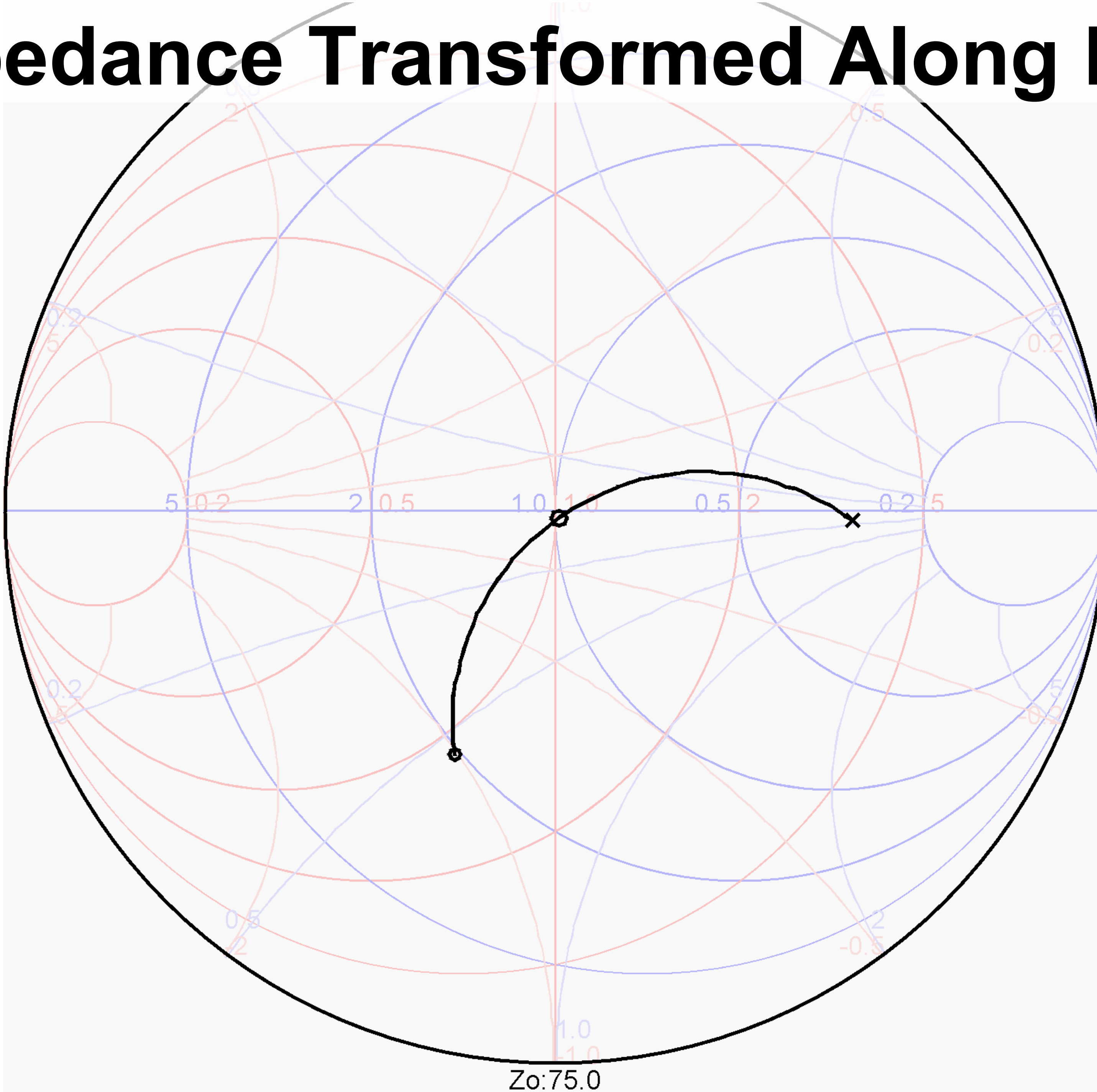
# Series Resonant Circuit, Zo = 75Ω



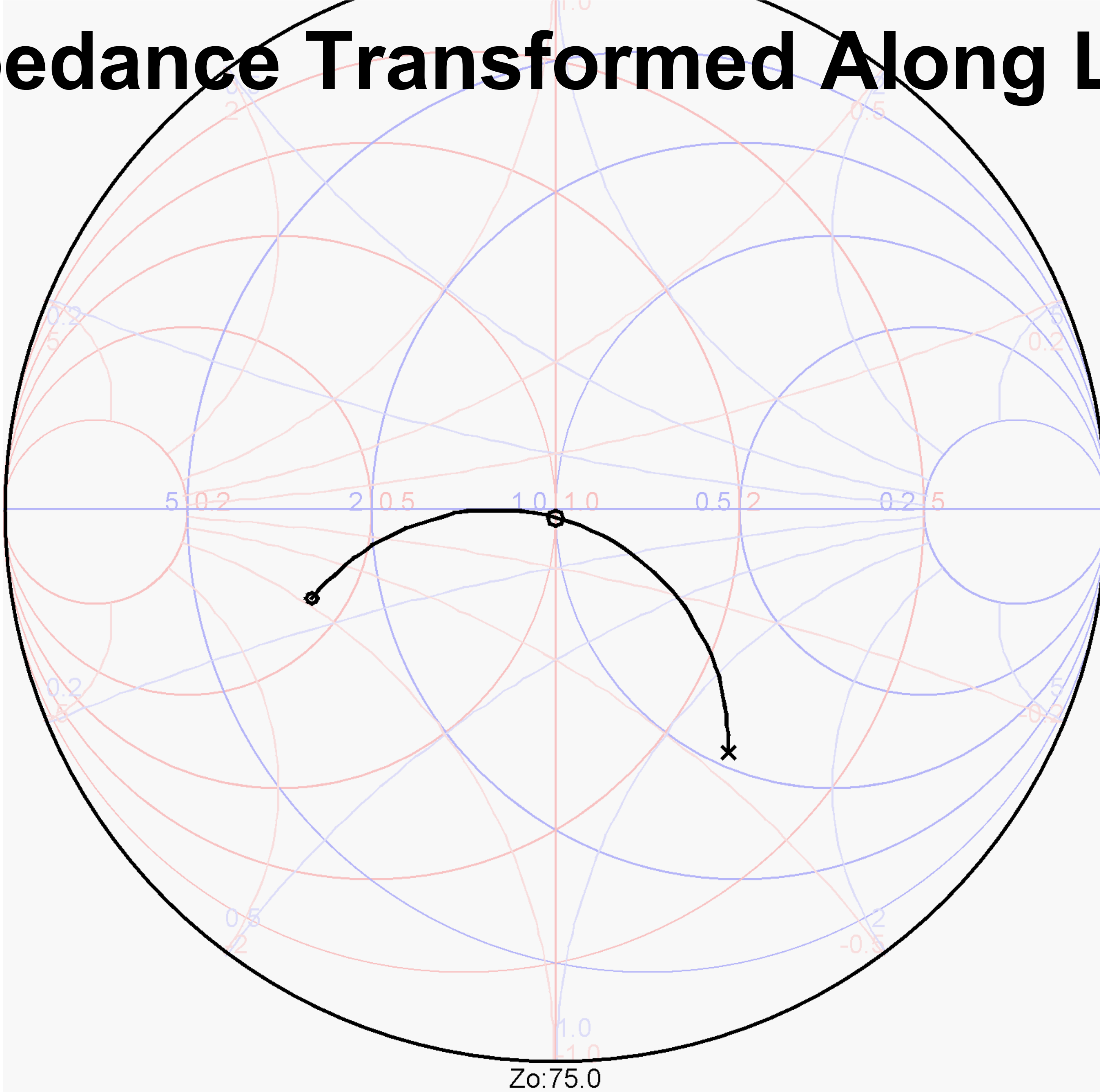
# The Dipole 75 Ω



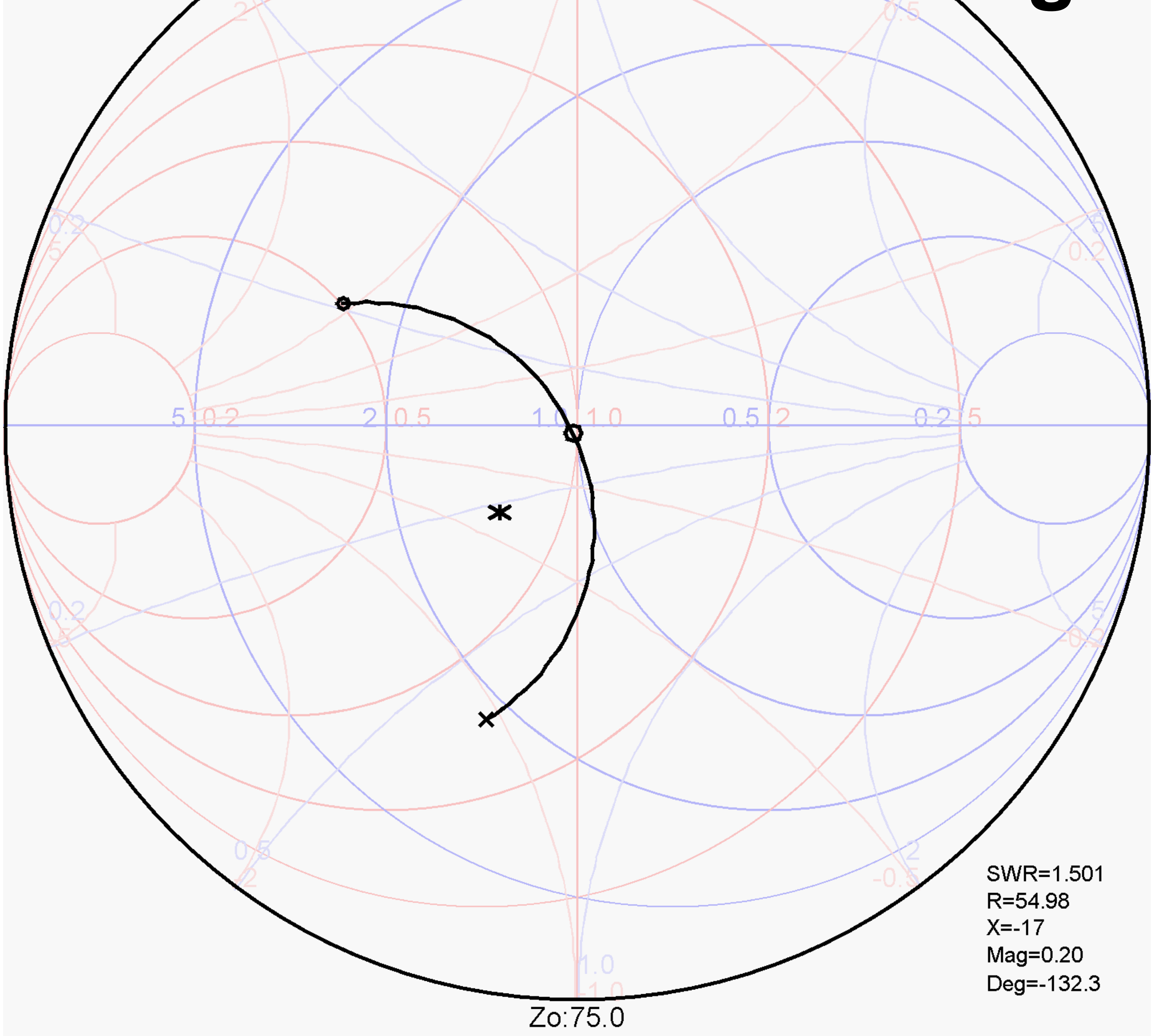
# Impedance Transformed Along Line



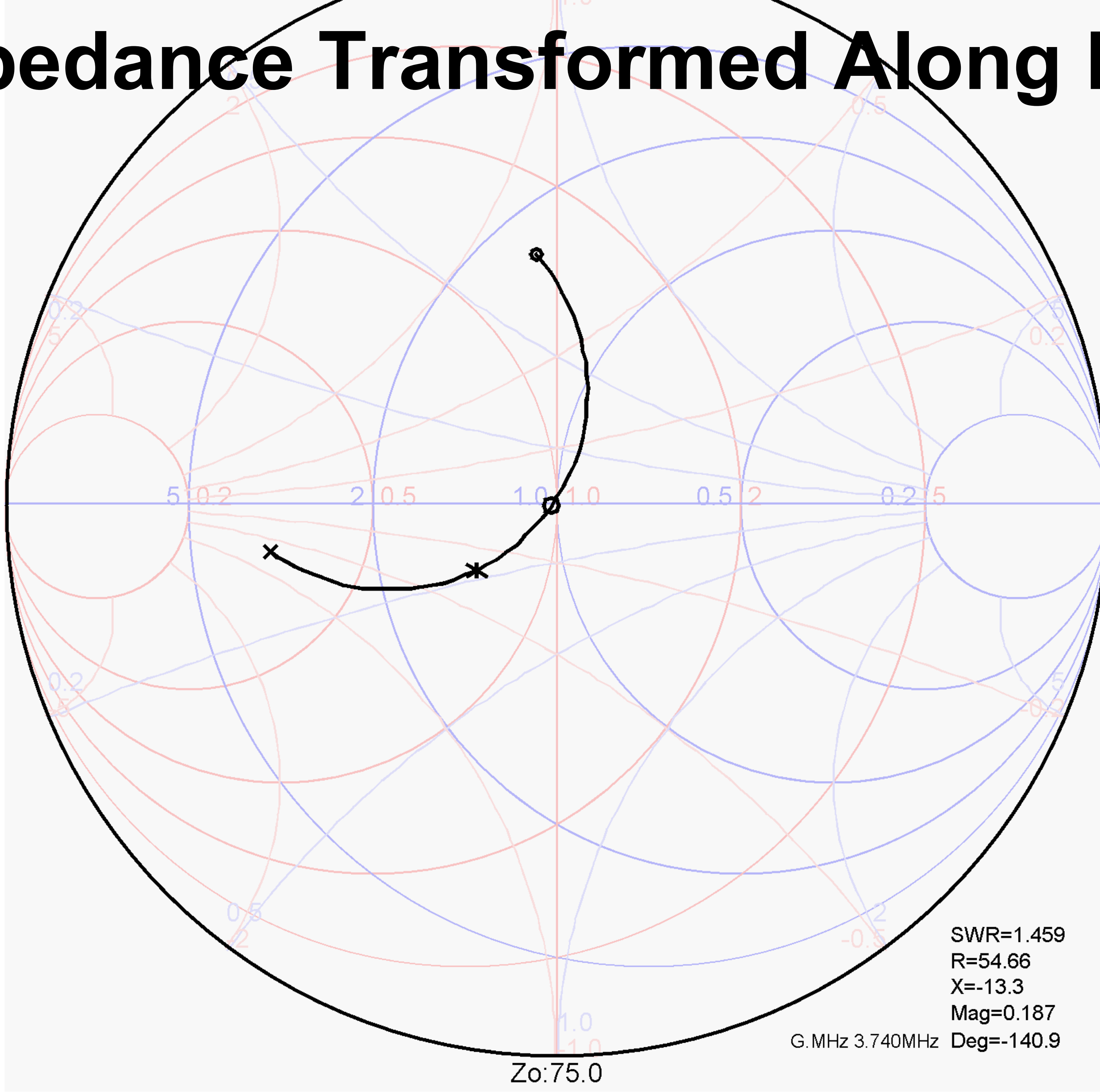
# Impedance Transformed Along Line



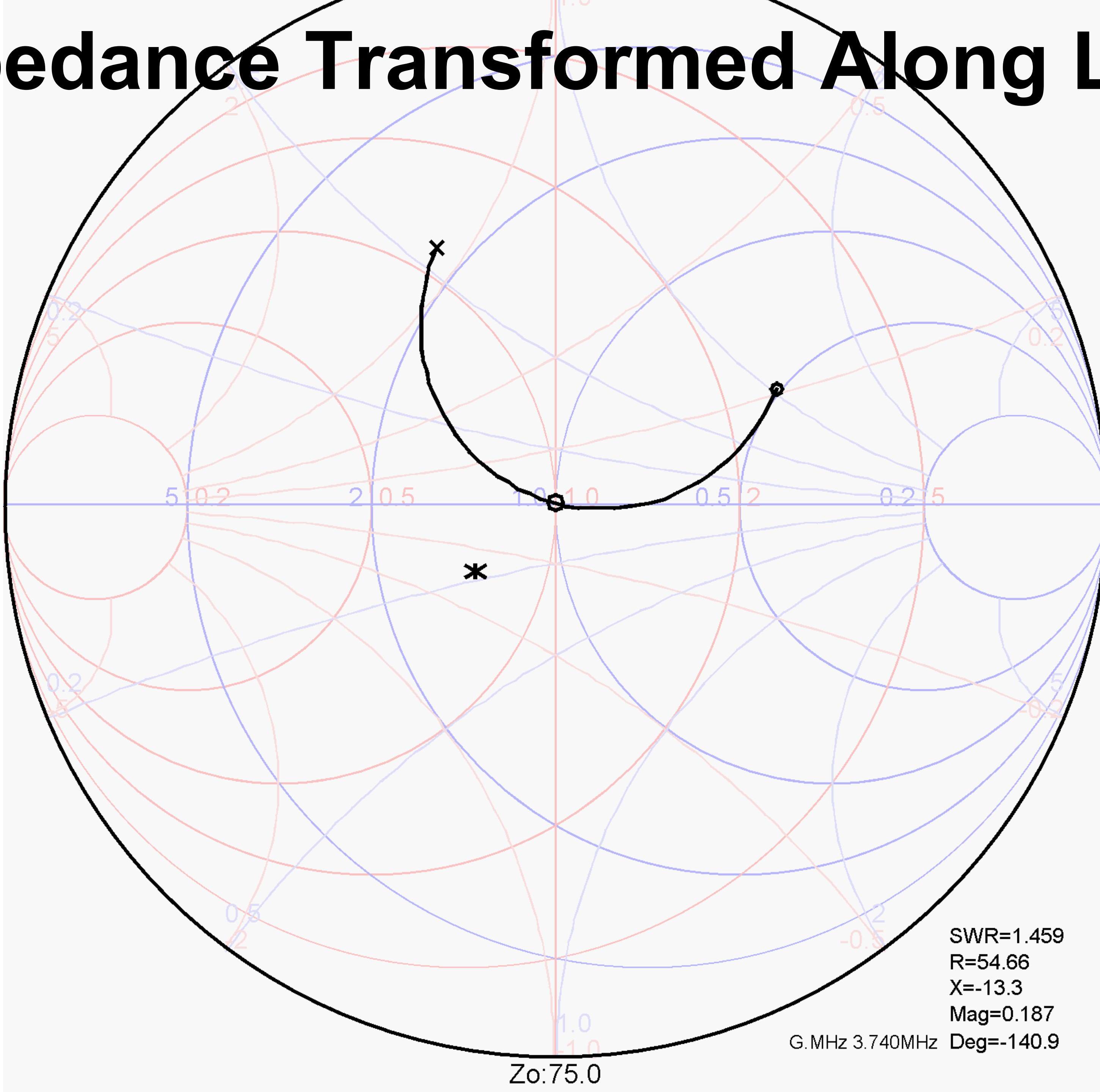
# Impedance Transformed Along Line



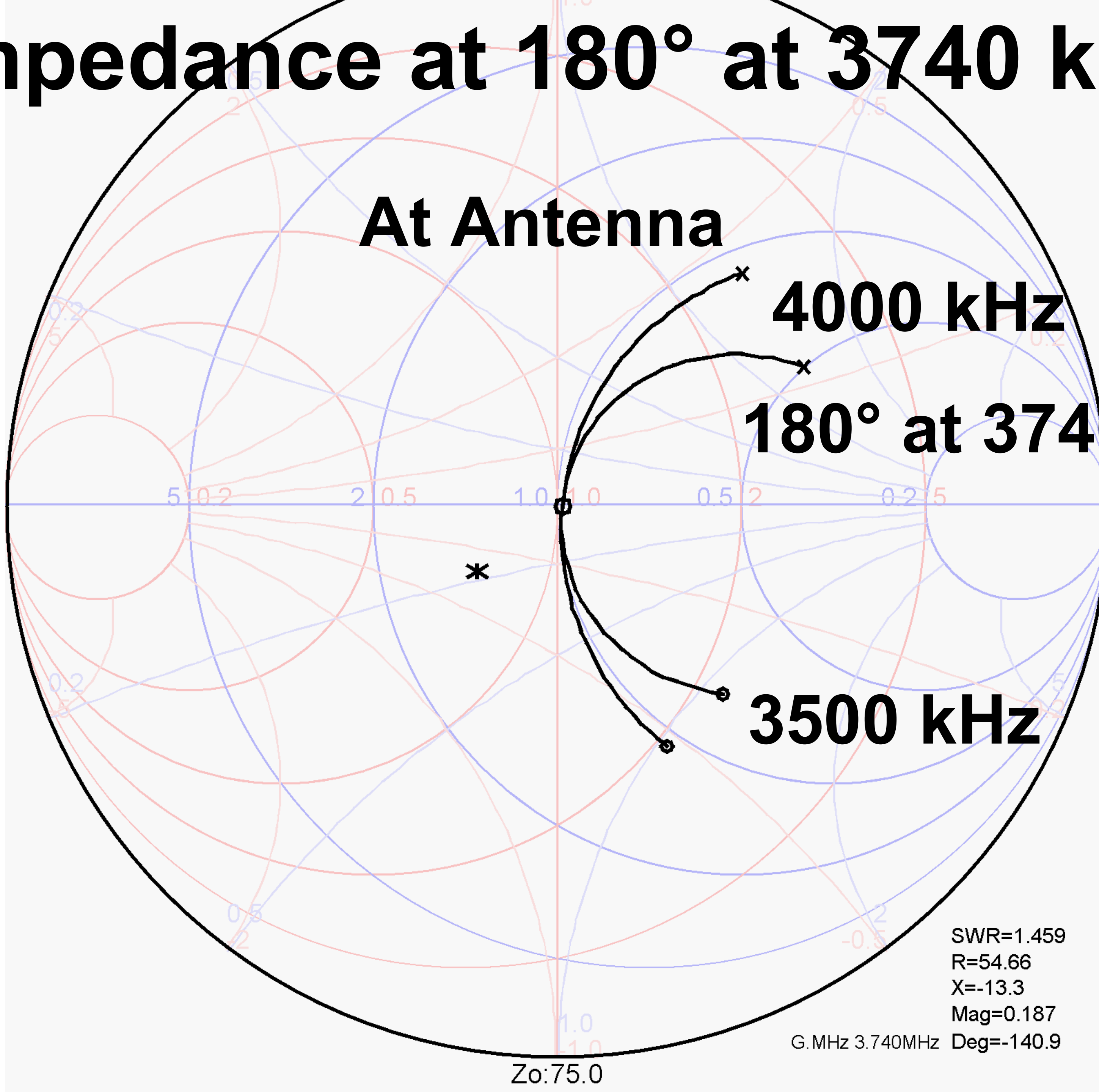
# Impedance Transformed Along Line



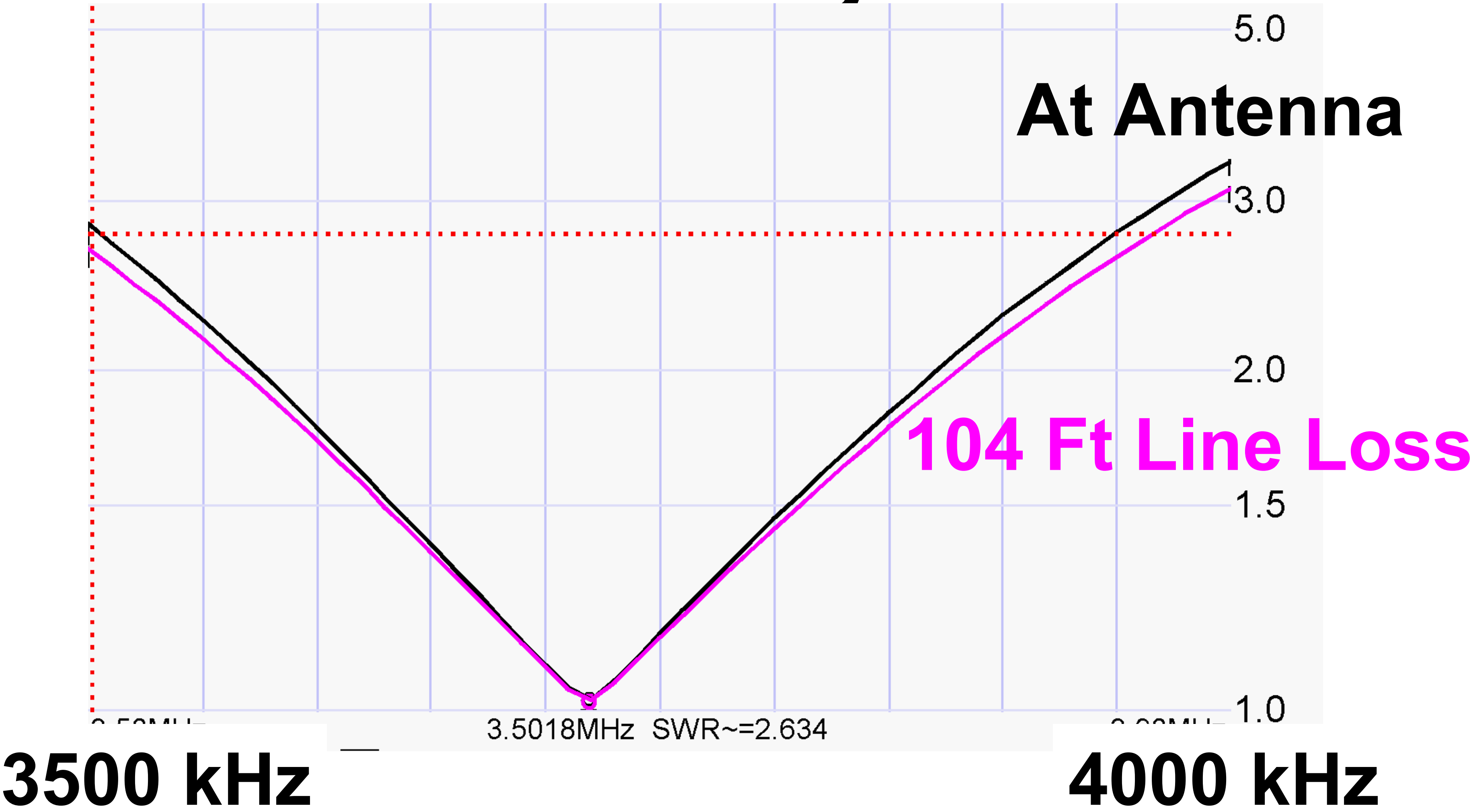
# Impedance Transformed Along Line



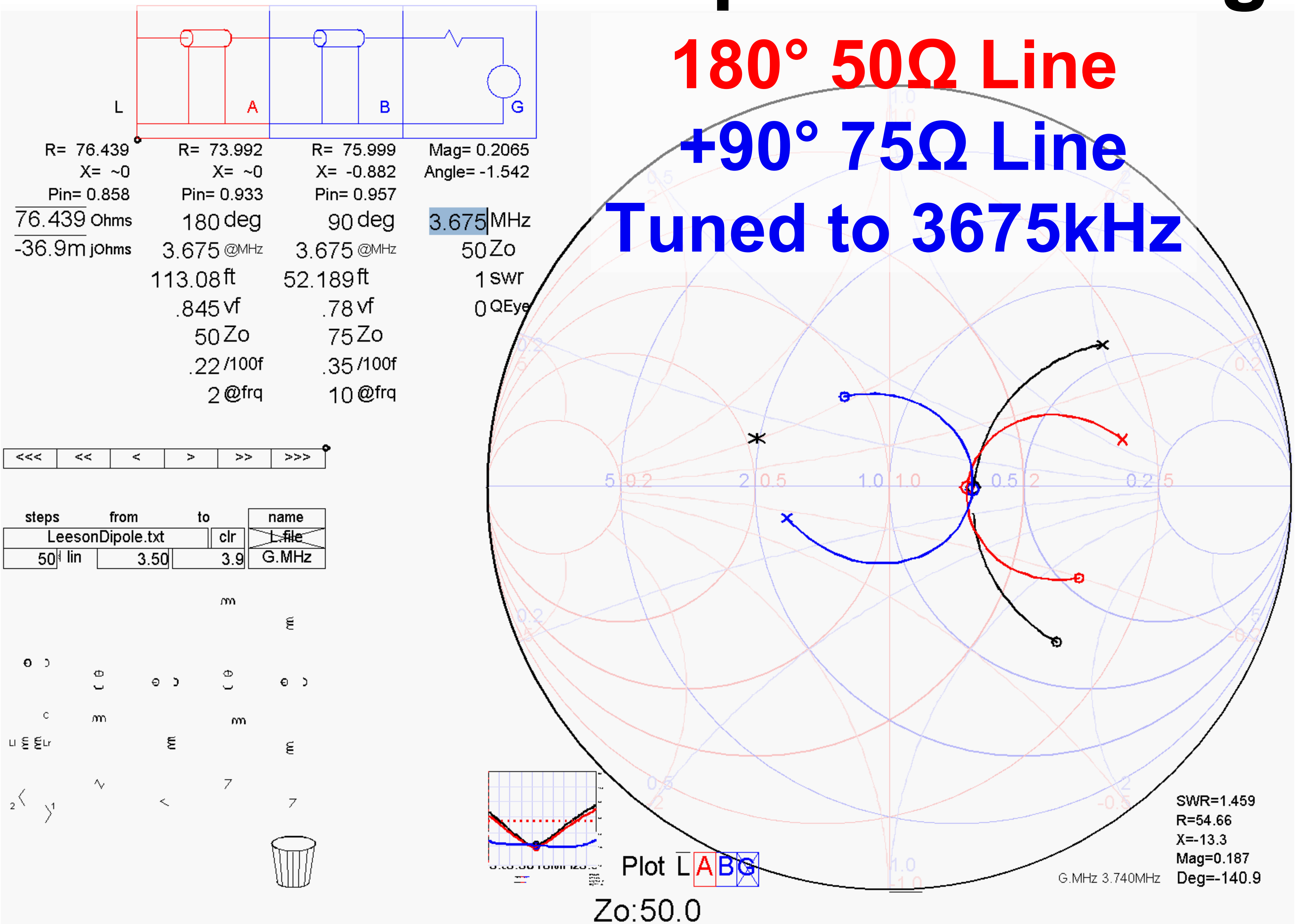
# Impedance at 180° at 3740 kHz



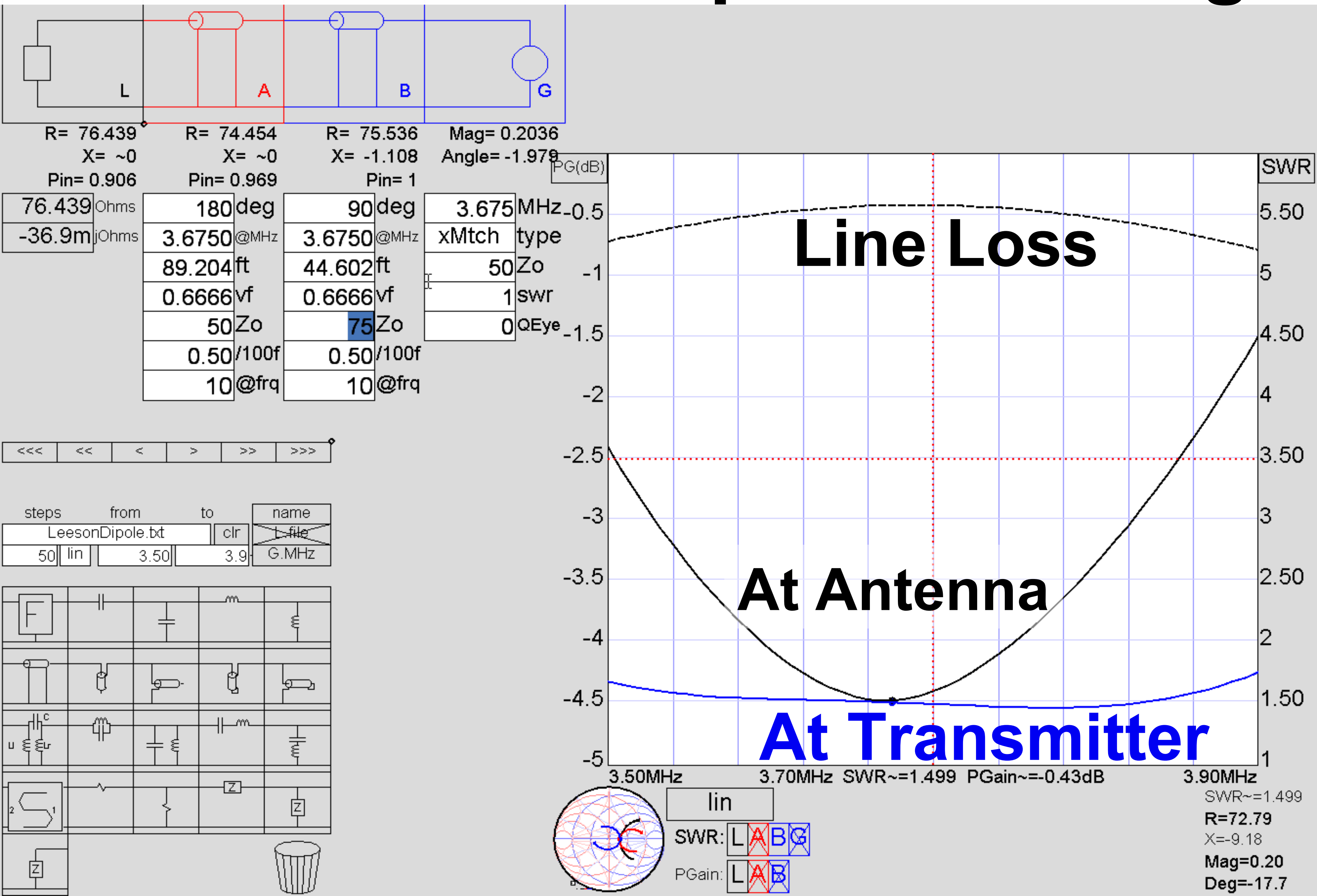
# SWR Reduced By Line Loss

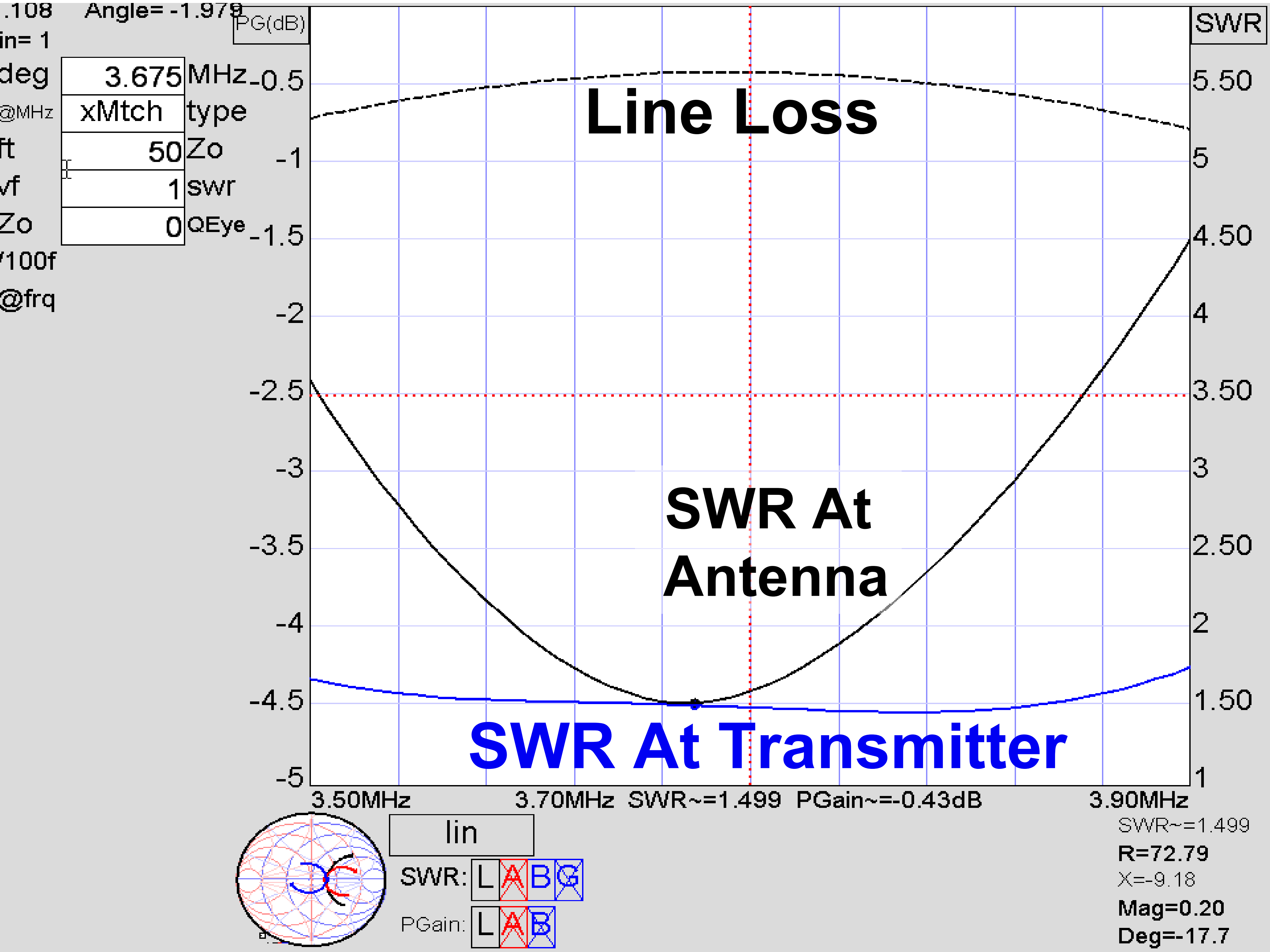


# “Leeson” 80M Dipole Matching

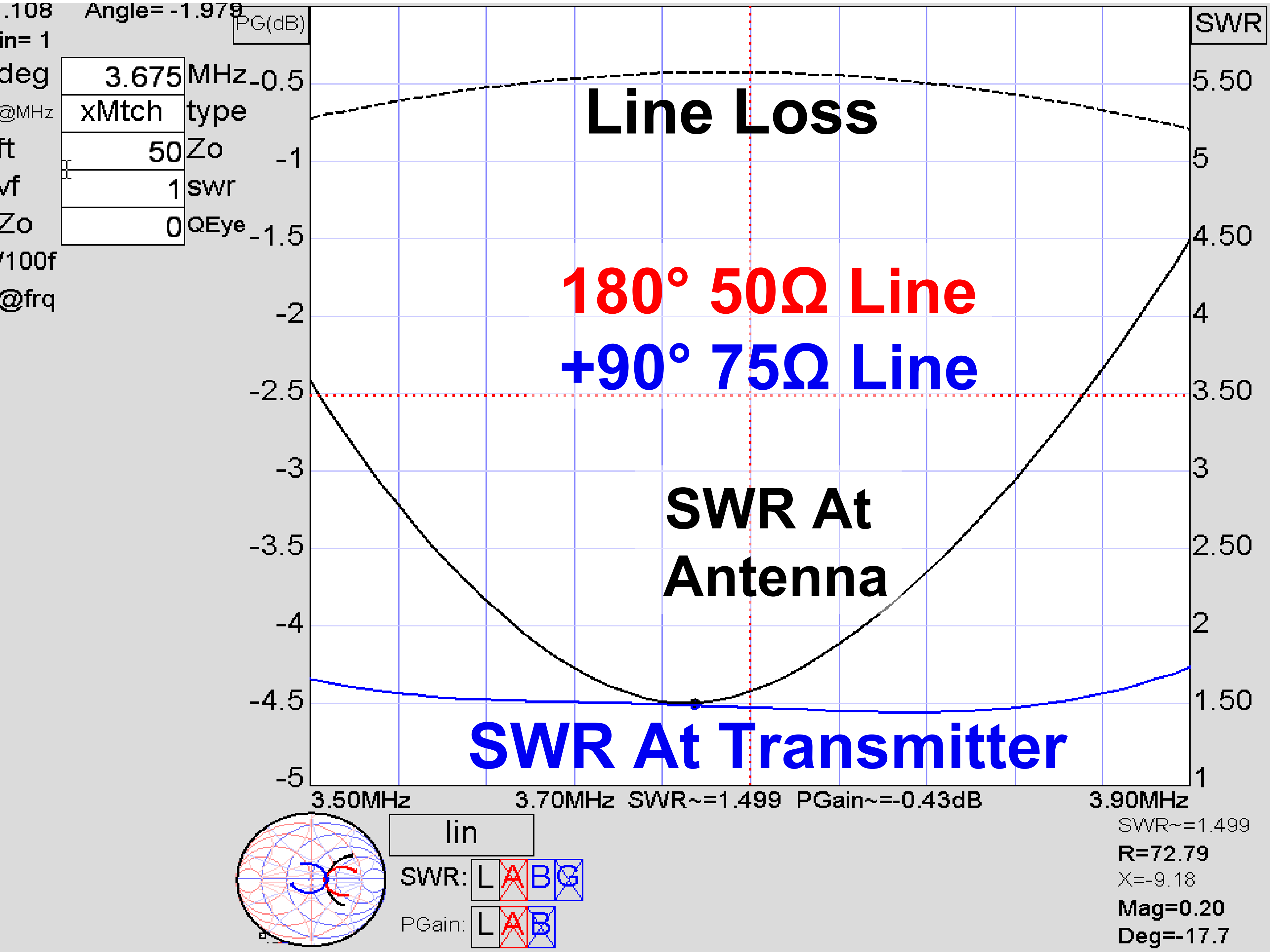


# "Leeson" 80M Dipole Matching



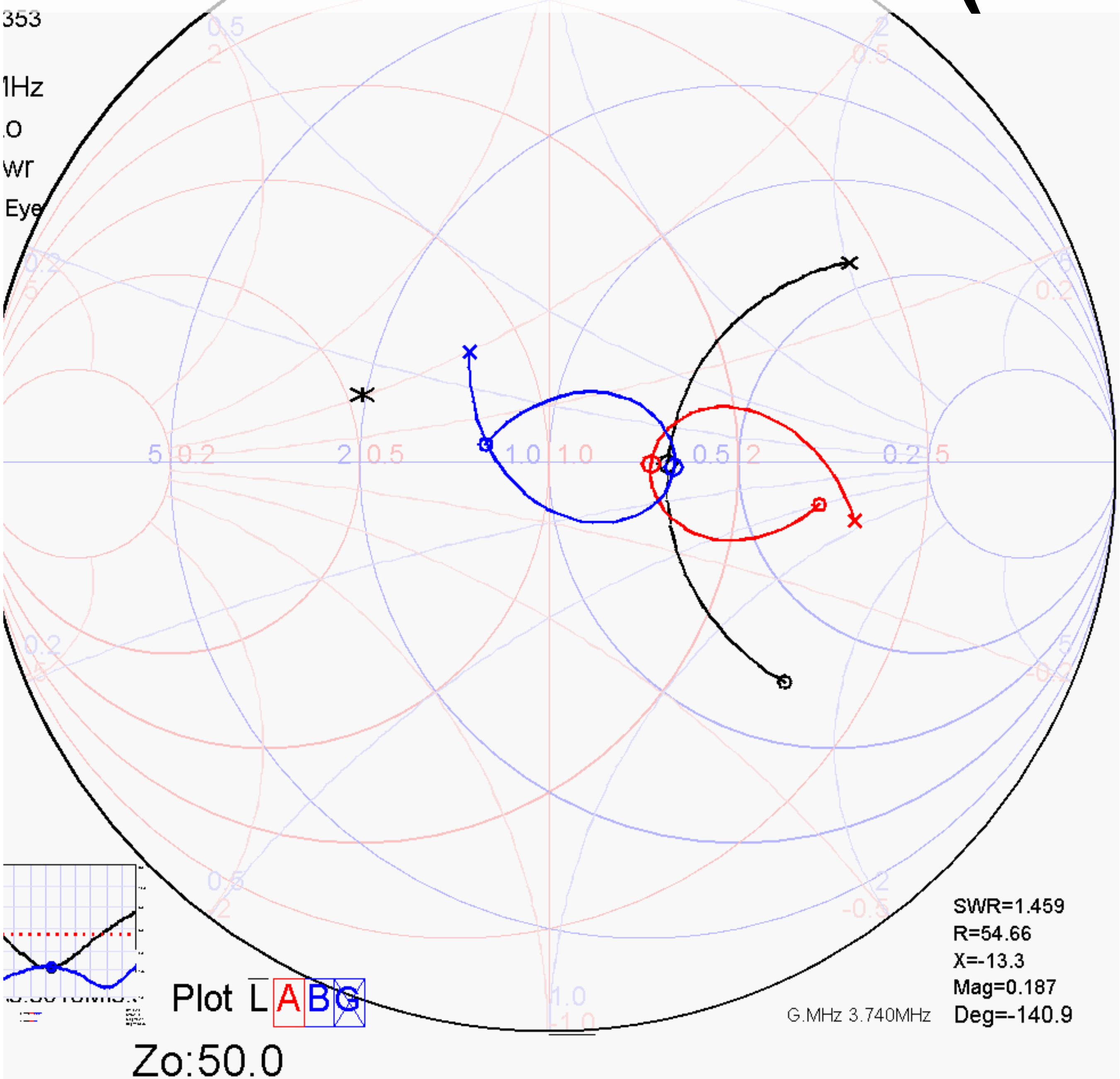


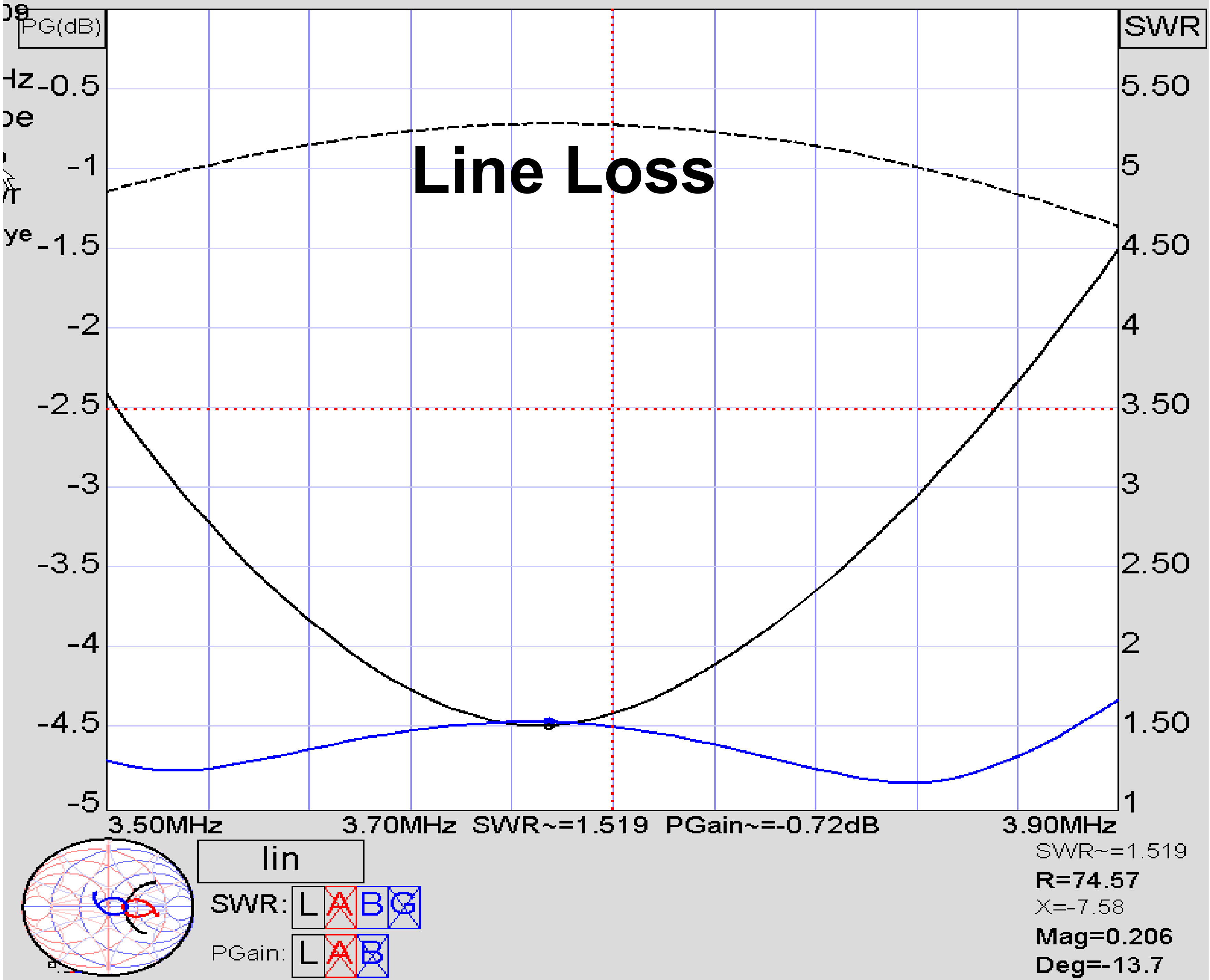
.108 Angle= -1.979
in= 1
deg
3.675 MHz
@MHz
xMtch type
ft
50 Zo
vf
1 swr
