Microwave theory, lecture 3, 2015

Anders Karlsson, anders.karlsson@eit.lth.se

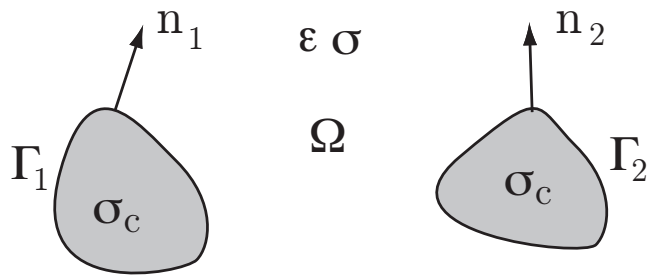
Electrical and information technology

Last lecture

- Standing wave ratio (SWR)
- Lossy line

Today

- Determination of R, L, G, C
- COMSOL example
- $S-$parameters
- Smith chart
- Introduction to hollow waveguides



Solve Laplace equation $\nabla^2\Phi(x,y)$ in Ω.

$$\nabla^2\Phi(x,y) = 0$$

$$\Phi(x,y) = \begin{cases} V/2 & \text{on } \Gamma_1 \\ -V/2 & \text{on } \Gamma_2 \end{cases}$$

$$C = \frac{Q}{V} = \frac{\oint_{\Gamma_1} \rho_S \, d\ell}{V}$$

or

$$C = 2\frac{W_e}{V^2}$$

L, G, R

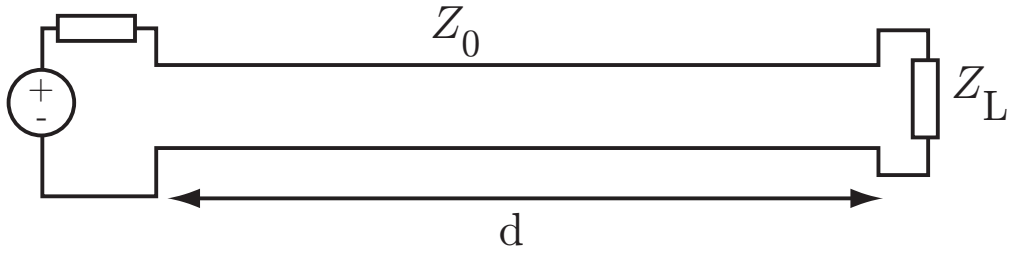
$$L = \frac{\mu_0 \epsilon_0 \epsilon}{C} \text{ (if losses are small)}$$

$$G = \frac{C\sigma}{\epsilon_0 \epsilon}$$

$$R = R_s \frac{\int_{\Gamma_1+\Gamma_2} (\rho_S)^2 \, d\ell}{\left(\int_{\Gamma_1} \rho_S \, d\ell \right)^2}$$

$$R_S = \sqrt{\frac{\omega \mu_0}{2\sigma_c}} = \text{surface resistance.}$$

Smith chart



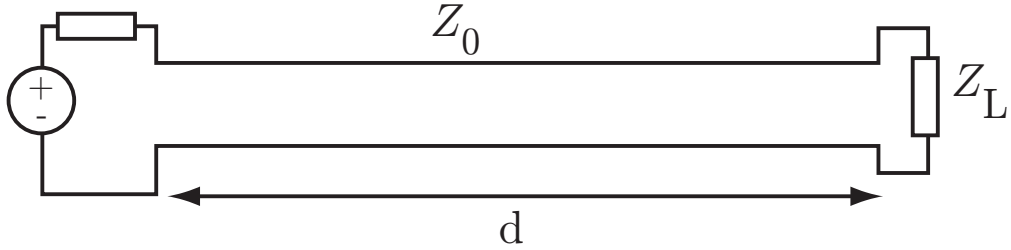
$$\Gamma(0) = \frac{Z(0) - Z_0}{Z(0) + Z_0} = \frac{Z_L - Z_0}{Z_L + Z_0} e^{-2\mathrm{j}\beta d} = \Gamma_d e^{-2\mathrm{j}\beta d}$$

Normalize with Z_0

$$z(0) = \frac{Z(0)}{Z_0} = \frac{R(0) + \mathrm{j}X(0)}{Z_0} = r(0) + \mathrm{j}x(0)$$

$$z_L = \frac{Z_L}{Z_0}$$

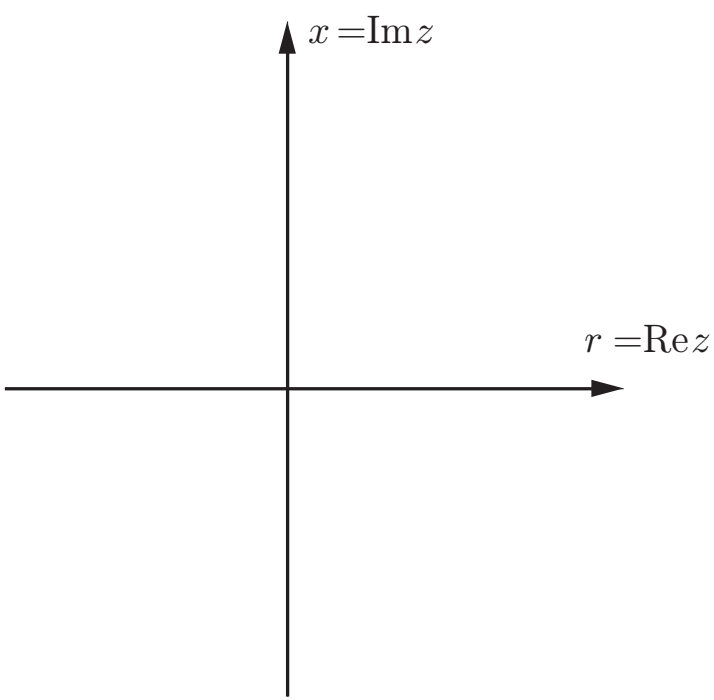
Smith chart

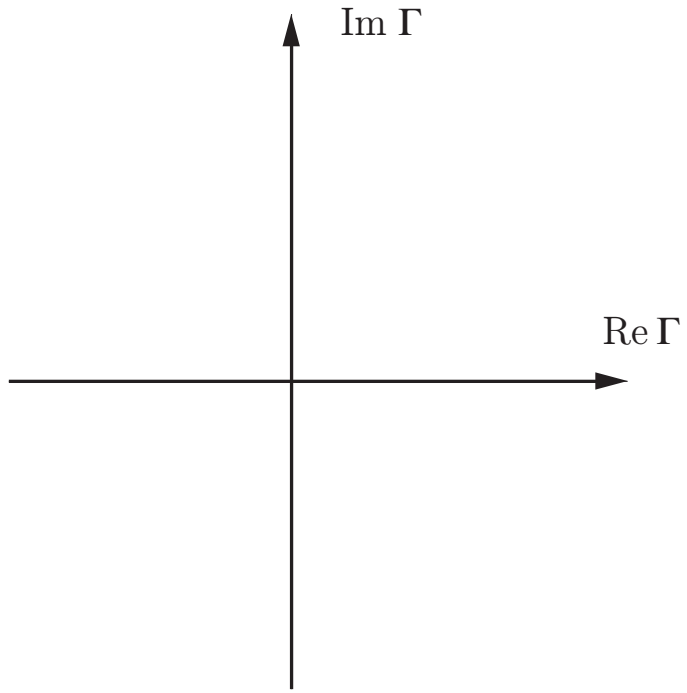


$$\Gamma(0) = \frac{z(0)-1}{z(0)+1} = \frac{z_L - 1}{z_L + 1} e^{-2\mathrm{j}\beta d}$$

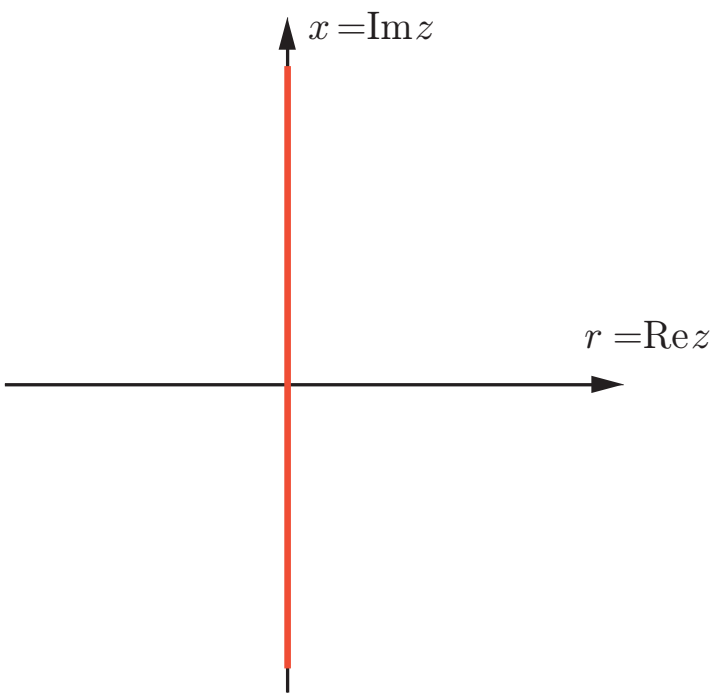
Plot $\Gamma(0)$, $r(0)$, $x(0)$ in the same diagram $\Rightarrow$ Smith chart!

