Lecture 5
2018/2019

Microwave Devices and Circuits for Radiocommunications

2018/2019

- 2C/1L, MDCR
- Attendance at minimum 7 sessions (course + laboratory)
- Lectures- associate professor Radu Damian
  - Friday 09-11, II.13
  - E – 50% final grade
  - problems + (2p atten. lect.) + (3 tests) + (bonus activity)
    - 3p=+0.5p
  - all materials/equipments authorized
- Laboratory – associate professor Radu Damian
  - Wednesday 12-14, II.12 odd weeks
  - L – 25% final grade
  - P – 25% final grade

Materials

- http://rf-opto.etti.tuiasi.ro

Laboratorul de Microunde si Opt

Not secure | rf-opto.etti.tuiasi.ro/microwave_cd.php?chg_lang=0

Main Courses Master Staff Research Students Admin

Microwave CD Optical Communications Optoelectronics Internet Antennas Practica Networks Educational software

Microwave Devices and Circuits for Radiocommunications (English)

Course: MDCR (2017-2018)

Course Coordinator: Assoc.P. Dr. Radu-Florin Damian
Code: EDOS412T
Discipline Type: DOS; Alternative, Specialty
Credits: 4
Enrollment Year: 4, **Sem.** 7

Activities

Course: Instructor: Assoc.P. Dr. Radu-Florin Damian, 2 Hours/Week, Specialization Section, Timetable:
Laboratory: Instructor: Assoc.P. Dr. Radu-Florin Damian, 1 Hours/Week, Group, Timetable:

Evaluation

Type: **Examen**

A: 50%, (Test/Colloquium)
B: 25%, (Seminary/Laboratory/Project Activity)
D: 25%, (Homework/Specialty papers)

Grades

Aggregate Results

Attendance

Course
Laboratory

Lists

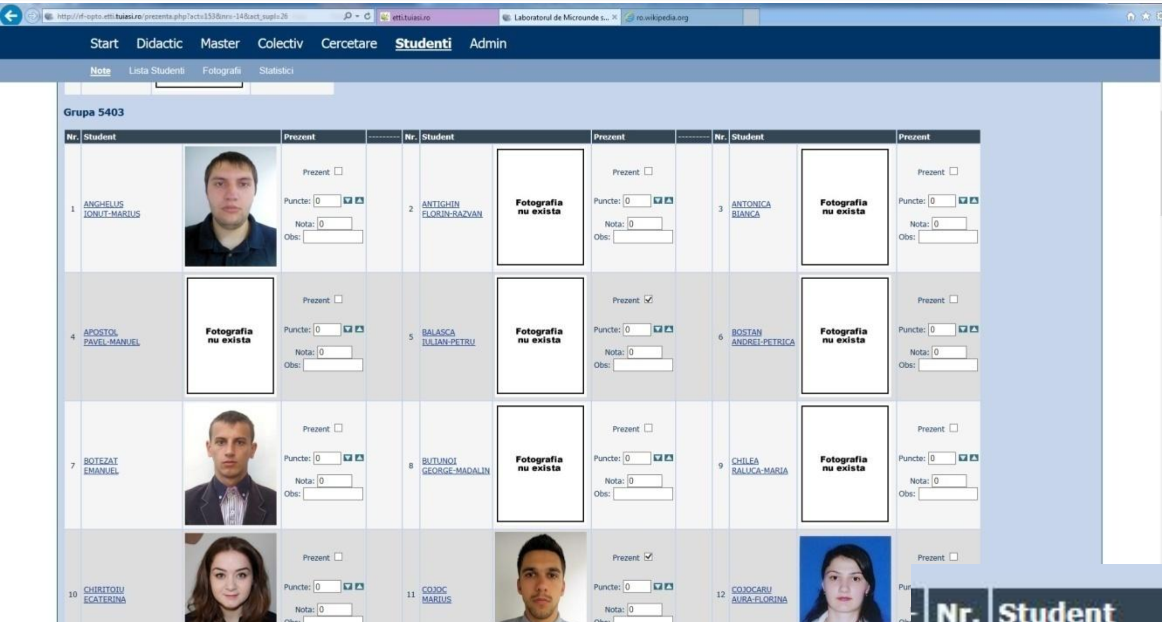
Bonus-uri acumulate (final)
Studenti care nu pot intra in examen

Materials

Course Slides

MDCR Lecture 1 (pdf, 5.43 MB, en,)
MDCR Lecture 2 (pdf, 3.67 MB, en,)
MDCR Lecture 3 (pdf, 4.76 MB, en,)
MDCR Lecture 4 (pdf, 5.58 MB, en,)

Photos



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Student
Prezent
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ANTIGHIN FLORIN-RAZVAN
ANTONICA BIANCA
APOSTOL PAVEL-MANUEL
BALASCA IULIAN-PETRU
BOSTAN ANDREI-PETRICA
BOTEZAT EMANUEL
BUTUNOI GEORGE-MADALIN
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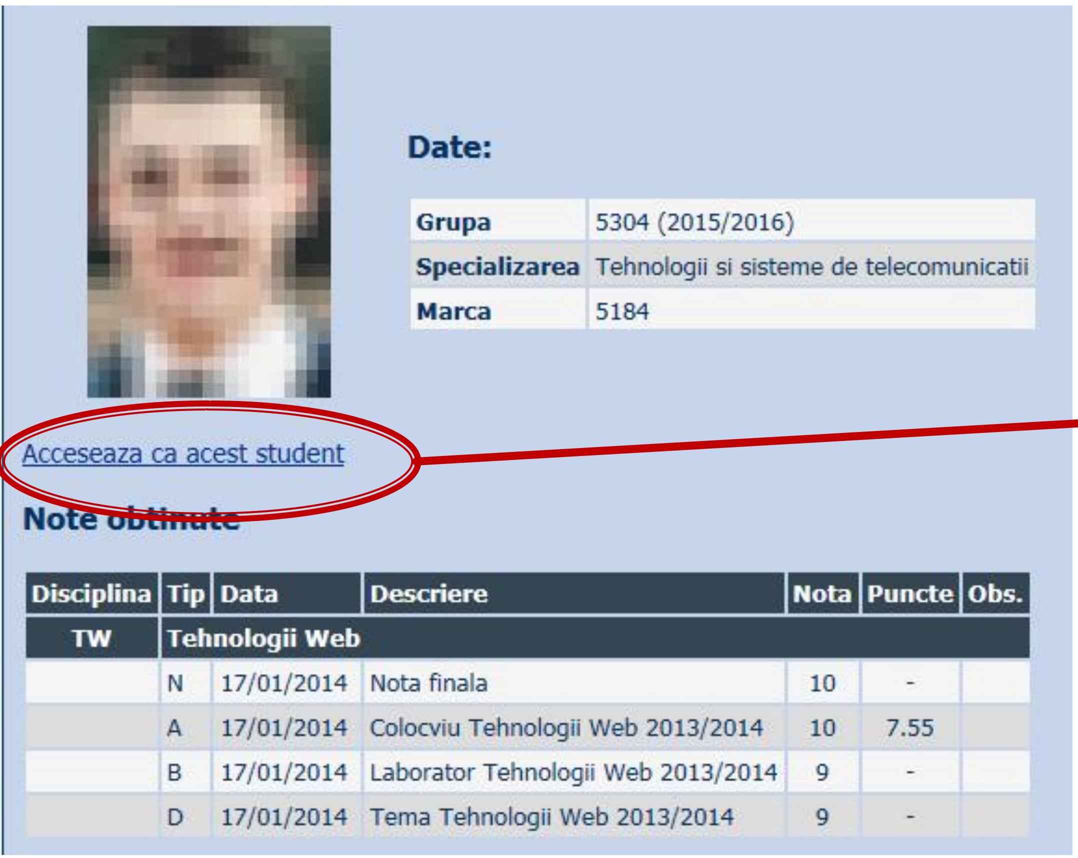


Date:

Grupa	5304 (2015/2016)
Specializarea	Tehnologii si sisteme de telecomunicatii
Marca	5184

Acceseaza ca acest student

Note obtinute

Disciplina	Tip	Data	Descriere	Nota	Puncte	Obs.
TW	Tehnologii Web					
	N	17/01/2014	Nota finala	10	-	
	A	17/01/2014	Colocviu Tehnologii Web 2013/2014	10	7.55	
	B	17/01/2014	Laborator Tehnologii Web 2013/2014	9	-	
	D	17/01/2014	Tema Tehnologii Web 2013/2014	9	-	

Examen: Logarithmic scales

dB $= 10 \cdot \log_{10}(P_2 / P_1)$

0 dB	= 1
+ 0.1 dB	= 1.023 (+2.3%)
+ 3 dB	= 2
+ 5 dB	= 3
+ 10 dB	= 10
-3 dB	= 0.5
-10 dB	= 0.1
-20 dB	= 0.01
-30 dB	= 0.001

dBm $= 10 \cdot \log_{10}(P / 1\ mW)$

0 dBm	= 1 mW
3 dBm	= 2 mW
5 dBm	= 3 mW
10 dBm	= 10 mW
20 dBm	= 100 mW
-3 dBm	= 0.5 mW
-10 dBm	= 100 µW
-30 dBm	= 1 µW
-60 dBm	= 1 nW

[dBm] + [dB] = [dBm]

[dBm/Hz] + [dB] = [dBm/Hz]

[x] + [dB] = [x]

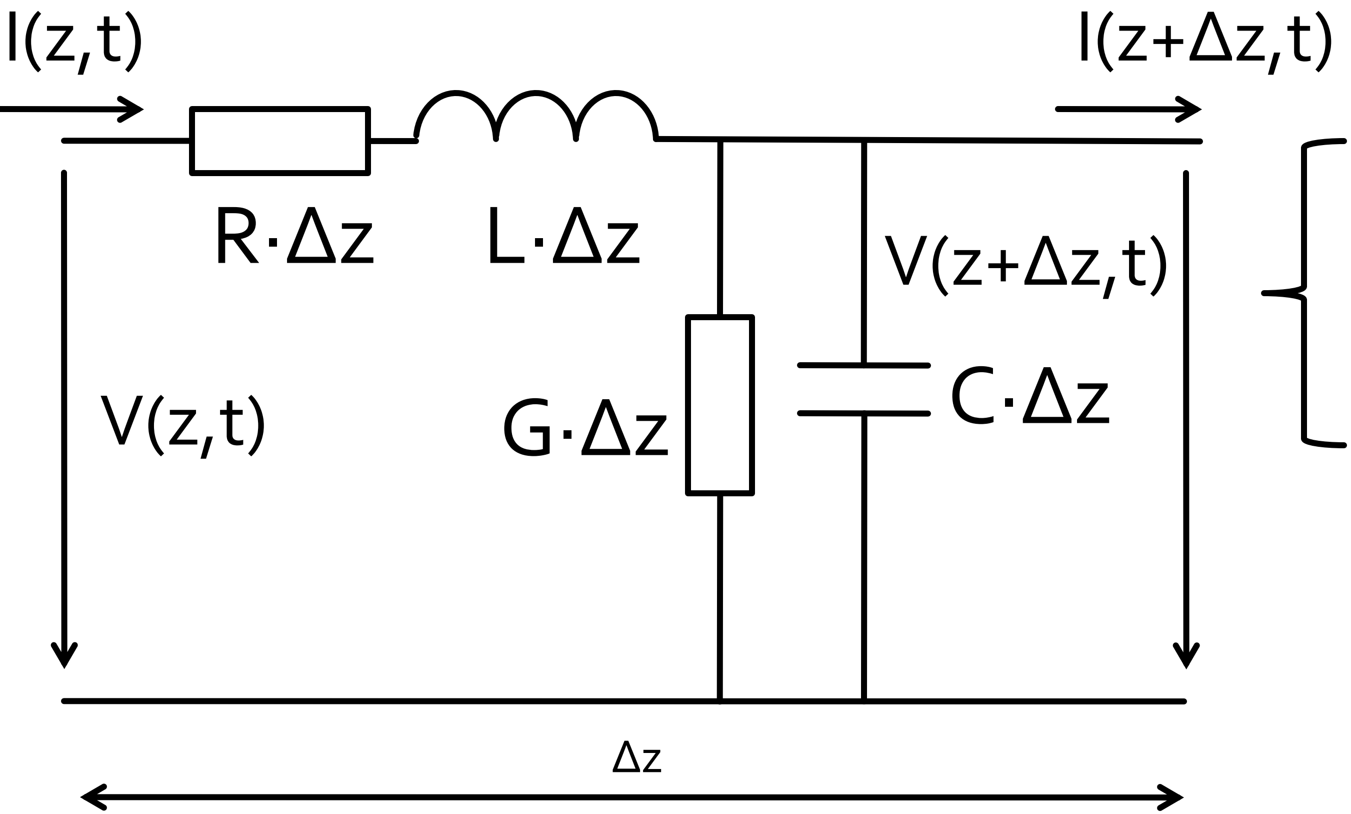
Examen

- Complex numbers arithmetic**!!!!**
- $z = a + j \cdot b$; **$j^2 = -1$**

TEM transmission lines

Transmission line equivalent model

- TEM wave propagation, at least two conductors



$$\begin{cases} V(z) = V_0^+ e^{-\gamma \cdot z} + V_0^- e^{\gamma \cdot z} \\ I(z) = I_0^+ e^{-\gamma \cdot z} + I_0^- e^{\gamma \cdot z} \end{cases}$$

The lossless line

$$V(z) = V_0^+ \cdot \left(e^{-j\cdot\beta\cdot z} + \Gamma \cdot e^{j\cdot\beta\cdot z}\right) \qquad I(z) = \frac{V_0^+}{Z_0} \cdot \left(e^{-j\cdot\beta\cdot z} - \Gamma \cdot e^{j\cdot\beta\cdot z}\right)$$

- time-average Power flow along the line

$$P_{avg} = \frac{1}{2} \cdot \mathrm{Re}\left\{V(z) \cdot I(z)^*\right\} = \frac{1}{2} \cdot \frac{\left|V_0^+\right|^2}{Z_0} \cdot \mathrm{Re}\left\{1 - \Gamma^* \cdot e^{-2j\cdot\beta\cdot z} + \Gamma \cdot e^{2j\cdot\beta\cdot z} - |\Gamma|^2\right\}$$

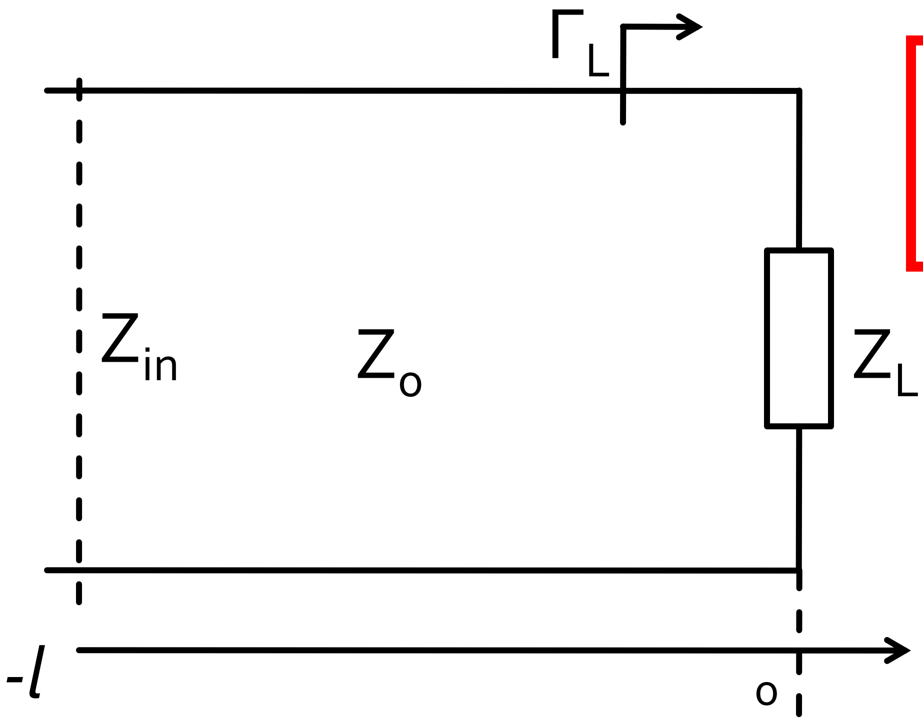
$$\left(z - z^*\right) = \mathrm{Im}$$

$$P_{avg} = \frac{1}{2} \cdot \frac{\left|V_0^+\right|^2}{Z_0} \cdot \left(1 - |\Gamma|^2\right)$$

- Total power delivered to the load = Incident power – "Reflected" power
- Return "Loss" [dB] $\qquad RL = -20 \cdot \log|\Gamma| \quad [\mathrm{dB}]$

The lossless line

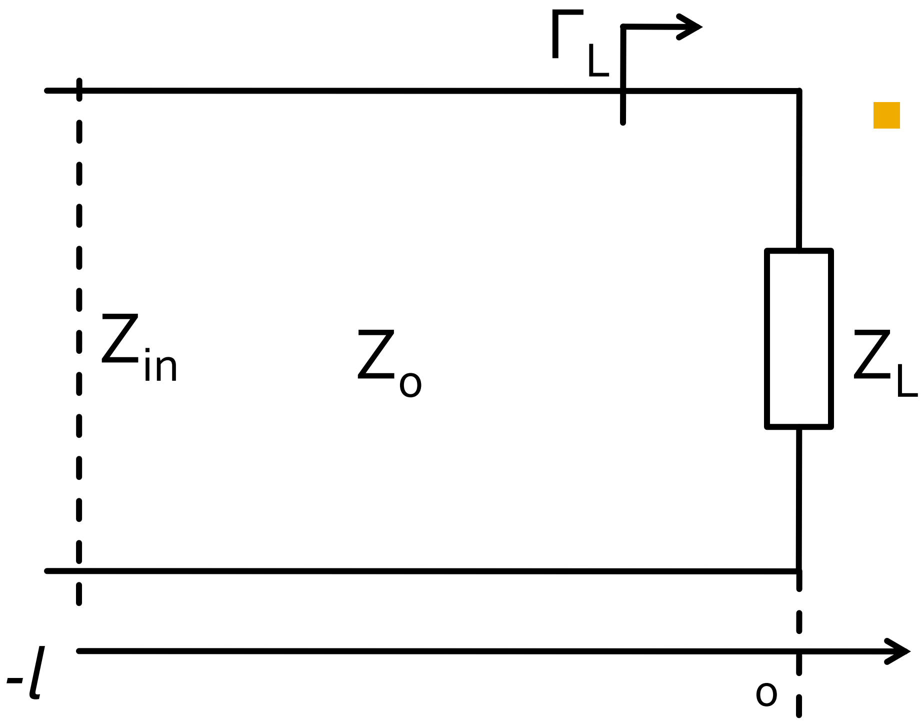
- input impedance of a length ***l*** of transmission line with characteristic impedance ***Z_o***, loaded with an arbitrary impedance ***Z_L***



$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

The lossless line, special cases

- $l = k \cdot \lambda/2$ $\quad \beta \cdot l = \frac{2\pi}{\lambda} \cdot l = k \cdot \pi$ $\quad \tan \beta \cdot l = 0$ $\quad Z_{in} = Z_0$
- $l = \lambda/4 + k \cdot \lambda/2$ $\quad \tan \beta \cdot l \to \infty$ $\quad Z_{in} = \frac{Z_0^2}{Z_L}$



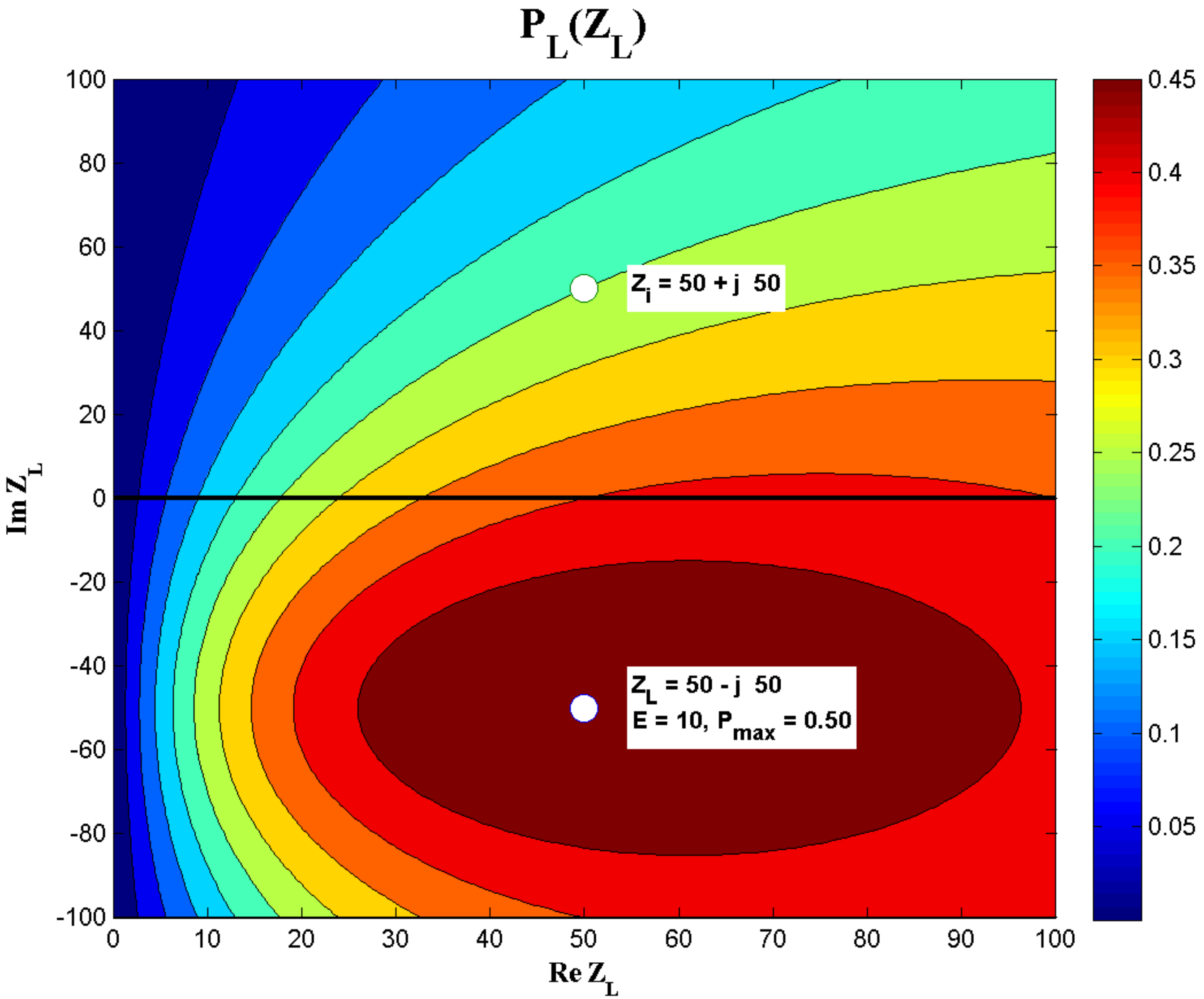
- quarter-wave transformer

$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Impedance Matching with Impedance Transformers (Lab 1)

