Antenna Tuners
(Antenna Couplers)

What is an Antenna Tuner?

- An antenna tuner (coupler is a more correct term) is an impedance matching device which minimizes “mismatch” loss (maximizes power transfer).
- NOT different from any other impedance matching circuit. It does NOT tune the antenna!
- Old R.L. Drake devices were named MN-4, MN-2000, MN-2700. Guess what the MN stands for.
- Also referred to as coupler, antenna coupler, transmatch, Matchbox, etc.

Basics: Correct or Incorrect?

- An antenna operated at its resonant frequency doesn't need a coupler.
  - *No, resonance only means the feed point is resistive and does not mean a low SWR.*
- Resonant antennas radiate better than non-resonant antennas.
  - *No, pattern may change from that at resonance and will need to match.*
- Most antennas are resonant at only one frequency.
  - *No, all antenna have multiple resonances.*

Basics: Correct or Incorrect?, Page 2

- The ability to match is more important than efficiency when choosing a coupler.
  - *Yes, if the coupler doesn't match not much else matters.*
- Coupler affects magnitude of current to antenna.
  - *Yes, this is how matching works.*
- Coupler does not affect the pattern of the antenna.
  - *Should be Yes, but only if the ratio of any common mode current on the feed line to the antenna currents remains the same.*

Basics: Correct or Incorrect?, Page 3

- The SWR presented by an antenna is minimum at the fundamental resonant frequency.
  - *No, often SWR is minimum but not a requirement.*
- A coupler placed at the antenna will always result in a more efficient system than one placed at the transmitter.
  - *Generally Yes, but impedance at antenna is different and coupler might not be able to match or be as efficient for this impedance.*

Basics: Correct or Incorrect?, Page 4

- Does 50Ω coax need to be used between coupler and transmitter?
  - *No, but do not use SWR meter in coupler if not 50Ω.*
- True open wire #12ga. 600Ω transmission line has lower loss than 1/2” 50Ω coax.
  - *Generally Yes, however if load is 5+j0, SWR on 50Ω line is 10:1 & 120:1 on open wire line. Loss for 100’ at 7MHz is 2.12dB (open wire) & 1.02dB (LMR-500).*
- Couplers should not be cascaded.
  - *Yes, if both auto-couplers but no otherwise*.

Basics: Correct or Incorrect?, Page 5

- A multiband coupler will have reduced matching at both the top and bottom of the frequency range.
  - *Yes!*
- A coupler in a radio that is specified to match 3:1 SWRs matches all 3:1 SWRs and not much else.
  - *No!*
- Couplers do not exist at VHF and above.
  - *No, but construction is done with transmission line sections and not lumped components.*

Does Coupler Use = Incompetency?

- Chest pounding by some would imply so.
  - I don't need a tuner since my antennas are designed properly. Tuners have too much loss. Idiots abound!
- A coupler is <u>one</u> of many tools that can be used.
- Couplers are more popular today than ever.
  - Covenants, small lot sizes, 11 HF bands (inc. 6m), etc.
  - The issue of stealth and camouflaged antennas could easily be another talk.

Choices?

- You don't have antennas to cover all desired frequencies with an acceptable SWR for your equipment.
  - Do nothing and just don't operate on some frequencies.
  - Lack of knowledge point of view. Most common and probably best if there are frequent antenna changes!
  - Estimating the impedance(s) needed to match by analysis or tables.
  - Knowing very closely the impedance(s) needed to match by measurement.

What do you really want/need?

- Matches nearly everything?, Match = 1.0:1 SWR?
- Improve SWR bandwidth?, Hardly ever adjusted?
- Peak/average power (mfg. ratings not reliable)?
- Adjust at low power?, Adjust at full power?
- Adjusts or can be adjusted very quickly?
- 160-10m, 80-10m, 6m, single band?
- Harmonic or band pass filtering?, Static bleed?
- Remotable?, Some combination of the above?

Matching Network Components

- Generally constructed from reactive components.
  - Exceptions: transmission lines, delta match, resistances such as the 800-900Ω resistor in the B&W terminated folded dipole, etc.
- Why reactive components?
  - Reactive components with high unloaded Qs do not dissipate much power.
  - However physically large components have reduced ranges and more stray inductance and capacitance.
  - Transmission line components ~ Q=100.

DIY Coupler

- In approximate order of ascending cost
  1) Fixed inductor
  2) Small value fixed capacitor
  3) Air variable capacitor
  4) Air differential capacitor
  5) Large voltage fixed capacitor
  6) High voltage/current switch
  7) Vacuum variable capacitor
  8) Roller inductor

Types of Tuners

- Auto, semi-auto, manual adjust, or fixed.
- Variable, switched, and/or fixed components.
- Is coupler part of transmitter or antenna?
  - If part of the antenna then changing transmitters easy.
- Included balun, antenna switch, dummy load etc.
- Power rating and matching range. Total BS!
- Coupler/antenna as a system (military & aircraft).
- No mention yet of coupler topology.

Tying it all together

- Reflection Coefficient: $$\Gamma = \frac{Z_L - Z_O}{Z_L + Z_O} \qquad \rho = \left|\Gamma\right| \qquad 0 \le \rho \le 1 \qquad \rho = \frac{SWR - 1}{SWR + 1}$$
- SWR: $$SWR = \frac{1+\rho}{1-\rho} \qquad \rho = \sqrt{\frac{(R_L - R_O)^2 + (X_L)^2}{(R_L + R_O)^2 + (X_L)^2}}$$
- Return Loss: $$RL_{dB} = -20 \times \log_{10}(\rho)$$ $$P_{Ref} = P_{Fwd} \times \rho^2$$ $$P_{Load} = P_{Fwd} - P_{Ref}$$
- Mismatch Loss: $$ML_{dB} = -10 \times \log_{10}\left(\frac{P_{Fwd} - P_{Ref}}{P_{Fwd}}\right) = -10 \times \log_{10}\left(1 - \rho^2\right)$$

SWR	ρ	Return Loss (dB)	Mismatch Loss (dB)	Power To Load[1]
1.1	0.05	26.44	0.01	100%
1.2	0.09	20.83	0.04	99%
1.5	0.20	13.98	0.18	96%
2	0.33	9.54	0.51	89%
2.5	0.43	7.36	0.88	82%
3	0.50	6.02	1.25	75%
5	0.67	3.52	2.55	56%
10	0.82	1.74	4.81	33%
20	0.90	0.87	7.41	18%
50	0.96	0.35	11.14	8%

Note 1: Does not include additional loss in transmission line due to SWR or any fold back in transmitter.

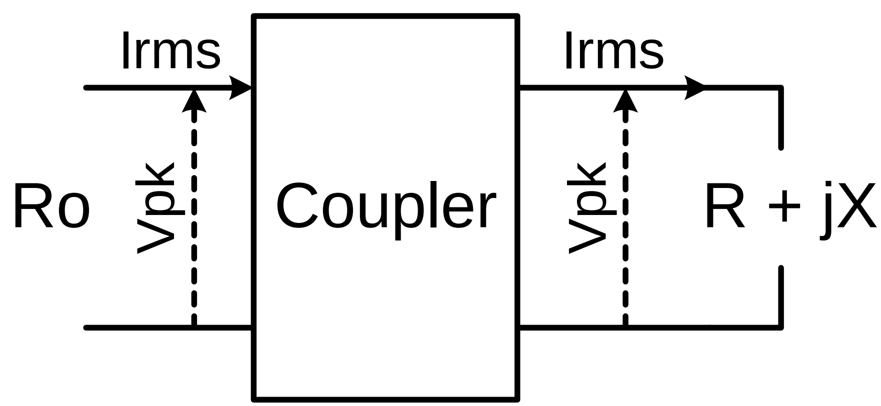
Voltages and Currents

$$Vpk = \sqrt{2 \times P \times R_O}$$

$$Vpk \le \sqrt{2 \times P \times R_O \times SWR}$$

$$Irms = \sqrt{\frac{P}{R_O}}$$

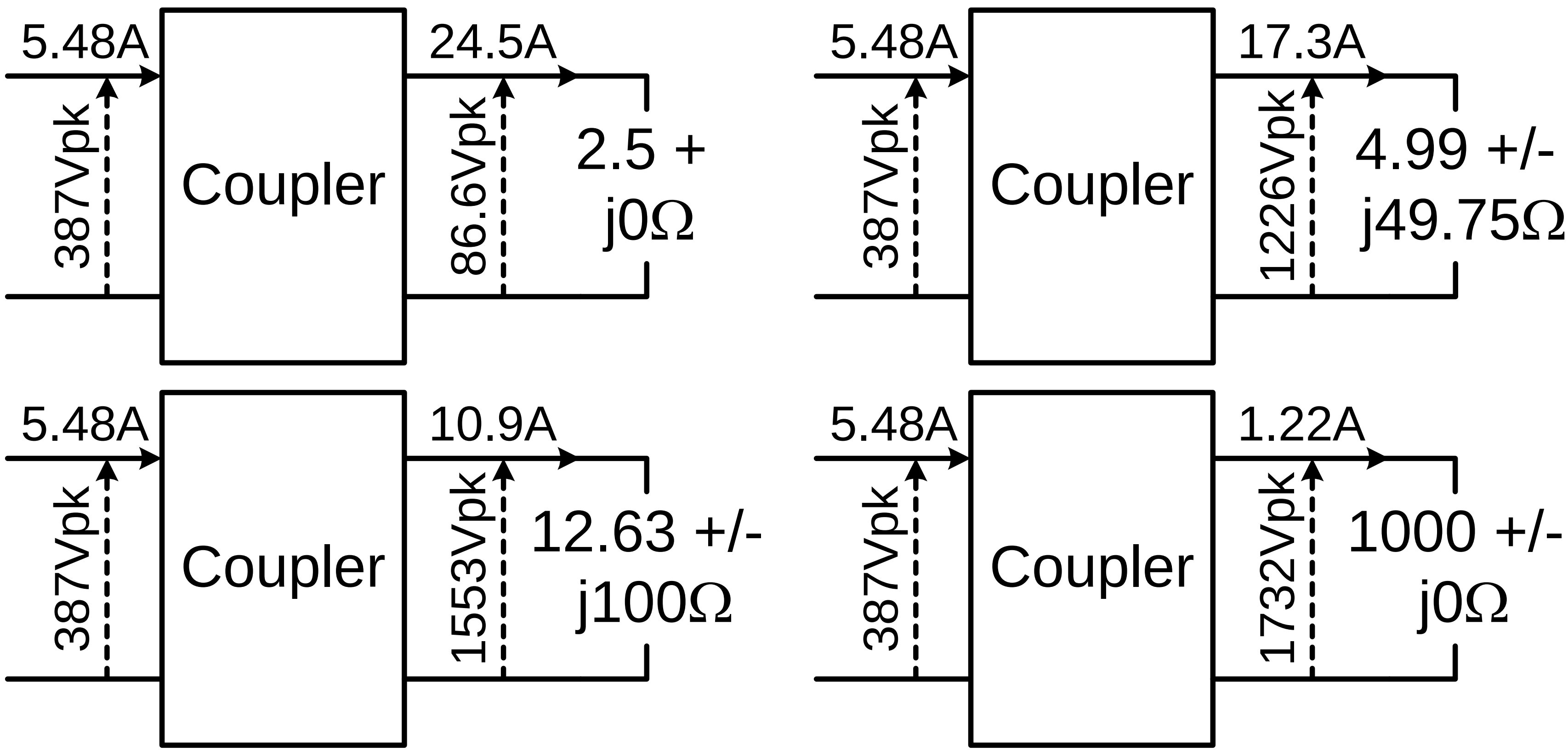
$$Irms \le \sqrt{\frac{P \times SWR}{R_O}}$$



SWR	Power	Vpk(max)	Irms(max)
1:1	100W 1500W	100V 387V	1.41A 5.48A
3:1	100W 1500W	173V 671V	2.45A 9.5A
10:1	100W 1500W	316V 1225V	4.47A 17.3A
20:1	100W 1500W	447V 1732V	6.32A 24.5A
50:1	100W 1500W	797V 2739V	10.0A 38.7A

Stresses Within the Tuner @ 1500W

- All are 20:1 SWRs. Stresses & losses are different.



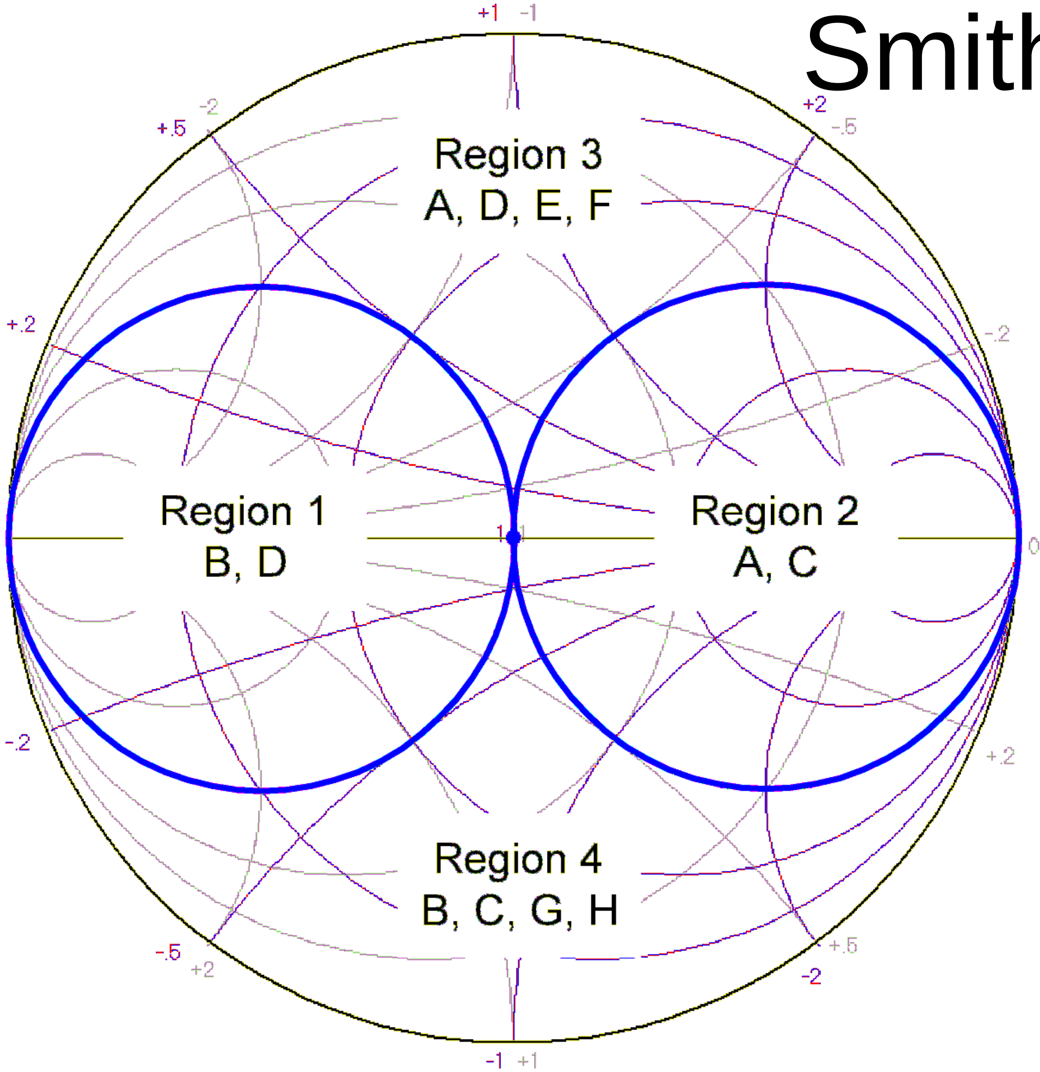
“Small” Antenna Examples

- Example#1
  - 1.8MHz using 40m (67.2’) dipole, 50’ high, #12 Cu wire
  - Z = 1.60 – j2420 (SWR ~73000:1)
  - Irms = 30.6A (1500W), Vpk = 104.7kV
- Example #2
  - 1.8MHz using 80m (135’) dipole, 50’ high, #12 Cu wire
  - Z = 5.9 – j1080 (SWR ~3950:1)
  - Irms = 15.94A (1500W), Vpk = 24.3kV
- No tuners match these impedances well!
- A little loss is desperately needed.

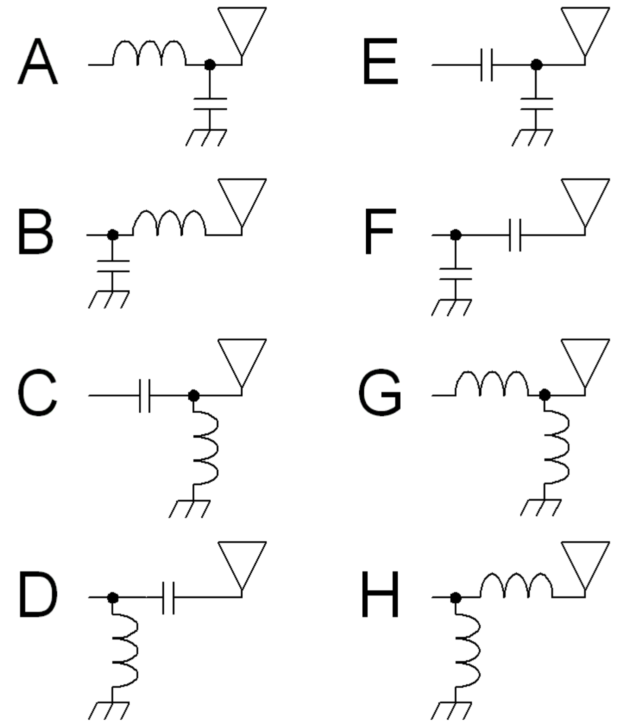
What is the Smith Chart

- A polar plot of the reflection coefficient including phase.
- This results in:
  - Plots of constant SWRs are circles.
  - Inductive impedances are above the center line.
  - Capacitive impedances are below the center line.
  - The horizontal axis goes from 0Ω at the far left to R_O at the center to infinity at the far right.

Smith Chart Regions



L type circuits



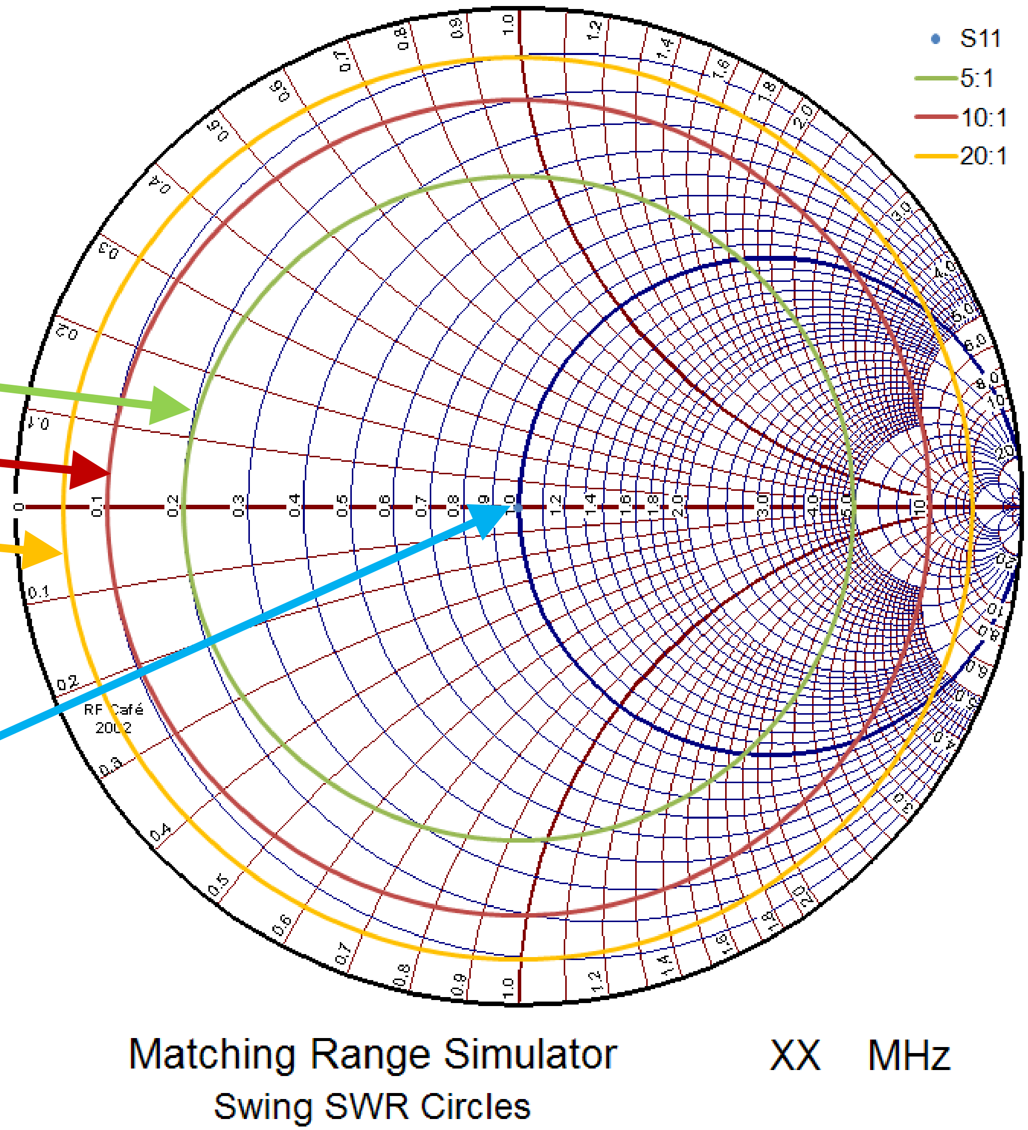
Example Smith Chart
showing SWR circles

5:1 = Green

10:1 = Red

20:1 = Orange

50 + j0 (SWR = 1:1)



Sample Design Goals

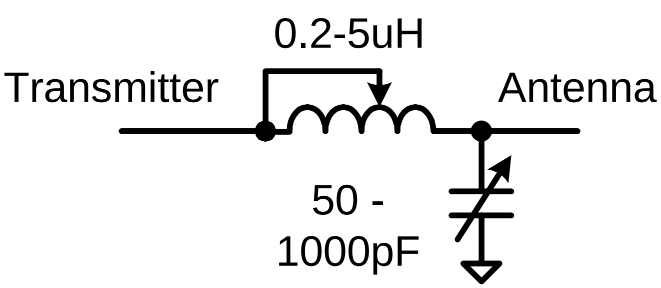
- Match all SWRs of at least 20:1 from 160m thru 20m with reduced SWRs up thru 6m.
- Do the basic design on 40m realizing that 4X more C & L will be needed on 160m etc.
- Ignore stray C & L for now.
- Explain old Johnson Matchbox with open wire line and large antennas vs today's use of a coupler.