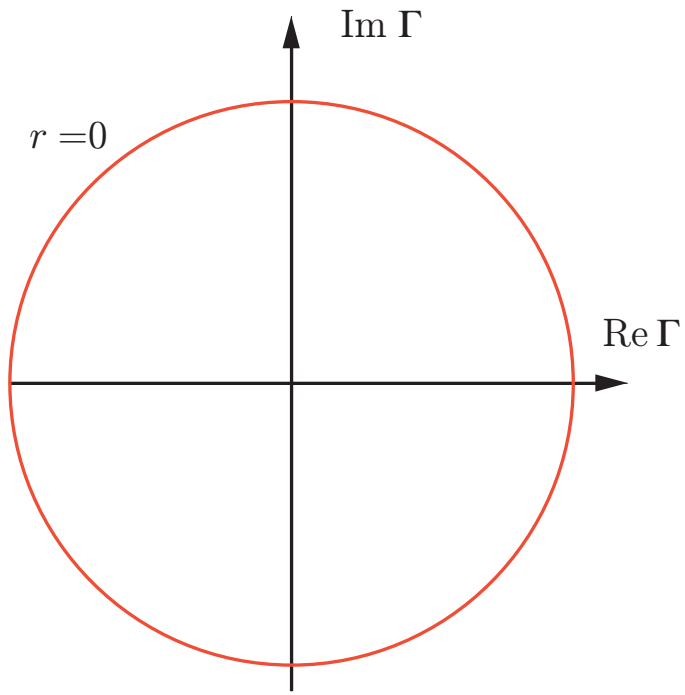
Smith chart



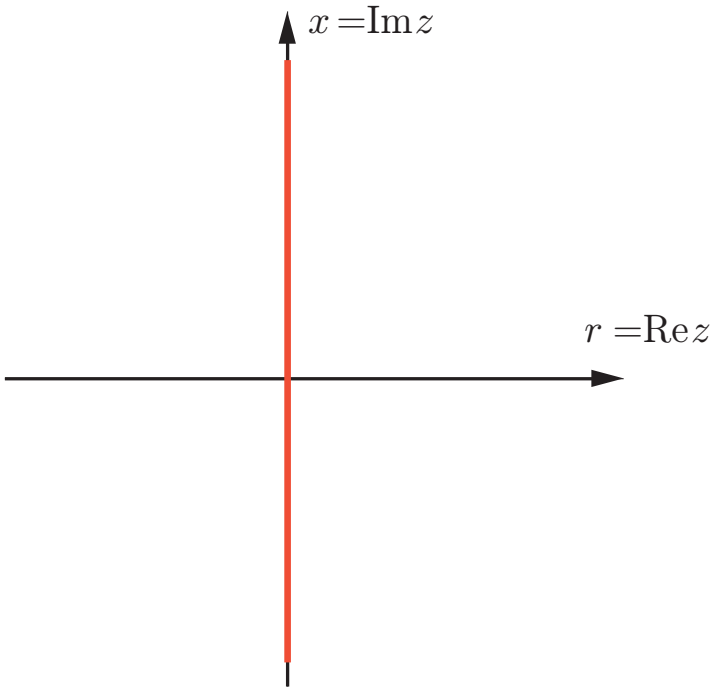


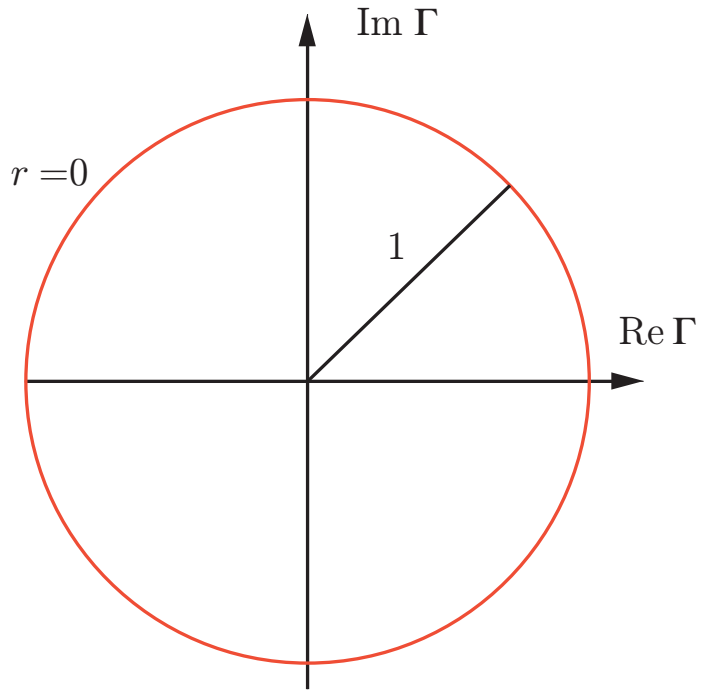
Smith chart



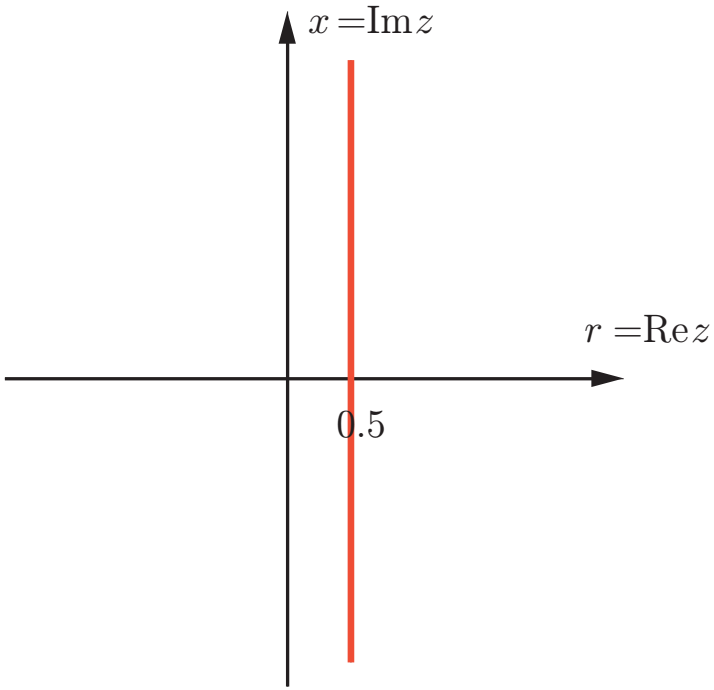


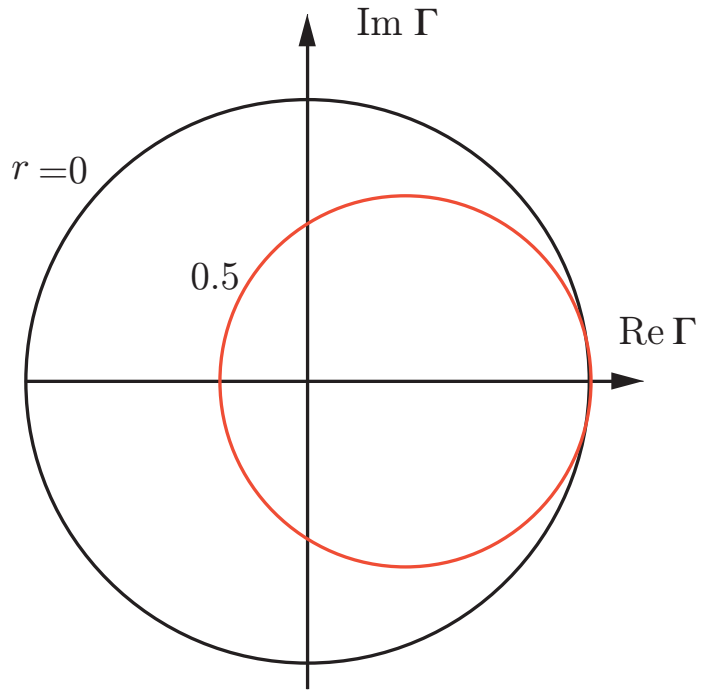
Smith chart



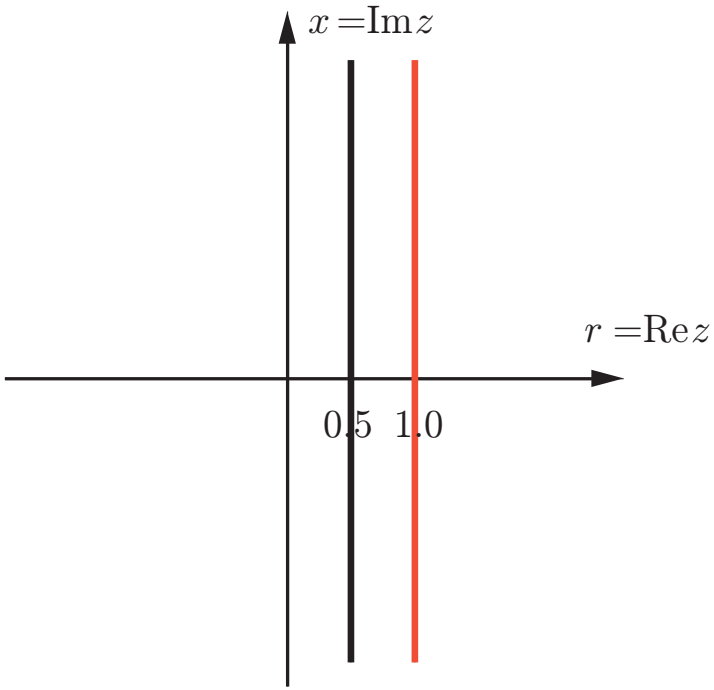


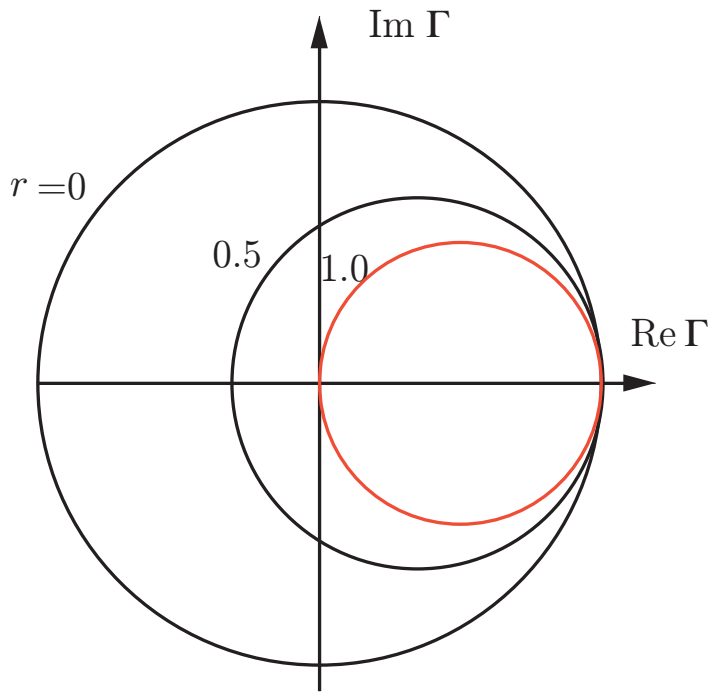
Smith chart


$x = \mathrm{Im}\, z$
$r = \mathrm{Re}\, z$
0.5

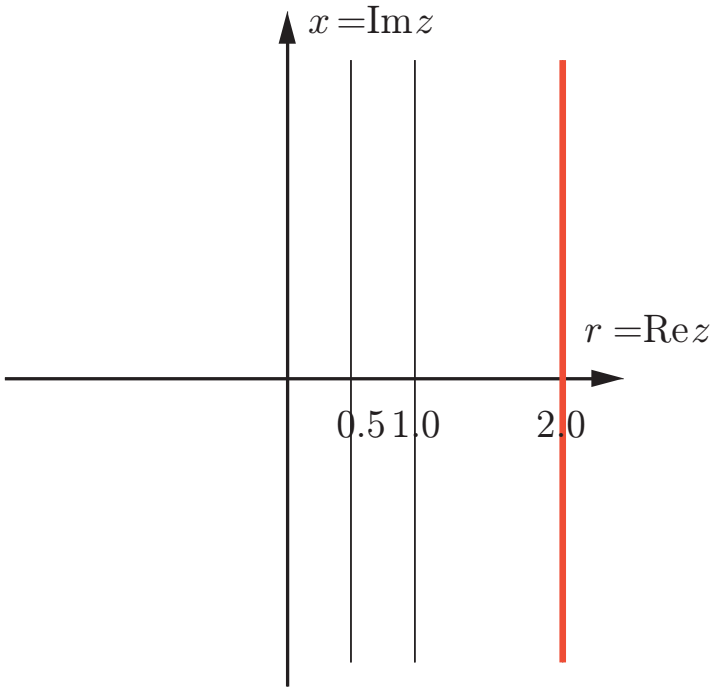

