Basics of Smith Charts and Antenna Measurements

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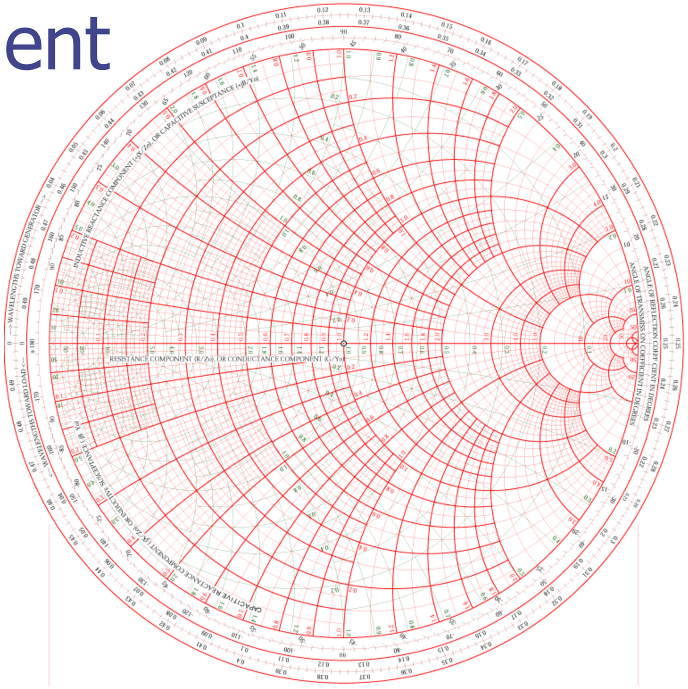
Agenda

- What is a Smith Chart
- Antenna Measurements & Transmission Line Effects
- Watching your Tuner adjustments
- BONUS – Matching Network Design with a Smith Chart

What is a Smith Chart

- A graphical tool to plot and compute:
  - Complex impedance
  - Complex reflection coefficient
  - VSWR
  - Transmission line effects
  - Matching networks
  - …and more
- Let’s break it down….



Normalized Impedance

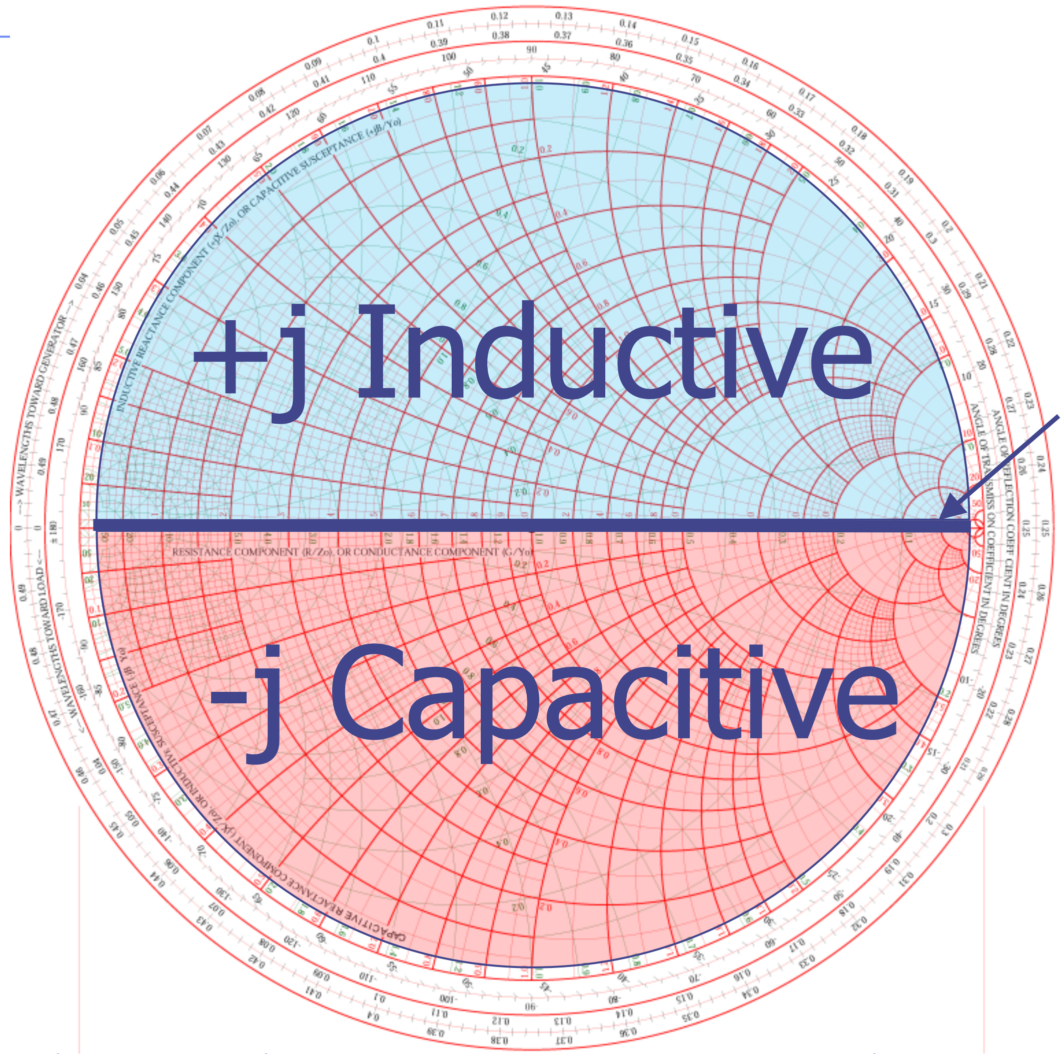
- Normalized Z = Actual Z / System Z_0
  - For Z_0=50Ω, divide values by 50
- Example:
  - $Z = 37 + j55$
  - $Z' = \frac{37}{50} + j\frac{55}{50}$
  - $Z' = 0.74 + j1.10$

