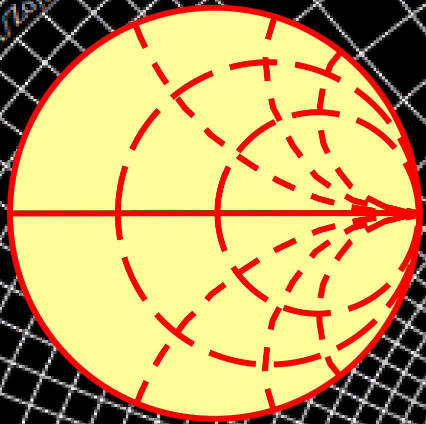
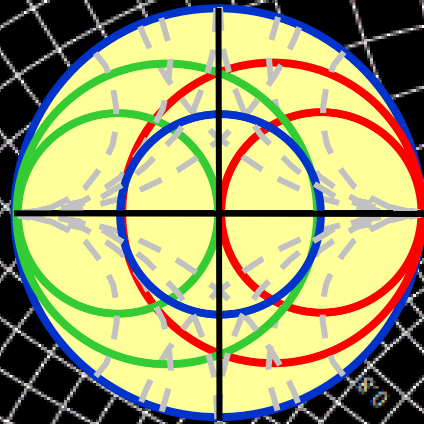
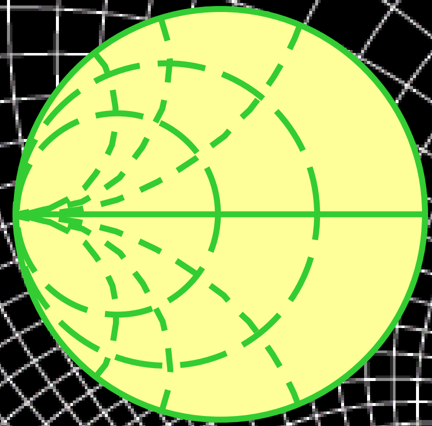
  

DX University: Smith Charts

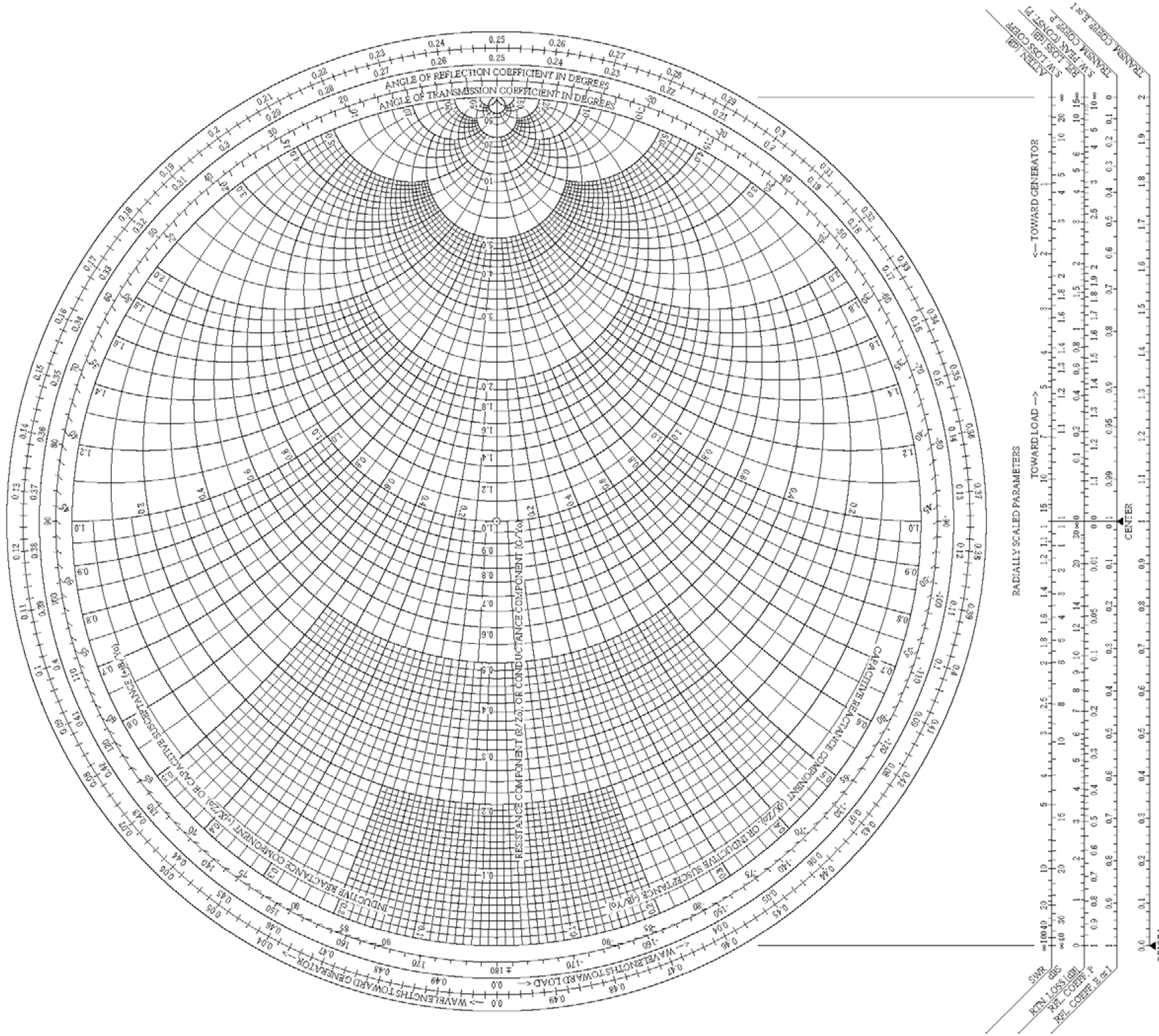
2010 August 9

Sponsored by the South Florida DX Association

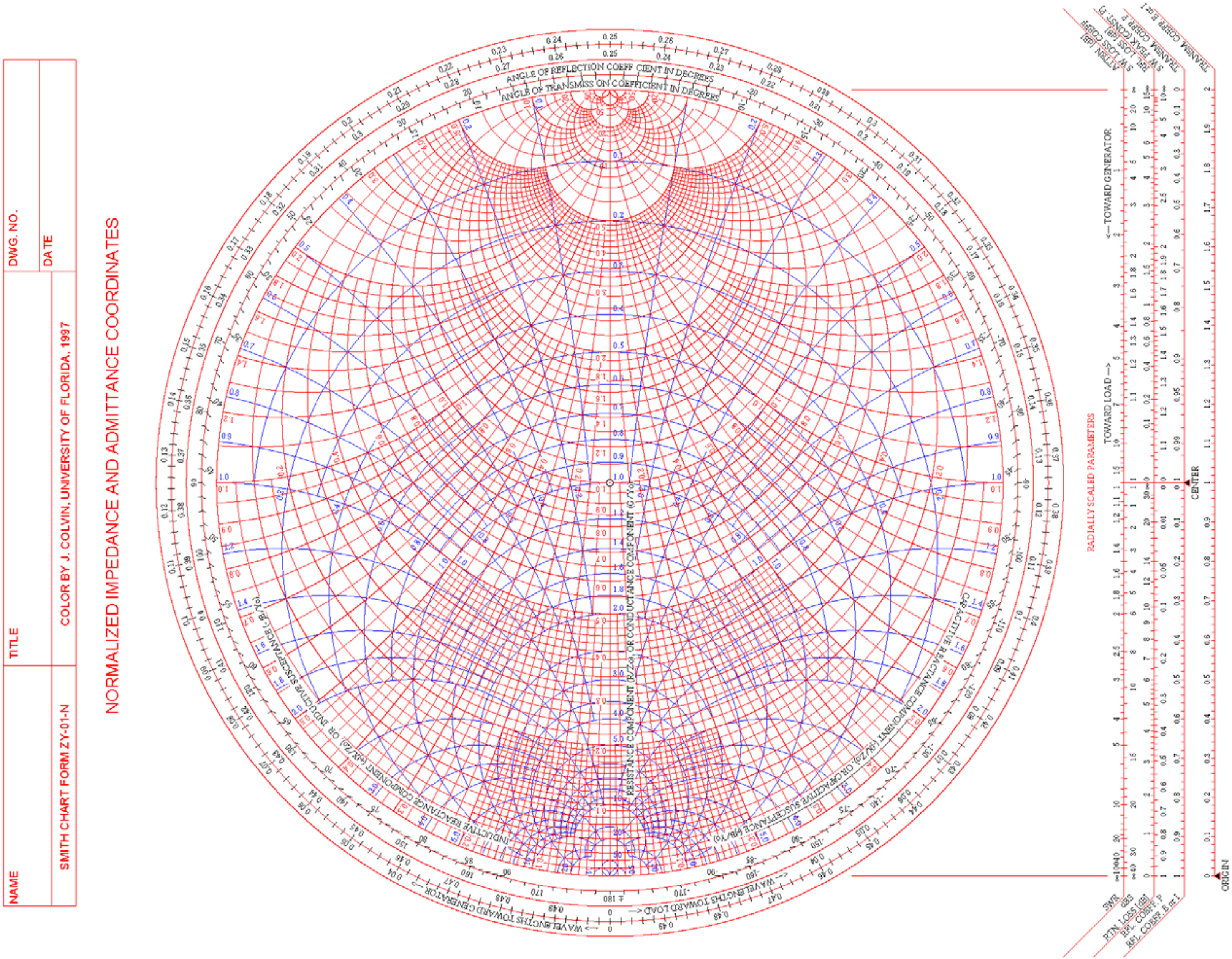
Kai Siwiak, ke4pt@amsat.org
Ed Callaway, n4ii@arrl.org

The Complete Smith Chart

Black Magic Design



Source: http://www.sss-mag.com/pdf/smithchart.pdf



Source: http://rfic.ucsd.edu/files/smith_chart.pdf

Contents

- Smith Chart is a graphical aid for impedance matching using series/parallel Inductors, Capacitors and Transmission Lines
  - The Smith Chart was developed by Phillip H. Smith during the 1930s
  - Others, including Wheeler, developed similar charts
- Smith Chart based on Reflection Coefficient
- Impedance ($0 \leq R \leq +\infty$ and $-\infty \leq X \leq +\infty$), admittance, VSWR, voltage reflection coefficient (Γ), all are in “the chart”
- Live examples
- Some observations