$\mathrm{Im}\, \Gamma$
$r = 0$
0.5
$\mathrm{Re}\, \Gamma$

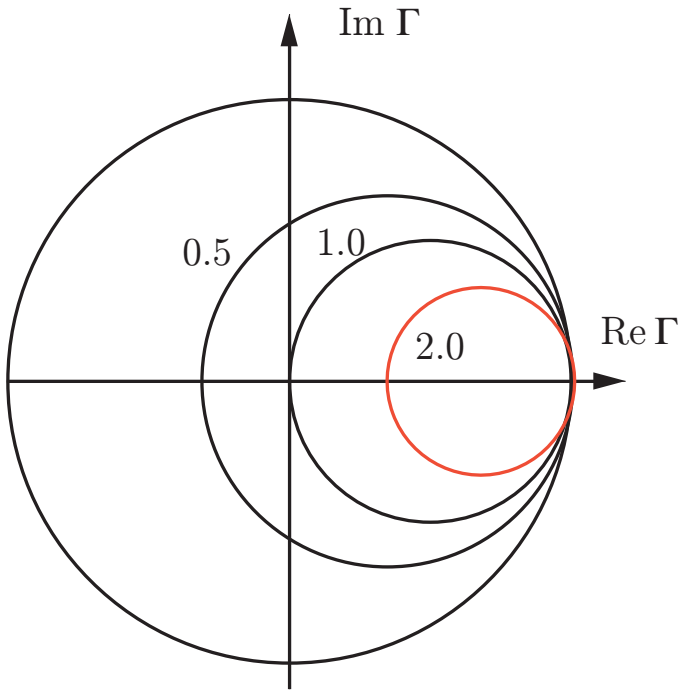
Smith chart


$x = \mathrm{Im}\, z$
$r = \mathrm{Re}\, z$
0.5
1.0

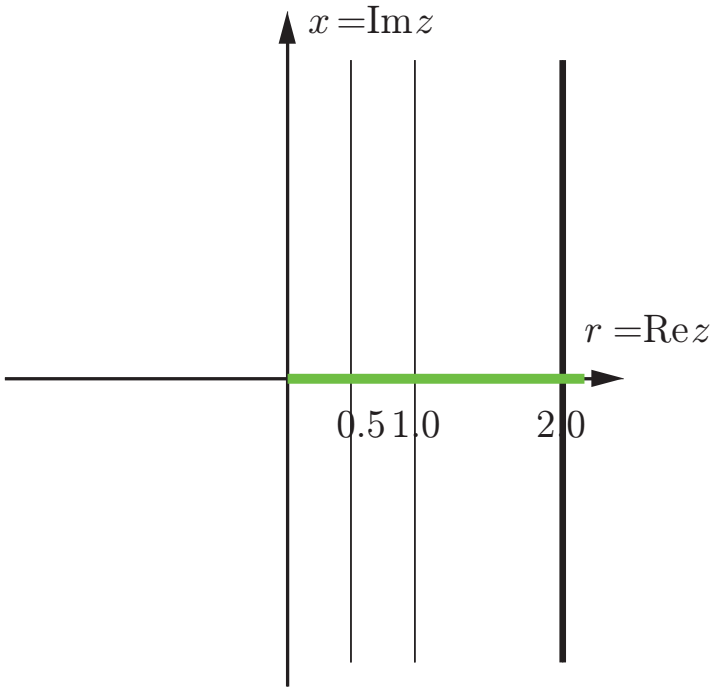

$\mathrm{Im}\, \Gamma$
$r = 0$
0.5
1.0
$\mathrm{Re}\, \Gamma$

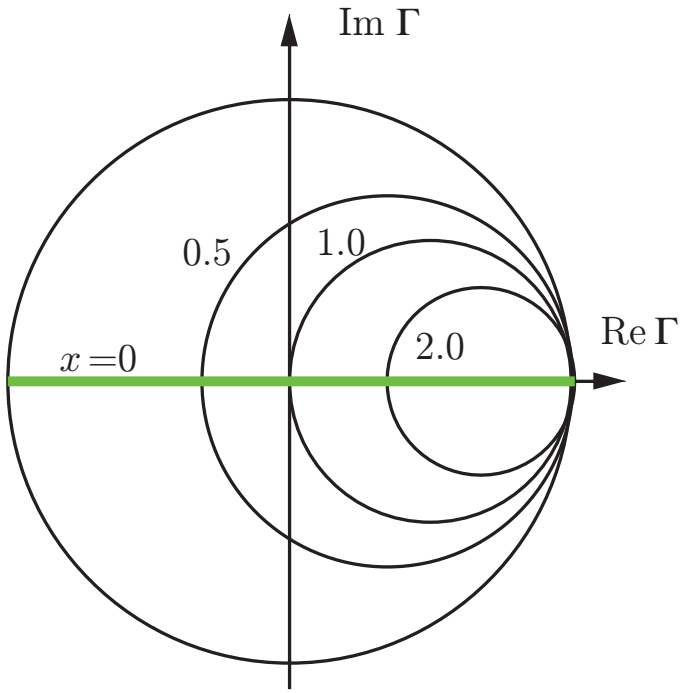
Smith chart


$x = \mathrm{Im}\, z$
$r = \mathrm{Re}\, z$
0.5
1.0
2.0

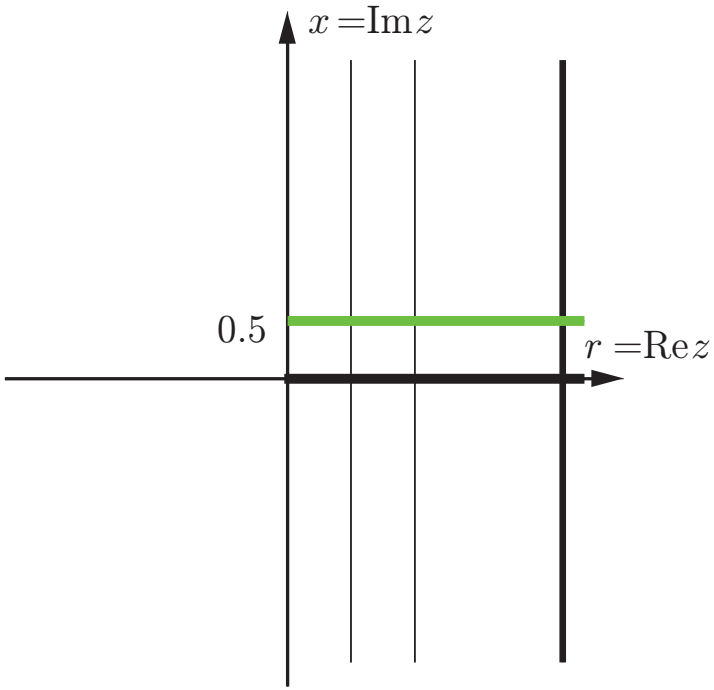