Impedance Matching

Matching, complex impedances



$$Z_L = Z_i^*$$

Matching , from the point of view of power transmission

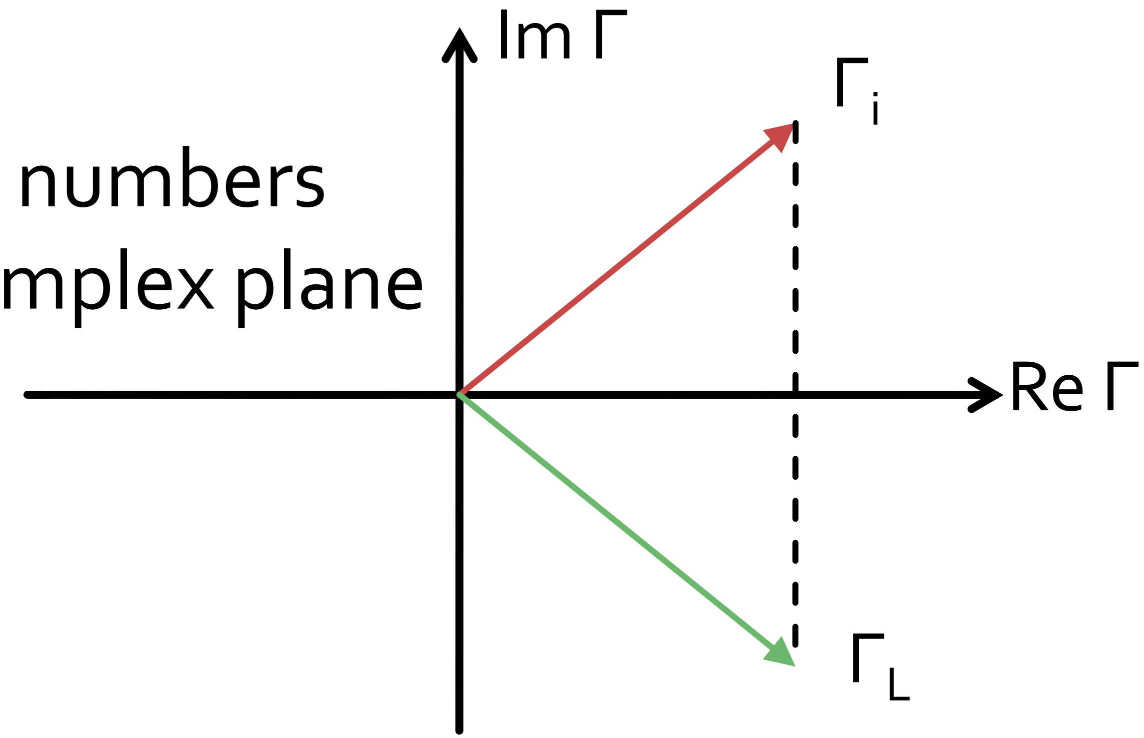
$$Z_L = Z_i^*$$

If we choose a real Zo

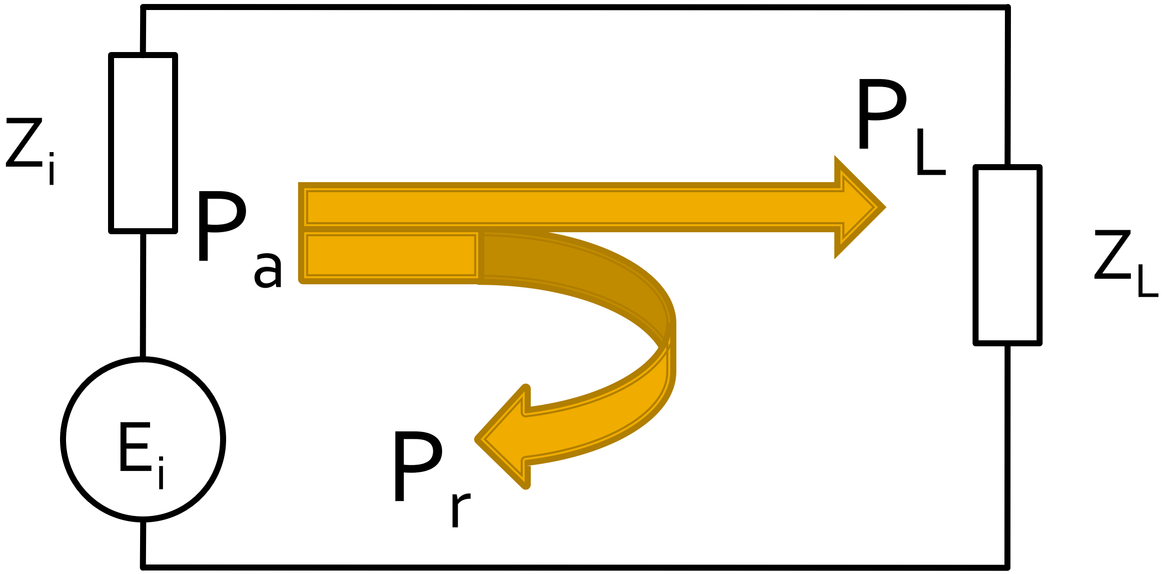
$$\Gamma = \frac{Z - Z_0}{Z + Z_0}$$

$$\Gamma_L = \Gamma_i^*$$

- complex numbers
- in the complex plane



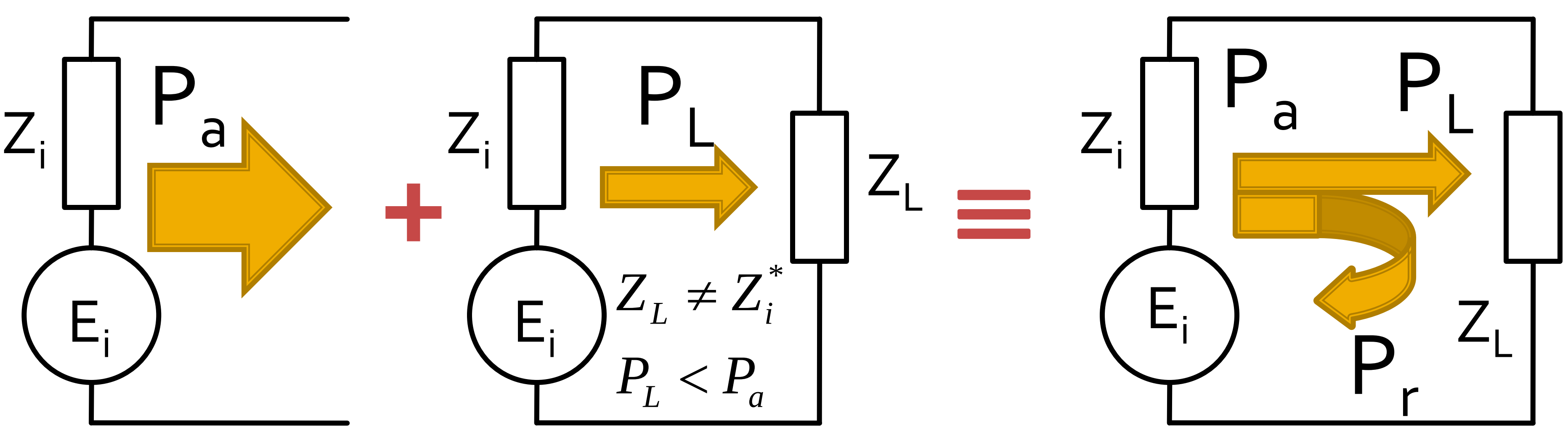
Reflection and power / Model



$$Z_L \neq Z_i^*$$

- ~~Power reflection~~
- Power of the reflected wave

Reflection and power / Model

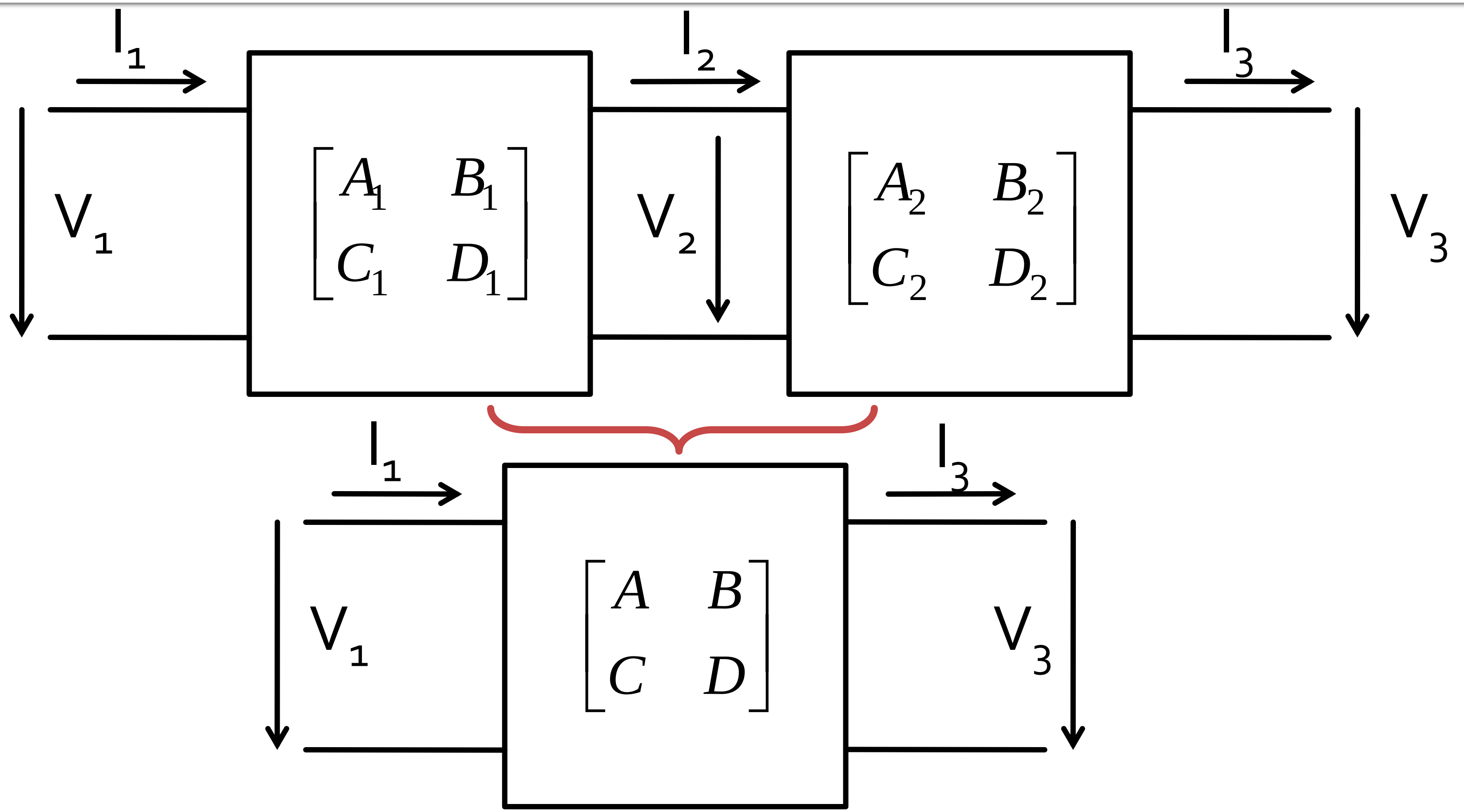


- The source has the ability to sent to the load a certain maximum power (available power) P_a
- For a particular load the power sent to the load is less than the maximum (mismatch) $P_L < P_a$
- The phenomenon is **"as if"** (model) some of the power is reflected $P_r = P_a - P_L$
- The power is a **scalar !**

Lecture 3-4

Microwave Network Analysis

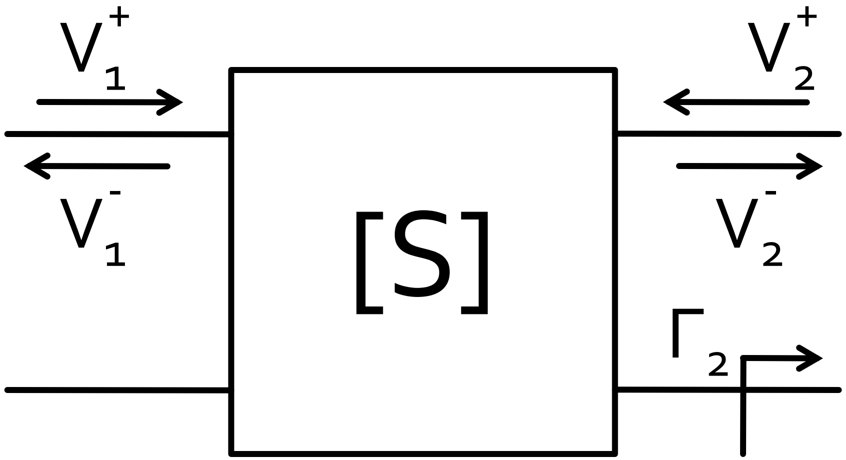
ABCD (transmission) matrix



$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdot \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix}$$

Scattering matrix – S

- Scattering parameters



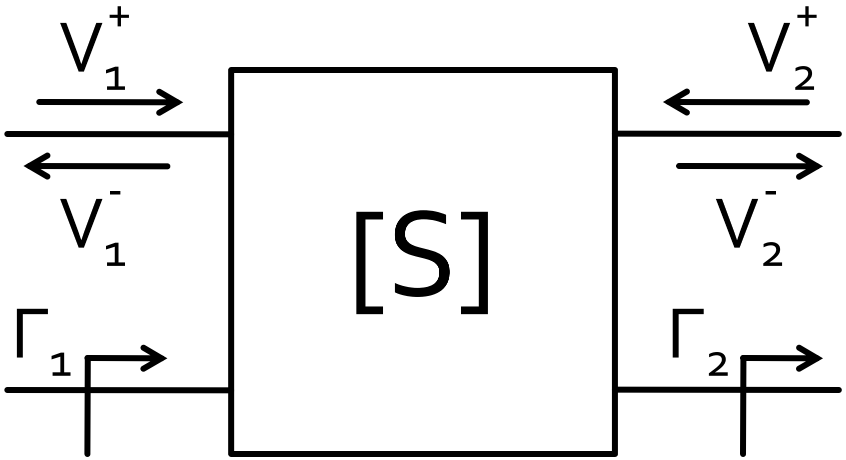
$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$S_{11} = \left. \frac{V_1^-}{V_1^+} \right|_{V_2^+=0} \qquad S_{21} = \left. \frac{V_2^-}{V_1^+} \right|_{V_2^+=0}$$

- $V_2^+ = 0$ meaning: port 2 is terminated in matched load to avoid reflections towards the port

$$\Gamma_2 = 0 \rightarrow V_2^+ = 0$$

Scattering matrix – S



$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$S_{11} = \left. \frac{V_1^-}{V_1^+} \right|_{V_2^+=0} = \Gamma_1 \big|_{\Gamma_2=0}$$

$$S_{21} = \left. \frac{V_2^-}{V_1^+} \right|_{V_2^+=0} = T_{21} \big|_{\Gamma_2=0}$$

- S11 is the reflection coefficient seen looking into port ***1*** when port ***2*** is terminated in matched load
- S21 is the transmission coefficient from port ***1*** (**second** index) to port ***2*** (**first** index) when port ***2*** is terminated in matched load

Scattering matrix – S

- S matrix can be extended to multiple ports

$$S_{ii} = \left.\frac{V_i^-}{V_i^+}\right|_{V_k^+=0,\forall k\neq i} \qquad S_{ij} = \left.\frac{V_i^-}{V_j^+}\right|_{V_k^+=0,\forall k\neq j}$$

  - S_{ii} is the reflection coefficient seen looking into port *i* when all other ports are terminated in matched loads
  - S_{ij} is the transmission coefficient from port *j* (**second** index) to port *i* (**first** index) when all other ports are terminated in matched loads

Properties of S matrix

- If port i is connected to a transmission line with charateristic impedance Z_{oi}

$$[Z_0]=\begin{bmatrix} Z_{01} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & Z_{0n} \end{bmatrix}$$

- Lecture 2

$$V(z)=V_0^+ e^{-j\cdot\beta\cdot z}+V_0^- e^{j\cdot\beta\cdot z} \qquad I(z)=\frac{V_0^+}{Z_0}e^{-j\cdot\beta\cdot z}-\frac{V_0^-}{Z_0}e^{j\cdot\beta\cdot z}$$

In the port's reference plane, z=o

$$V_i=V_i^+ + V_i^- \qquad I_i=\frac{V_i^+}{Z_{0i}}-\frac{V_i^-}{Z_{0i}}$$

- Relation to Z matrix

$$[Z]\cdot[I]=[V]$$

$$[Z]\cdot[I]=[Z_0]^{-1}\cdot[Z]\cdot[V^+]-[Z_0]^{-1}\cdot[Z]\cdot[V^-] \qquad [V]=[V^+]+[V^-]$$

$$[Z_0]^{-1}\cdot[Z]\cdot[V^+]-[Z_0]^{-1}\cdot[Z]\cdot[V^-]=[V^+]+[V^-] \qquad ([Z]-[Z_0])\cdot[V^+]=([Z]+[Z_0])\cdot[V^-]$$

$$[V^-]=[S]\cdot[V^+] \qquad \boxed{[S]=([Z]-[Z_0])\cdot([Z]+[Z_0])^{-1}}$$

Generalized Scattering Parameters

- We define the power wave amplitudes a and b

$$a = \frac{V + Z_R \cdot I}{2 \cdot \sqrt{R_R}}$$ the incident power wave

$$Z_R = R_R + j \cdot X_R$$

Any complex impedance, named reference impedance

$$b = \frac{V - Z_R^* \cdot I}{2 \cdot \sqrt{R_R}}$$ the reflected power wave

- Total voltage and current in terms of the power wave amplitudes

$$V = \frac{Z_R^* \cdot a + Z_R \cdot b}{\sqrt{R_R}}$$

$$I = \frac{a - b}{\sqrt{R_R}}$$

Power waves for N ports

$$[b]=[F]\cdot\left([Z]-[Z_R]^*\right)\cdot\left([Z]+[Z_R]\right)^{-1}\cdot[F]^{-1}\cdot[a]$$

- The scattering matrix for power waves, $[S_p]$

$$[b]=\left[S_p\right]\cdot[a]$$

$$\left[S_p\right]=[F]\cdot\left([Z]-[Z_R]^*\right)\cdot\left([Z]+[Z_R]\right)^{-1}\cdot[F]^{-1}$$

- But: $[S]=\left([Z]-[Z_0]\right)\cdot\left([Z]+[Z_0]\right)^{-1}$

- Typically

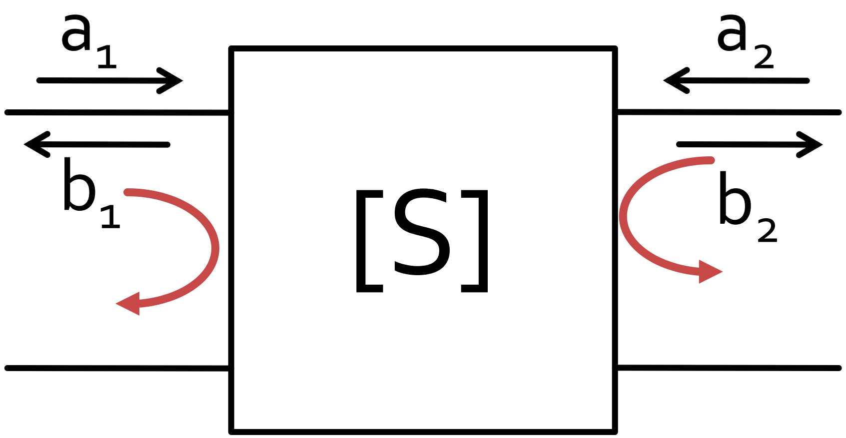
$$Z_{0i}=Z_{Ri}=R_0,\forall i$$

$$R_0=50\Omega$$

$$\left[S_p\right]\equiv[S]$$

- **they coincide!!!**

Scattering matrix – S

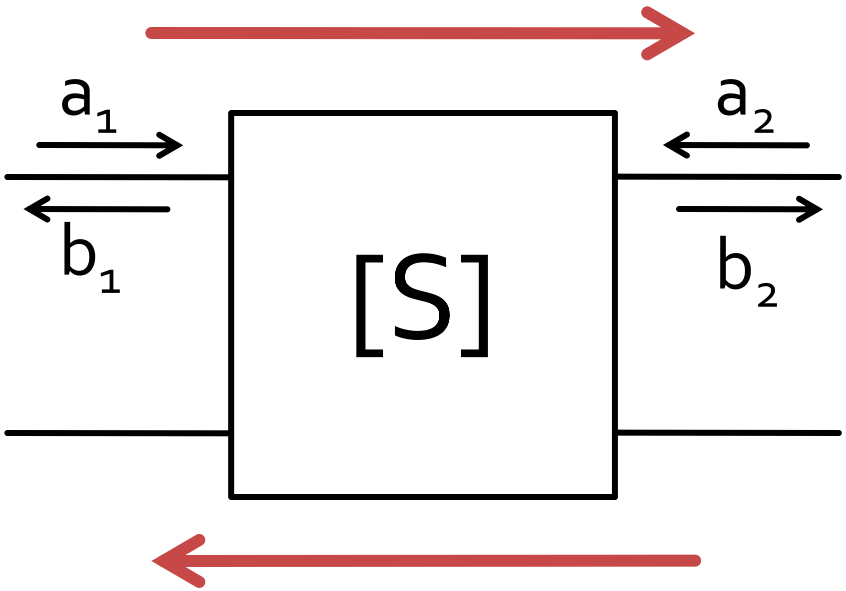


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} \qquad S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0}$$

- S_{11} and S_{22} are reflection coefficients at ports 1 and 2 when the other port is matched

Scattering matrix – S

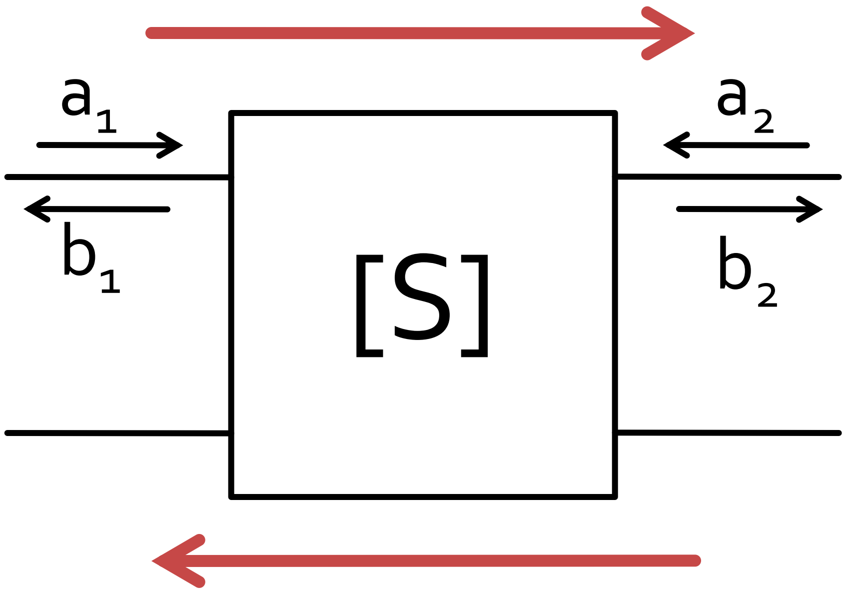


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{21} = \left. \frac{b_2}{a_1} \right|_{a_2=0} \qquad S_{12} = \left. \frac{b_1}{a_2} \right|_{a_1=0}$$

- S_{21} si S_{12} are signal amplitude gain when the other port is matched

Scattering matrix – S



$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$|S_{21}|^2 = \frac{Power\ in\ Z_0\ load}{Power\ \ from\ Z_0\ source}$$

- a,b
  - information about signal power **AND** signal phase
- S_{ij}
  - network effect (gain) over signal power **including** phase information

Measuring S parameters - VNA

- Vector Network Analyzer

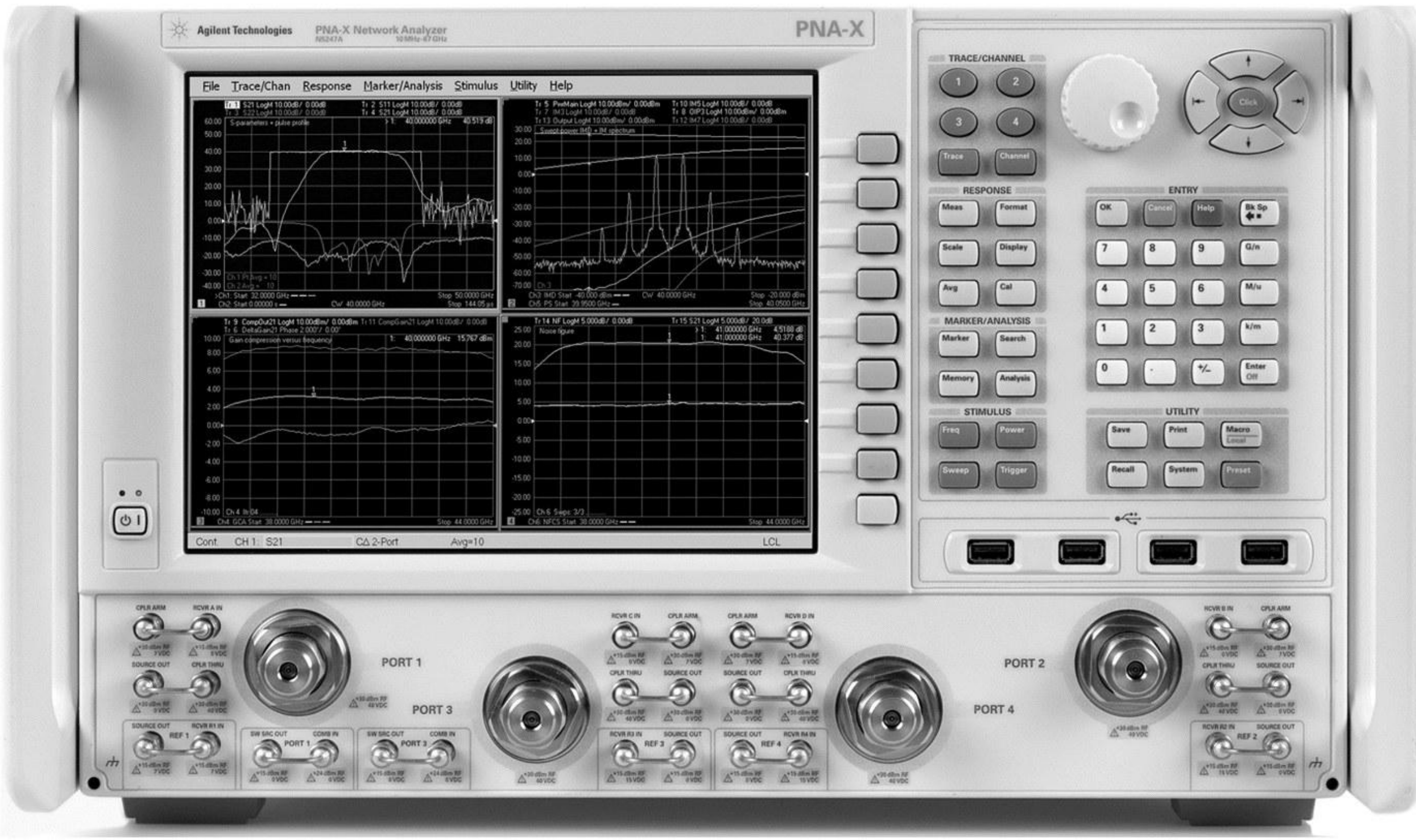
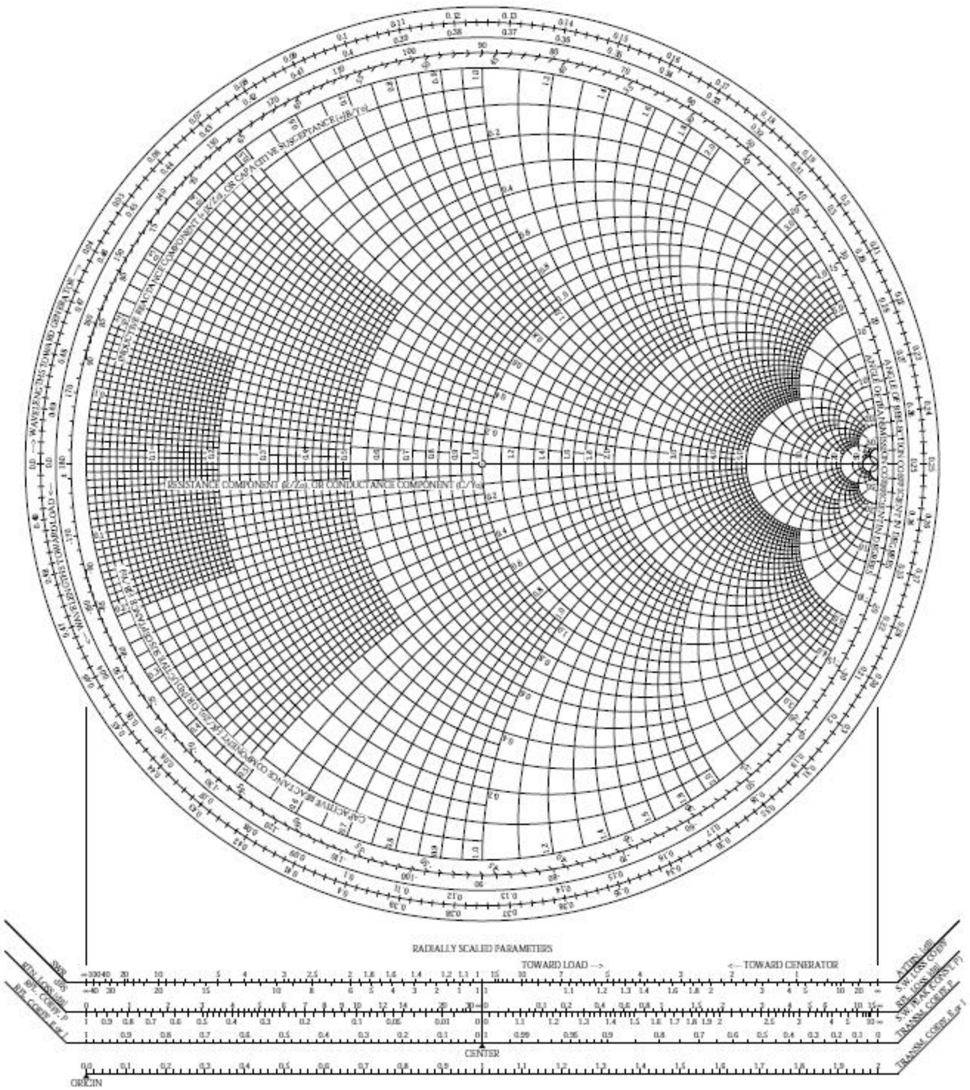