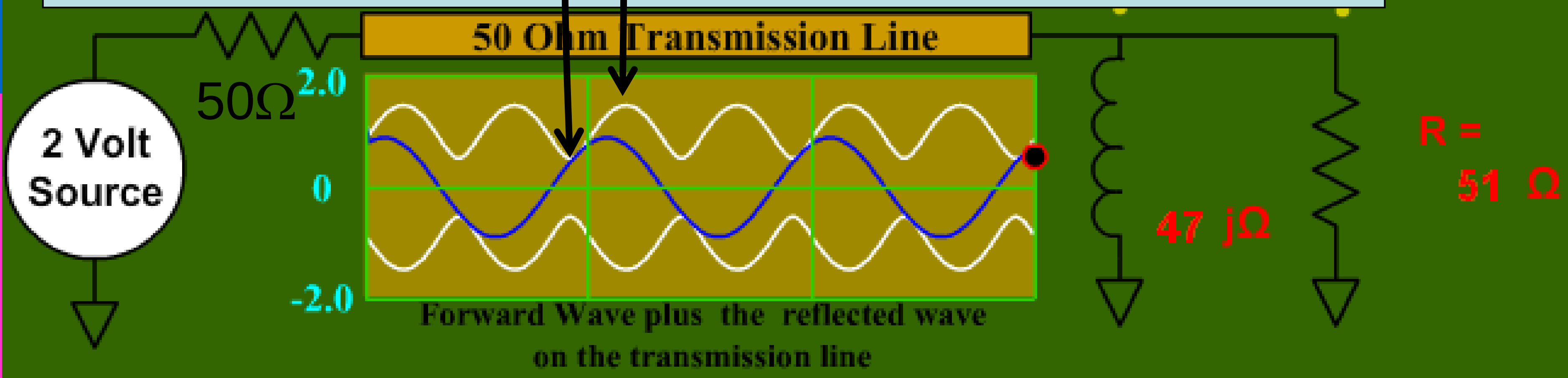
"Smith" *was* a registered trademark of Analog Instruments Company, cancelled May 22, 2010

What is VSWR?

Source: www.fourier-series.com F&Rwaves

$$VSWR = \frac{V_{PEAK}}{V_{MIN}}$$

Slotted lines were used in *days of auld* to measure V_{peak} and V_{min}



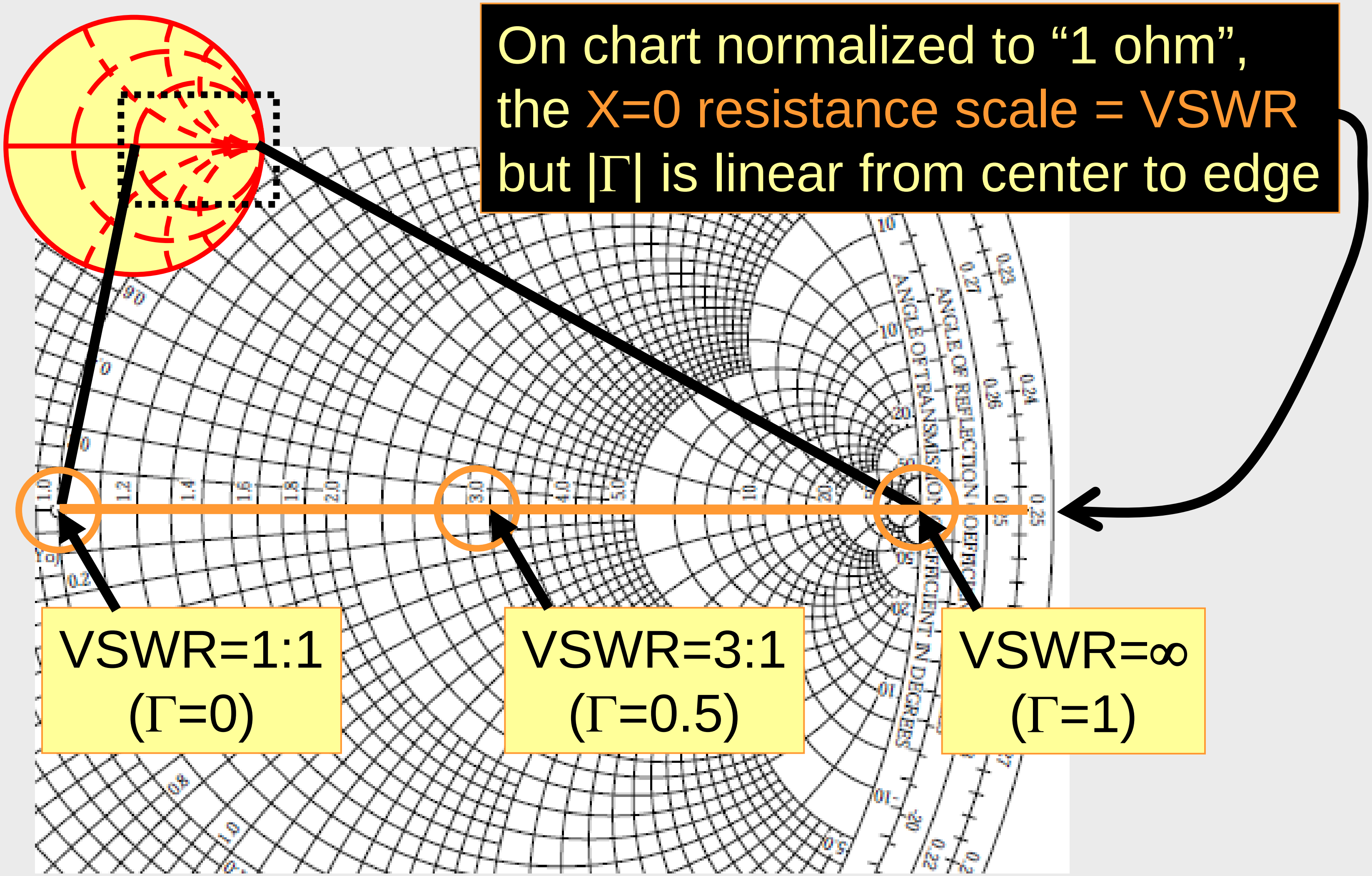
What is Voltage Refection Coefficient Γ?

"Watt meter" is really a <u>Directional Volt Meter</u> with scale reading $V^2/50$ [watts]

In the "SWR" mode …
Add a linear scale marked:
"0 to 1.0"
so 'half scale' = 'half of max V'

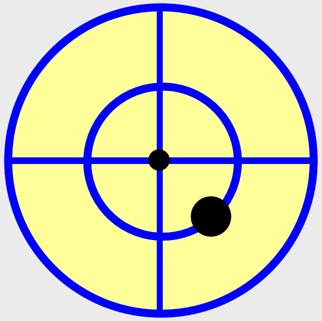
Now instead of reading **SWR from 1 to ∞**, just read the reflection coefficient **Γ from 0 to 1** on linear scale!

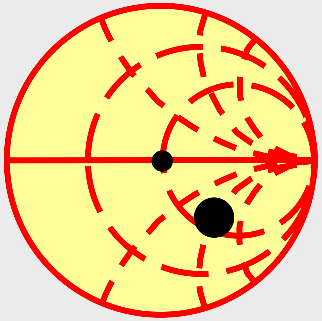
VSWR on the Smith Chart

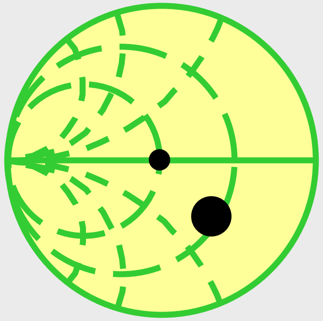


There are 3 "Circle Charts" for representing the same point

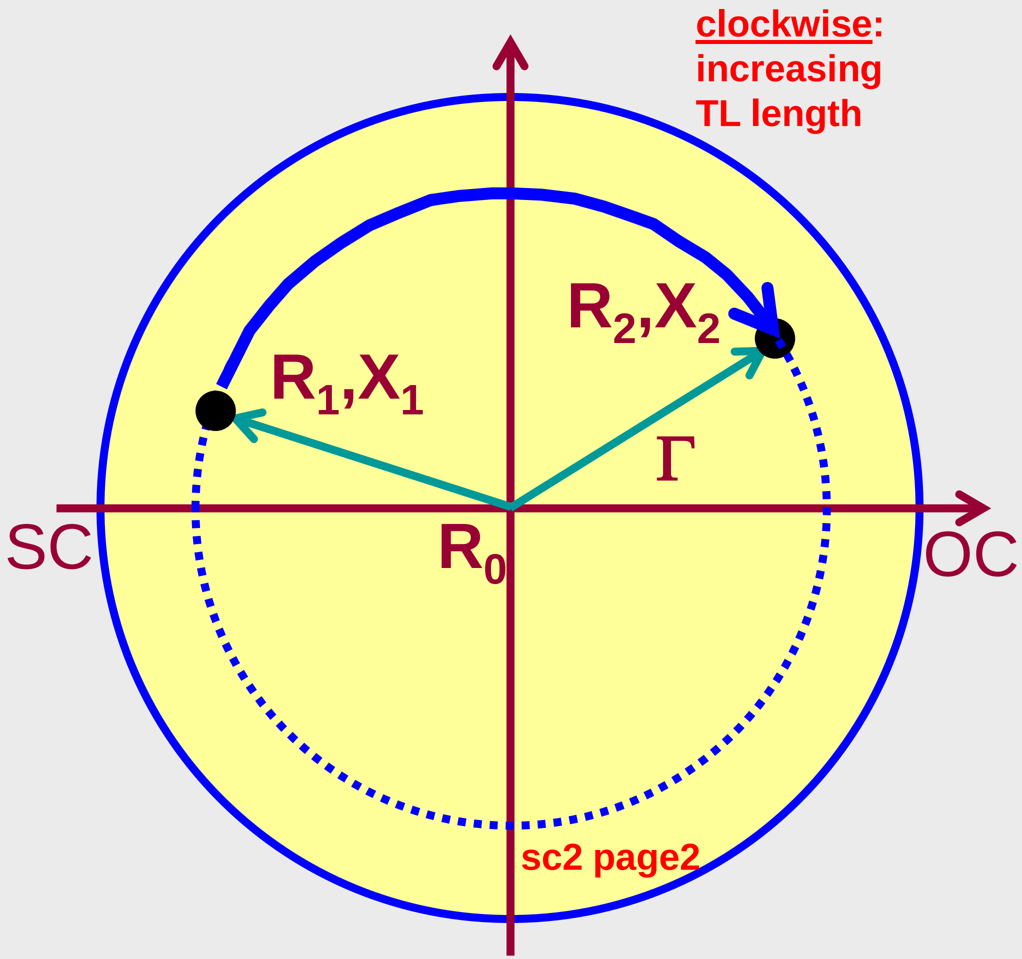
- Reflection Coefficient grid, Γ *for TL*
  - Radius from center equals reflection coefficient magnitude and angle
- Impedance grid, *Z=R+jX* *for series LC*
  - Circles of constant resistance R
  - Circle segments of constant reactance X
- Admittance grid, *Y=G+jB* *for parallel LC*
  - Circles of constant conductance G
  - Circle segments of constant susceptance B







