2012-III: Transmission Lines and Antennas

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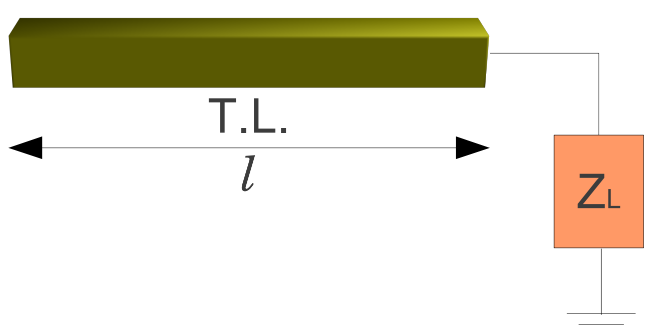
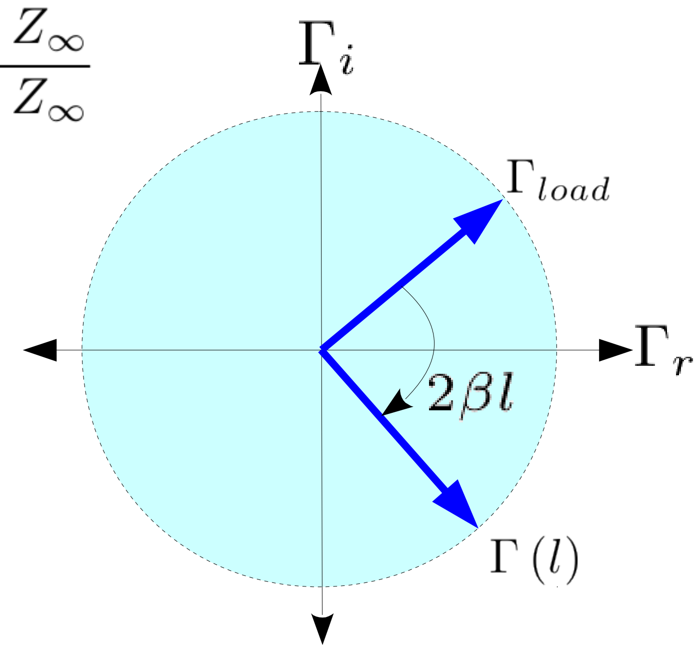
The Smith Chart - Justification

For lossless lines, as we move away from the load, reflection coefficient (ratio between backward and forward wave voltages) describes a CW circle in the complex plane.

$$\Gamma(l) = \Gamma_{load} e^{-2j\beta l}$$

$$\Gamma_{load} = \frac{Z_L - Z_\infty}{Z_L + Z_\infty}$$





Impedance Transformation

- A general transformation is obtained if everything is expressed in terms of the normalized impedance:

$$Z_L = R_L + jX_L$$

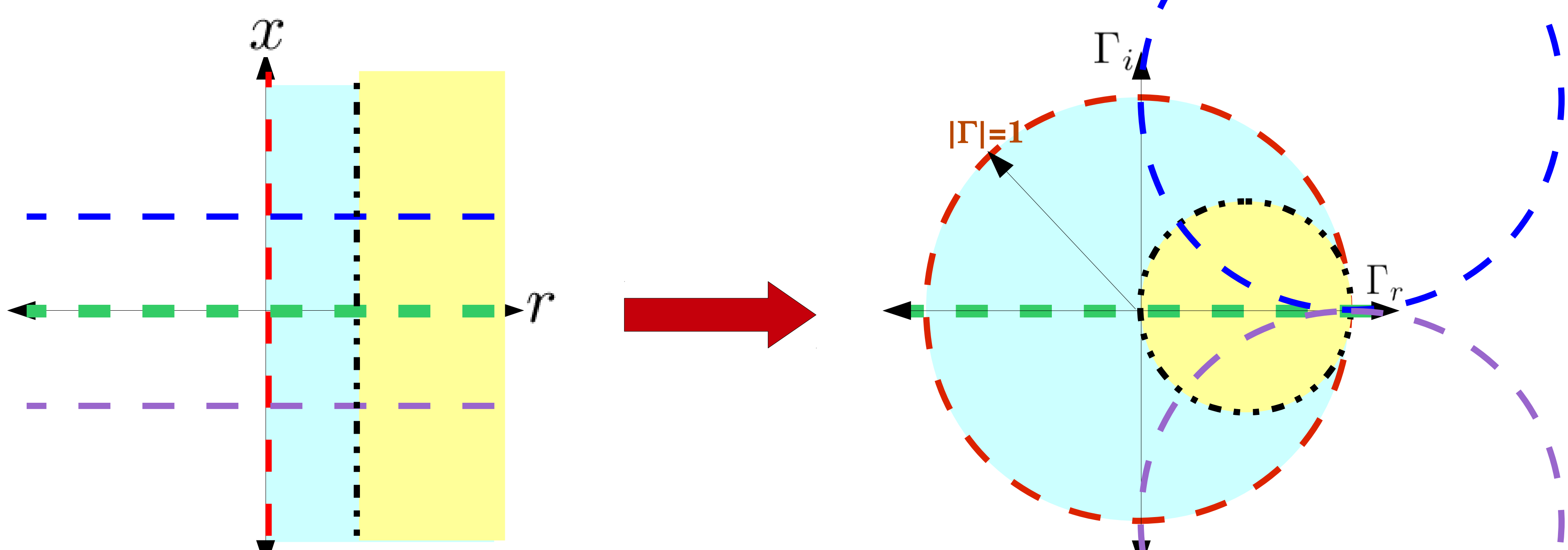
$$z_l = \frac{Z_L}{Z_\infty} = r + jx$$

$$r = \frac{R_L}{Z_\infty} \qquad x = \frac{X_L}{Z_\infty}$$

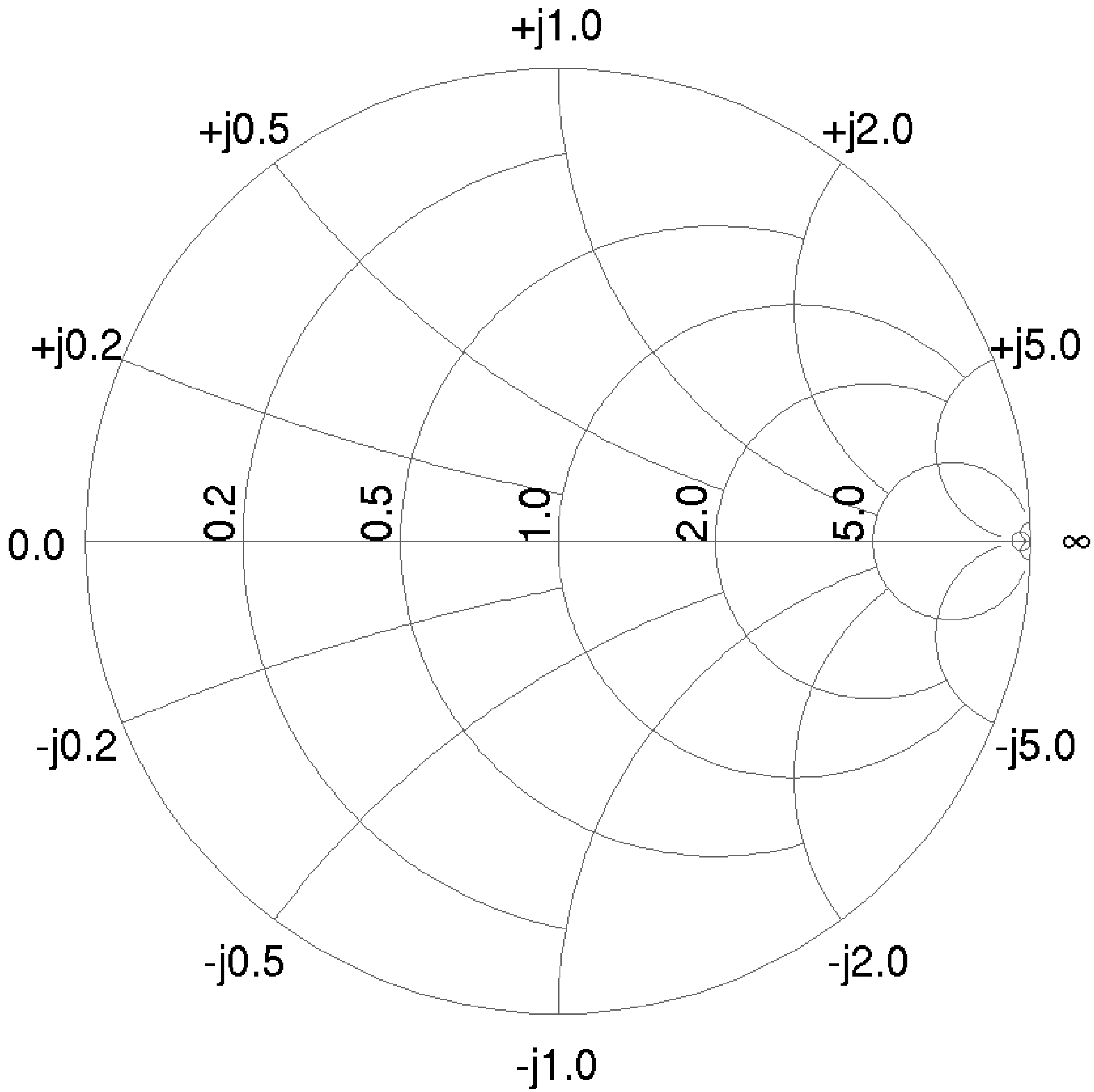
$$\Gamma = \frac{z_l - 1}{z_l + 1}$$

$$\left(\Gamma_r - \frac{r}{r+1}\right)^2 + \Gamma_i^2 = \frac{1}{(r+1)^2}$$

$$(\Gamma_r - 1)^2 + \left(\Gamma_i - \frac{1}{x}\right)^2 = \frac{1}{x^2}$$



The Smith Chart

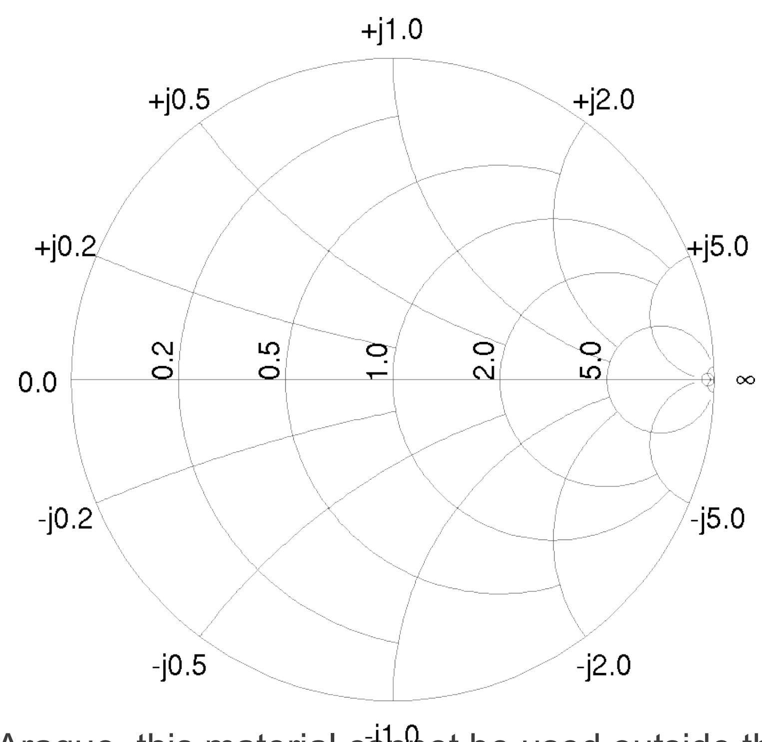


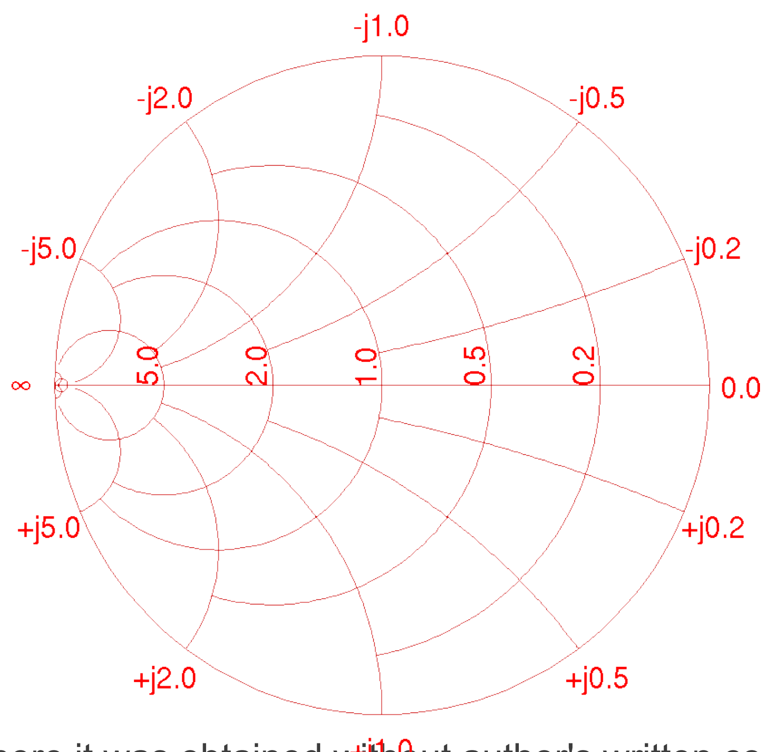
Impedance Vs. Admittance charts