Figure 4.7
Courtesy of Agilent Technologies

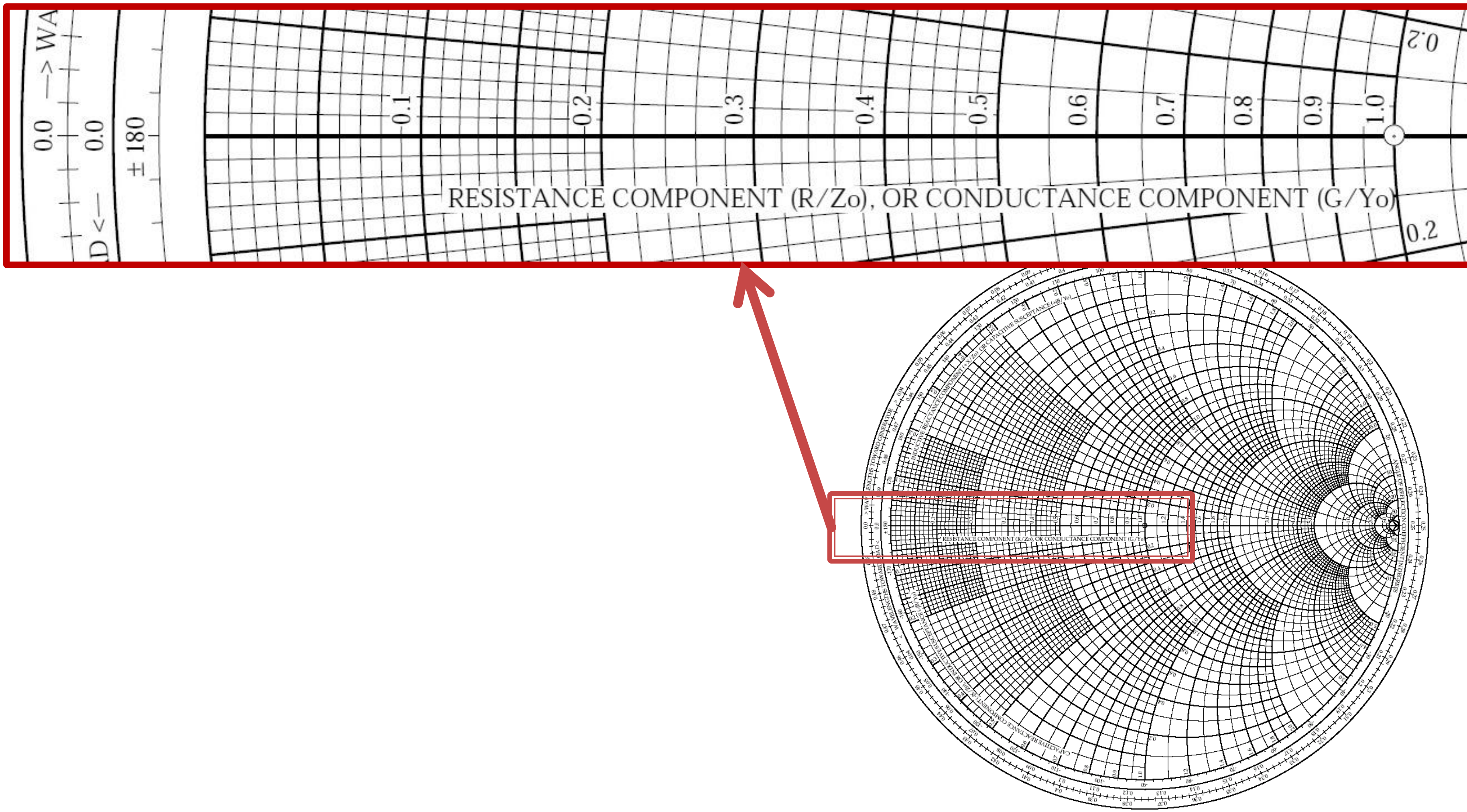
Impedance Matching

The Smith Chart

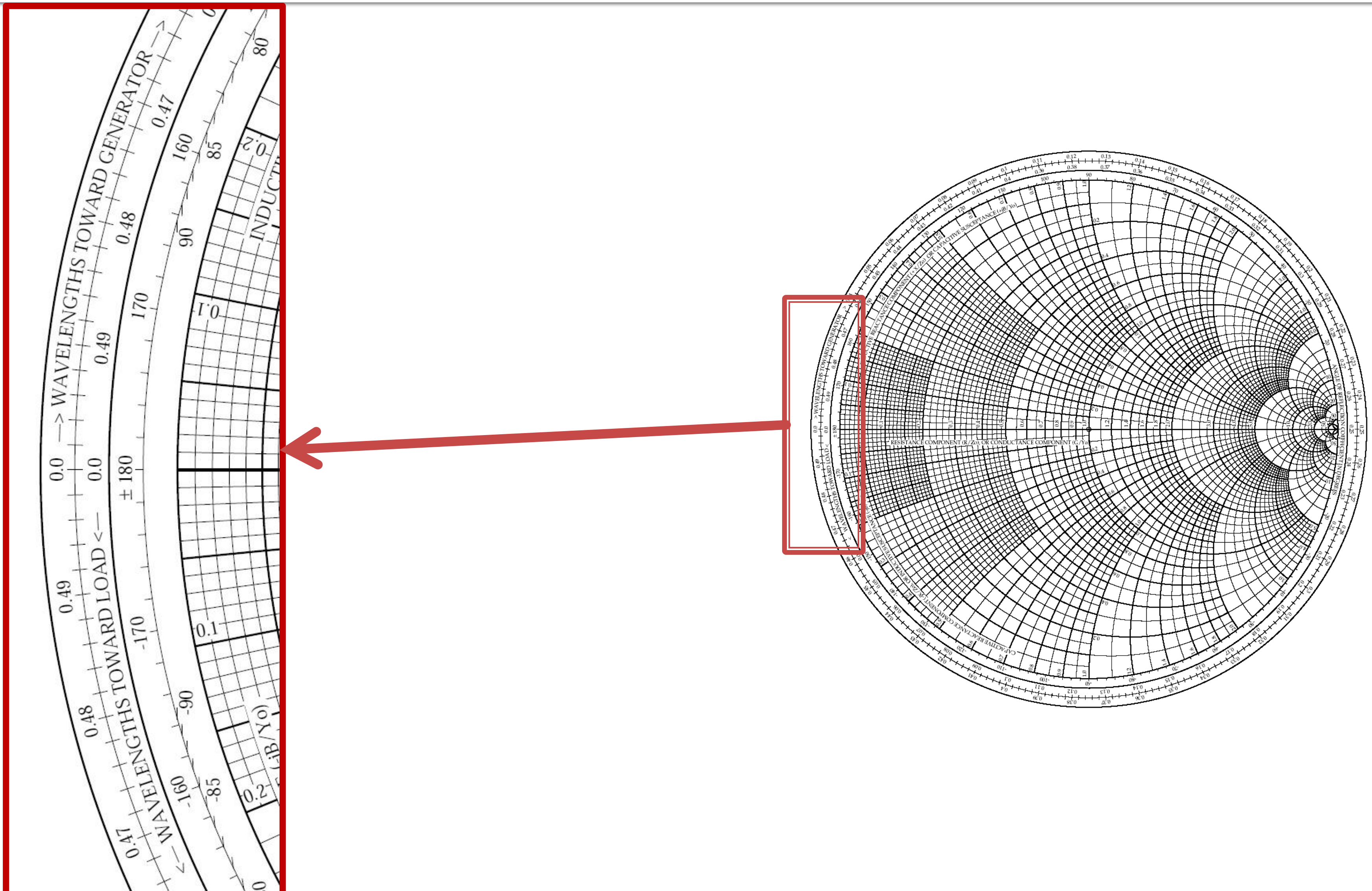
The Smith Chart



The Smith Chart



The Smith Chart



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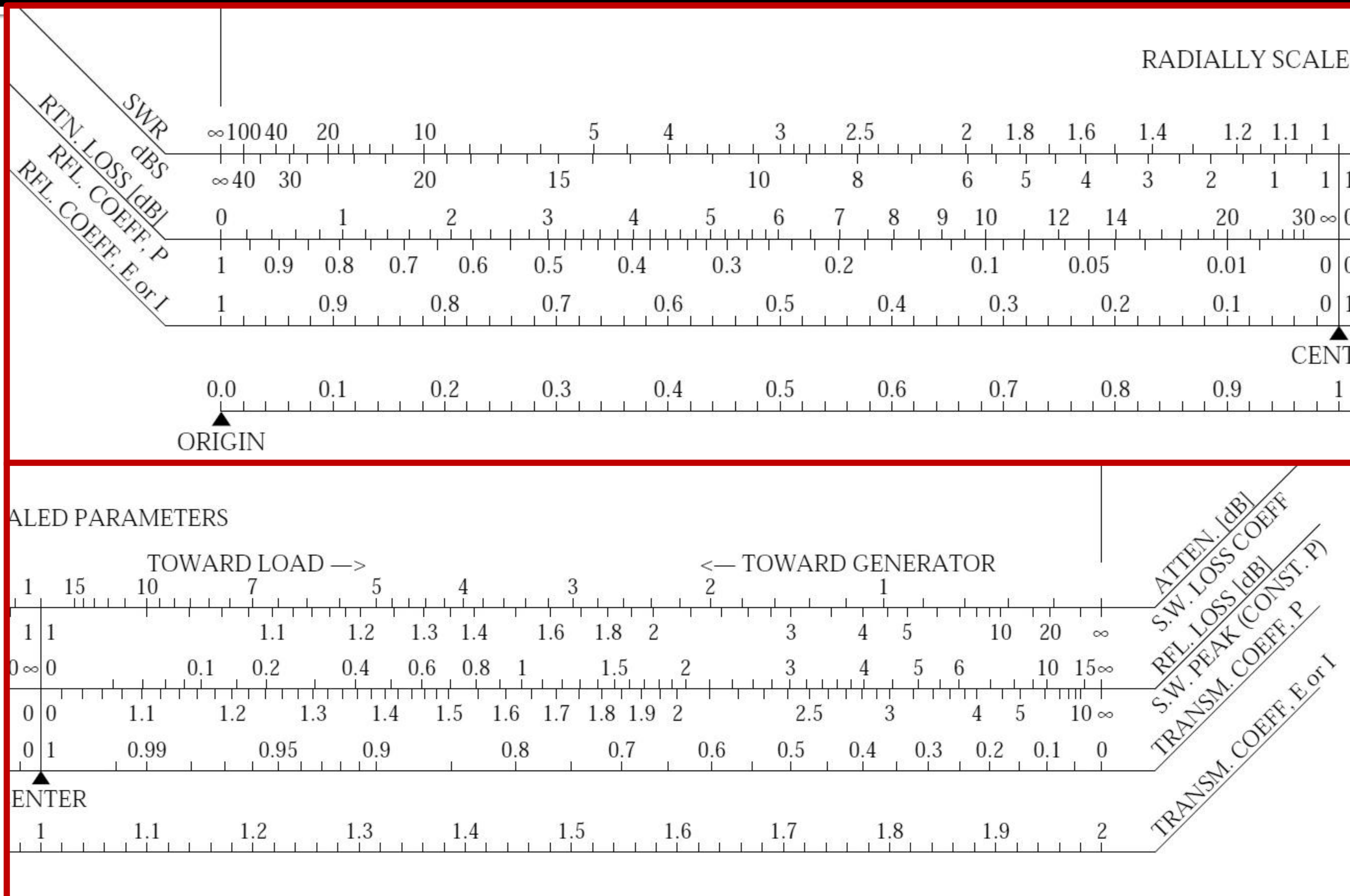
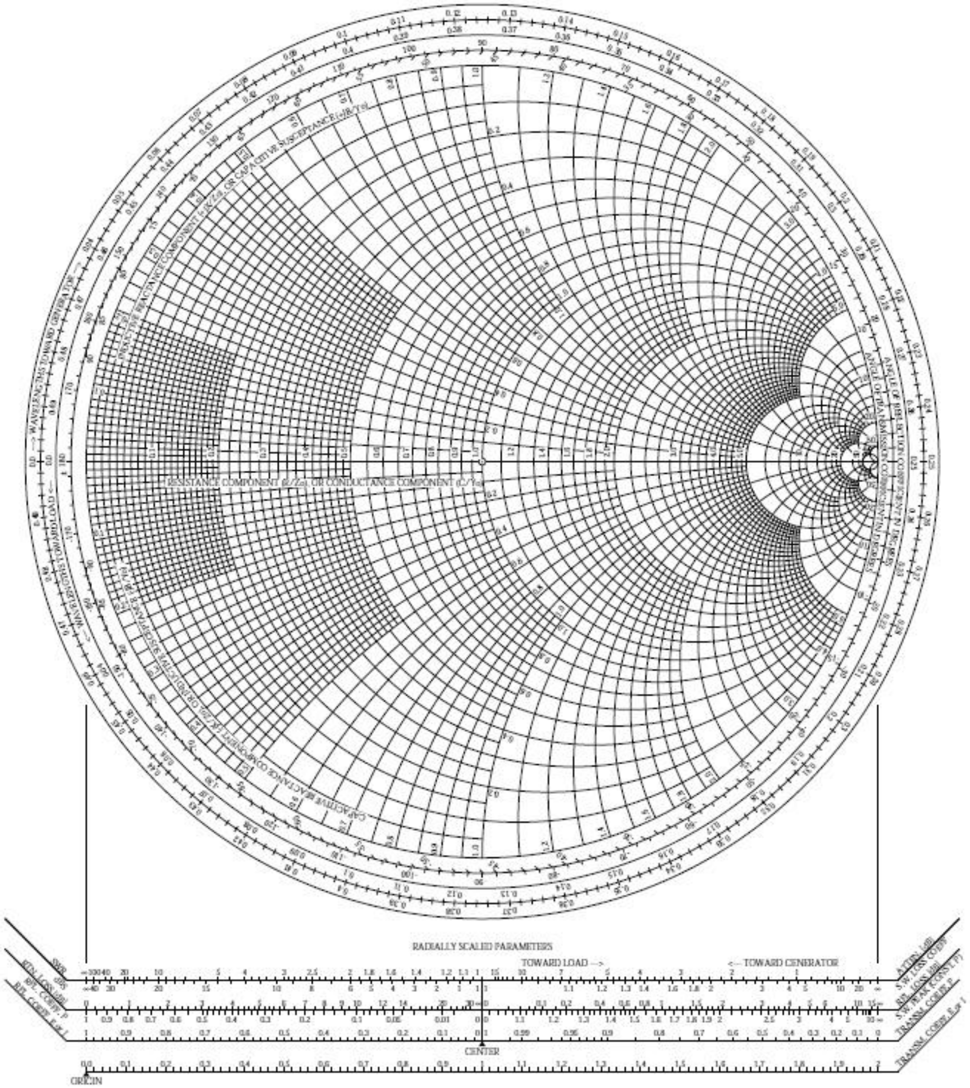
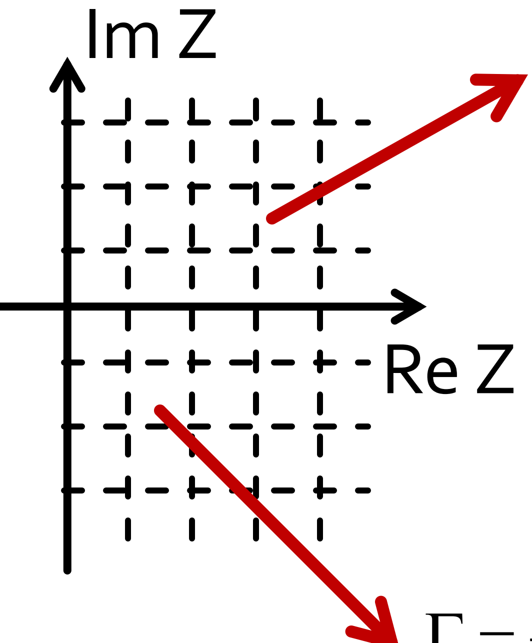


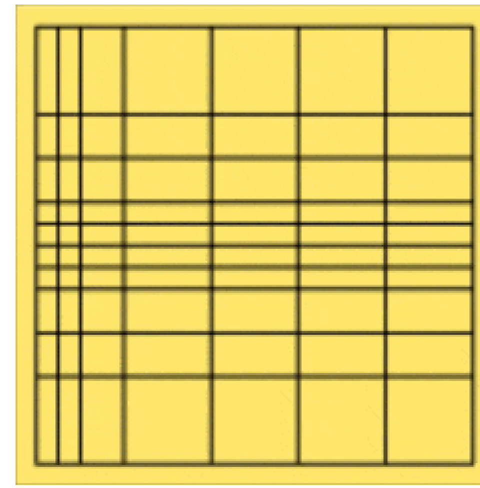
The Smith Chart



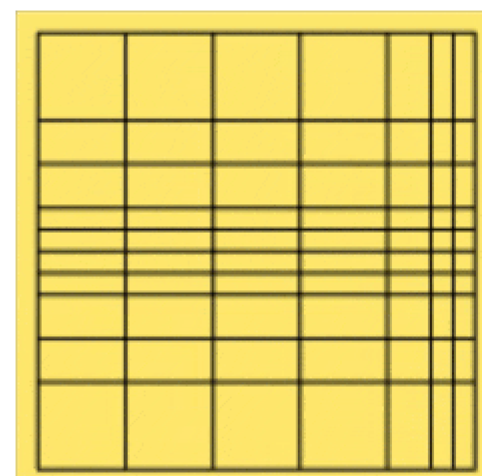
The Smith Chart



$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{z_L - 1}{z_L + 1}$$

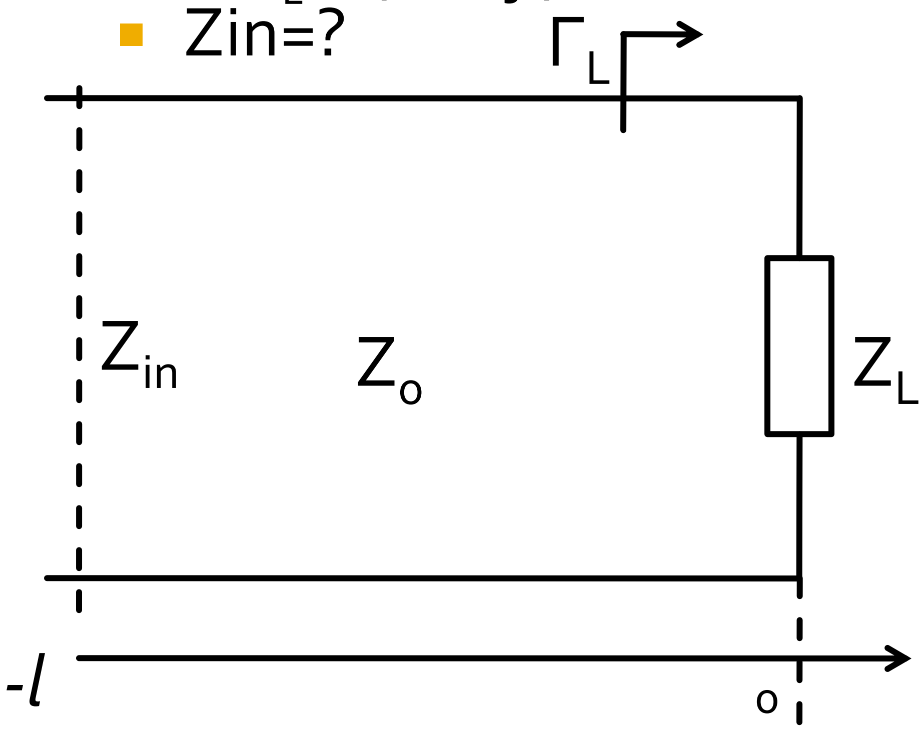


$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{Y_0 - Y_L}{Y_0 + Y_L} = \frac{1 - y_L}{1 + y_L}$$



Traditional usage

- transmission line
  - 100Ω characteristic impedance
  - 0.3λ length
  - $Z_L = 40\Omega + j \cdot 70\Omega$ load
- Zin=?



$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

$$Z_{in} = 36.5340\,\Omega - j \cdot 61.1190\,\Omega$$

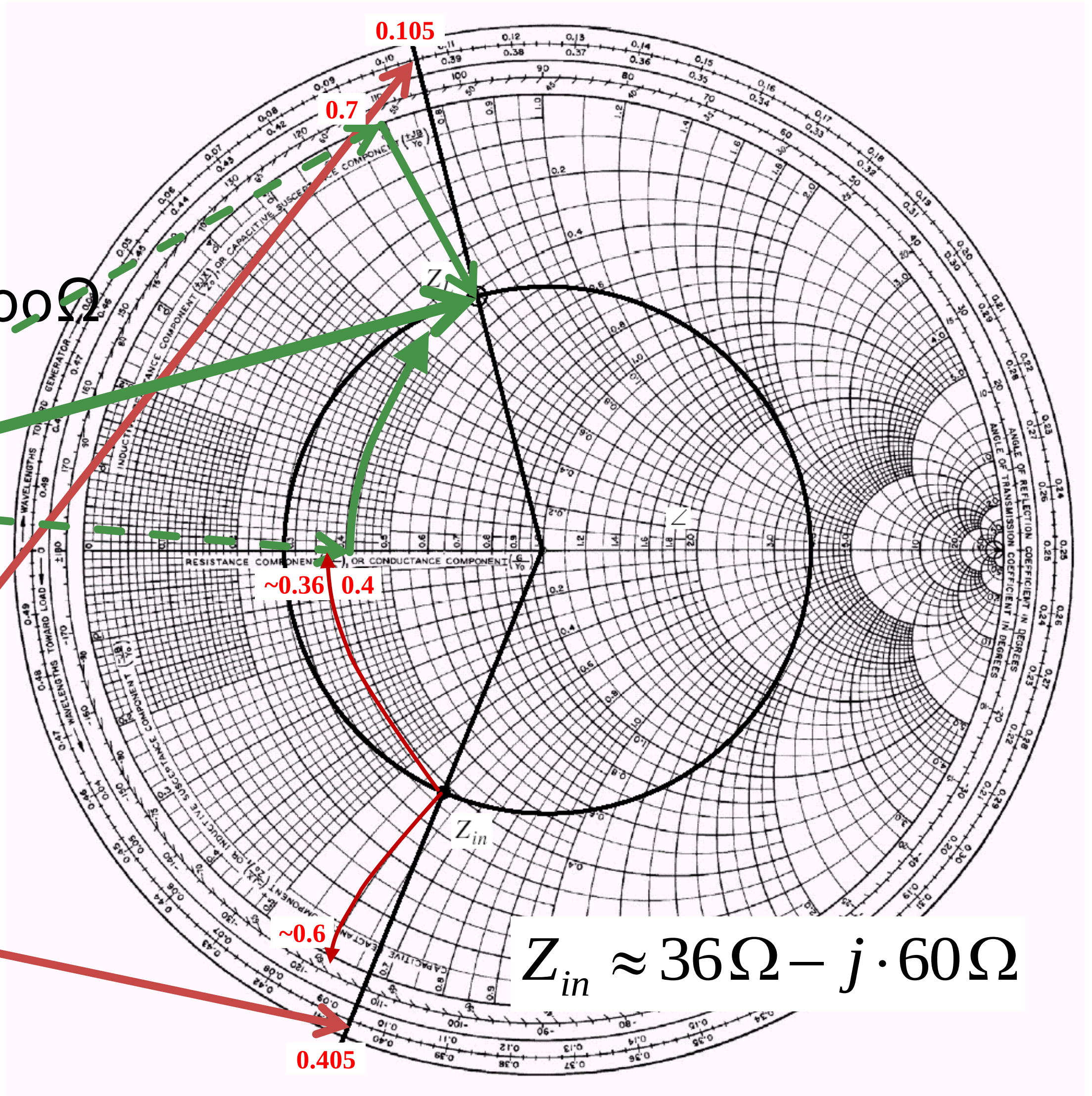
Traditional usage

- transmission line
  - 100Ω impedance
  - 0.3λ length
  - $Z_L = 40\Omega + j\cdot 70\Omega$ load
- normalization with $Z_0 = 100\Omega$