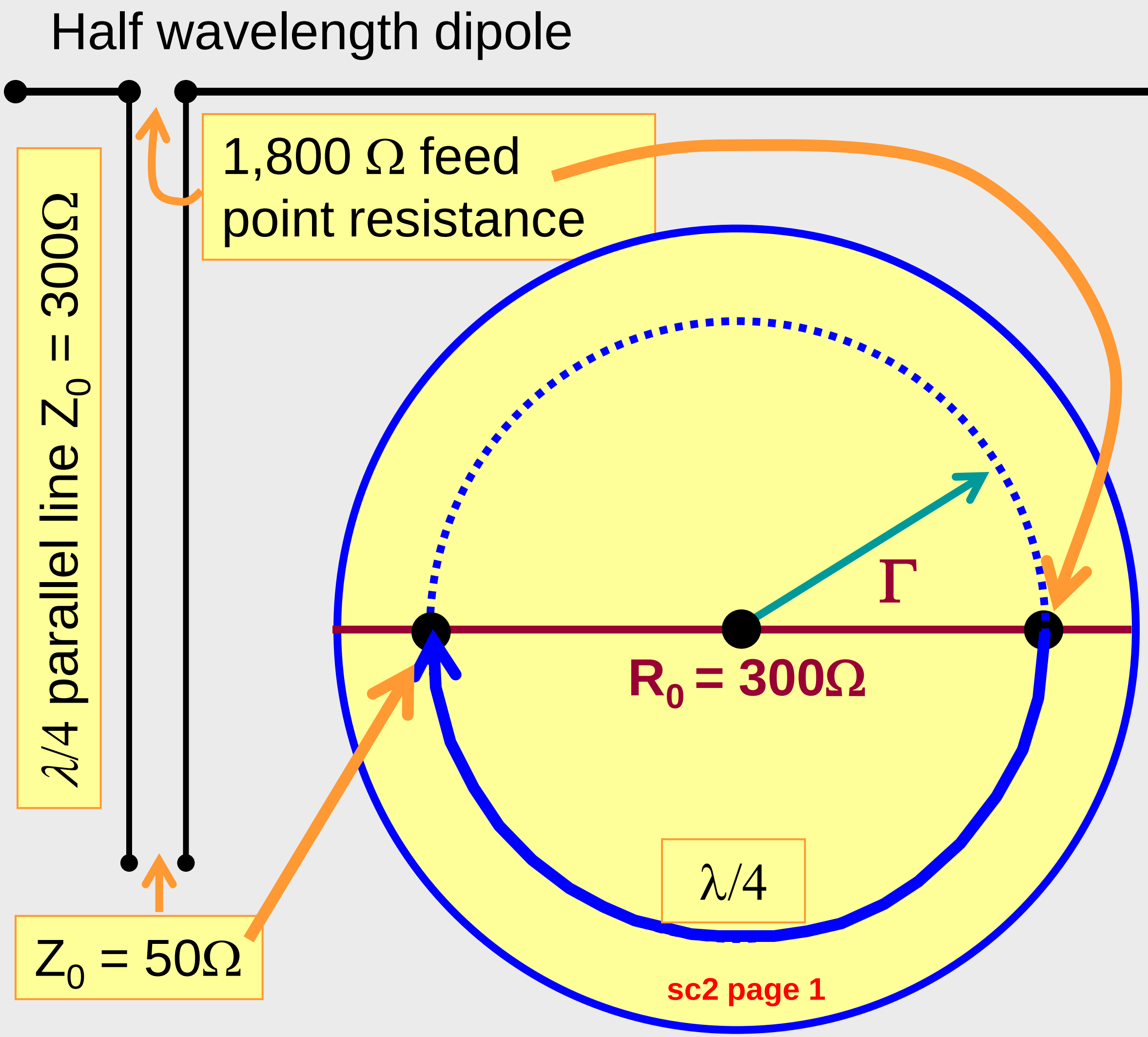
Constructing a Smith Chart: *<u>transmission line</u> on the Γ grid*



- T.L. maintains constant |Γ| (and constant VSWR)
- Impedance is transformed
- Full circle = half a wavelength

sc3 page 1

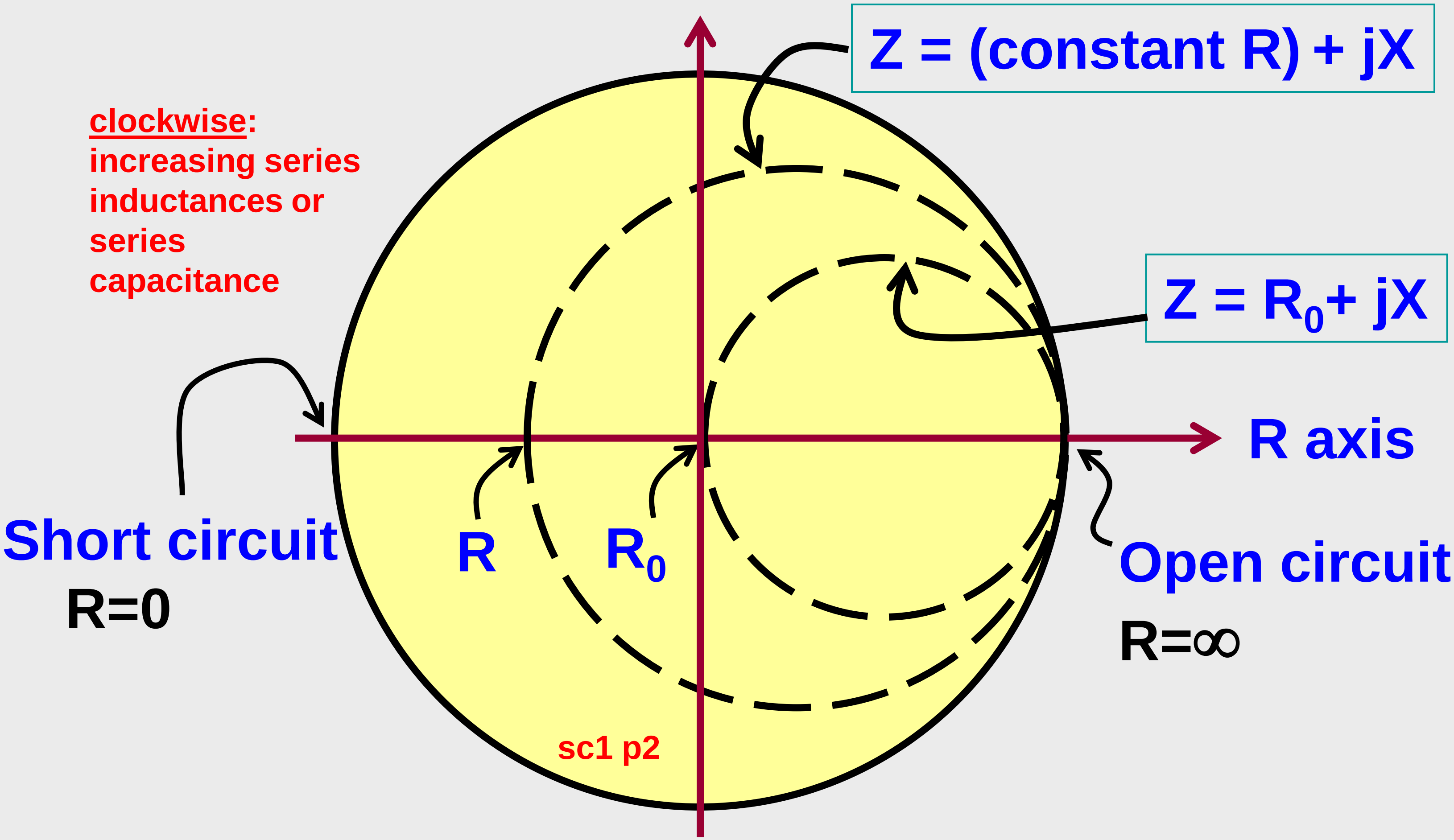
Example: Match an OCF Dipole Using a Transmission Line