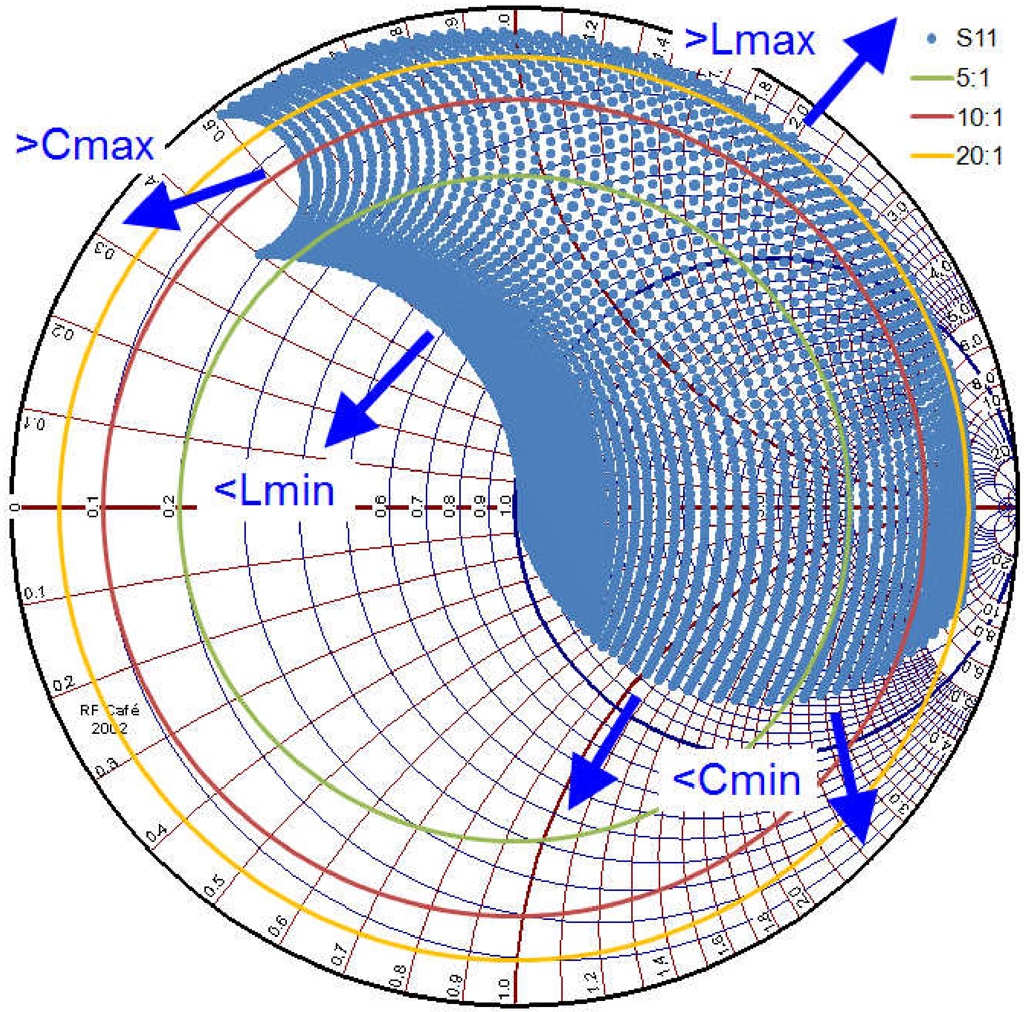
Low Pass "L" Network

Type "A"

- Shunt "C" on ANT Side
- Series "L"

- Need >Cmax & <Cmin





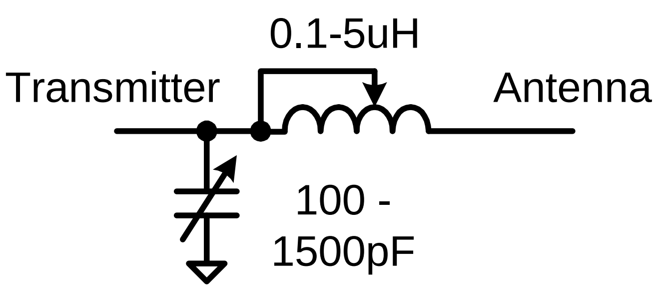
Low Pass "L" Network
"Lseries-Cshunt"
7 MHz

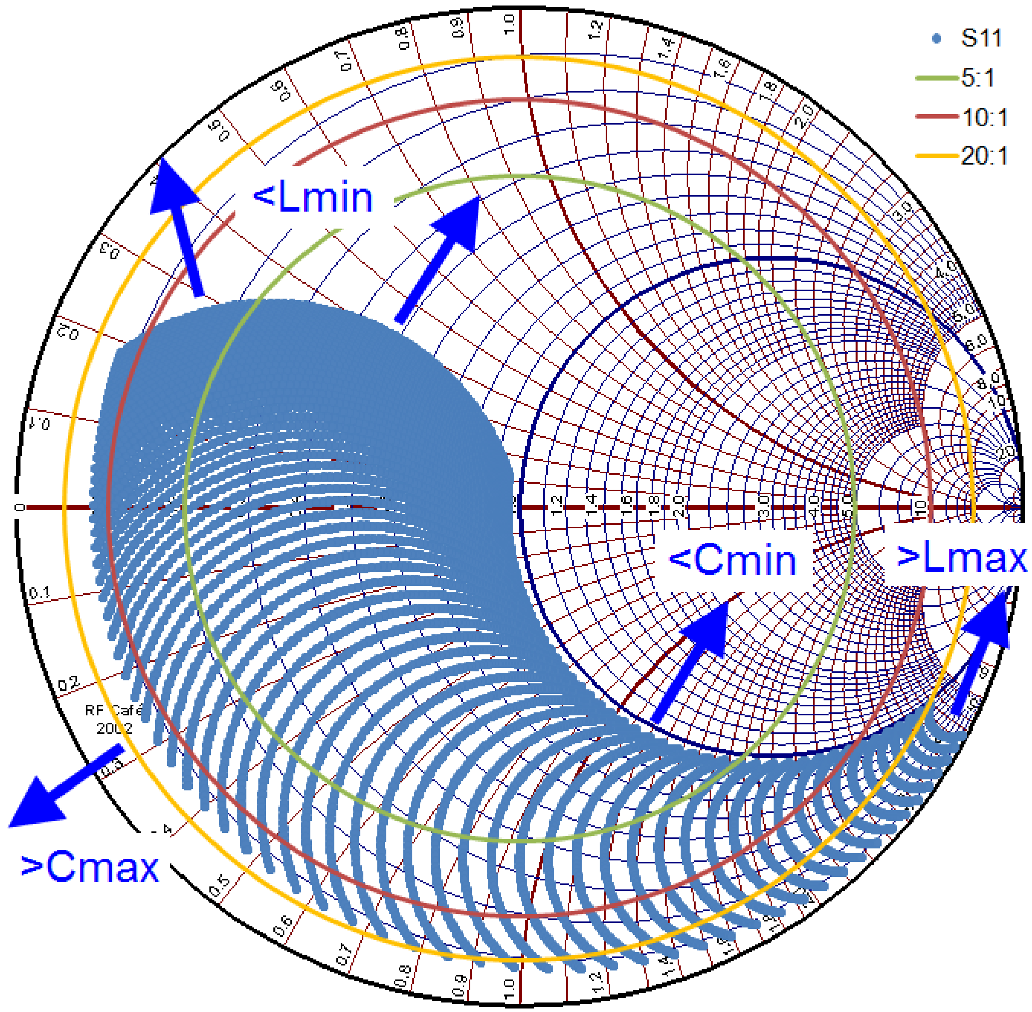
Low Pass “L” Network

Type “B”

– Shunt “C” on TX Side
– Series “L”

– Need <Lmin & >Cmax





Low Pass "L" Network 7 MHz
"Cshunt-Lseries"

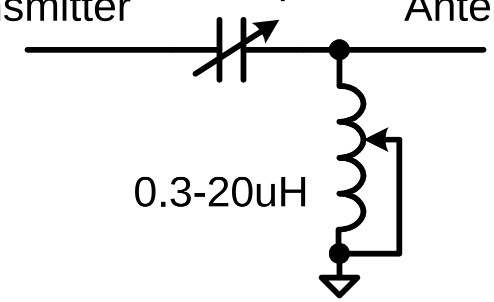
Low Pass “L” Network Results

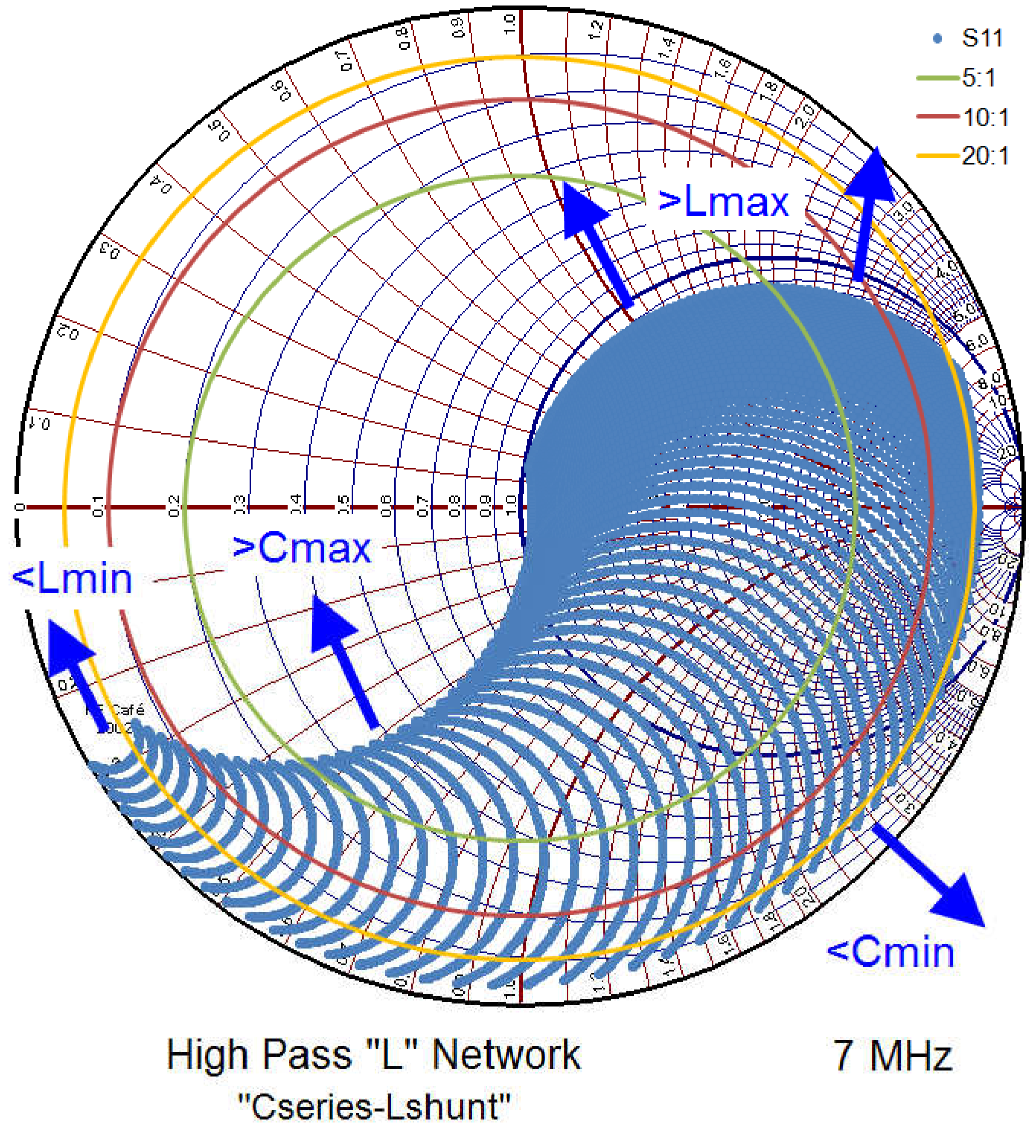
- Cmax ~= 8000pF & Lmax ~= 20uH on 160m
- Cmin ~= 5pF & Lmin ~= .02uH on 6m
- Pretty ugly component values.
- This happens when only 2 adjustable components, wide frequency, & wide matching range are wanted.
- Need some switchable offset components or variable offset components to help match especially on the higher frequencies.

High Pass "L" Network

Type "C"

- Shunt "L" on ANT Side
- Series "C"
- Need >Lmax (not good)

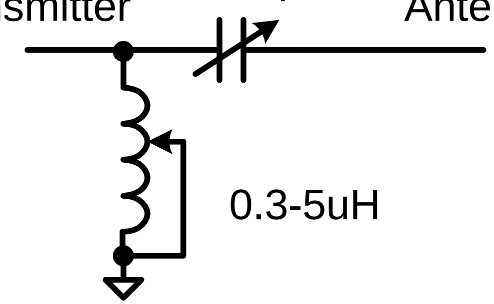


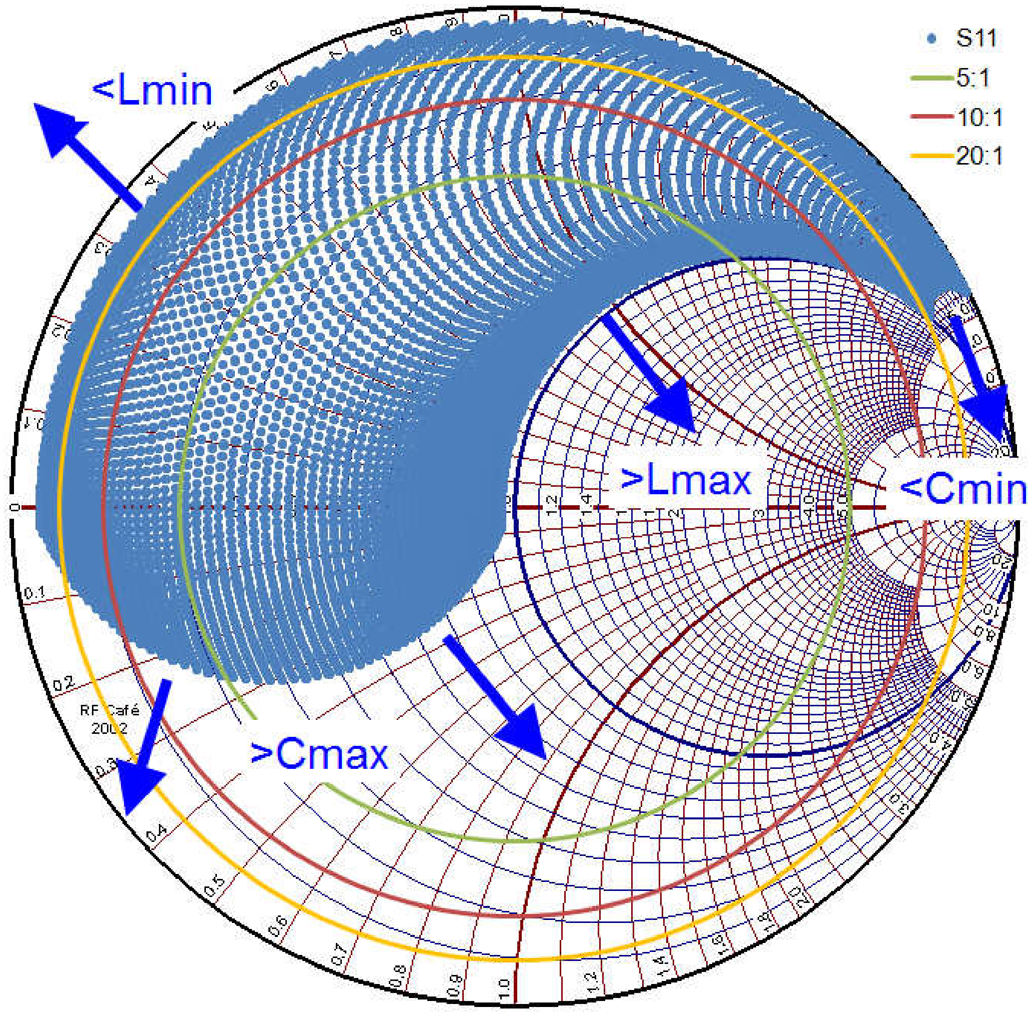


High Pass "L" Network
Type "D"

- Shunt "L" on TX Side
- Series "C"

- Need >Cmax (not good)





High Pass "L" Network
"Lshunt-Cseries"
7 MHz

High Pass “L” Network Results

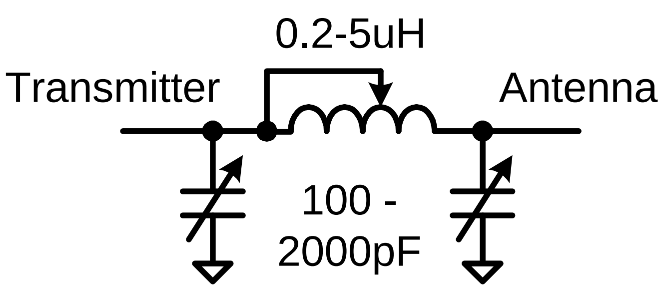
- Worse component values than Low Pass “L”.
- Variable component “L” networks are not commonly used for wide range matching on the lower frequencies for good reason.
- Low Pass “L” networks are used in most switched component tuners with reduced 160m & 80m matching range.
- Often good choice if match impedance is known.

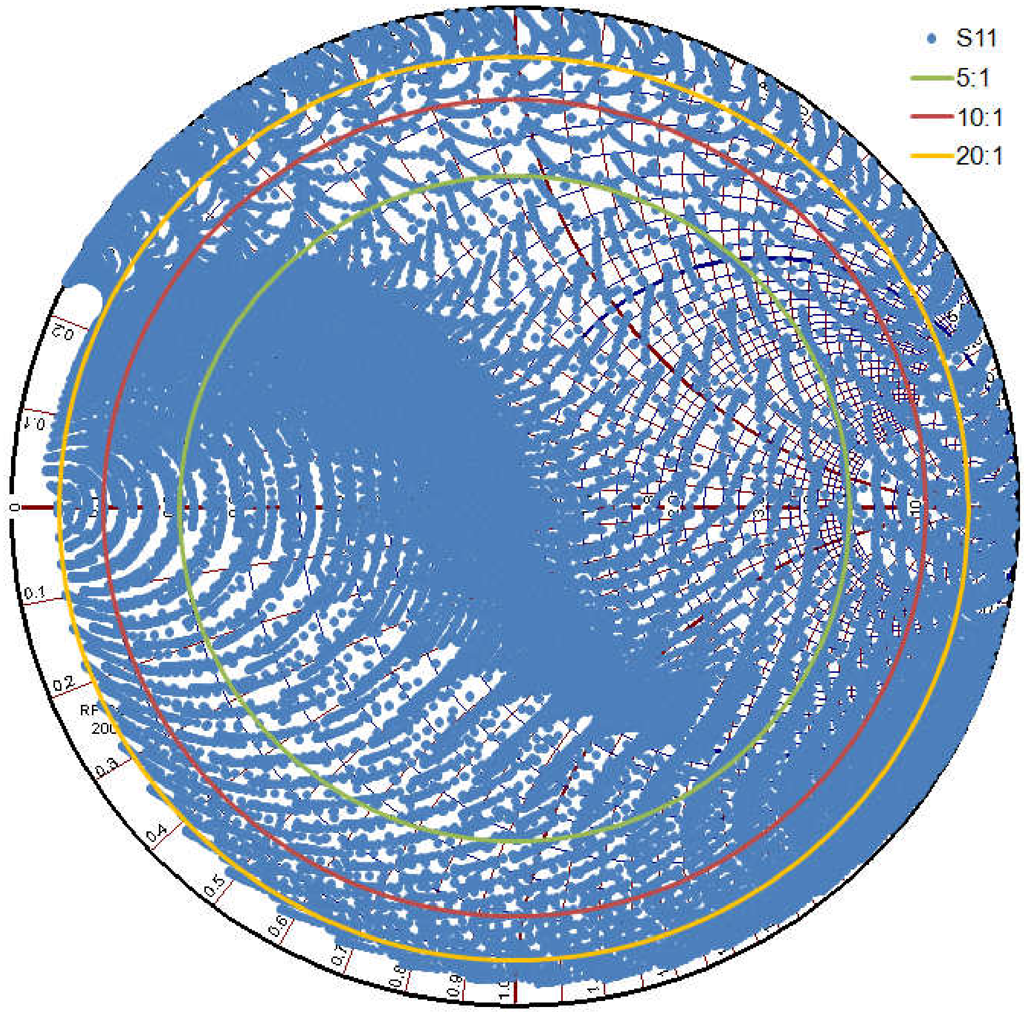
Adding a 3rd Component

- Does adding a 3rd adjustable component help the matching range?
- Could the Low Pass “Pi” could be this network?
- A “Pi” network is still a 2 terminal network.

Low Pass "Pi" Network

- Great matching range
- Similar component values to the Low Pass "L" network

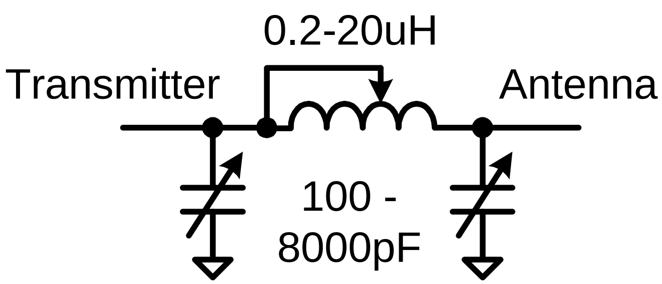


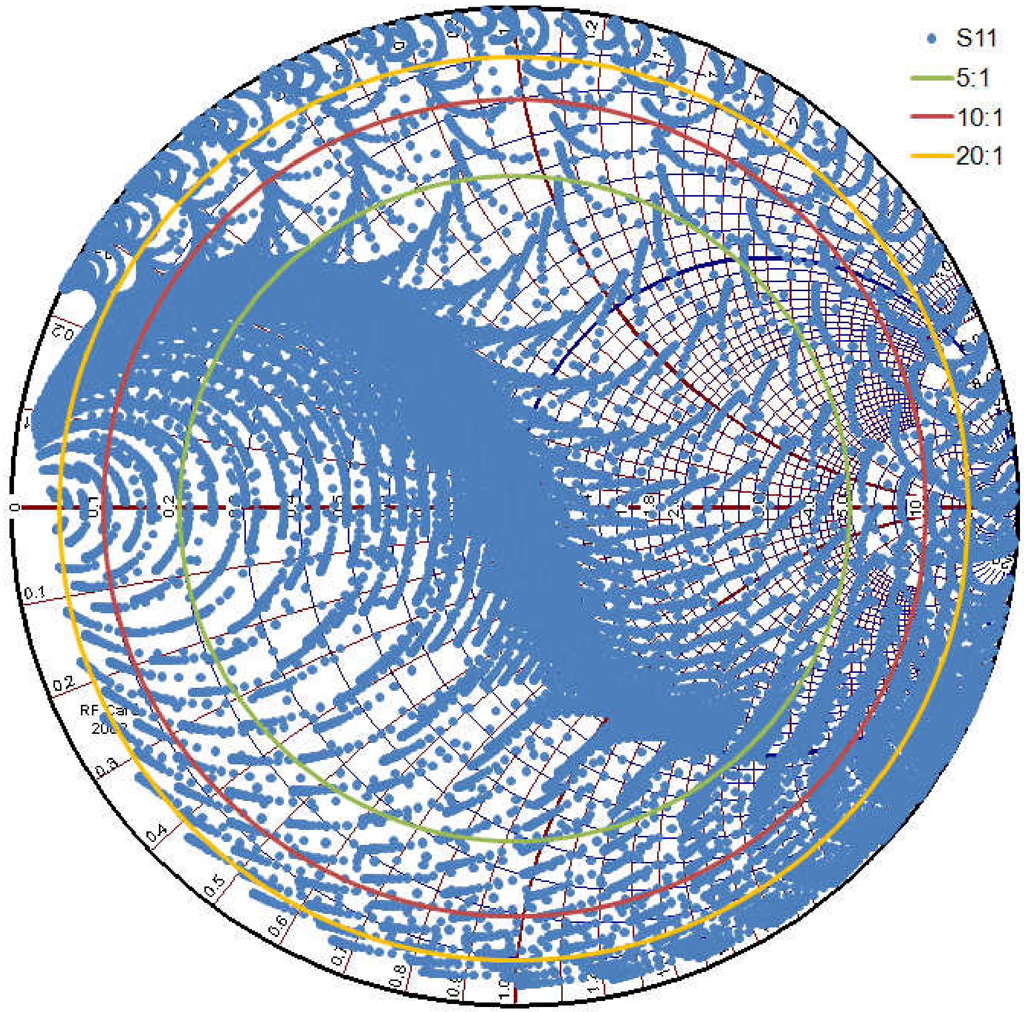


Low Pass "Pi" Network 7 MHz
"Cshunt-Lseries-Cshunt"

Low Pass “Pi” Network

- Great matching range
- Notice new scaled component values!

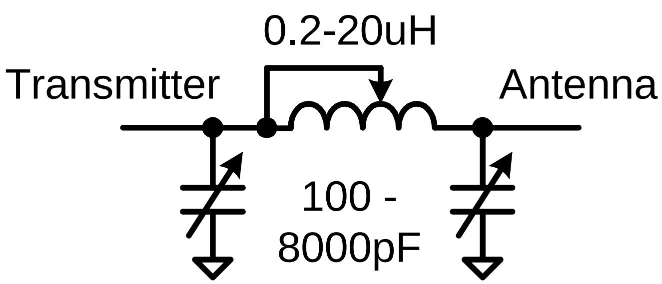


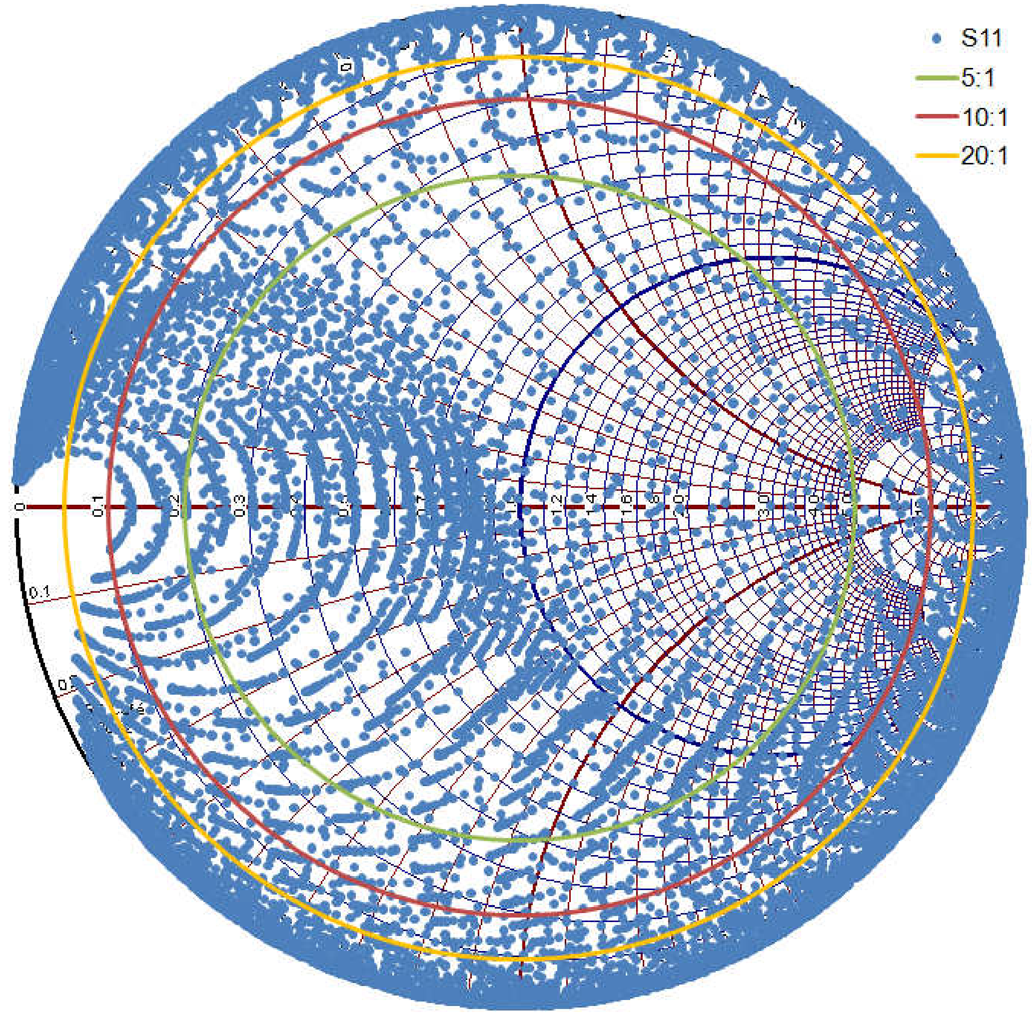


Low Pass "Pi" Network "Cshunt-Lseries-Cshunt" 1.8 MHz

Low Pass "Pi" Network

– Still good matching range



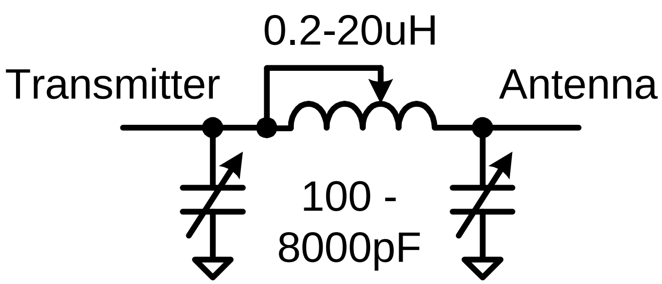


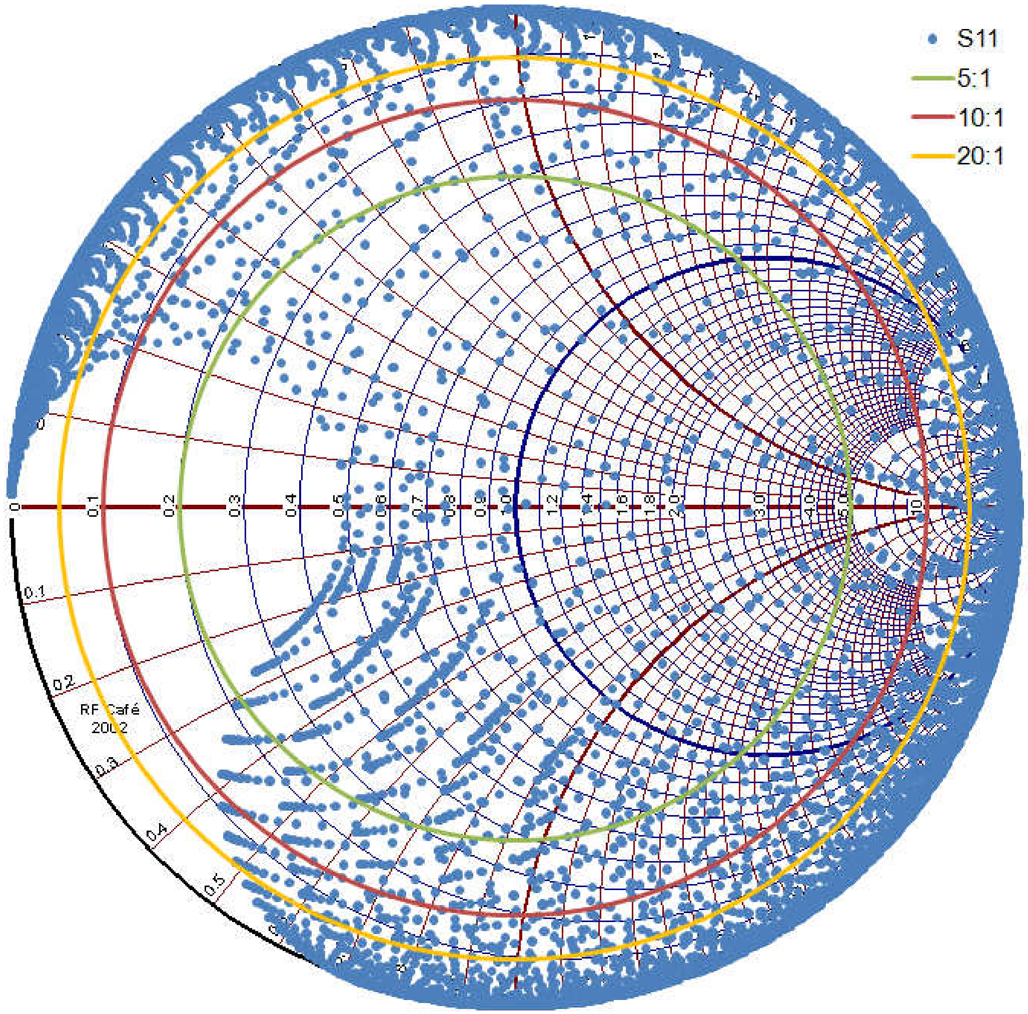
Low Pass "Pi" Network
"Cshunt-Lseries-Cshunt"