Zo
0 QEye
/100f
@frq
PG(dB)
SWR
Line Loss
SWR At Antenna
SWR At Transmitter
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
5.50
5
4.50
4
3.50
3
2.50
2
1.50
1
3.50MHz
3.70MHz
SWR~=1.499
PGain~=-0.43dB
3.90MHz
SWR~=1.499
R=72.79
X=-9.18
Mag=0.20
Deg=-17.7
lin
SWR:
L A B G
PGain:
L A B



.108 Angle= -1.979
in= 1
deg
@MHz
ft
vf
Zo
/100f
@frq
3.675 MHz
xMtch type
50 Zo
1 swr
0 QEye
PG(dB)
SWR
Line Loss
180° 50Ω Line
+90° 75Ω Line
SWR At
Antenna
SWR At Transmitter
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
5.50
5
4.50
4
3.50
3
2.50
2
1.50
1
3.50MHz
3.70MHz
SWR~=1.499
PGain~=-0.43dB
3.90MHz
lin
SWR: L A B G
PGain: L A B
SWR~=1.499
R=72.79
X=-9.18
Mag=0.20
Deg=-17.7

# One More Time Around (360°)

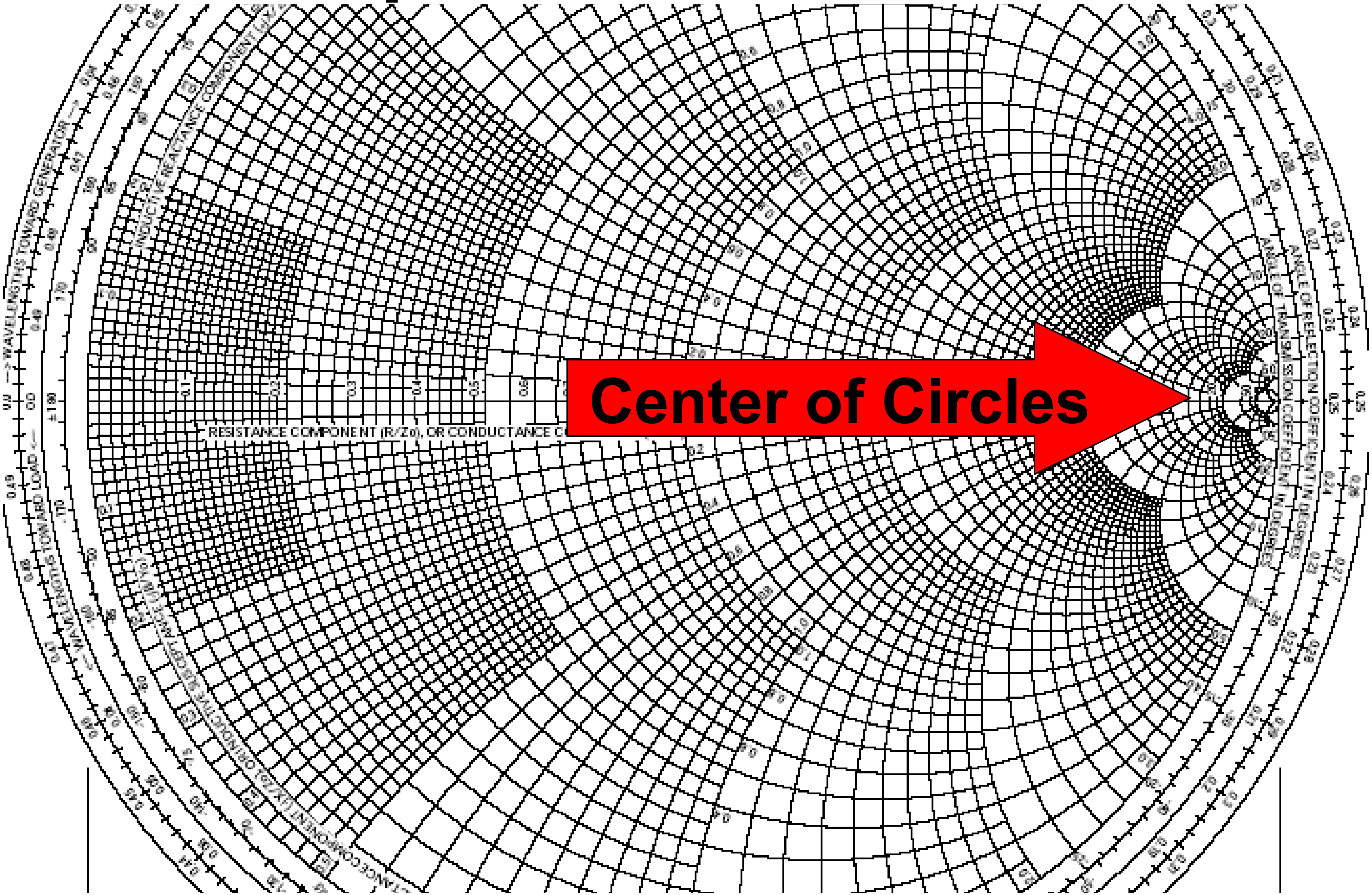



PG(dB)
SWR
Line Loss
-0.5
-1
-1.5
-2
-2.5
-3
-3.5
-4
-4.5
-5
5.50
5
4.50
4
3.50
3
2.50
2
1.50
1
3.50MHz
3.70MHz
SWR~=1.519
PGain~=-0.72dB
3.90MHz
lin
SWR: L A B G
PGain: L A B
SWR~=1.519
R=74.57
X=-7.58
Mag=0.206
Deg=-13.7