$$z_L = \frac{Z_L}{Z_0} = 0.4 + j\cdot 0.7$$

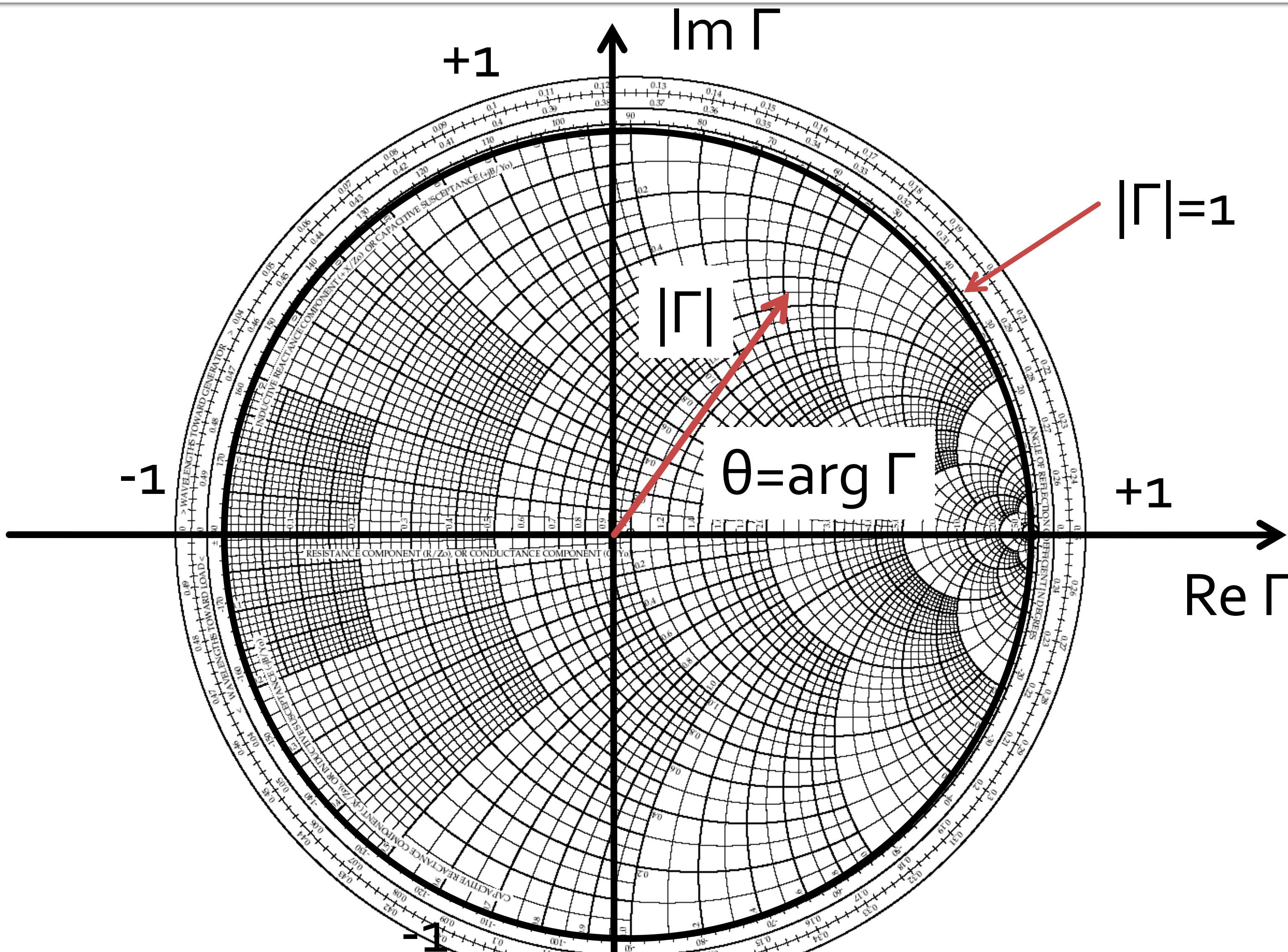
- movement with 0.3λ on a line with $Z_0 = 100\Omega$ (**circle**)
  - from z_L (0.105λ)
  - to z_{in} (0.405λ)

$$z_{in} \approx 0.36 - j\cdot 0.6 = \frac{Z_{in}}{Z_0}$$

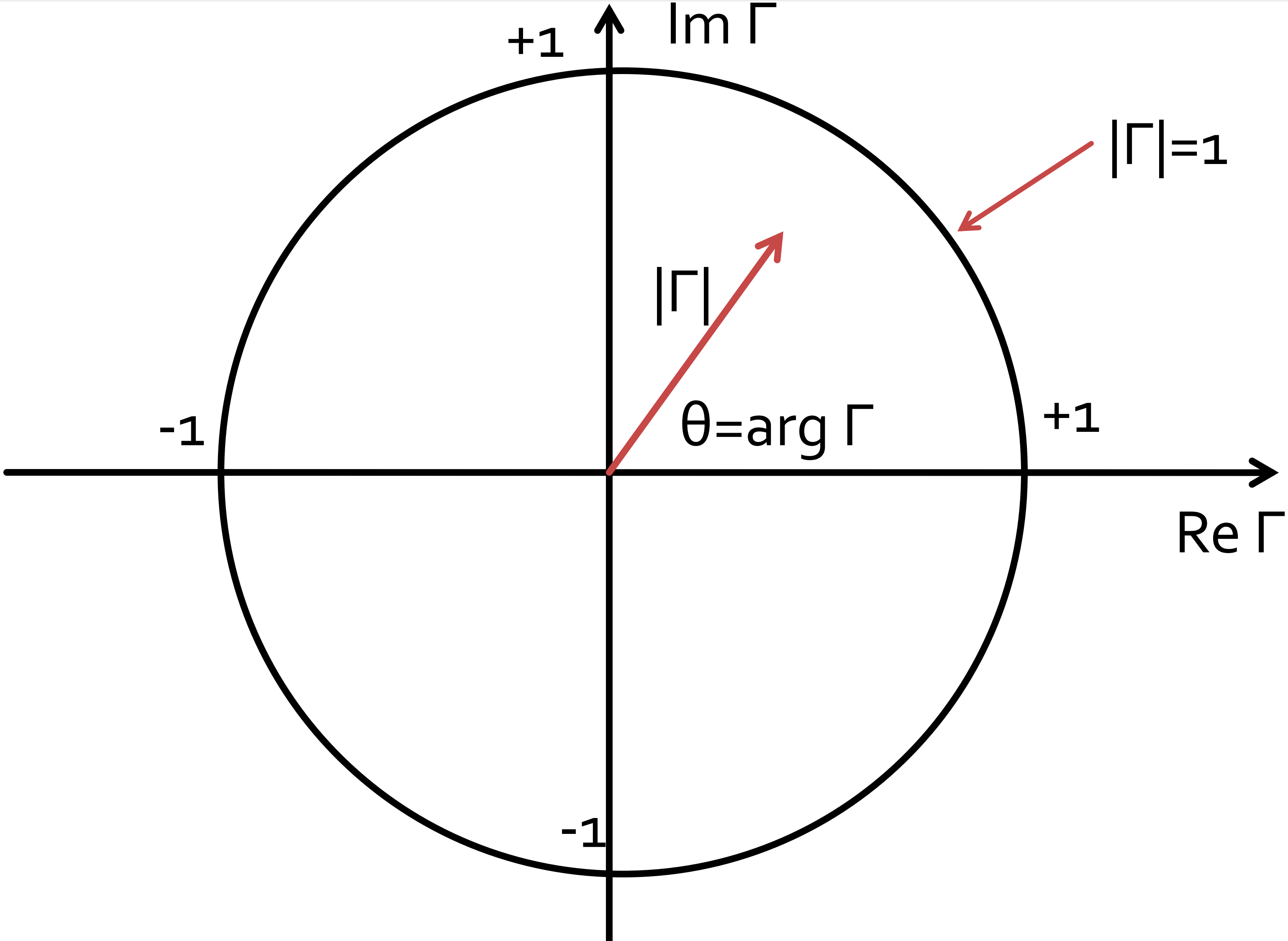


$$Z_{in} \approx 36\Omega - j\cdot 60\Omega$$

The Smith Chart

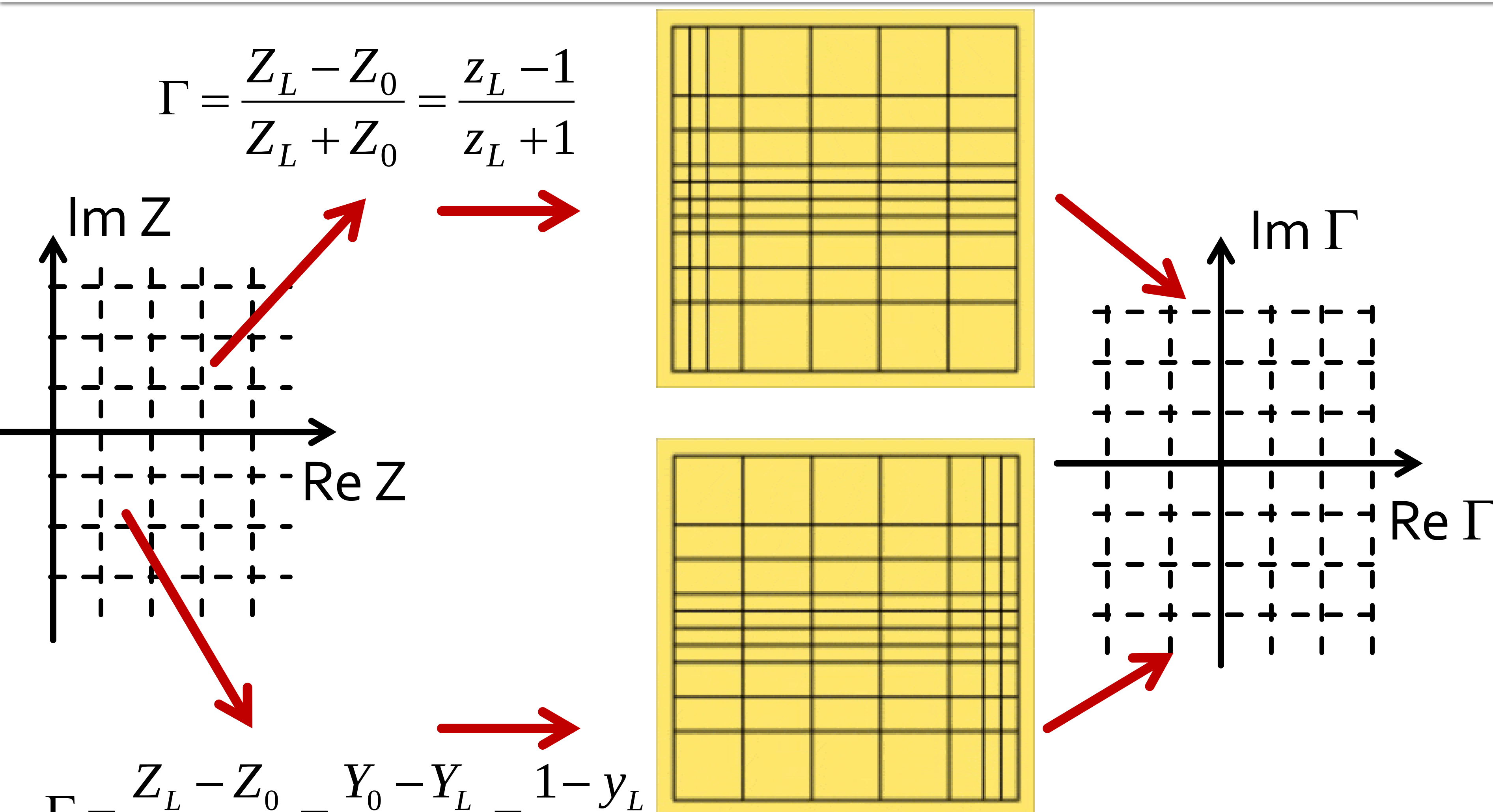


The Smith Chart



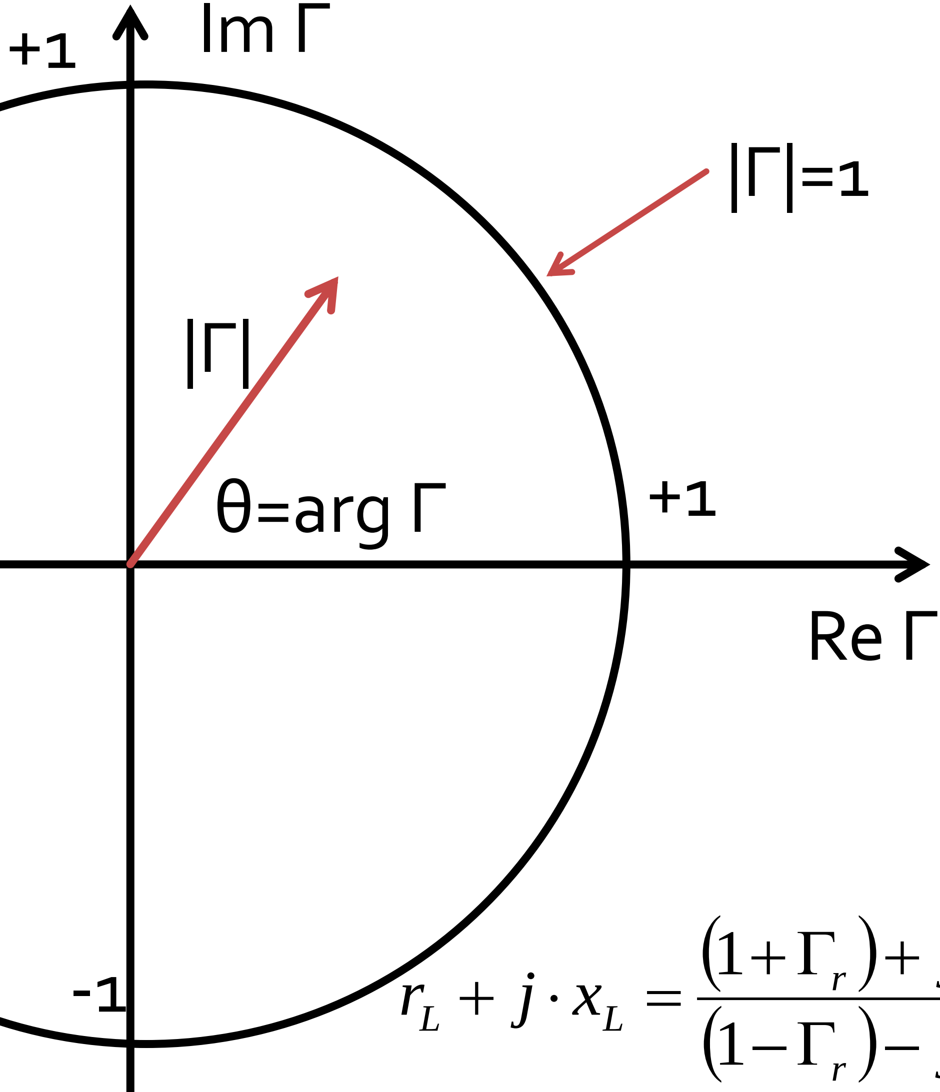
The Smith Chart

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{z_L - 1}{z_L + 1}$$



$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{Y_0 - Y_L}{Y_0 + Y_L} = \frac{1 - y_L}{1 + y_L}$$

The Smith Chart



$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{z_L - 1}{z_L + 1} = |\Gamma| \cdot e^{j\theta}$$

$$z_L = \frac{Z_L}{Z_0} \qquad y_L = \frac{Y_L}{Y_0} = \frac{Z_0}{Z_L}$$

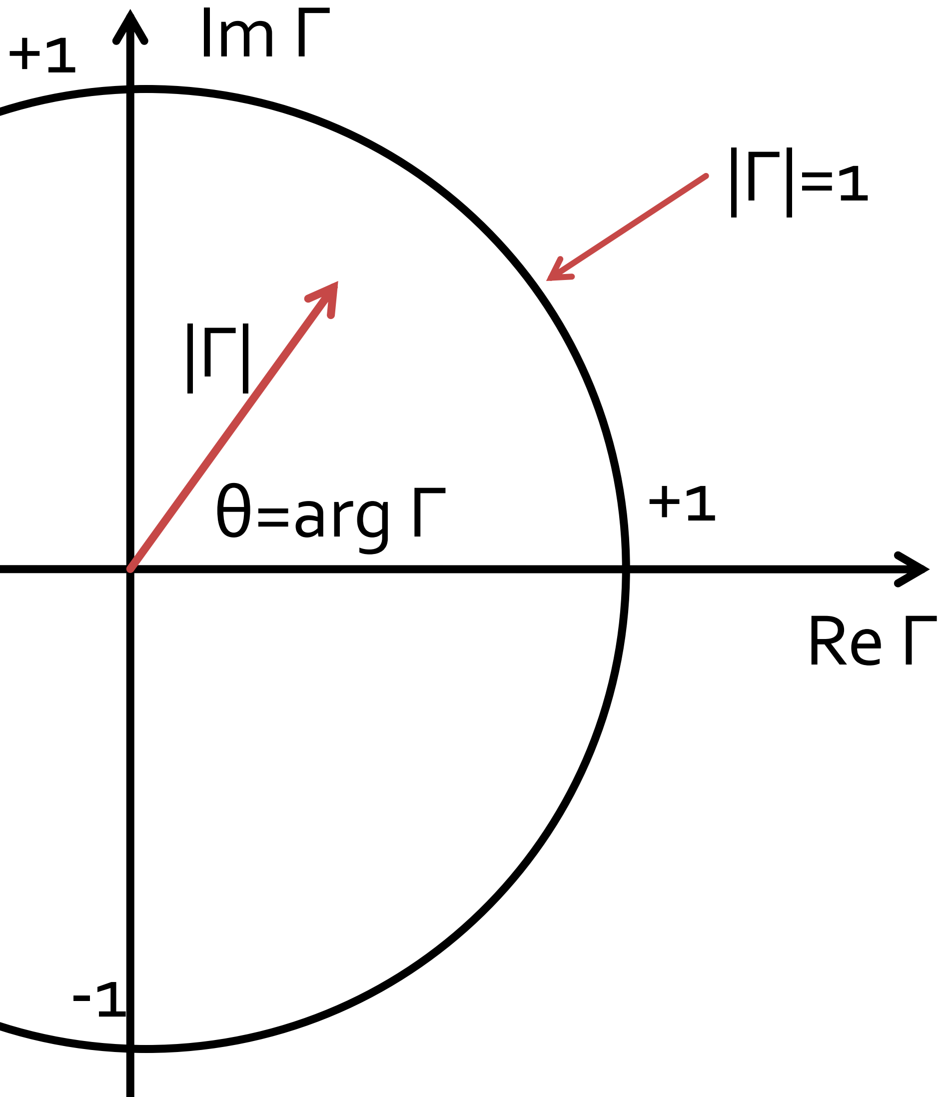
normalization $Z_L \rightarrow z_L$ allows using the same chart for any reference impedance Z_o (the plot becomes independent of the chosen Z_o)

$$\Gamma = \Gamma_r + j \cdot \Gamma_i$$

$$z_L = \frac{1 + |\Gamma| \cdot e^{j\theta}}{1 - |\Gamma| \cdot e^{j\theta}} = r_L + j \cdot x_L$$

$$r_L + j \cdot x_L = \frac{(1 + \Gamma_r) + j \cdot \Gamma_i}{(1 - \Gamma_r) - j \cdot \Gamma_i} = \frac{1 - \Gamma_r^2 - \Gamma_i^2}{(1 - \Gamma_r)^2 + \Gamma_i^2} + j \cdot \frac{2 \cdot \Gamma_i}{(1 - \Gamma_r)^2 + \Gamma_i^2}$$

The Smith Chart



$$r_L = \frac{1-\Gamma_r^2-\Gamma_i^2}{(1-\Gamma_r)^2+\Gamma_i^2}$$

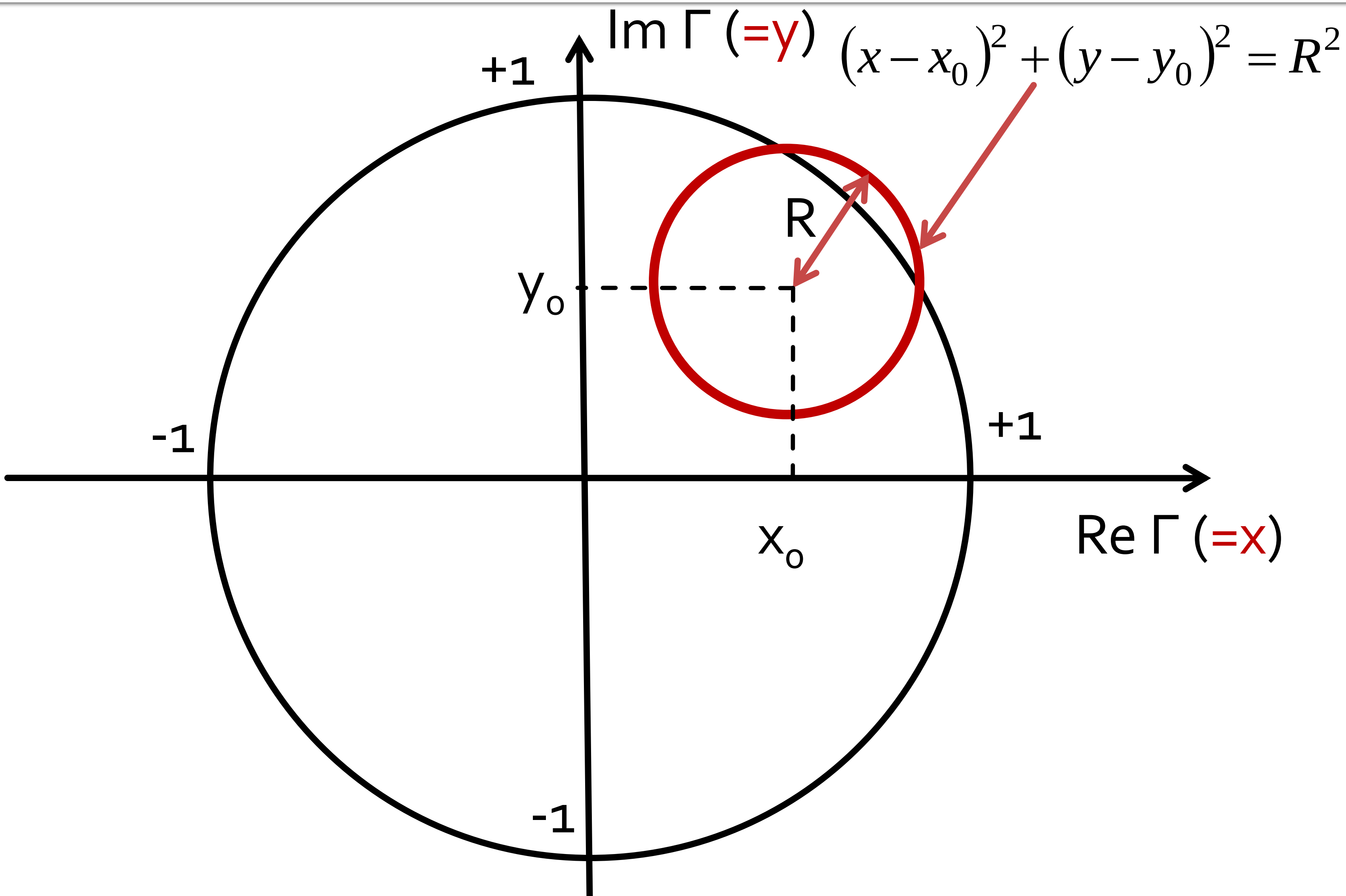
$$x_L = \frac{2\cdot\Gamma_i}{(1-\Gamma_r)^2+\Gamma_i^2}$$

- Rearranged

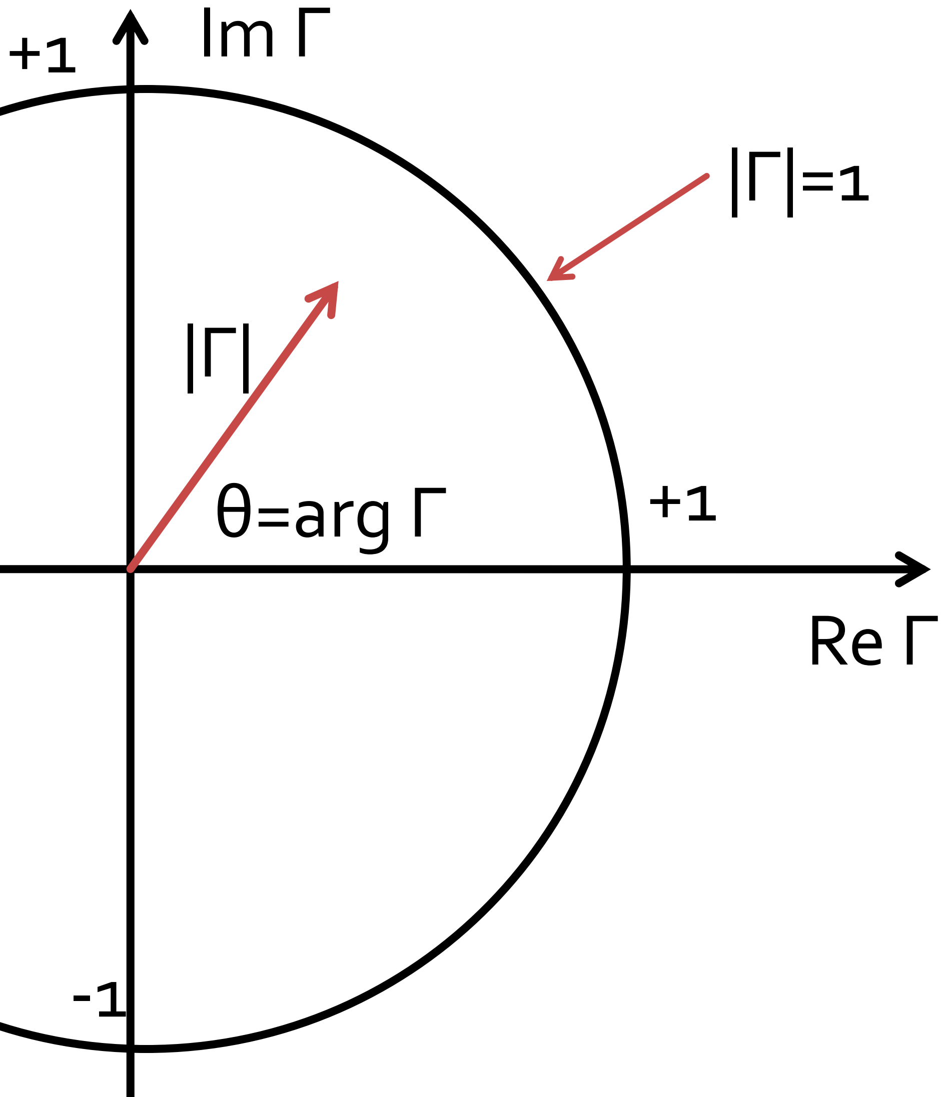
$$\left(\Gamma_r - \frac{r_L}{1+r_L}\right)^2 + \Gamma_i^2 = \left(\frac{1}{1+r_L}\right)^2$$