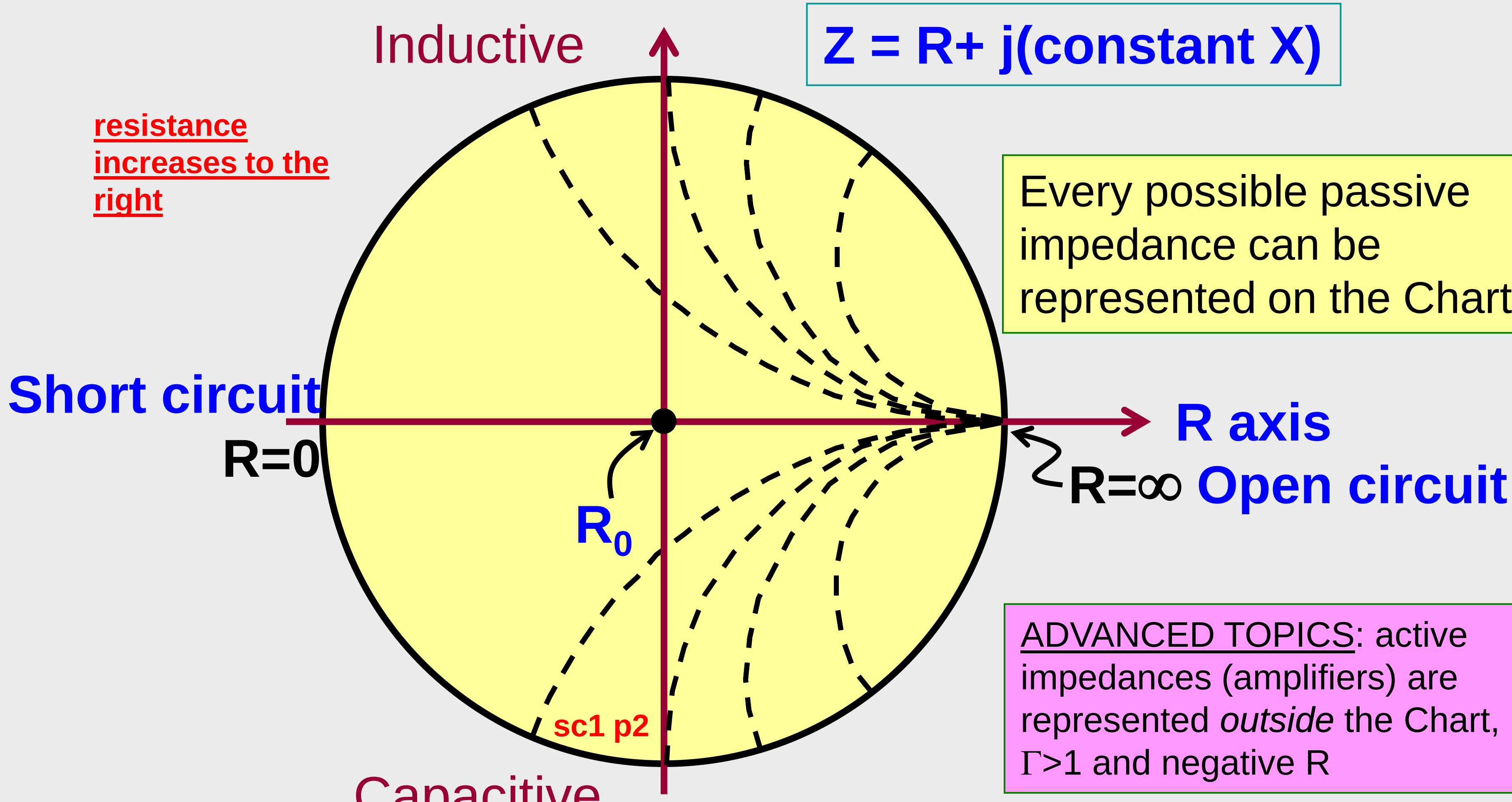
Normalize chart to the 300 Ω line impedance

Impedance swings (transforms) clockwise along a constant radius (same VSWR, same Γ)

Constructing a Smith Chart: ***constant resistance circles***



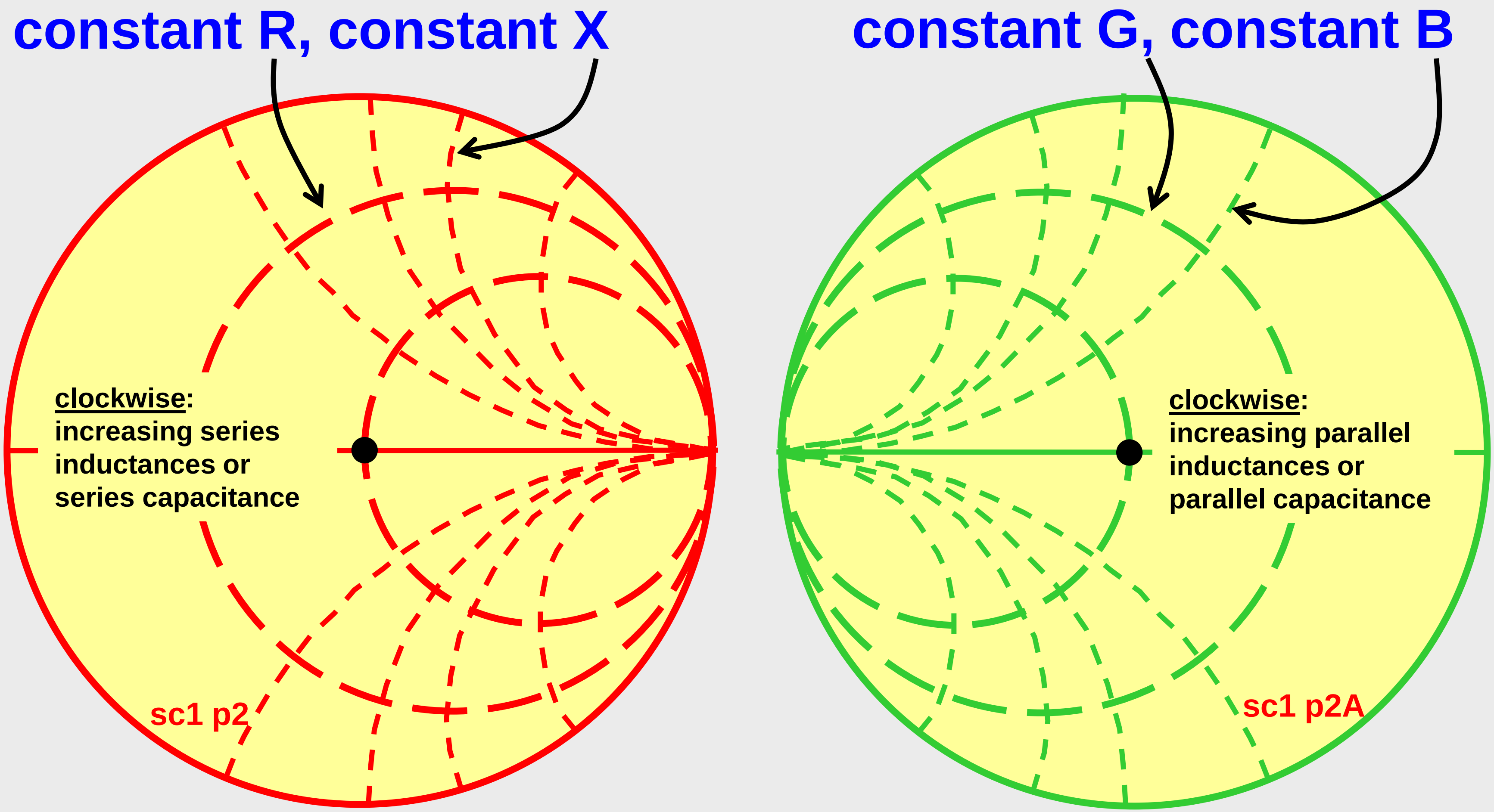
Constructing a Smith Chart
constant reactance segments



Every possible passive impedance can be represented on the Chart

ADVANCED TOPICS: active impedances (amplifiers) are represented *outside* the Chart, Γ>1 and negative R

Admittance *Y* Chart is Mirror Image of Impedance *Z* Chart

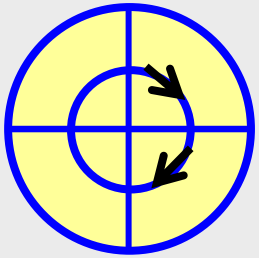


Series resistance and reactance

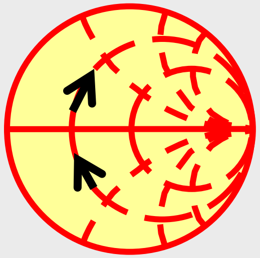
Parallel conductance and susceptance

Always Clockwise Movement

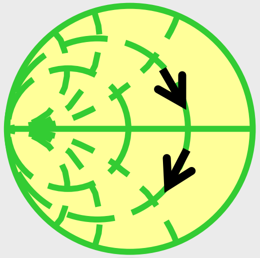
- Increasing *TL length* moves impedance point clockwise
  - Along a constant radius



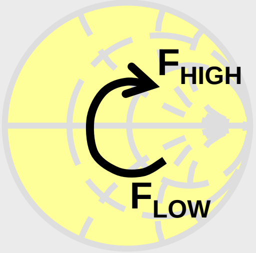
- Increasing *series L(inductance) C(capacitance)*
  - Moves impedance point clockwise
  - Along circles of constant resistance R



- Increasing *parallel L(inductance) C(capacitance)*
  - Moves impedance point clockwise
  - Along circles of constant conductance G



- Impedance *vs*. Frequency
  - Frequency (Hz) increases clockwise



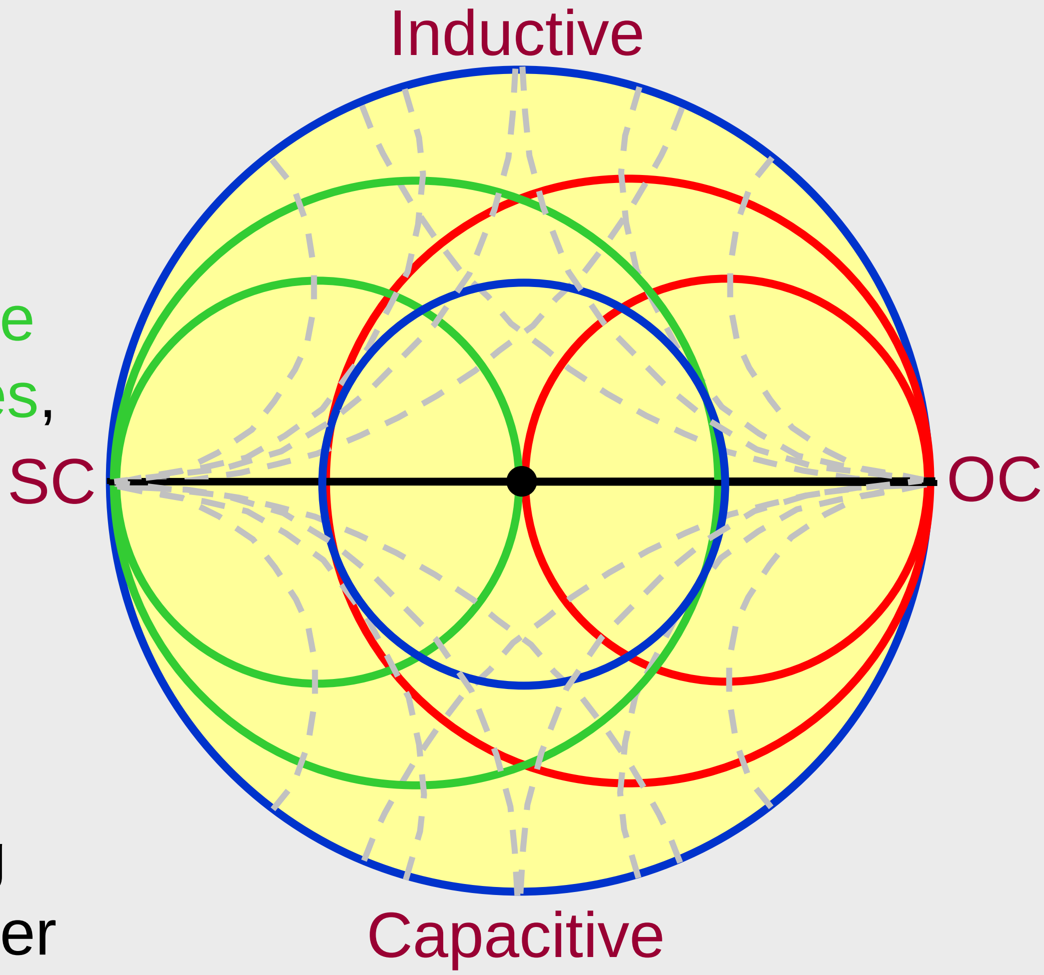
Matching using L, C, TL, with the aid of a Smith Chart