# Designing Matching Networks

- We need to learn a bit more about the Smith Chart to design networks
- There are two versions of the Smith Chart
- The standard version works with impedance (Z = R + jX Ohms)
  - Good for adding series reactance to a circuit
  - Centers of circles are on the right

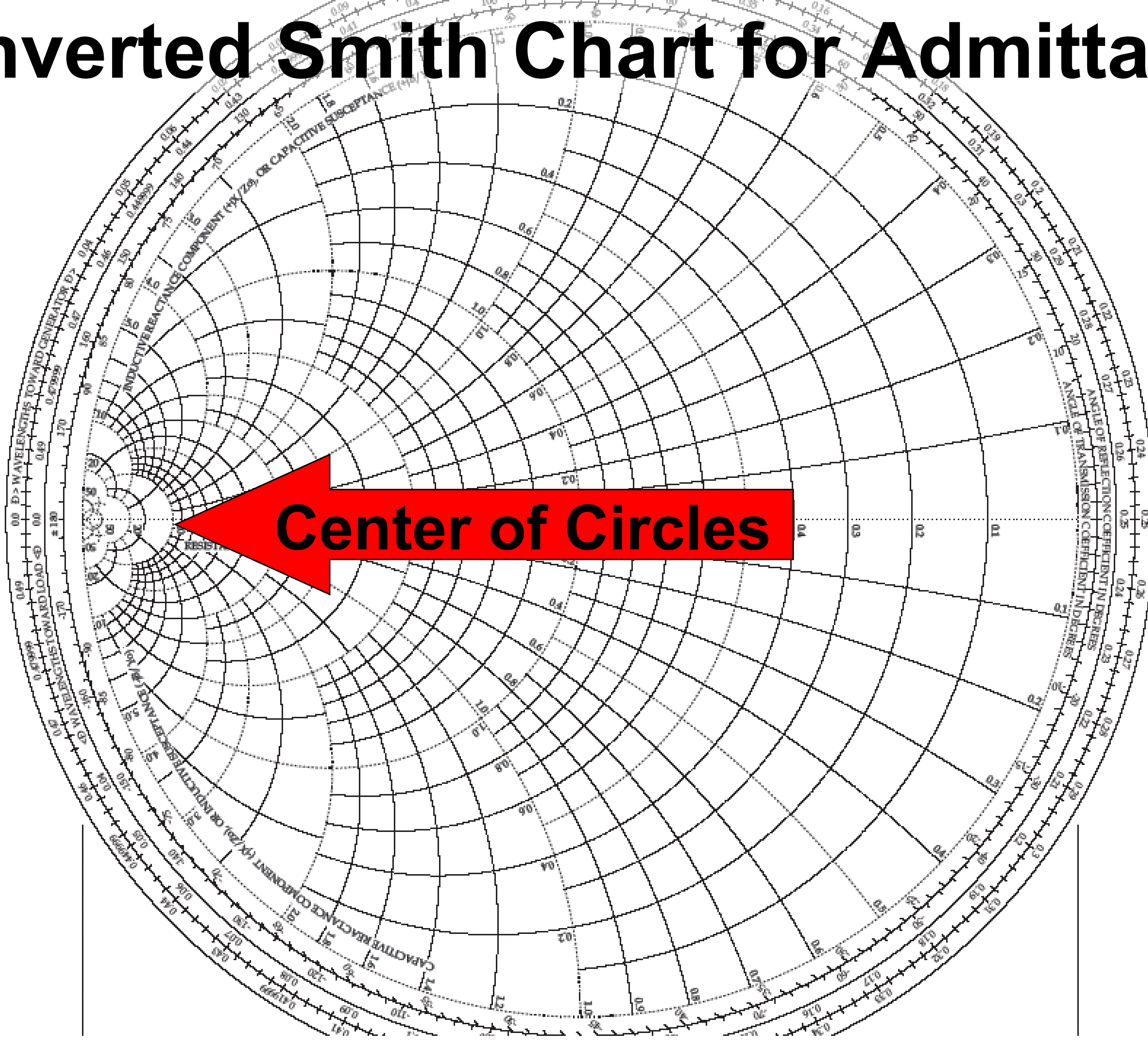
# The Impedance Smith Chart



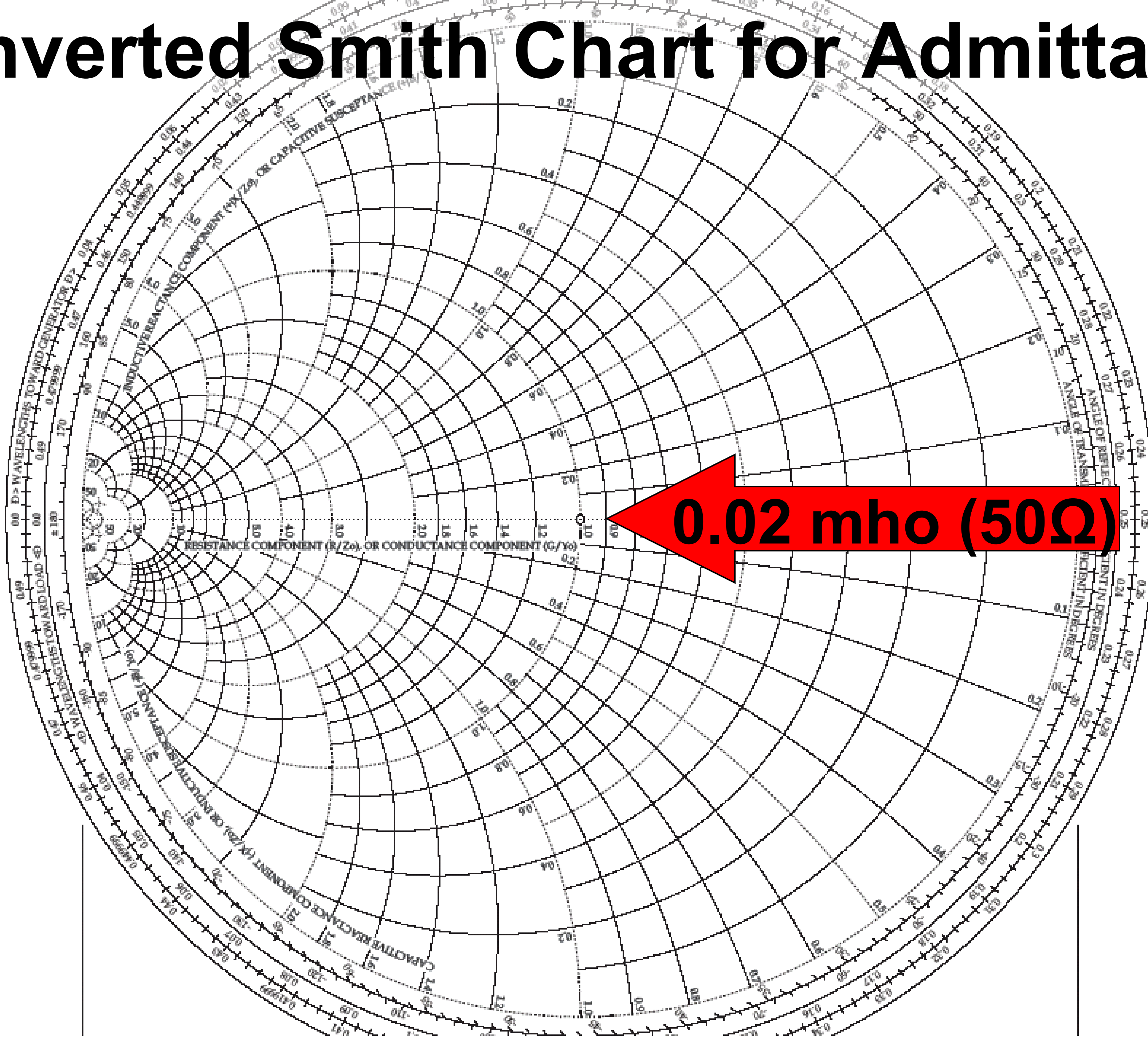
# Two Versions of Smith Chart

- **The inverted version works with admittance (Y = G +jB)**
  - **Good for adding components in <u>parallel</u> in a circuit**
- **Centers of circles are on the left**

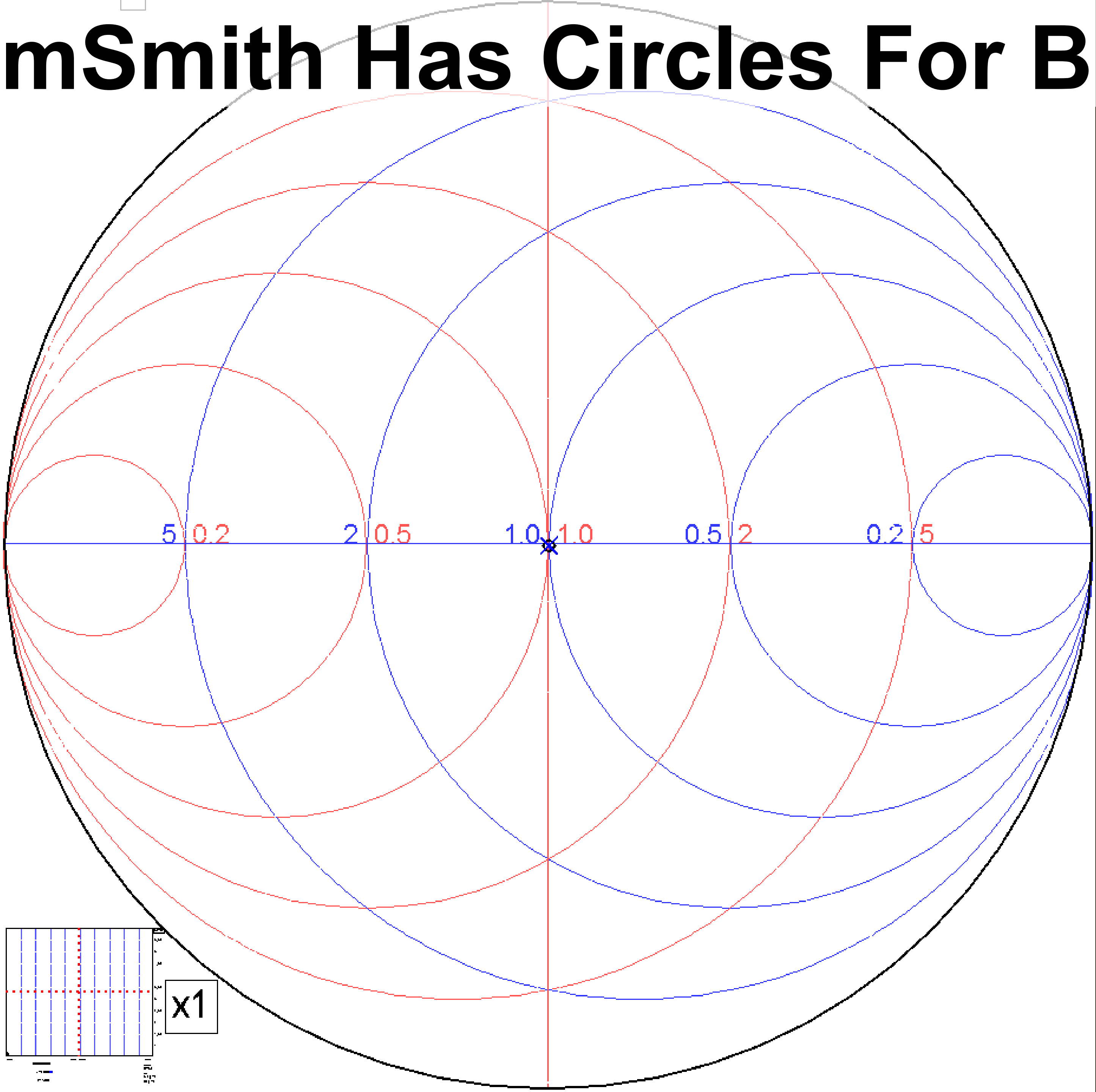
# Inverted Smith Chart for Admittance



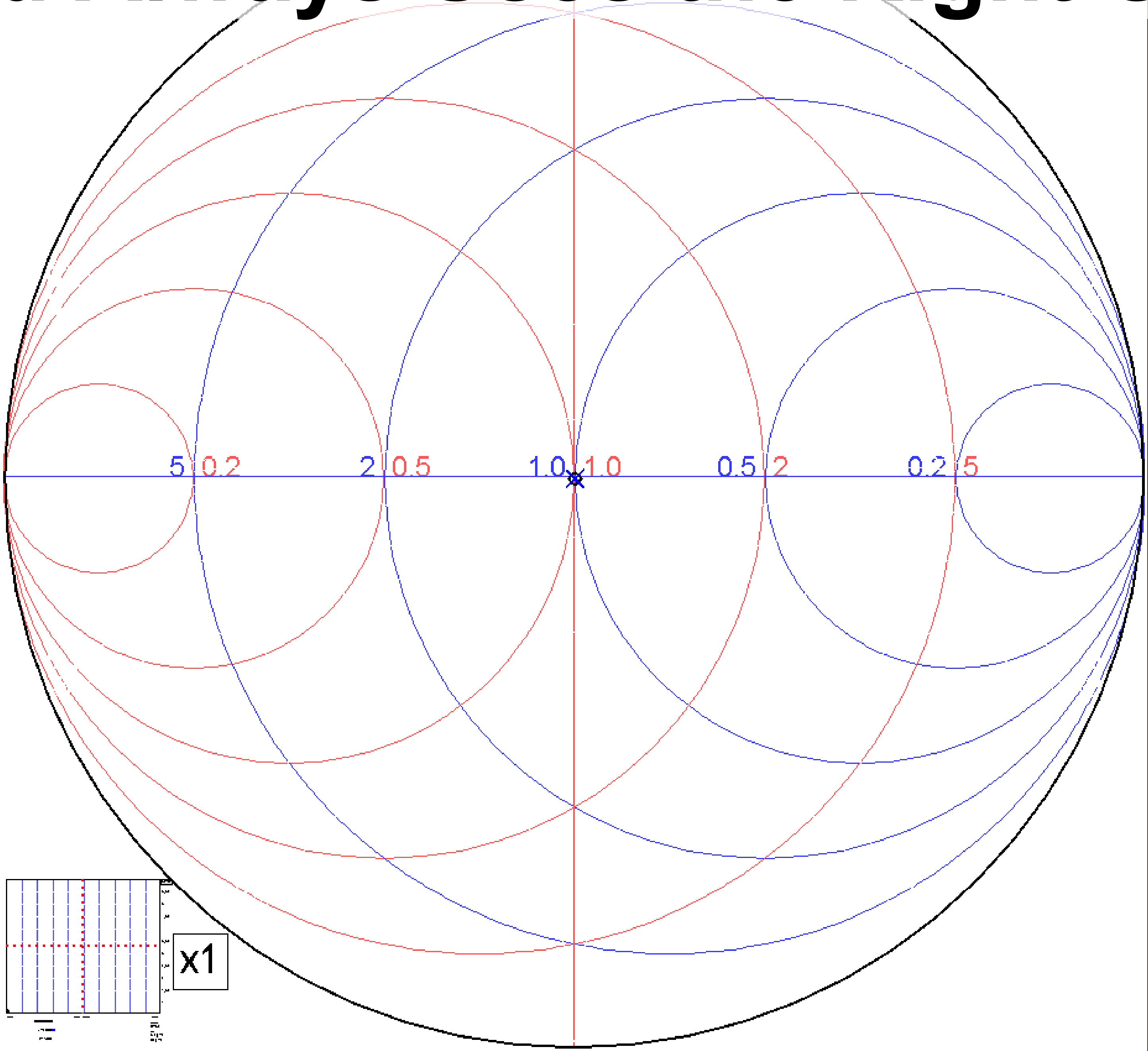
# Inverted Smith Chart for Admittance

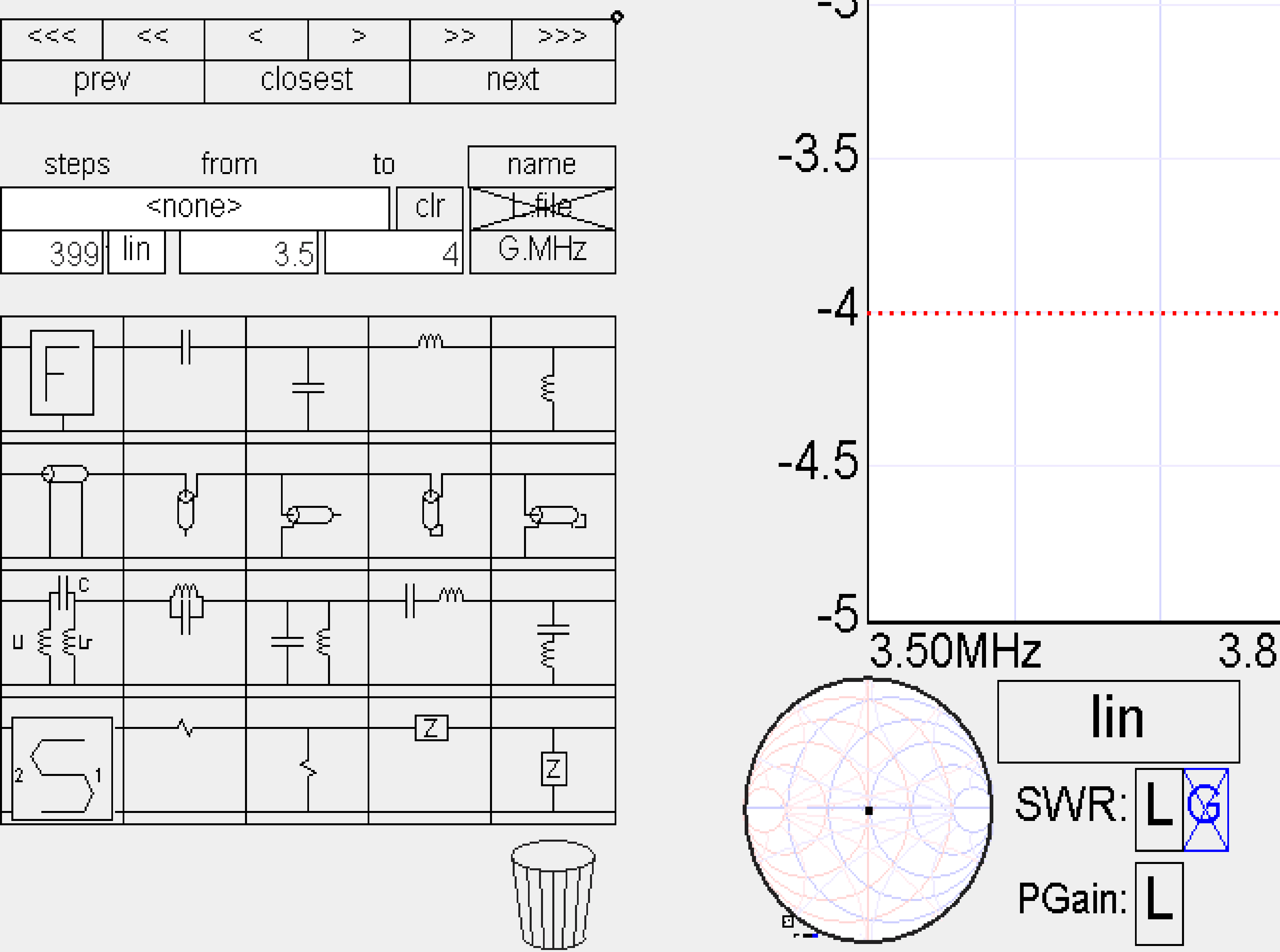


# SimSmith Has Circles For Both

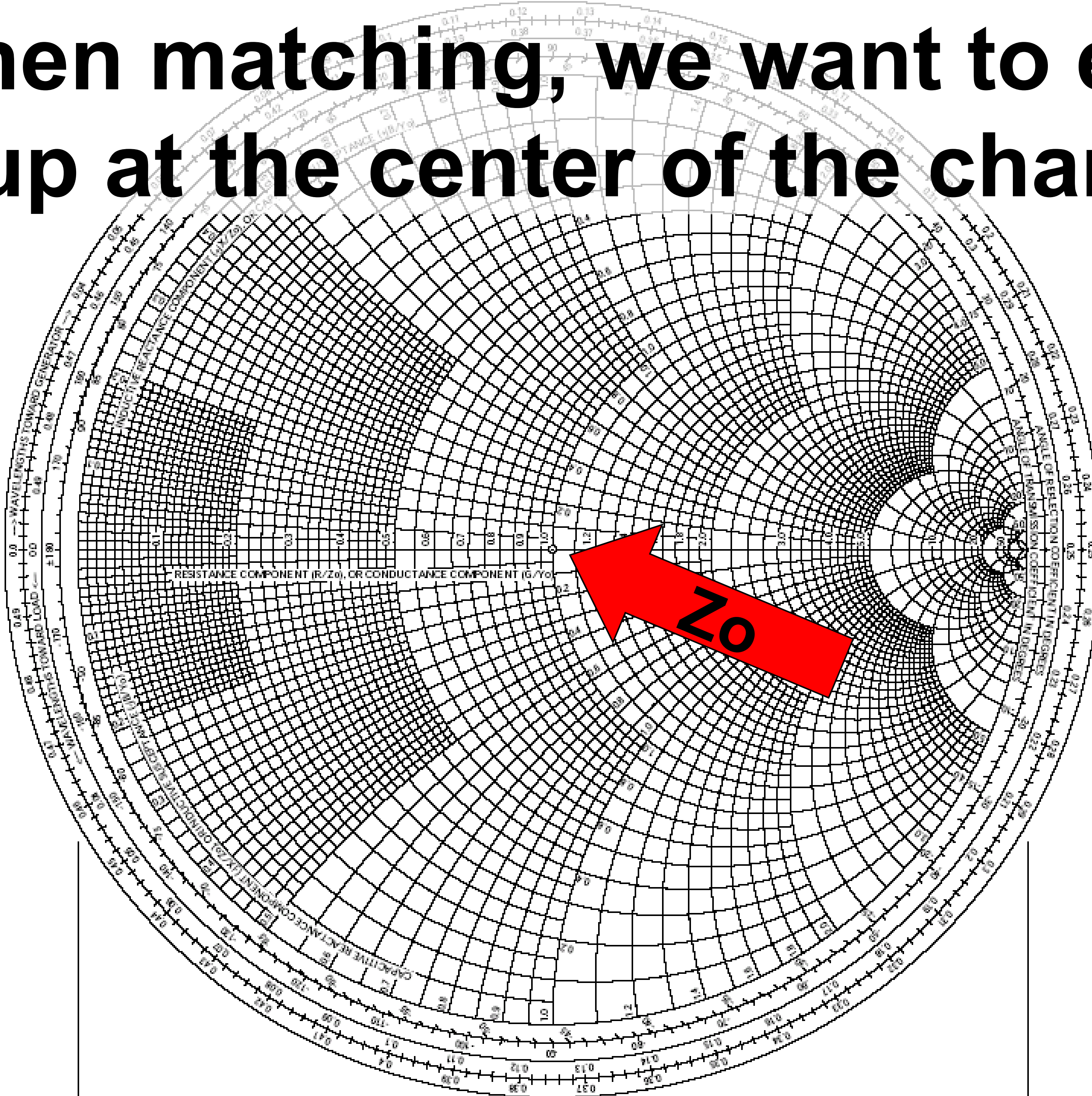


# And Always Uses the Right Ones




<<<
<<
<
>
>>
>>>
prev
closest
next
steps
from
to
name
<none>
clr
L.file
399
lin
3.5
4
G.MHz
C
Lr
Z
Z
-3.5
-4
-4.5
-5
3.50MHz
3.8
lin
SWR:
L
G
PGain:
L