This is what we plot on the chart

- **Makes it usable for any system Z_0**

Z Regions on the Smith Chart

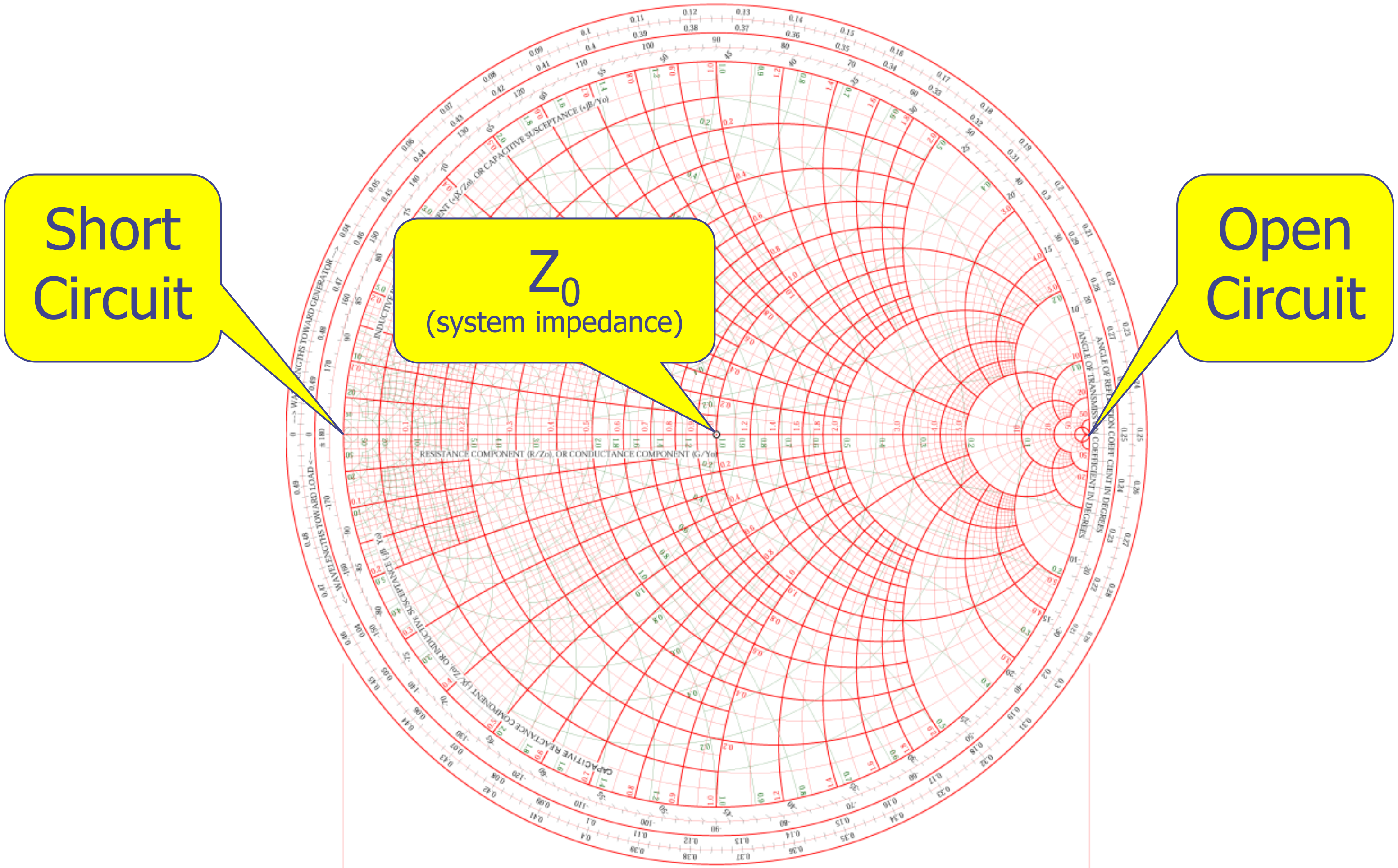
$R + jX$



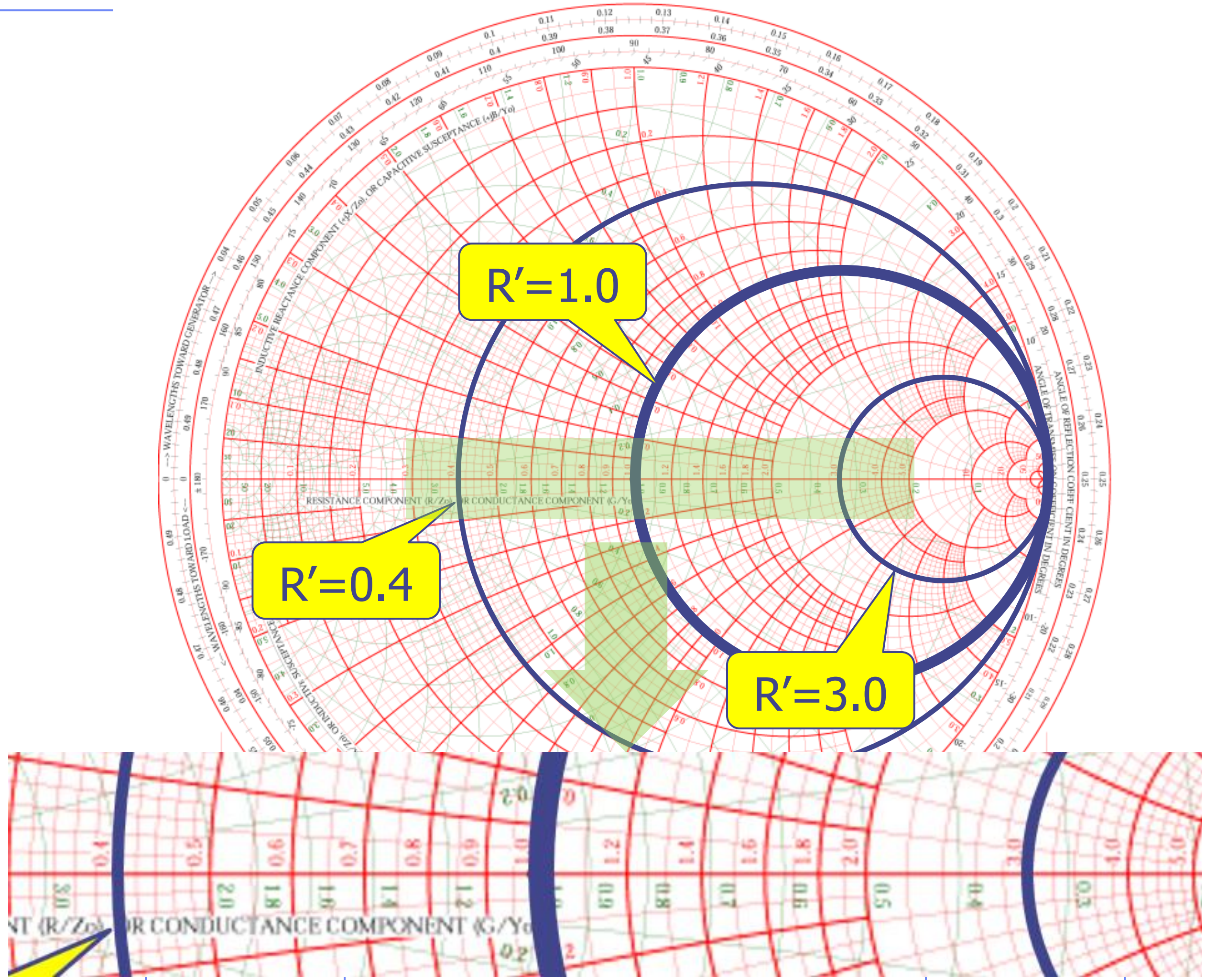
Purely Resistive
$jX = 0$

$R - jX$

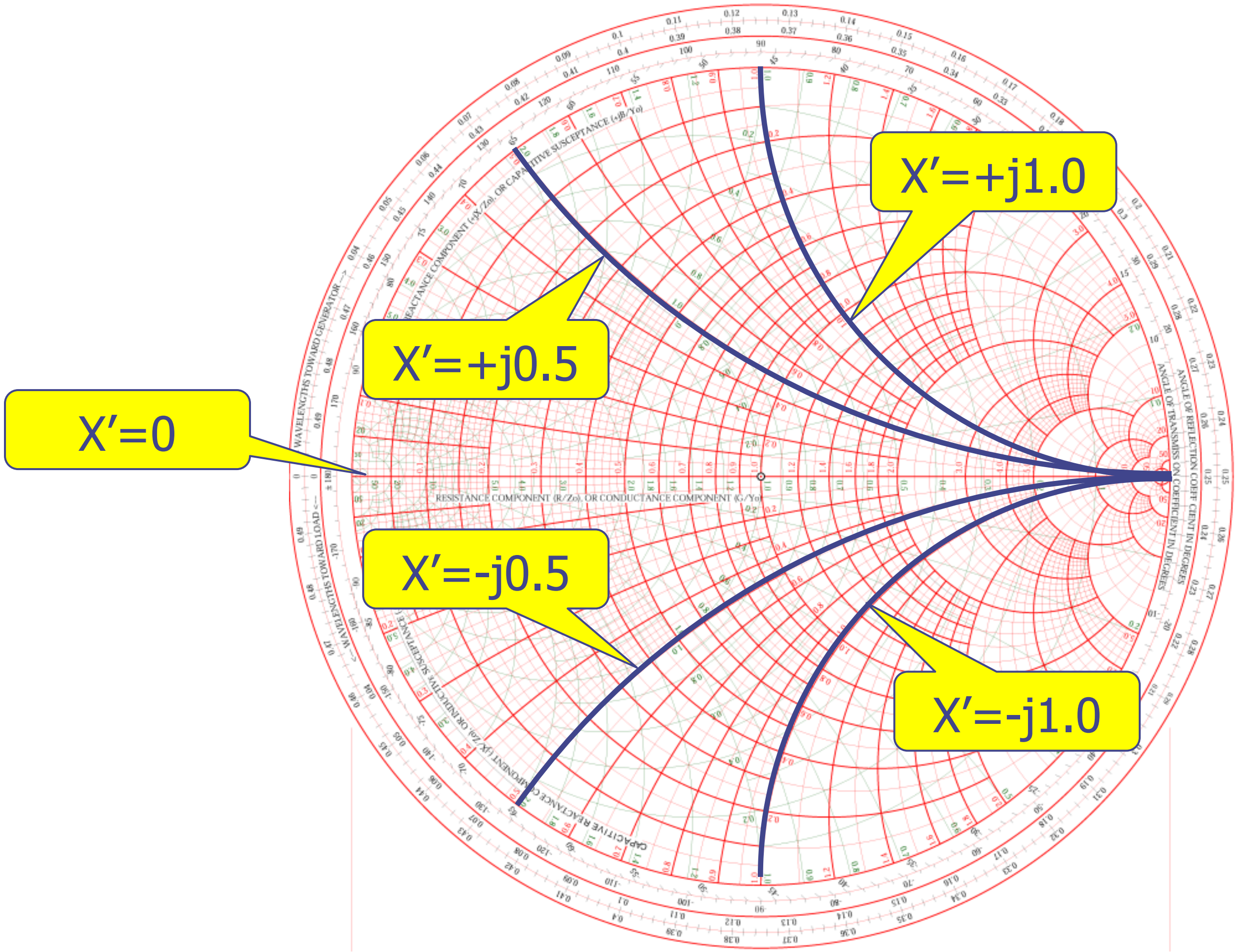
Key Values on the chart



Constant Resistance Circles

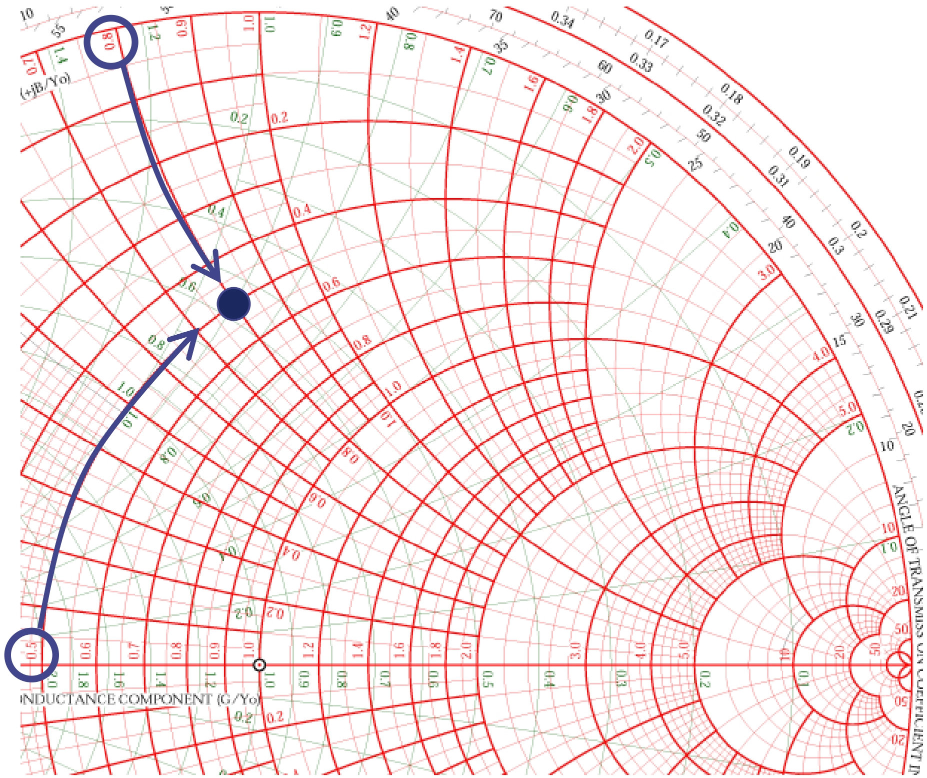


Constant Reactance 'Arcs'