series L,C move along the constant resistance circles, and

parallel L,C move along the constant conductance circles, and

transmission lines move along a constant radius,

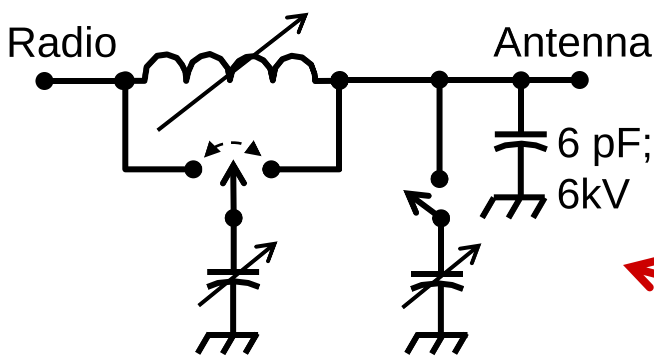
goal: move *clockwise* along the circles to reach the center



Antenna impedances are matched by tuner one frequency at a time

AH-4 component range:

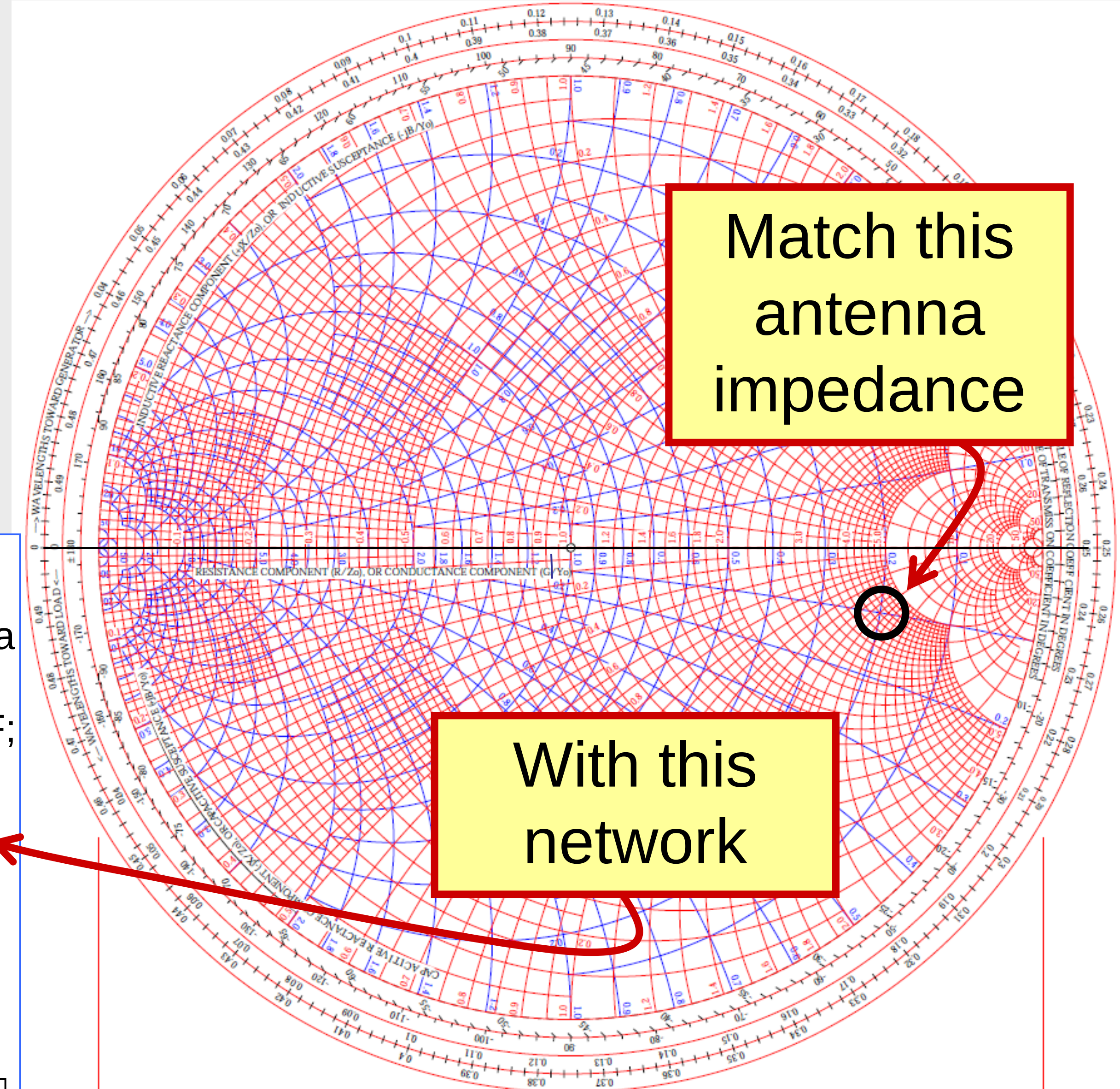
0 to 19 μH, 9 inductors



0–2,400 pF
by 9.375 pF;
6 kV 0–75 pF,
3 kV to 590 pF,
2 kV higher values

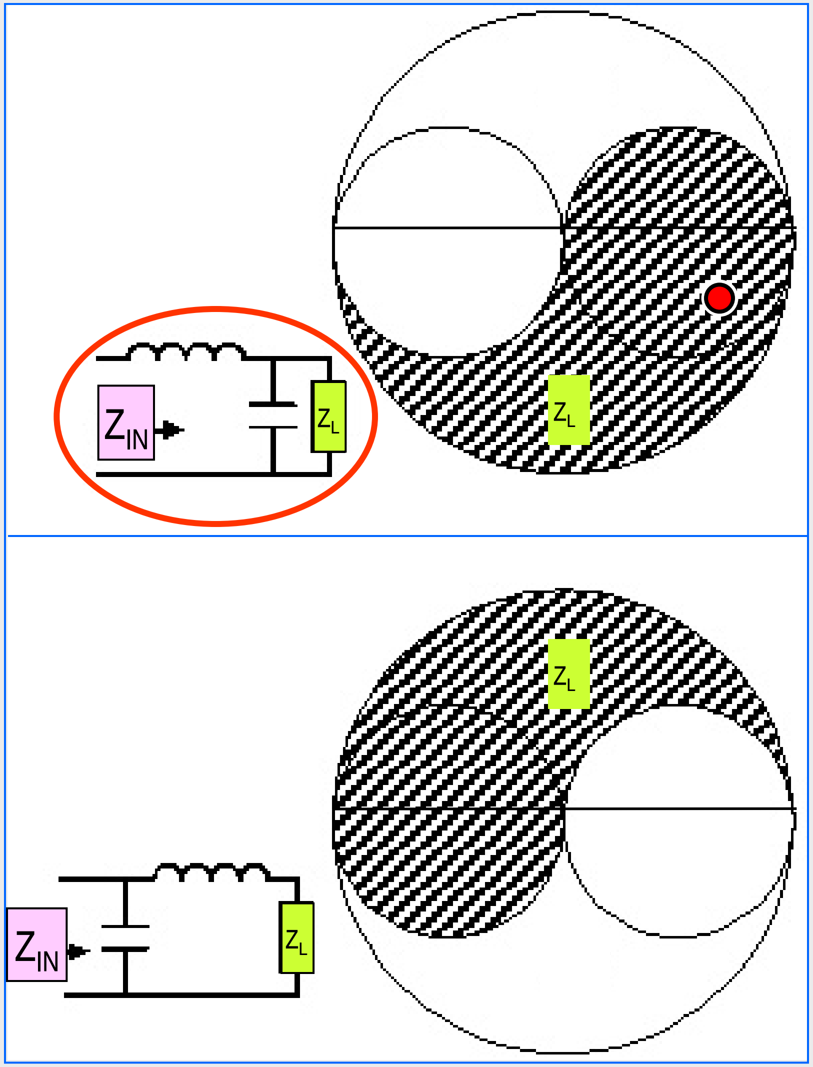
0, 13 or
100 pF; 6kV

1,048,576
combinations



Generated by 4nec2
http://home.ict.nl/~arivoors/

Choose a Network Topology



<u>Which way?</u>
Parallel capacitor on load side or input side?