- When load is expressed in terms of normalized admittance *y*, expression for reflection coefficient is simply the negative of the one used from normalized impedance z, → the original chart can be used by simply a 180° rotation of the axes in the Γ plane.

$$\Gamma_z(x) = \frac{x-1}{x+1}$$

$$\Gamma_y(x) = \frac{1/x-1}{1/x+1} = -\Gamma_z(x)$$

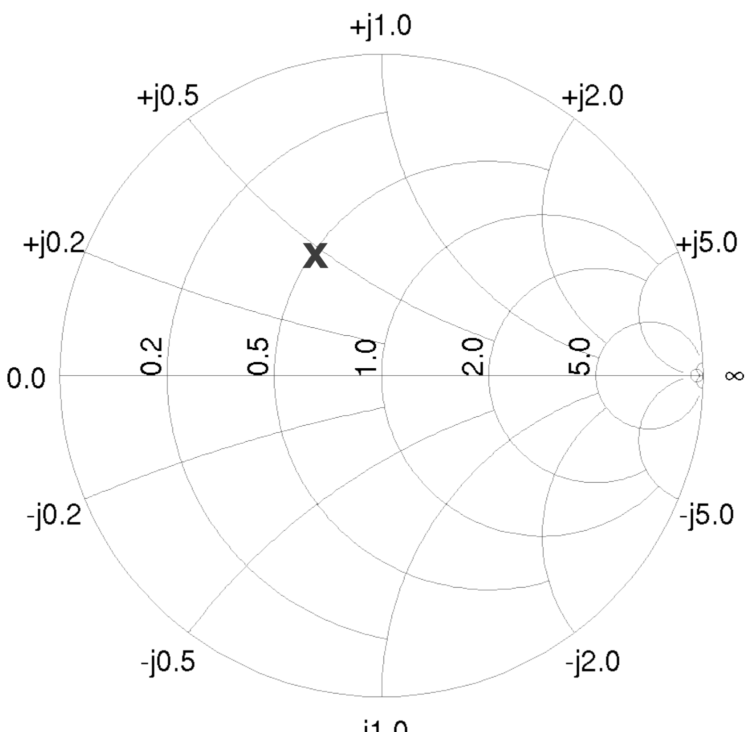




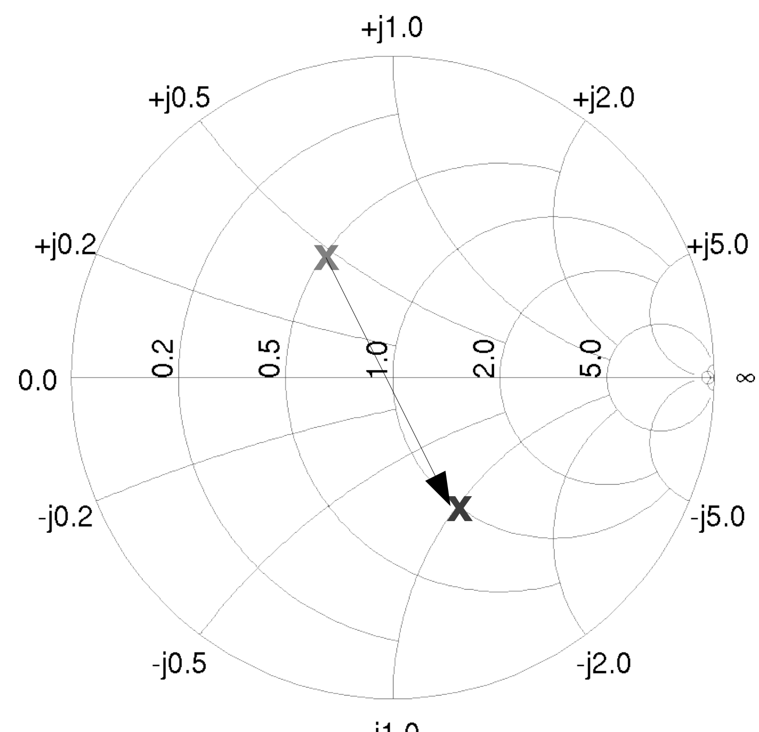
Working with Impedance Chart Only

- The property above means that we pass from Impedance chart to admittance and viceversa by the transformation $\Gamma \rightarrow -\Gamma$