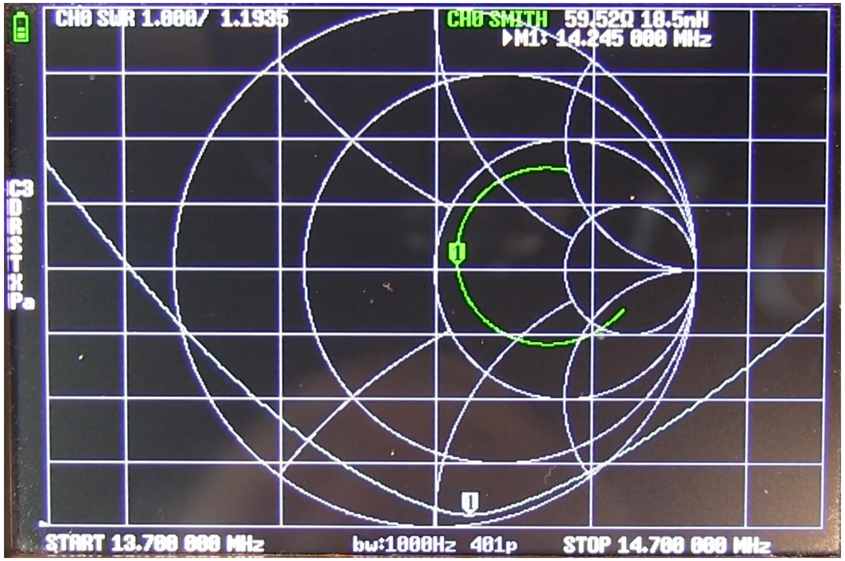
Plot a Complex Impedance

- $Z = 25 + j40$
- Divide by 50 to normalize…
- $Z' = 0.5 + j0.8$
- Find intersection of R'=0.5 circle and X'=0.8 arc



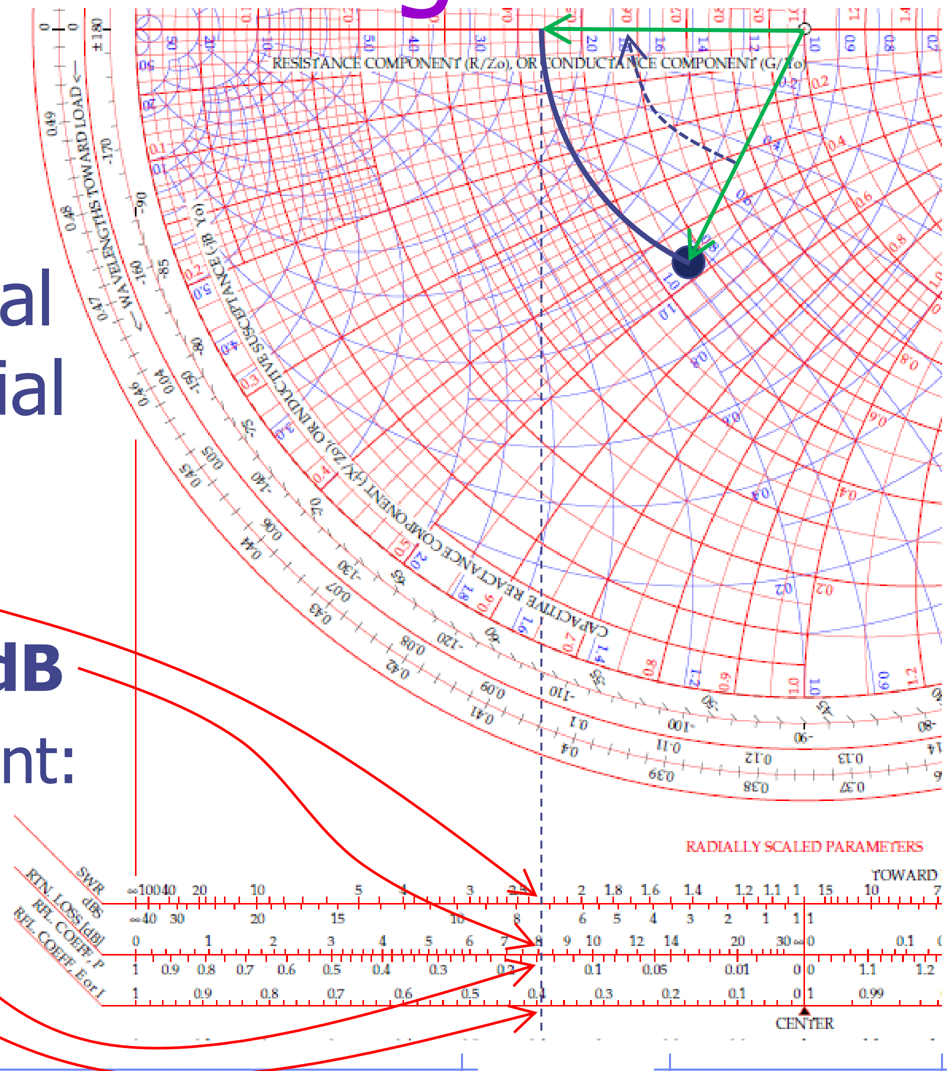
Antenna Impedance vs Freq.

- Complex Impedance vs. Frequency on Smith Chart (green)
  - Frequency is only indicated by markers
- SWR shown in white
- Markers at the same frequency on both plots



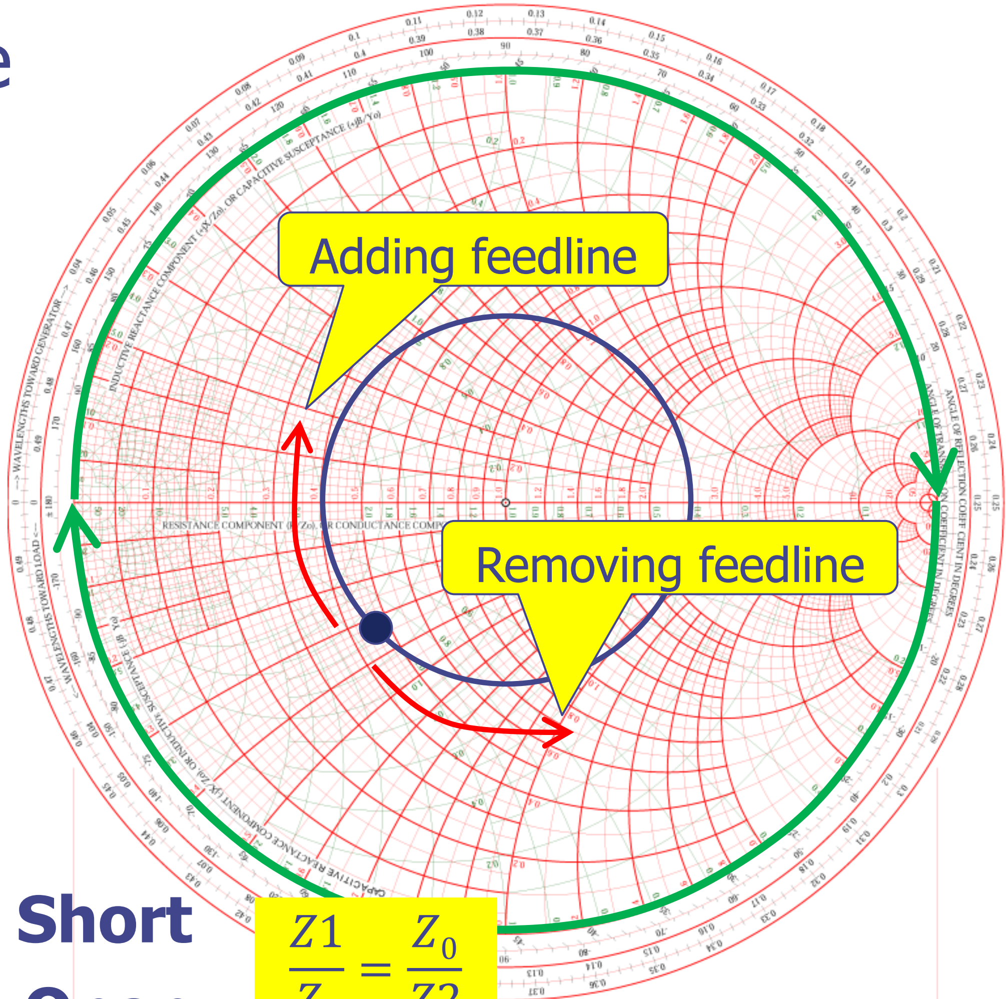
More Smith Chart Magic

- **Radially Scaled Parameters**
- Rotate vector to real axis, extend to radial scales:
  - VSWR: **2.3:1**
  - Return Loss: **8.10dB**
  - Reflection Coefficient:
    Power: **0.155**
    V or I: **0.39**



VSWR and Transmission Lines

- Constant VSWR circle
  - Impedance varies
  - VSWR stays same
- One trip around Smith chart is ½ wavelength
  - Impedance **repeats**
- Half-way around is ¼ wavelength:
  - **Open** transformed to **Short**
  - **Short** transformed to **Open**