$\mathrm{Im}\, \Gamma$
$\mathrm{Re}\, \Gamma$
0.5
1.0
2.0

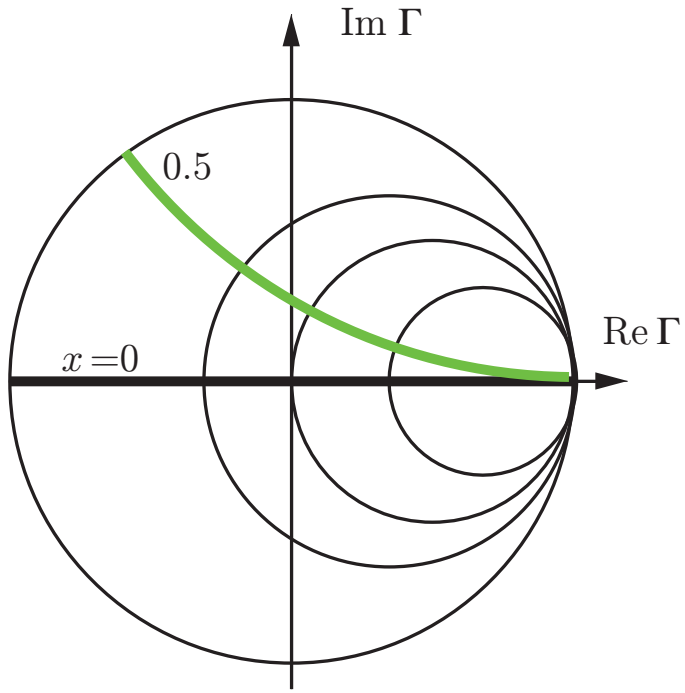
Smith chart


$x = \mathrm{Im}\, z$
$r = \mathrm{Re}\, z$
0.5
1.0
2.0

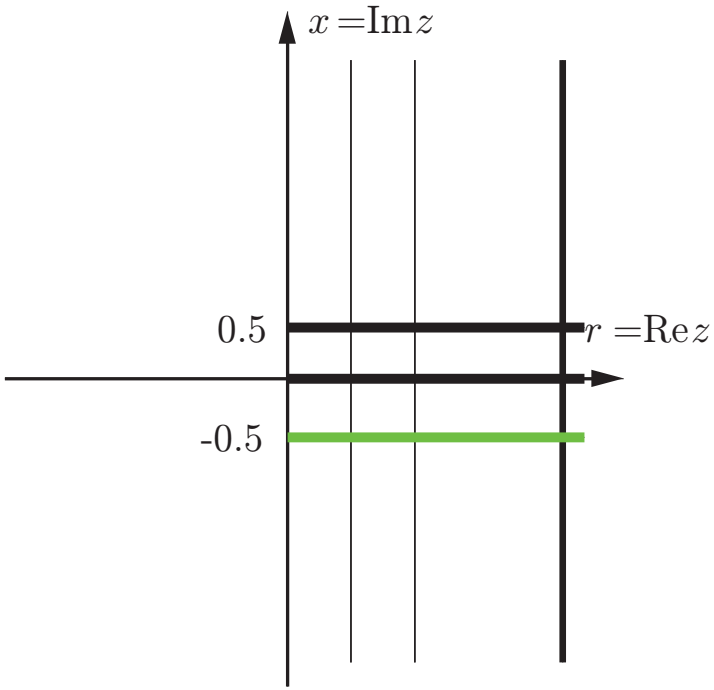

$\mathrm{Im}\, \Gamma$
$\mathrm{Re}\, \Gamma$
$x = 0$
0.5
1.0
2.0

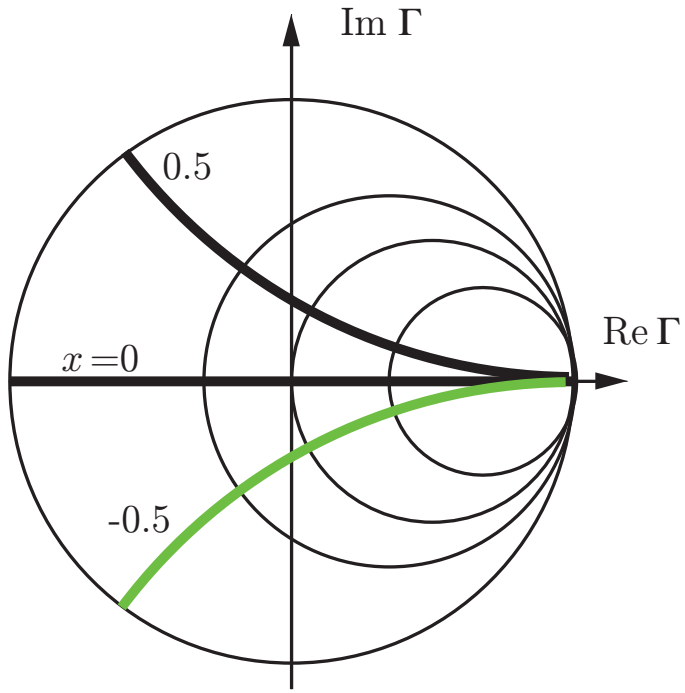
Smith chart


$x = \mathrm{Im}\, z$
0.5
$r = \mathrm{Re}\, z$


$\mathrm{Im}\, \Gamma$
0.5
$x = 0$
$\mathrm{Re}\, \Gamma$