14 MHz

Low Pass “Pi” Network

- – Not good matching range
- – Needs <Cmin and <Lmin



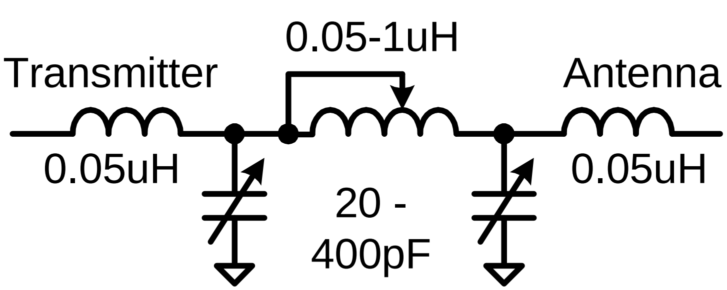


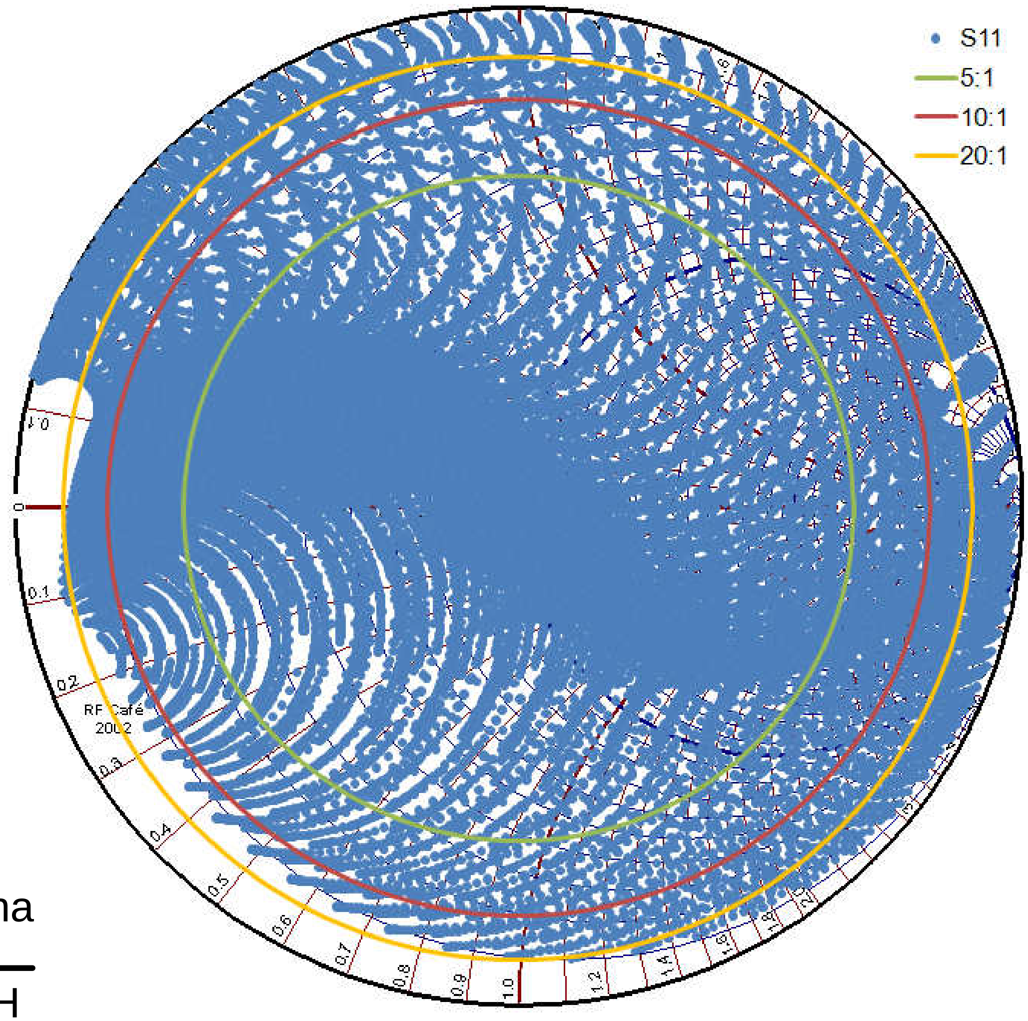
Low Pass "Pi" Network
"Cshunt-Lseries-Cshunt"

28 MHz

Low Pass “Pi” Network

– Very good matching range
– Modified for Cmin which includes stray C to Gnd
– Includes stray L on input and output

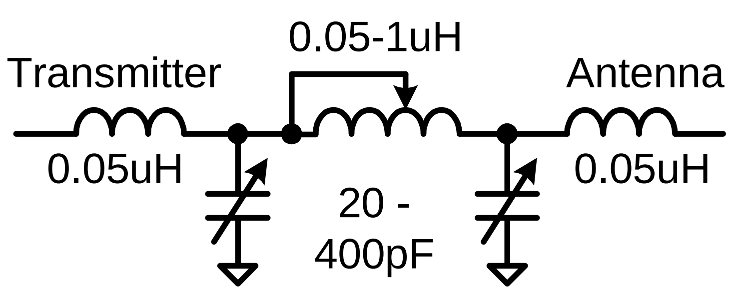


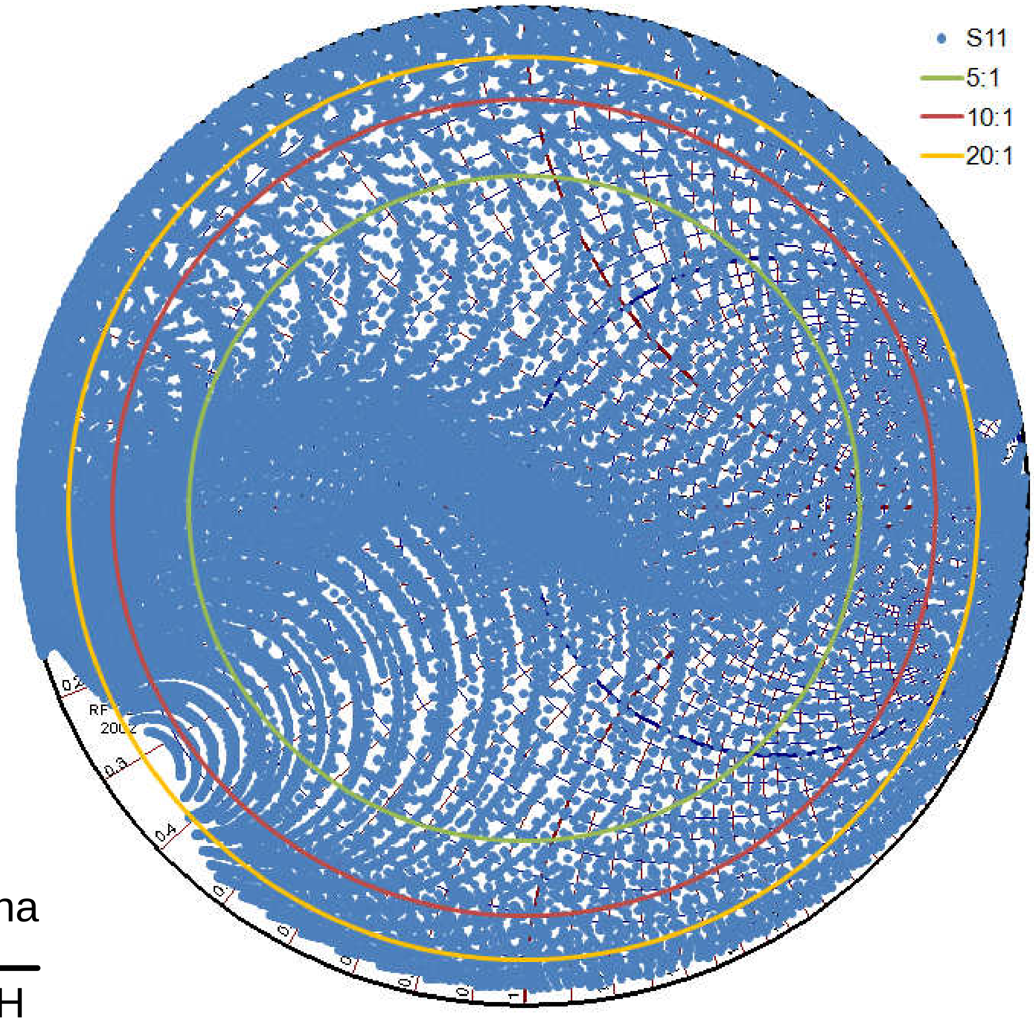


Low Pass "Pi" Network 28 MHz
"Cshunt-Lseries-Cshunt"

Low Pass “Pi” Network

- Very good matching range
- Modified for <Cmin which includes stray C to Gnd
- Includes stray L on input and output
- 6m range better than 10m due to 0.05uH





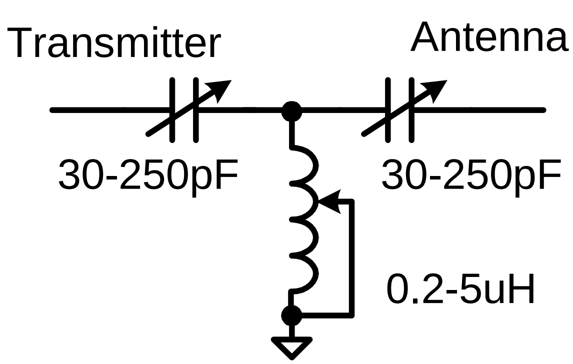
Low Pass "Pi" Network 50 MHz
"Cshunt-Lseries-Cshunt"

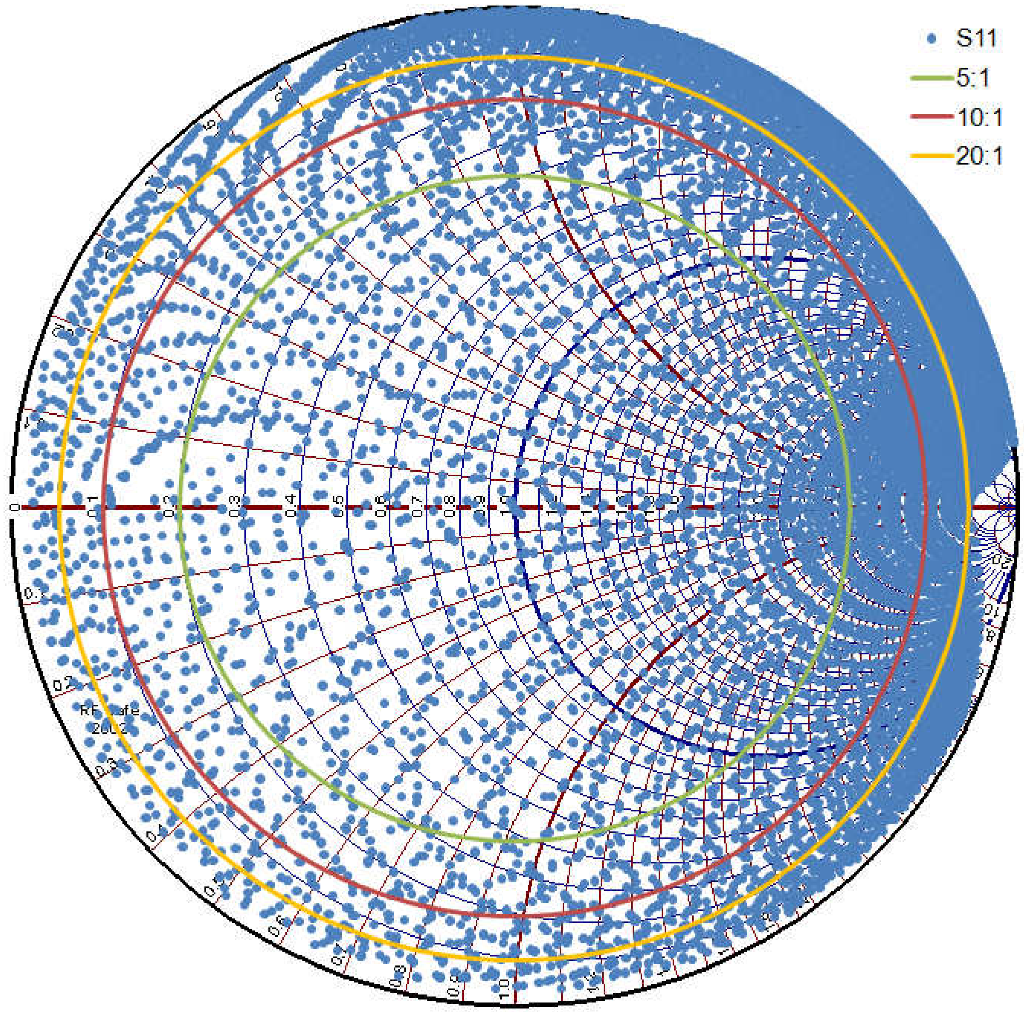
High Pass "Tee" Network

- Neither the "L" or Low Pass "Pi" networks seems like a good candidate for use as an all band general matching network.
- The "Tee" network has an effective 3rd node which increases flexibility at the expense of possible additional loss.
- 80-90% of any coupler loss is in the inductor(s) so improving inductor Q can offset loss concerns.

High Pass "Tee" Network

- Pretty easy to see why the high pass "Tee" network is popular
- Nice component values

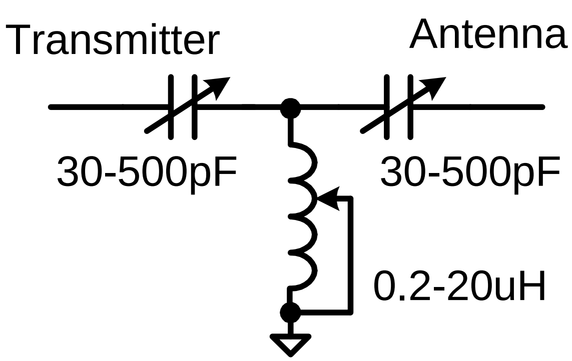


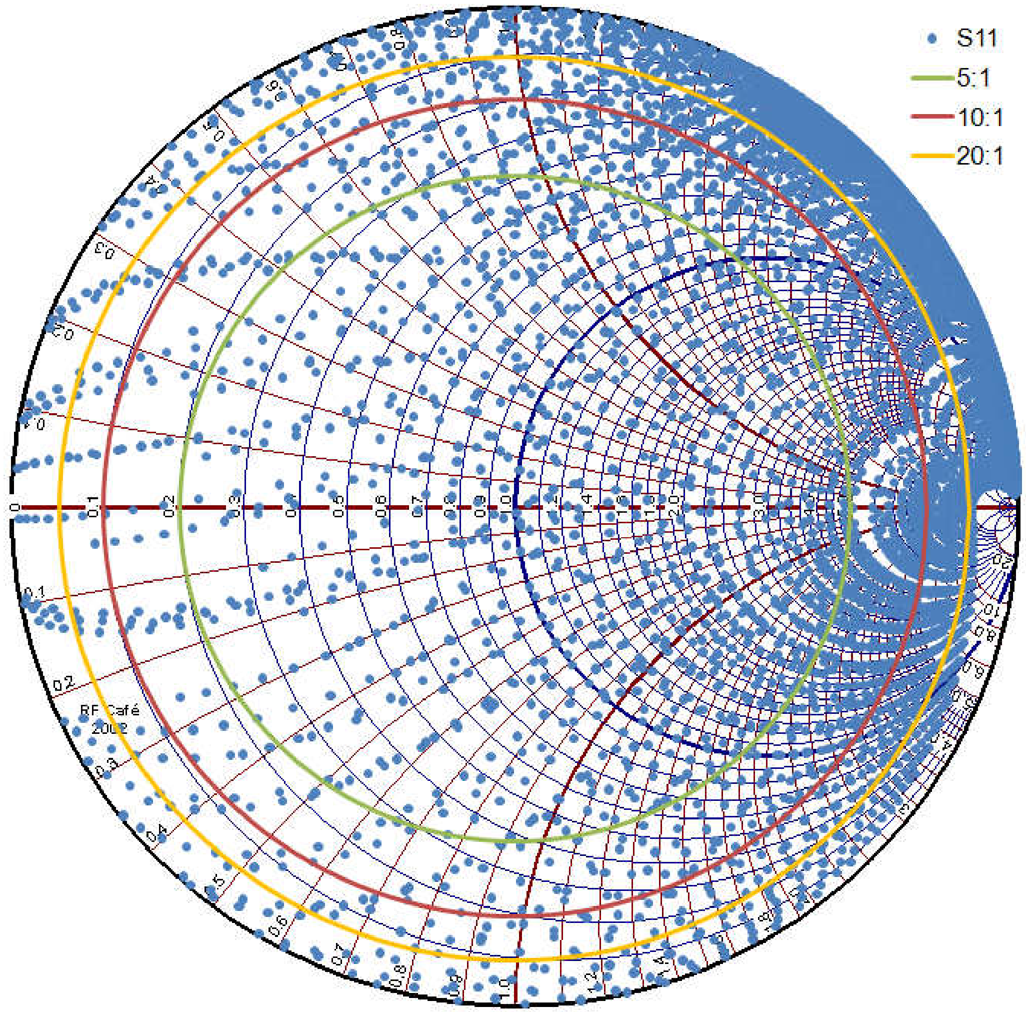


High Pass Tee Network "C-L-C" 7 MHz

High Pass “Tee” Network

– Great matching range



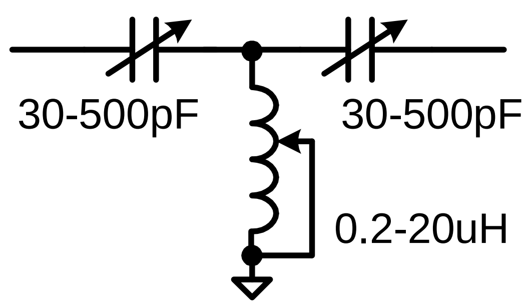


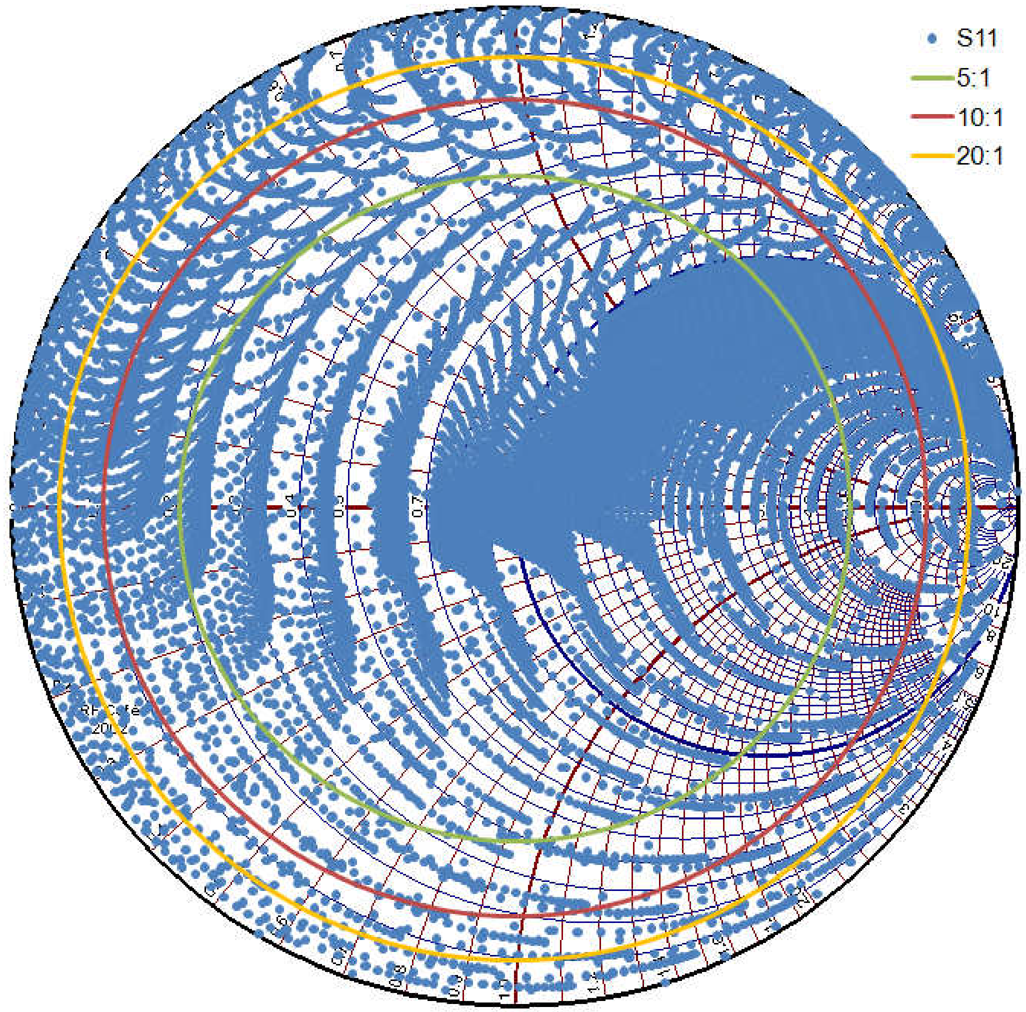
High Pass "Tee" Network 1.8 MHz

"C-L-C"