# When matching, we want to end up at the center of the chart



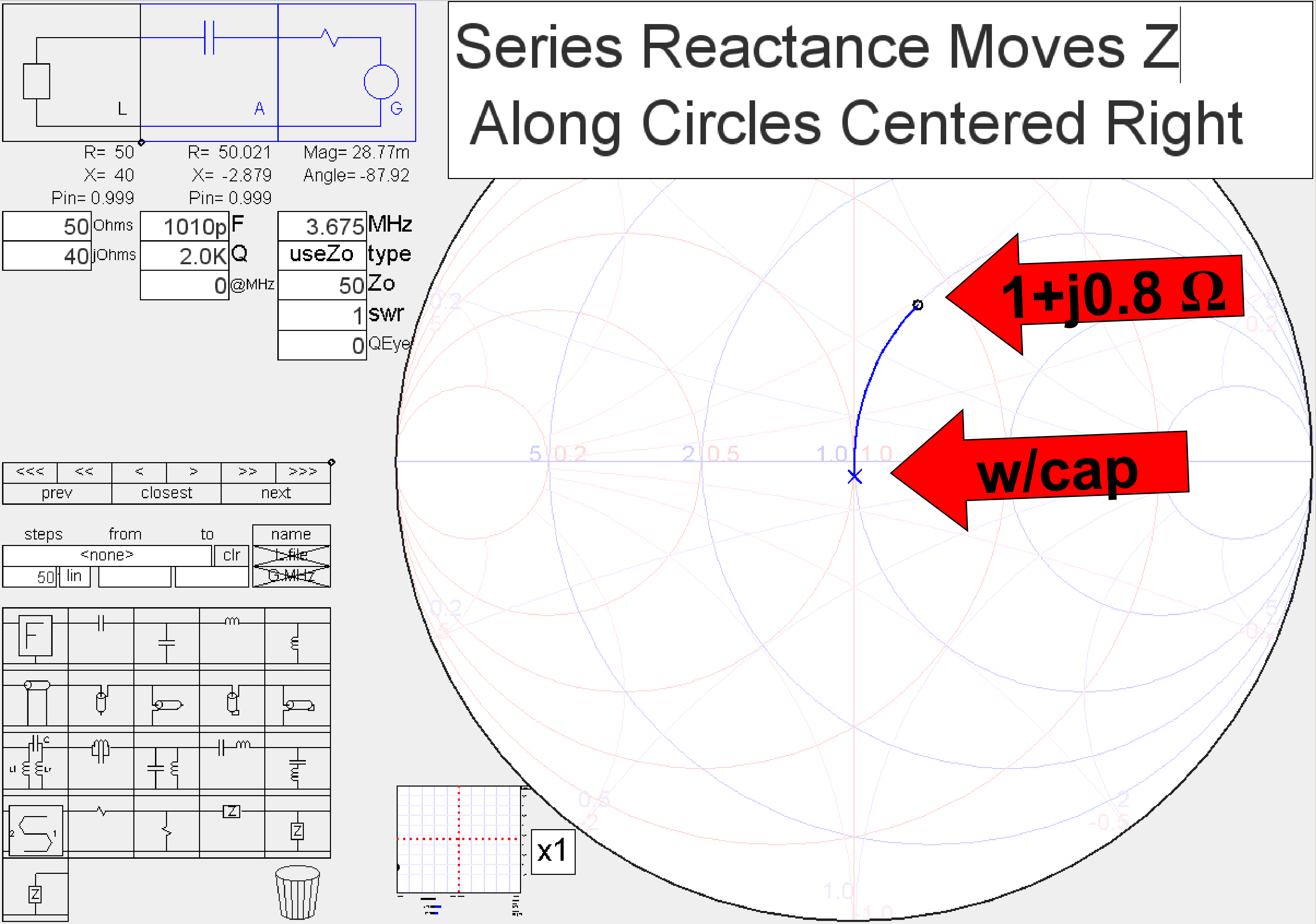
# Designing Simple Networks

- Adding reactance moves the impedance along the circles
- Series reactance moves Z along circles centered to the right
- Parallel reactance moves Z along circles centered to the left
  - Capacitance moves Z downward
  - Inductance moves Z upward

# A Simple Problem, at Only One Frequency

- We have a 50 + j40 Ω load (it’s inductive)
- We add a series capacitor
- Z moves along a right-centered circle, because it’s a series cap

# Series Reactance Moves Z Along Circles Centered Right



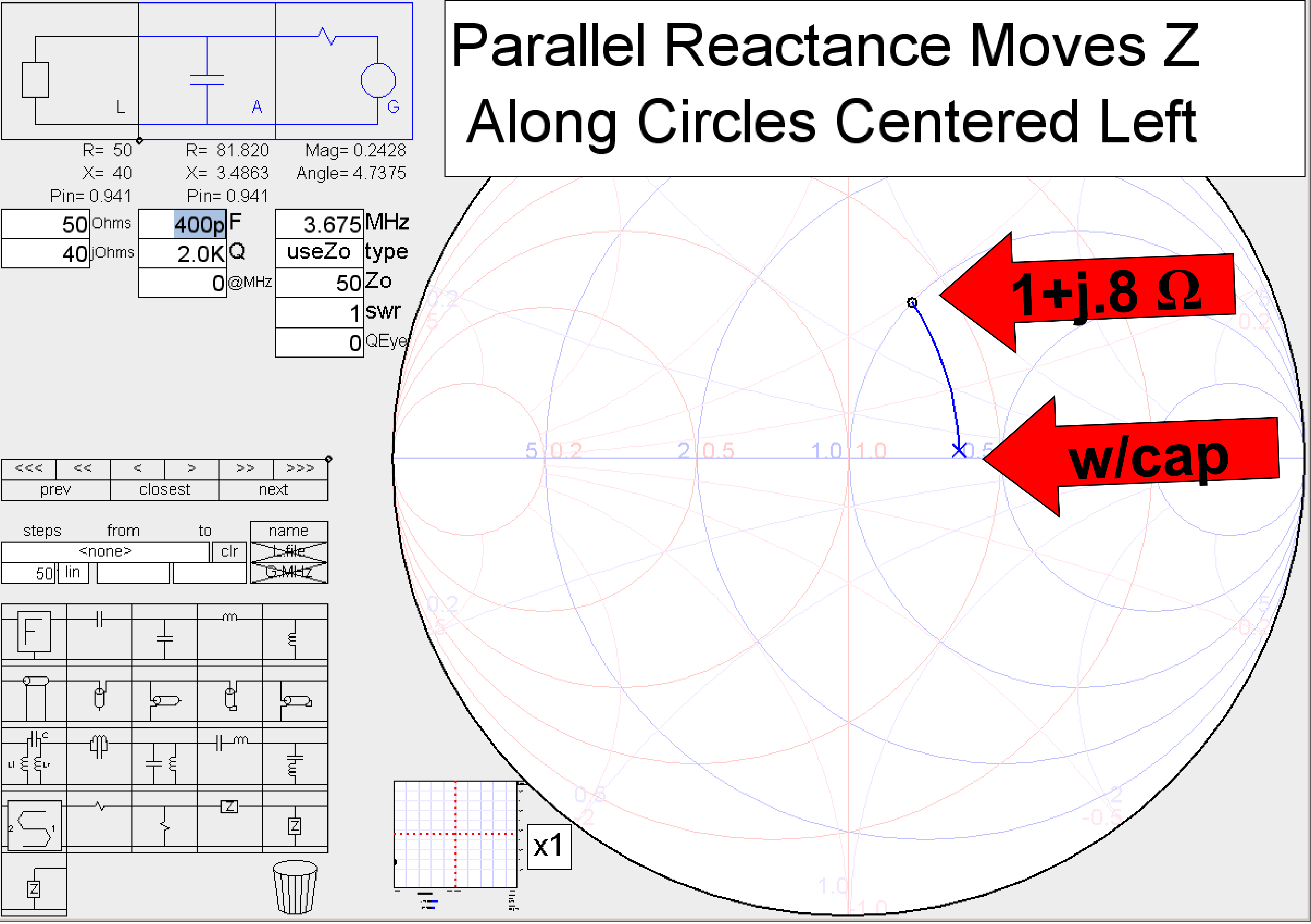
# A Parallel Example

- **Same 50+j40 Ω load (.0122 +j.0097 siemens)**
- **On a paper Smith Chart, we would turn the chart upside down and plot it as 0.61 + j .485**
- **We're used to thinking impedance, and there's a lot of trig in making that conversion**

# SimSmith to the Rescue

- **We draw the circuit with R, L, C, stubs, transmission lines, etc.**
- **Sim Smith does all the math, plots everything in the right place, computes the right way, always displays the result in Ohms (the Impedance Smith Chart)**

# Parallel Reactance Moves Z Along Circles Centered Left



# Our Simple Example

- Obviously, series C was the best solution for this network, but most matching stubs are connected in parallel
- We'll nearly always be following the left-centered circles

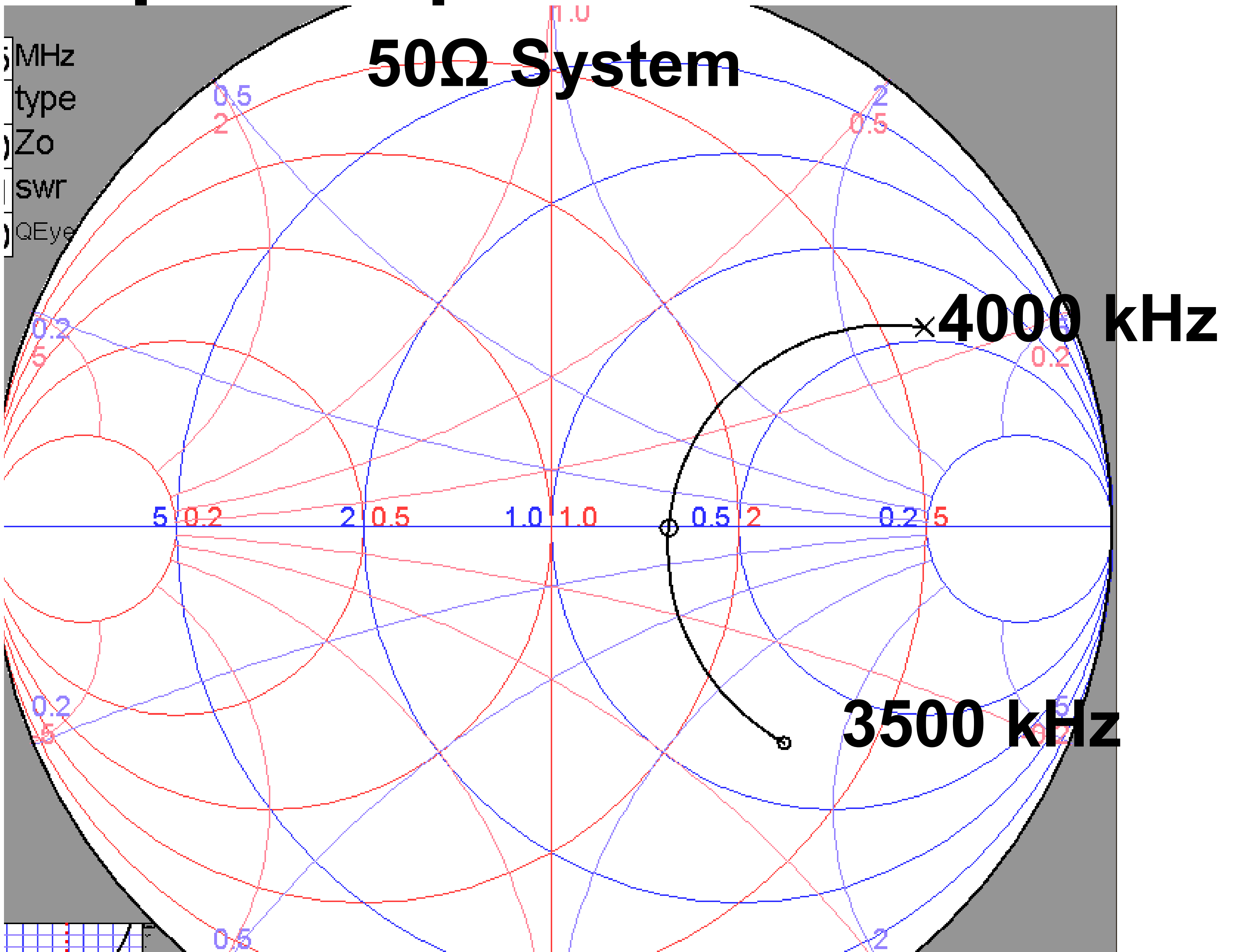
# Back to Antennas

- **We design antennas to cover an entire band, not just one frequency**
- **NEC designs and antenna measurements produce not just one point on the Smith Chart, but many points**
- **SimSmith plots those points as a curve for the frequency range we are interested in**

# Back to Antennas

- **Each point on the curve follows it's own circle**
- **This can be tricky to visualize, so let's look at our 80M dipole**

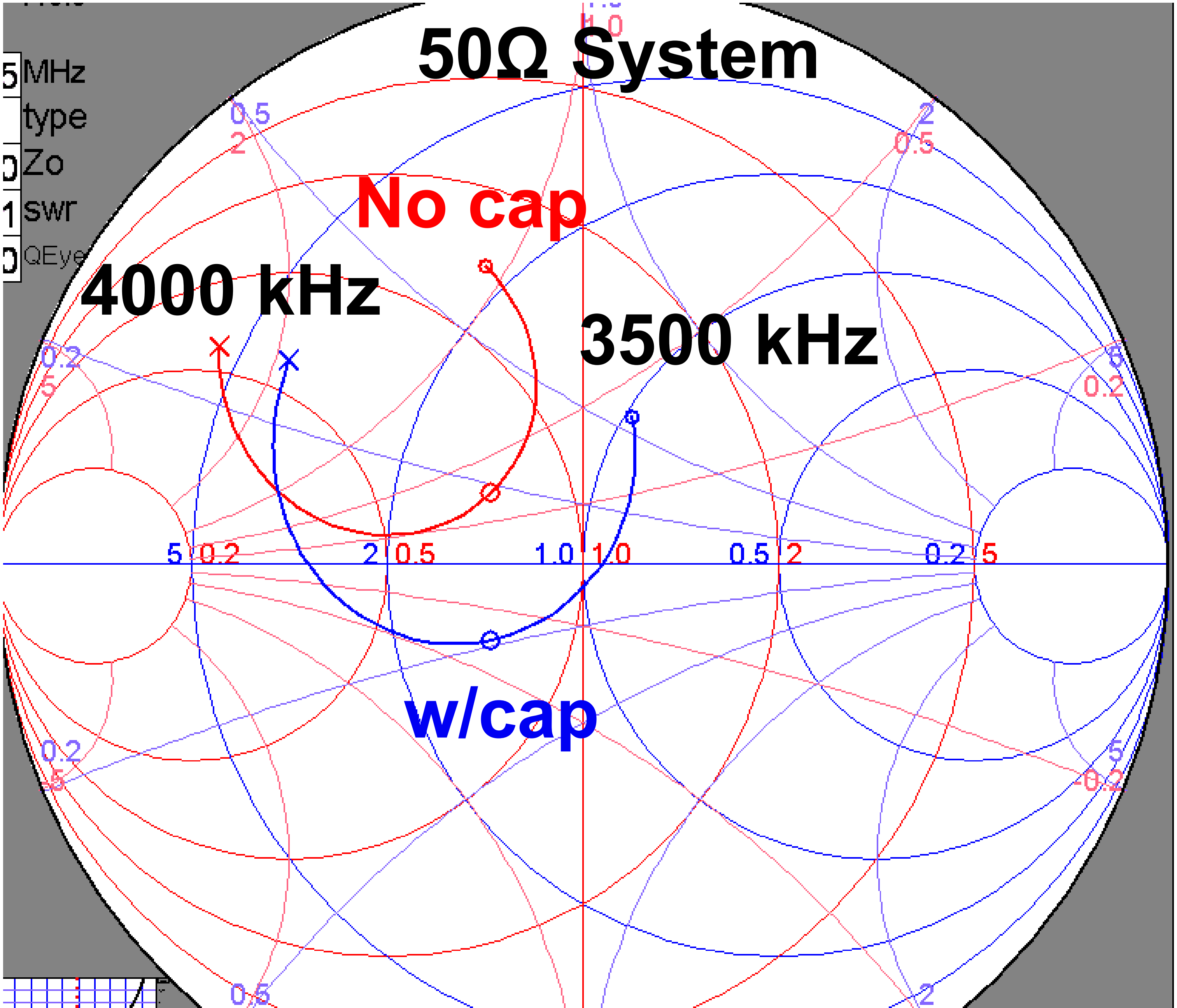
# 80M Dipole Imported From NEC



# Back to Antennas

- Adding 110° of coax, we get the Red curve
- Adding the parallel capacitor we get the Blue curve

# 110 Degrees Along Line, Add Cap



# Stub Matching

- **A stub is a short length of transmission line connected in parallel with the main transmission line**
- **An *open* stub <90° looks capacitive**
- **Find a point on the line where the impedance is inductive (the top half of the Smith Chart) and add an open stub**
- **Or add a shorted stub <90° at a point where impedance is capacitive (in the bottom half of the Smith Chart)**

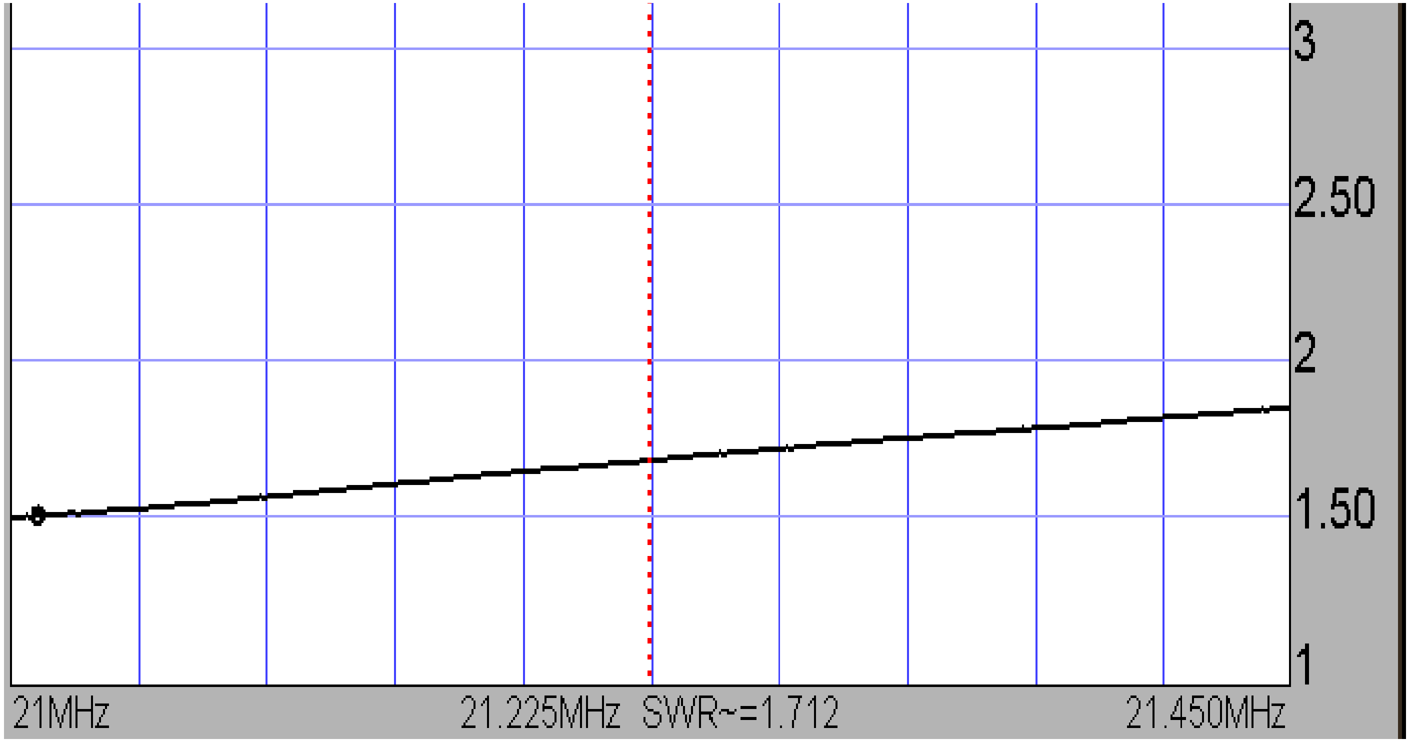
# Simple Stub Matching

- Find a point on the transmission line where we can move along a left circle to bring the curve closer to the center
- Usually easiest to add a small length of line, but we can also move along the line toward the antenna
- Add a stub that moves the impedance
  - Open stub to move down
  - Shorted stub to move up
- Tweak position and stub for best SWR

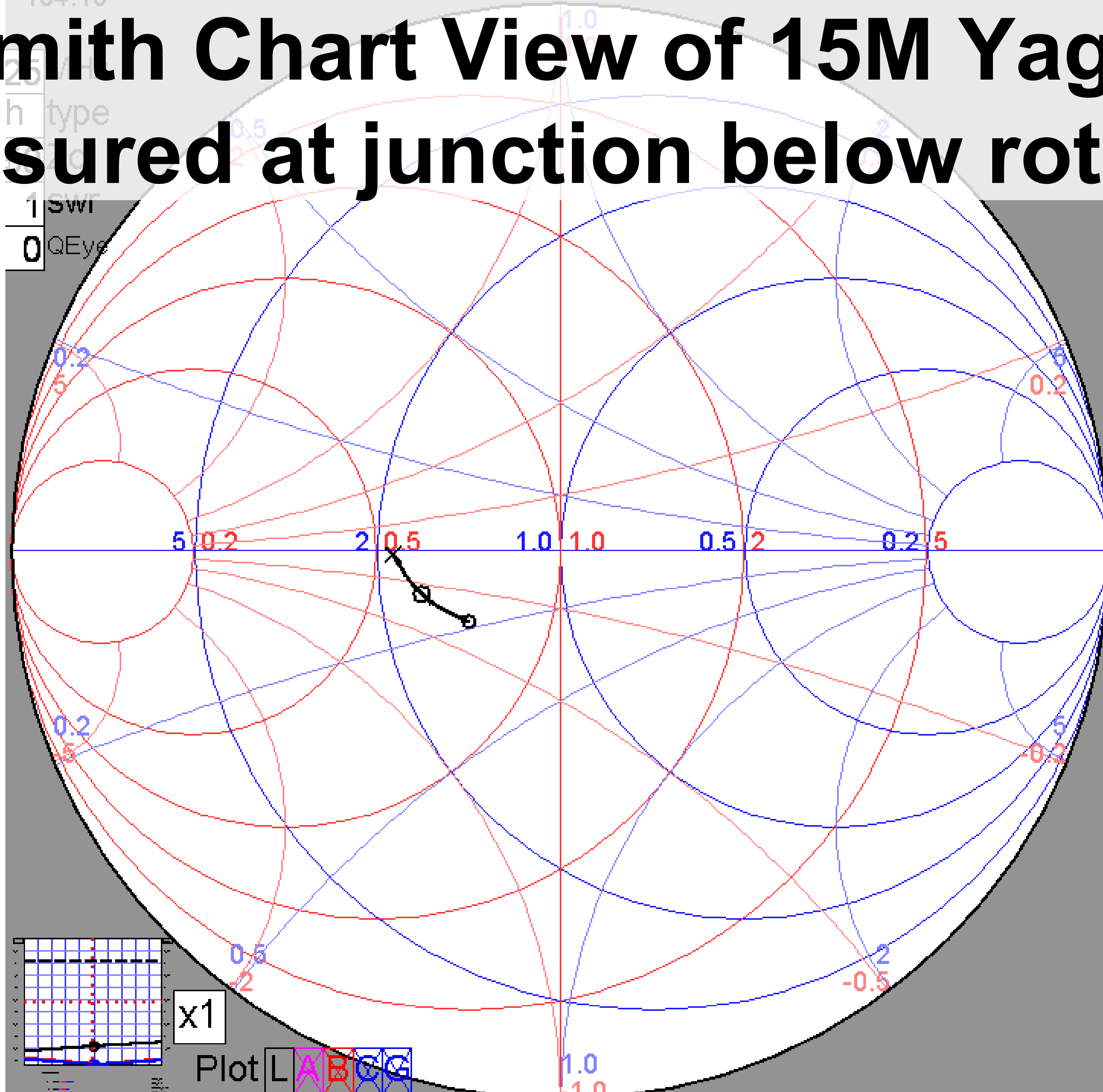
# Example – My 15M Yagi

- Home brew 4-element, I didn't get the match quite right, and it's up there
- A stub near the antenna will reduce SWR on the long run to the shack, also reducing cable loss
- There's a coax splice below the rotator, a good place for a stub
- I made a VNA measurement there