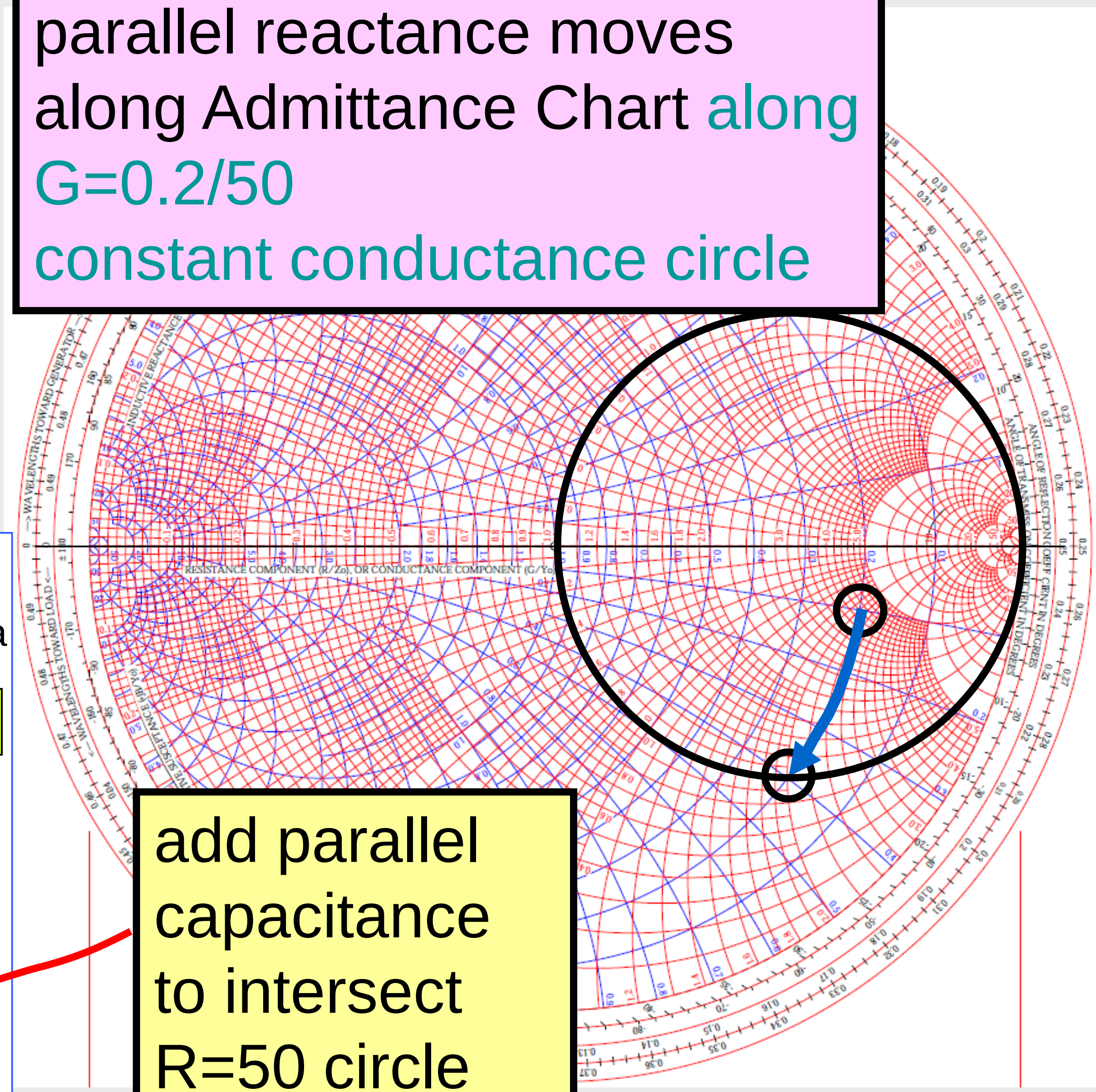
Load impedances in the <u>shaded region</u> can be matched with the network topology shown on the left

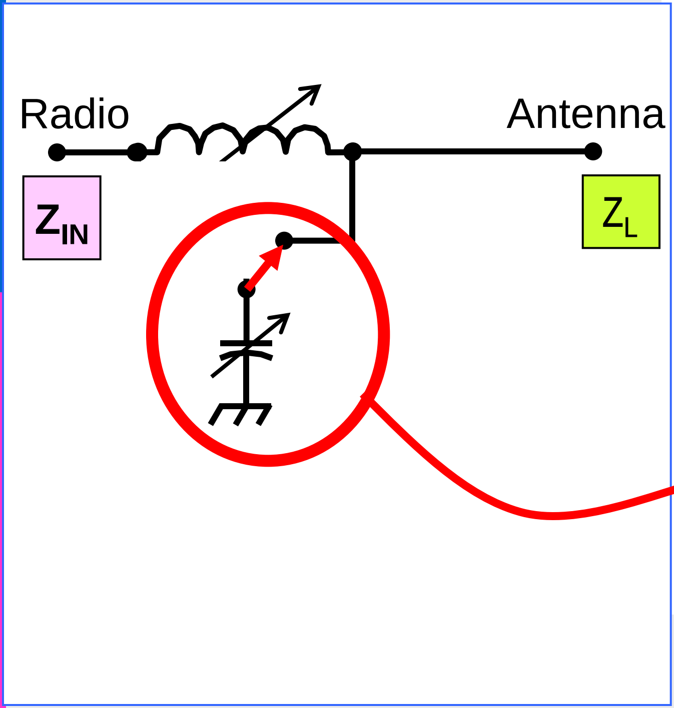
<u>ADVANCED TOPICS</u>: the *range* of L and C determines how much of shaded area can be matched.

<u>After</u>: V.Iyer, QuickSmith analysis software, http://www.nathaniyer.com/qsdw.htm

Tuner uses 2 variable elements to match within VSWR<1.5 Goal circle

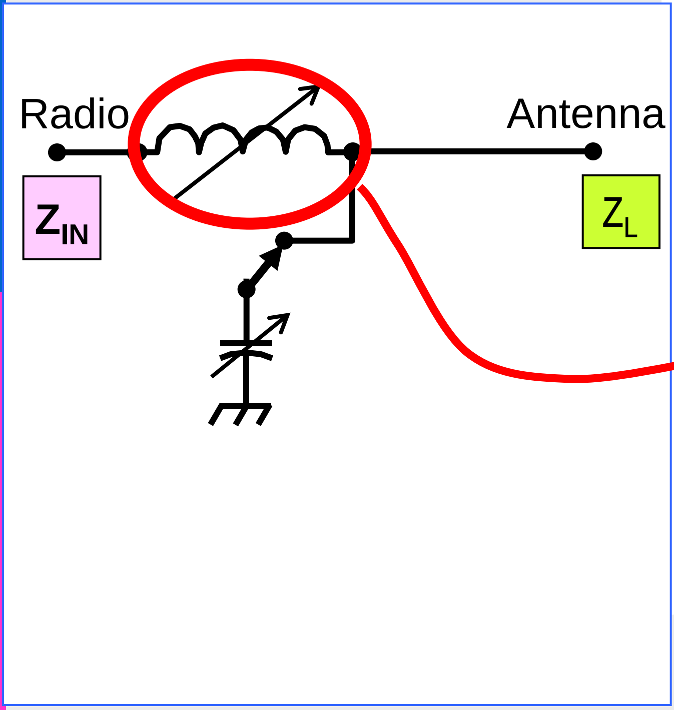
parallel reactance moves along Admittance Chart along G=0.2/50 constant conductance circle

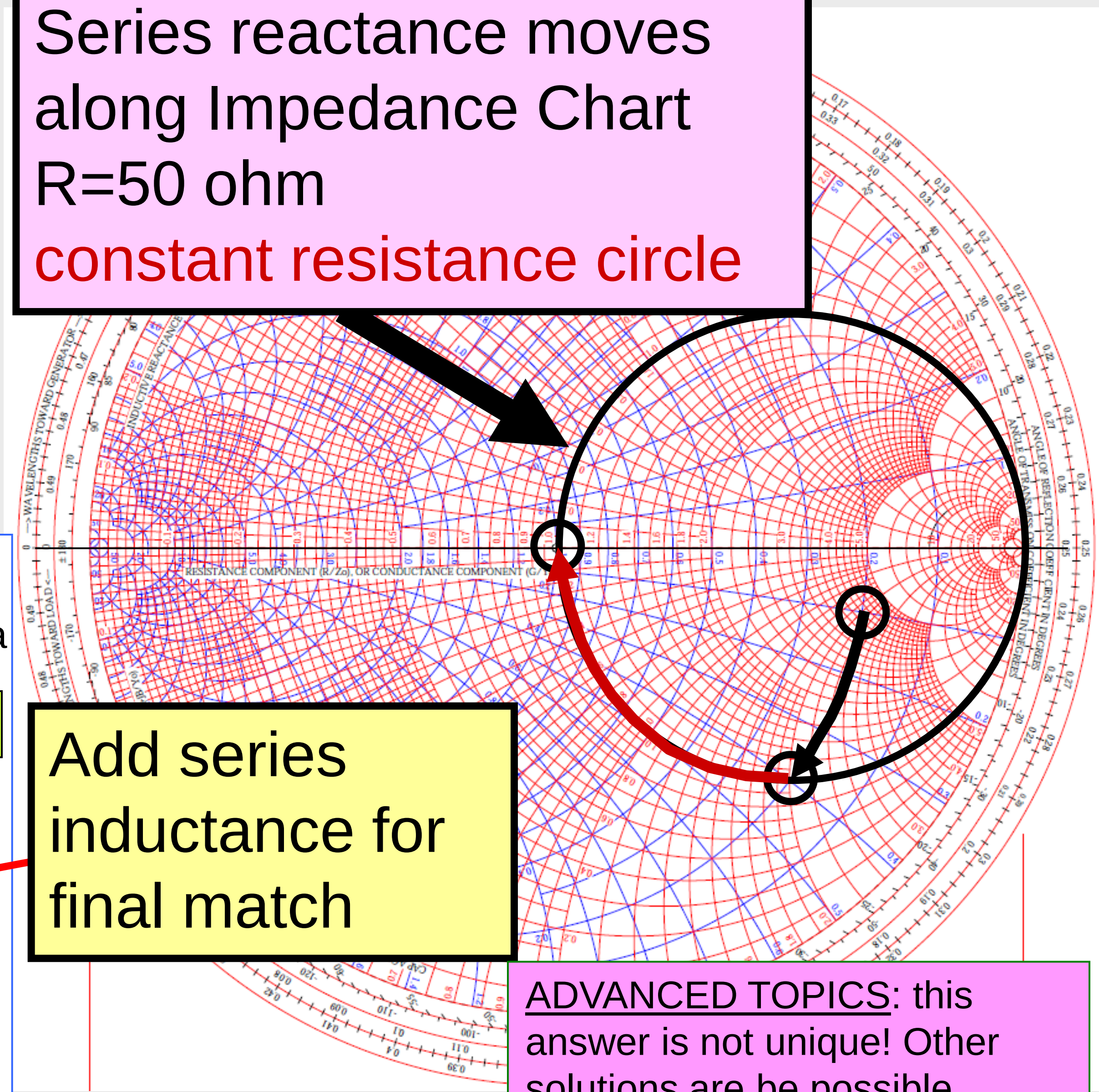




add parallel capacitance to intersect R=50 circle

Tuner uses 2 variable elements to match within VSWR<1.5 Goal circle





Series reactance moves along Impedance Chart R=50 ohm constant resistance circle

Add series inductance for final match

ADVANCED TOPICS: this answer is not unique! Other solutions are be possible.