High Pass "Tee" Network

– Still great matching range

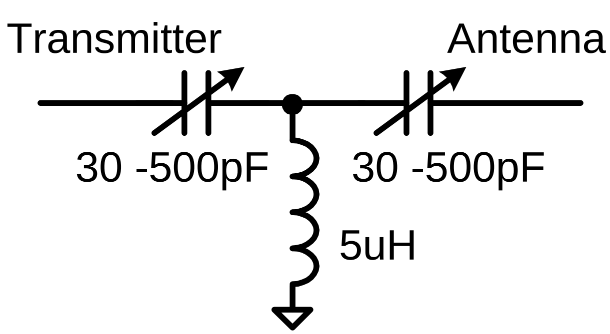


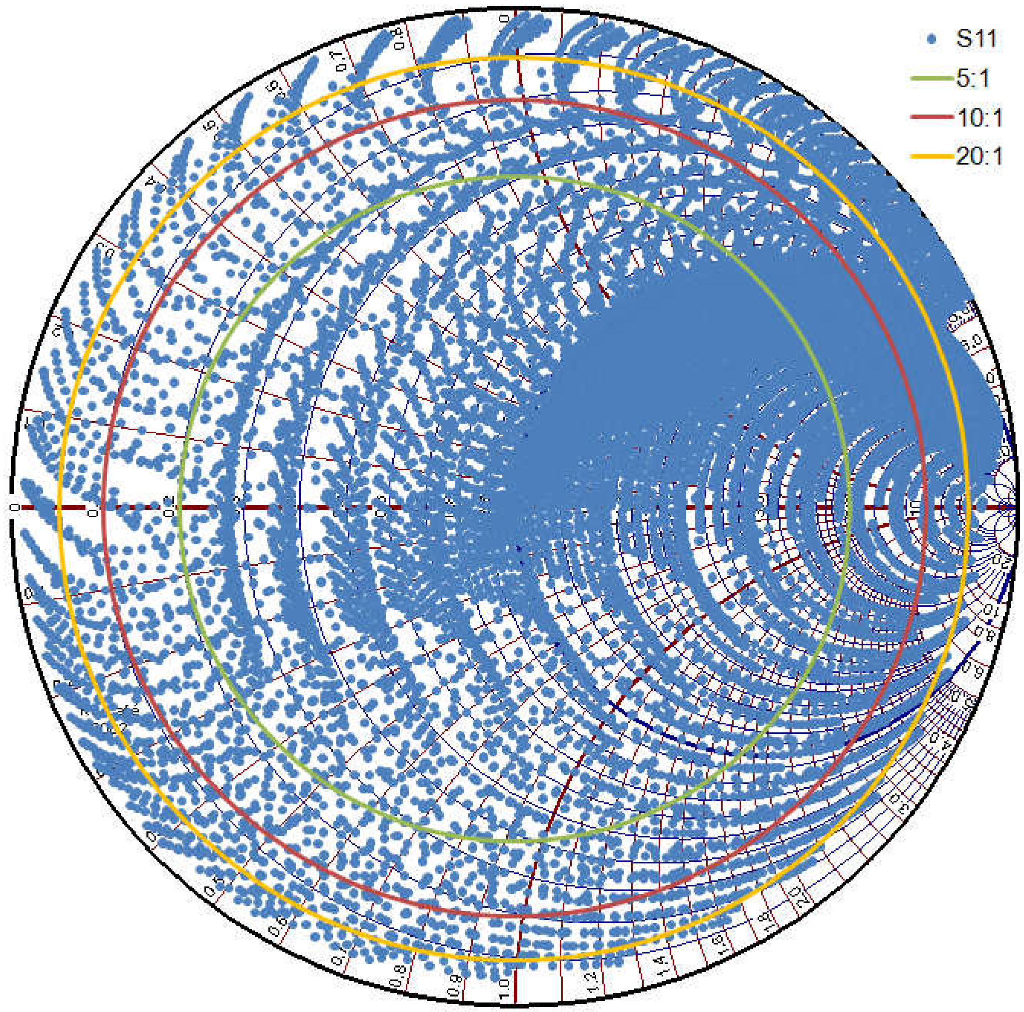


High Pass "Tee" Network "C-L-C" 14 MHz

High Pass “Tee” Network

- Very good matching range

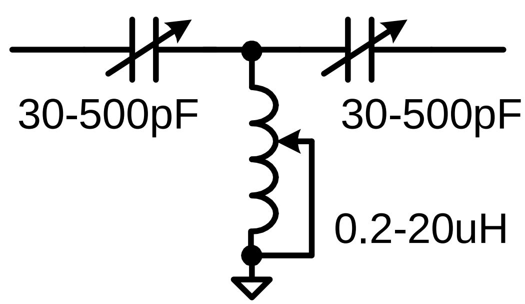


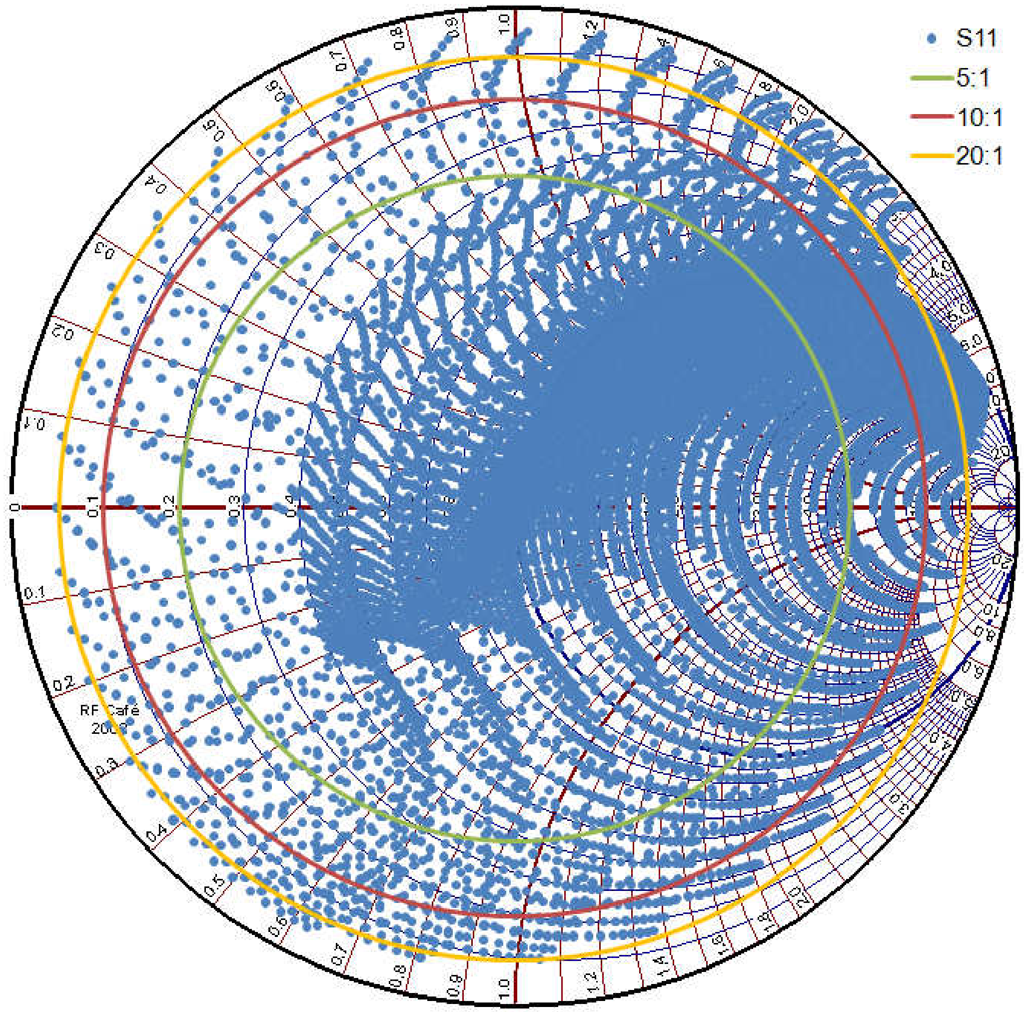


High Pass "Tee" Network 21 MHz
"C-L-C"

High Pass "Tee" Network

- Obvious why the High Pass "Tee" is popular

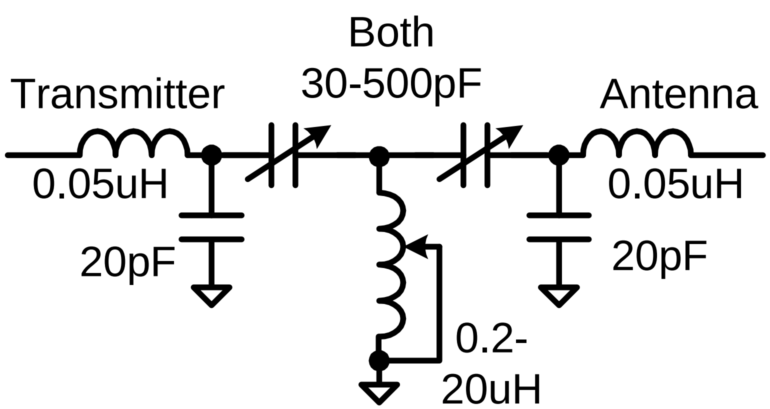


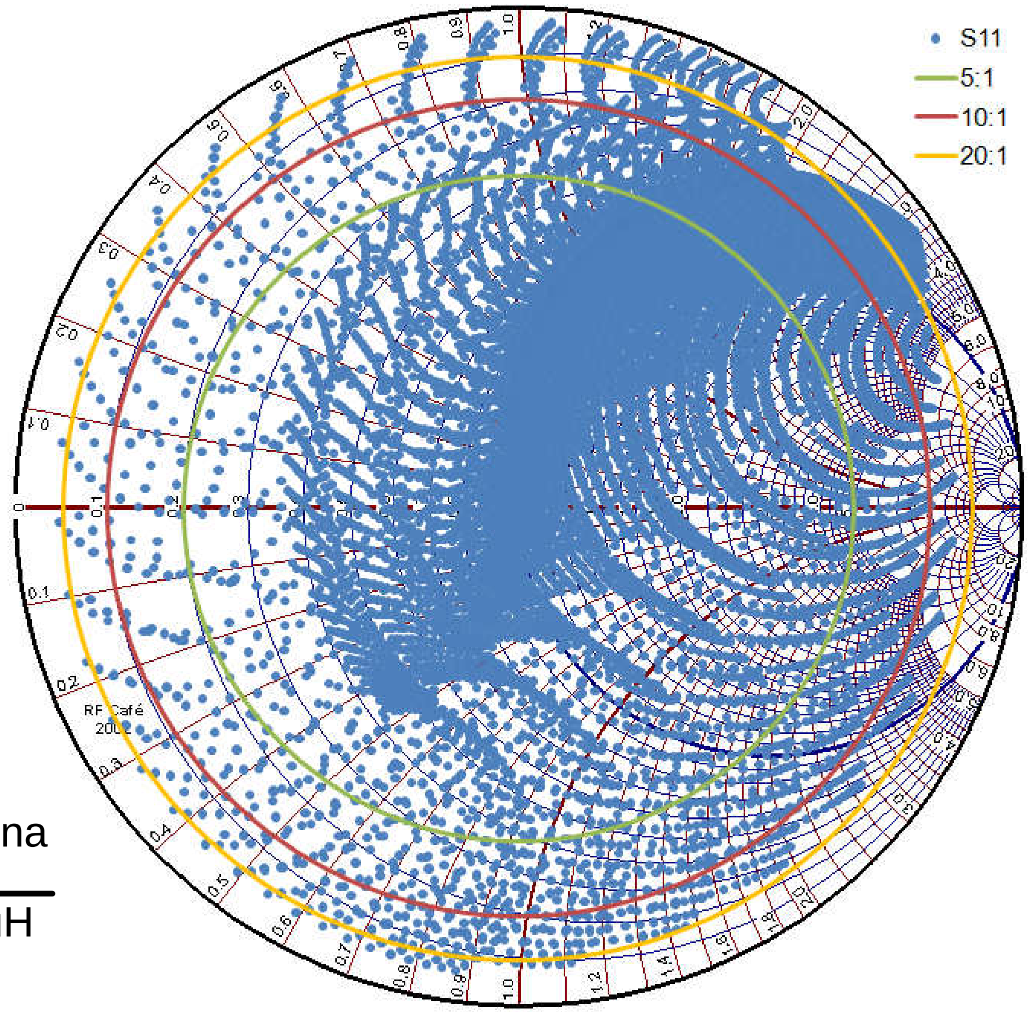


High Pass "Tee" Network "C-L-C" 28 MHz

High Pass "Tee" Network

- What if we include the stray Cs & Ls
- Still great matching range

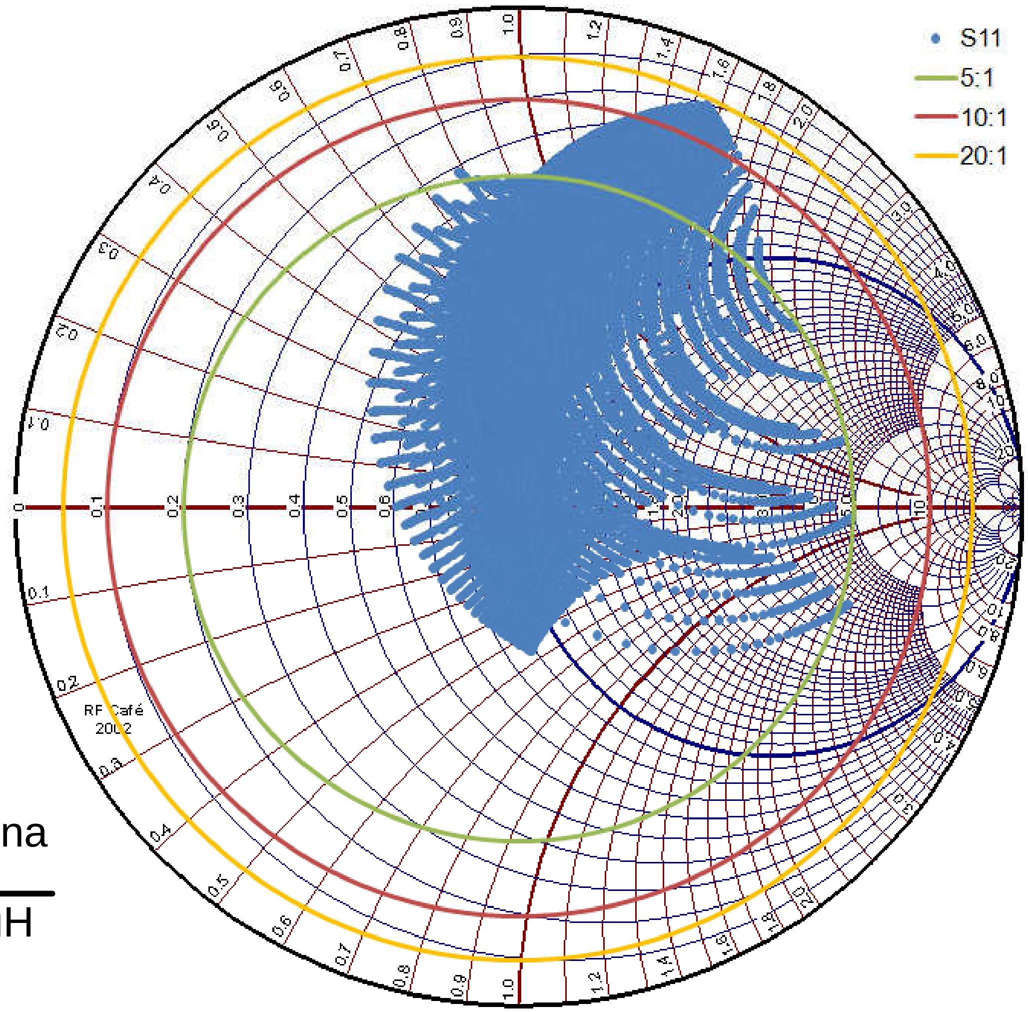




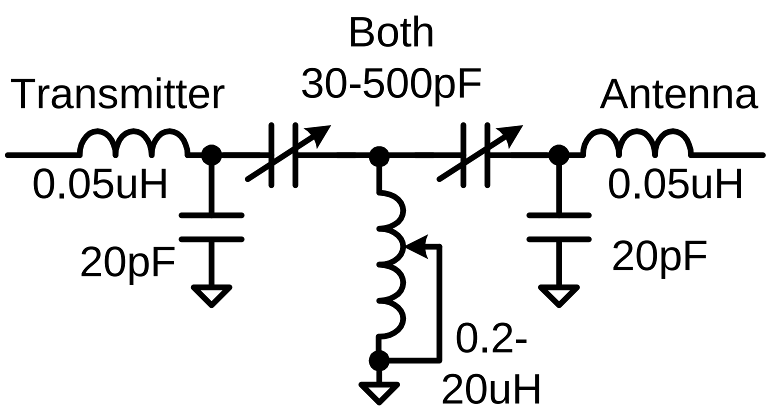
High Pass "Tee" Network 28 MHz
"C-L-C"

High Pass “Tee” Network

- Matching range is poor
- Lmin is too large (reactance = +j63 @50MHz)

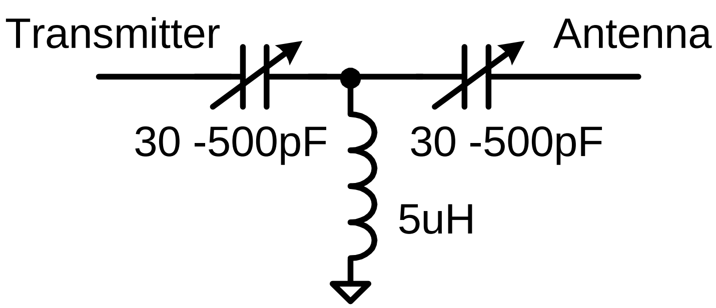


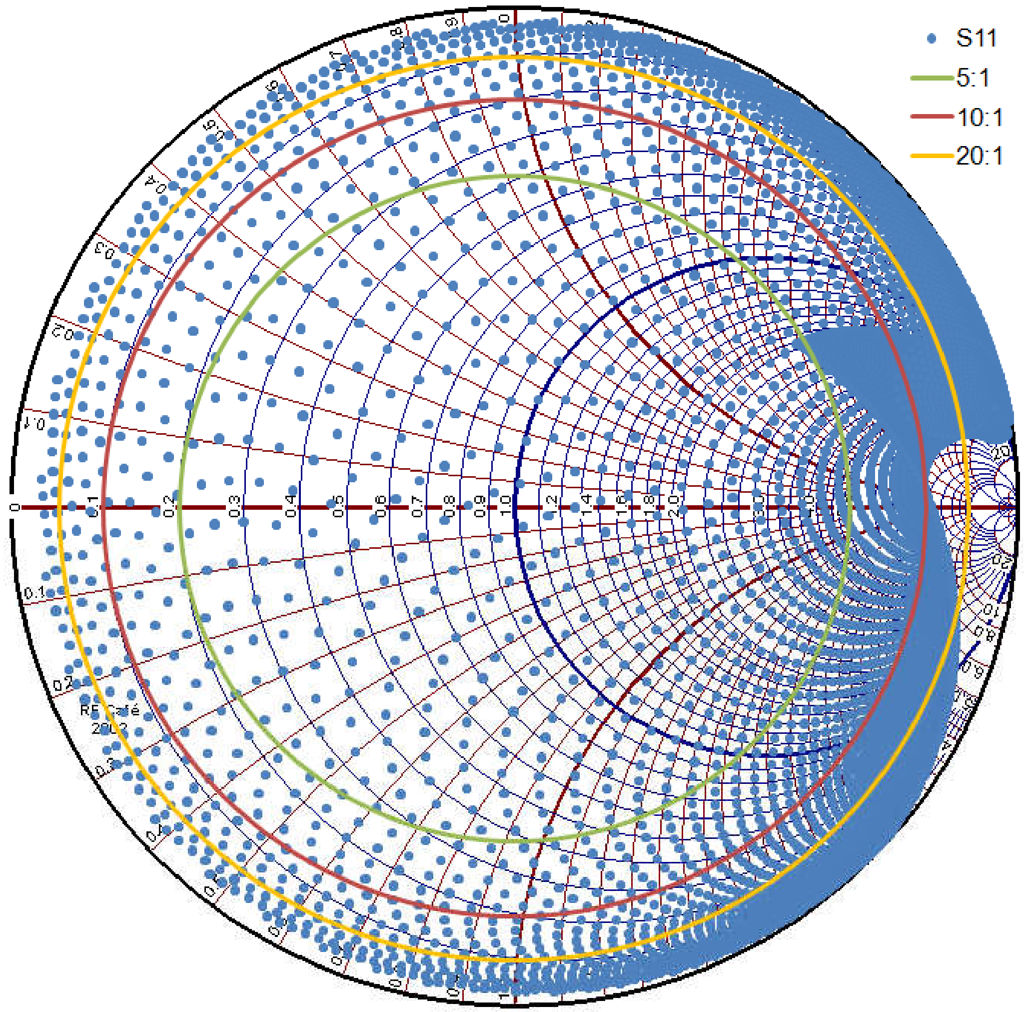
High Pass "Tee" Network 50 MHz
"C-L-C"



Fixed "L" High Pass "Tee" Network

- Fixed "L" can cover 2 bands pretty well.
- Inductor easy to make very high Q.
- Coupler best @ ~5MHz
- Matches all 10:1 SWRs & 95% of 20:1 SWRs

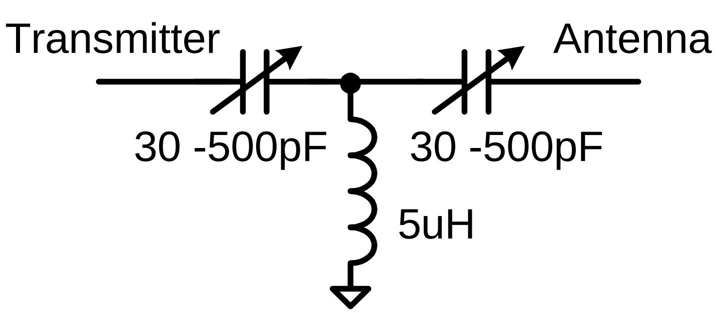


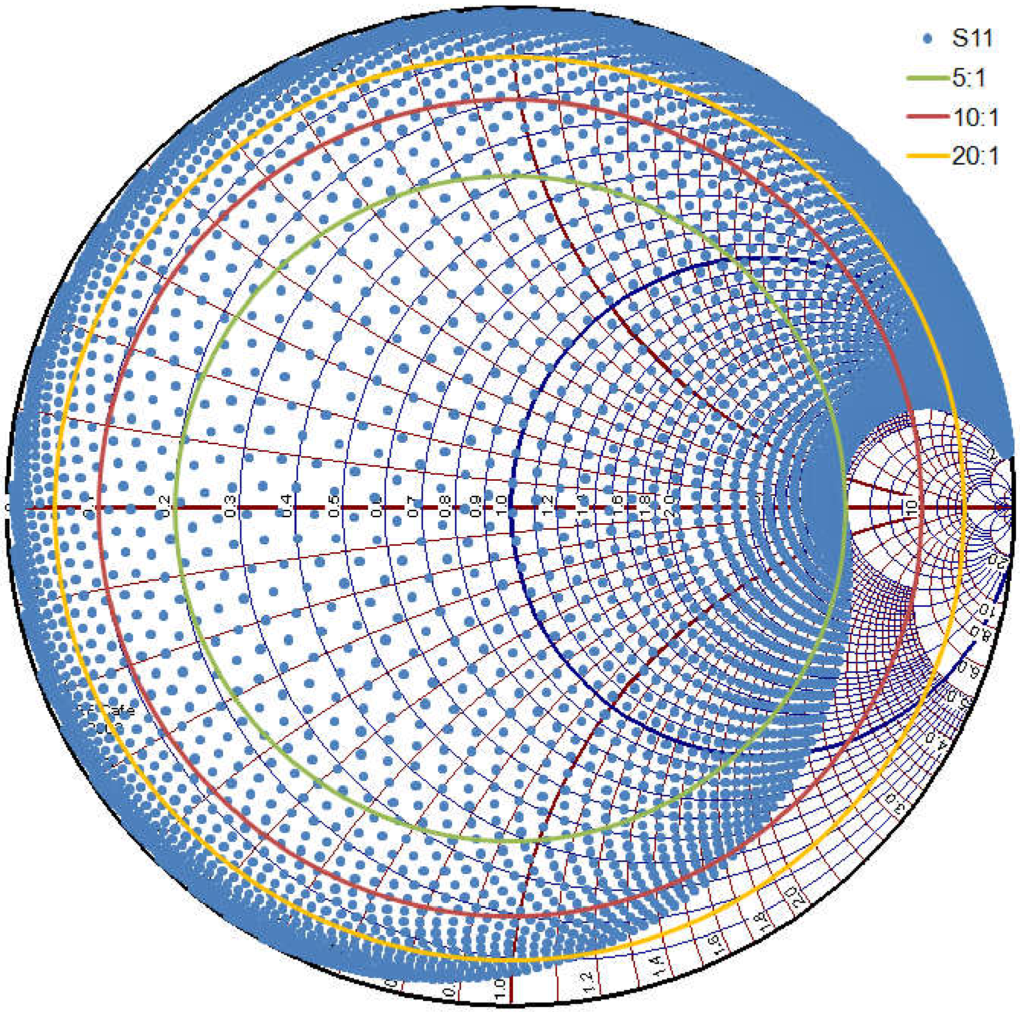


High Pass "Tee" Network 5 MHz
"C-Fixed L-C"

Fixed "L" High Pass "Tee" Network

– Matches all 5:1 SWRs & 75% of 20:1 SWRs

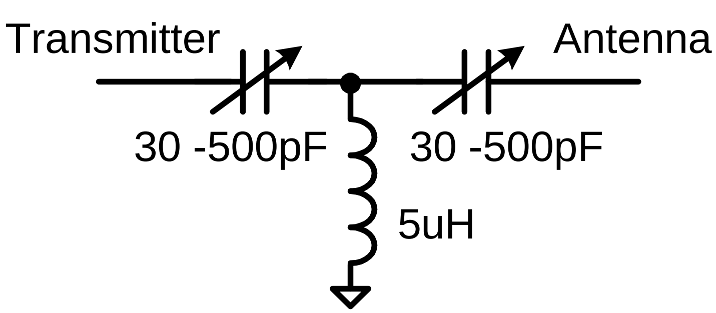


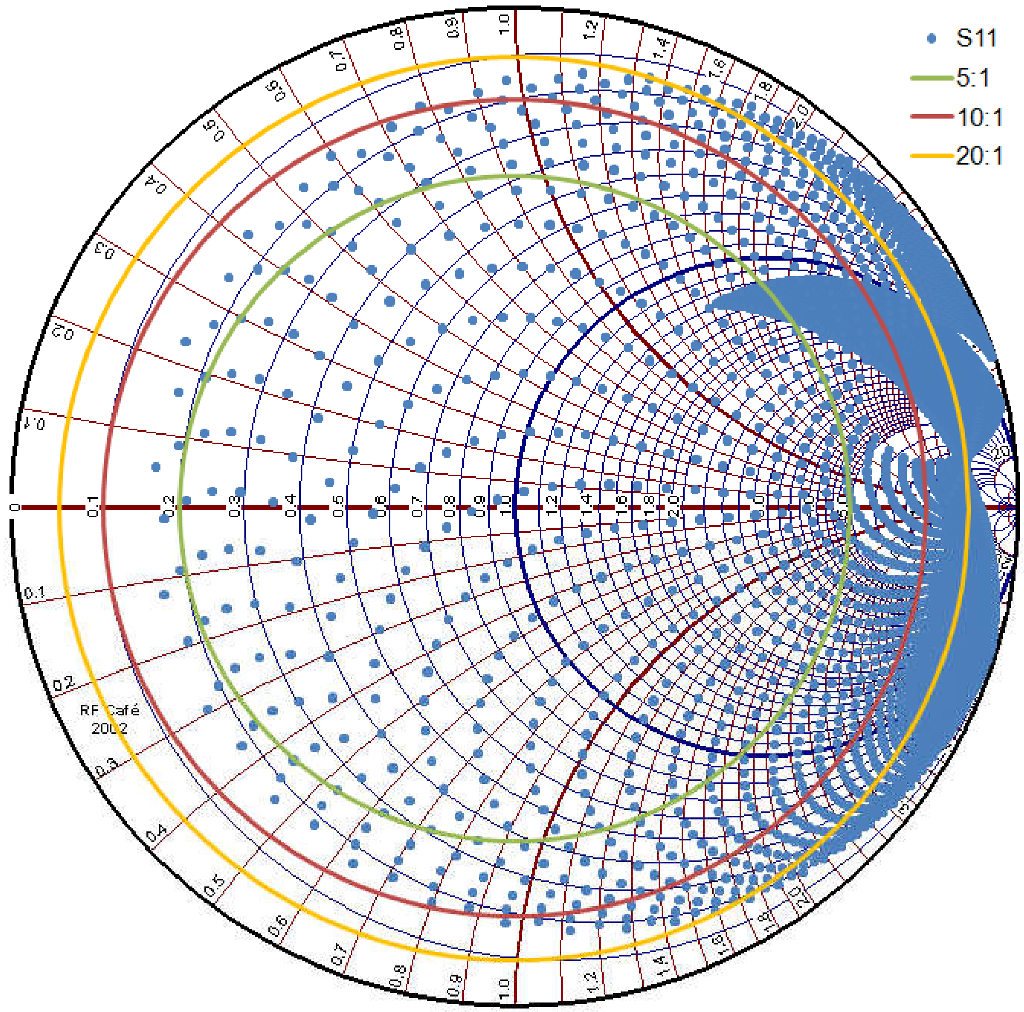


High Pass "Tee" Network 3.5 MHz
"C-Fixed L-C"

Fixed "L" High Pass "Tee" Network

– Matches all 7:1 SWRs, 60% of 10:1 SWRs, & 40% of 20:1 SWRs

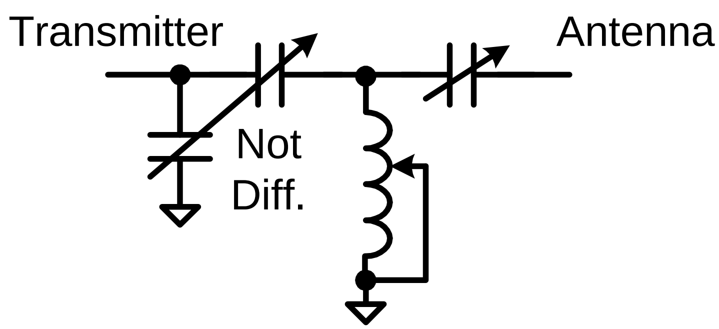




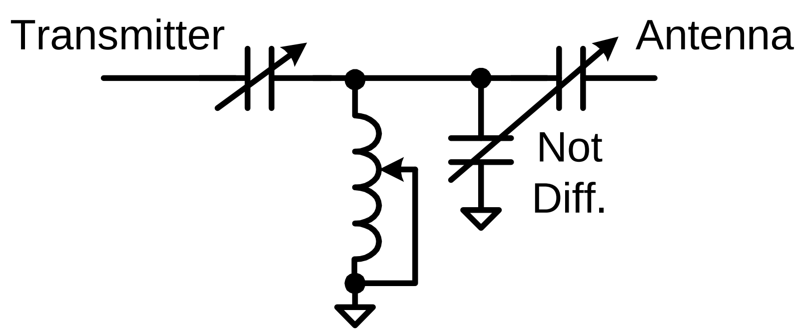
High Pass "Tee" Network 7 MHz
"C-Fixed L-C"

Other Network Topologies

- Lew McCoy W1ICP, Ultimate Transmatch (1970)



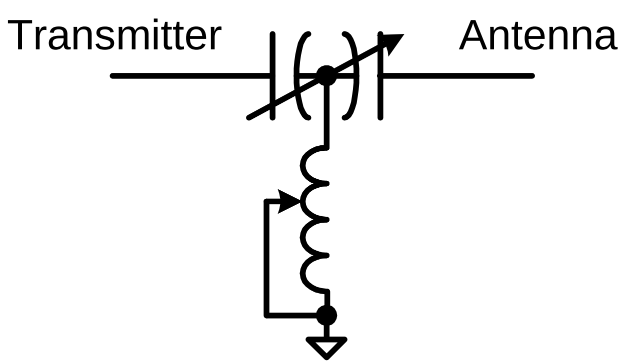
- Doug DeMaw W1FB, SPC Transmatch (1980)



Both had minimal to moderate harmonic suppression with a reduction in matching range vs the basic High Pass “Tee”.