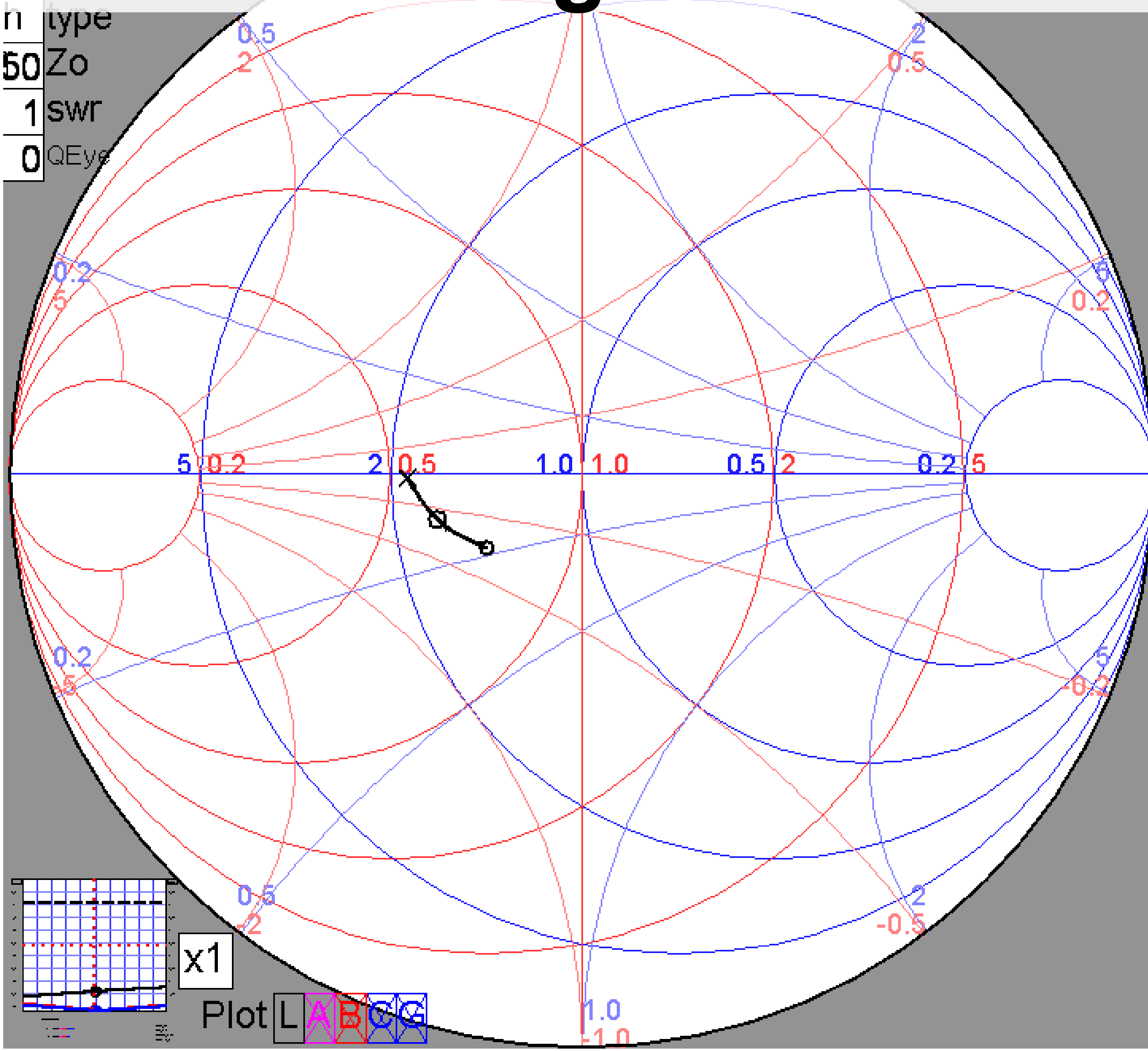
# SWR of 15M Yagi



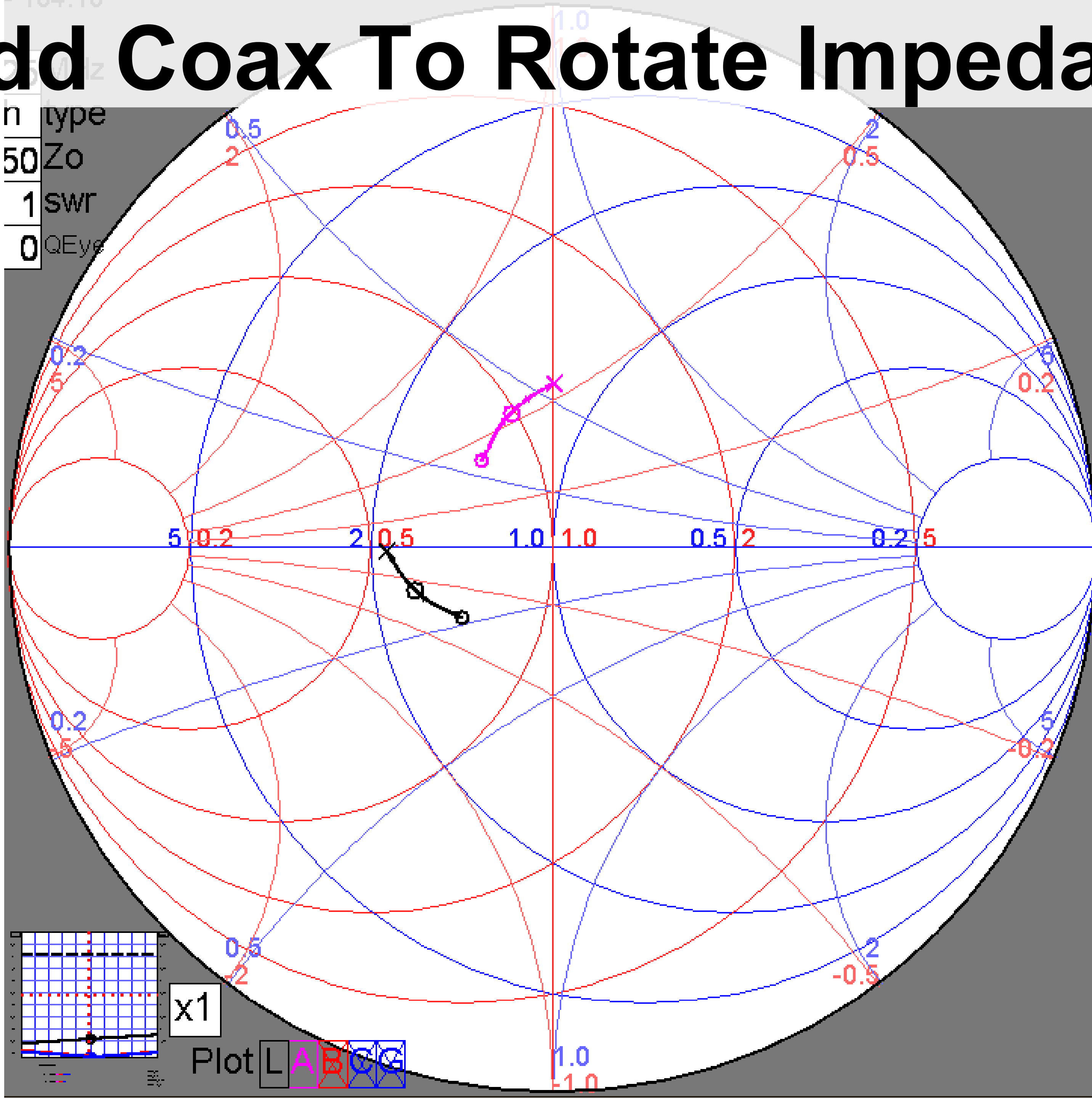
# Smith Chart View of 15M Yagi, measured at junction below rotator