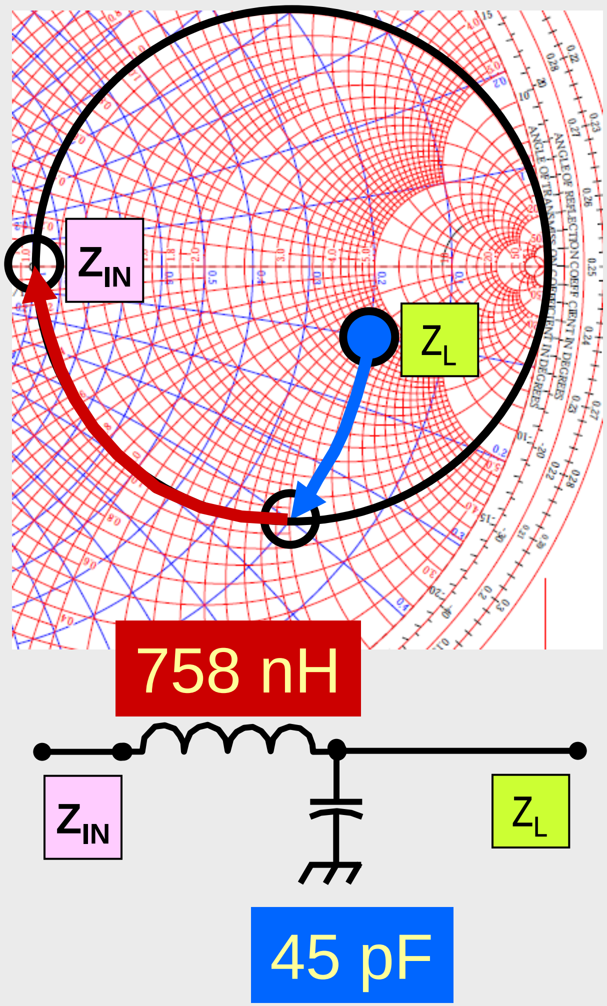
Component Values at f=21MHz

- Starting at $1/Z_L$=1/(200-j100) = Y=(0.2+j0.1)/50

- Parallel capacitor to get to Y=(0.2+j0.4)/50
- C=(0.4–0.1)/(50×2πf)= 45 pf

- Z=1/Y =(1–j2)50 = (50–j100)
- Series L=100/2πf = 758 nH

QSMITH.EXE.lnk

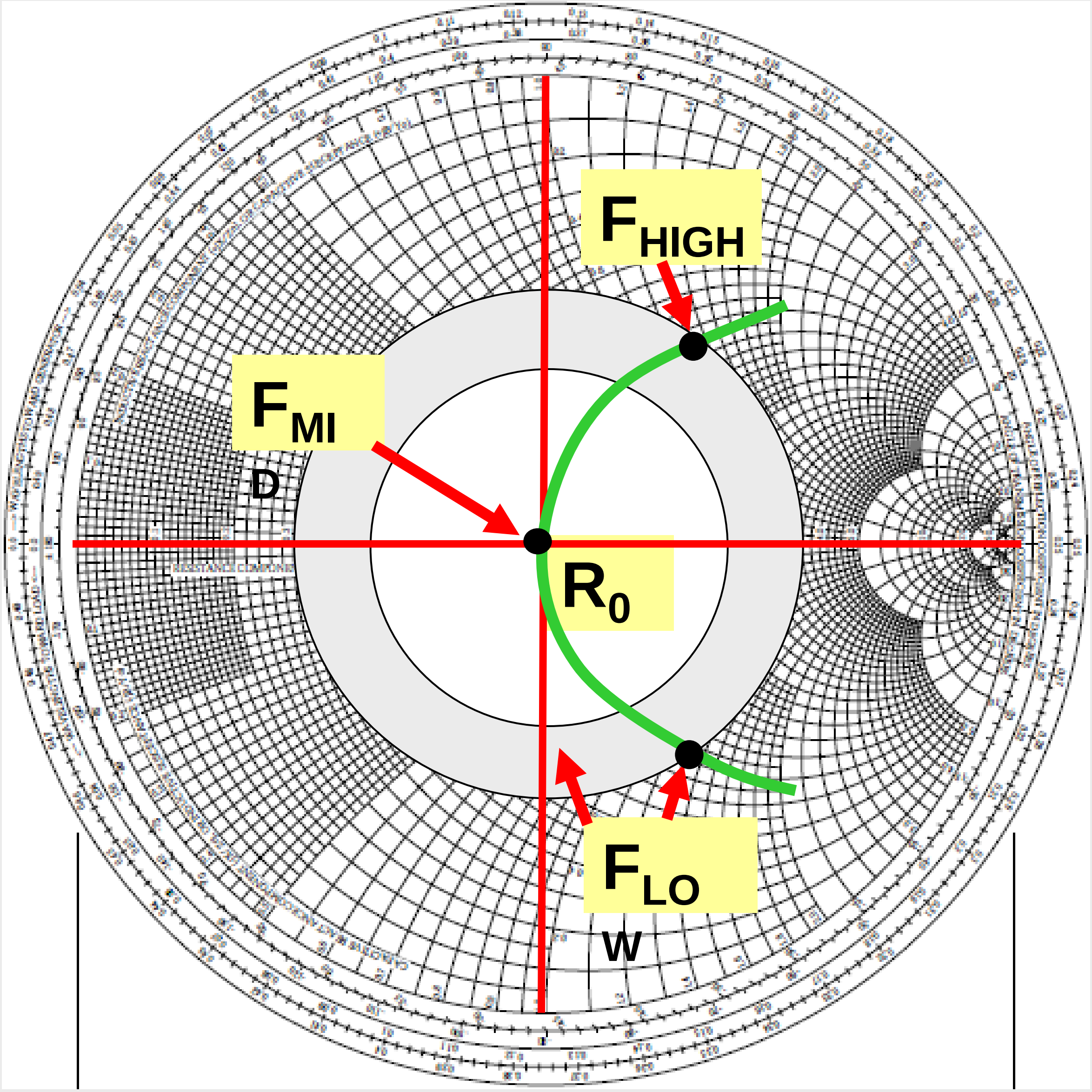


Matching over a Bandwidth

- Impedance vs. frequency trace moves in a clockwise direction
- An ideal match at mid frequency is not the same as a band – optimized match

ADVANCED TOPICS: Optimization can be done over a bandwidth; different criteria yield different results

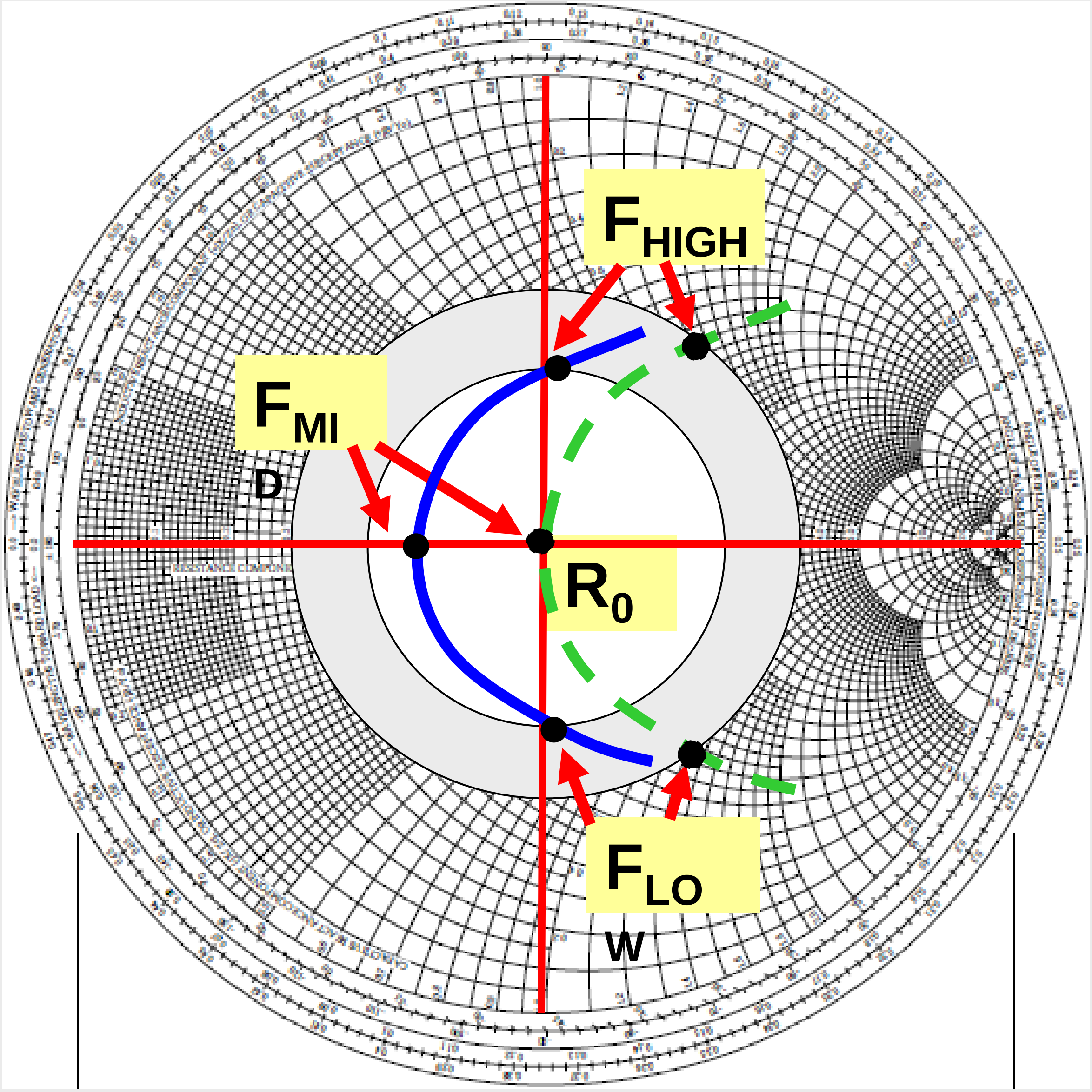
Mid-band Single-tuning Matching



- Midband match – F_{HIGH} and F_{LOW} are outside the white VSWR goal circle
- Mid band is perfectly matched, but band edges are out of spec

ADVANCED TOPICS: answer not unique: match can be optimized for best mid band match or best bandwidth