Other Network Topologies

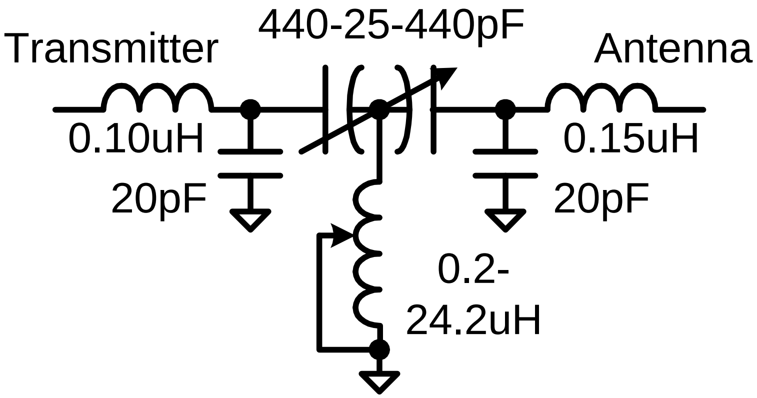
- Link Coupled (Johnson Matchbox)
  - Very good for higher R matches
  - Link coupling very efficient
- High Pass Differential Tee (MFJ & later Palstar)
  - Only 2 controls to adjust

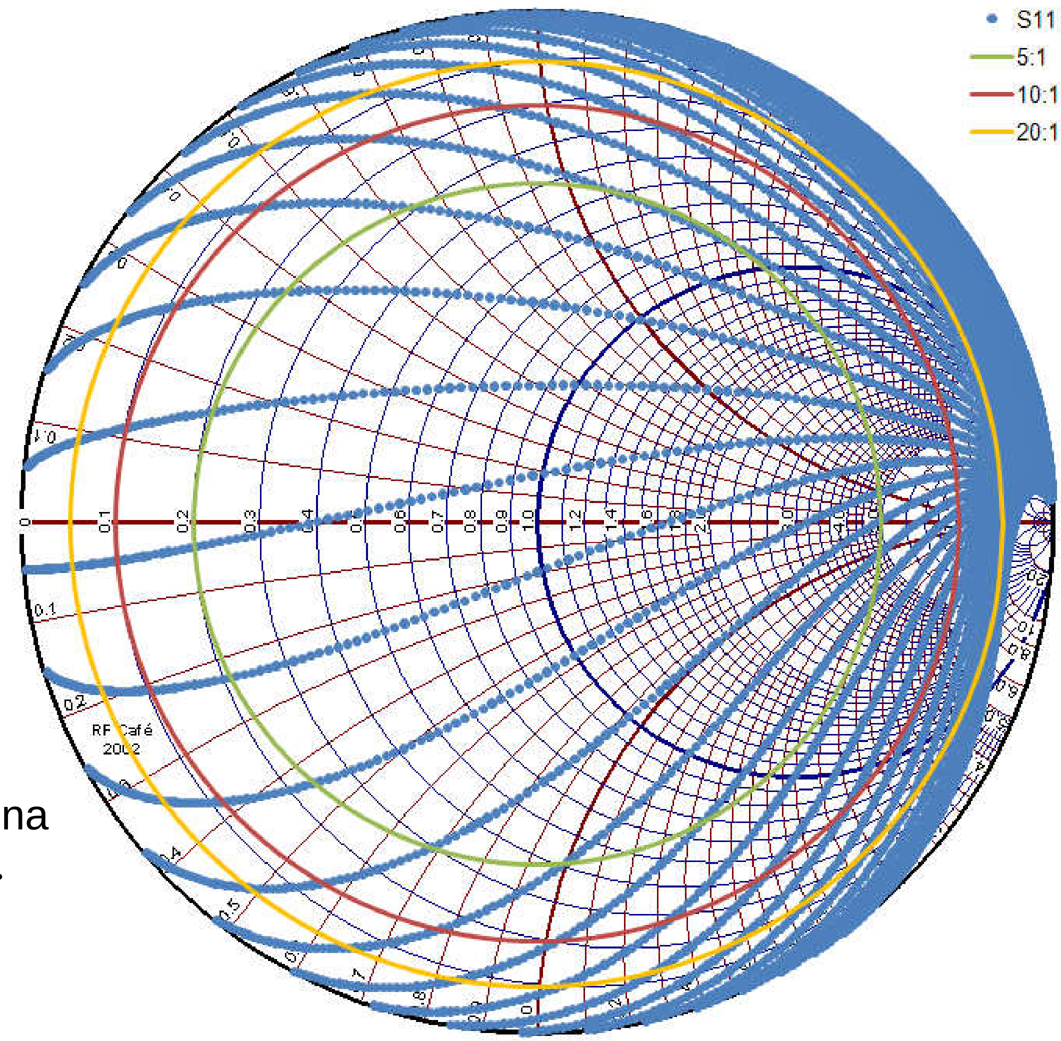


Slightly to significantly more loss than standard High Pass Tee & reduced matching range on higher frequencies but easier to adjust.

High Pass Differential "Tee" Network

- Based on measurements and component values of the Palstar AT-Auto with last version of inductor

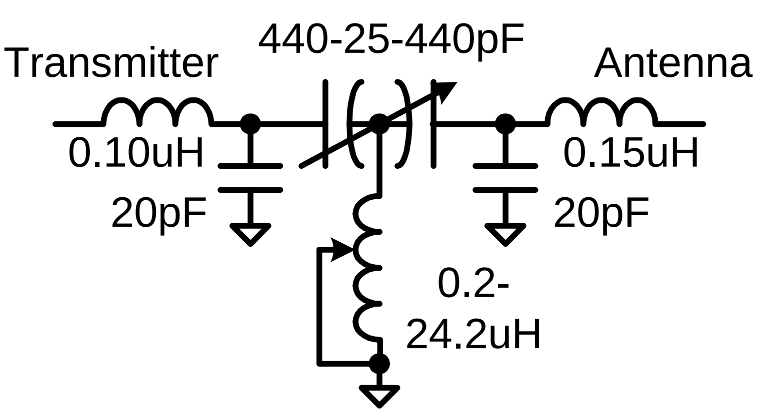


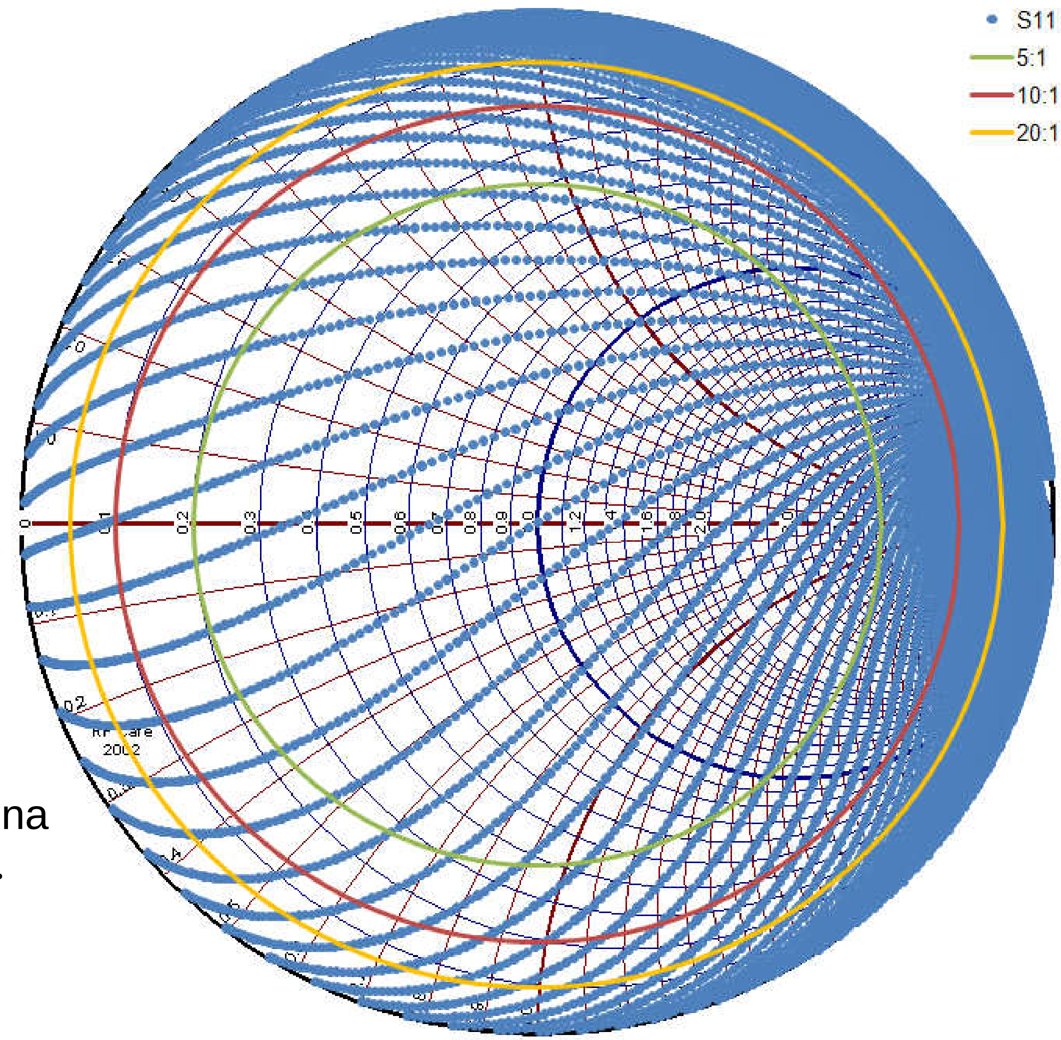


High Pass Differential "Tee" C-L-C 1.8 MHz

High Pass Differential "Tee" Network

– Palstar AT-Auto

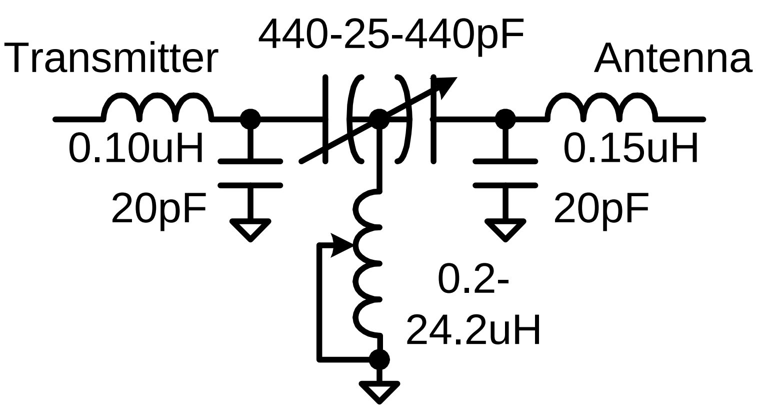


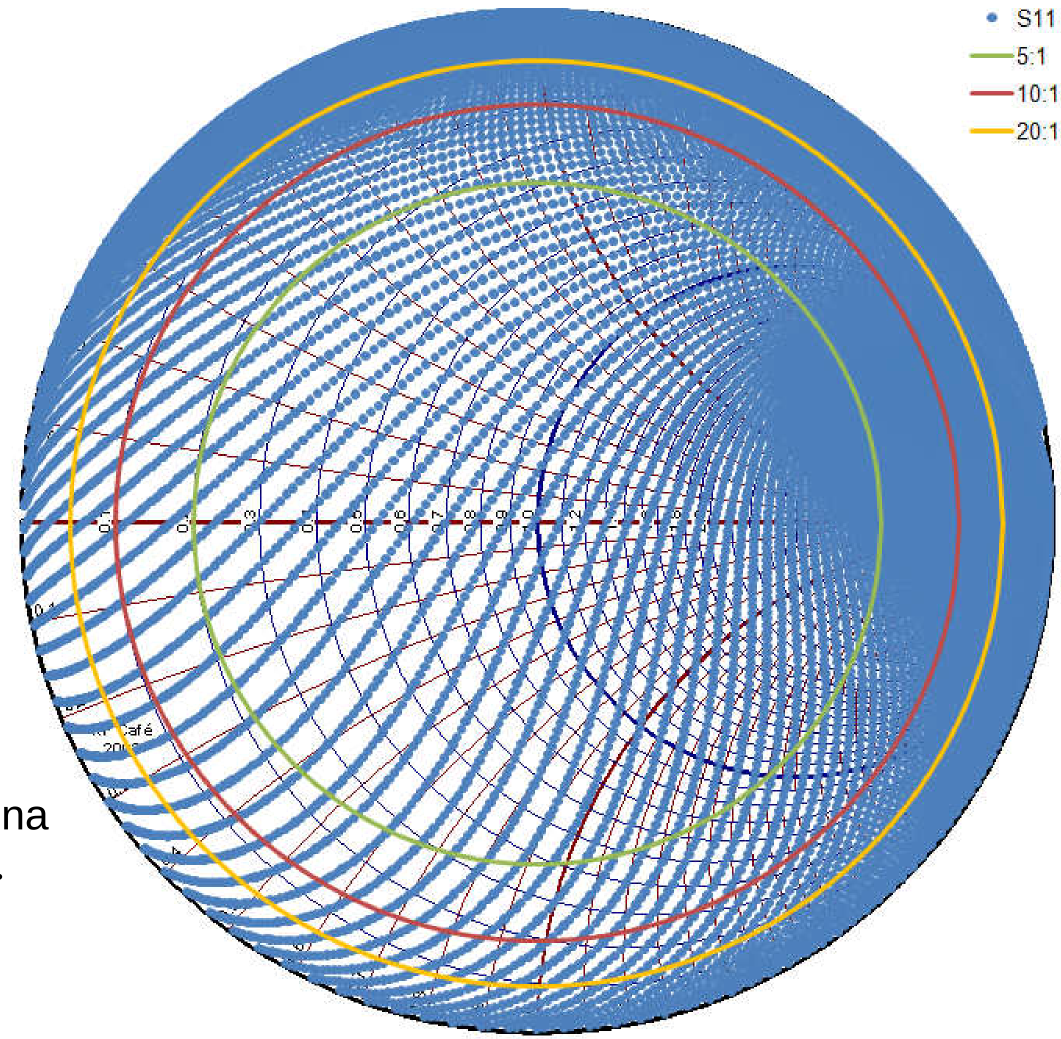


High Pass Differential "Tee" C-L-C 3.5 MHz

High Pass Differential "Tee" Network

– Palstar AT-Auto

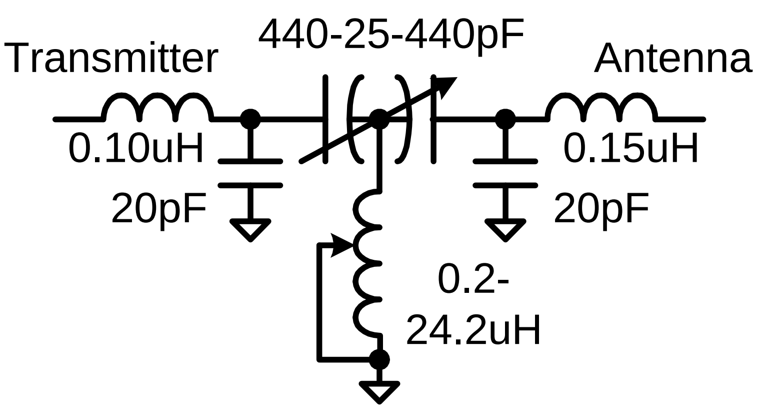


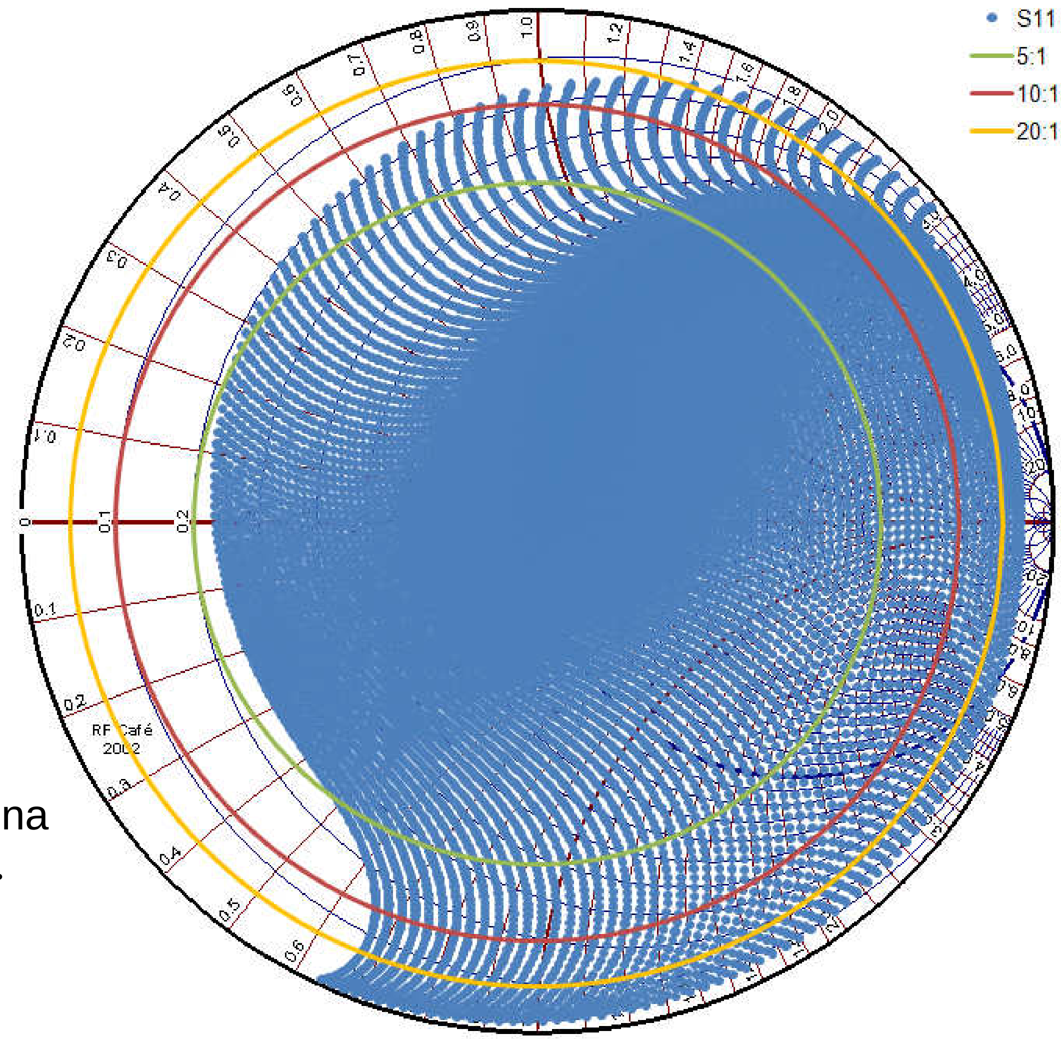


High Pass Differential "Tee" C-L-C 7 MHz

High Pass Differential
"Tee" Network

- Palstar AT-Auto
- No longer matches all 5:1 SWRs
- Add 4' of 50Ω .66VF coax for 90 deg. CW rotation if needed.