Smith chart


$x = \mathrm{Im}\, z$
0.5
$r = \mathrm{Re}\, z$
-0.5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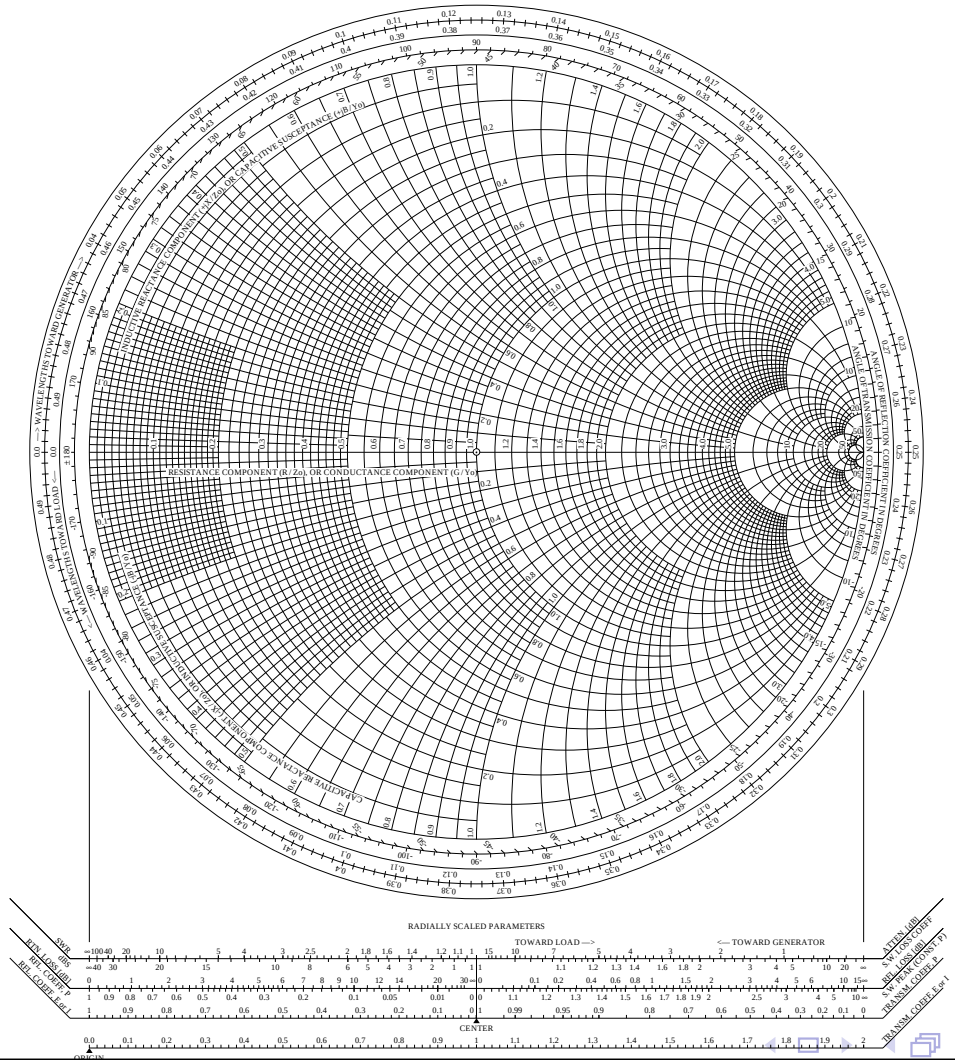
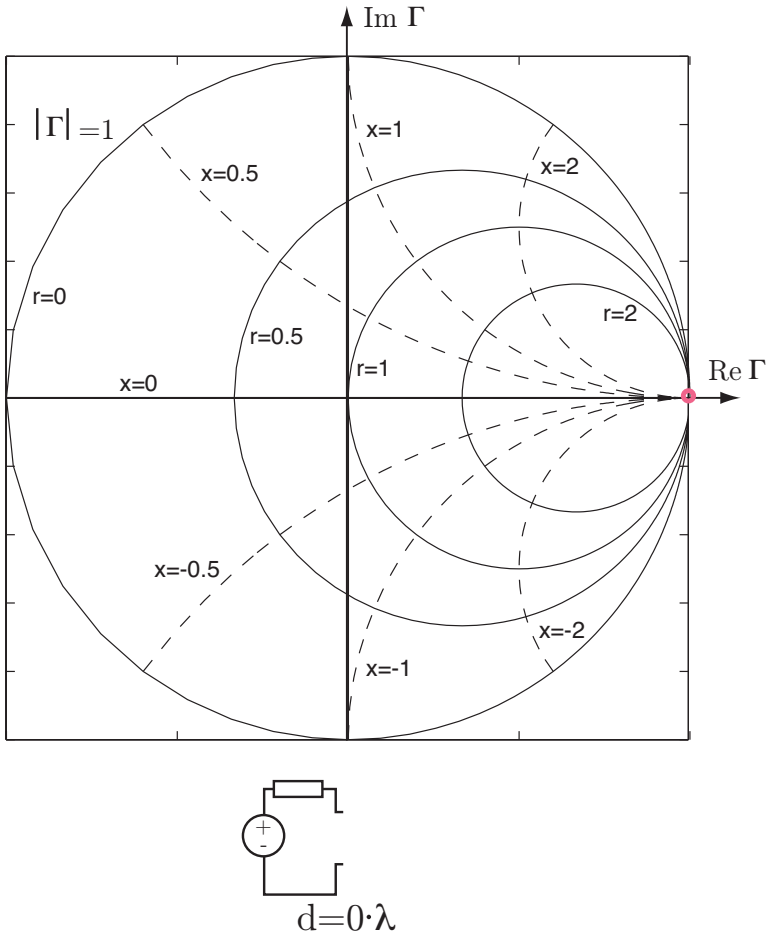
Smith chart

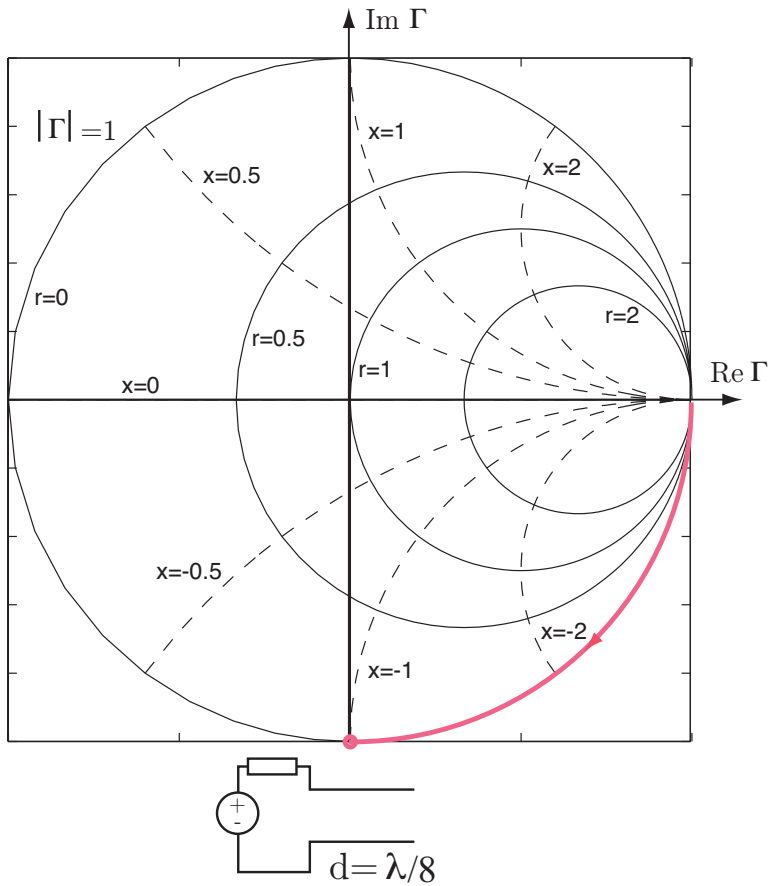

The Complete Smith Chart
Black Magic Design
RESISTANCE COMPONENT (R/Zo) OR CONDUCTANCE COMPONENT (G/Yo)
RADIALLY SCALED PARAMETERS
TOWARD LOAD —>
<— TOWARD GENERATOR
CENTER