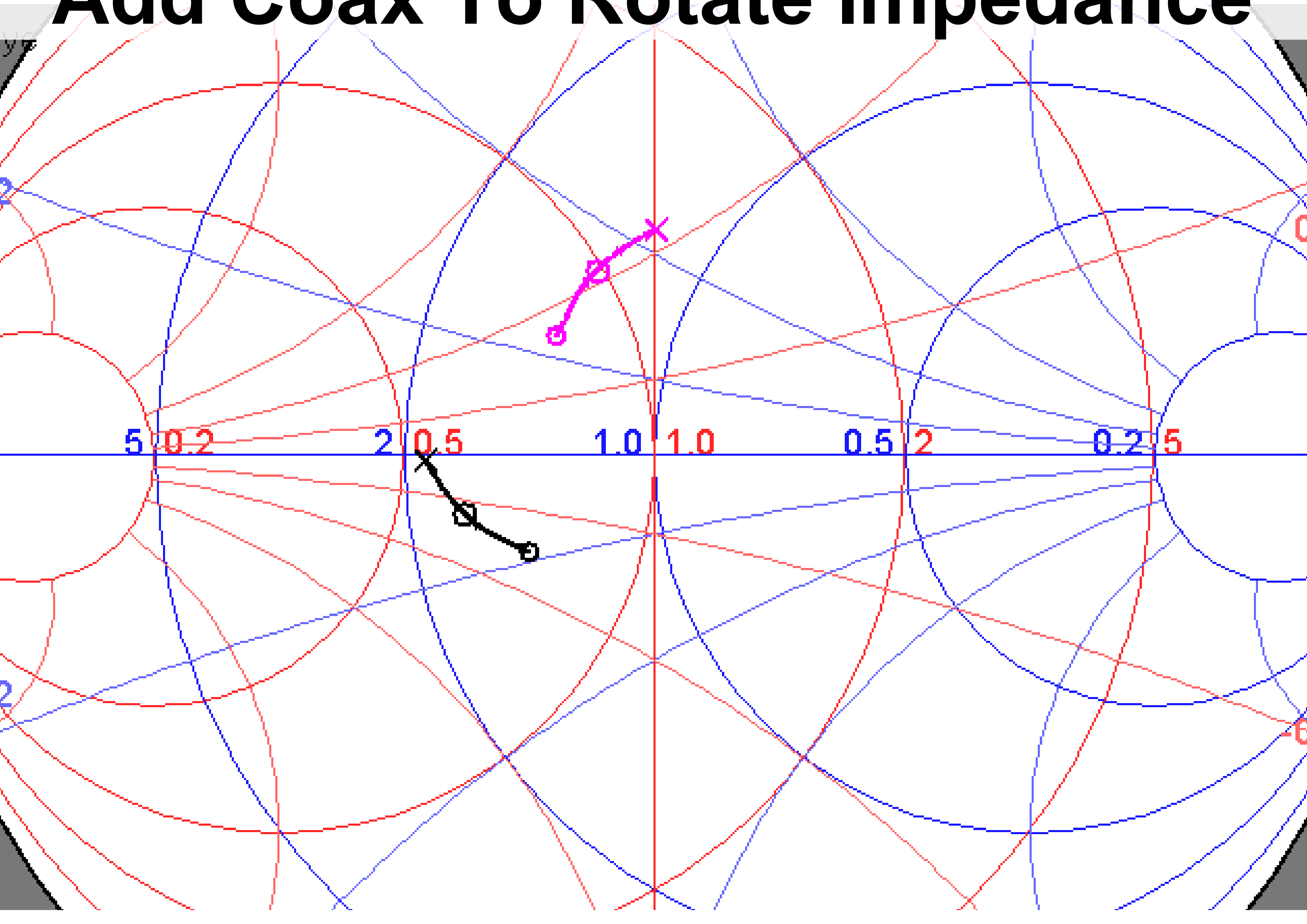
# Let’s Design a Stub



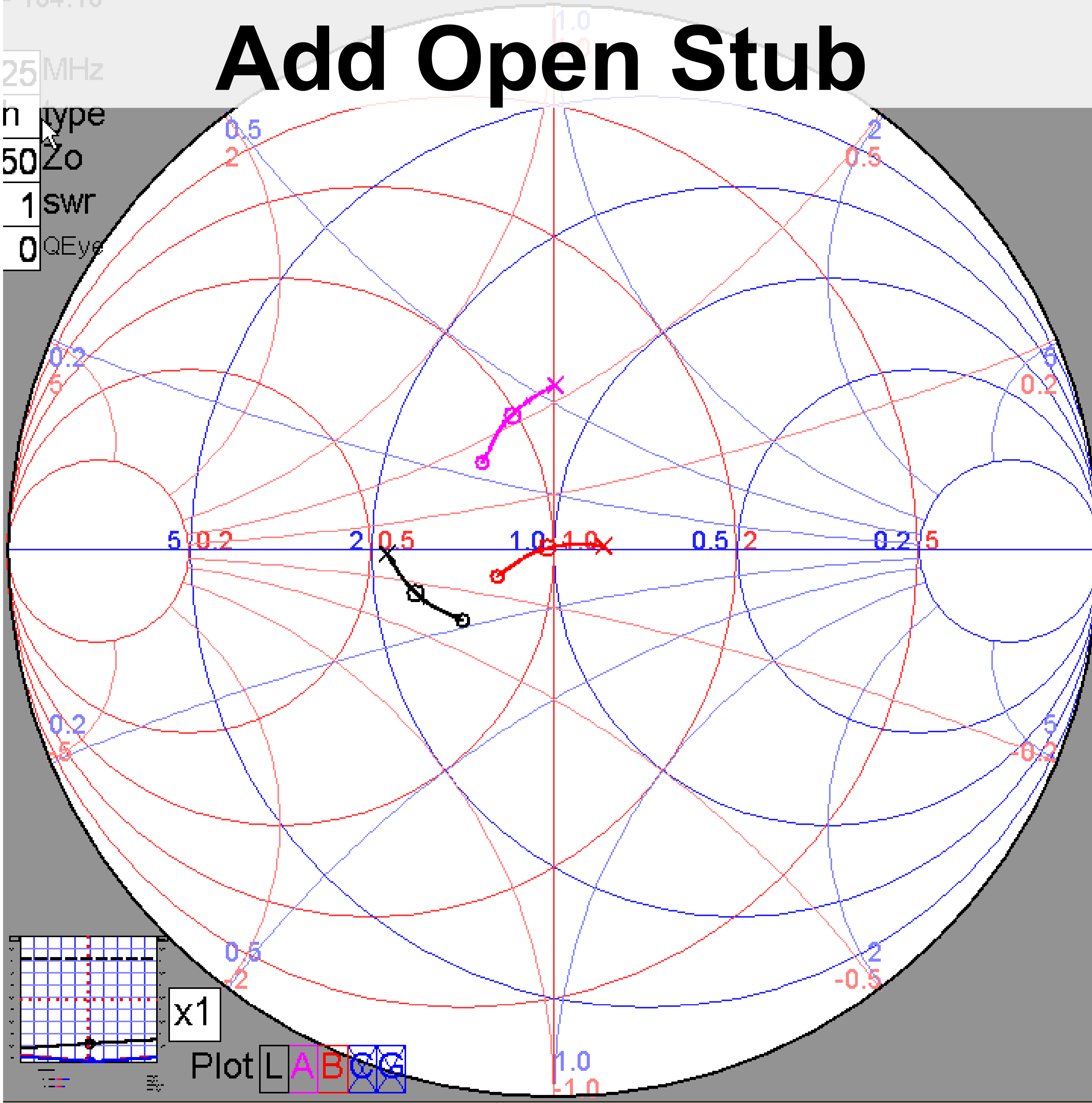
# Add Coax To Rotate Impedance



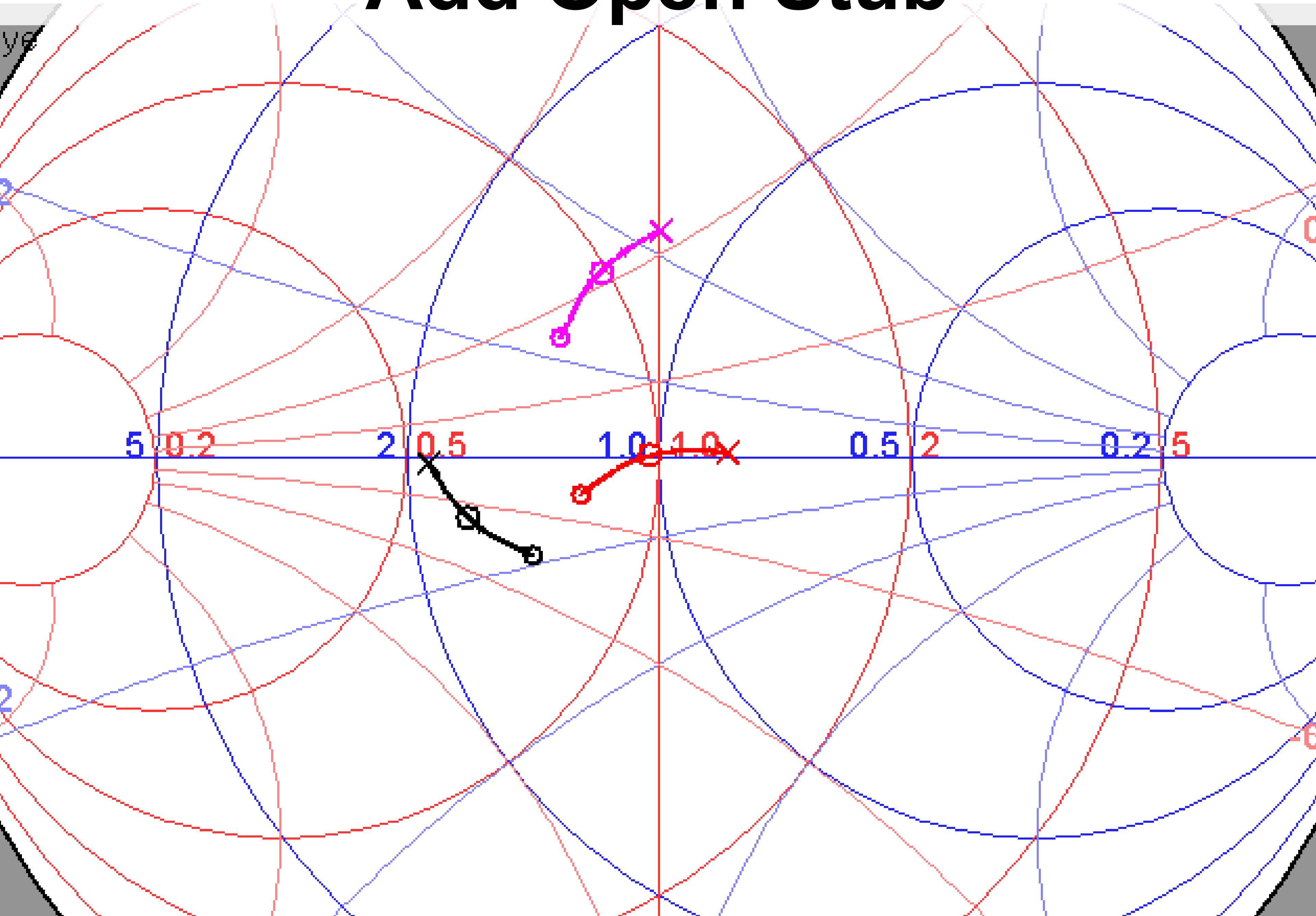
# Add Coax To Rotate Impedance



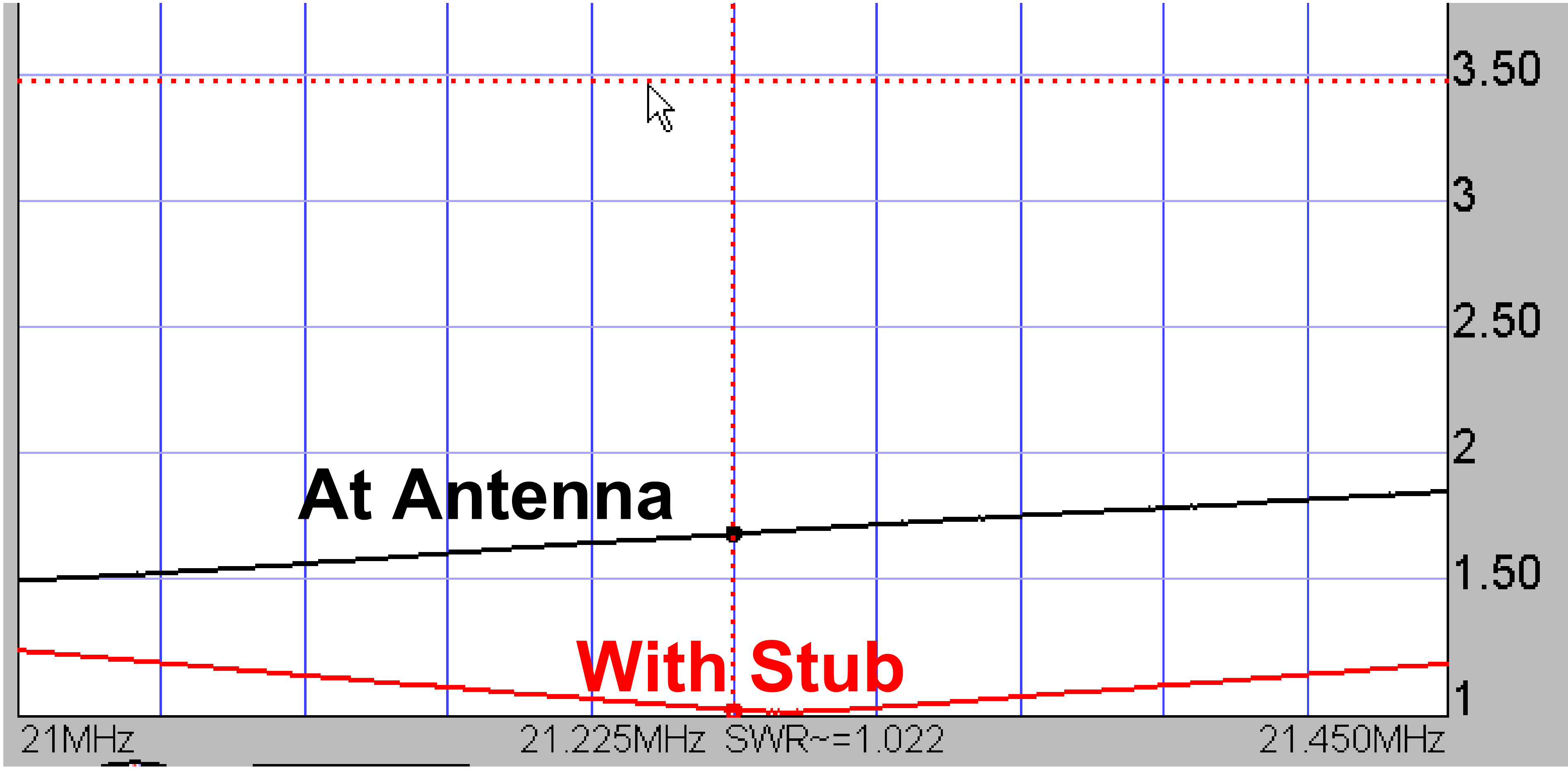
# Add Open Stub



# Add Open Stub

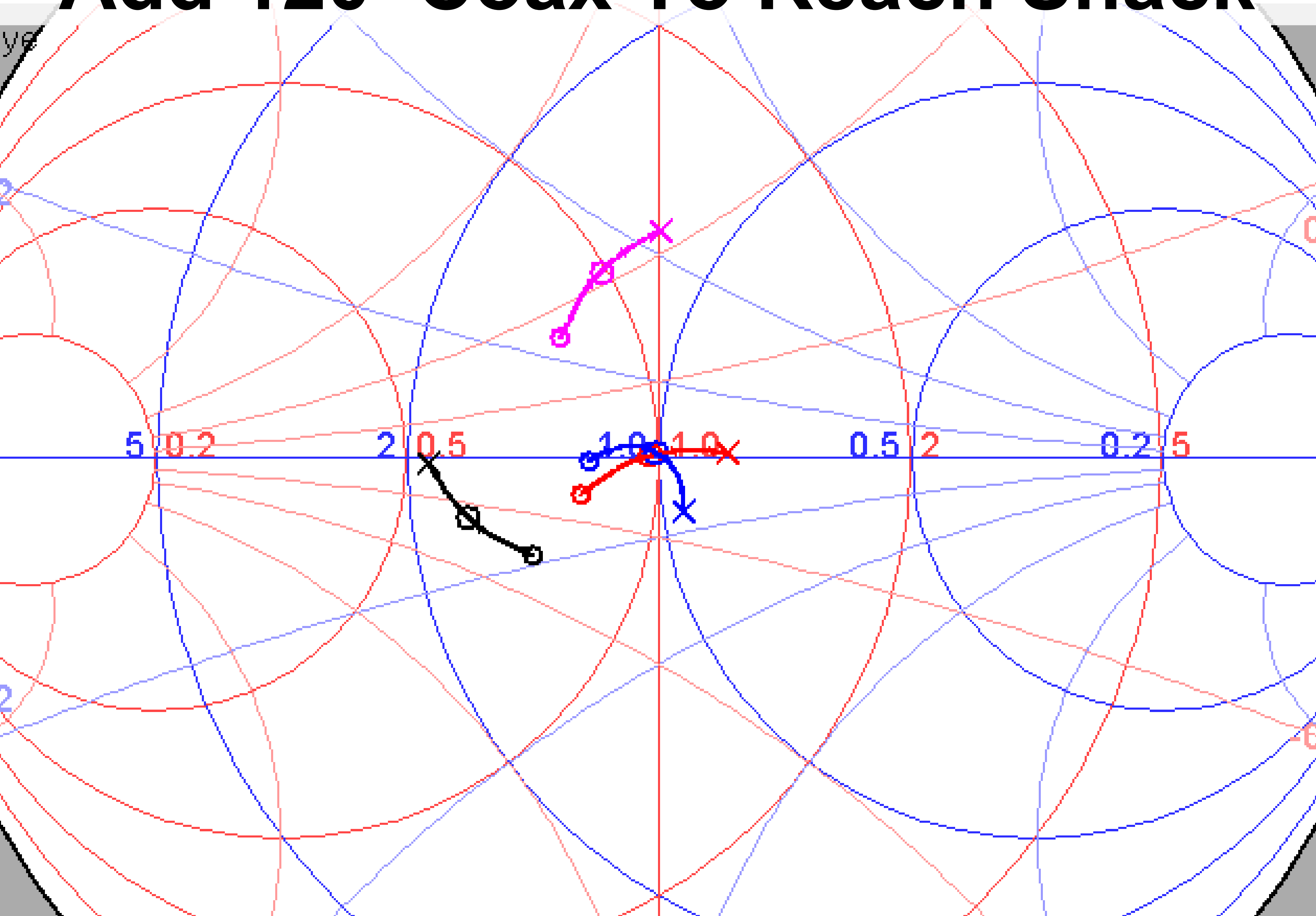


# SWR View

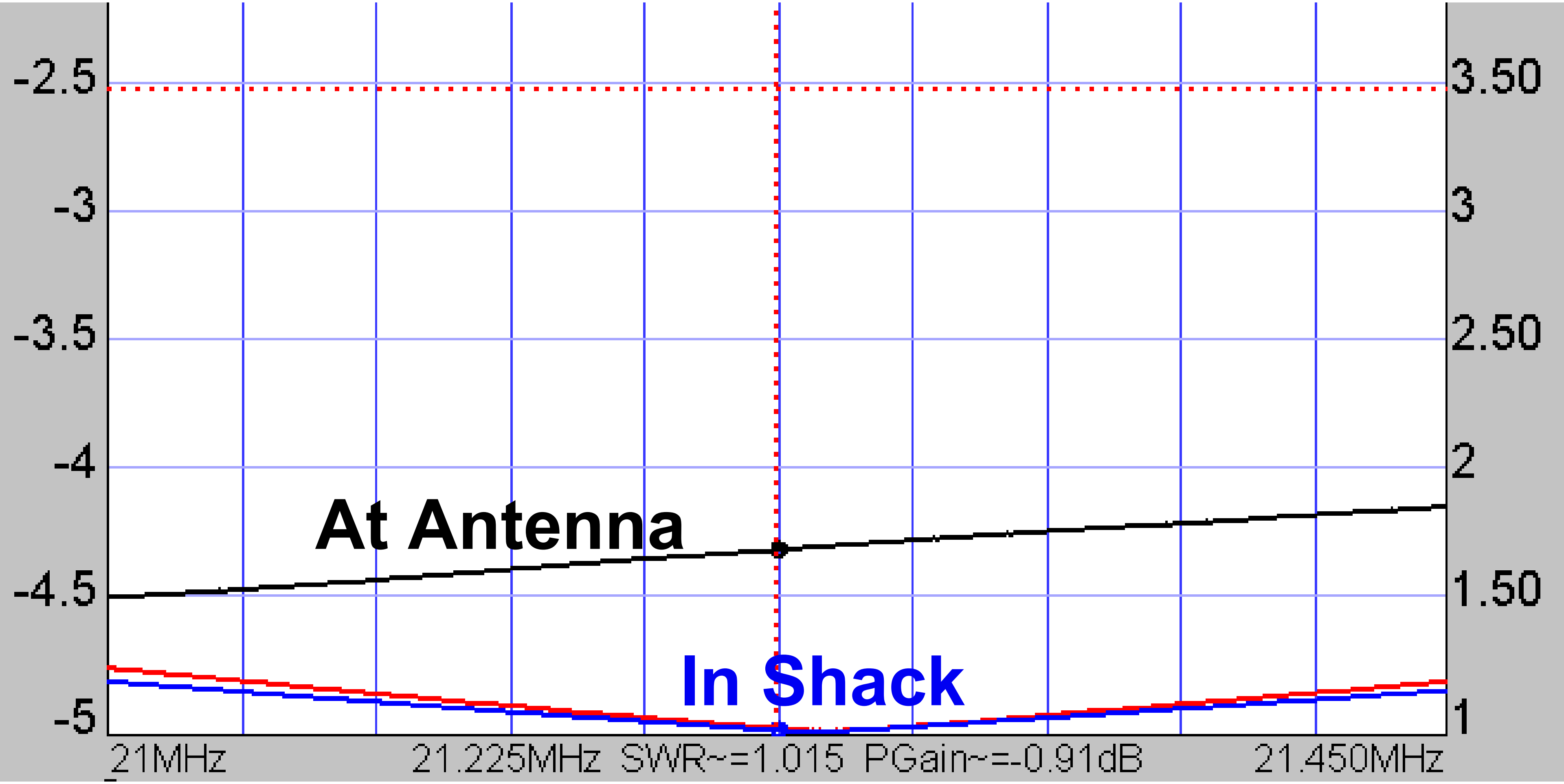


3.50
3
2.50
2
1.50
1
At Antenna
With Stub
21MHz
21.225MHz SWR~=1.022
21.450MHz

# Add 120’ Coax To Reach Shack

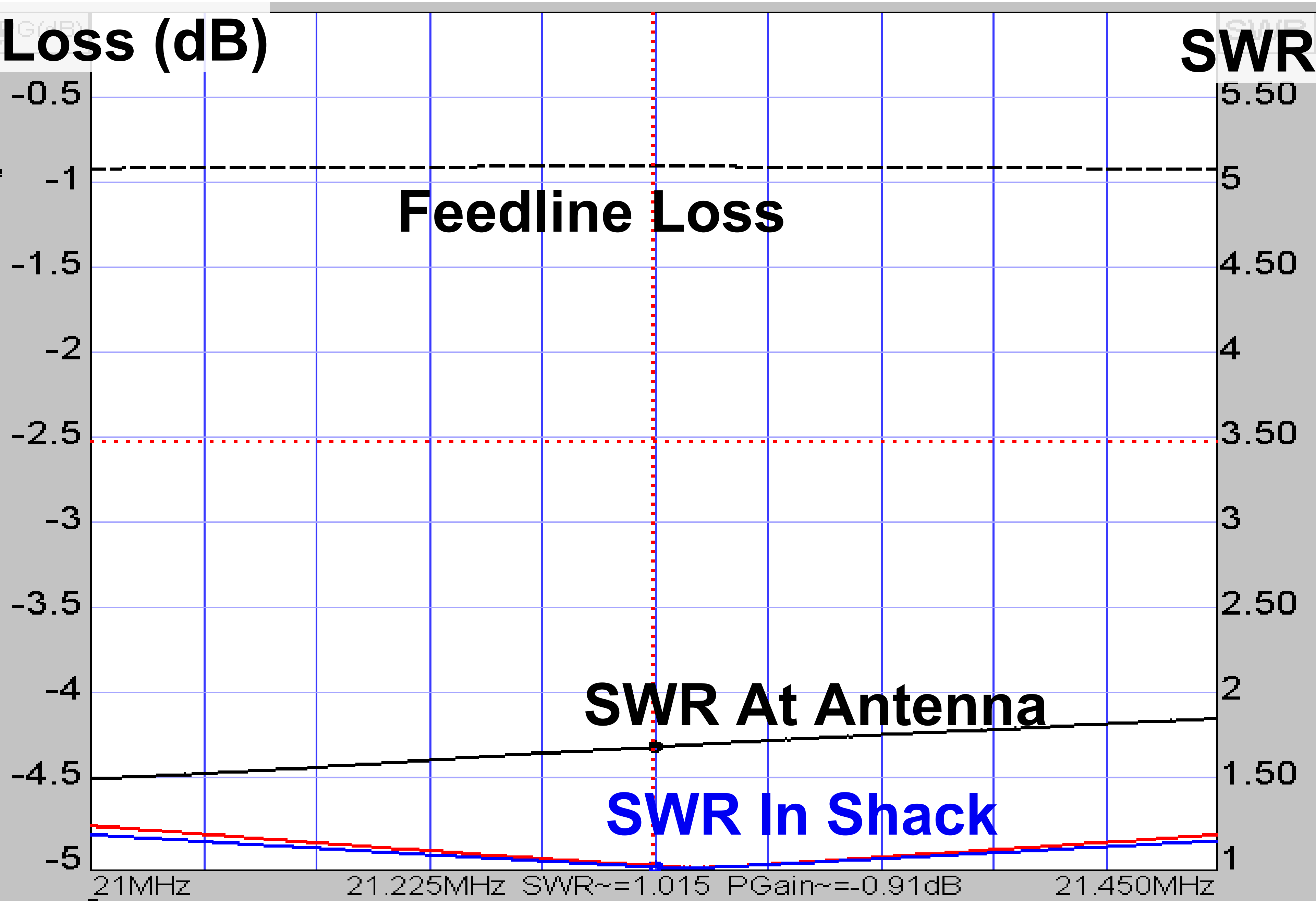


# SWR View

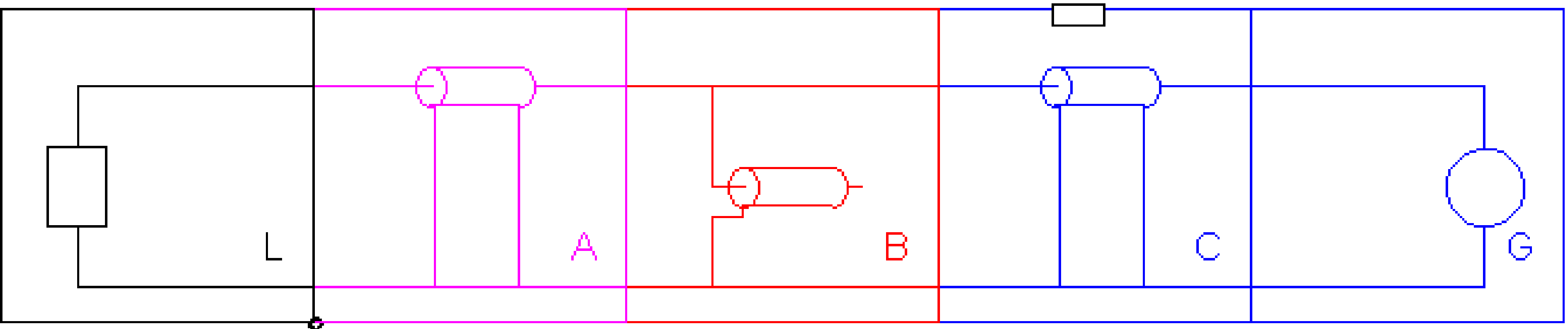


-2.5
-3
-3.5
-4
-4.5
-5
3.50
3
2.50
2
1.50
1
At Antenna
In Shack
21MHz
21.225MHz SWR~=1.015 PGain~=-0.91dB
21.450MHz

# SWR and Feedline Loss

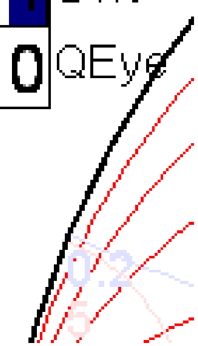


# Circuit For Stub

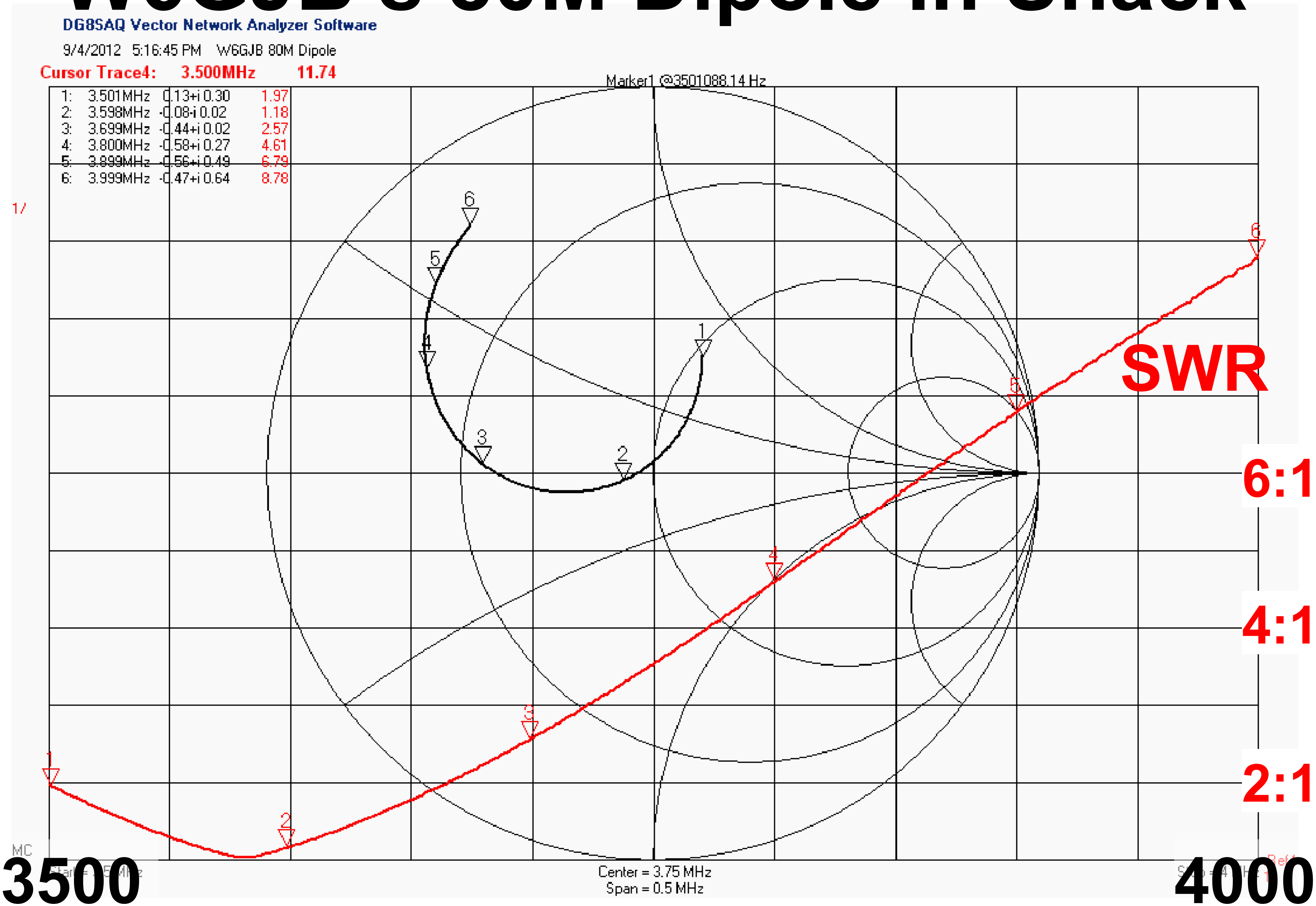



| L | A | B | C | G |
|---|---|---|---|---|
| R= 29.644 | R= 38.304 | R= 49.027 | R= 49.812 | Mag= 7.527m |
| **X= -4.946** | **X= 20.308** | **X= 0.4088** | **X= 0.7273** | **Angle= 104.10** |
| Pin= 0.812 | Pin= 0.820 | Pin= 0.820 | Pin= 1 | |

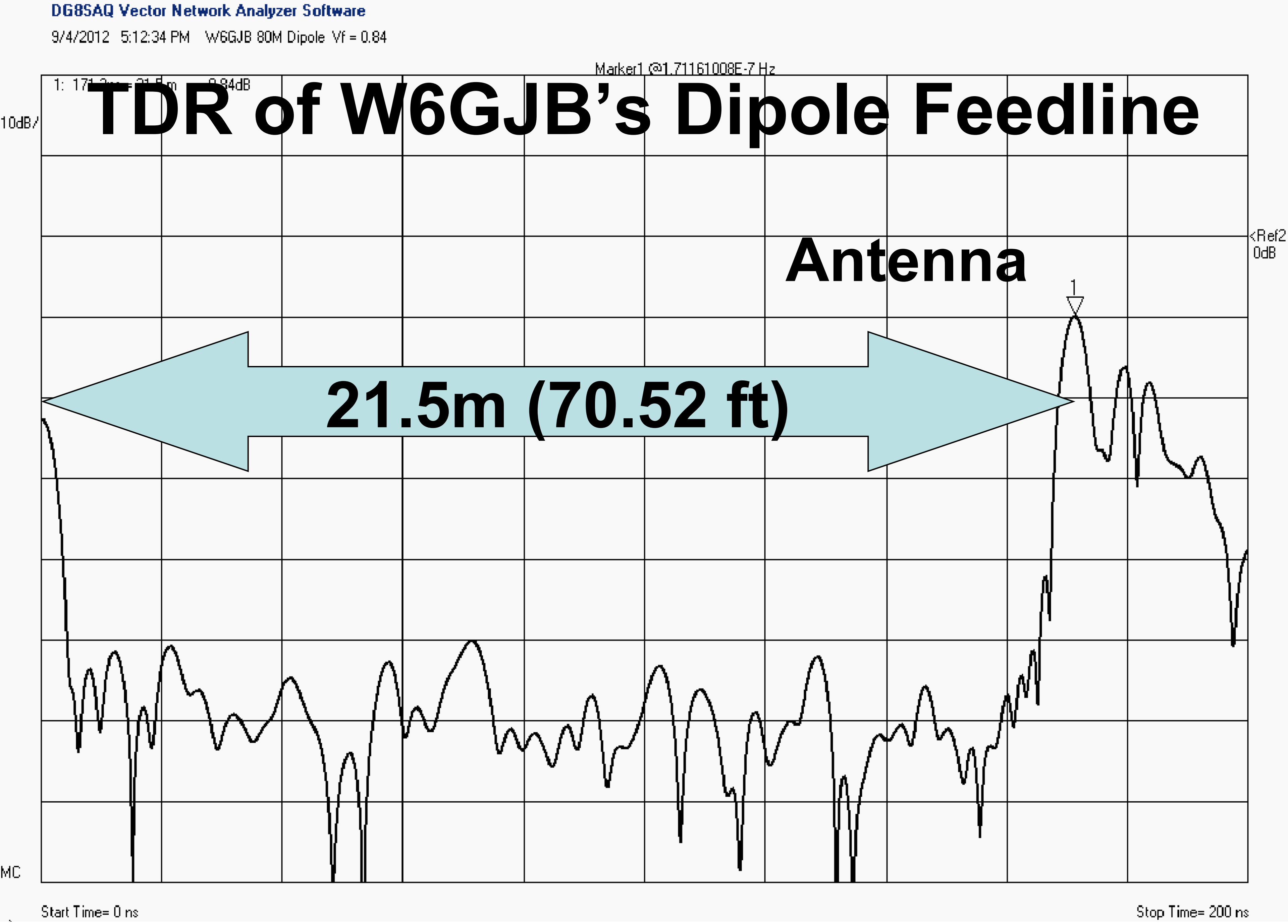
| L | | A | | B | | C | | G | |
|---|---|---|---|---|---|---|---|---|---|
| 29.644 | Ohms | 45 | deg | 28 | deg | 1.103K | deg | 21.225 | MHz |
| -4.946 | jOhms | 21.225 | @MHz | 21.225 | @MHz | 21.225 | @MHz | xMtch | type |
| | | 3.8613 | ft | 2.4026 | ft | 120 | ft | 50 | Zo |
| | | 0.6666 | vf | 0.6666 | vf | .845 | vf | 1 | swr |
| | | 50 | Zo | 50 | Zo | 50 | Zo | 0 | QEye |
| | | 0.50 | /100f | 0.50 | /100f | .22 | /100f | | |
| | | 10 | @frq | 10 | @frq | 2 | @frq | | |



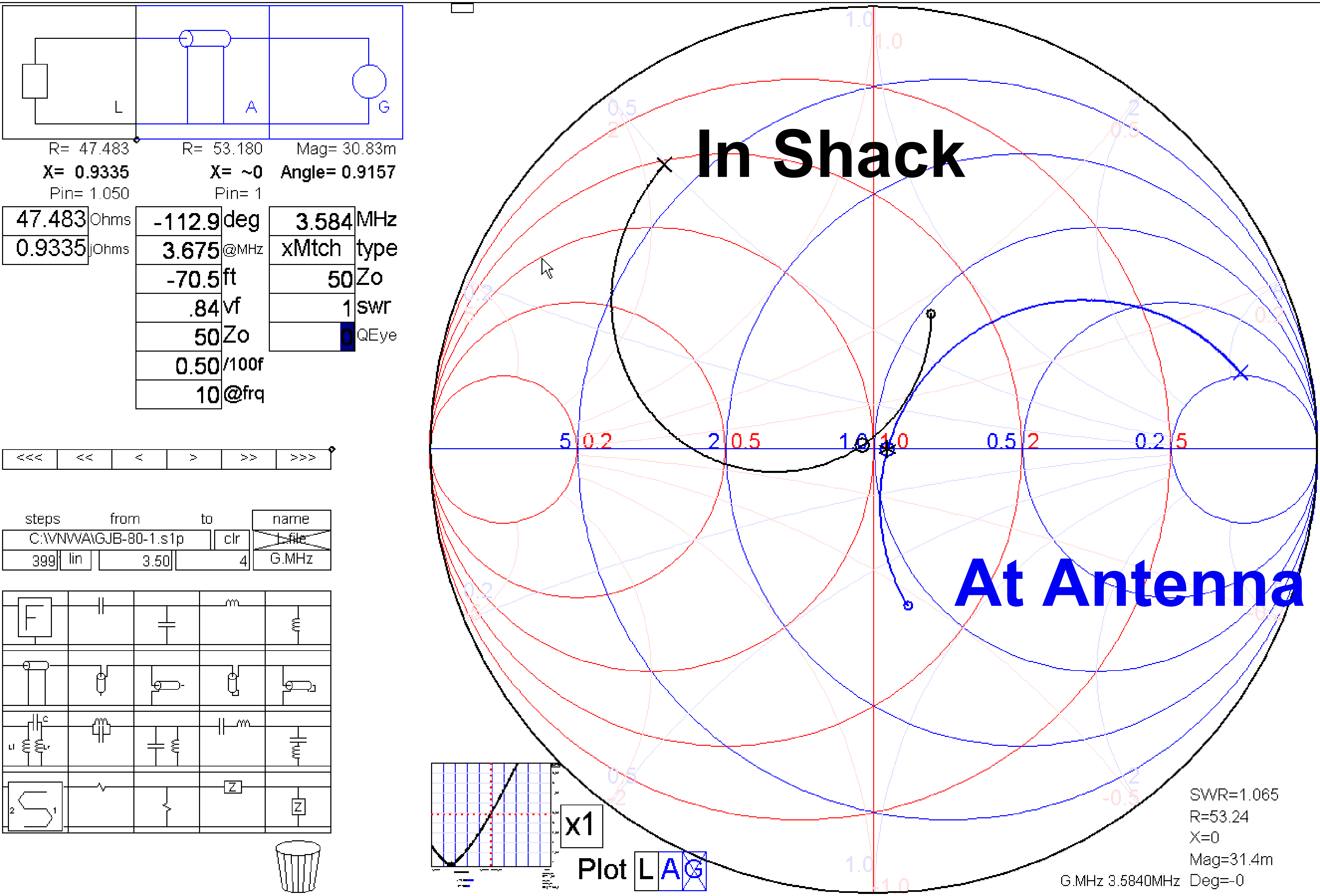
# W6GJB's 80M Dipole In Shack



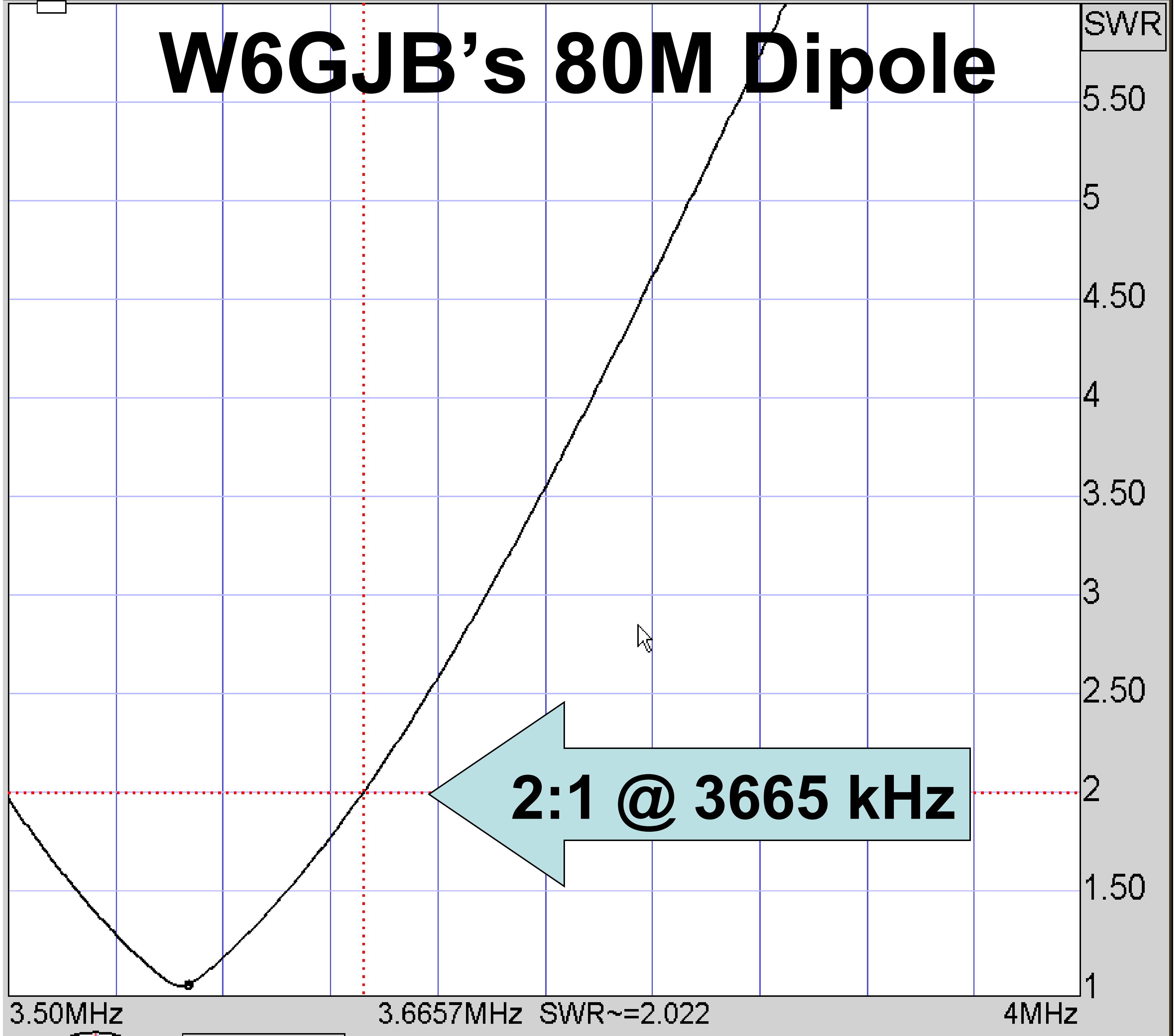
# TDR of W6GJB's Dipole Feedline



# W6GJB's 80M Dipole



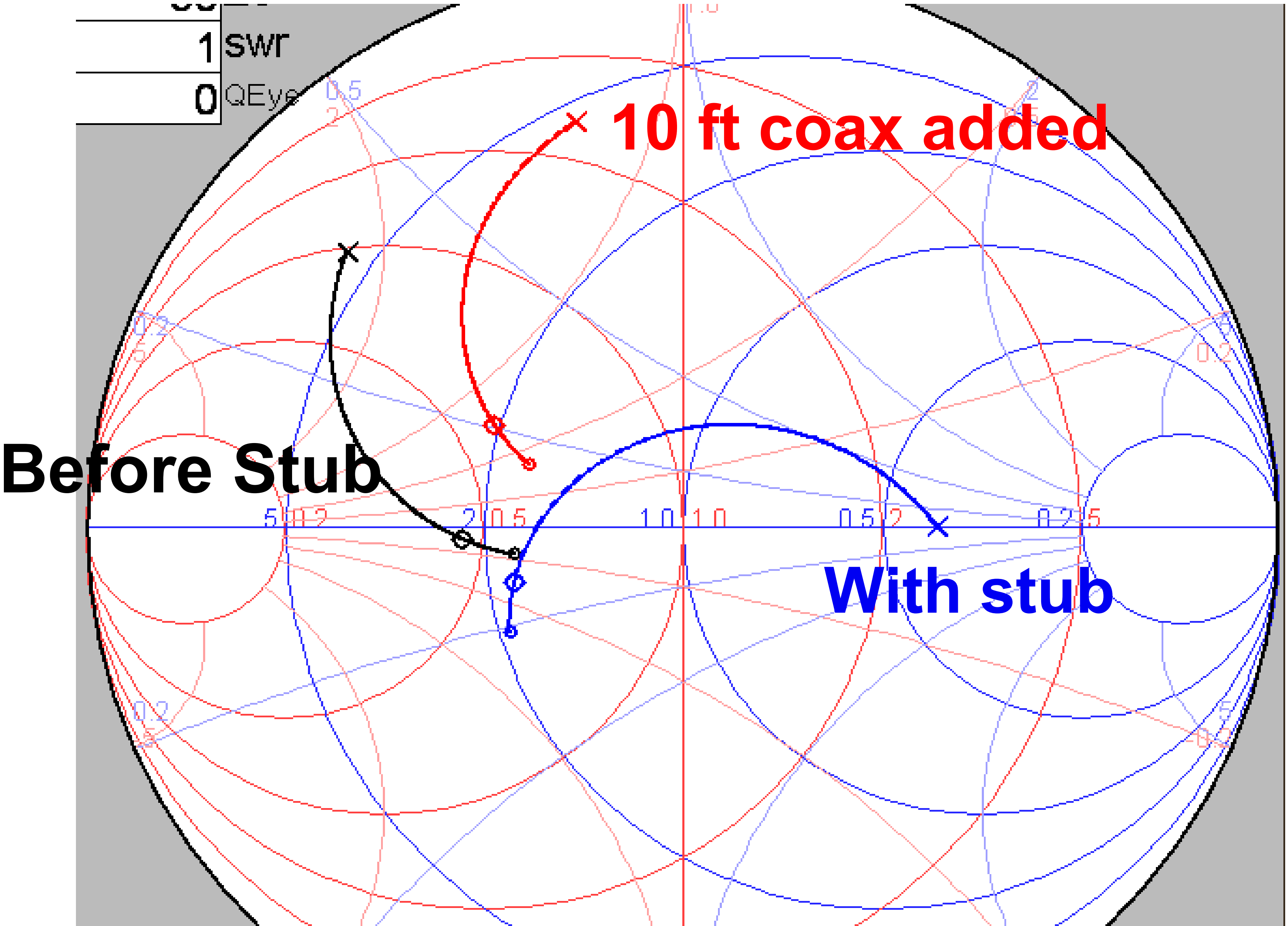
# W6GJB's 80M Dipole



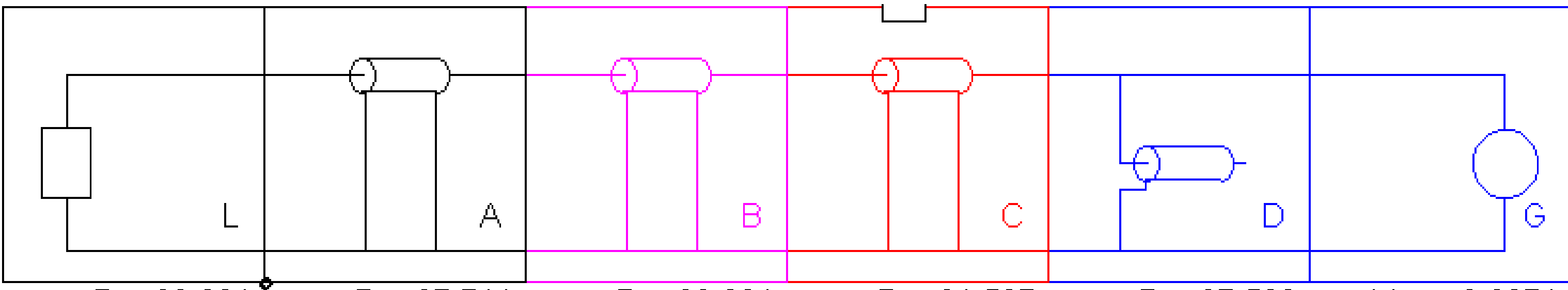
# A Stub to Match for 75M SSB

- SWR too high for power amp to load above 3650 kHz
- Set Sim Smith display limits to 3650 – 3900 kHz (makes it easier to see what you're doing)
- Add length to make Z inductive
- Add open stub