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

The Smith Chart



The Smith Chart



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

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

- **Circles** in the (Γ_r , Γ_i) complex plane

$$(x - x_0)^2 + (y - y_0)^2 = R^2$$

The Smith Chart, resistance

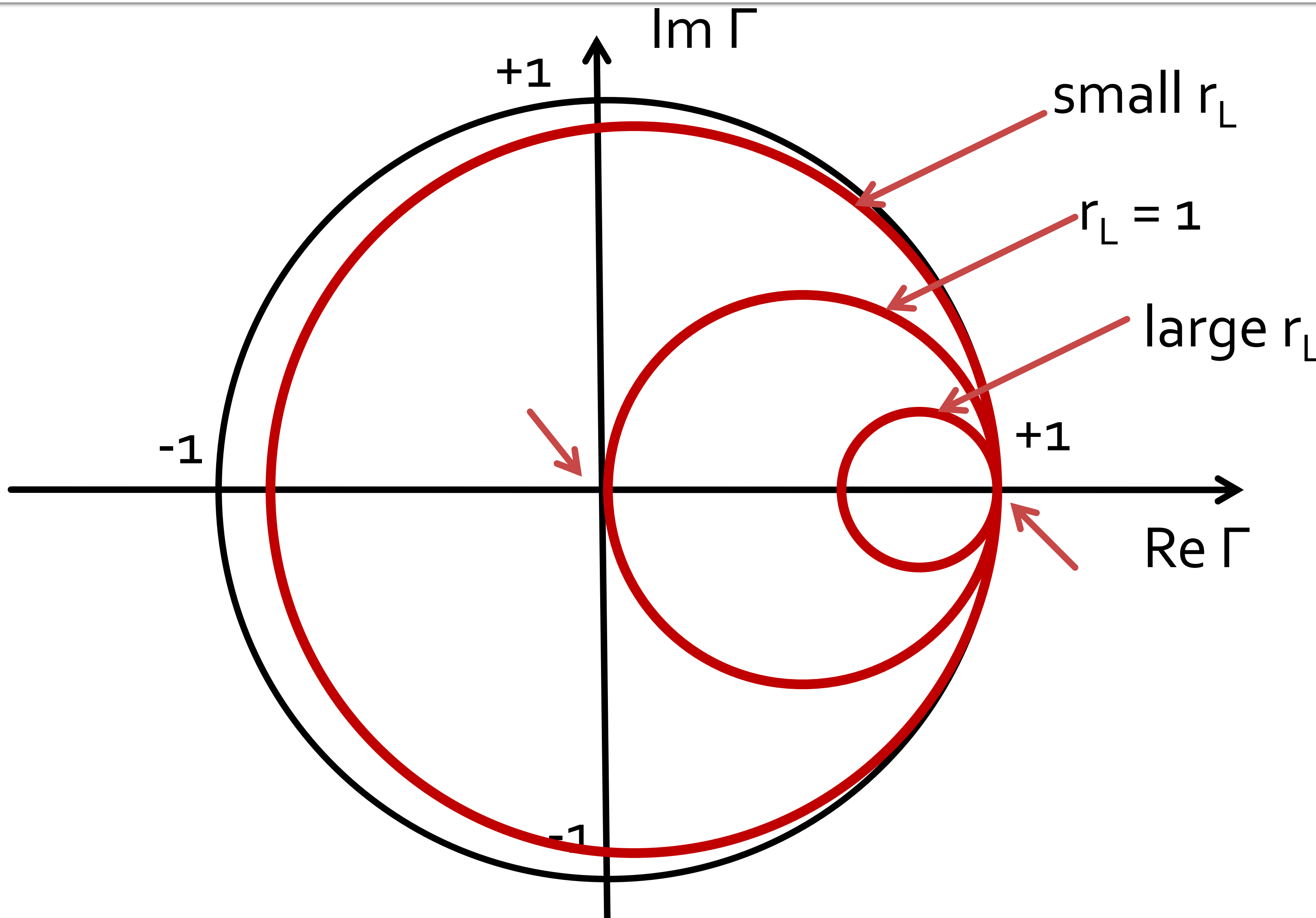
$$\left(\Gamma_r - \frac{r_L}{1+r_L}\right)^2 + \Gamma_i^2 = \left(\frac{1}{1+r_L}\right)^2$$

$$(x-x_0)^2 + (y-y_0)^2 = R^2$$

$$\begin{cases} x_0 = \dfrac{r_L}{1+r_L} \\ y_0 = 0 \\ R = \dfrac{1}{1+r_L} \end{cases}$$

- The locus (the set of all points whose location satisfies one or more specified conditions) of the points generated by all impedances having normalized resistance r_L is a circle which:
  - have its **center on the horizontal axis** (y_o=0)
  - passes through **x=1,y=0** point, whatever x_o,r_L $\quad \left(1-\frac{r_L}{1+r_L}\right)^2 + 0 = \left(\frac{1}{1+r_L}\right)^2$
  - have its radius between 0 and 1
    - tends to 0 for large r_L
    - tends to 1 for small r_L
  - when r_L is **1** passes also through **origin** $\quad \left(0-\frac{r_L}{1+r_L}\right)^2 = \left(\frac{1}{1+r_L}\right)^2 \leftrightarrow r_L = 1$

The Smith Chart, resistance



The Smith Chart, reactance

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

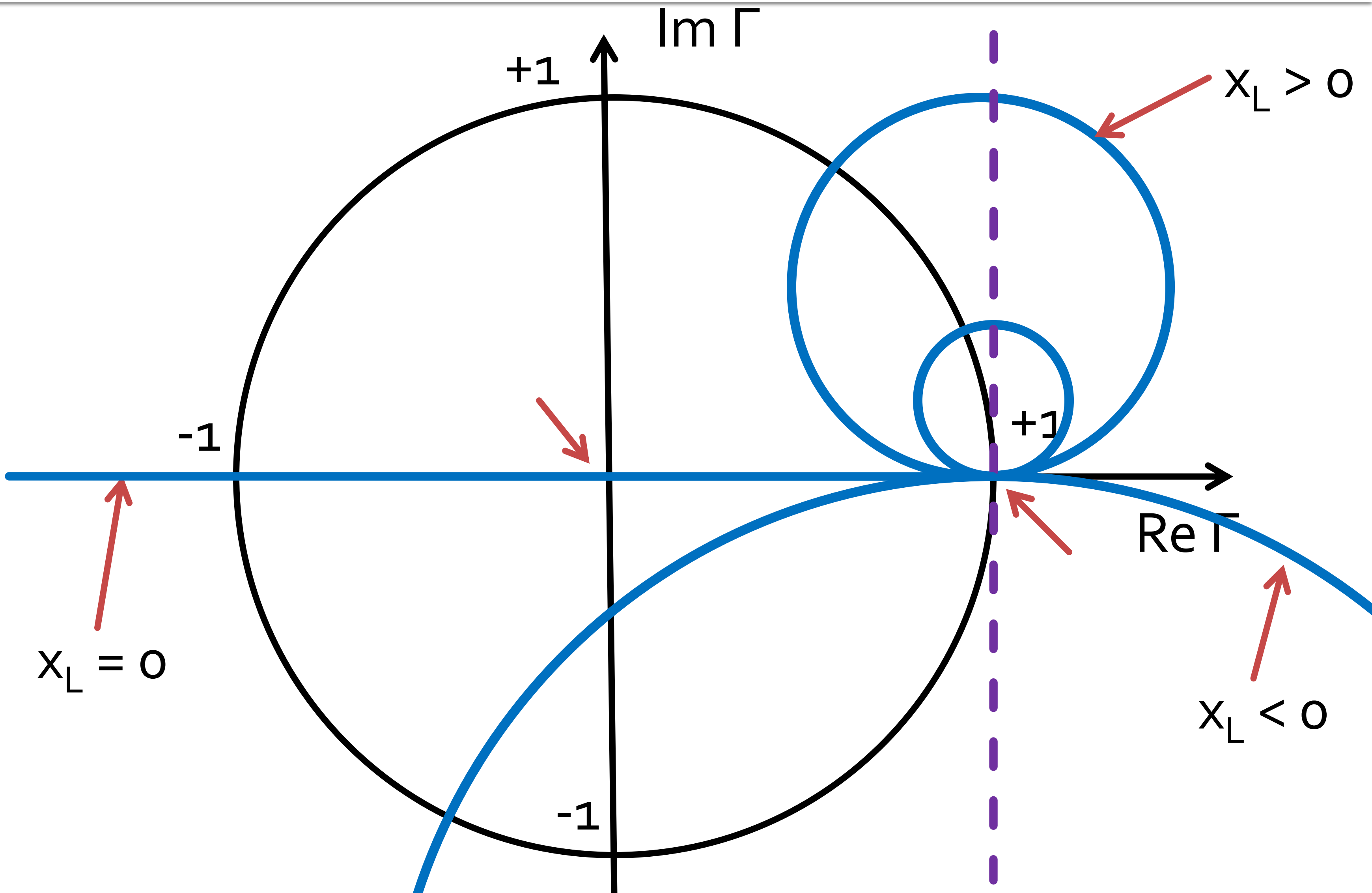
$$(x - x_0)^2 + (y - y_0)^2 = R^2$$

$$\begin{cases} x_0 = 1 \\ y_0 = \dfrac{1}{x_L} \\ R = \dfrac{1}{x_L} \end{cases}$$

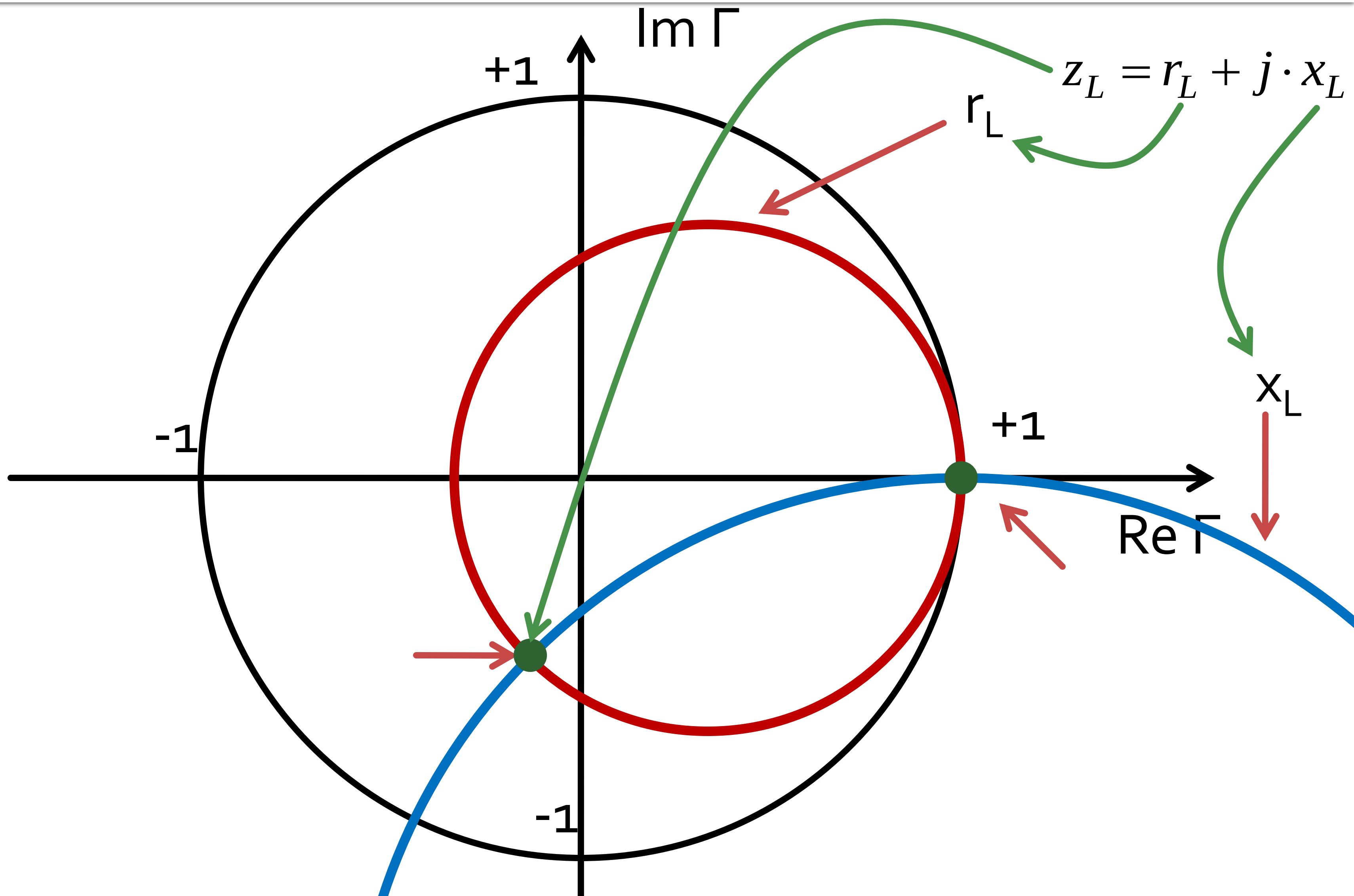
- The locus of the points generated by all impedances having normalized resistance x_L is a circle which:
  - have its **center on a line parallel with the vertical axis** (x_0=1)
  - passes through **x=1,y=0** point, whatever x_0,x_L
  - have its radius between 0 and ∞
    - tends to 0 for large $|x_L|$
    - tends to ∞ for small $|x_L|$
  - when x_L is **0** transforms itself in the **horizontal axis**
  - if x_L > 0 the circle is above the horizontal axis, otherwise is bellow it

$$0 + \left(0 - \frac{1}{x_L}\right)^2 = \left(\frac{1}{x_L}\right)^2$$

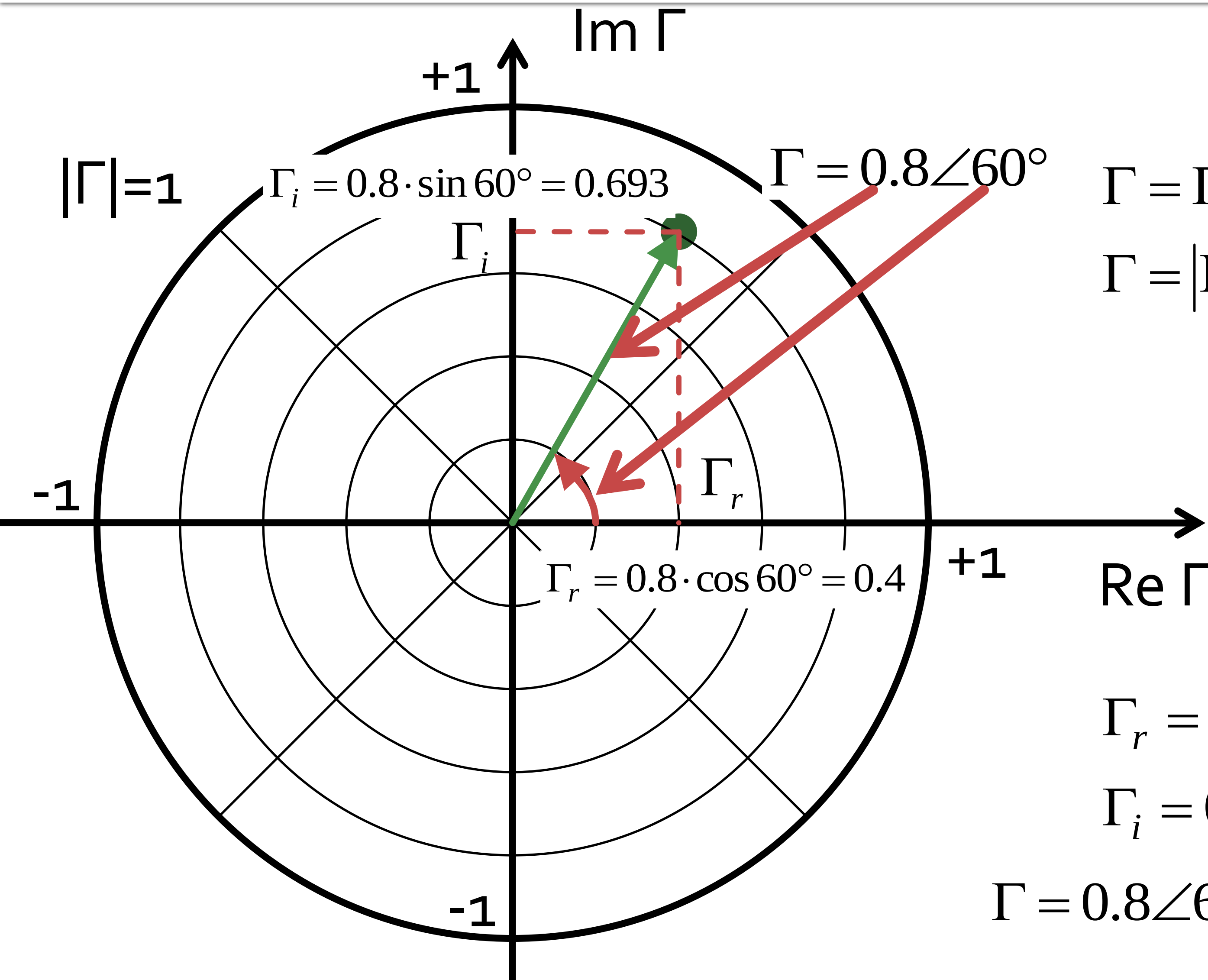
The Smith Chart, reactance



The Smith Chart, impedance



The Smith Chart, reflection coefficient, Cartesian coordinate system



$$\Gamma = \Gamma_r + j \cdot \Gamma_i$$

$$\Gamma = |\Gamma| \cdot (\cos\theta + j \cdot \sin\theta)$$

$$\Gamma = |\Gamma| \cdot e^{j\theta}$$

$$\Gamma = |\Gamma| \angle \theta°$$

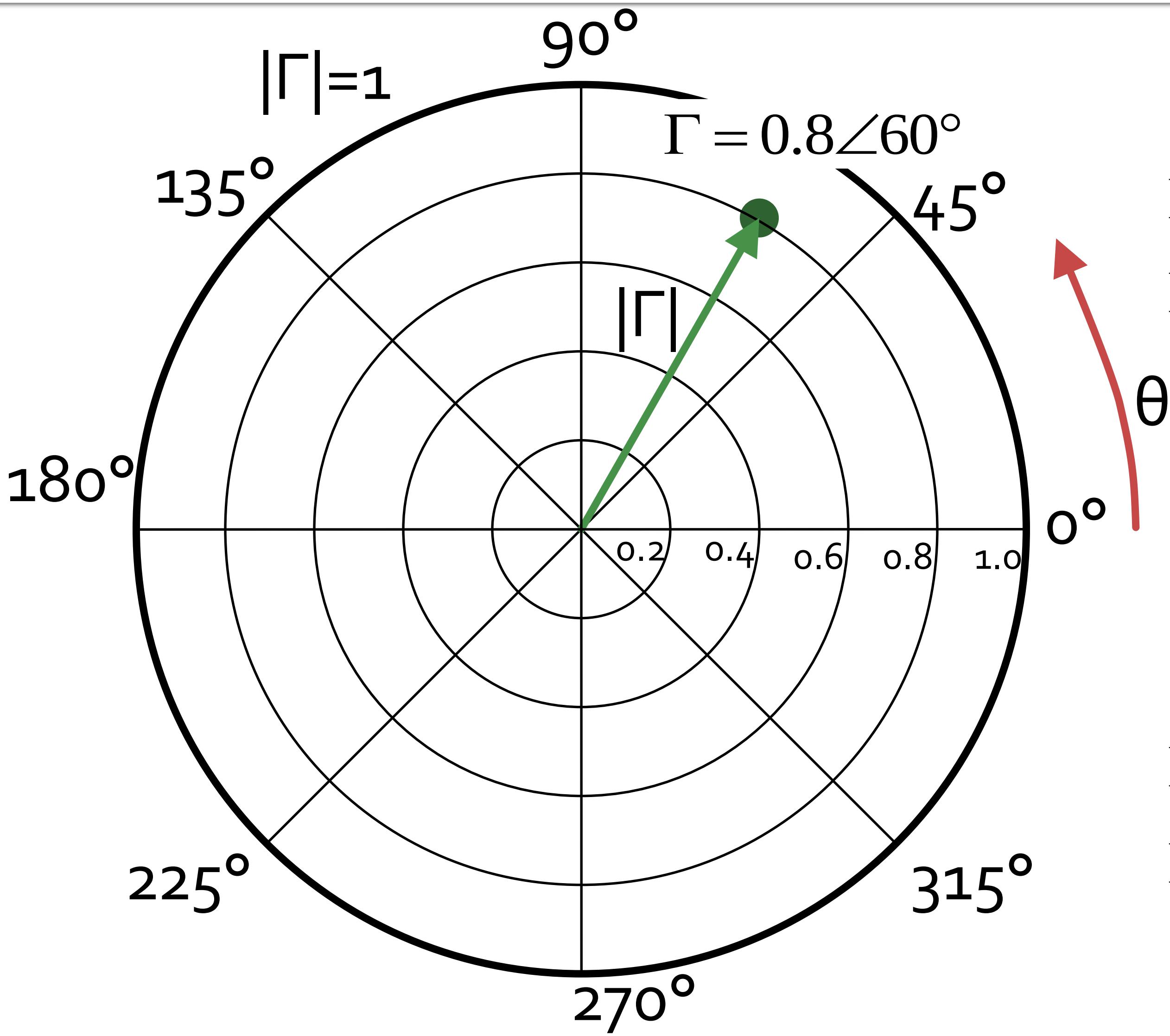
$$\Gamma = 0.8\angle 60°$$

$$\Gamma_r = 0.8 \cdot \cos 60° = 0.4$$

$$\Gamma_i = 0.8 \cdot \sin 60° = 0.693$$

$$\Gamma = 0.8\angle 60° = 0.4 + j \cdot 0.693$$

The Smith Chart, reflection coefficient, Polar coordinate system



$$\Gamma = \Gamma_r + j \cdot \Gamma_i$$

$$\Gamma = |\Gamma| \cdot (\cos\theta + j \cdot \sin\theta)$$

$$\Gamma = |\Gamma| \cdot e^{j\theta}$$

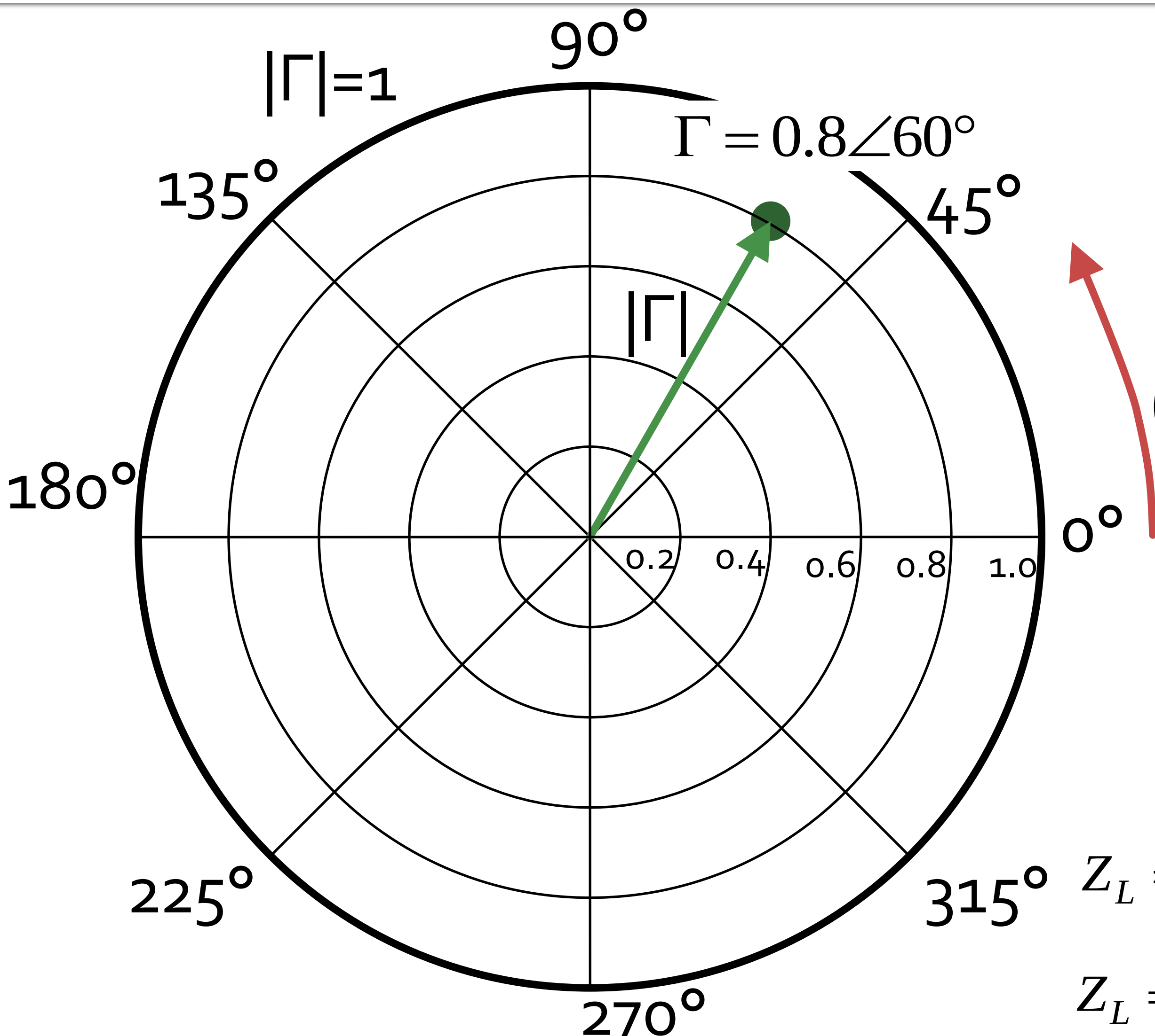
$$\Gamma = |\Gamma| \angle \theta^\circ$$

$$\Gamma = 0.8 \angle 60^\circ$$

$$\Gamma_r = 0.8 \cdot \cos 60^\circ = 0.4$$

$$\Gamma_i = 0.8 \cdot \sin 60^\circ = 0.693$$

The Smith Chart, reflection coefficient, impedance



$$\Gamma = |\Gamma| \cdot e^{j\theta}$$

$$\Gamma = |\Gamma| \angle \theta^\circ$$

$$\Gamma = 0.8\angle 60^\circ$$

$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{z_L - 1}{z_L + 1}$$

$$z_L = \frac{1+\Gamma}{1-\Gamma} = \frac{1+0.8\angle 60^\circ}{1-0.8\angle 60^\circ}$$