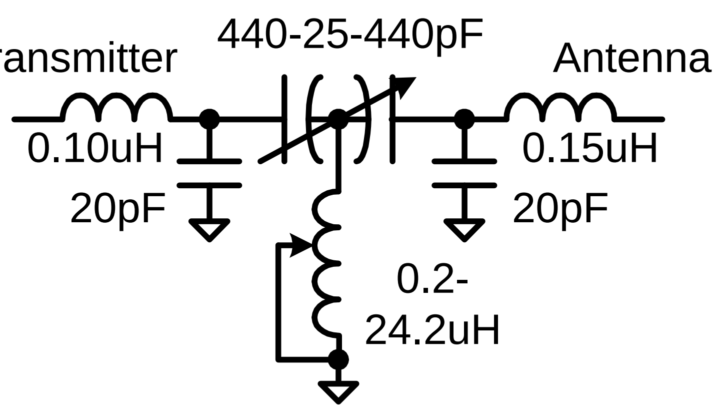


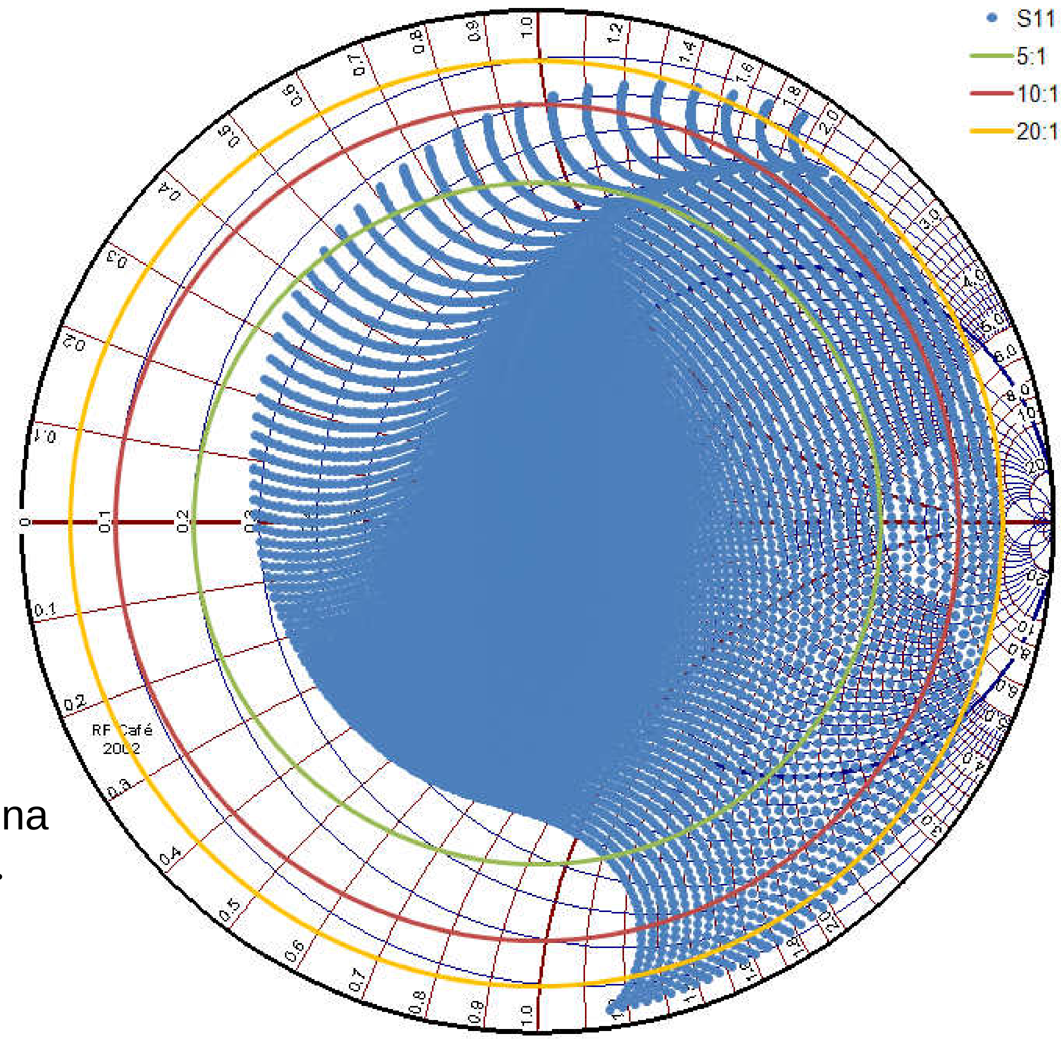


High Pass Differential "Tee" C-L-C 21 MHz

High Pass Differential "Tee" Network

- Palstar AT-Auto
- Matching range severely reduced

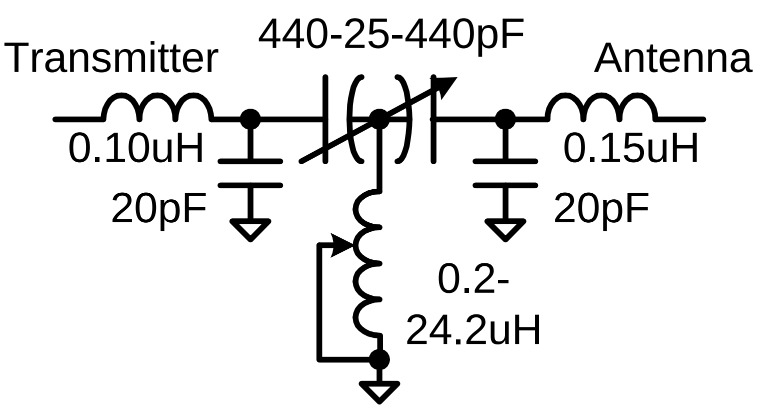


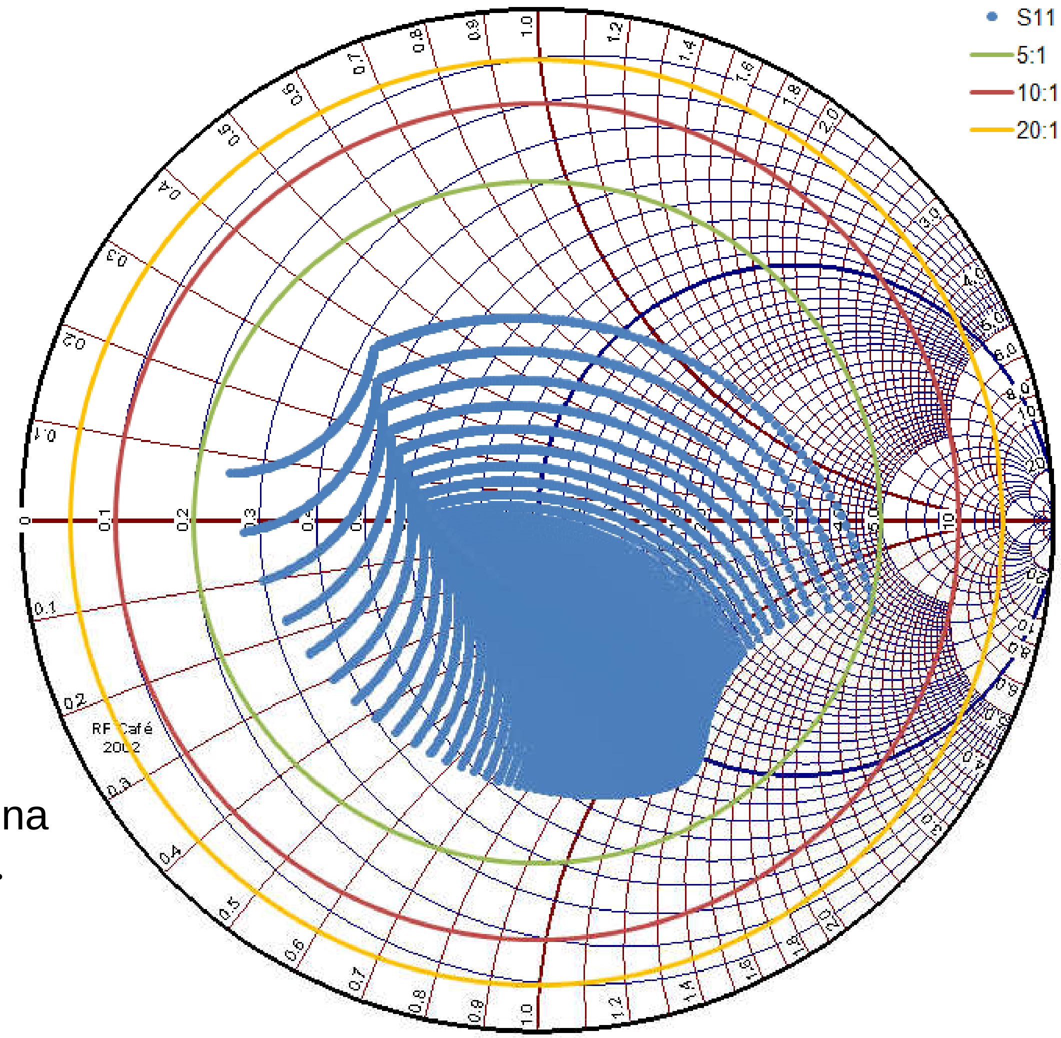


High Pass Differential "Tee" C-L-C 28 MHz

High Pass Differential “Tee” Network

- Palstar AT-Auto
- Matching range very limited





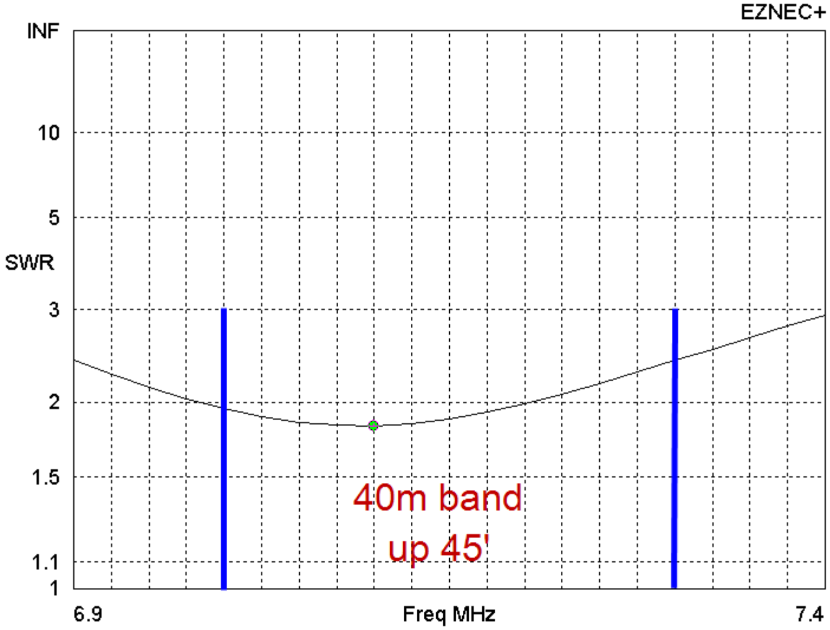
High Pass Differential "Tee" C-L-C 54 MHz

The End!

Other Topics

- Why might a full sized dipole need matching?
- Coupler topologies and stresses.
- Converting series to parallel impedances.
- Johnson Matchbox or other link couplers.
- Quarter wave section for variable impedances.
- Transmission line only tuner.
- Complex conjugate impedances.
- Graphical look at reflections.

Does a Full Sized Dipole Need Matching?



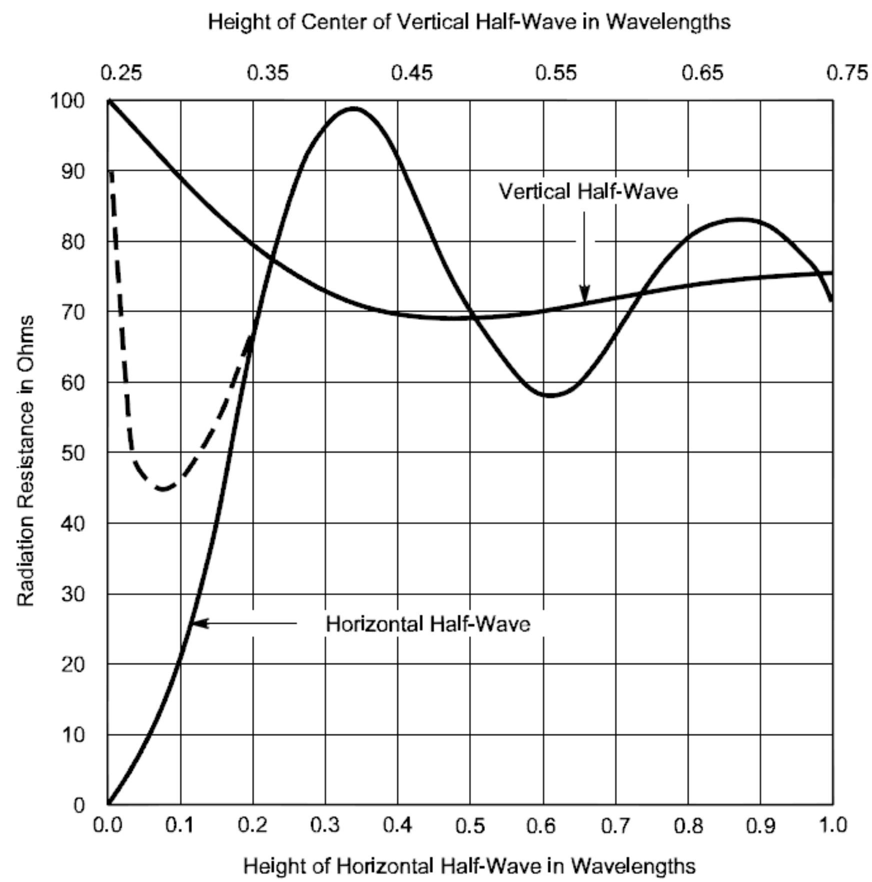


Fig 1—Variation in radiation resistance of vertical and horizontal half-wave antennas at various heights above flat ground. Solid lines are for perfectly conducting ground; the broken line is the radiation resistance of horizontal half-wave antennas at low height over real ground. Chapter 3, ARRL Antenna Book 21st edition

Dipole Matching

- 7.0MHz = 88.9 –j13.8   7.1MHz = 93.2 +j8.1
  7.2MHz = 97.7 +j29.9   7.3MHz = 102.2 +j51.5
- Match with 99 deg. of 75Ω transmission line at antenna. SWR < 1.4:1 across entire band.
- Match with 2.55uH across antenna and 408pF in series toward TX. SWR < 1.4:1 across entire band.
- All matches with Q significantly less than the Q of the dipole will have 1.4:1 band edge SWRs.

Z = 20 – j0 (SWR 2.5:1), 28MHz, 1500W

Type	Transmitter Side		Antenna Side
LP-"L" Cp-Ls	Cp = 139.2pF 387Vpk, 6.7A	Ls = 0.14uH 300Vpk, 8.7A	
HP-"L" Lp-Cs	Lp = 0.23uH 387Vpk, 6.7A	Cs = 232pF 300Vpk, 8.7A	
HP-"Tee" 250pF Cs1-Lp-Cs2	Cs1 = 250pF 176Vpk, 5.5A	Lp = 0.18uH 426Vpk, 9.4A	Cs2 = 200pF 348Vpk, 8.7A
HP-"Tee" 500pF Cs1-Lp-Cs2	Cs1 = 500pf 88Vpk, 5.5A	Lp = 0.20uH 397Vpk, 8.0A	Cs2 = 223pF 313Vpk, 8.7A
LP-"Pi" 200pF Cp1-Ls-Cp2	Cp1 = 188.1pF 387Vpk, 9.1A	Ls = 0.18uH 472Vpk, 10.6A	Cp = 200pF 245Vpk, 6.1A

Z = 5 – j200 (SWR 157:1), 1.8MHz, 1500W

Type	Transmitter Side		Antenna Side
LP-"L" Cp-Ls	Cp = 5302pF 387Vpk, 16.4A	Ls = 19.01uH 5265Vpk, 17.3A	
HP-"L" Cs-Lp	Cs = 140.3pF 4882Vpk, 5.5A	Lp = 13.45uH 4897Vpk, 22.8A	
HP-"Tee" 250pF Cs1-Lp-Cs2	Cs1 = 50.7pF 13511Vpk, 5.5A	Lp = 37.17uH 13517Vpk, 22.7A	Cs2 = 250pF 8634Vpk, 17.3A
HP-"Tee" 500pF Cs1-Lp-Cs2	Cs1 = 74.4pF 9205Vpk, 5.5A	Lp = 25.31uH 9213Vpk, 22.8A	Cs2 = 500pF 4323Vpk, 17.3A
HP-"Tee" 1000pF Cs1-Lp-Cs2	Cs1 = 97.2pF 7046Vpk, 5.5A	Lp = 19.38uH 7056Vpk, 22.8A	Cs2 = 1000pF 2163Vpk, 17.3A
LP-"Pi" 100pF Cp1-Ls-Cp2	Cp1 = 6621pF 387Vpk, 20.5A	Ls = 15.53uH 5270Vpk, 21.2A	Cp = 100pF 4897Vpk, 3.9A
LP-"Pi" 1000pF Cp1-Ls-Cp2	Cp1 = 18103pF 387Vpk, 56.1A	Ls = 5.85uH 5270Vpk, 56.3A	Cp = 1000pF 4884Vpk, 39.1A

Z = 2000 – j0 (SWR 40:1), 7.0MHz, 1500W

Type	Transmitter Side		Antenna Side
LP-"L" Ls-Cp	Ls = 7.10uH 2148Vpk, 5.5A	Cp = 71.0pF 2449Vpk, 5.4A	
HP-"L" Cs-Lp	Cs = 72.8pF 2418Vpk, 5.5A	Lp = 7.28uH 2449Vpk, 5.4A	
HP-"Tee" 250pF Cs1-Lp-Cs2	Cs1 = 72.7pF 2421Vpk, 5.5A	Lp = 7.23uH 2452Vpk, 5.4A	Cs2 = 250pF 111Vpk, 0.9A
HP-"Tee" 500pF Cs1-Lp-Cs2	Cs1 = 72.8pF 2419Vpk, 5.5A	Lp = 7.25uH 2450Vpk, 5.4A	Cs2 = 500pF 56Vpk, 0.9A
LP-"Pi" 250pF Cp1-Ls-Cp2	Cp1 = 250pF 387Vpk, 3.0A	Ls = 6.74uH 2610Vpk, 6.2A	Cp = 81pF 2449Vpk, 6.2A
LP-"L" Ls-Cp	Ls = 7.10uH 2148Vpk, 5.5A	Cp = 71.0pF 2449Vpk, 5.4A	

Series/Parallel Conversion

$$Rp = \frac{Rs^2 + Xs^2}{Rs} \qquad Xp = \frac{Rs^2 + Xs^2}{Xs}$$

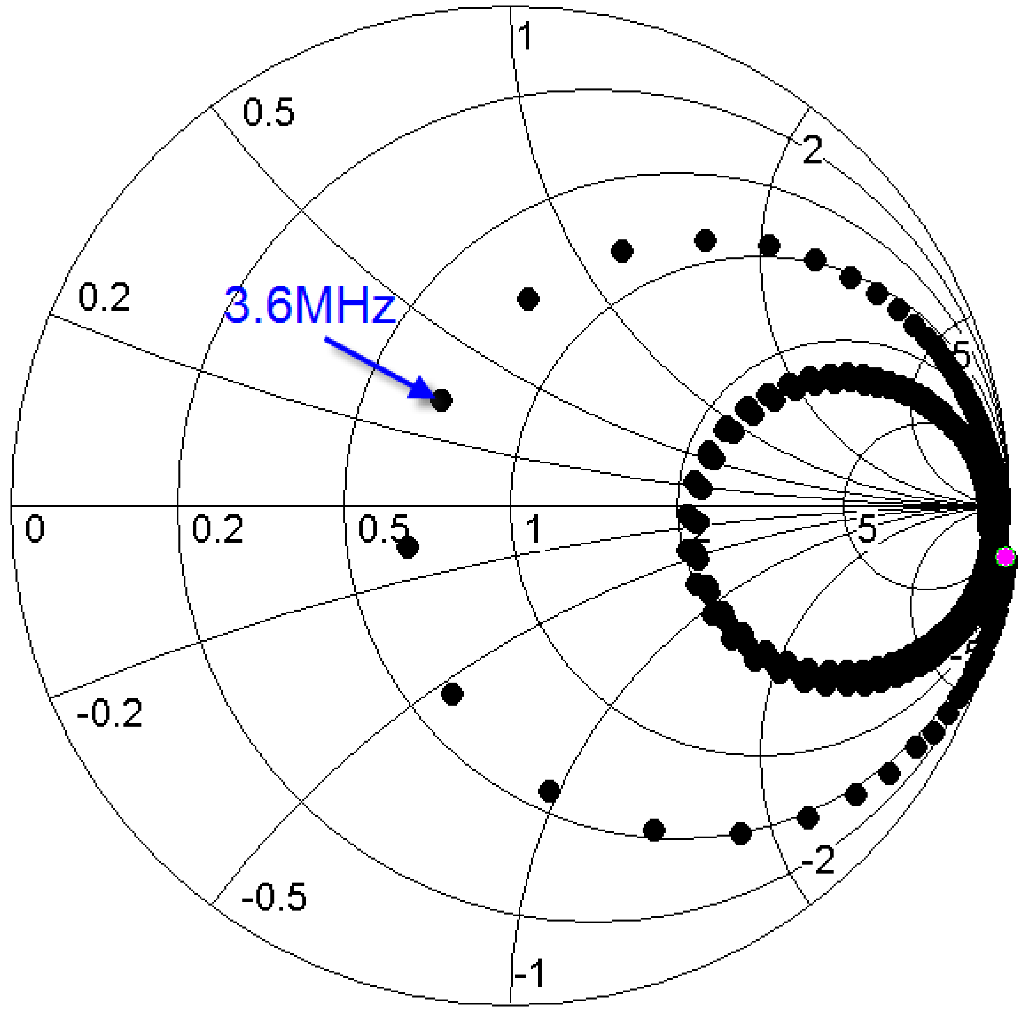
$$Rs = \frac{Rp \times Xp^2}{Rp^2 + Xp^2} \qquad Xs = \frac{Rp^2 \times Xp}{Rp^2 + Xp^2}$$

Note: If impedance was capacitive in series form then it is still capacitive in parallel form. Same is true for inductive impedances. Sign of Xp and Xs is the same.

80m full size dipole

- #12 wire up 40'
- No feedline
- Pink dot = 1.8MHz

What can be expected when used at all HF frequencies?

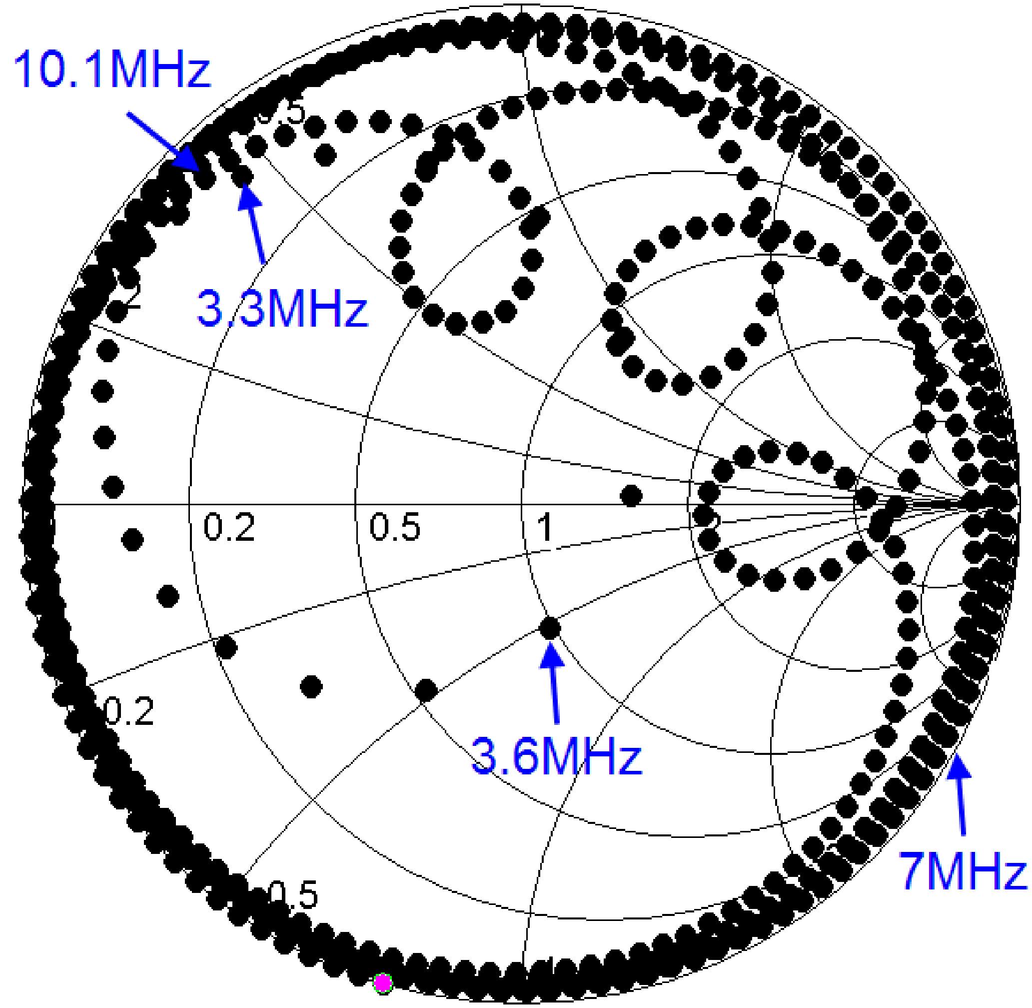


80m full size dipole

– 50’ of .66VF 50Ω lossless coax

Very wide range of impedances!

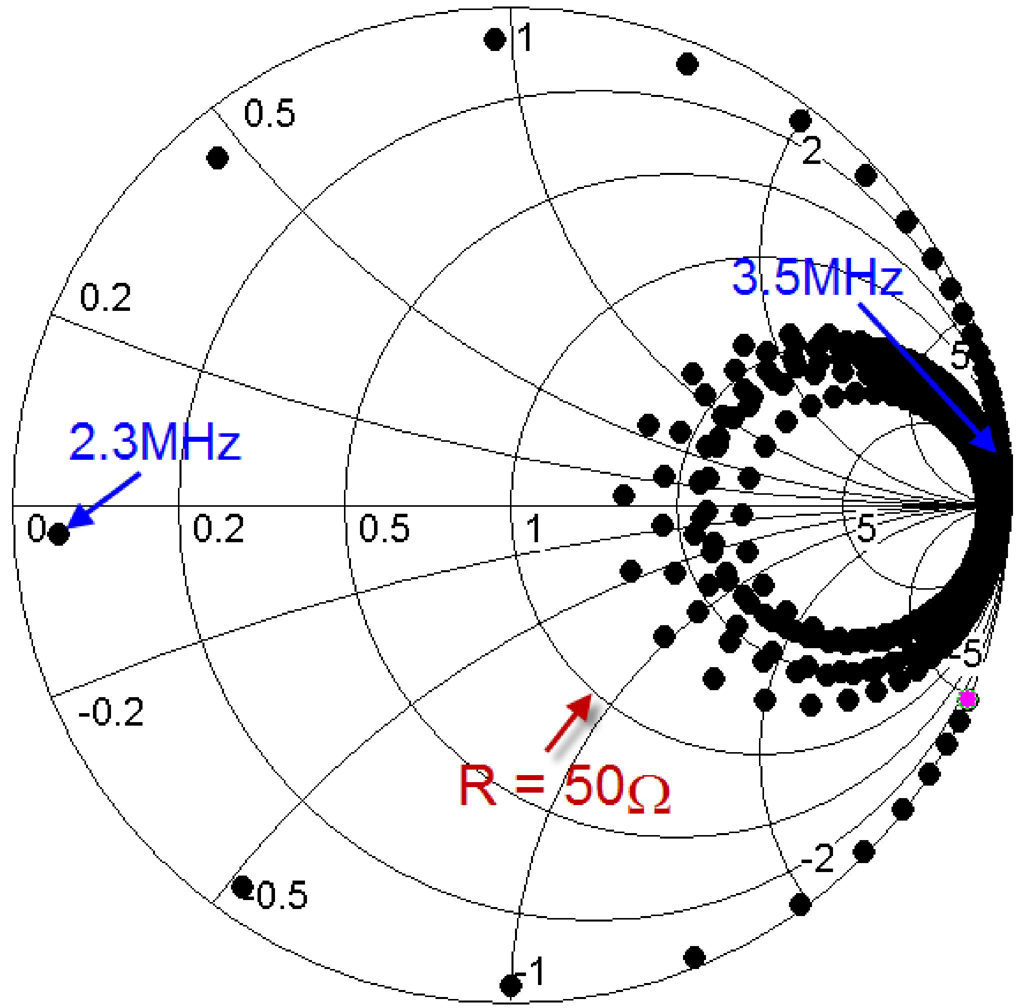
Even if loss in real coax is ignored this is a tough matching problem.