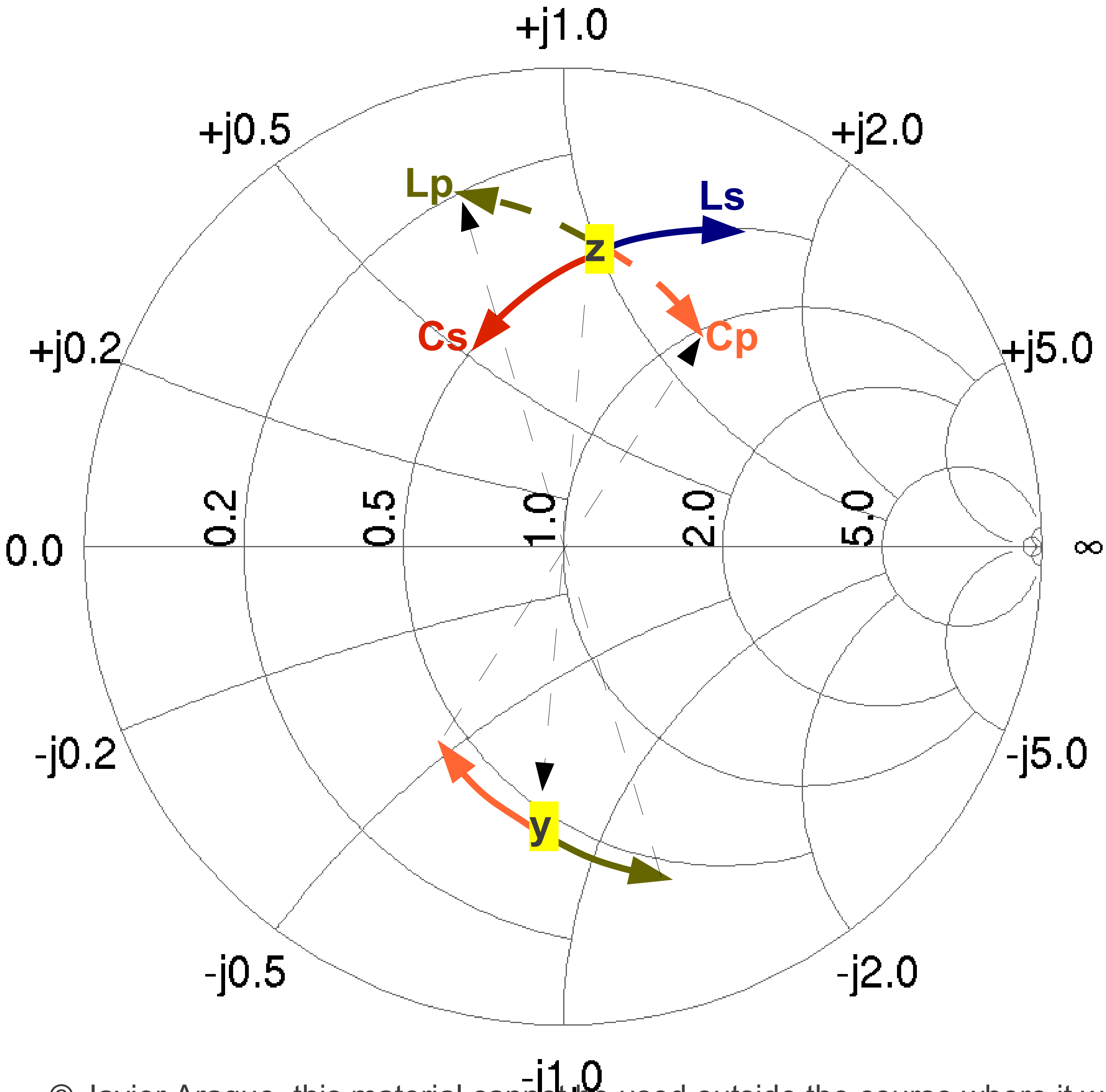
Impedance chart:
z= 0.5 + j0.5
Complex plane is Γ
grid gives complex Impedance (normalized)



Admittance chart:
y = 1/z = 1- j
Complex plane is Γ
grid gives complex admittance (normalized)



Effect of Lumped Elements on z (y)