Smith chart: example 1



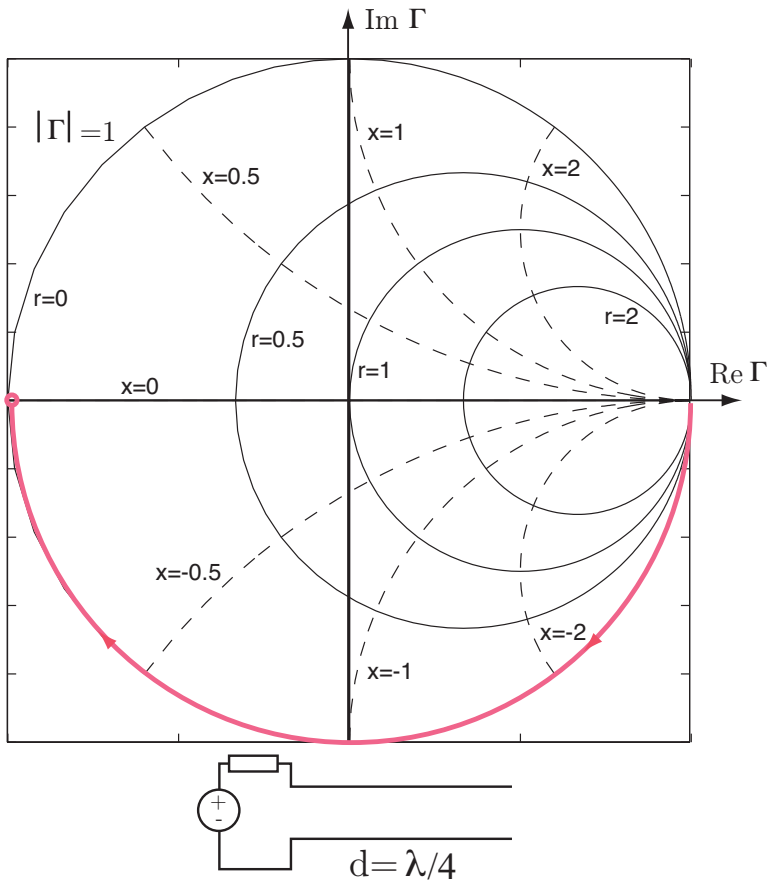
$$\beta d = 0 \Rightarrow \Gamma(0) = \Gamma_d = 1$$

Smith chart: example 1



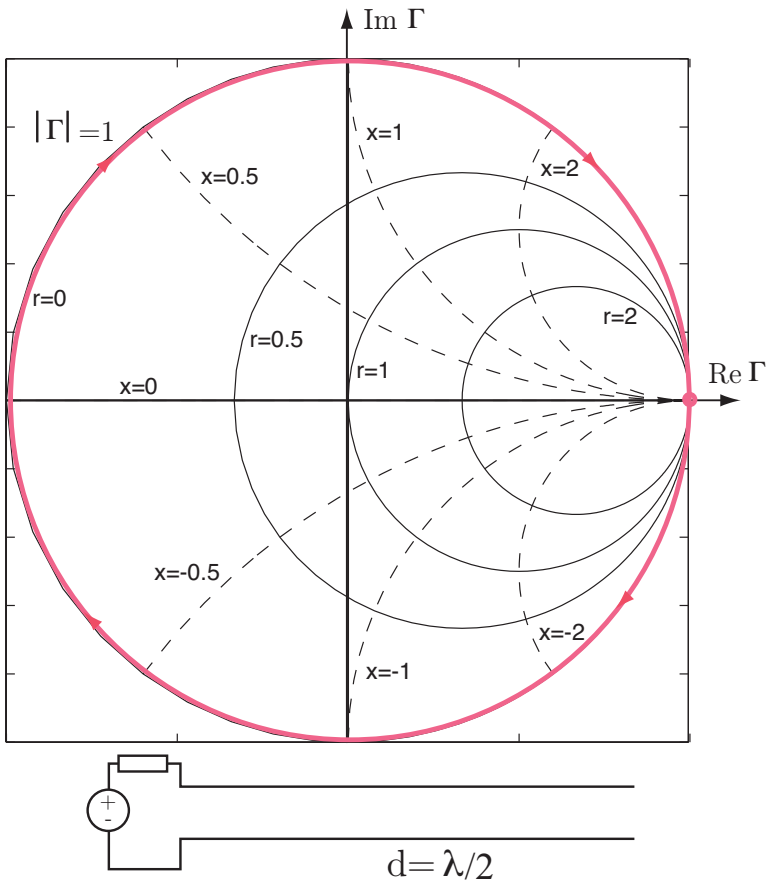
$$\beta d = \pi/4 \Rightarrow \Gamma(0) = -i$$

Smith chart: example 1



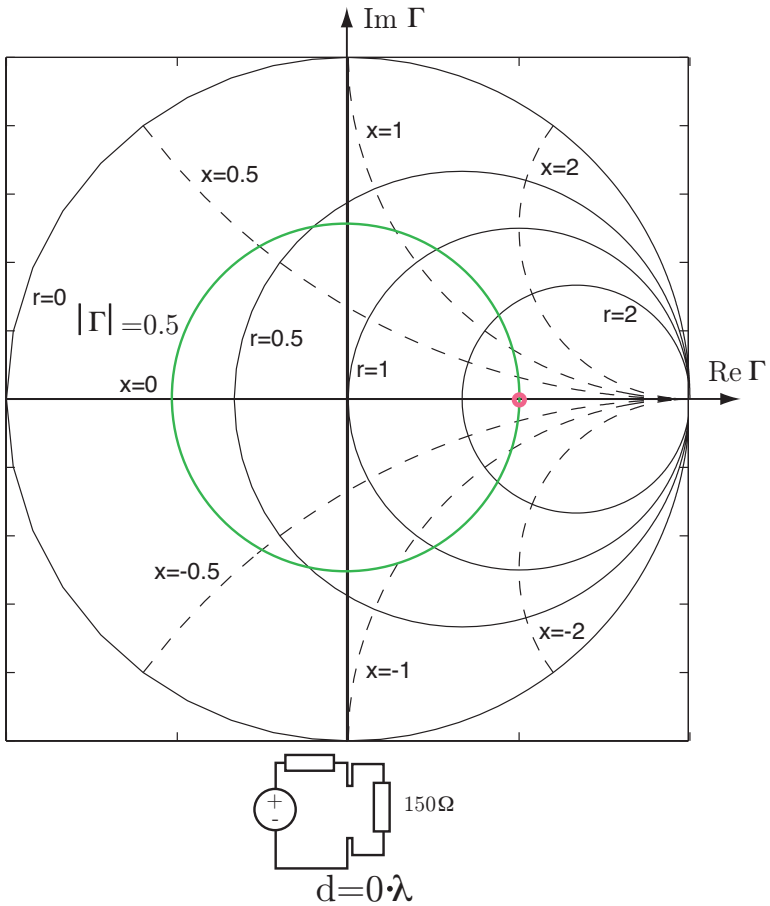
$$\beta d = \pi/2 \Rightarrow \Gamma(0) = -1$$

Smith chart: example 1



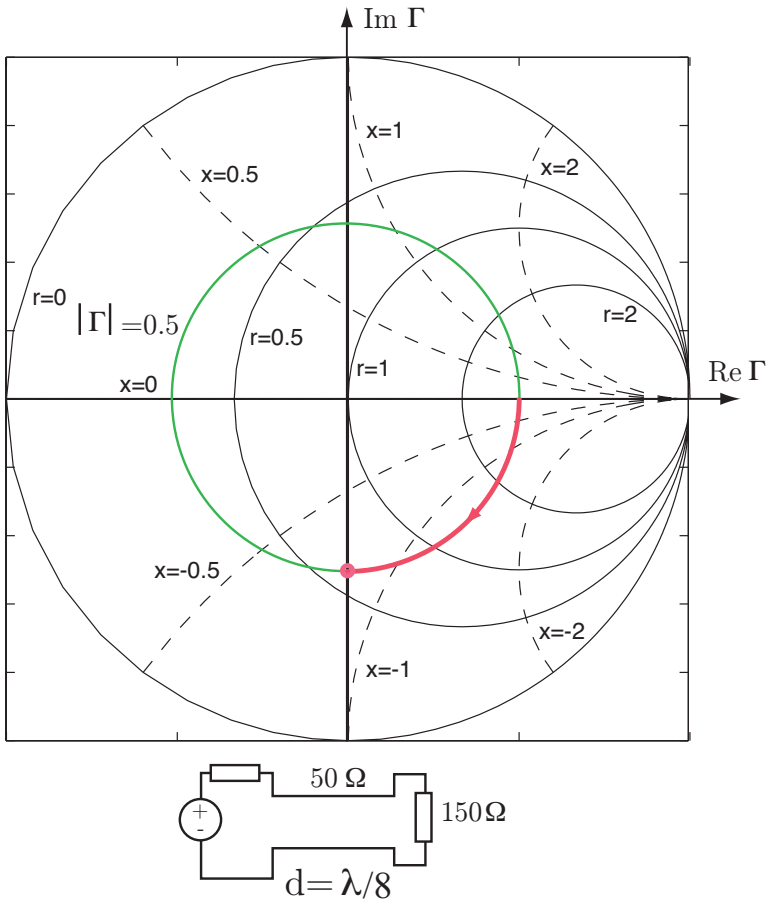
$$\beta d = \pi \Rightarrow \Gamma(0) = \Gamma_d = 1$$