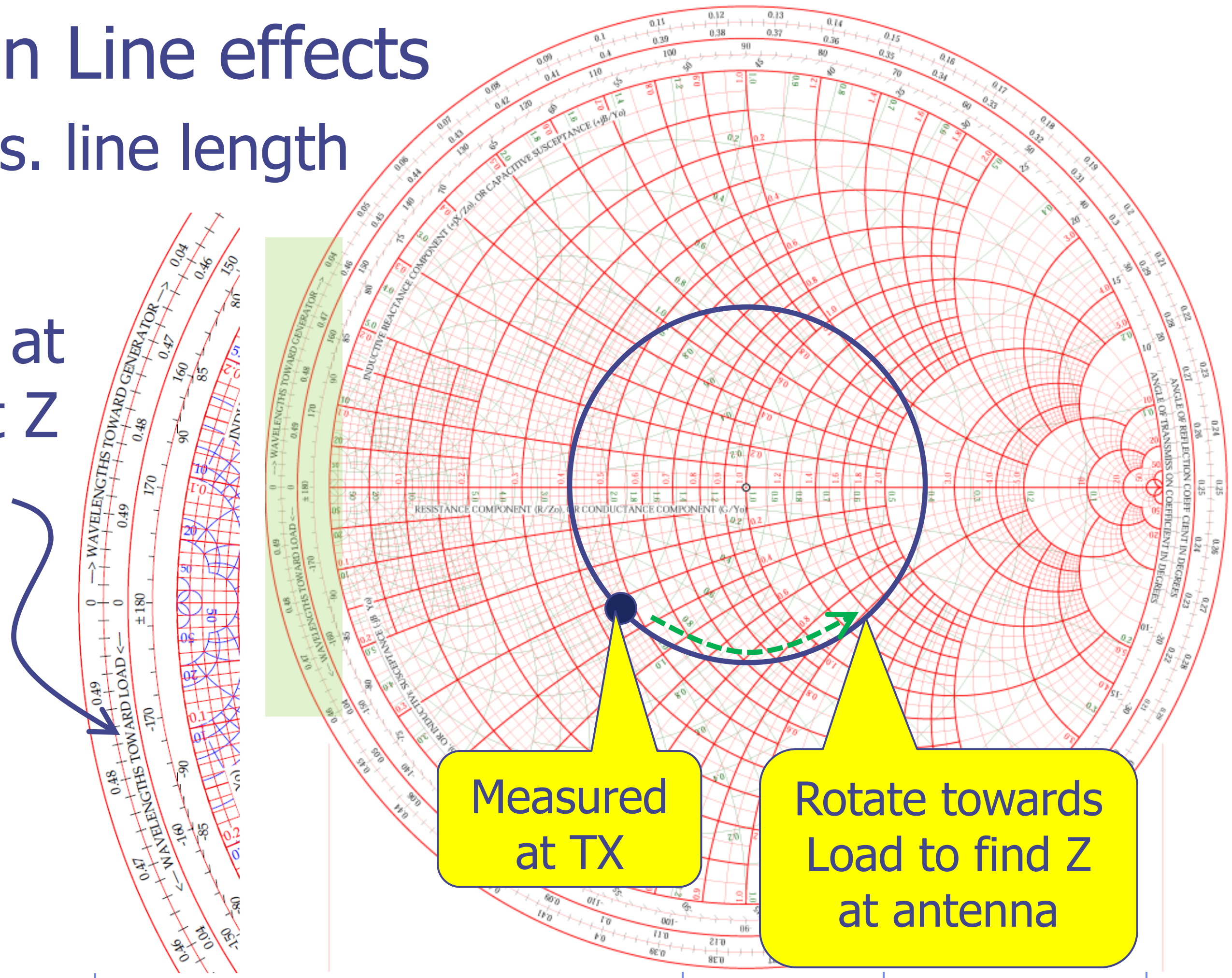
$$\frac{Z1}{Z_0} = \frac{Z_0}{Z2}$$

Adding coax length

- Same antenna measured with gradually increasing transmission line length
  - Starting point
  - Added about 3 feet of coax
  - Added another 3 feet of coax
  - Added a final 3 feet of coax
- Note – no change in SWR, just a change in impedance!

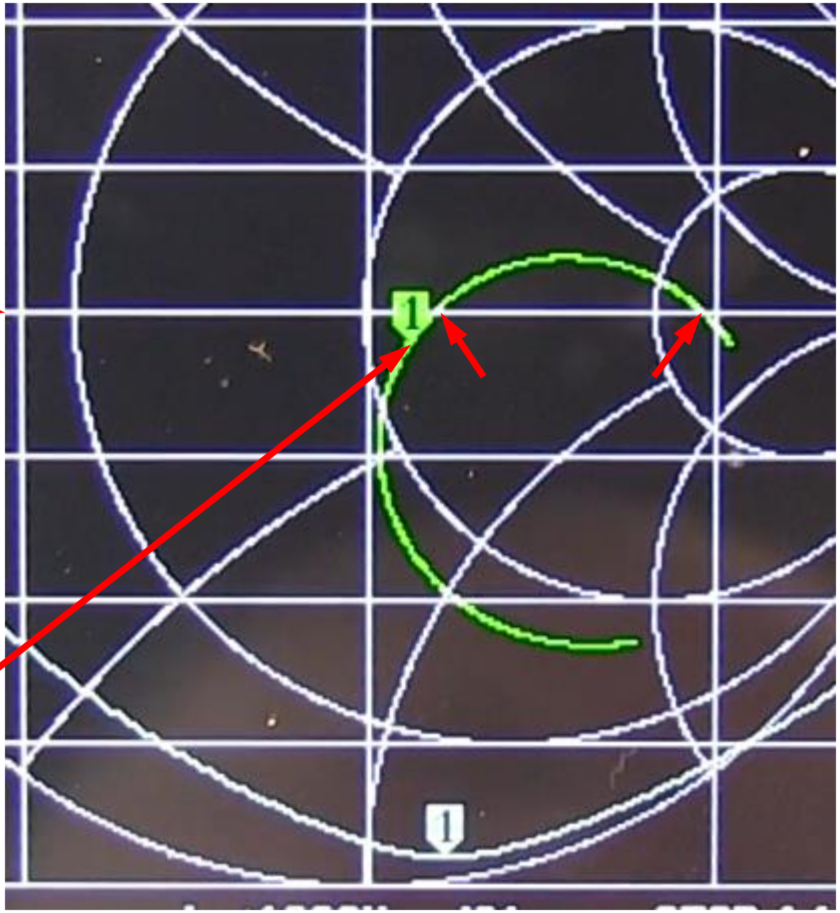
VSWR and Transmission Lines

- Transmission Line effects
  - Predict Z vs. line length
- Example:
  - Measure Z at TX, predict Z at antenna



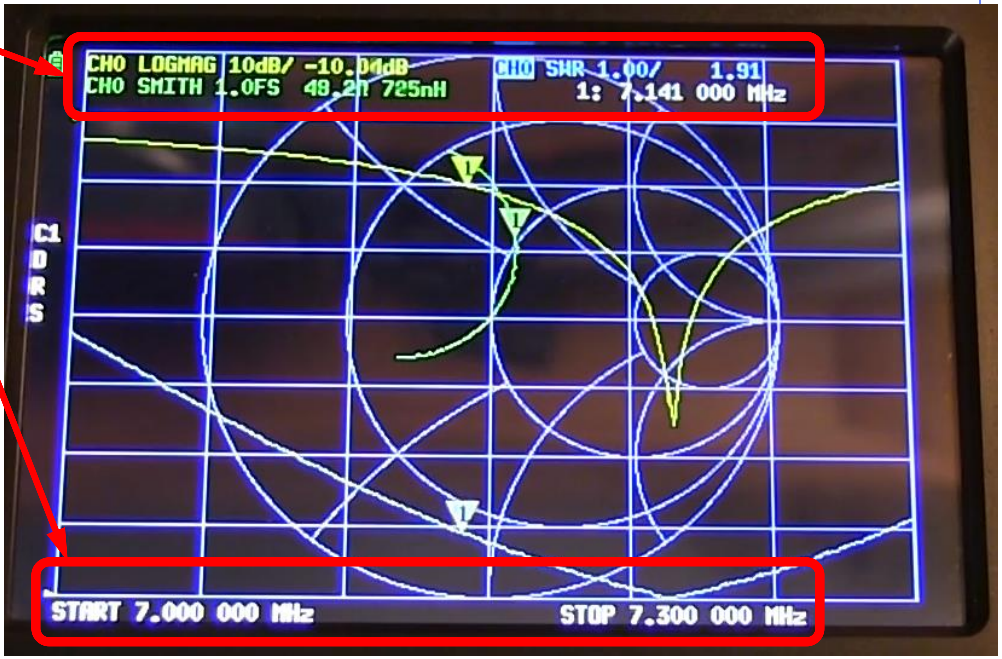
Resonance and Min SWR

- **Resonance** *only* means that the reactance is Zero
- How many resonant frequencies are here?
- Minimum **SWR** does not always occur at resonance!