# Smith Chart View of the Stub

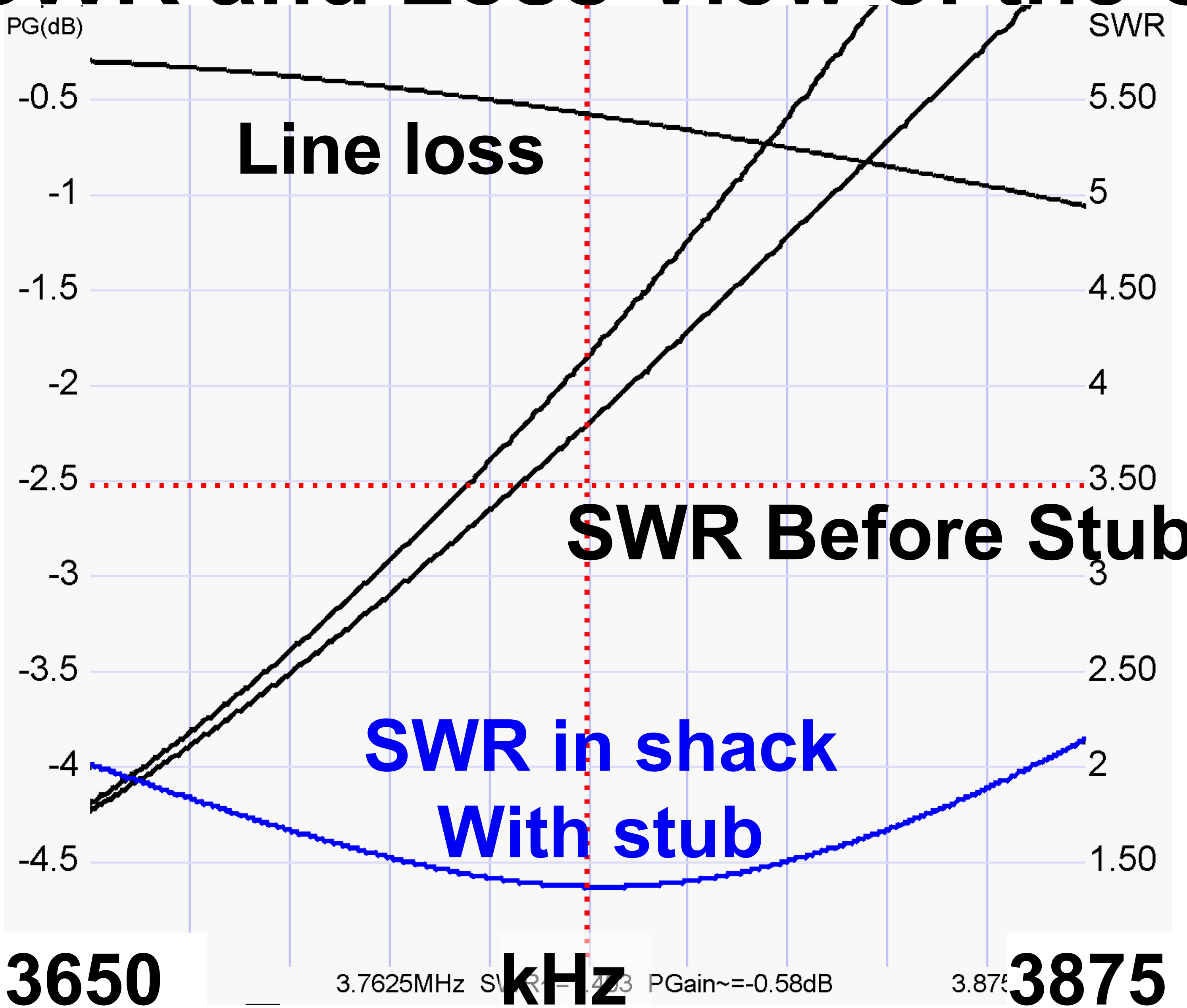


# Sim Smith Circuit for the Stub




| L | A | B | C | D | G |
|---|---|---|---|---|---|
| R= 23.004 | R= 67.741 | R= 23.004 | R= 24.597 | R= 27.583 | Mag= 0.2974 |
| **X= -0.992** | **X= 45.078** | **X= -0.992** | **X= 10.358** | **X= -5.708** | **Angle= -161.5** |
| Pin= 0.979 | Pin= 0.924 | Pin= 0.979 | Pin= 0.993 | Pin= 1 | |
| 23.004 Ohms | -112.9 deg | 112.89 deg | 16.441 deg | 47.387 deg | 3.675 MHz |
| -0.992 jOhms | 3.675 @MHz | 3.675 @MHz | 3.675 @MHz | 3.675 @MHz | xMtch type |
| | -70.5 ft | 70.5 ft | 10.267 ft | 29.593 ft | 50 Zo |
| | .84 vf | .84 vf | .84 vf | .84 vf | 1 swr |
| | 50 Zo | 50 Zo | 50 Zo | 50 Zo | 0 QEye |
| | 0.50 /100f | 0.50 /100f | 0.50 /100f | 0.50 /100f | PG(dB) |
| | 10 @frq | 10 @frq | 10 @frq | 10 @frq | -0.5 |

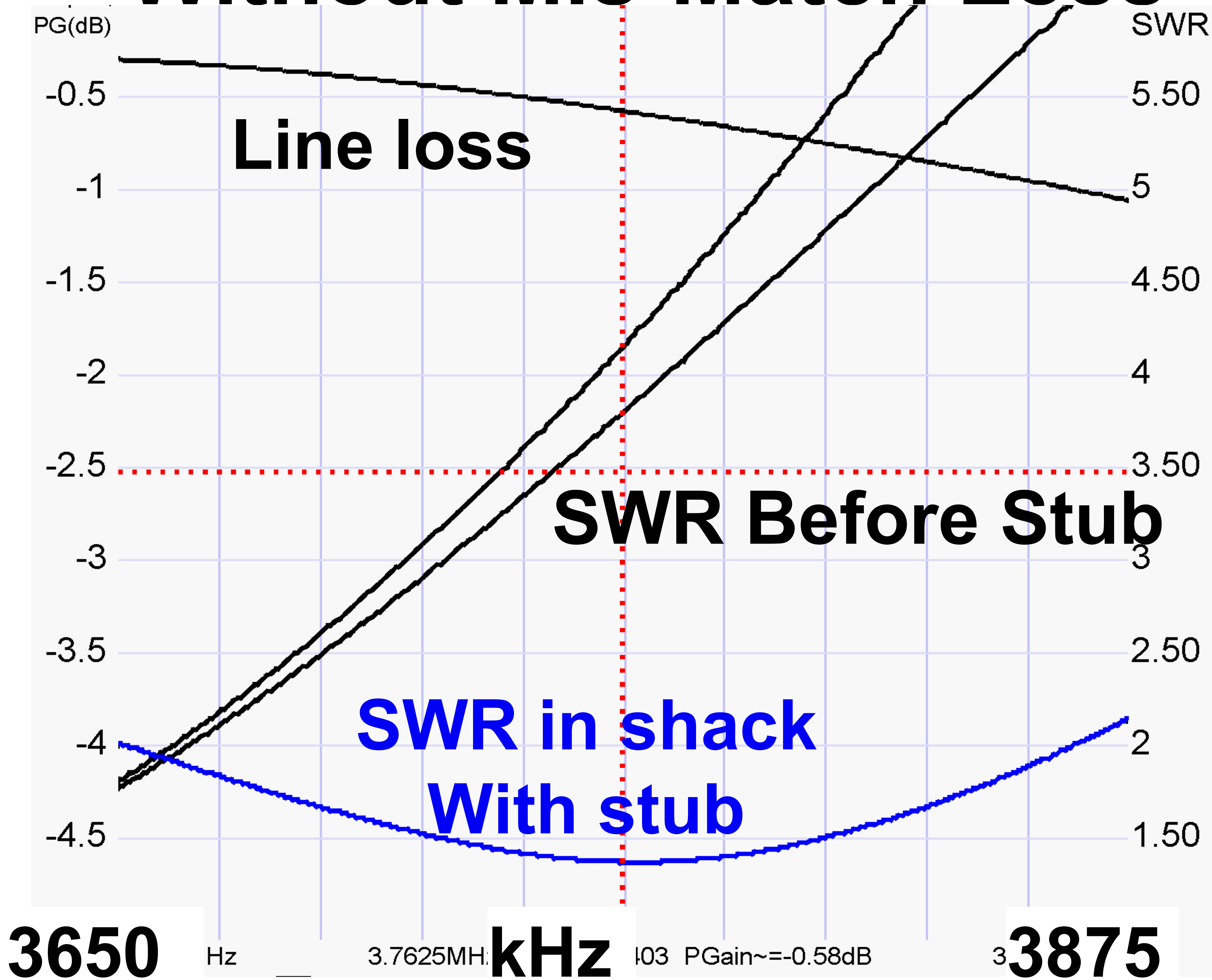
# SWR and Loss View of the Stub



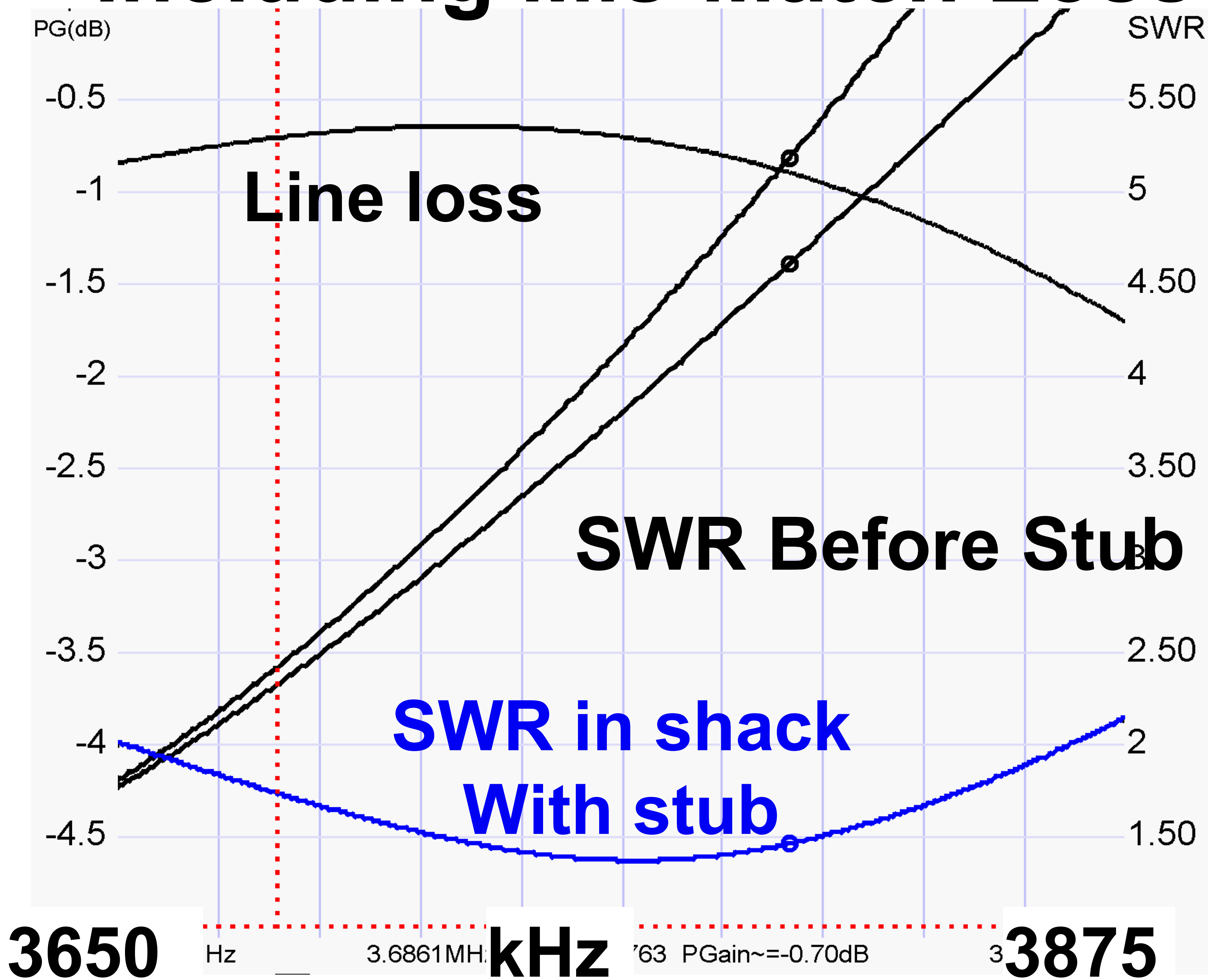
# Two Methods to Compute Loss

- Include impedance mis-match between transmitter and line (called “mismatch loss”)
  - Not really loss, simply less power transferred to line
- Ignore mis-match, assume some sort of antenna tuner is used, or that Zs is significantly less than Zo

# Without Mis-Match Loss



# Including Mis-Match Loss



# When To Include Mis-Match Loss

- **Most VHF/UHF systems**
  - **The path between the output devices and the output terminals is quite likely to be matched**
  - **The source is likely to be 50Ω**
- **When you <u>know</u> the source Z is really the same as Zo**

# When To Ignore Mis-Match Loss

- Any time an antenna tuner or matching network not part of the model is used to drive the line
- Any “tuned” power amp
- The source impedance, Zs, of most HF power amps, including transceiver output stages, is likely to be closer 25Ω than 50Ω

# Maximum Power Transfer

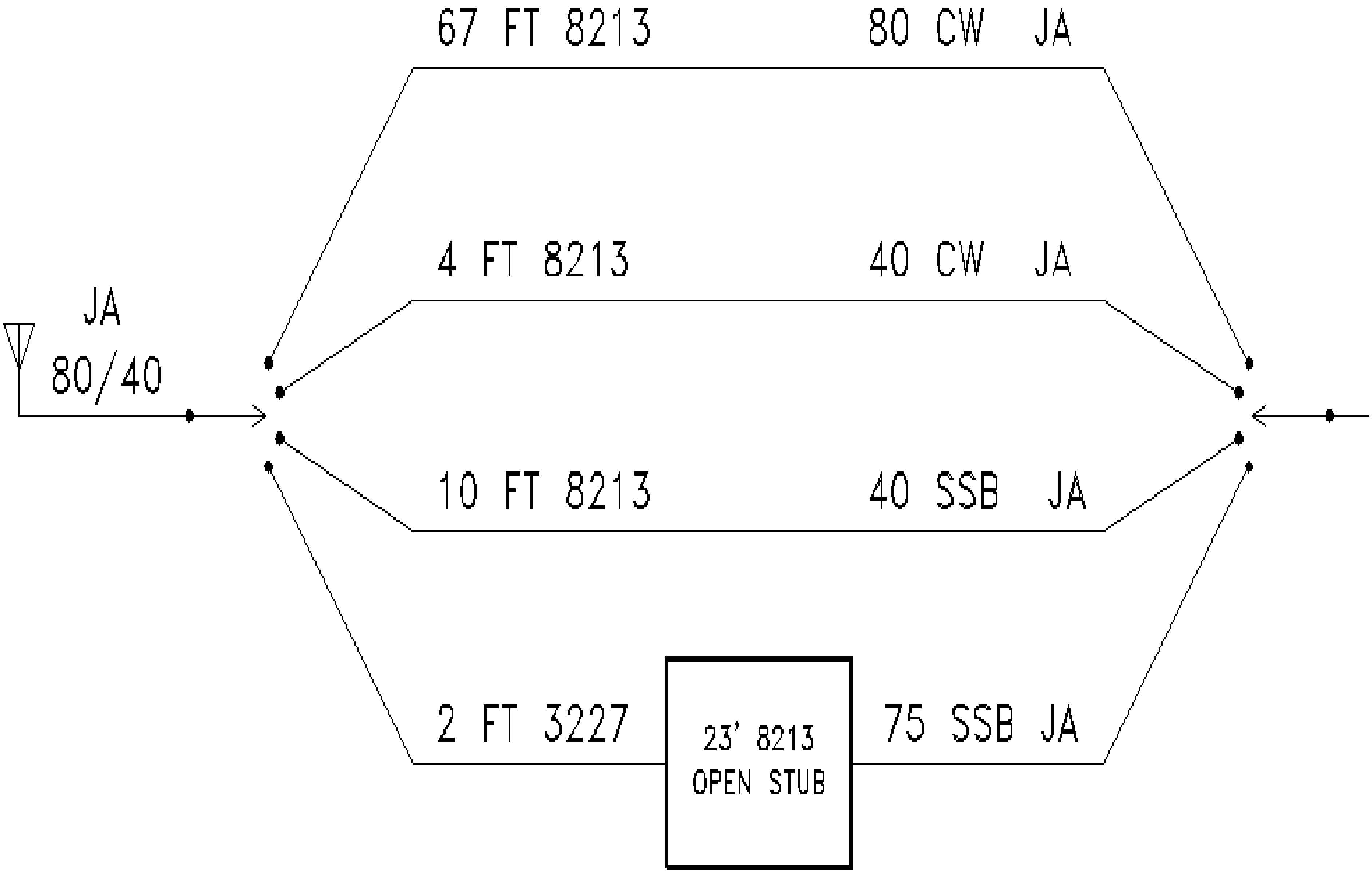
- **The classic theorem requiring $Z_L$ = the conjugate of $Z_{SOURCE}$ applies to a variable <u>LOAD</u> impedance**
- **If $Z_{SOURCE}$ is variable, maximum power transfer occurs when $Z_{SOURCE} << Z_L$**

# Maximum Power Transfer

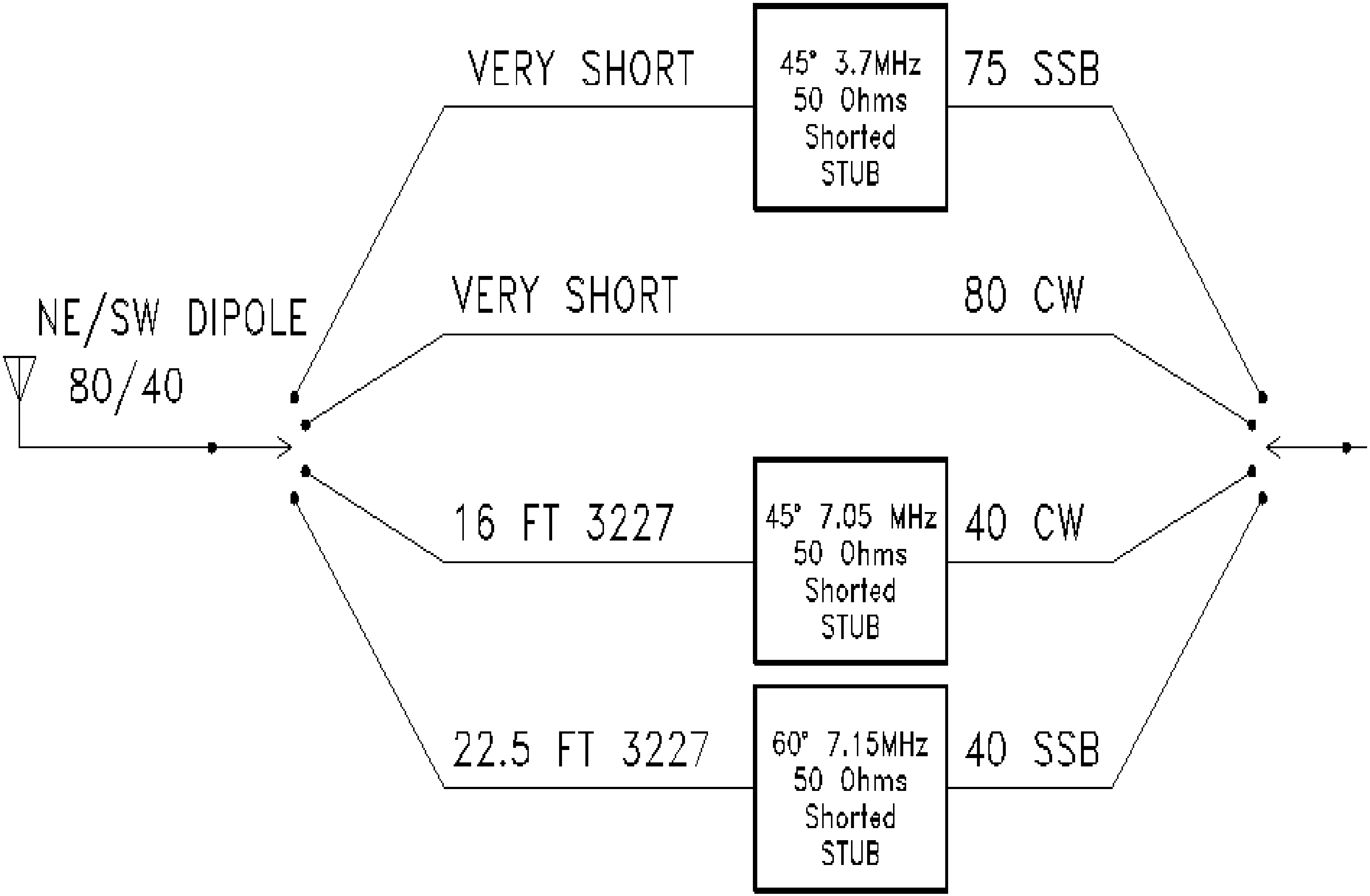
- **The maximum power transfer theorum was derived for linear circuits**
- **Impedance matching at power amp outputs is really a matter of providing an impedance that the output devices want to see**
- **That may or may not be**