Smith chart: example 2



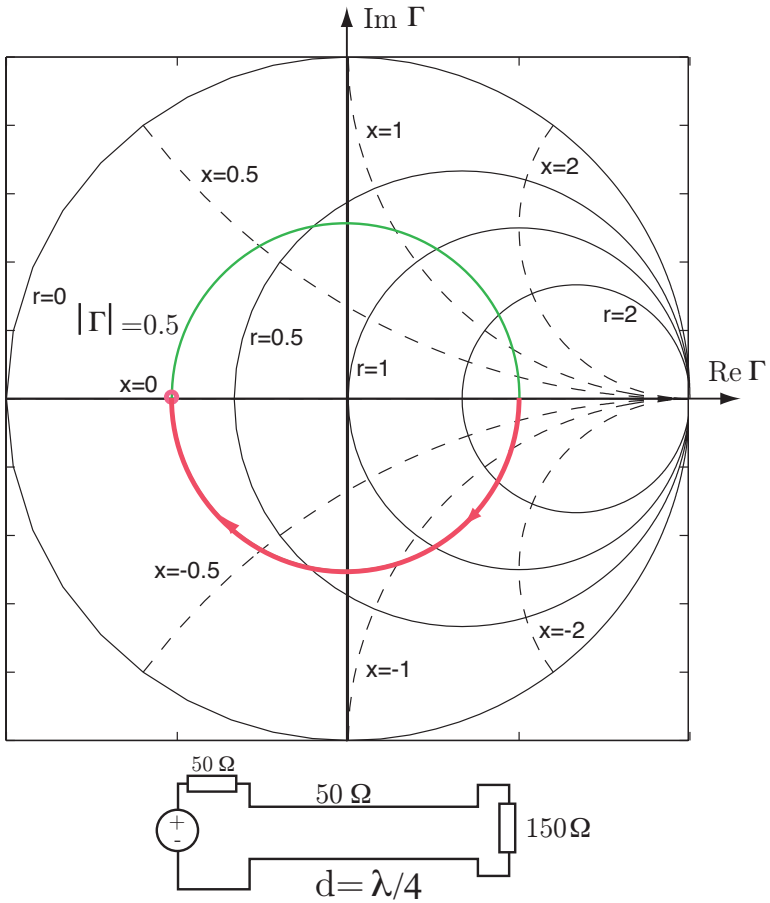
$$\beta d = 0 \Rightarrow \Gamma(0) = \Gamma_d = \frac{150 - 50}{150 + 50} = 0.5$$

Smith chart: example 2



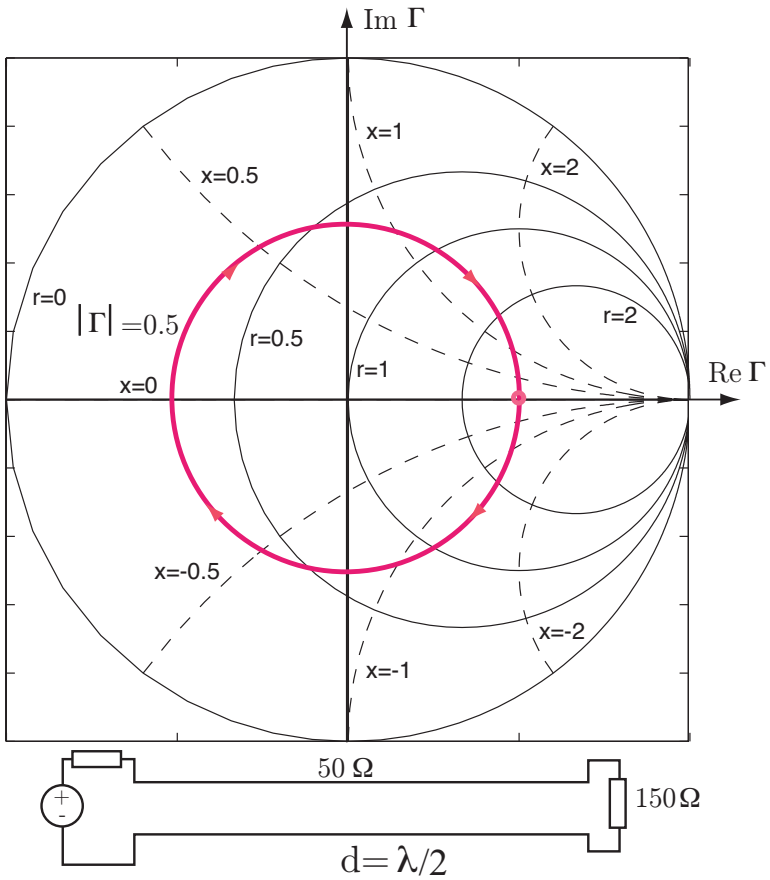
$$\beta d = \pi/4 \Rightarrow \Gamma(0) = -0.5\mathrm{i}$$

Smith chart: example 2



$$\beta d = \pi/2 \Rightarrow \Gamma(0) = -0.5$$

Smith chart: example 2



$$\beta d = \pi \Rightarrow \Gamma(0) = \Gamma_d = 0.5$$

Smith chart

The admittance diagram

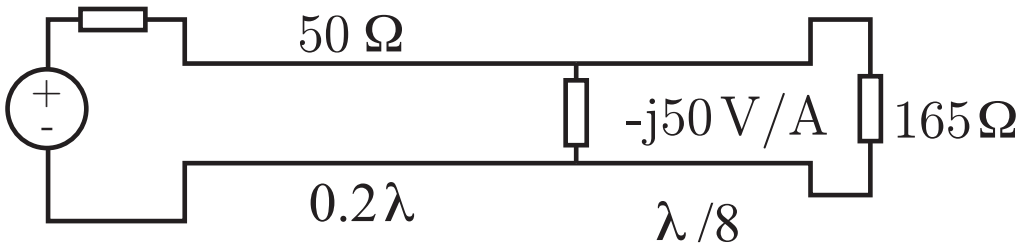
$Y = \frac{1}{Z} = G + \mathrm{j}B$ =admittance

G =conductance, B =susceptance.