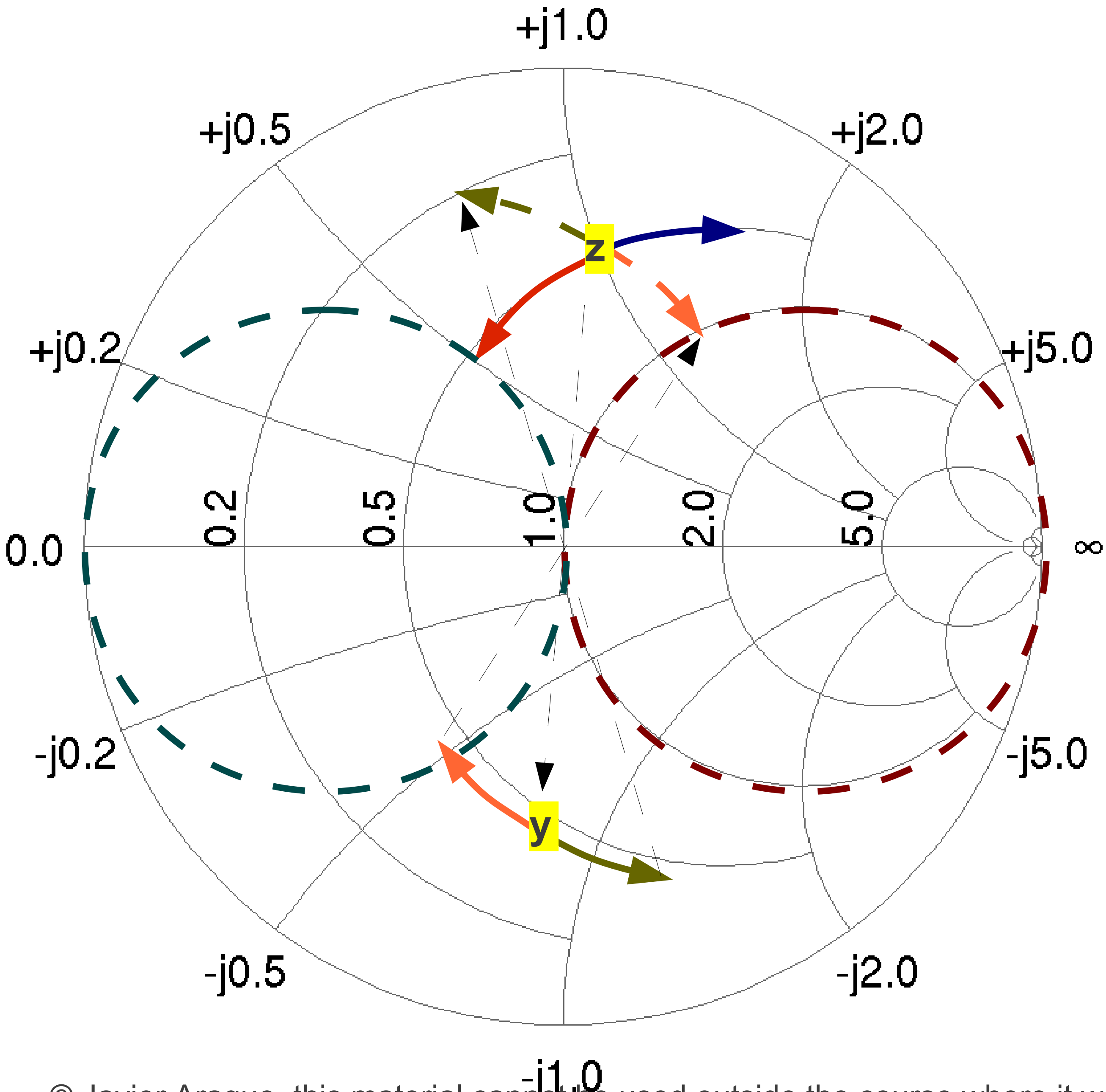


- **Series inductor: increases reactance only CW in r = const**
- **Series capacitor: decreases reactance only, CCW in r = const**
- **Parallel inductor: decreases susceptance only, CCW in g=cnst**
- **Parallel capacitor: increases susceptance only, CW in g=cnst**
- **Around z, solid lines are constant-resistance circles, dashed are constant-conductance. Around y, lines are constant conductance.**
- **Similar behavior for the addition of resistance/conductance**

Matching arbitrary Loads Using Lumped Elements

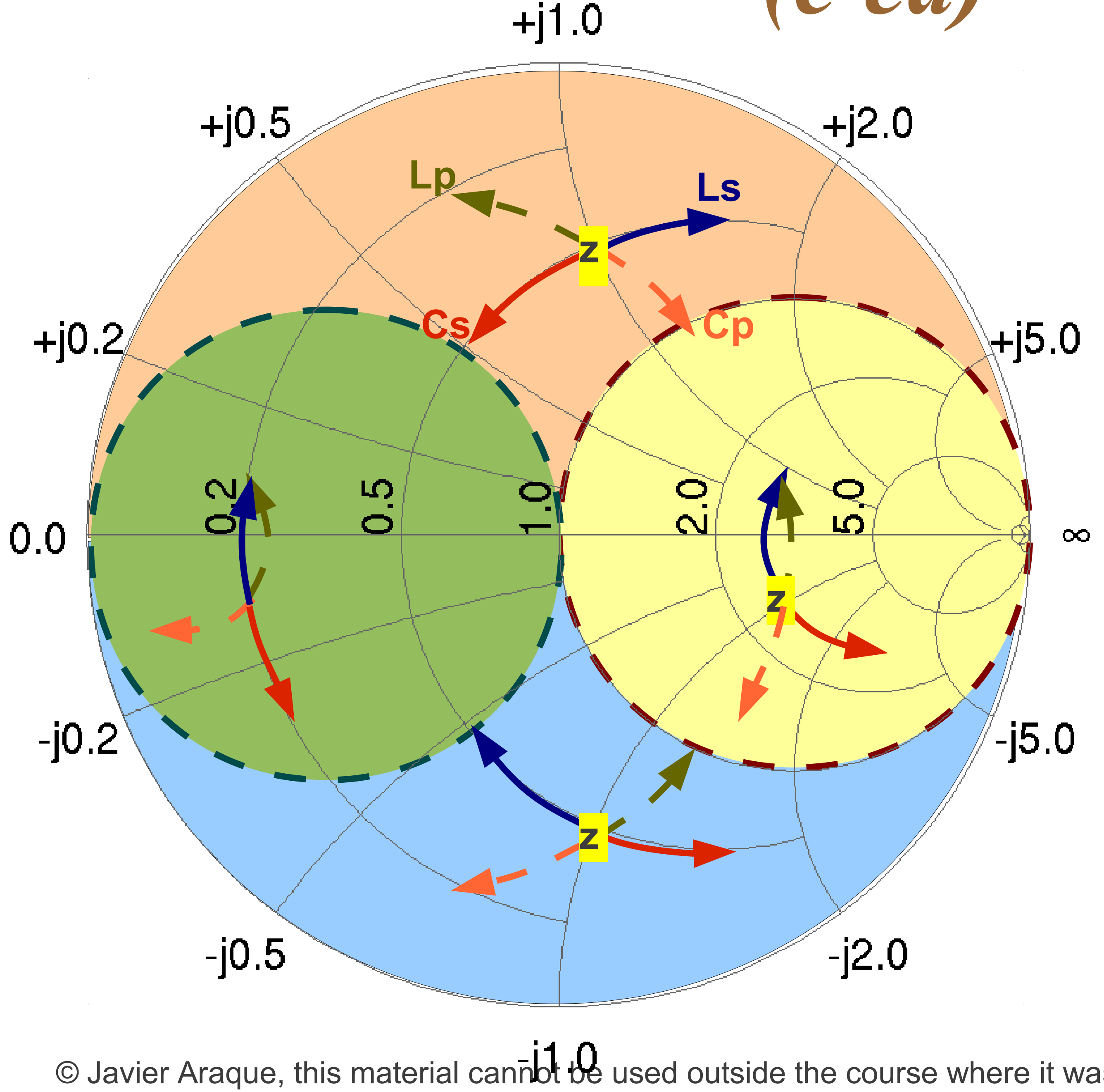
- Goal: transform an arbitrary load impedance to a value equal to the reference impedance to achieve maximum power transfer.
- A perfectly matched load presents $\Gamma=0$, i.e. All power is accepted (transform load impedance to bring it as close as possible to the center of the chart).
- Constraints:
  - Use only reactive elements: L, C (lossless matching)
  - Use as few components as possible
  - Use practical component values

Matching with Lumped Elements



- Impedances located on the unit resistance (unit conductance) circles can be matched with a single series (shunt) element.
- Other impedances cannot be taken to the origin in one step, however these can be moved to one of the circles described above with an appropriate component.
- Two elements suffice for a narrowband matching