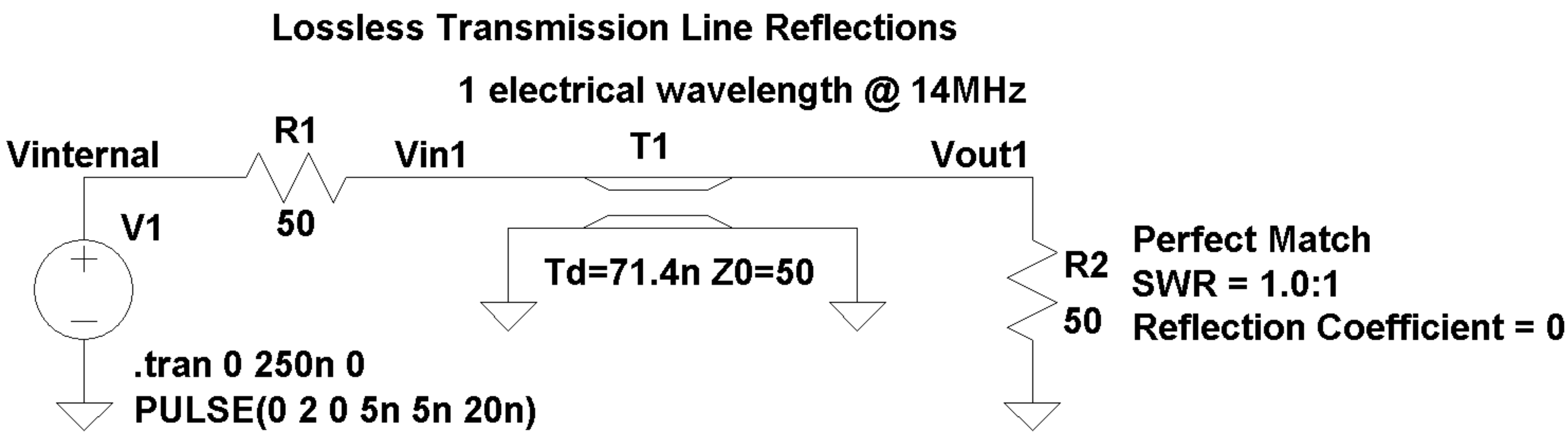


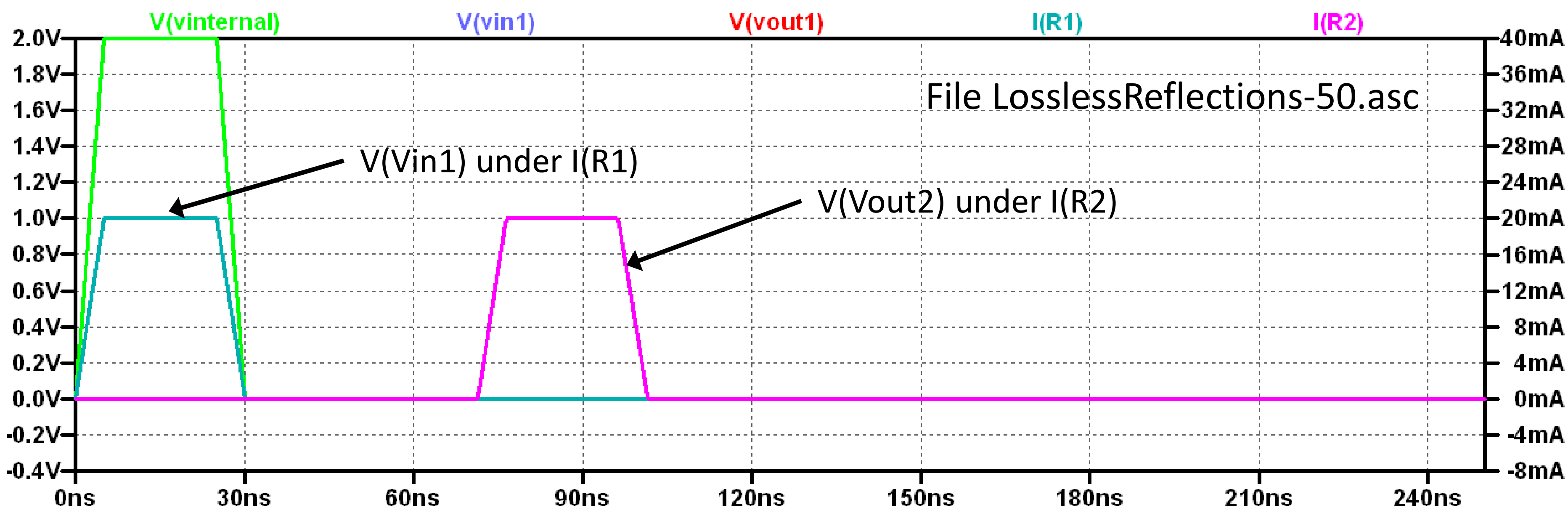
80m full size dipole
- 50' of 600Ω lossless open wire line

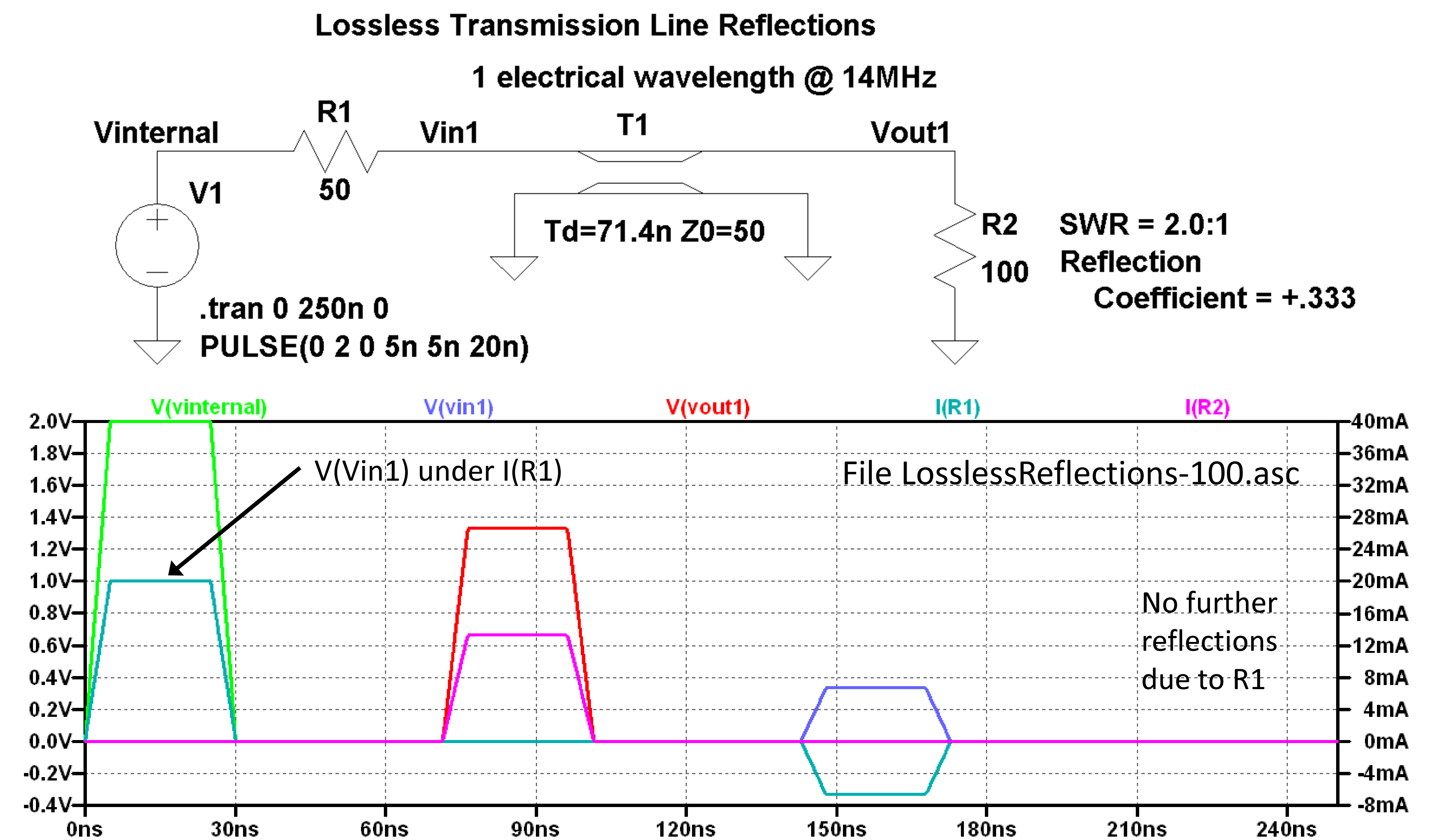
Notice how impedances are high at all freq. above 3.5MHz.

The Johnson Matchbox efficiently matches higher impedances!

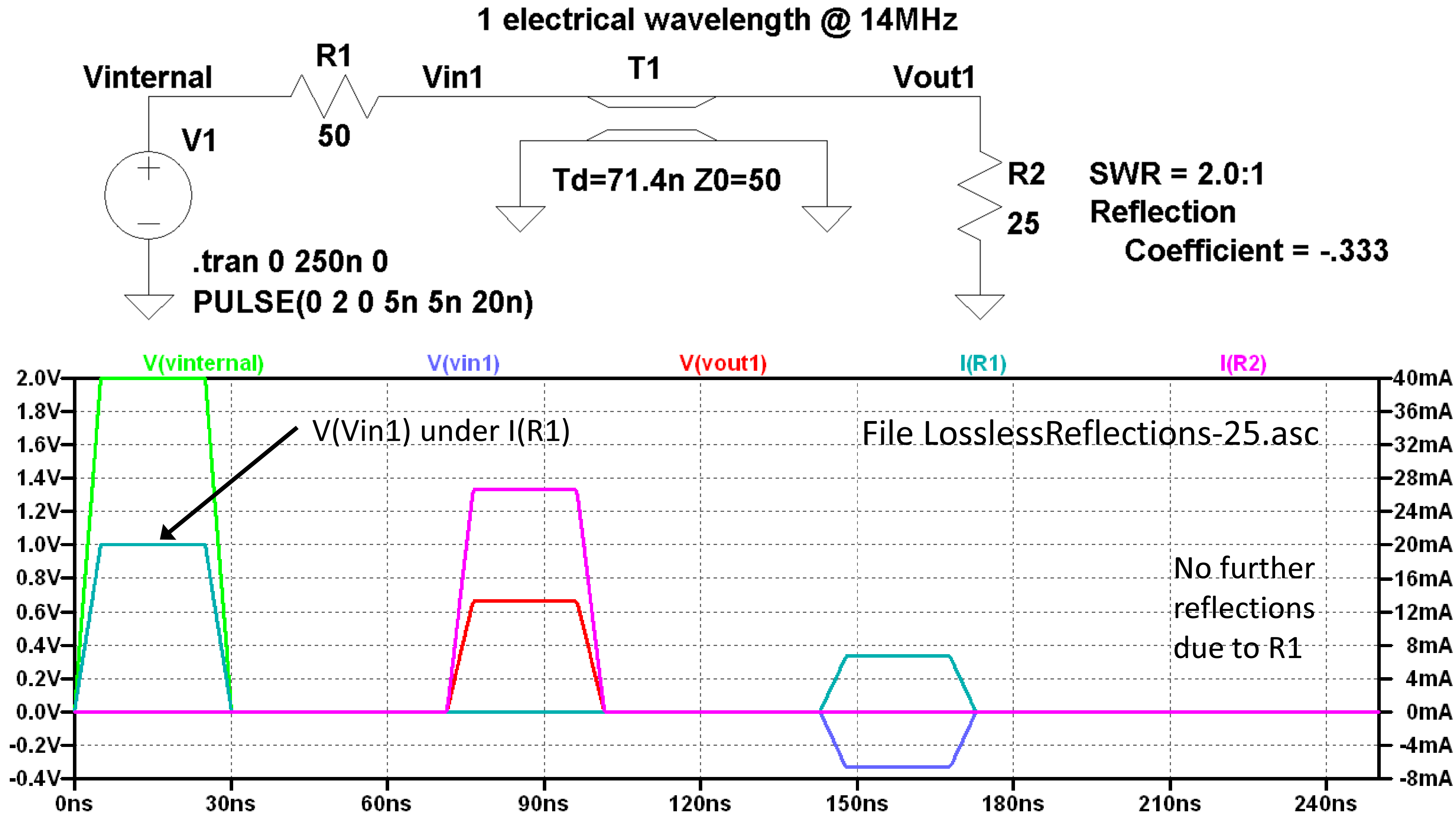



Lossless Transmission Line Reflections
1 electrical wavelength @ 14MHz
Vinternal
R1
Vin1
T1
Vout1
V1
50
Td=71.4n Z0=50
R2
50
Perfect Match
SWR = 1.0:1
Reflection Coefficient = 0
.tran 0 250n 0
PULSE(0 2 0 5n 5n 20n)


V(vinternal)
V(vin1)
V(vout1)
I(R1)
I(R2)
File LosslessReflections-50.asc
V(Vin1) under I(R1)
V(Vout2) under I(R2)
2.0V
1.8V
1.6V
1.4V
1.2V
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
-0.4V
40mA
36mA
32mA
28mA
24mA
20mA
16mA
12mA
8mA
4mA
0mA
-4mA
-8mA
0ns
30ns
60ns
90ns
120ns
150ns
180ns
210ns
240ns

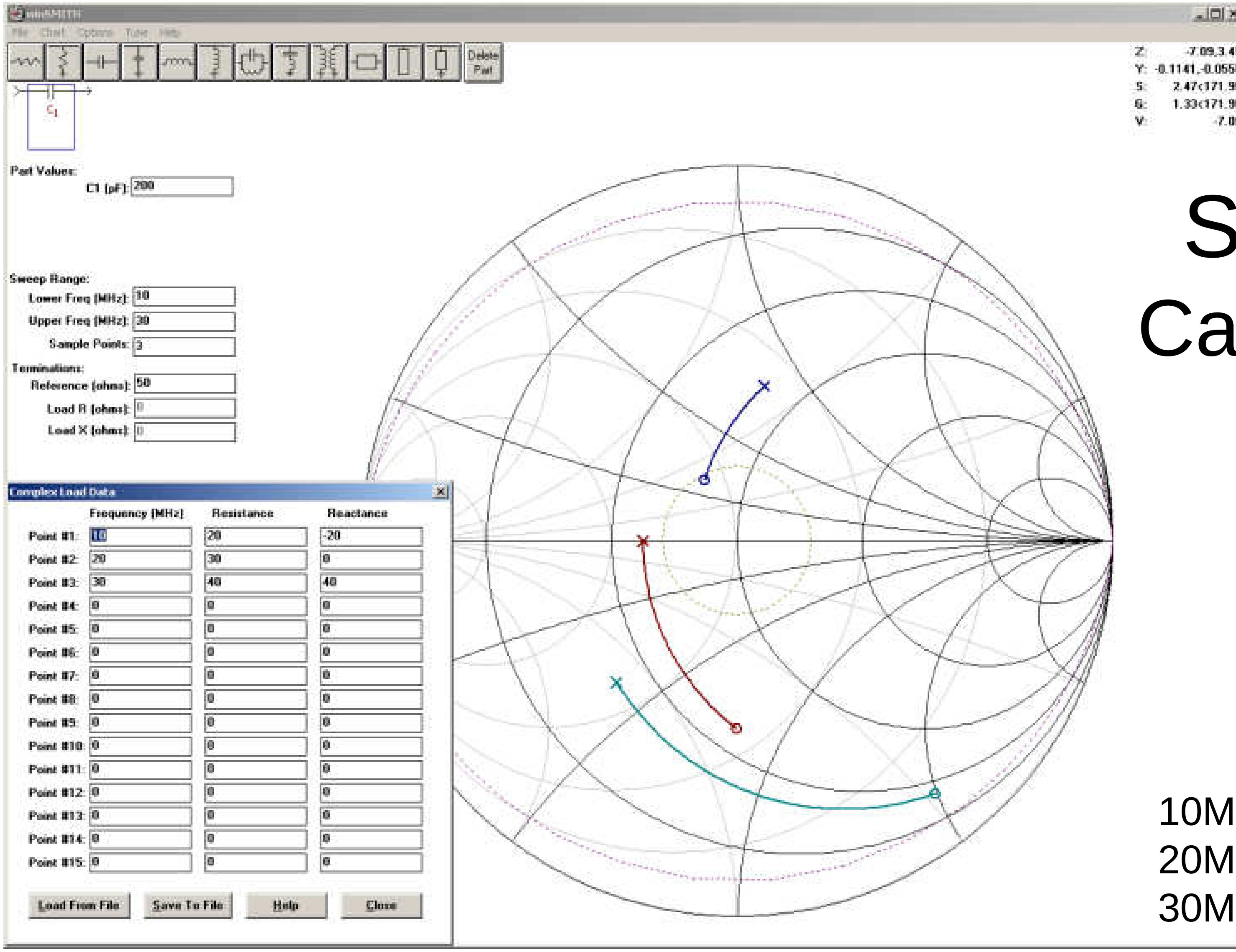

Lossless Transmission Line Reflections
1 electrical wavelength @ 14MHz
Vinternal
R1
Vin1
T1
Vout1
V1
50
Td=71.4n Z0=50
R2
100
SWR = 2.0:1
Reflection Coefficient = +.333
.tran 0 250n 0
PULSE(0 2 0 5n 5n 20n)
V(vinternal)
V(vin1)
V(vout1)
I(R1)
I(R2)
V(Vin1) under I(R1)
File LosslessReflections-100.asc
No further reflections due to R1
2.0V
1.8V
1.6V
1.4V
1.2V
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
-0.4V
40mA
36mA
32mA
28mA
24mA
20mA
16mA
12mA
8mA
4mA
0mA
-4mA
-8mA
0ns
30ns
60ns
90ns
120ns
150ns
180ns
210ns
240ns

Lossless Transmission Line Reflections



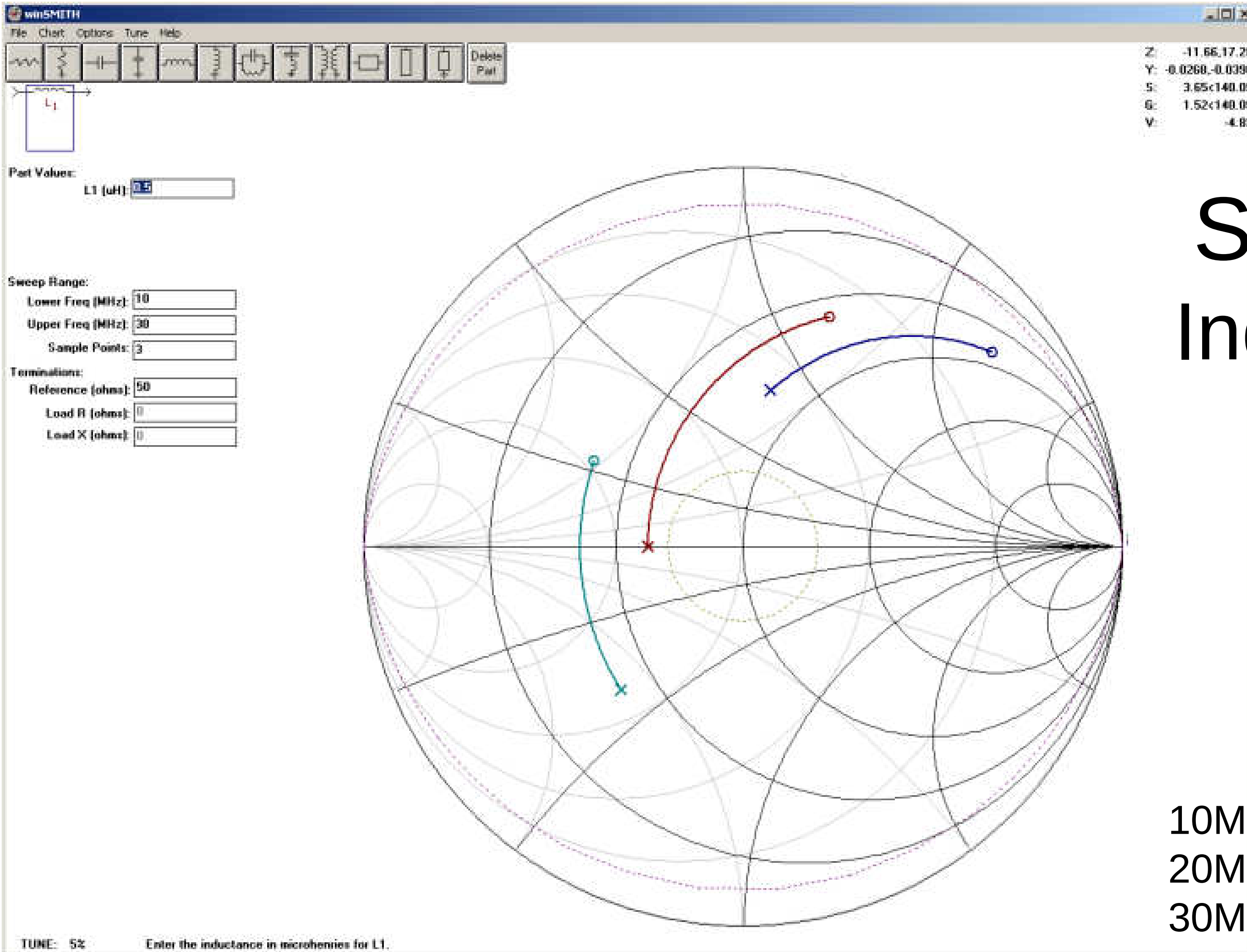
Smith Chart

- Smith Chart basics
  - Zo at center, constant SWR = circles
  - X axis is reflection coefficient (-1 to +1)
  - Top half is inductive, bottom half is capacitive
  - Need to think in terms of Z = R +/-jX & Y = G +/-jB
- The Smith Chart allows the user to see graphical solutions to matching problems which enhances the understanding of impedance matching
- Smith Chart could easily be an entire presentation