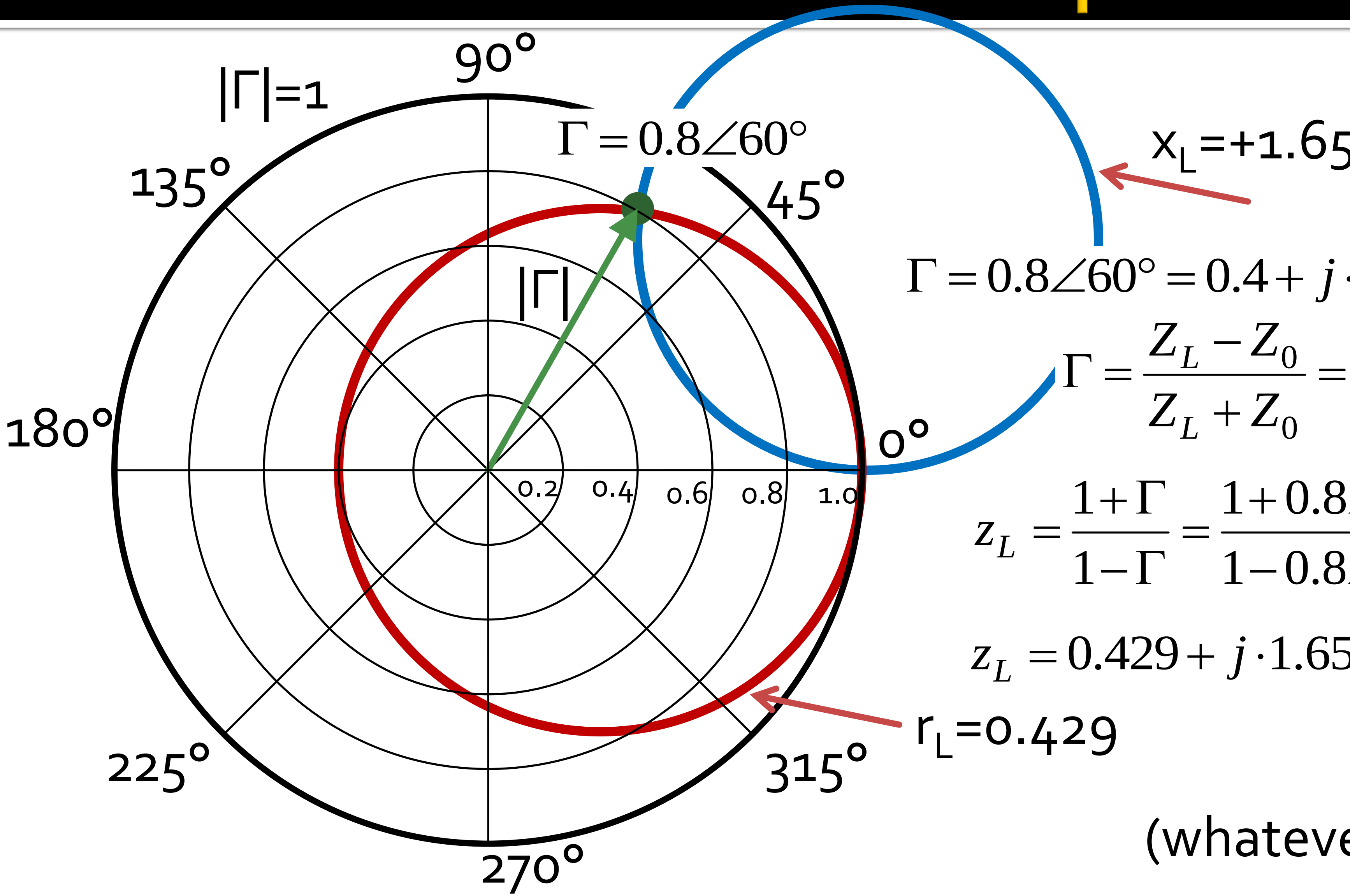
$$z_L = 0.429 + j \cdot 1.65$$

$$Z_L = Z_0 \cdot \frac{1+\Gamma}{1-\Gamma} = 50\Omega \cdot \frac{1+0.8\angle 60^\circ}{1-0.8\angle 60^\circ}$$

$$Z_L = 21.429\Omega + j \cdot 82.479\Omega$$

Equivalence

reflection coefficient ⇔ impedance



$$\Gamma = 0.8\angle 60^\circ = 0.4 + j\cdot 0.693$$

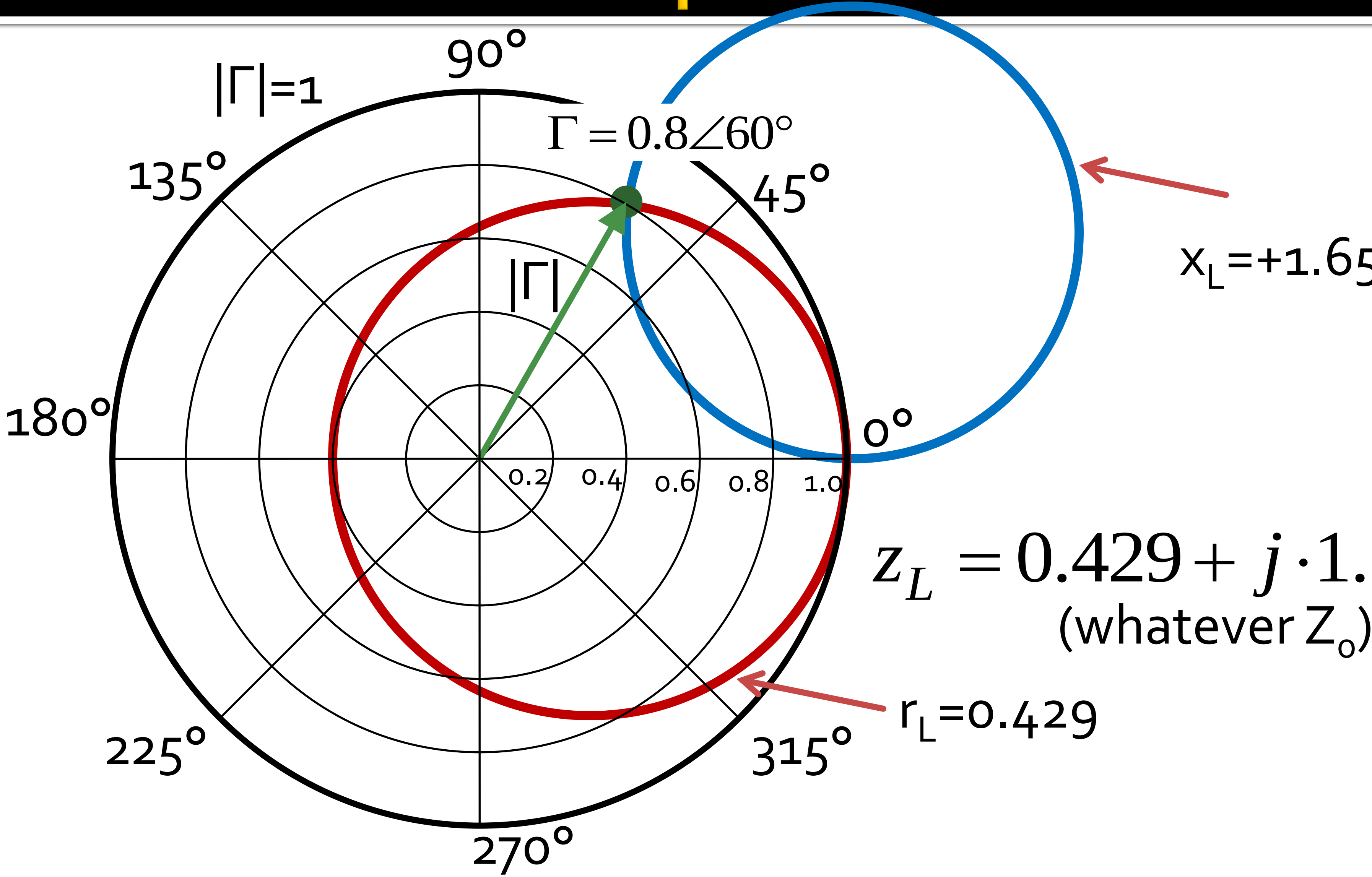
$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{z_L - 1}{z_L + 1}$$

$$z_L = \frac{1+\Gamma}{1-\Gamma} = \frac{1+0.8\angle 60^\circ}{1-0.8\angle 60^\circ}$$

$$z_L = 0.429 + j\cdot 1.65$$

(whatever Z_o)

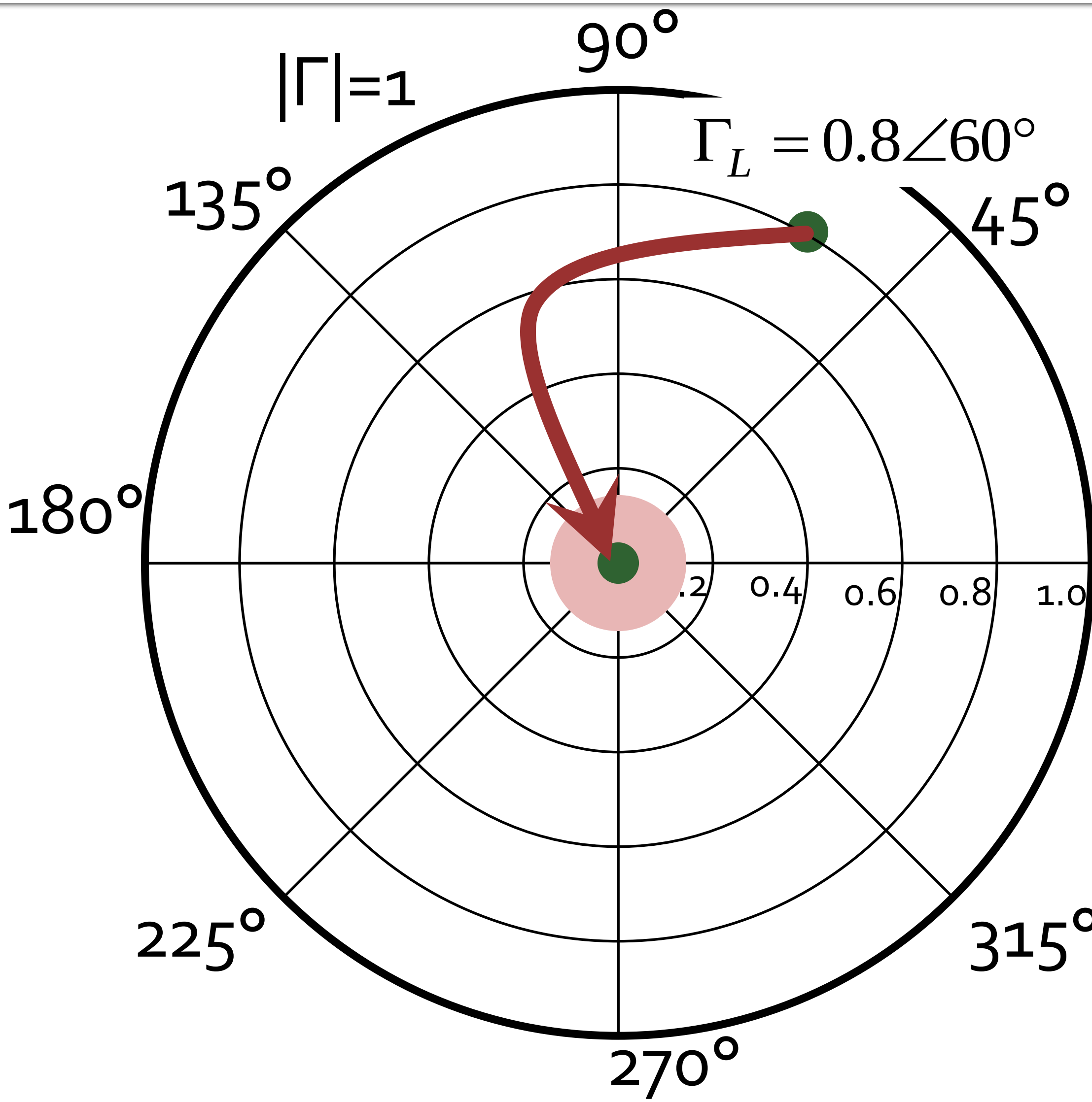
The Smith Chart, reflection coefficient ⇔ impedance

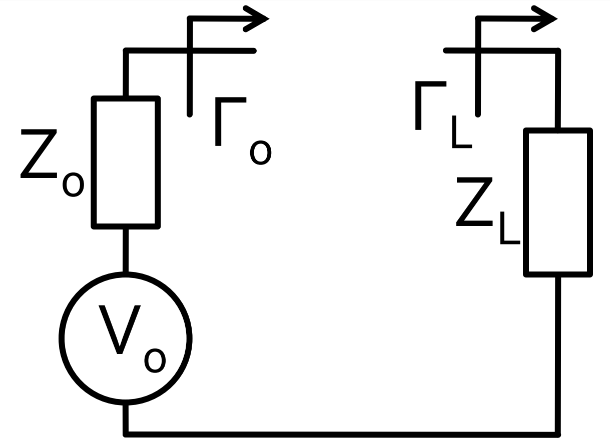


$$z_L = 0.429 + j \cdot 1.65$$

(whatever Z_o)

The Smith Chart, reflection coefficient, matching





Matching Z_L load to Z_o source.
We normalize Z_L over Z_o

$$Z_L = 21.429\Omega + j \cdot 82.479\Omega$$

$$z_L = 0.429 + j \cdot 1.65$$

$$\Gamma_L = 0.8\angle 60°$$

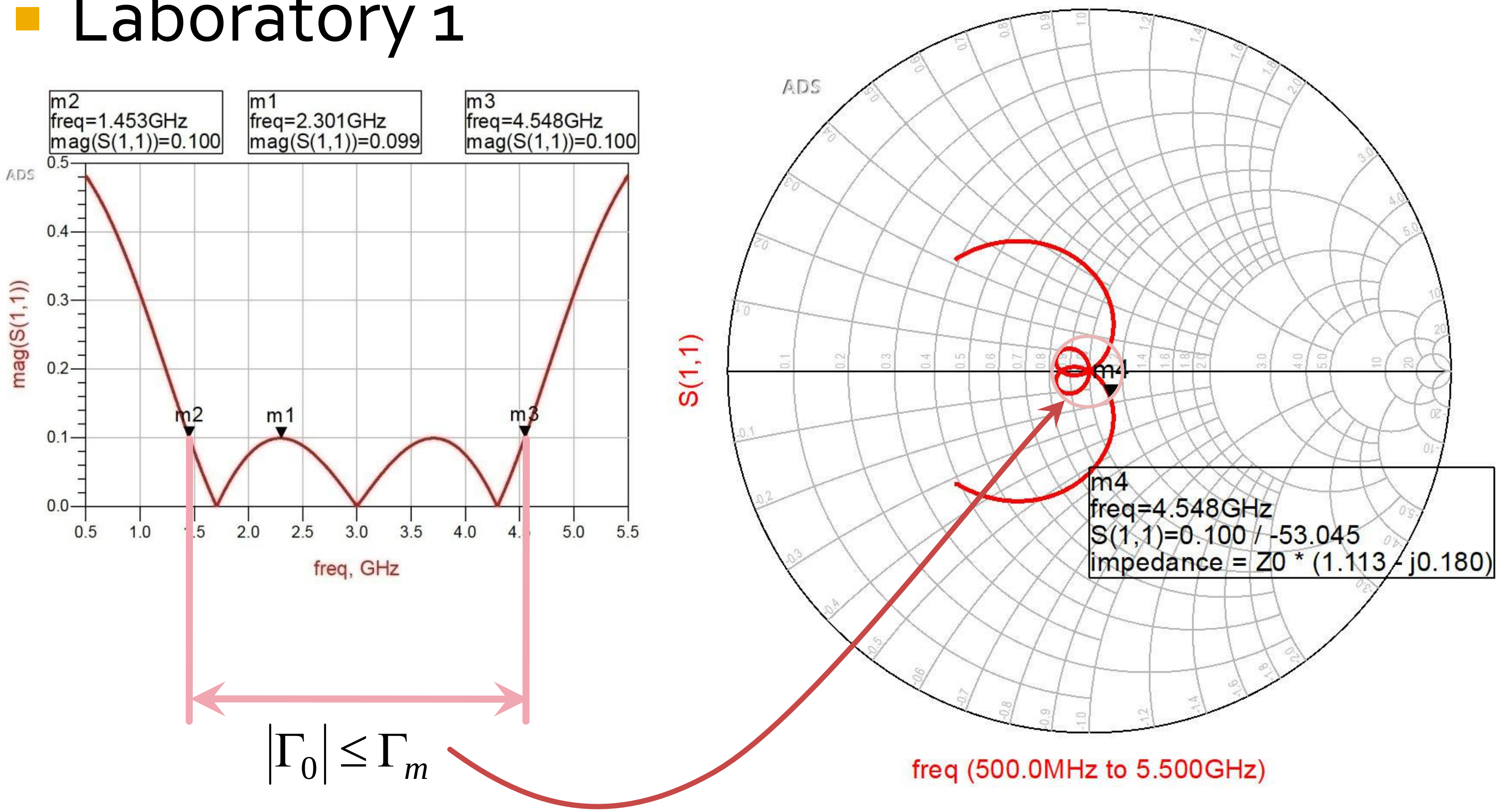
We must move the point denoting the reflection coefficient in the area where with a Z_o source we have:

$\Gamma_0 = 0$ perfect match

$|\Gamma_0| \leq \Gamma_m$ "good enough" match

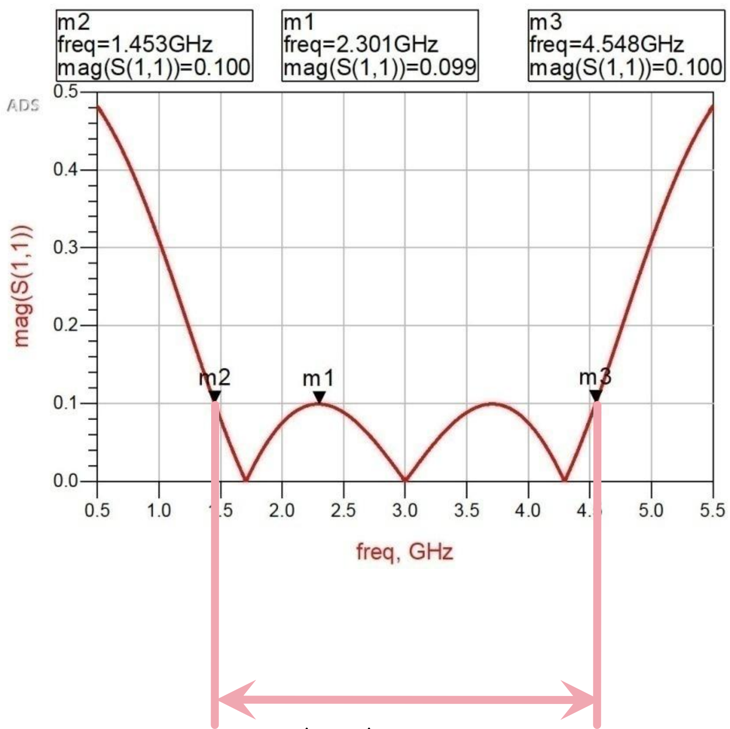
Example

- Laboratory 1

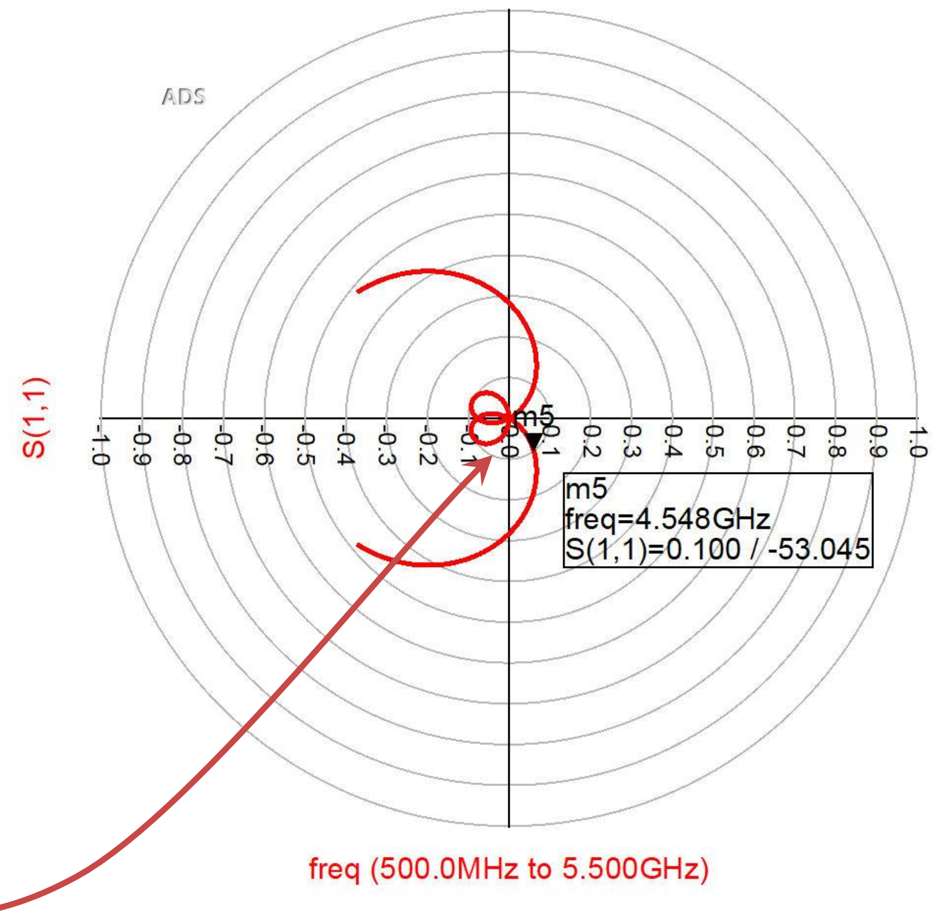


Example

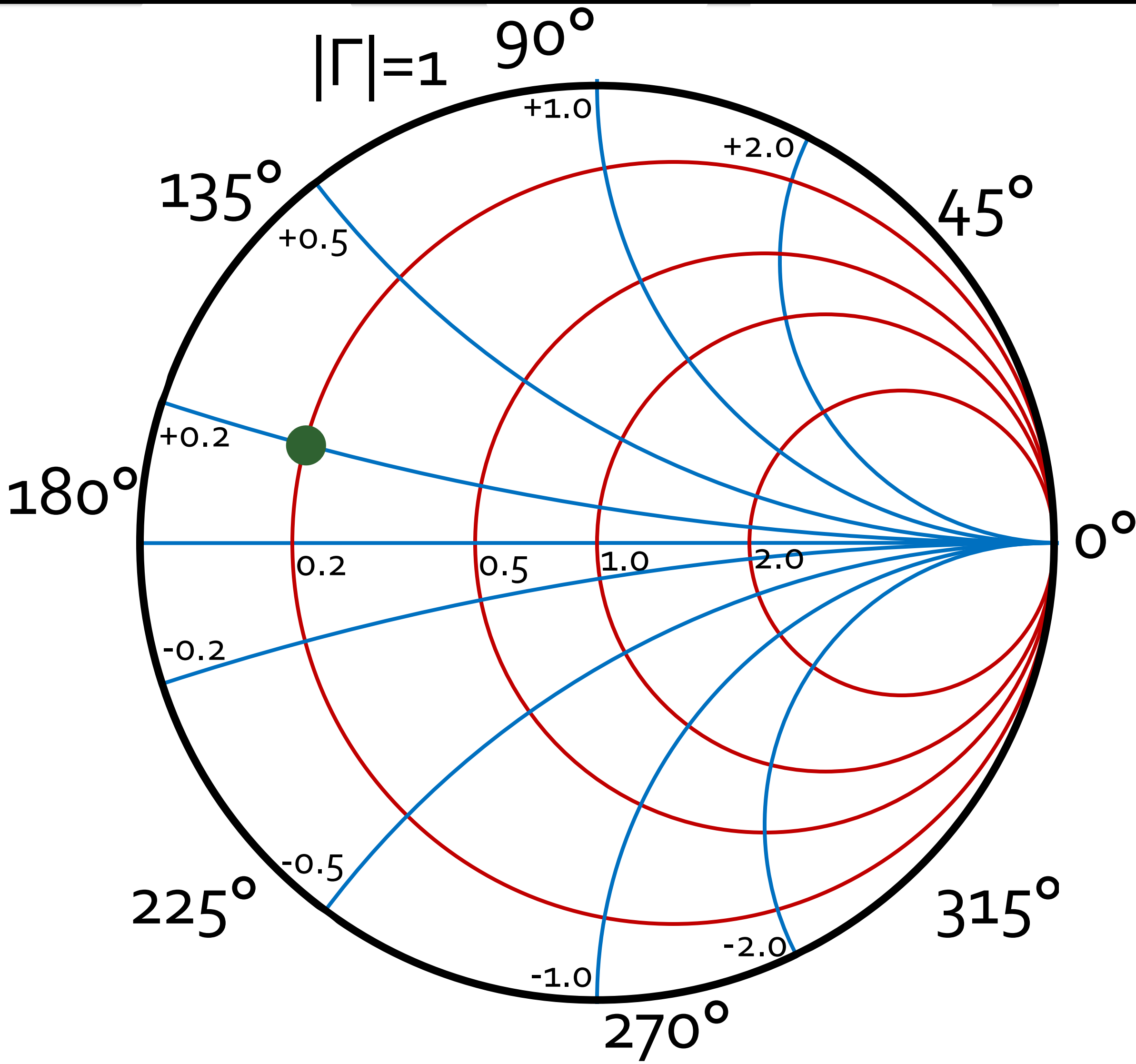
- Laboratory 1

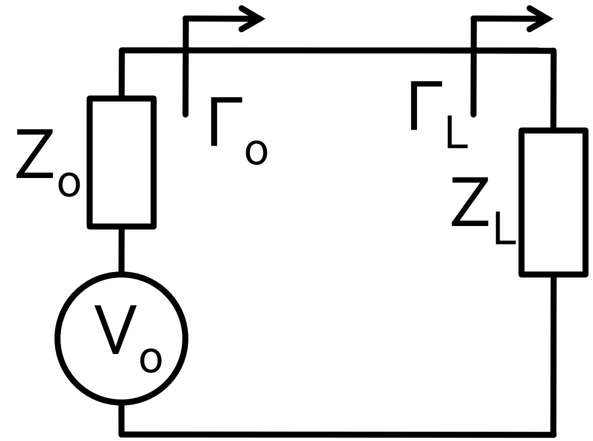


$$|\Gamma_0| \leq \Gamma_m$$



The Smith Chart, impedance/reflection coefficient





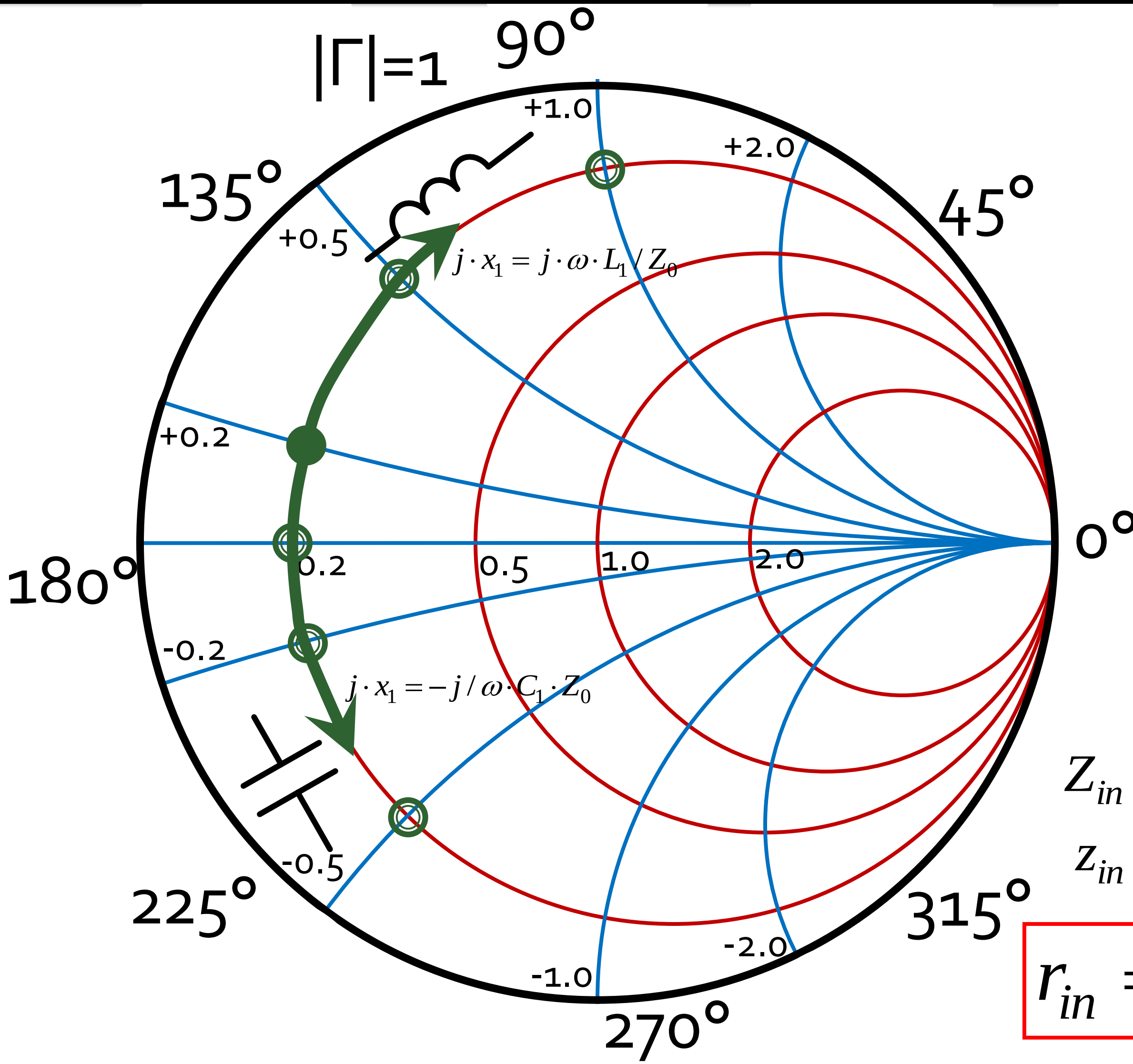
$$Z_0 = 50\Omega$$

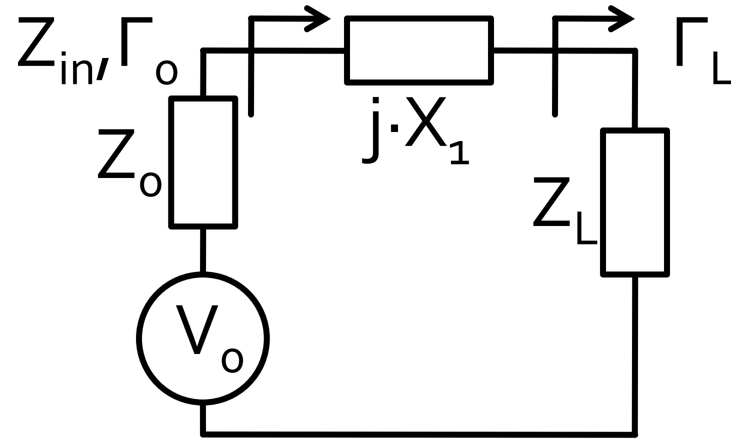
$$Z_L = 10\Omega + j \cdot 10\Omega$$

$$z_L = 0.2 + j \cdot 0.2$$

$$\Gamma_L = \Gamma_0 = 0.678\angle 156.5$$

The Smith Chart, series reactance





$$Z_0 = 50\Omega$$

$$Z_L = R_L + j\cdot X_L = 10\Omega + j\cdot 10$$

$$z_L = r_L + j\cdot x_L = 0.2 + j\cdot 0.2$$

$$\Gamma_L = 0.678\angle 156.5°$$

$$Z_{in} = Z_L + j\cdot X_1 = R_L + j\cdot\left(X_L + X_1\right.$$

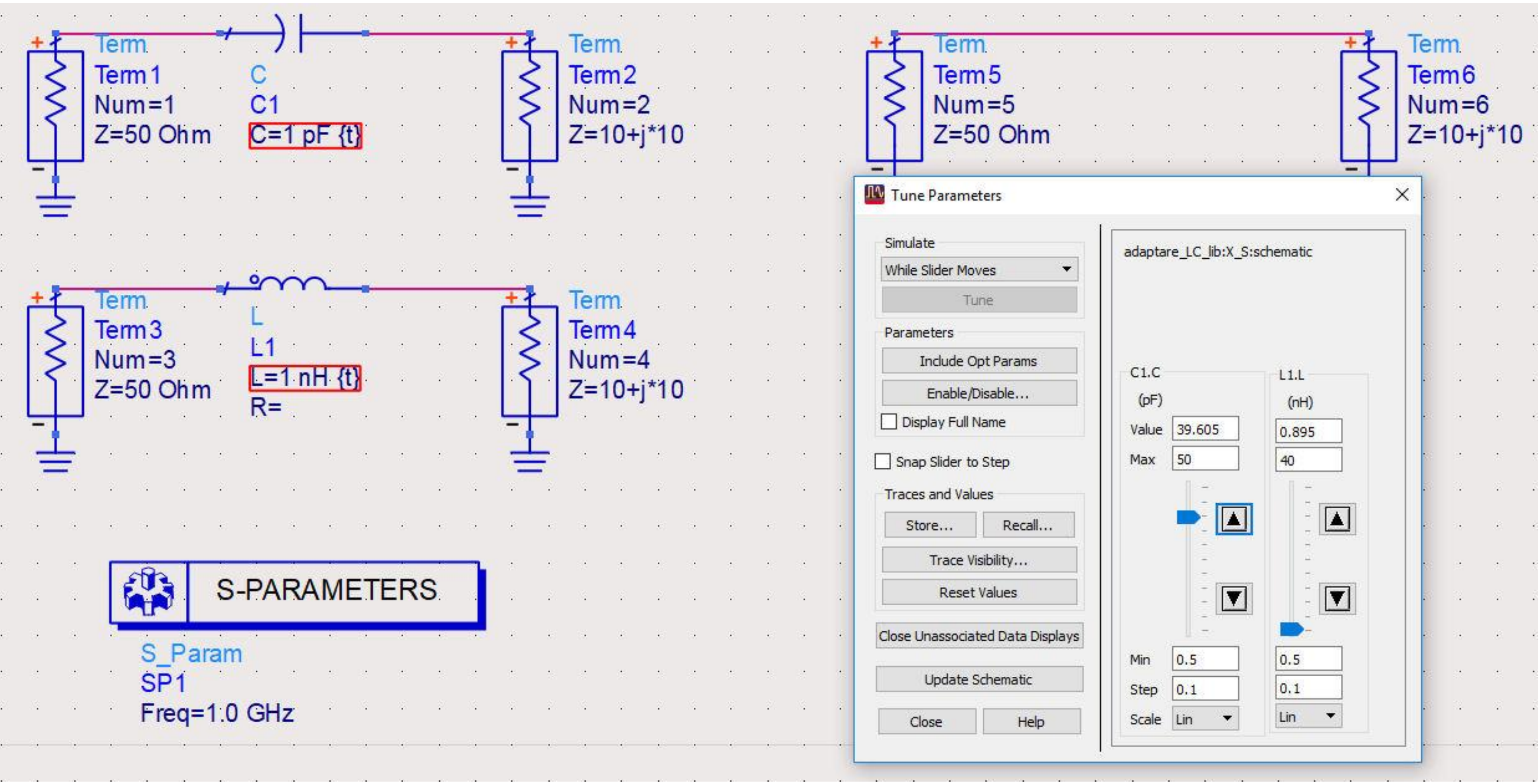
$$z_{in} = r_L + j\cdot\left(x_L + x_1\right)$$

$$r_{in} = r_L$$

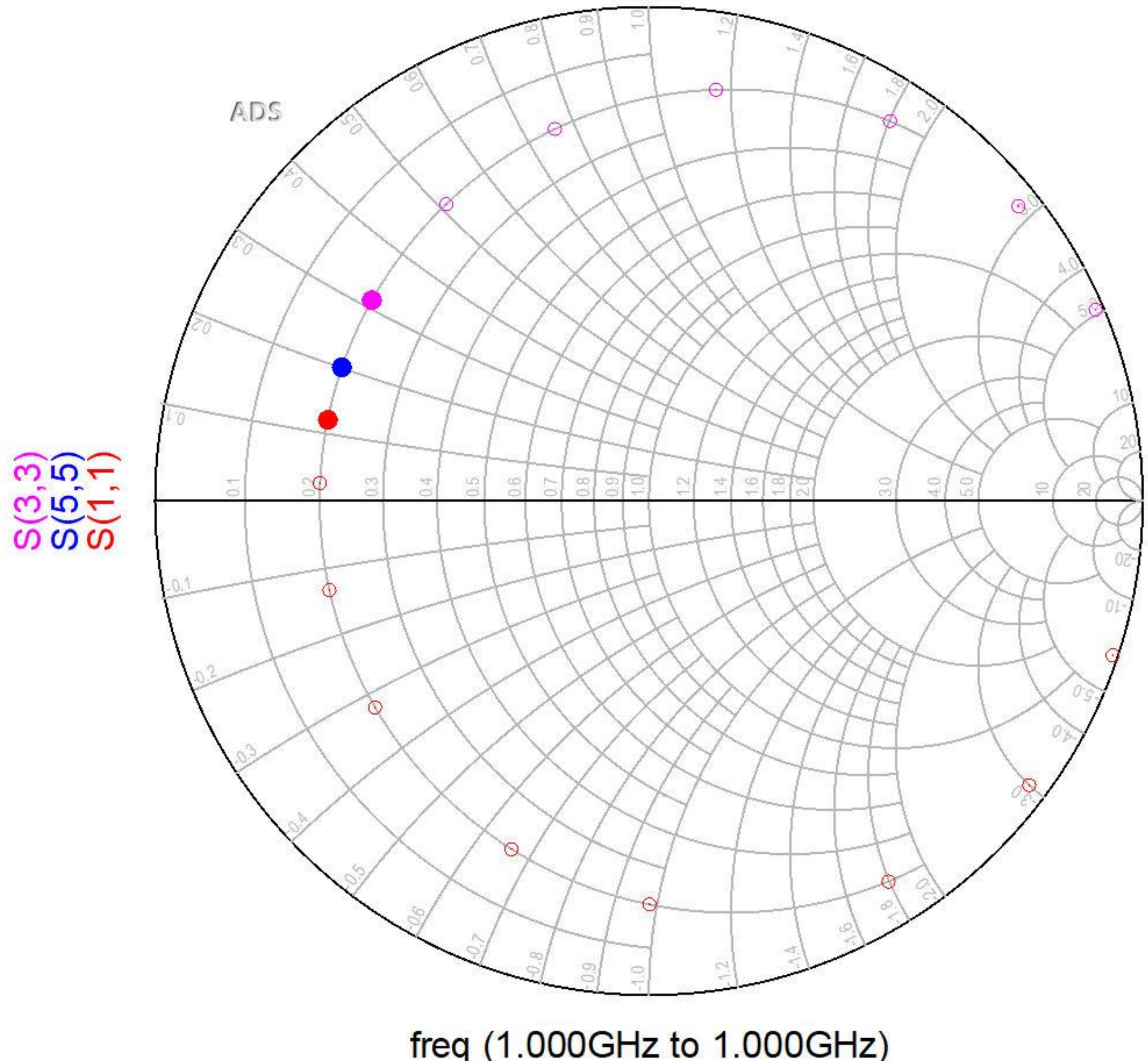
$$j\cdot x_1 = j\cdot\omega\cdot L_1 / Z_0 > 0$$

$$j\cdot x_1 = -j / \omega\cdot C_1\cdot Z_0 < 0$$

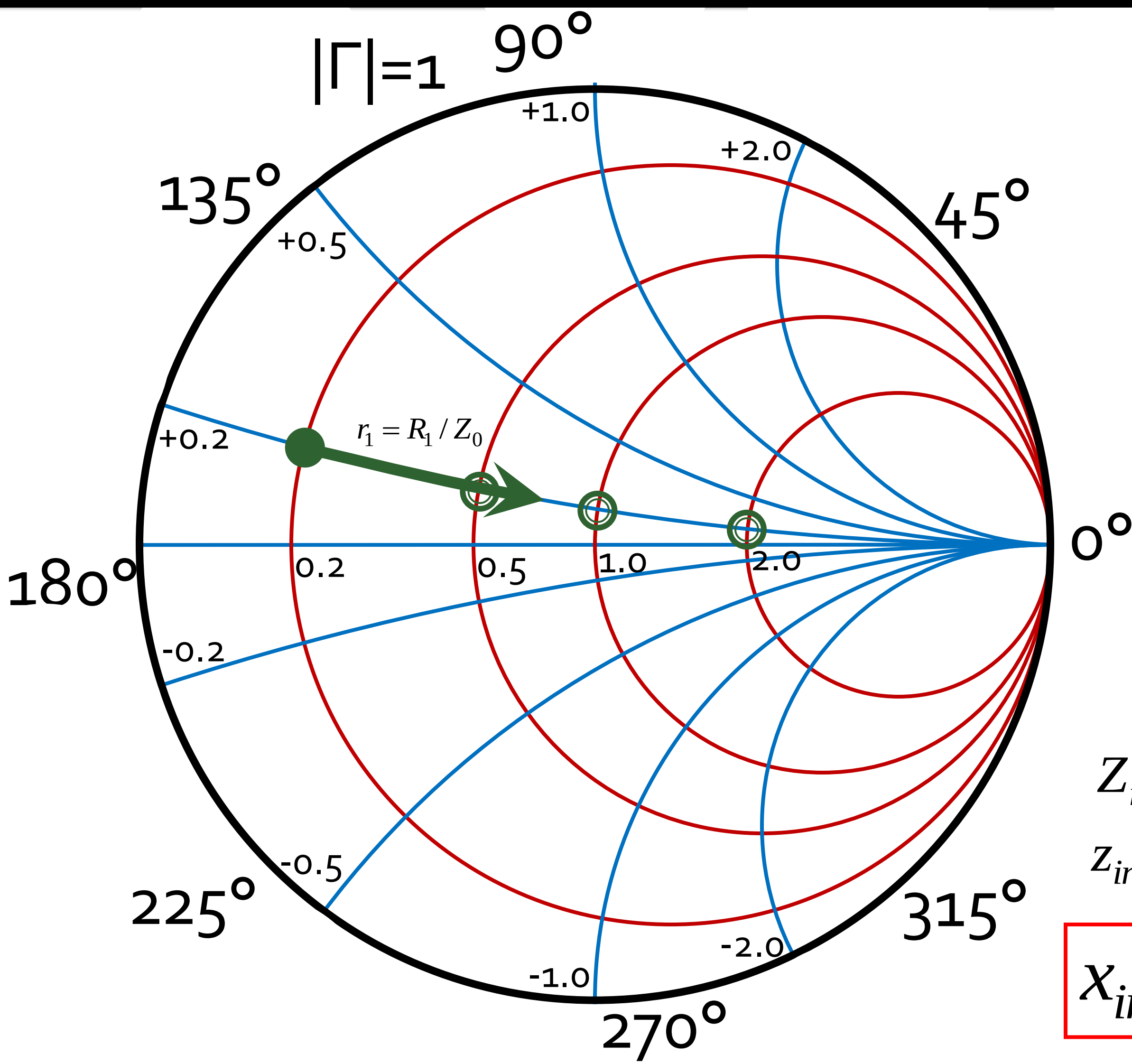
ADS, Smith Chart, series reactance

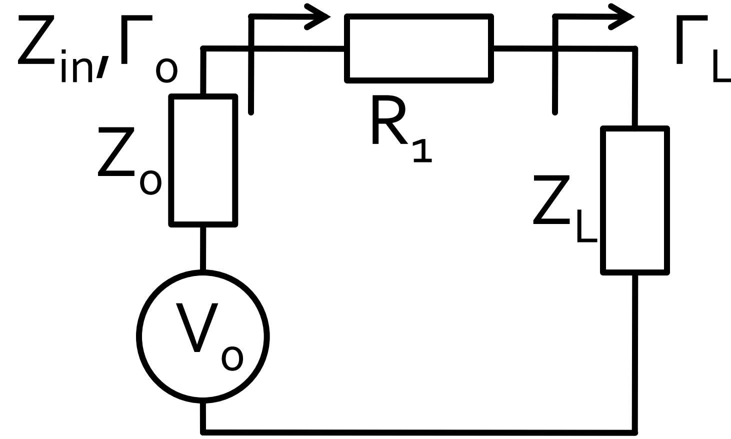


ADS, Smith Chart, series reactance



The Smith Chart, series resistance





$$Z_0 = 50\Omega$$

$$Z_L = R_L + j \cdot X_L = 10\Omega + j \cdot 10$$

$$z_L = r_L + j \cdot x_L = 0.2 + j \cdot 0.2$$

$$\Gamma_L = 0.678\angle 156.5°$$

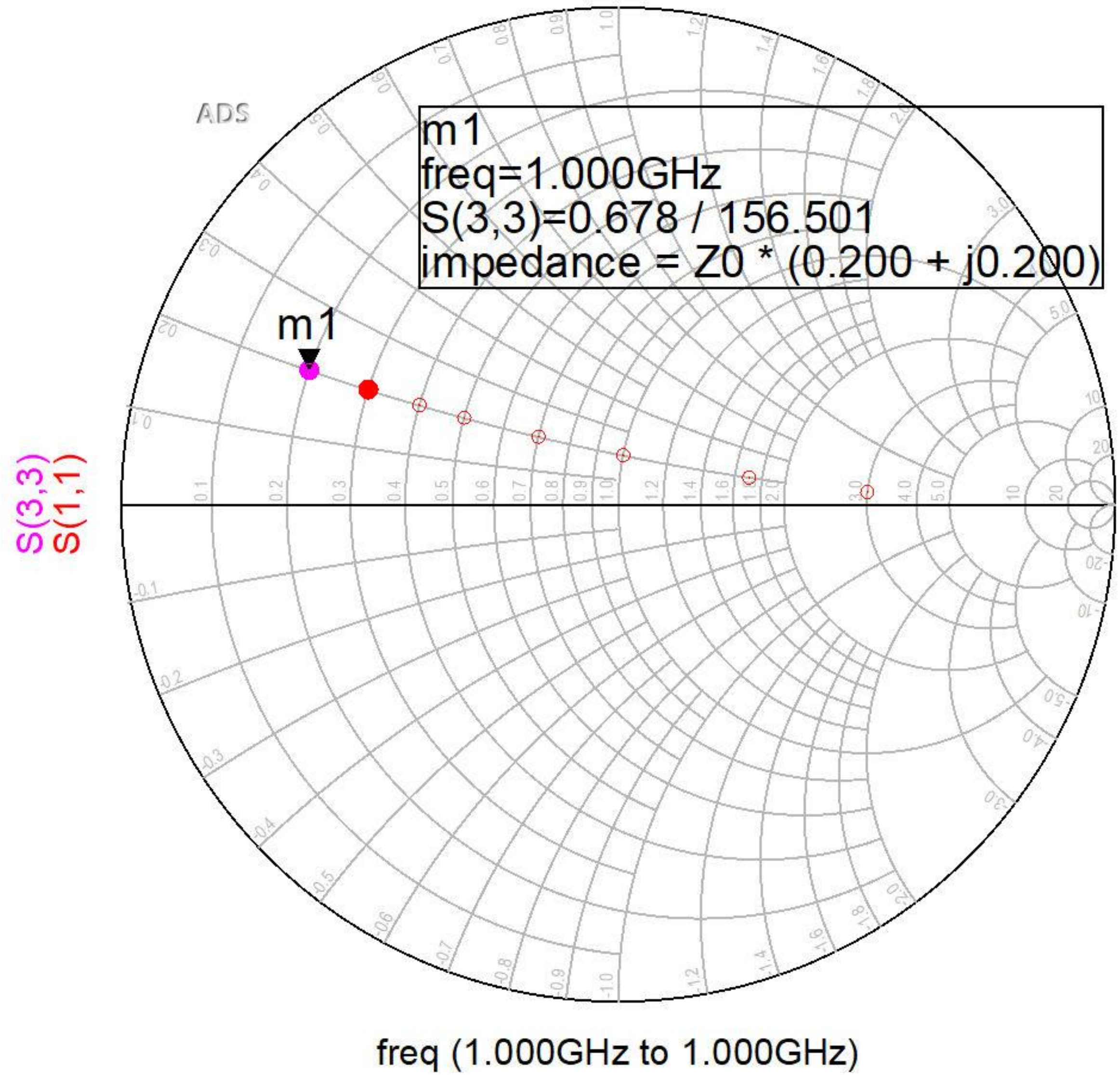
$$Z_{in} = Z_L + R_1 = (R_L + R_1) + j \cdot X_L$$

$$z_{in} = z_L + r_1 = (r_L + r_1) + j \cdot x_L$$

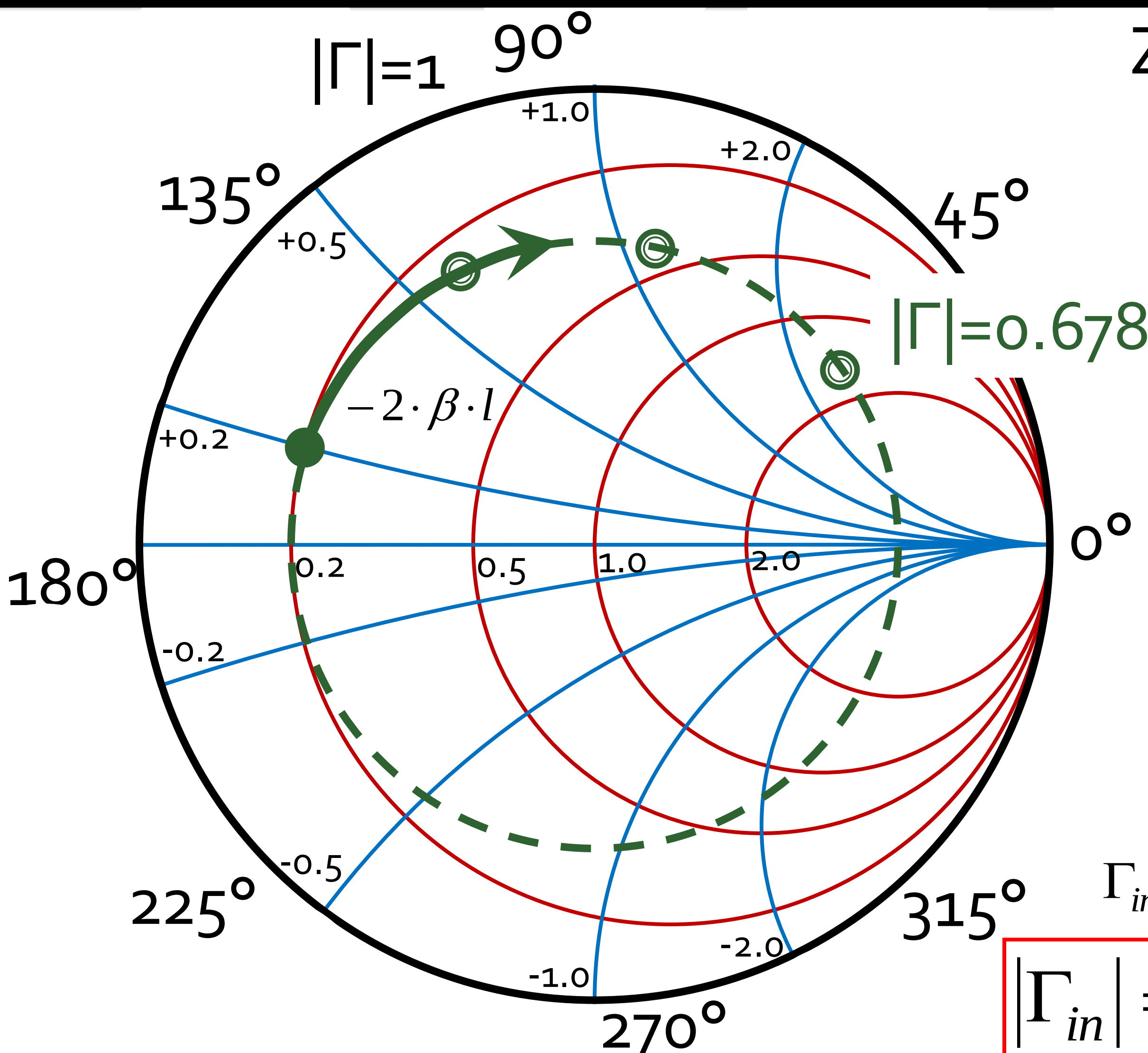
$$x_{in} = x_L$$

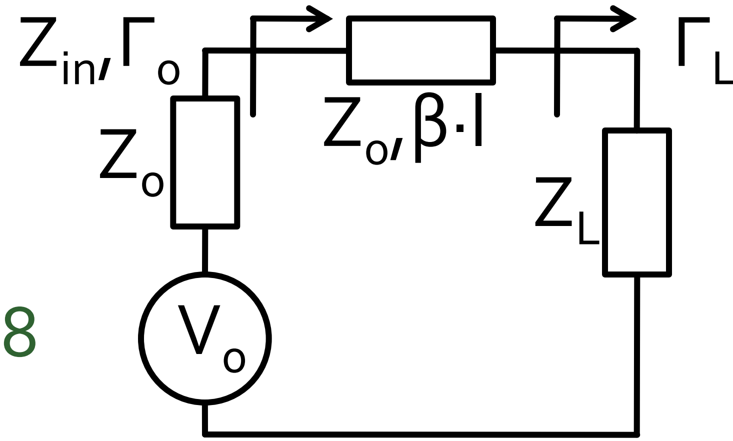
$$r_{in} = r_L + R_1 / Z_0$$

ADS, Smith Chart, series resistance



The Smith Chart, series transmission line, Z_o





$$Z_0 = 50\Omega$$

$$Z_L = R_L + j\cdot X_L = 10\Omega + j\cdot 10$$

$$z_L = r_L + j\cdot x_L = 0.2 + j\cdot 0.2$$

$$\Gamma_L = 0.678\angle 156.5^\circ$$

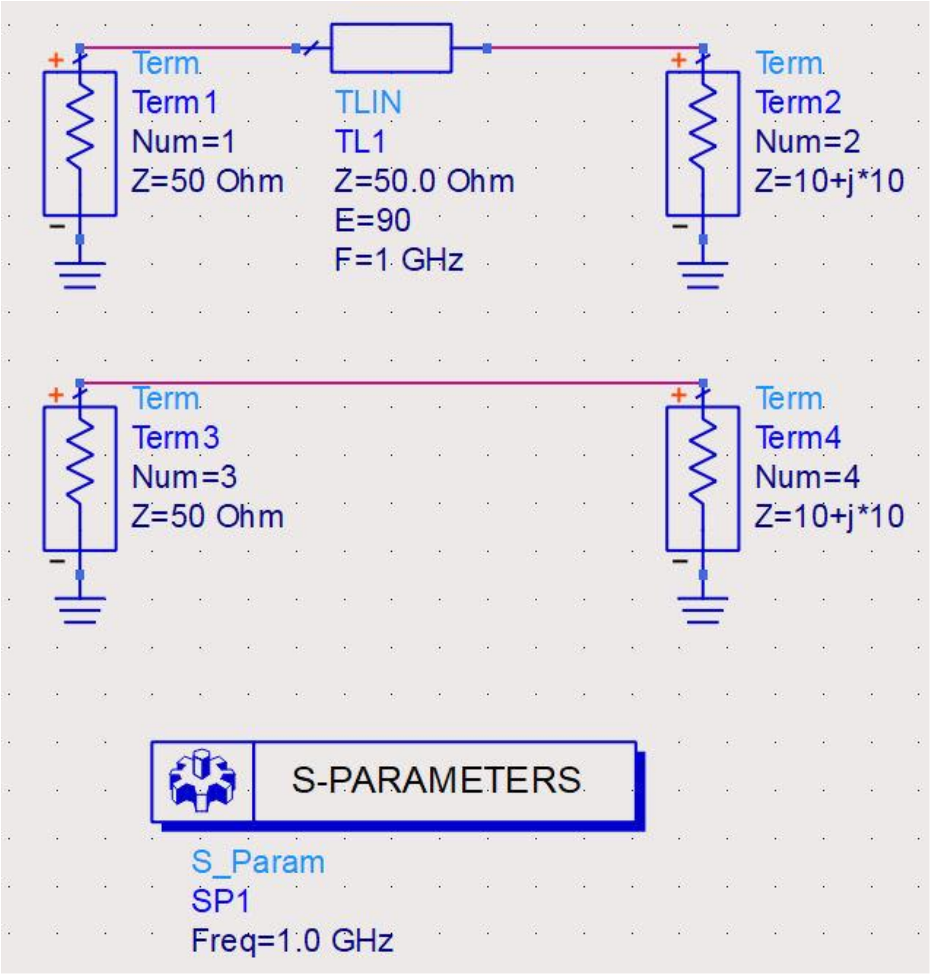
$$Z_{in} = Z_0 \cdot \frac{1+\Gamma_L\cdot e^{-2j\cdot\beta\cdot l}}{1-\Gamma_L\cdot e^{-2j\cdot\beta\cdot l}}$$