Matching with Lumped Elements (c'ed)



- Four distinct regions:

r>1:

Lp – Cs or Cp – Ls

g>1:

Ls-Cp or Cs-Lp

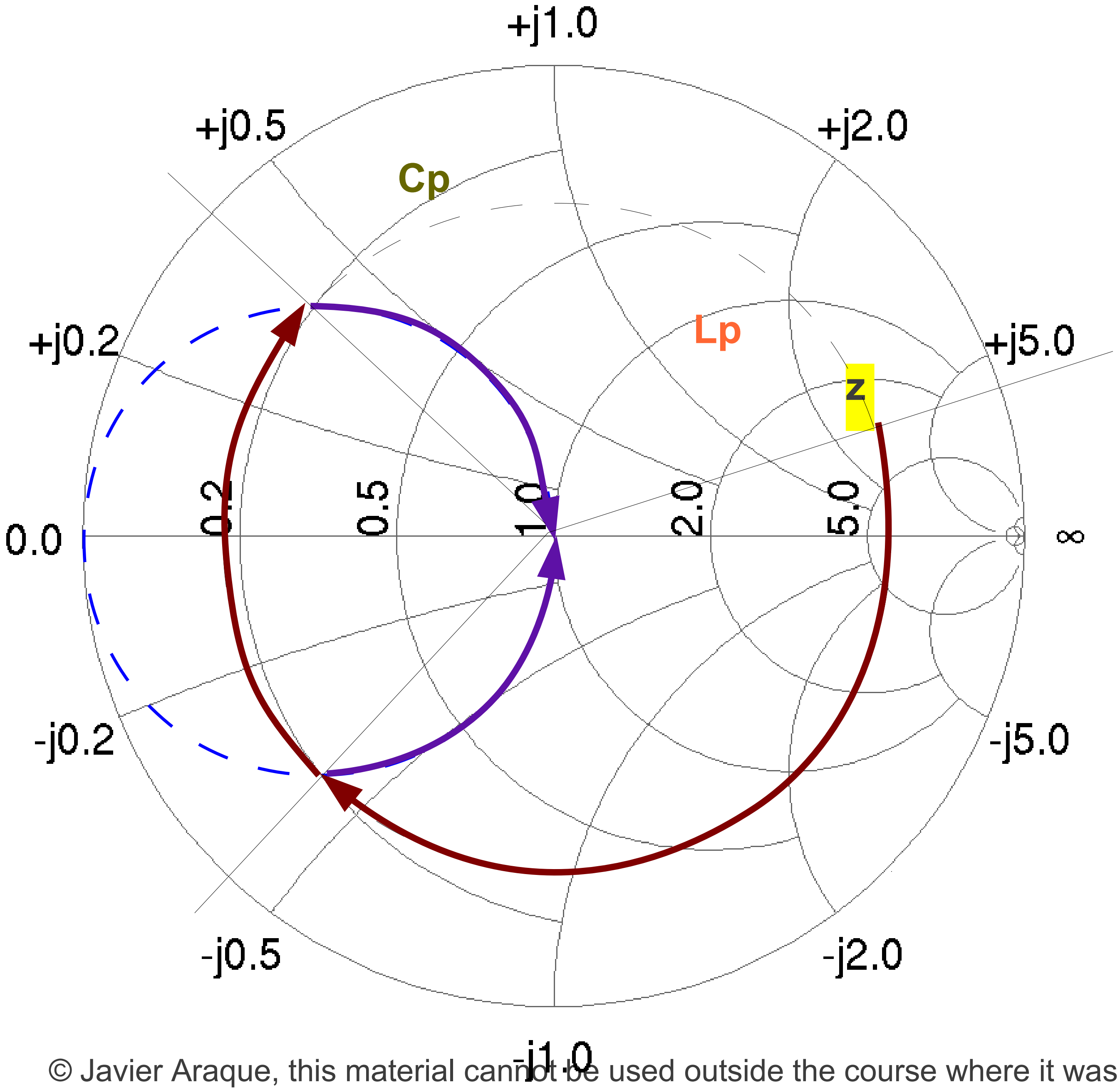
x>0, r<1, g<1:

Cp-Cs or Cs-Cp

x<0, r<1, g<1:

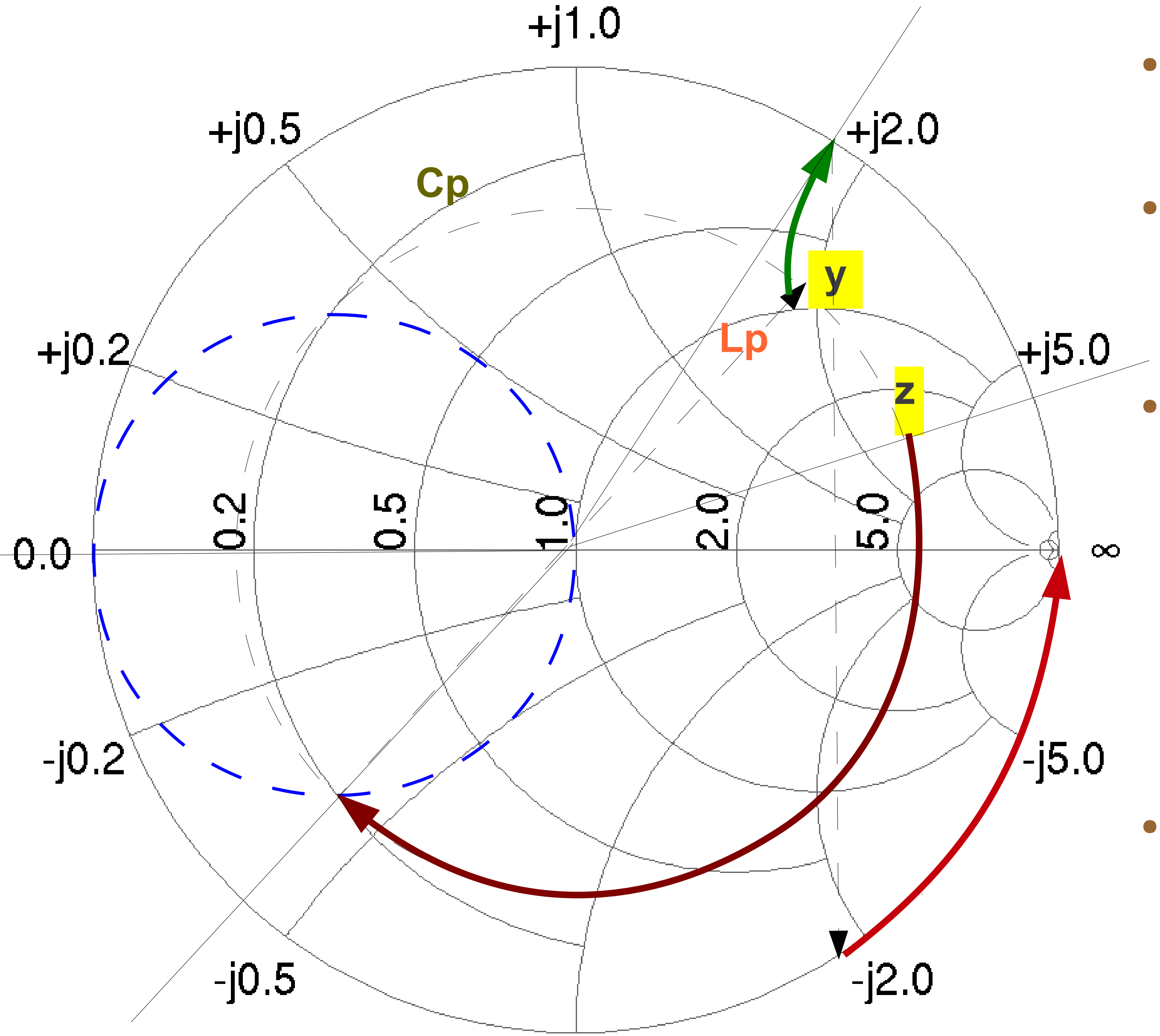
Lp-Ls or Ls-Lp

Matching with T.L.



- Transmission lines are the most convenient way to match loads: e.g. Printed lines are inexpensive, able to achieve arbitrary component values.
- T.L. cannot simulate series impedances, only transformation and shunt reactances (open/shorted stubs)
- With fixed caracteristic impedance, equal to the reference impedance, only the **series**-**shunt** configuration is possible

Length of Shunt T.L. Element

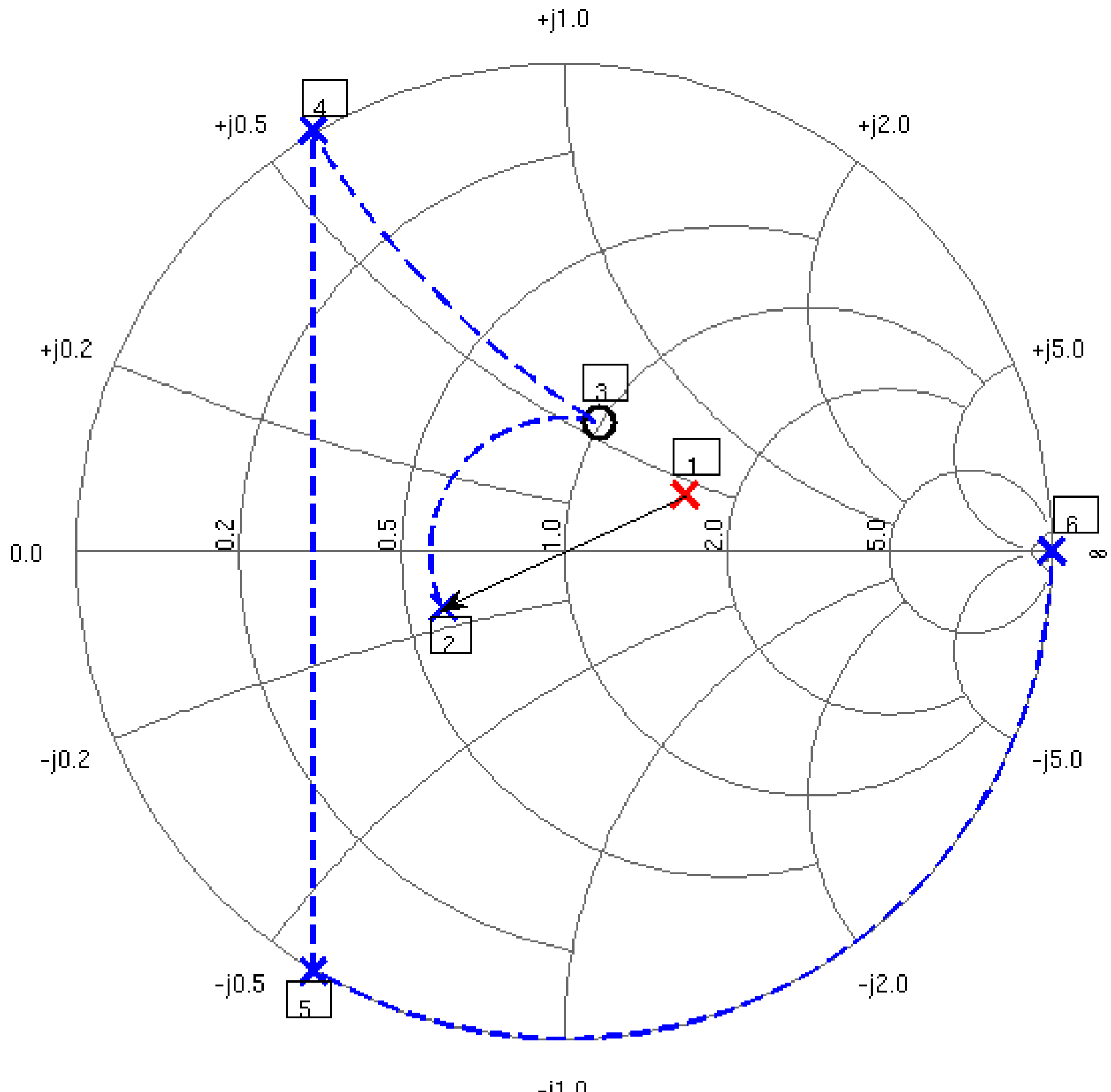


- Series TL moves impedance point to the g=1 circle.
- Moving to admittance chart we see the need to cancel the remaining susceptance.
- Stub length is obtained by locating the negative value of susceptance (to cancel out the initial value), discard g and move ”towards the load” till a short or open is found
- Stopping at y=0 (left) gives length of open stub, at y-> infty length of shorted stub

Reading Scales in Smith Chart

- SWR
- RL
- Reflection coefficient (P and E/I)
- Transmission coefficient (P and E/I)
- Attenuation

Example: matching with TL



Match the load Zl=(80 + j20) Ohm to a 50 Ohm line using minimum-length lines.