Setup NanoVNA to measure an antenna

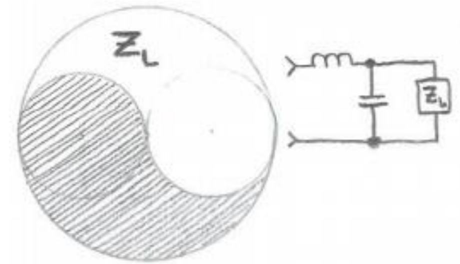
- Select your Traces
  - SWR, LOGMAG, Smith
  - All use CH0
- Set Stimulus Range
  - Not too wide!
- Calibrate
  - …where TX connects
- Measure

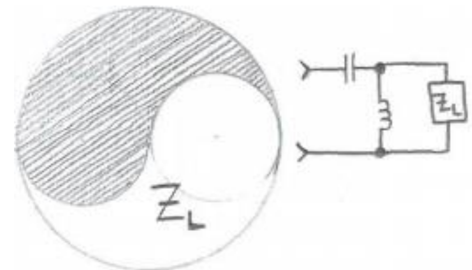


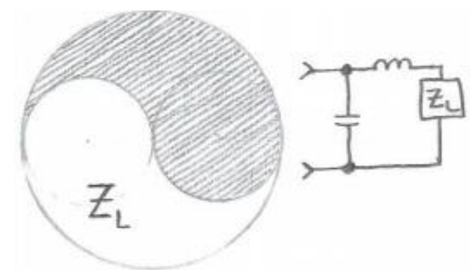
Video: NanoVNA setup and use

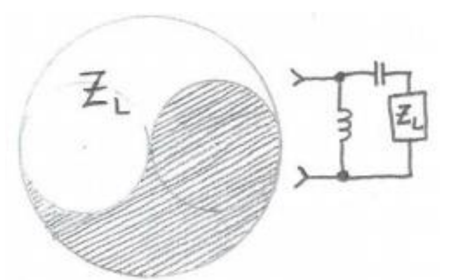
Impedance Matching: L-Network

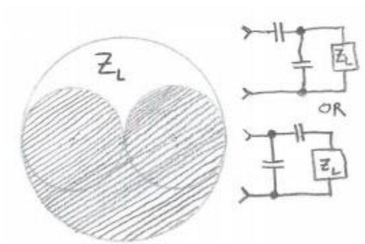
- Add series/parallel inductor/capacitor to move Z_L to Z_0
- L-Network topology based on where Z_L is on the Smith Chart
- Sometimes more than one network topology works

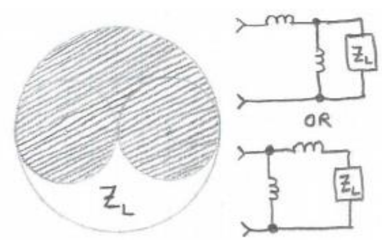






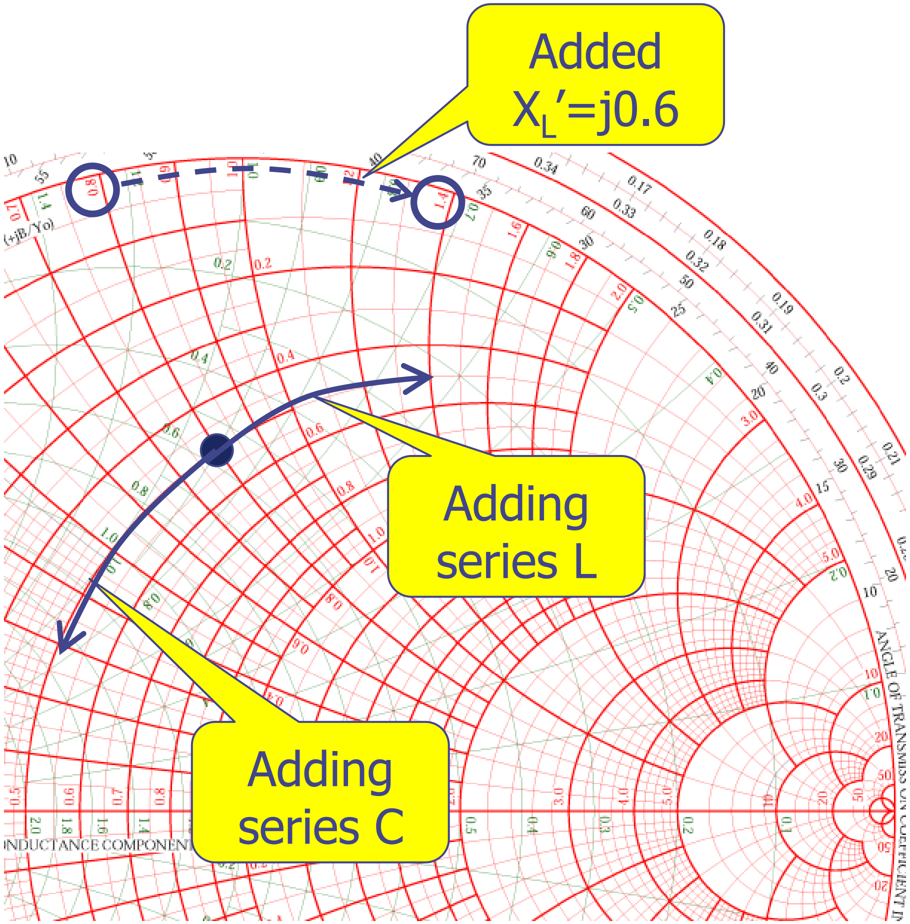






Adding Series Elements

- Add components to move around the Smith Chart
- Series L & C move along constant-R circles
  - Series L moves CW
  - Series C moves CCW



What about Admittance?

- Admittance is handy when adding elements in parallel
- Converting Impedance to Admittance is easy with Smith Chart

$$Admittance: Y = \frac{1}{Z}$$

$$Conductance: G = \frac{1}{R} \; *$$

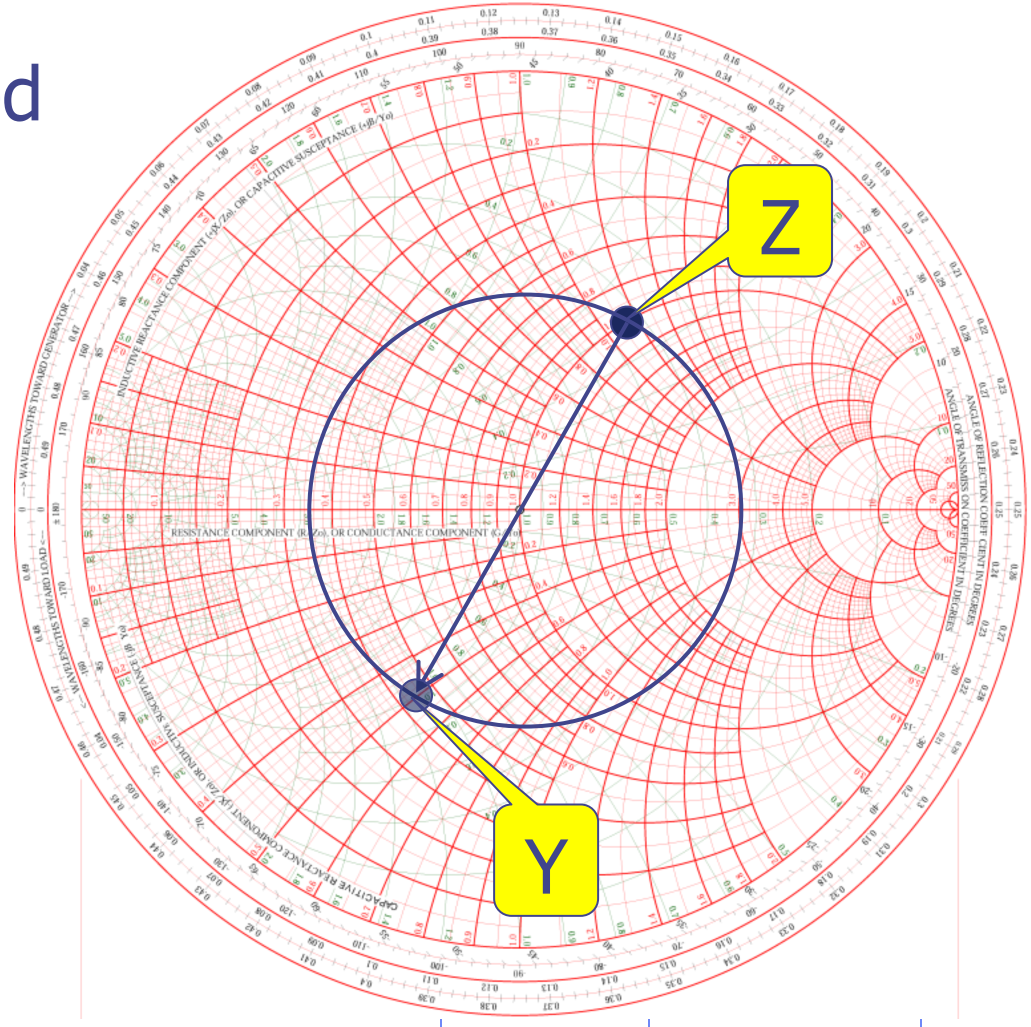
$$Susceptance: B = \frac{1}{X} \; *$$

* (when “real” component = 0)