Series Capacitor

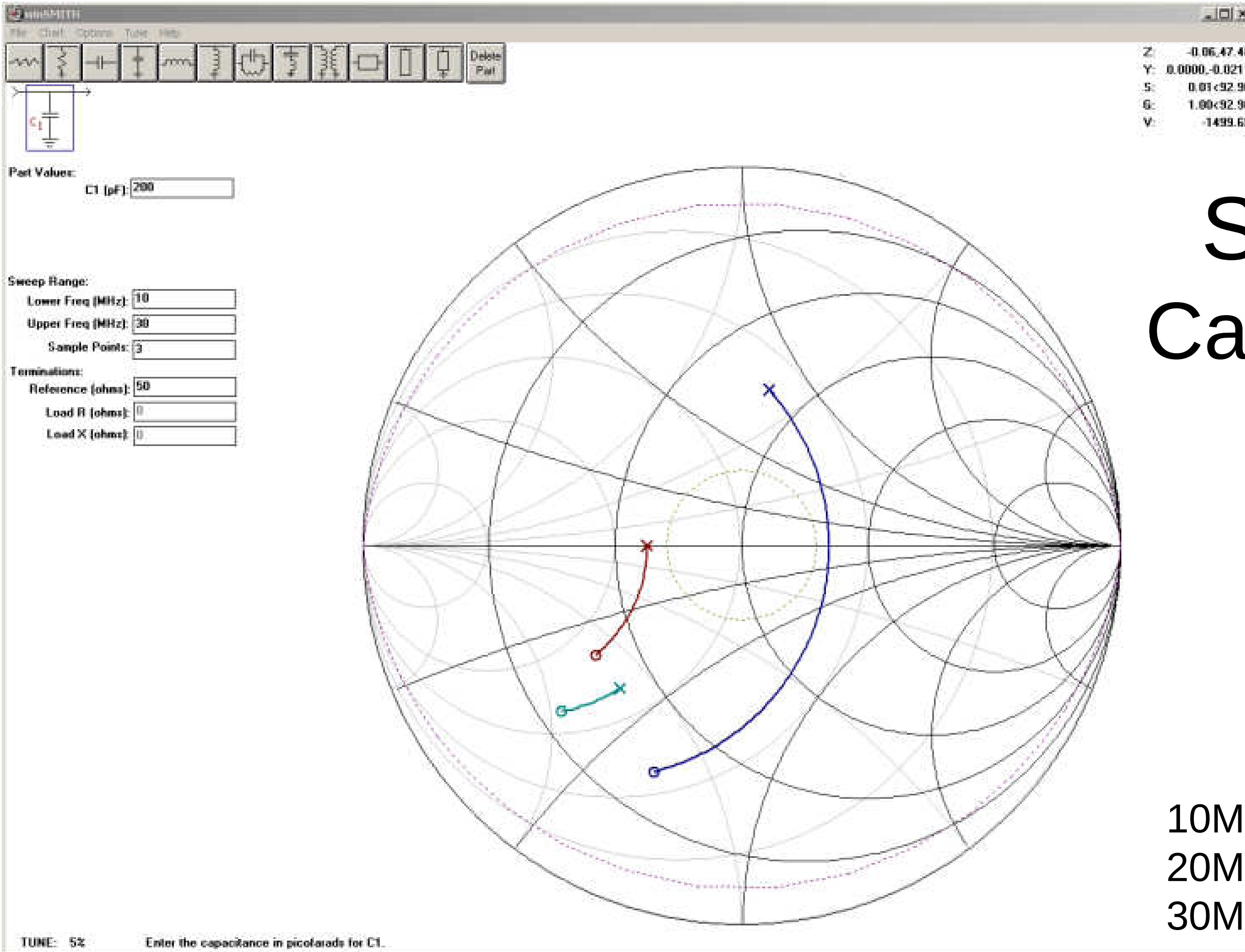
10MHz = Green
20MHz = Red
30MHz = Blue



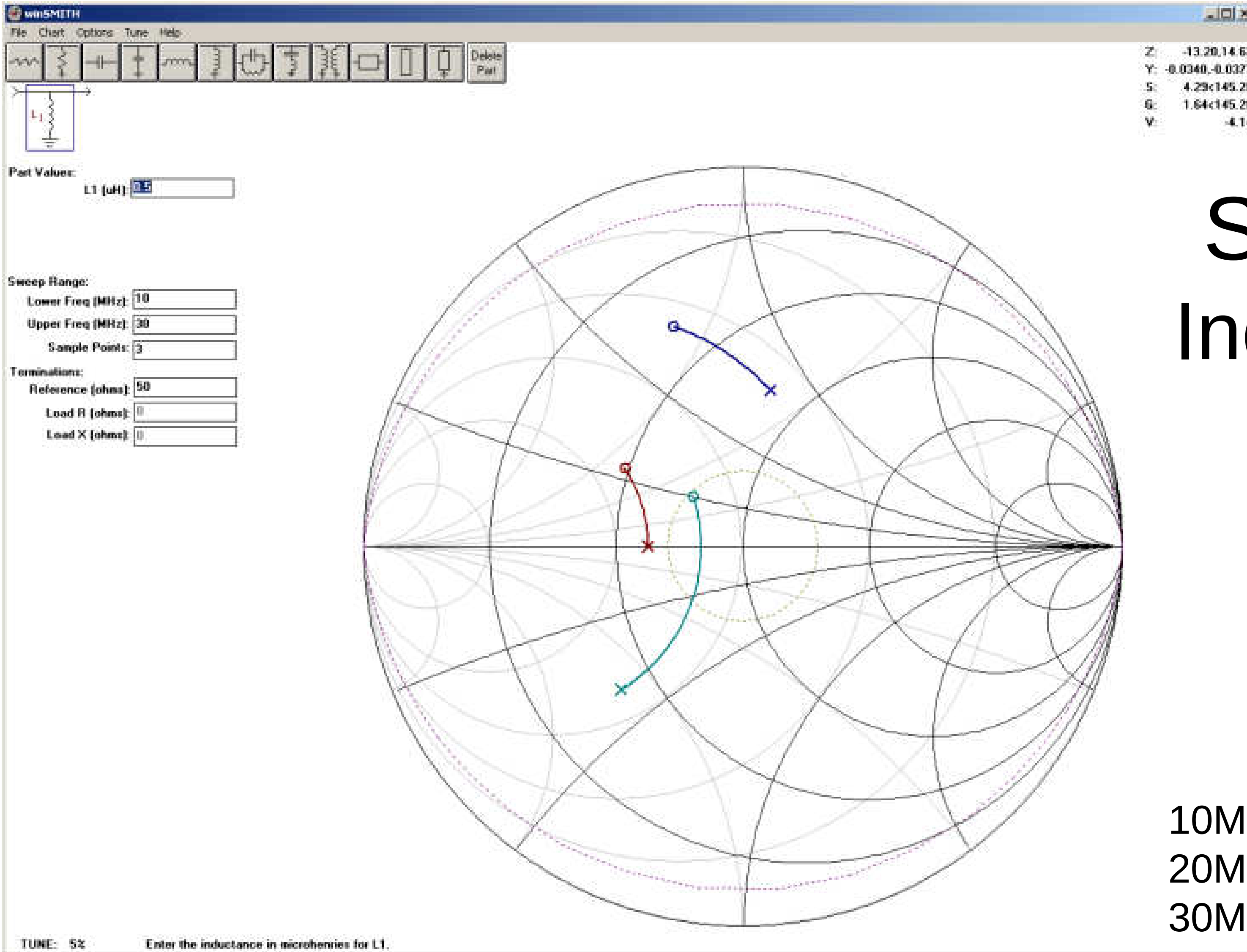
Series Inductor

10MHz = Green
20MHz = Red
30MHz = Blue

Shunt Capacitor



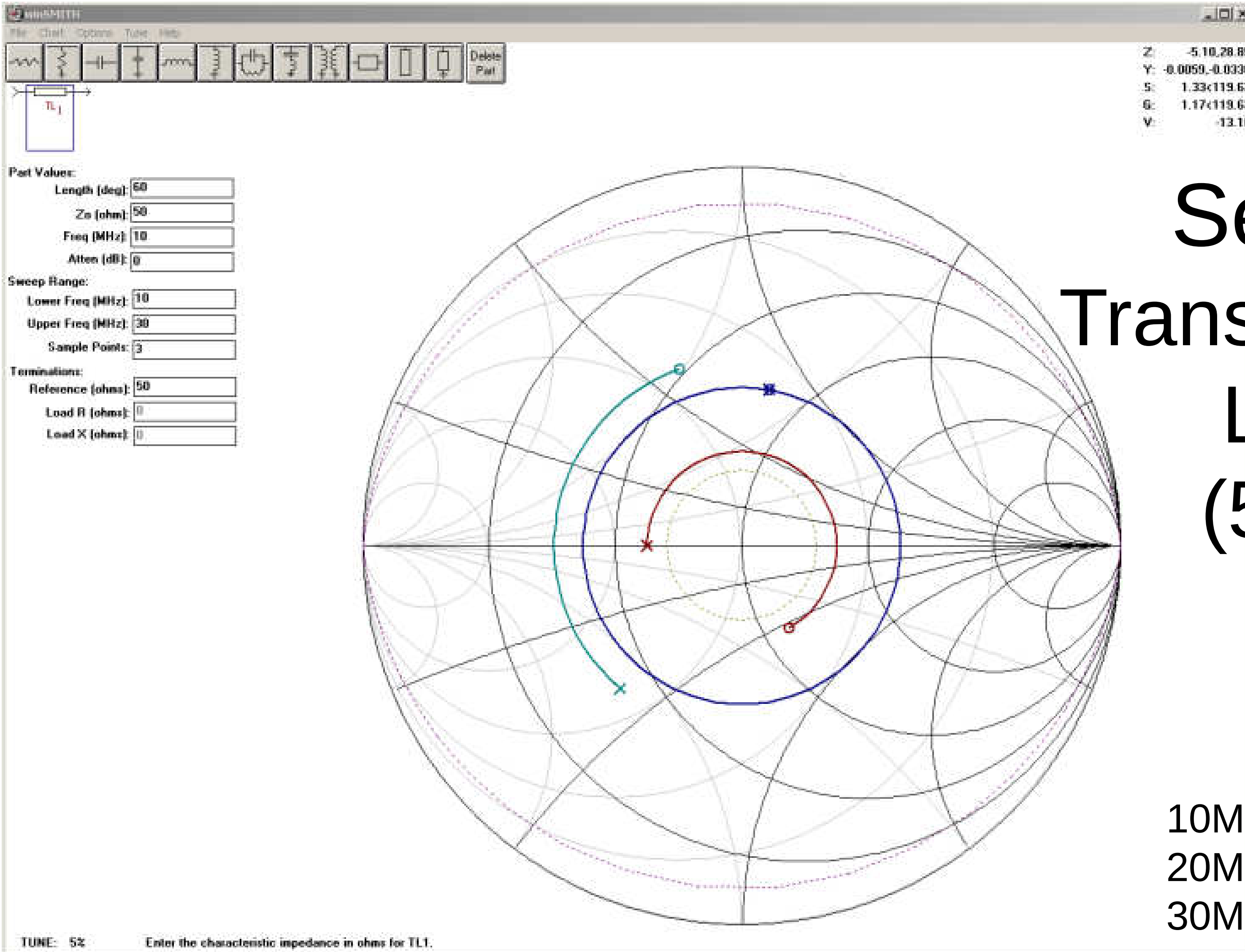
10MHz = Green
20MHz = Red
30MHz = Blue



Shunt Inductor

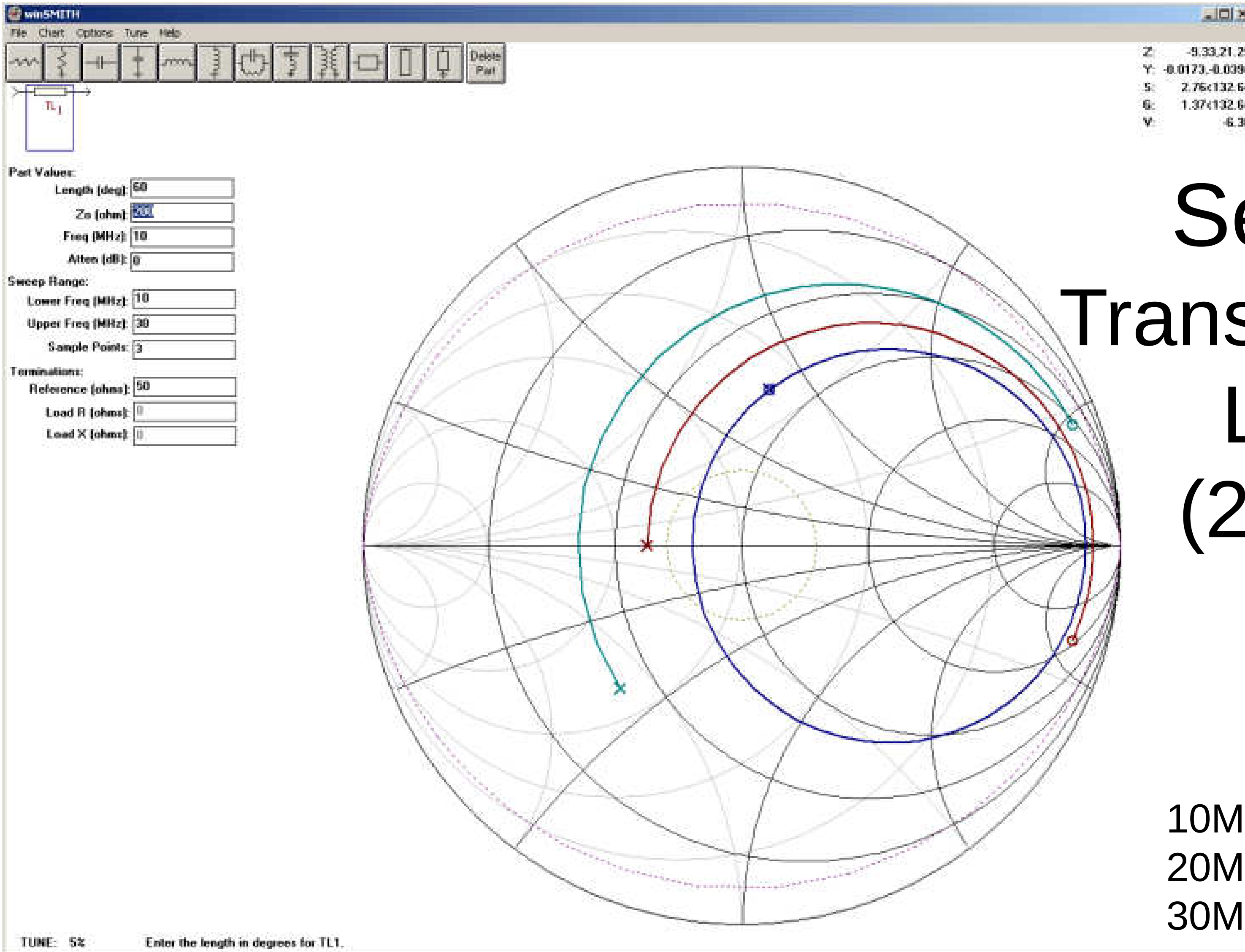
10MHz = Green
20MHz = Red
30MHz = Blue

Series Transmission Line (50Ω)



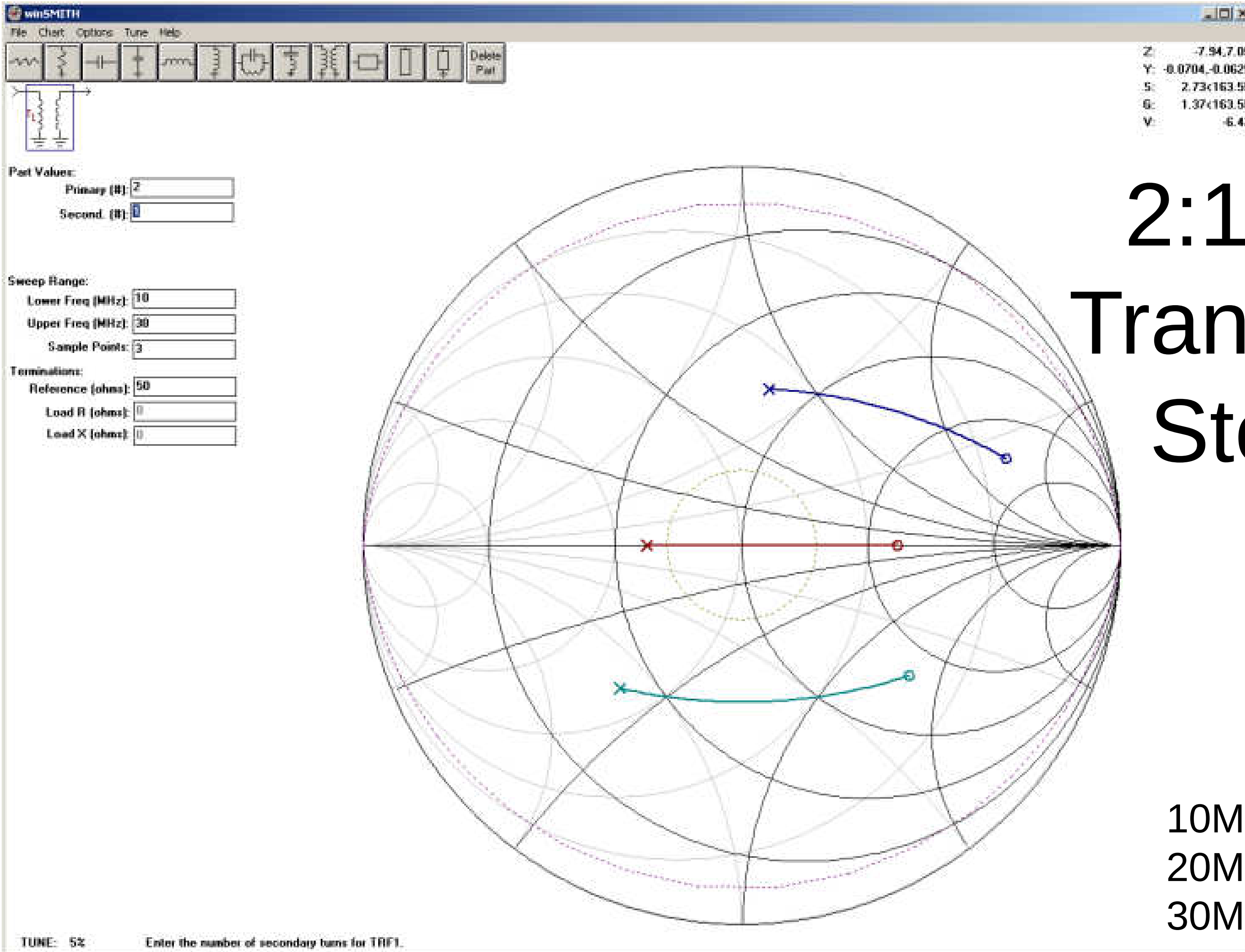
10MHz = Green
20MHz = Red
30MHz = Blue

Series Transmission Line (200Ω)

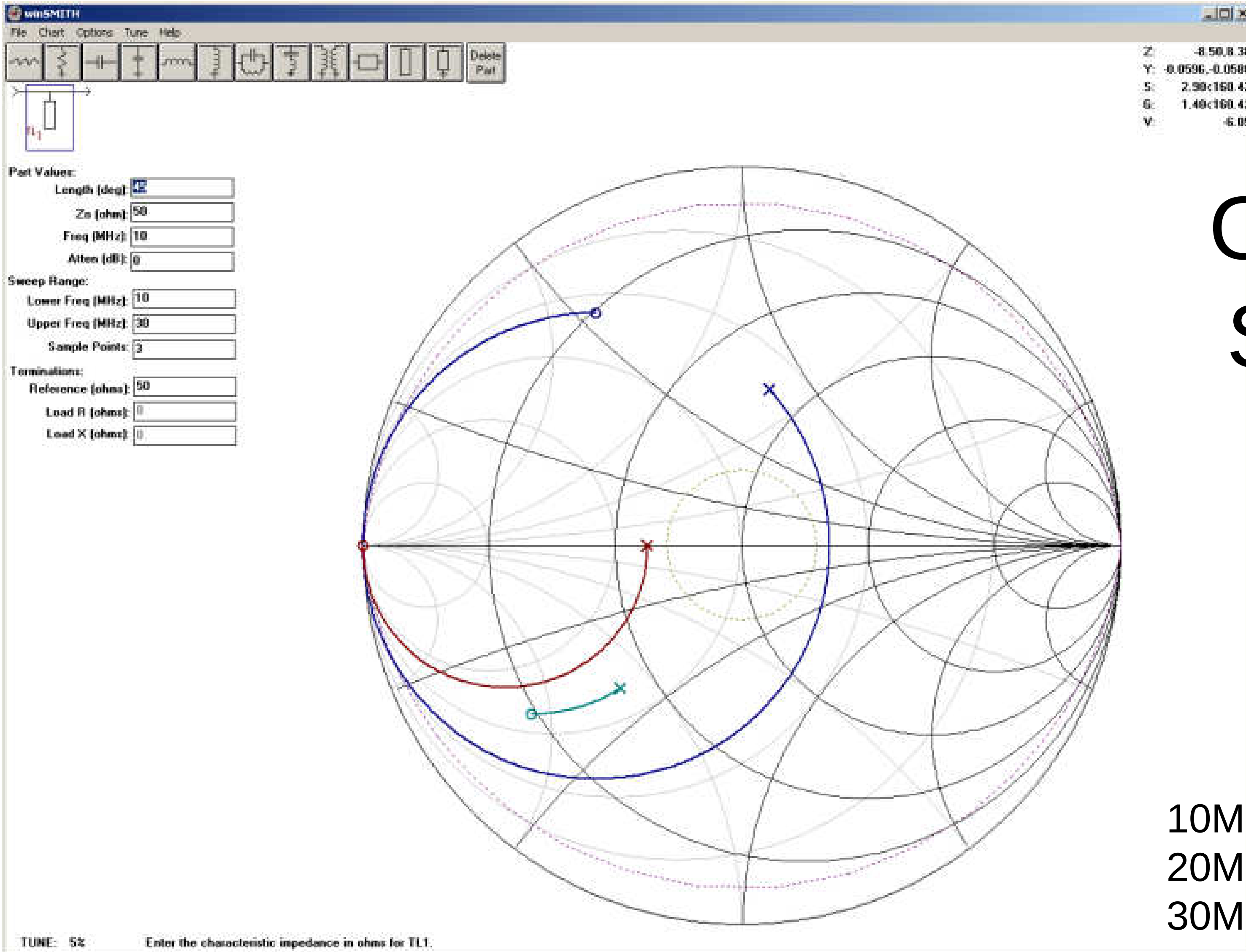


10MHz = Green
20MHz = Red
30MHz = Blue

2:1 Turns Transformer Step Up

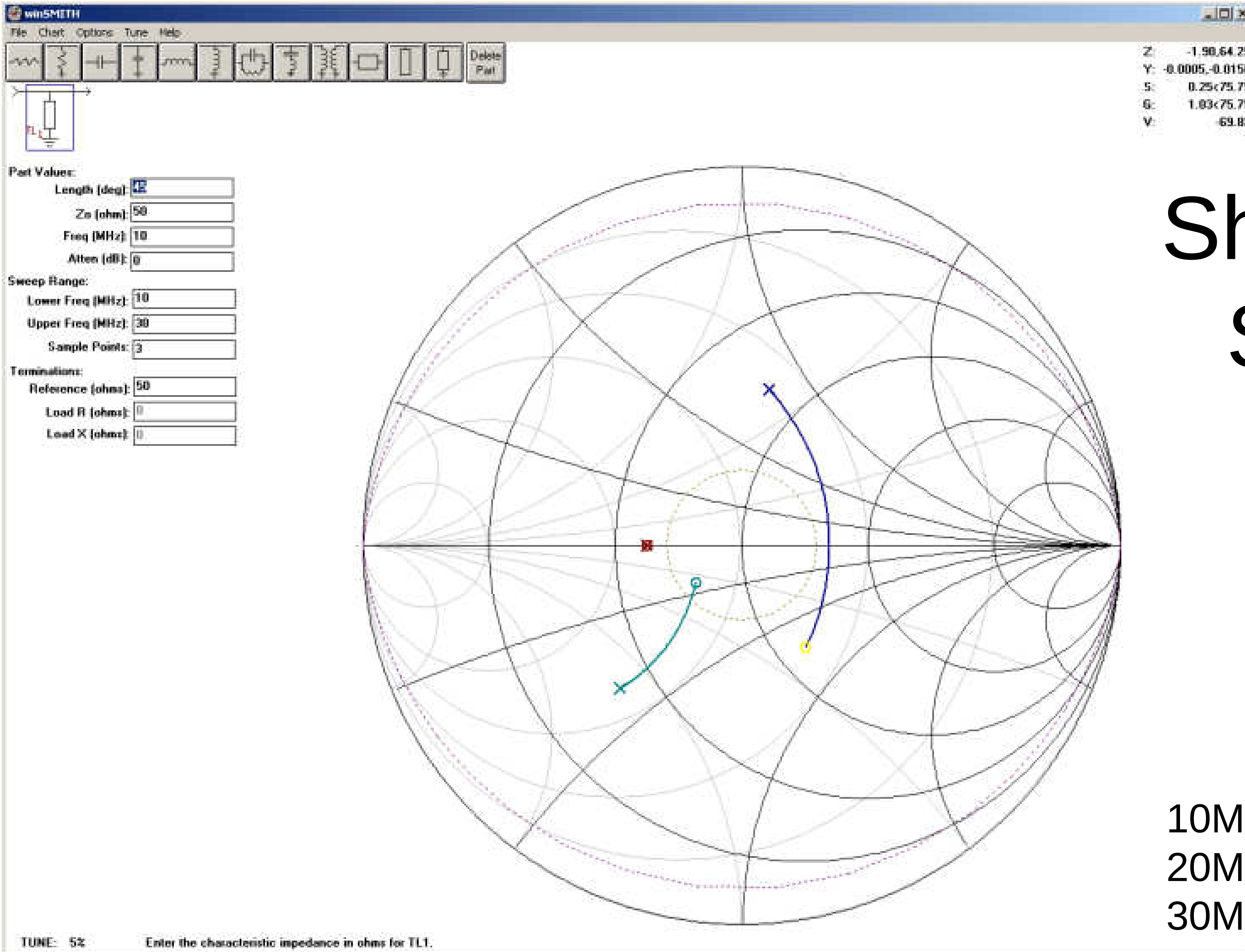


10MHz = Green
20MHz = Red
30MHz = Blue



Open Stub

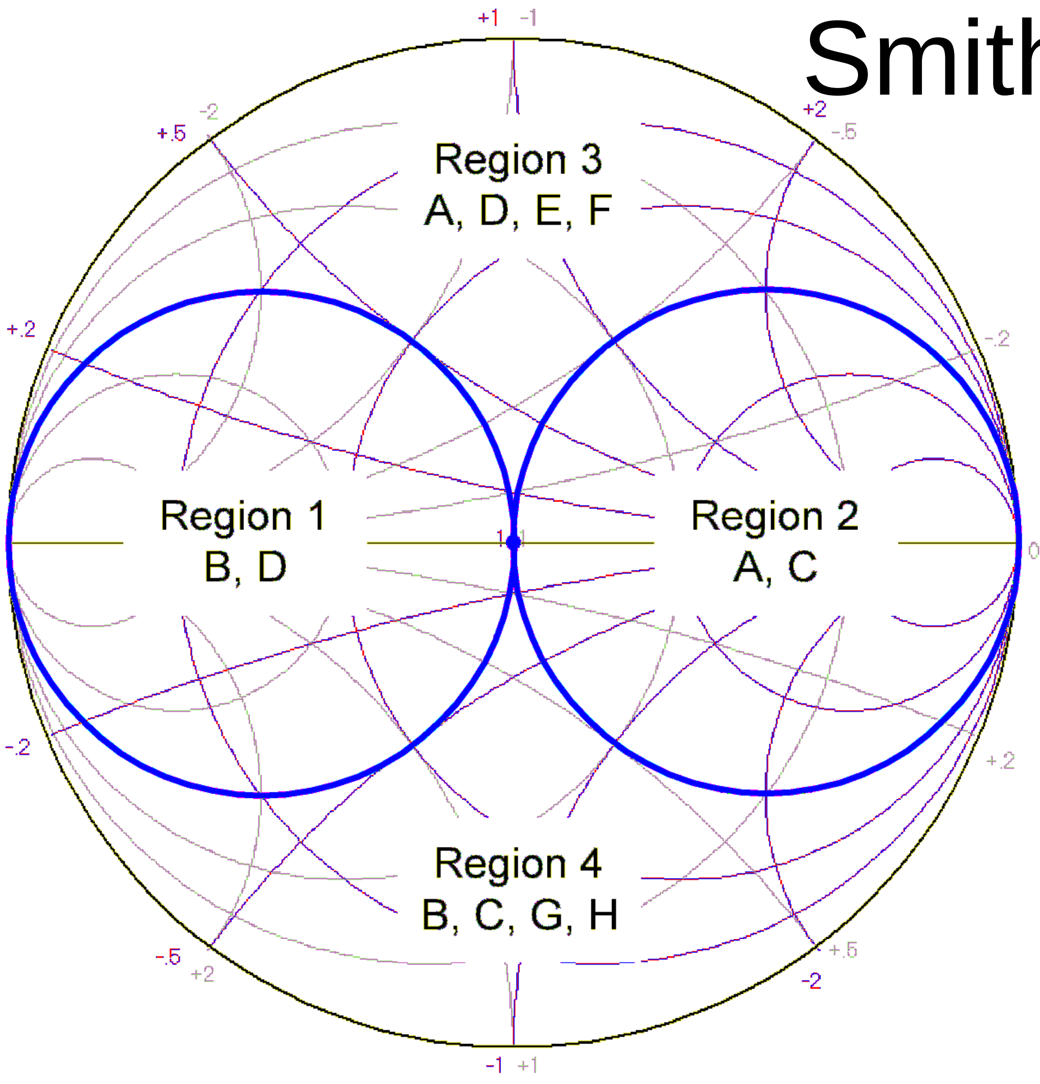
10MHz = Green
20MHz = Red
30MHz = Blue



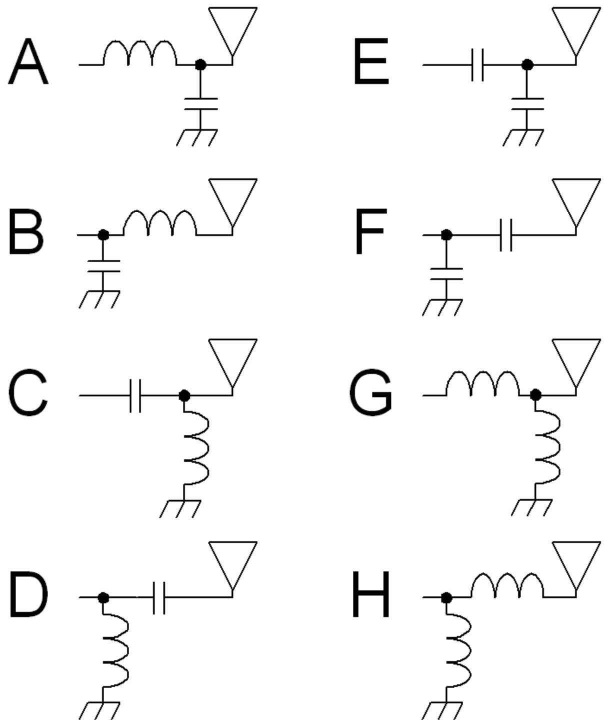
Shorted Stub

10MHz = Green
20MHz = Red
30MHz = Blue

Smith Chart Regions



L type circuits



Surge Impedance Again

- Zo = $\sqrt{L/C}$ per unit length, equivalent circuit no loss
- Zo = $\left(\frac{138}{\sqrt{\varepsilon}}\right) * \log_{10}\left(\frac{OD}{ID}\right)$ for round coax
- Why a particular impedance?
  – Maximum power 30Ω, minimum loss 77Ω, max. voltage breakdown 60Ω (1929 Bell Laboratories Study)
  – Maximum power per pound of copper 52Ω (F. Terman?)
  – Today 75Ω, 50Ω, 52Ω, 53.5Ω, 25Ω, 80Ω, 93Ω, etc.