1. Locate z = 1.6 + 0.4j

2. Move into admittance chart by reflecting this, results y = 0.59 – j0.15

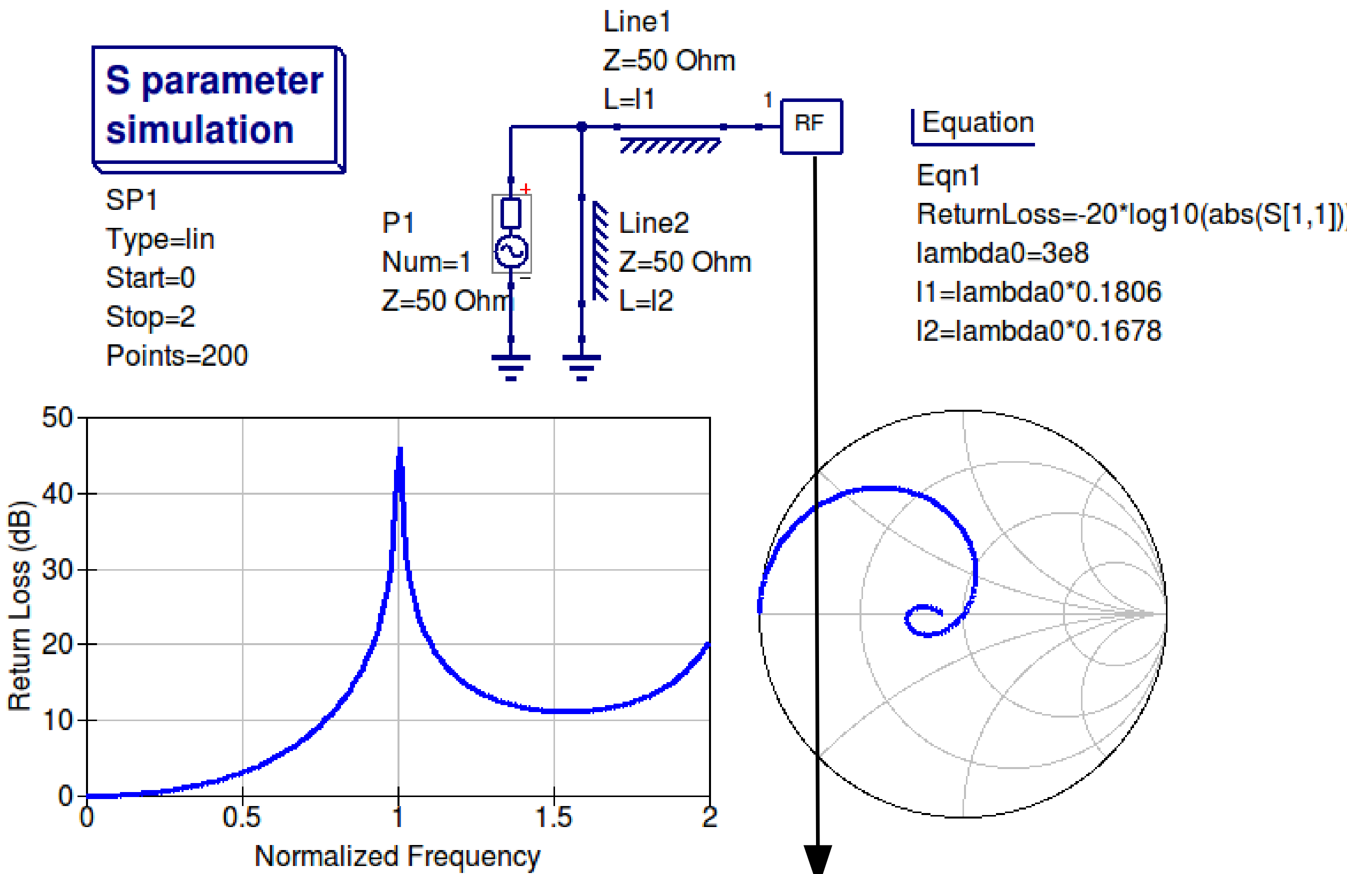
3. Insert a series line long enough to arrive to the g=1 circle (length = 0.18λ). Susceptance value therein is b = 0.57.

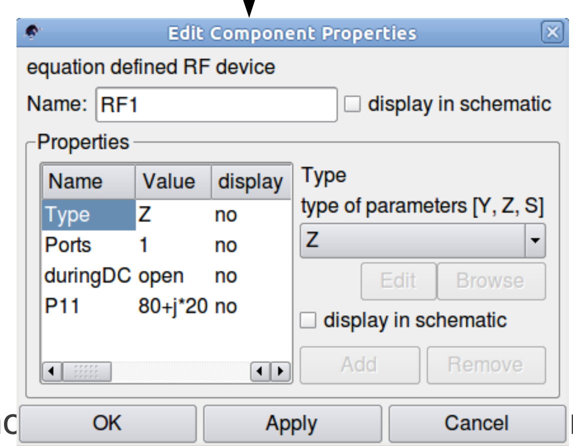
4. Set g=0, keep b to reach the susceptance value that must be cancelled by the stub.

5. Reflect w.r.t. real axis to obtain the susceptance value that must be achieved by stub.

6. Move towards load till the first among open circuit and short circuit. In this case we stop at y = ∞, meaning a shorted stub, length = 0.17λ

Validating the Previous Solution





- Simulation is performed in the 0 – 2*f0 band to assess performance of the matching network.
- Impedance is assumed constant throughout the band; it is defined via the equation-defined RF component, 1-port and setting Z11 to the impedance value given.
- Return loss is very high at the design frequency, line lengths have to be slightly tuned.
- 20-dB bandwidth of design is about log2(1.1/0.92) = 0.26 octaves.