$$Z_L = Z_{SOURCE}$$

# Matching my 80/40 JA Fan Dipole

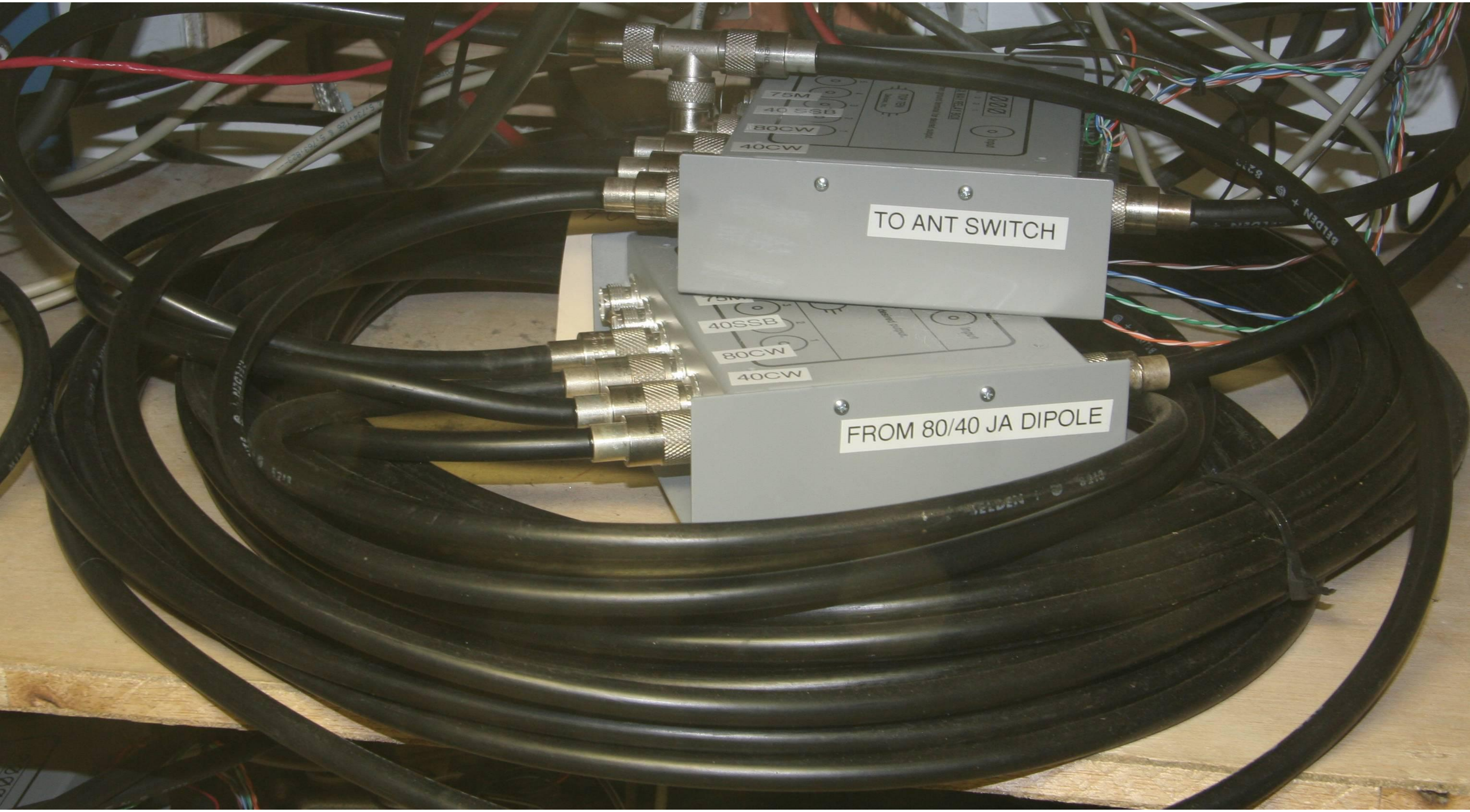


# My 80/40 EU/VK Fan Dipole

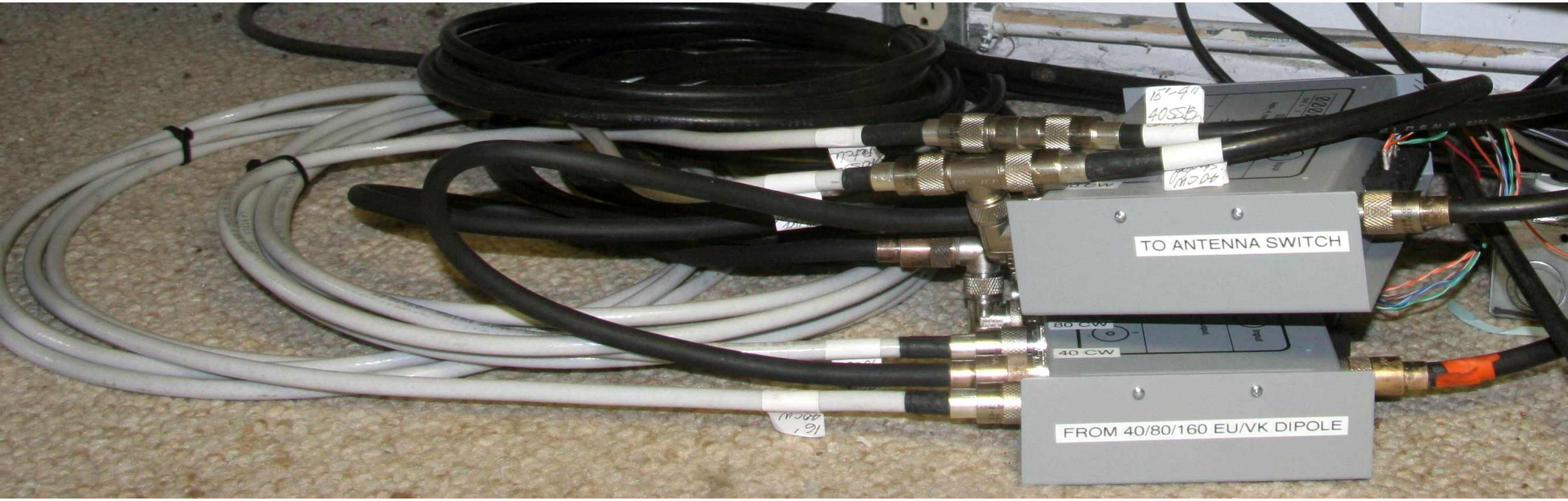


# User Controls

# Stubs for my JA Fan Dipole



# Stubs for my EU/VK Fan Dipole



# Tuners I Replaced
# (one more was added after photo)

# Cost/Benefit Analysis – <u>Benefits</u>

- Antenna tuners are gone
- SWR <1.5:1 all bands
- Switching is simple, instantaneous
- Exactly resettable
- Much less clutter on operating desk, space above desk for P3 VGA
- Ready for YCCC "Mother of All Antenna Switches" to control it

# Cost/Benefit Analysis – <u>Benefits</u>

- **I had a lot of fun designing and building it (and learning things)**
- **I'll use the VNA to tune bandpass filter boxes**
- **The VNA is a big help in finding issues in the antenna system, and in evaluating products like relay boxes**

# Cost/Benefit Analysis – Costs

- Some good coax, ~ 200 ft
- Top Ten 1x6 switches ($110 each)
- Connectors
  - PL259s ~ $3 each
  - Tees, a few at ~ $11 each
  - Elbows, a few, ~ $ 9 each
- Vector analyzer $500 - $1,500
  - Lower cost units plenty good enough for HF work
  - Or borrow one

# Cost/Benefit Analysis – Savings

- Antenna tuners, manual switching
  - I've already sold five for a total of about $1,100
  - I had ordered three of the new Elecraft tuners and am beta-testing one with my Titans, but I could live without them
  - I'll keep the beta unit for CQP

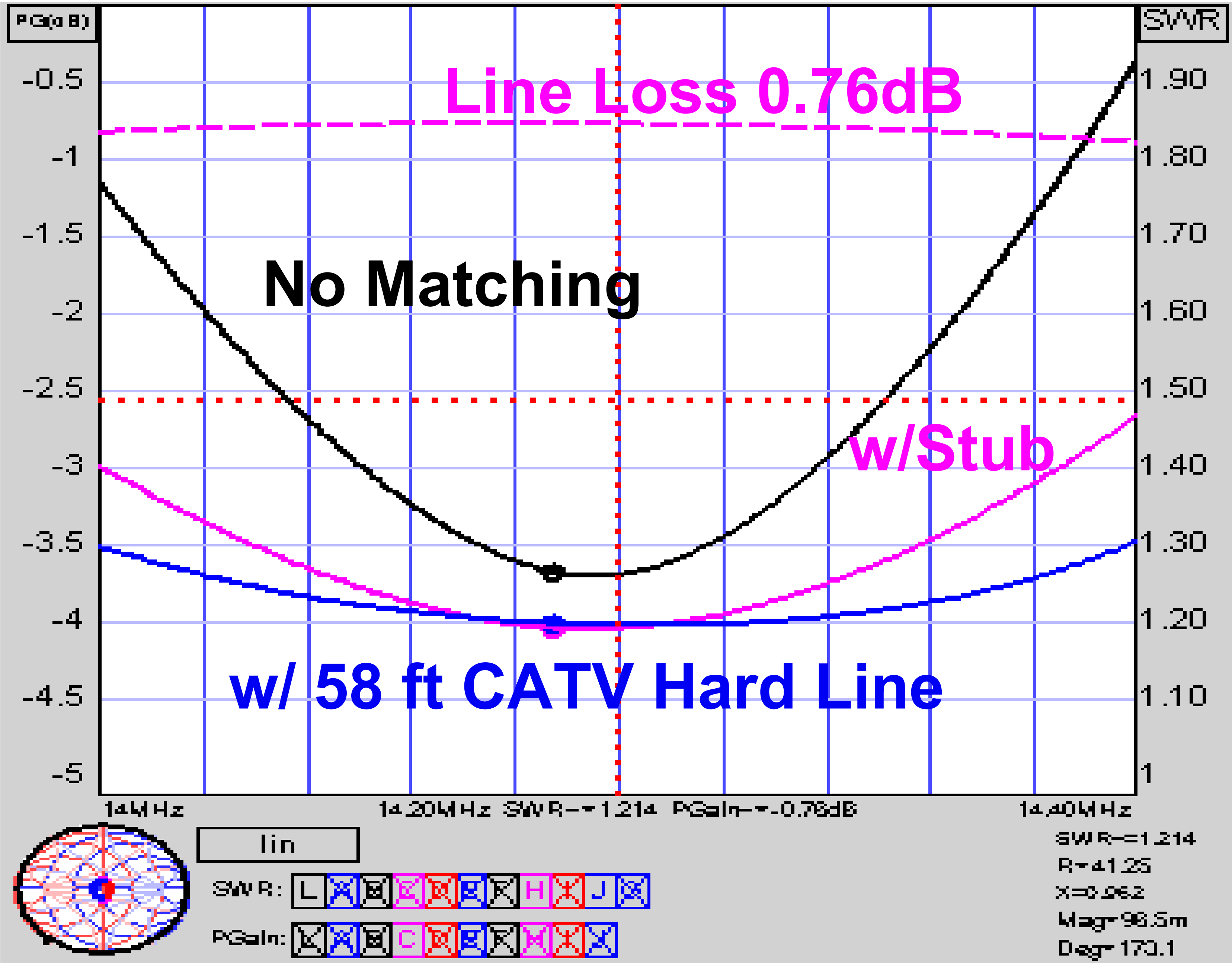
# Rules of Thumb for Matching

- Locate matching elements as close to the antenna as practical
  - Generally yields a better match
  - Reduces line loss by minimizing the length of line with high SWR
  - Practical for monoband antennas
- Matching in the shack works fine too, and is easier to switch

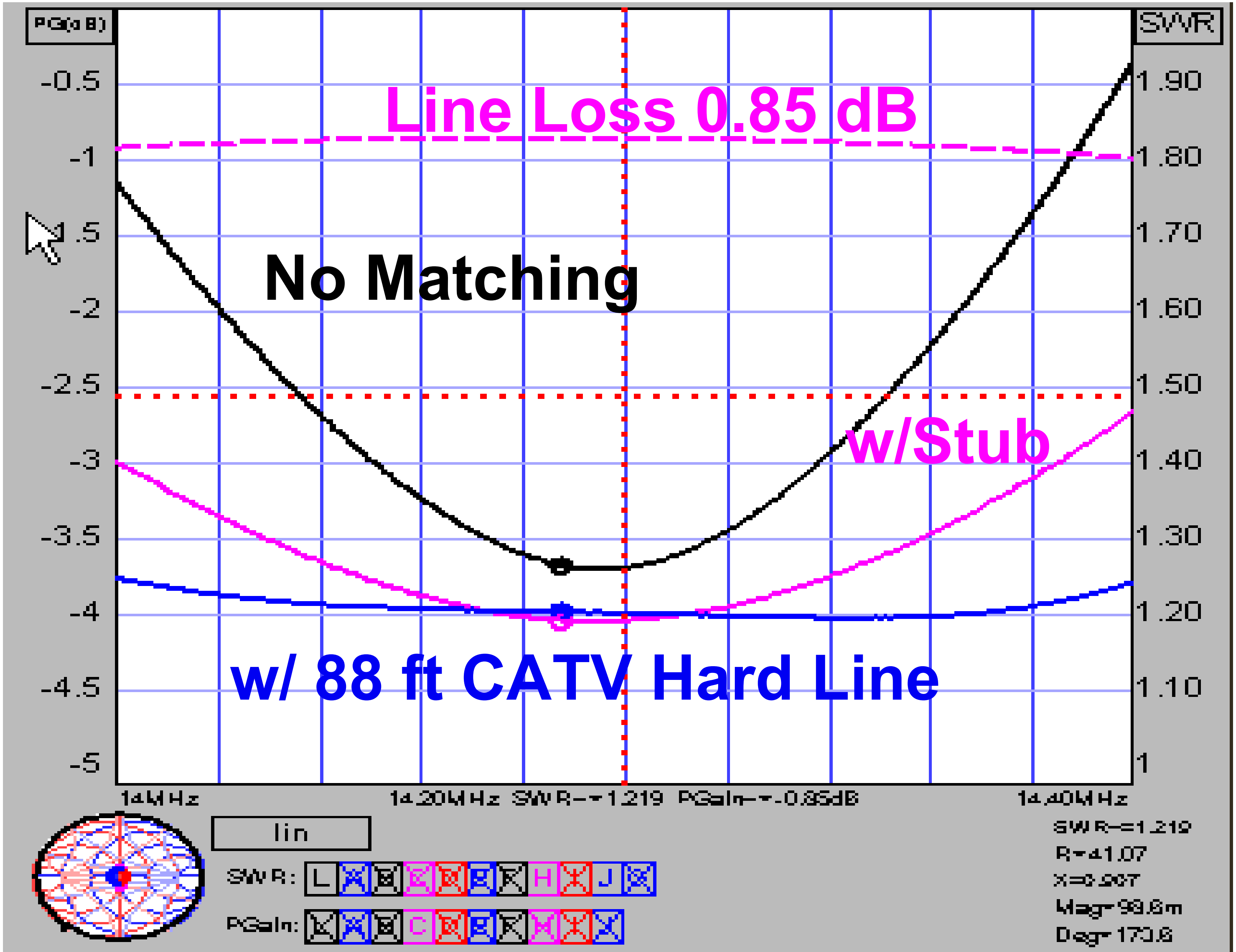
# Ideas for Matching

- Try a 75Ω matching section in 50Ω line for an antenna near resonance
  - 90°, 180° and multiples of 180°
  - Add coax if needed to adjust length between 75Ω section and antenna so curve crosses the center horizontal (zero reactance line)
  - Tweak lengths watching SWR at TX

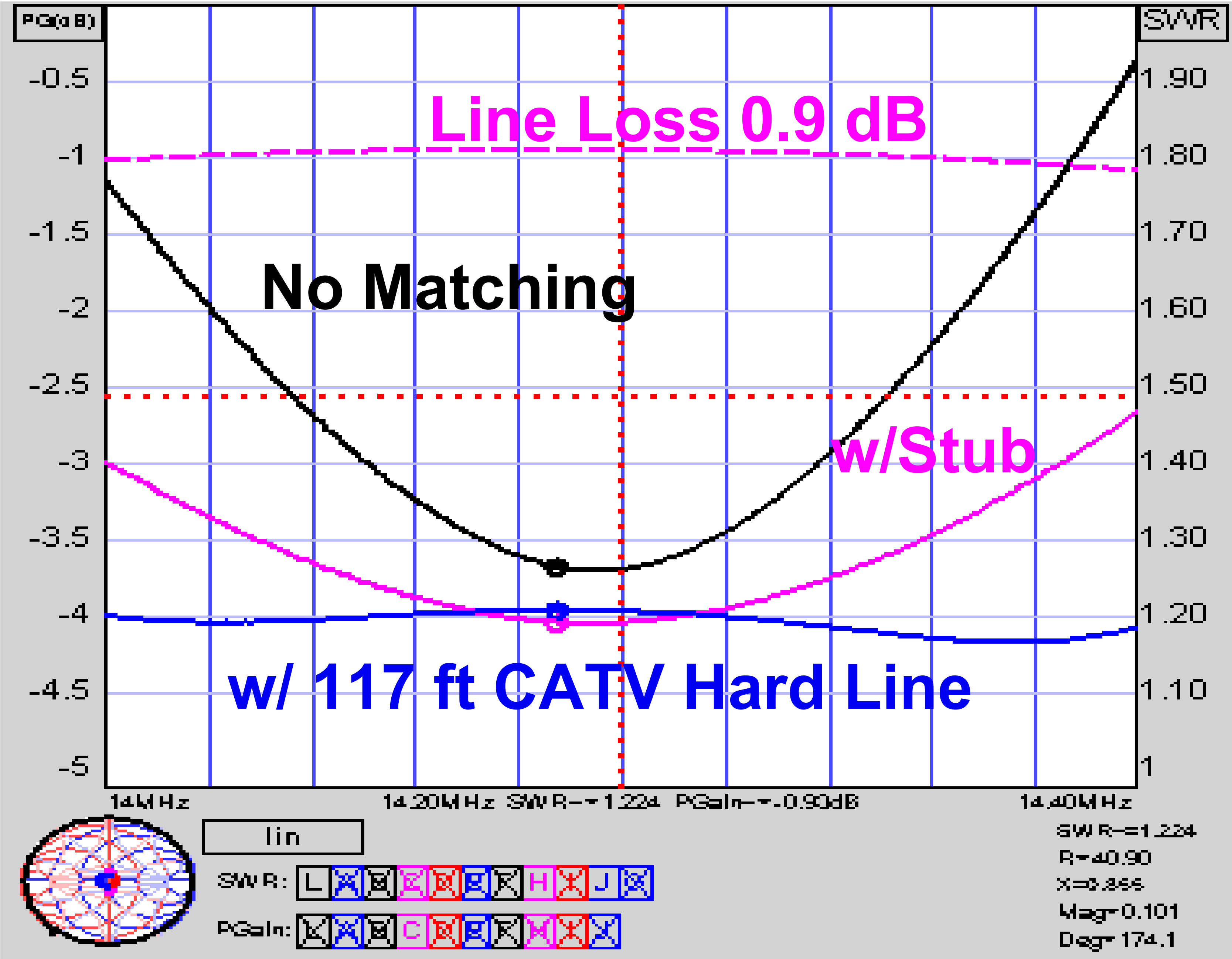
# 1λ of 75Ω CATV Hard Line



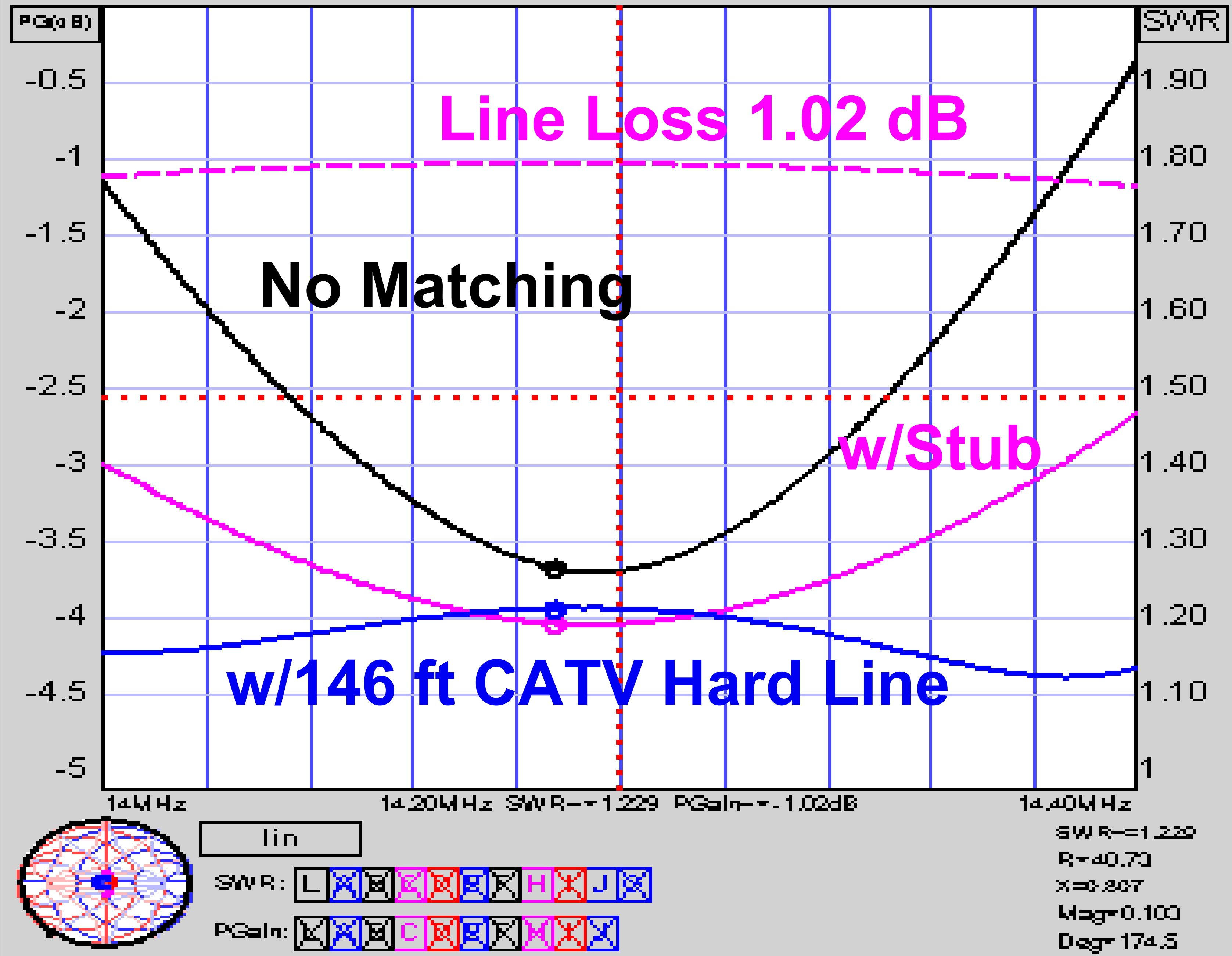
# 3λ/2 of 75Ω CATV Hard Line



# 2λ of 75Ω CATV Hard Line



# 5λ/2 of 75Ω CATV Hard Line



# Rules of Thumb for Matching

- **Don't rule out a 75 ohm matching section with a tri-bander**
- **2λ on 20M (117 ft of CATV hard line) is 3λ on 15M and 4λ on 10M**
- **I'm using 117 ft lengths of CATV hard line on my 20M and 15M monobanders, and may put one half that length on my 10M Yagi (because it's much closer)**

# Rules of Thumb for Stubs

- Try for an open stub first
  - It's usually shorter for moderate mismatches
- Higher $V_F$ coax requires more coax, but cutting errors will be lower
- Use good coax, but don't worry about small loss differences

# Other Smith Chart Uses

- Smith charts can work for design of L – C networks too
- Many networks can be built with L and C or stubs, or even a mix
- BUT – although stubs are "sort-of like" L and C, they are fundamentally different

# How Stubs Are Different

- **An open stub <90° is capacitive, but it's <u>capacitance varies with frequency</u>**
- **Likewise, the <u>inductance</u> of an <u>shorted</u> stub <90° also varies with frequency**
- **A stub or matching section that is 90° or 180° at some frequency F is 85.5° or 171° at 0.95x F**

# How Stubs Are Different

- These subtle differences often make one or the other kind of component a better choice for any given circuit

# Thinking About Stubs and Antennas

- **Near resonance, a half wave dipole (or quarter wave vertical) acts much like a series resonant circuit**
- **Near resonance, an open $\lambda/4$ stub or shorted $\lambda/2$ stub acts like much series resonant circuit**
- **Near resonance, a shorted $\lambda/4$ stub or open $\lambda/2$ stub acts much like a parallel resonant circuit**

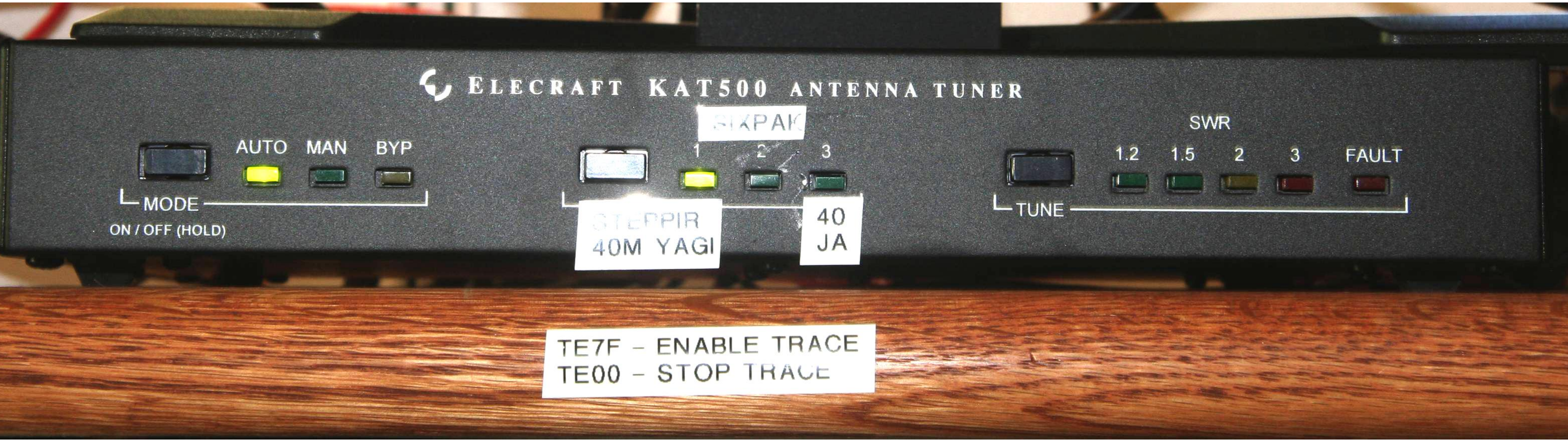
# Thinking About Stubs and Antennas

- **An open stub shorter than λ/4 looks capacitive, and can tune out inductance**
- **A shorted stub shorter than λ/4 looks inductive, and can tune out capacitance**
- **Stubs move impedance along left-centered curves to, or away from, center of Smith chart**

# The Ultimate Matching Section

- **Loss in <u>any</u> line causes the impedance to move closer to the center of the chart (lower SWR)**
- **High losses >>> low SWR**
- **1,000 ft of RG58 makes almost any antenna look perfectly matched**
  - **Approaches 1:1 for almost any load**
  - **Burns 99% of the TX power at HF**

# The New Toy (Beta)



# References

- **SimSmith info, download http ://www.ae6ty.com/Smith_Charts.html**
- ***SimSmith and Smith Chart Tutorial***

  **http://www.ae6ty.com/Papers_files/QRParticle.pdf**
- ***SimSmith Primer***
  **http://www.ae6ty.com/Smith_Charts_files/SimSmith%20Primer.pdf**
- **Ward Silver, N0AX QST**
  **Dec ’07, Jan ’08, Feb ’08 (Smith Charts)**
  **Nov ’04, Nov ’07 (Stubs)**

  **http://www.arrl.org/hands-on-radio**
- **Jim Brown, K9YC Some Q&A on Coax and Stubs http://audiosystemsgroup.com/Coax-Stubs.pdf**
- **Steve Stearns, K6OIK, Mysteries of the Smith Chart http://archive.k6ya.org/docs/smith_chart.pdf**

# Using Sim Smith to Improve Antenna Matching

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k9yc@arrl.net

http://audiosystemsgroup.com/publish.htm