Converting to Admittance

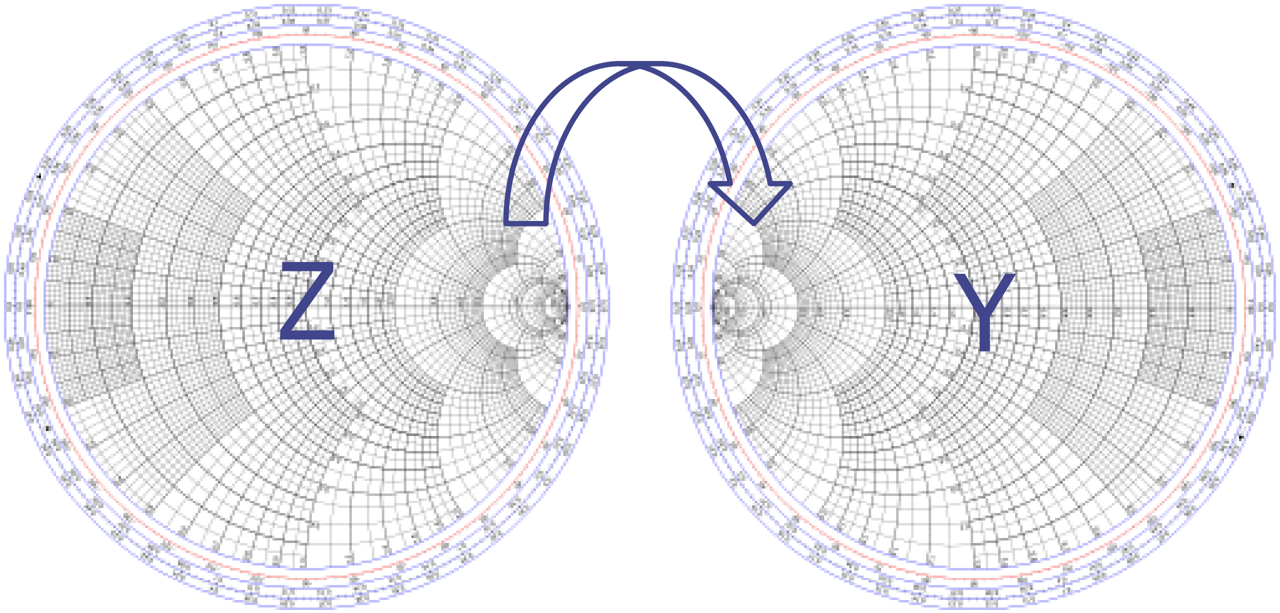
- Draw circle centered on Z_0 that crosses through Z point
- Bisect circle thru Z and Z_0
- Y is 180° away on circle

$$Z' = 1 + j1.1$$
$$Y' = 0.45 - j0.5$$



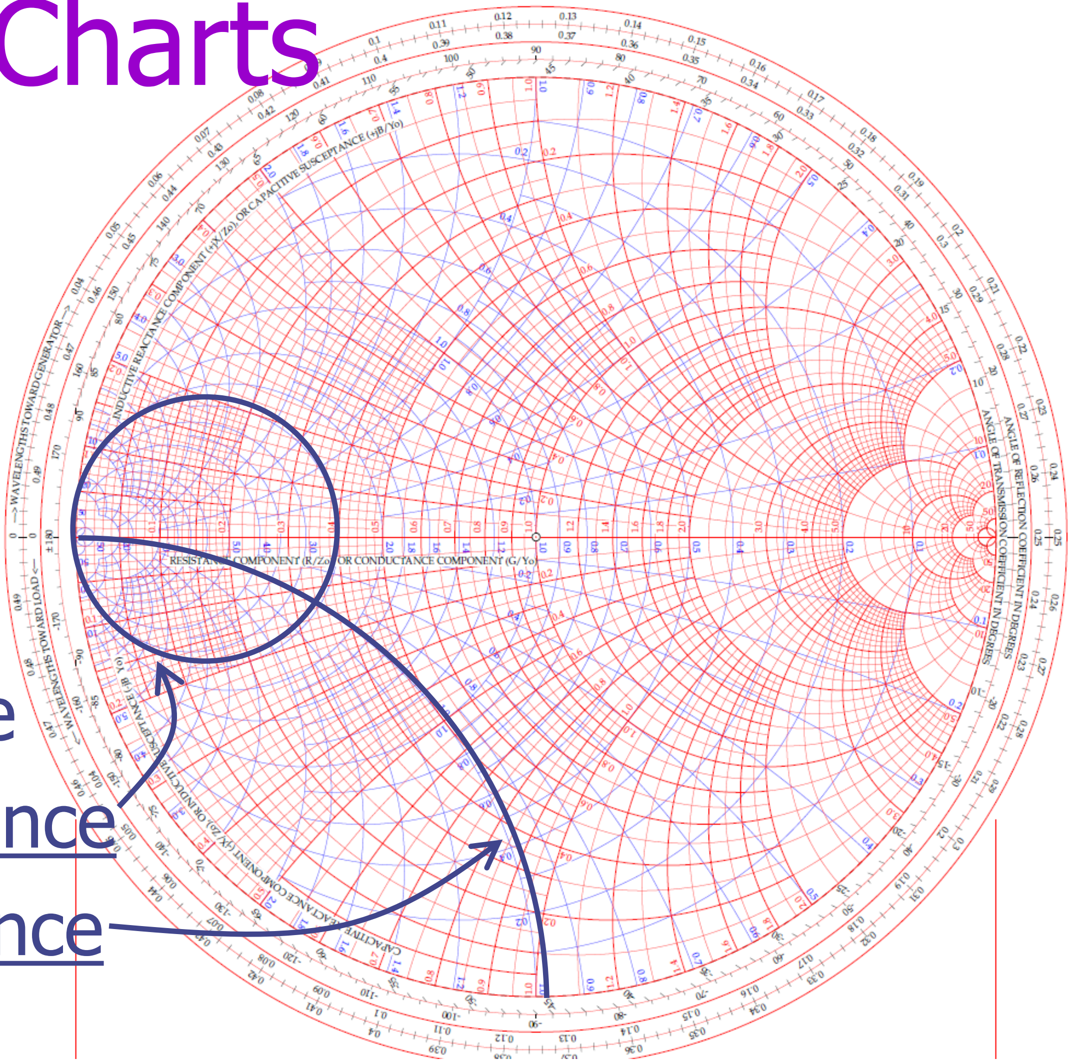
Admittance Curves

Admittance Curves are obtained by simply rotating the Smith Chart by 180°



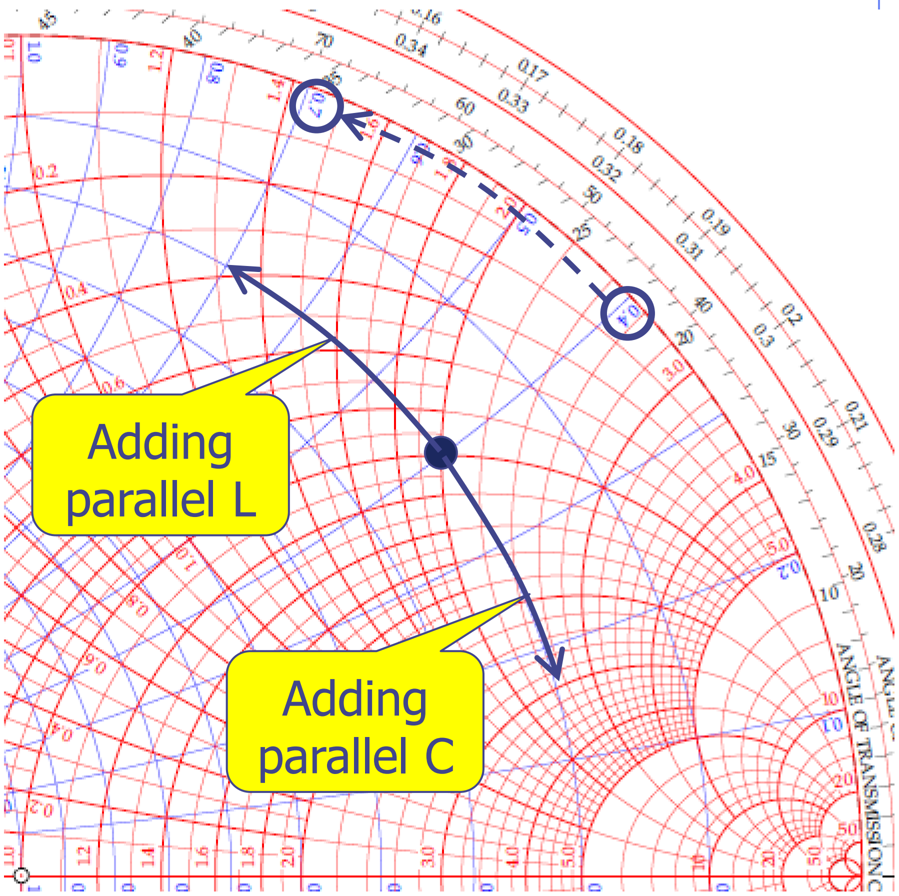
Combination Charts

- Look carefully – Admittance curves are here!
- Both **Z-only** and **combo** charts are available
- Constant <u>Conductance</u>
- Constant <u>Susceptance</u>