Optimum BW Single-tuning Matching



- Midband match – F_{HIGH} and F_{LOW} are outside the VSWR goal circle
- Wheeler Band Edge minimum VSWR tuning – F_{HIGH} and F_{LOW} on vertical axis, has best BW

Resources: http://www.fourier-series.com

- Reflection.swf
  - Reflection and transmission coefficient
- smithchart1.swf
  - Mapping resistance and reactance
- smithchart2.swf
  - Adding a transmission line
- smithchart_L_C_match.swf
  - Parallel and Series equivalent
  - Match Circuit with 2 lumped elements
- smithchart3.swf
  - Transmission line, and matching stub
- smithchart4.swf
  - T.L. and a series/parallel element
  - Relation to circuit element

More Resources:

- QuickSmith, by V. Iyer, Smith Chart based linear circuit simulation software program for Microsoft Windows
  - http://www.nathaniyer.com/qsdw.htm
- "How does a Smith Chart Work?" Rick Nelson, Test and Measurement World, July 2001
  - http://www.sss-mag.com/pdf/smith_chart_basics.pdf
- Images of a Smith Charts:
  - Impedance: http://www.sss-mag.com/pdf/smithchart.pdf
  - Immittance: http://rfic.ucsd.edu/files/smith_chart.pdf
- "ARRL Radio Designer and the Circles Utility Part 1: Smith Chart Basics", W. E. Sabin, WØIYH: QEX, Sept/Oct 1998, pp.3-9
  - http://www.sss-mag.com/pdf/arrl_circles.pdf

Summary

- Smith Chart – a graphical tool for matching
- Combinations of transmission lines, series/parallel inductors/capacitors are used
- Examples illustrate some matching uses of the Smith Chart
- Best match over a bandwidth and perfect match at one frequency are not the same!
- See ‘Resources’ for additional information
- Advanced topics: –R = amplifier, outside chart; optimization vs. frequency; range of matching components; using TL stubs

Extra Slides

VSWR is an Obsolete Holdover from the days of slotted line measurements

$$VSWR = \frac{V_{PEAK}}{V_{MIN}} = \frac{V_{FORWARD} + V_{REFLECTED}}{V_{FORWARD} - V_{REFLECTED}}$$

$$\Gamma = \frac{V_{REFLECTED}}{V_{FORWARD}}$$

We actually measure and use reflection coefficient Γ

Impedance Z, Admittance Y and Reflection Coefficient Γ are Related

- Each point can be expressed in three ways: *Z*, *Y*, and Γ
- All impedances and admittances fall inside Γ=1 circle
- VSWR relates to the *magnitude* of reflection coefficient |Γ|
- *Reactances (susceptances)* convert to inductors and capacitors

$$\Gamma = \frac{Z - Z_0}{Z + Z_0} = \frac{Y_0 - Y}{Y_0 + Y}$$

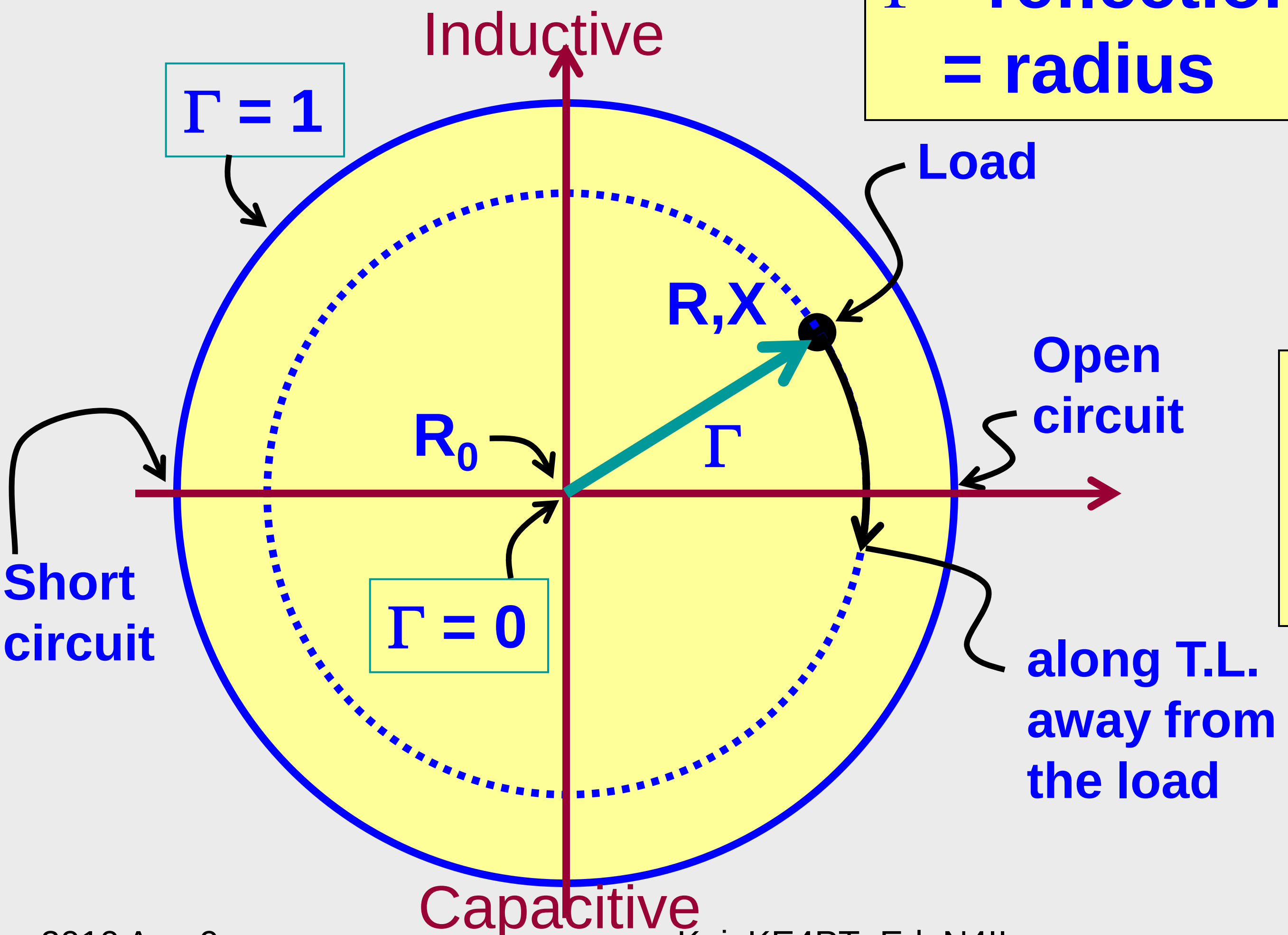
$$Z = \frac{1}{Y}$$

$$|\Gamma| = \frac{VSWR - 1}{VSWR + 1}$$

$$C = 1 \big/ 2\pi f X_{CAP}$$

$$L = 2\pi f X_{IND}$$

Constructing a Smith Chart: the *reflection coefficient grid*



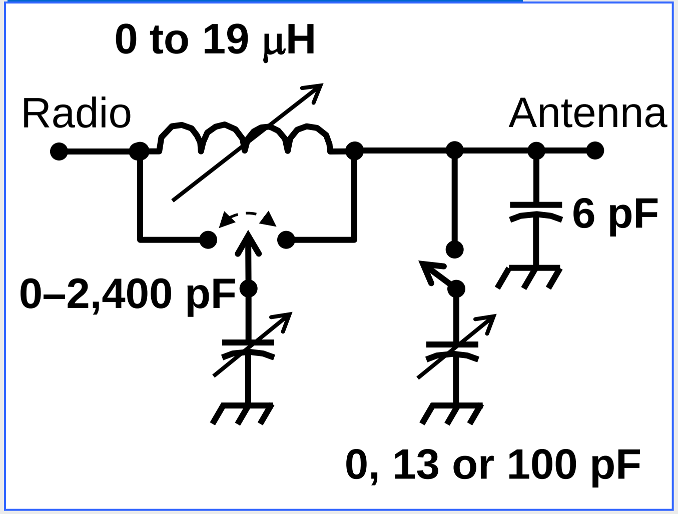
Γ = reflection coefficient = radius

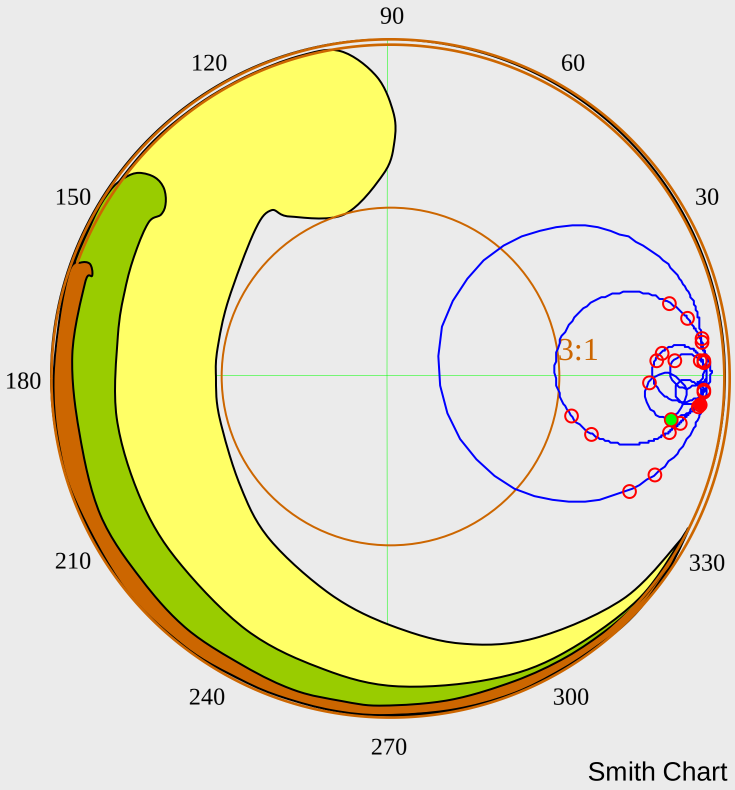
R_0 is any convenient value

Impedances and un-tunable range

- A coupler matches any impedance, except for a crescent shaped region, in the left extreme of the Smith chart
- As you operate lower in frequency, this un-tunable crescent becomes larger; and an un-tunable region at the outer radius of the Smith chart begins to grow

AH-4 component range:





For the AH-4 parts range:

Not tunable below 7.0 MHz

Not tunable below 4.0 MHz

Not tunable below 1.8 MHz