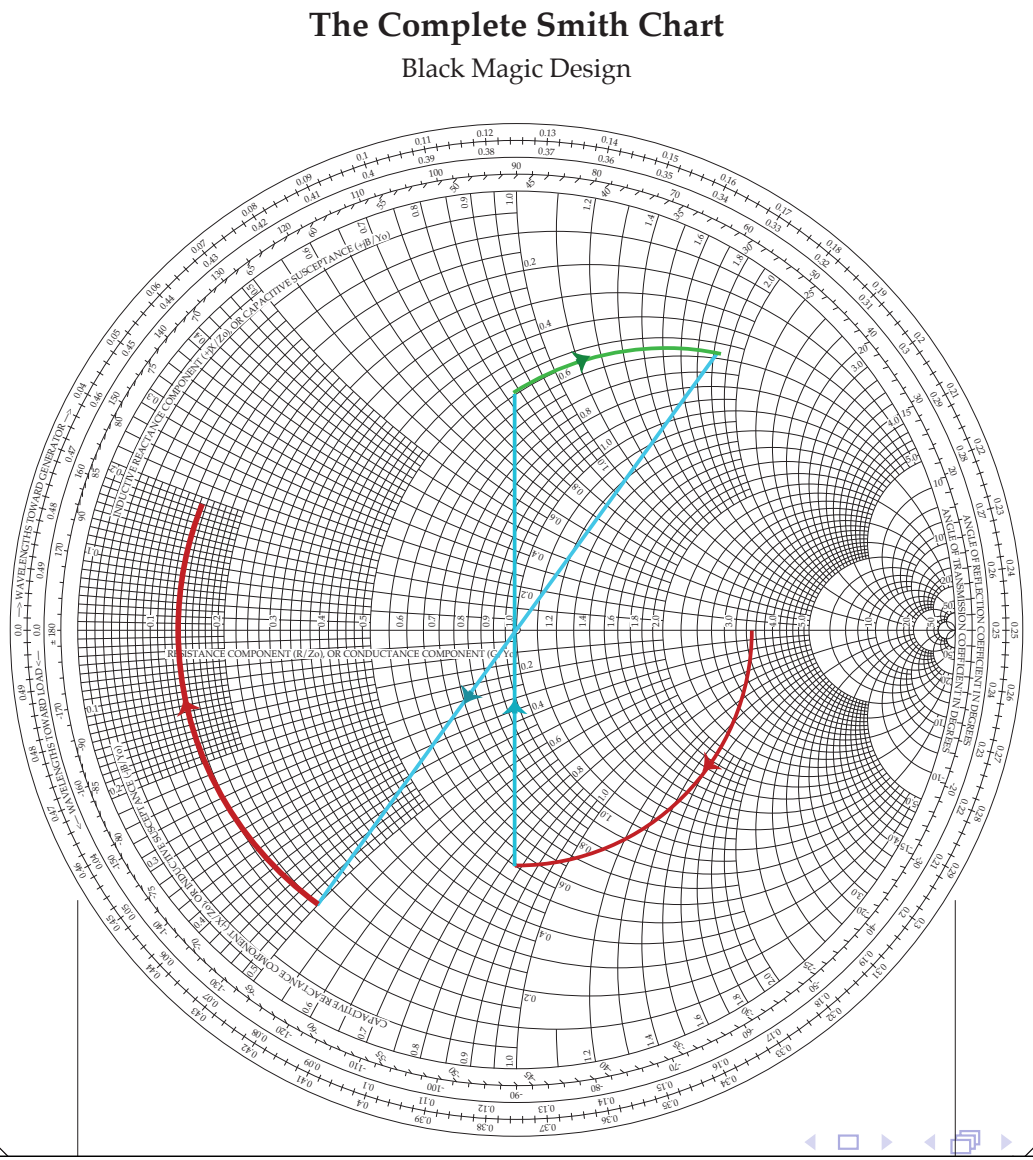
$$\Gamma(0) = \frac{z(0)-1}{z(0)+1} = \frac{1-y(0)}{1+y(0)} = -\frac{y(0)-1}{y(0)+1}$$

Go to $-\Gamma$ in Smith chart and exchange g for r and b for x.

Smith chart



Smith chart



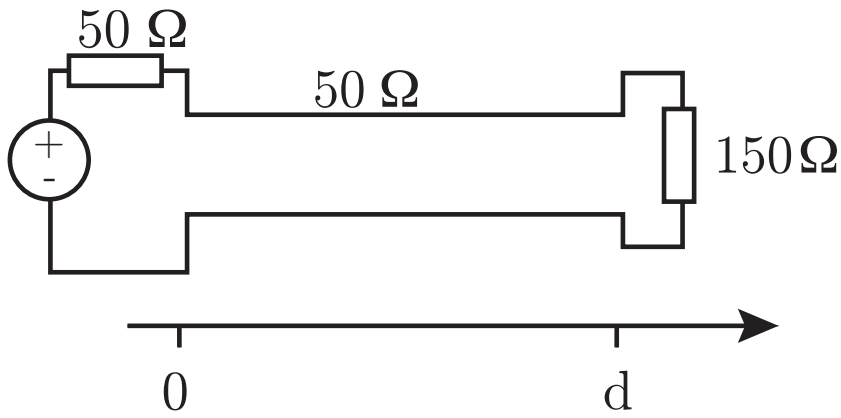
Impedance match by Smith chart

Goal: Try to reach $z = 1 \Rightarrow \Gamma = 0$.
Rules:

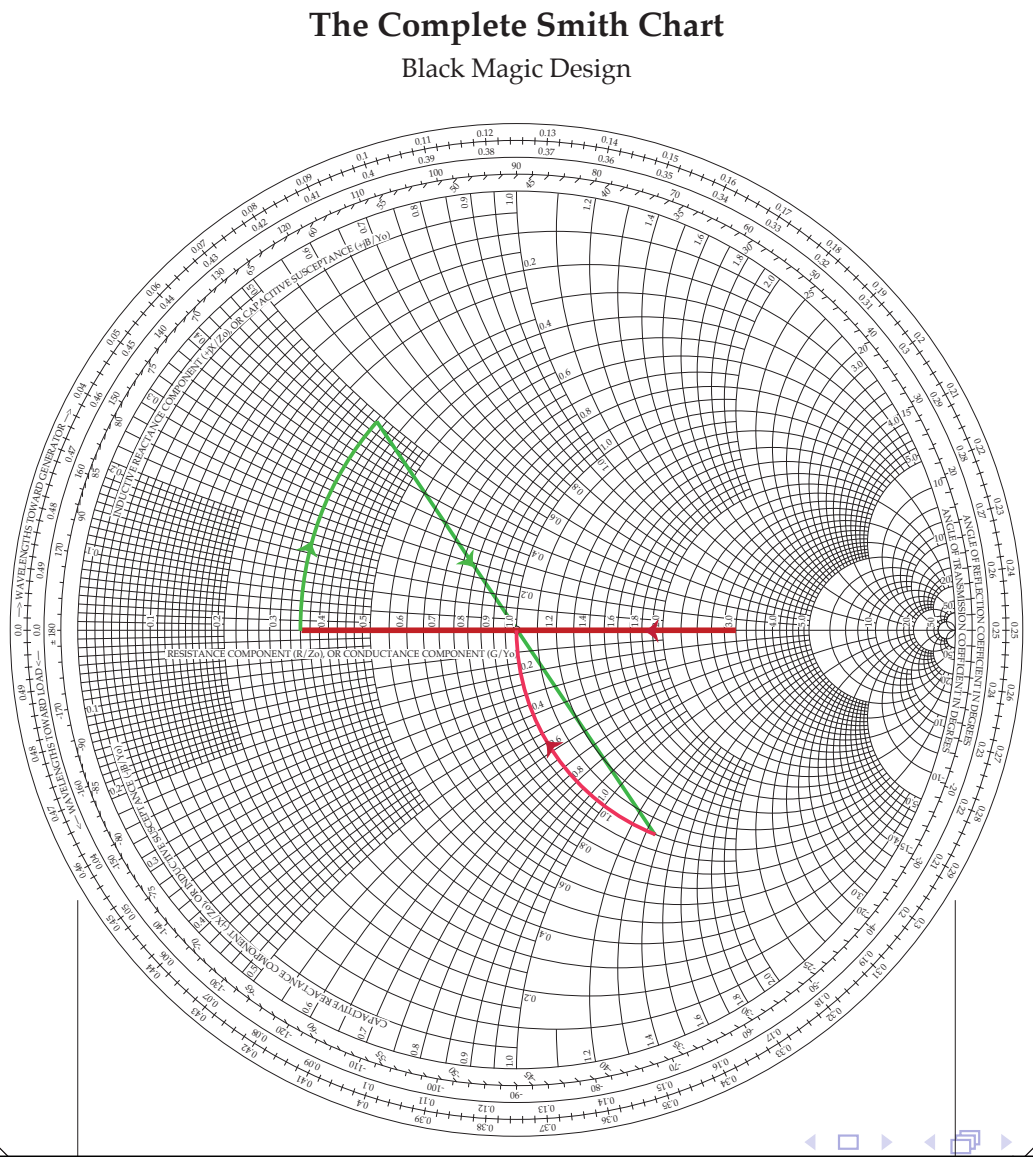
- You cannot add resistance, only reactive components.
- You are allowed to move along the transmission line.
- You are allowed to go to admittance diagram and add susceptance.

Impedance match by Smith chart example

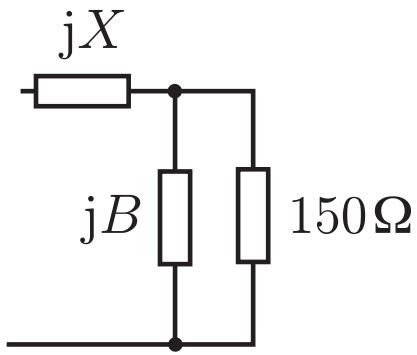
Goal: Match with two reactive components at $z = d$.



Impedance match by Smith chart example



Impedance match by Smith chart example



$$B = \frac{0.475}{50} = 9.5 \text{ mA/V and } X = 1.38 \cdot 50 = 69 \text{ V/A.}$$

$$Z = \text{j}69 + \frac{1}{\frac{1}{150} + \text{j}\frac{0.475}{50}} \approx 49.5\,\Omega - \text{j}1.5 \text{ V/A}$$