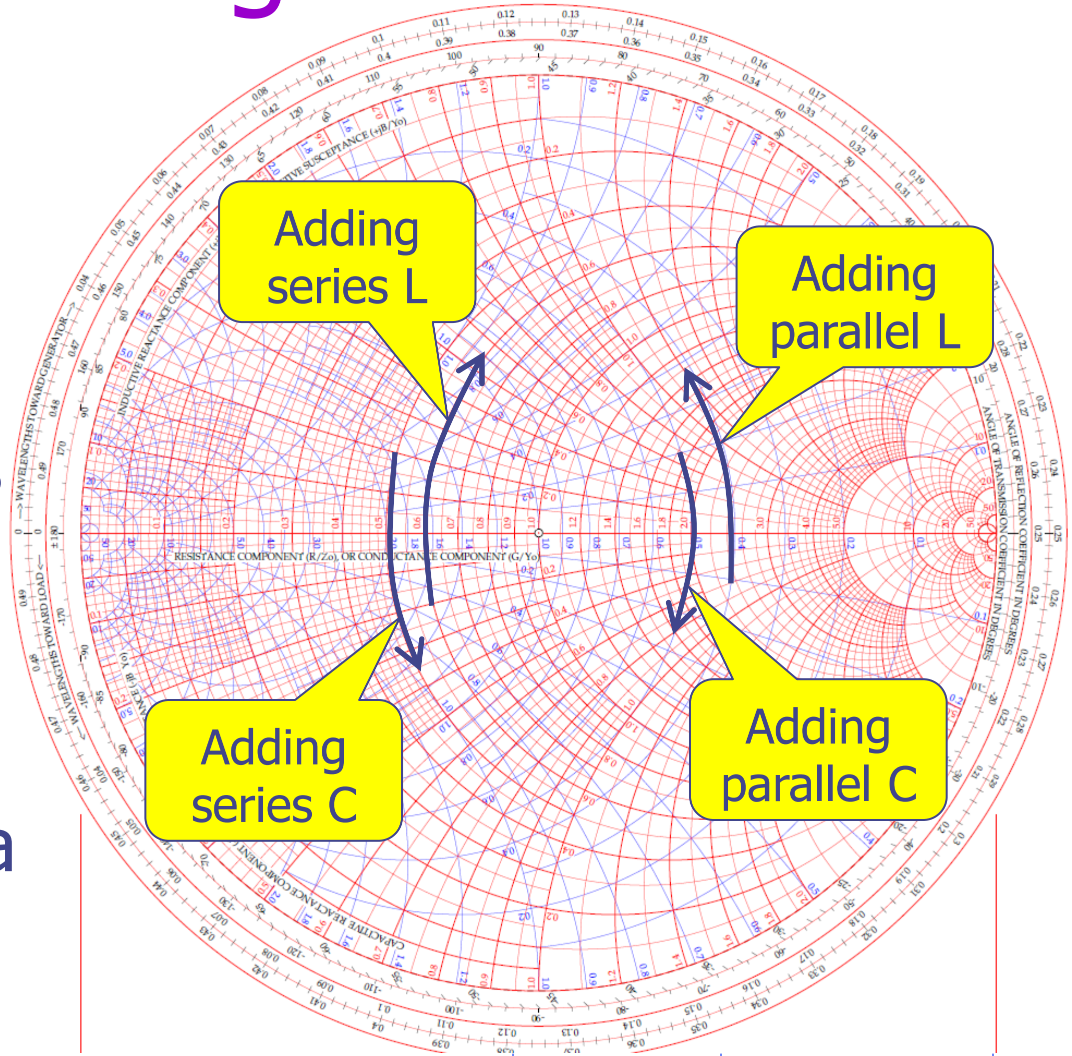
Adding elements in parallel

- Adding parallel or shunt L & C moves along constant conductance circles
- Easiest to do with "combo" Smith Chart
  - Shunt L with $B'_L = j0.3$ is shown



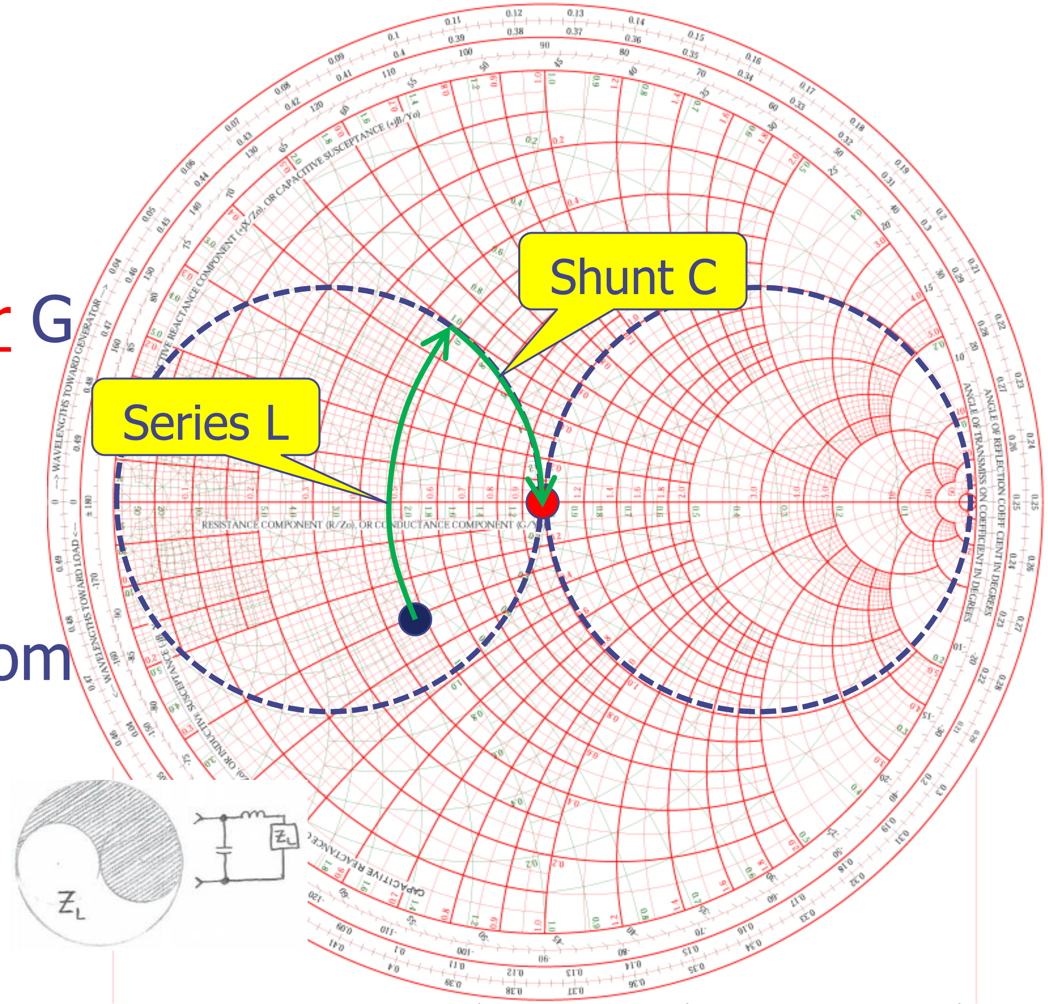
Quick tip – adding elements

- Adding inductors "e**L**evate" thru real axis
- Adding capacitors "**C**rash" down thru real axis
- Remember this when we design a matching circuit!



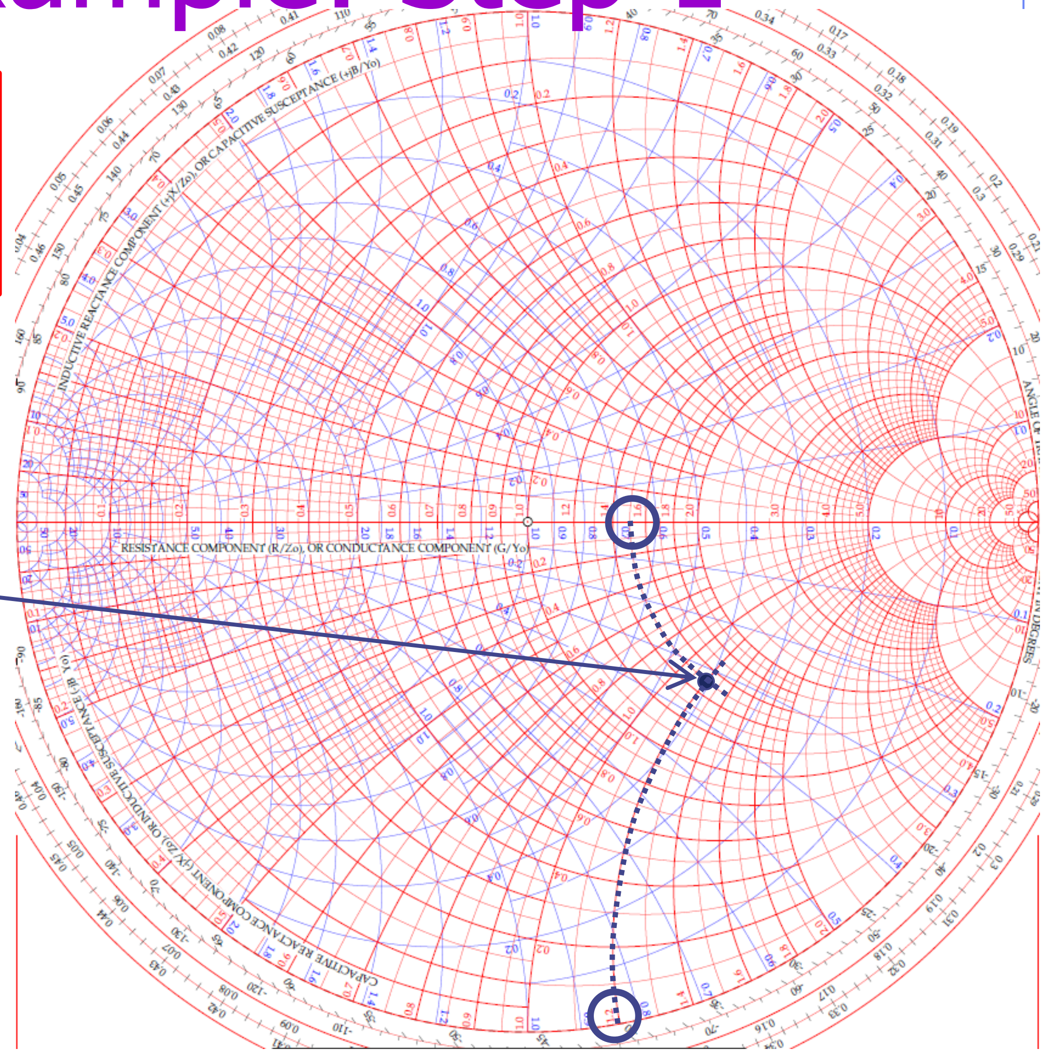
L-Network Design Process

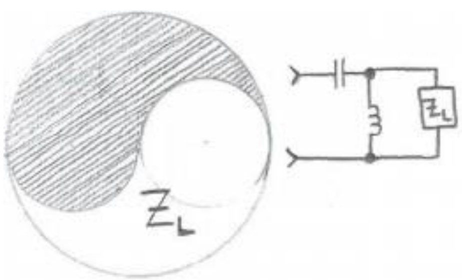
- Pick a topology
- Process:
  - Add ser/par L/C to rotate to unity R or G circle
  - Add ser/par L/C to rotate to Z_0
  - Compute values from ΔX′ and ΔB′
- Example:
  - Series L, shunt C



L-Network Example: Step 1

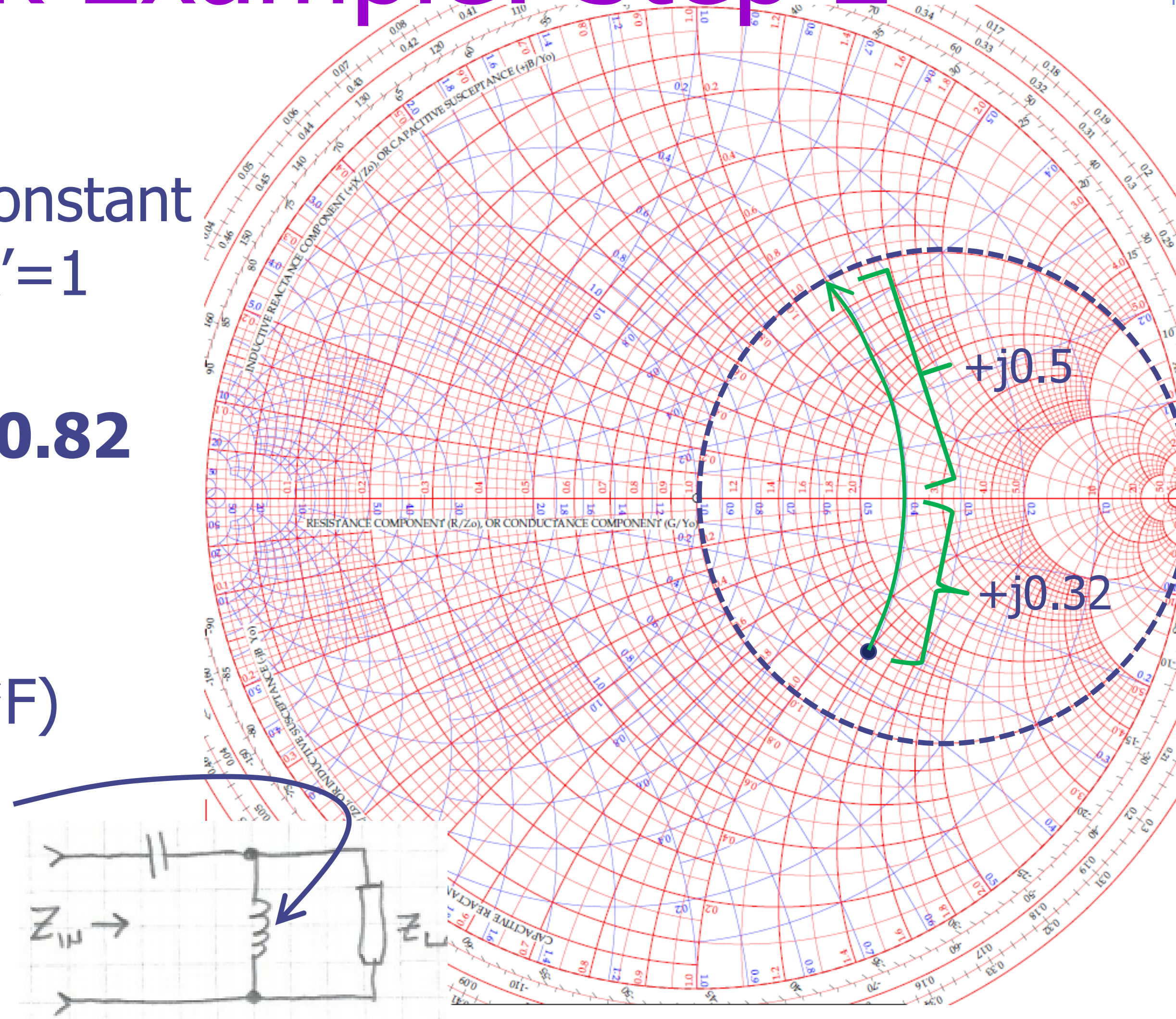
- Freq = 432.1MHz
- $Z_L = 75 - j60$
- Normalize…
- $Z_L' = 1.5 - j1.2$
- Plot it
- Pick a topology:





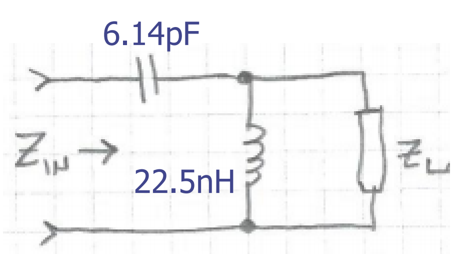
L-Network Example: Step 2

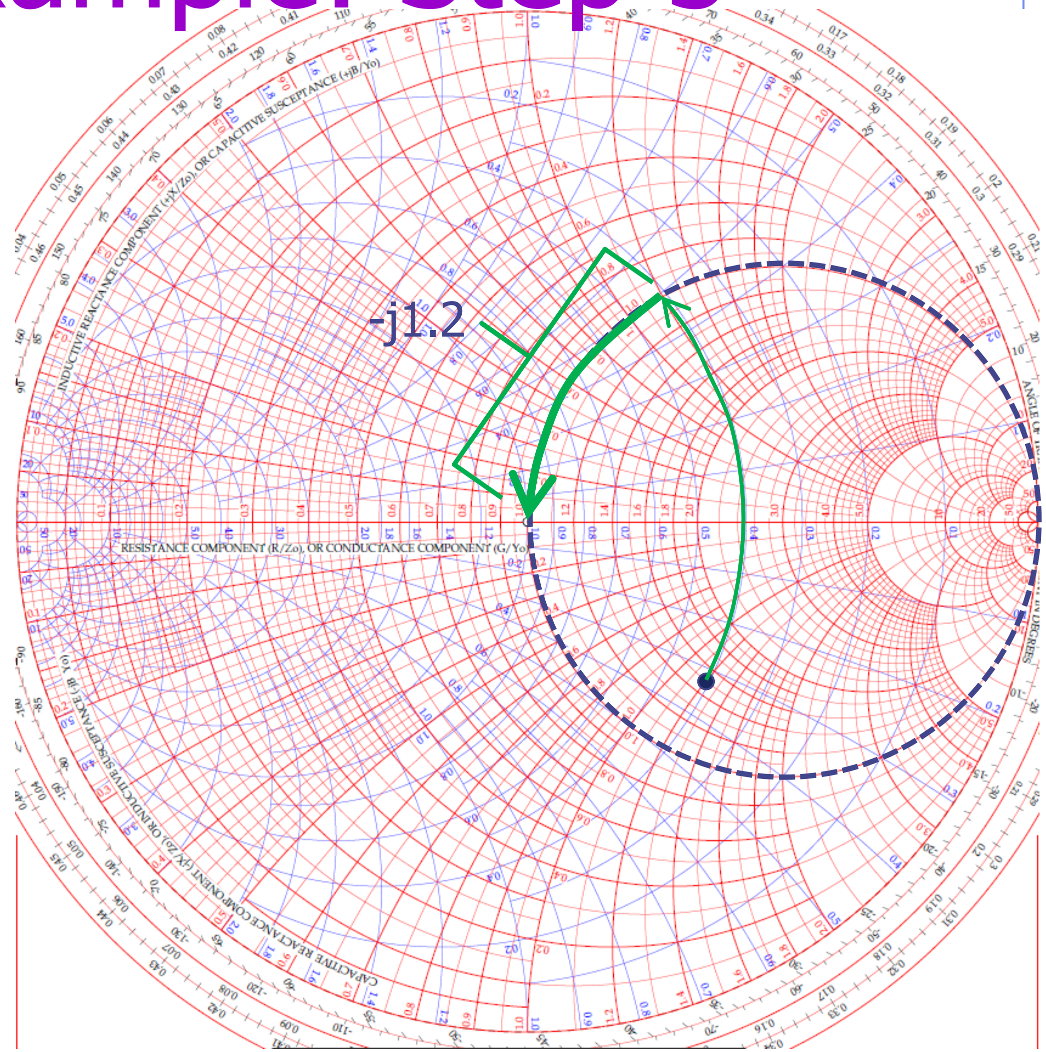
- Add Shunt L
  - Rotate on constant G until hit R′=1
  - Added B'_L is 0.32+0.5=**j0.82**
  - X'_L=j1.22
  - X_L=j61
  - L=X_L/(2*pi*F)
  - **L=22.5nH**



L-Network Example: Step 3

- Add Series C
  - Rotate on R'=1 until hit Z_0
  - Added X'_C = **-j1.2**
  - X_C=-j60
  - $C=1/(X_C*2*pi*F)$
  - **C=6.14pF**





Antenna related NanoVNA vids

- #312: Basics of a VNA – what is it?
- #313: Why and how to perform a VNA Calibration
- #314: Measuring an Antenna and observing the tuning process
- #316: Measuring coax length with the NanoVNA
- #325: The effect of adding coax length
- #326: Measure the impedance of unknown coax with NanoVNA
- #334: Tuning a Duplexer with a NanoVNA

Summary

- The Smith Chart is a highly useful tool:
  - Determining VSWR, RL, and much more
  - Transmission Line impedance transformations
  - Antenna analysis and tuning system aide
  - Matching Network Design
  - …and a lot more that we haven't touched on

Thank you!

- Check out my YouTube channel:
  - http://www.youtube.com/w2aew
- Contact info: w2aew@arrl.net