$$\Gamma_{in} = \Gamma_L \cdot e^{-2j\cdot\beta\cdot l}$$

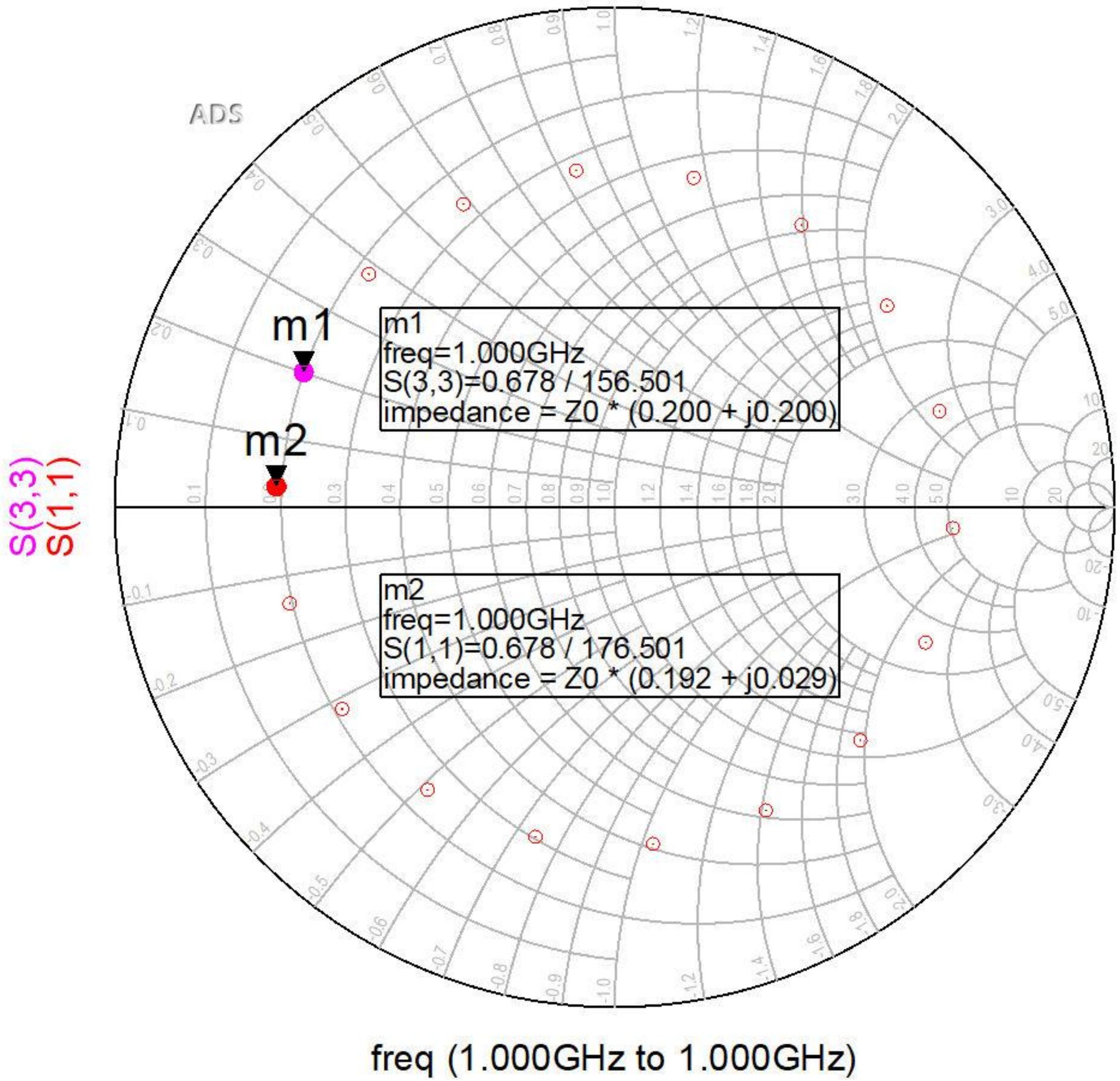
$$|\Gamma_{in}| = |\Gamma_L|$$

$$\arg(\Gamma_{in}) = \arg(\Gamma_L) - 2\cdot\beta\cdot$$

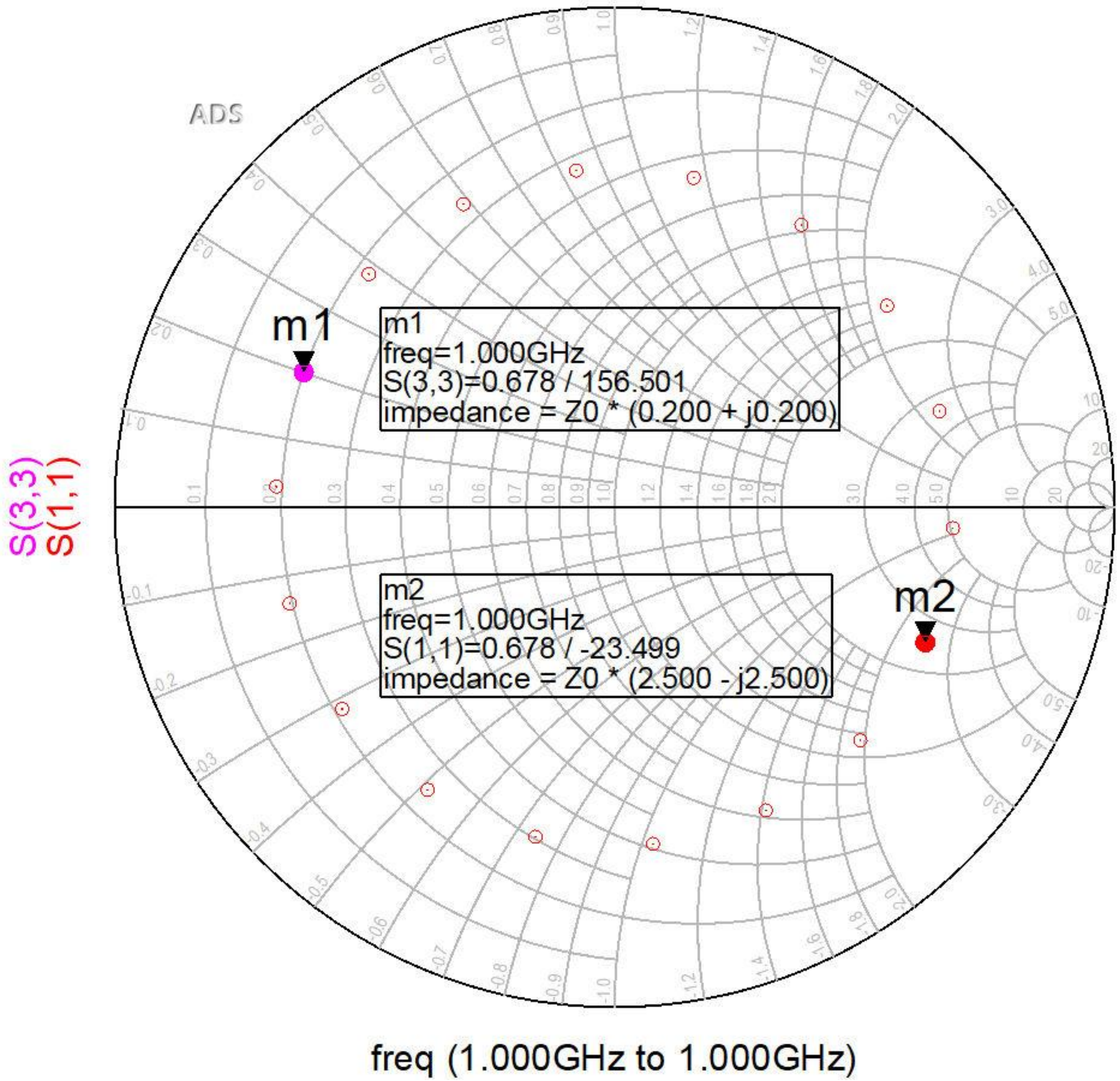
ADS, Smith Chart, series transmission line



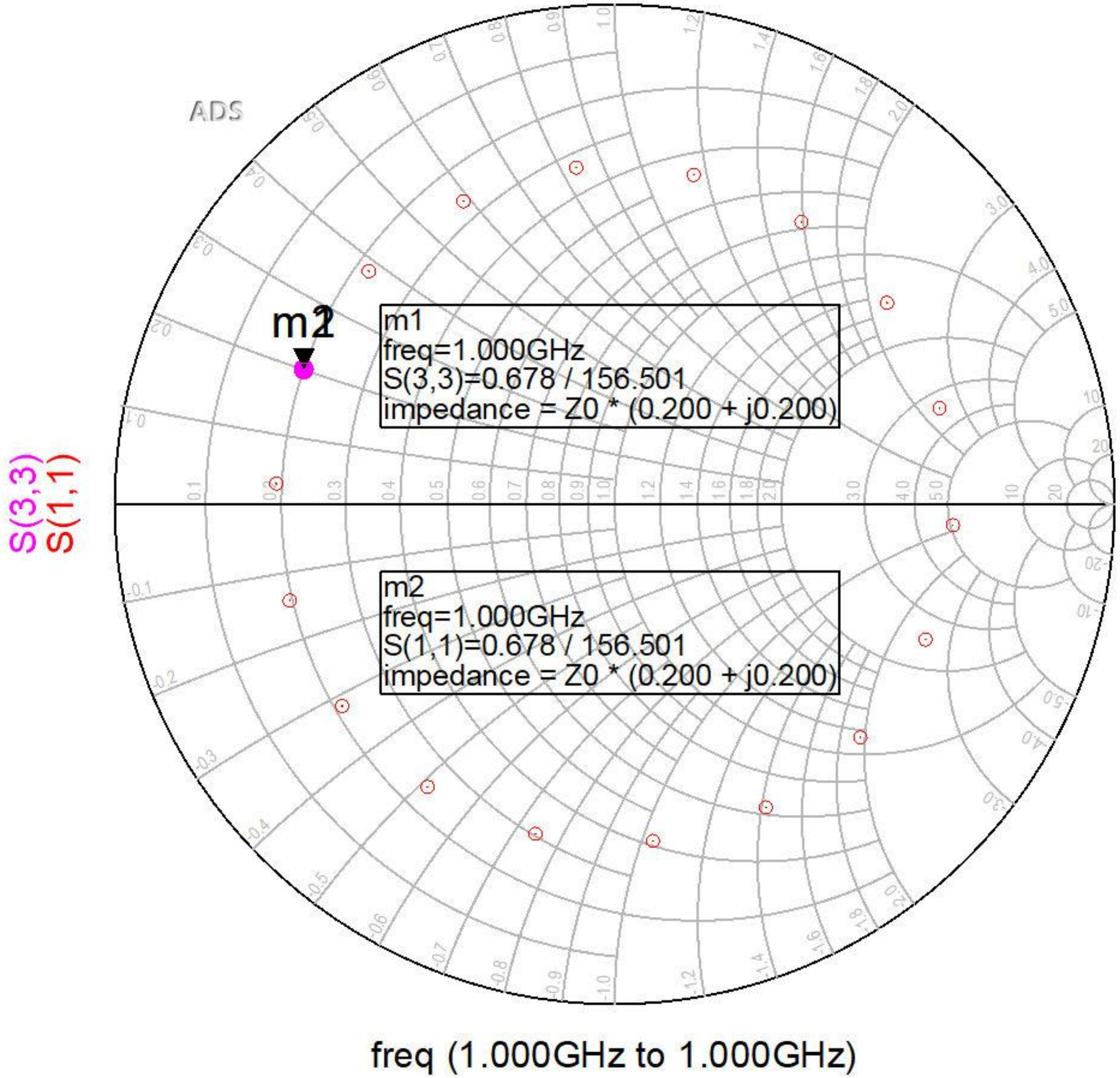
ADS, Smith Chart, series transmission line



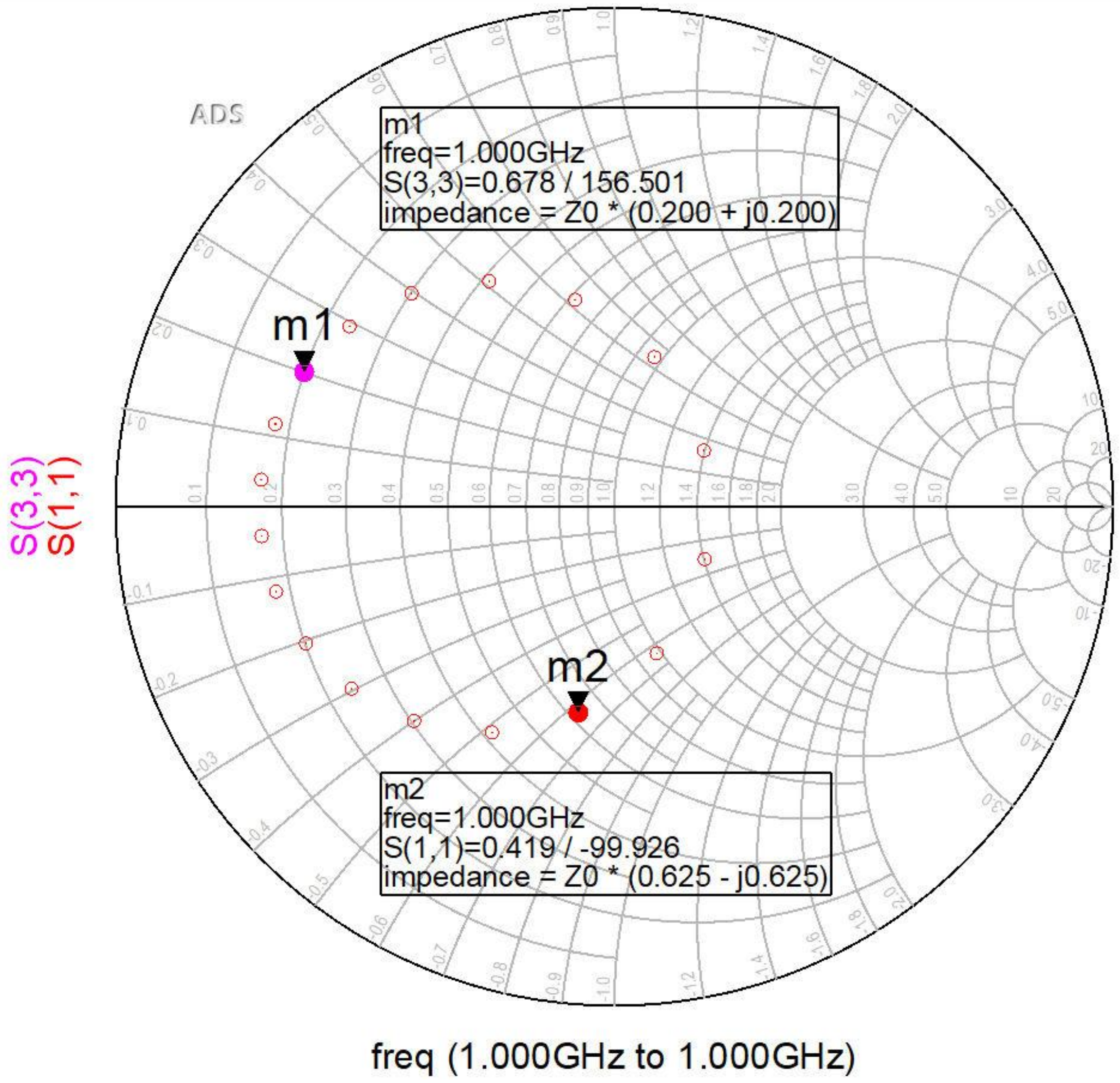
ADS, Smith Chart, series transmission line, E=90°



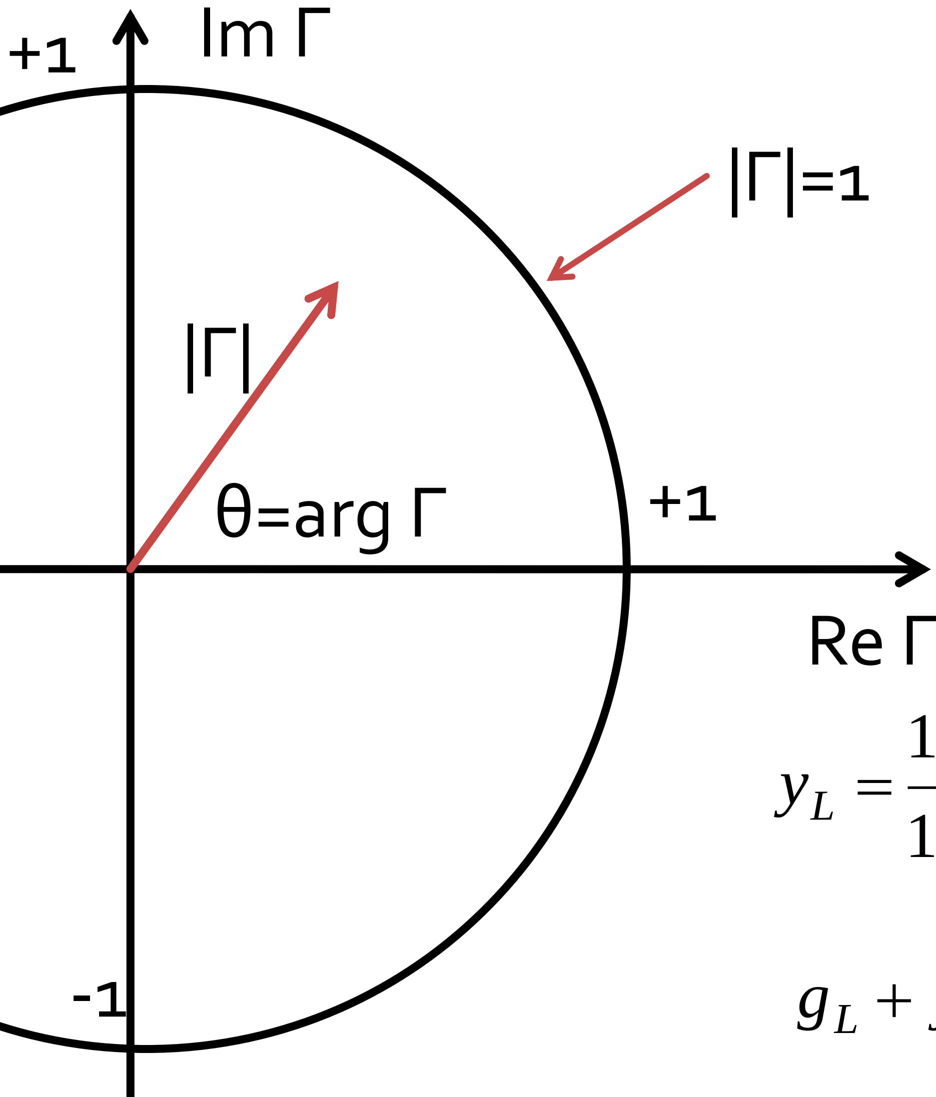
ADS, Smith Chart, series transmission line, E=180°



ADS, Smith Chart, series transmission line, Z=25Ω≠Z_o



The Admittance Smith Chart



$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{z_L - 1}{z_L + 1} = |\Gamma| \cdot e^{j\theta}$$

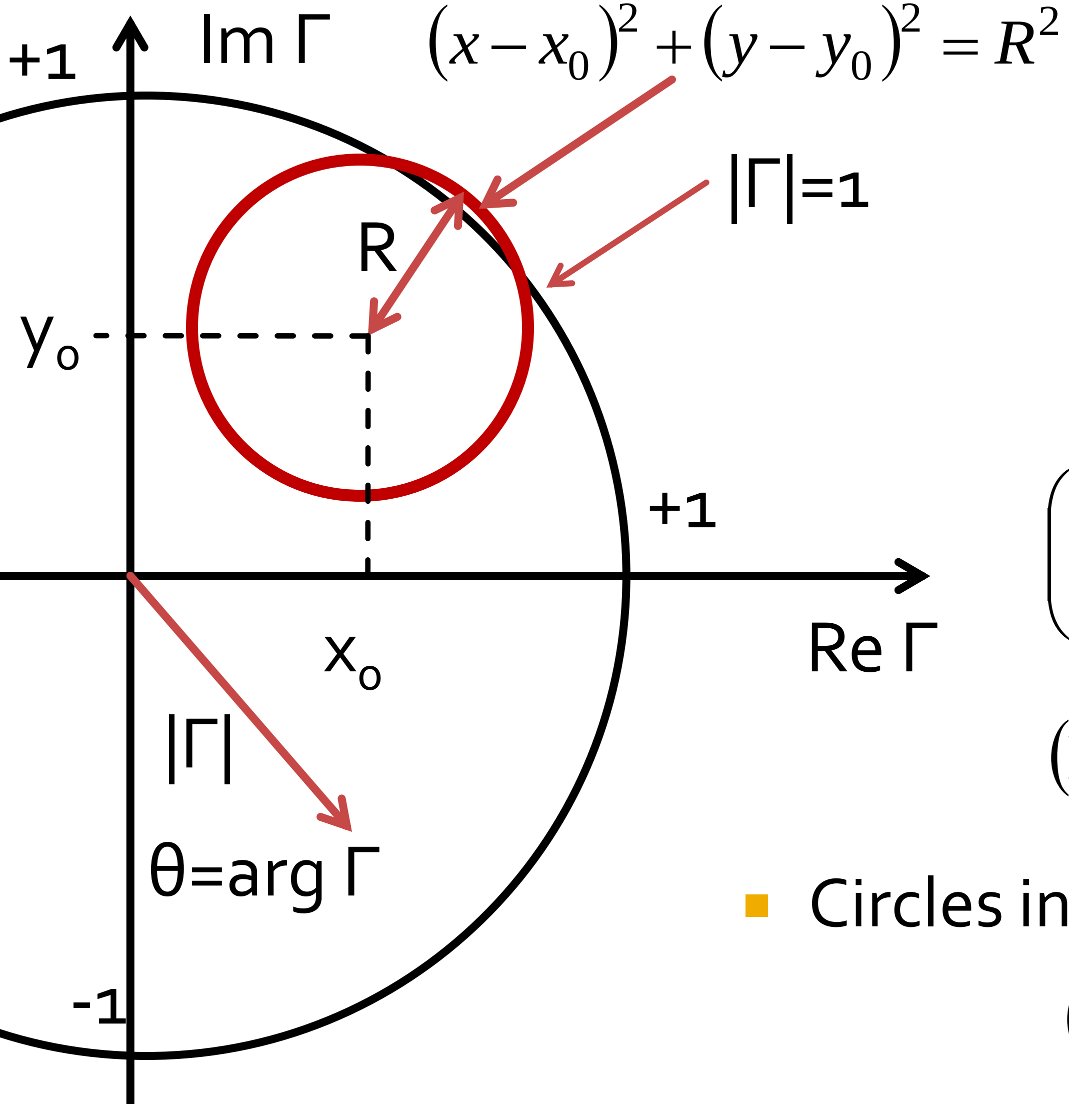
$$\Gamma = \Gamma_r + j \cdot \Gamma_i$$

$$z_L = \frac{1 + |\Gamma| \cdot e^{j\theta}}{1 - |\Gamma| \cdot e^{j\theta}} = r_L + j \cdot x_L$$

$$y_L = \frac{1 - |\Gamma| \cdot e^{j\theta}}{1 + |\Gamma| \cdot e^{j\theta}} = \frac{1}{r_L + j \cdot x_L} = g_L + j \cdot b_L$$

$$g_L + j \cdot b_L = \frac{(1 - \Gamma_r) - j \cdot \Gamma_i}{(1 + \Gamma_r) + j \cdot \Gamma_i}$$

The Admittance Smith Chart



$$g_L=\frac{1-\Gamma_r^2-\Gamma_i^2}{(1+\Gamma_r)^2+\Gamma_i^2}$$

$$b_L=\frac{-2\cdot\Gamma_i}{(1+\Gamma_r)^2+\Gamma_i^2}$$

- Rearranged

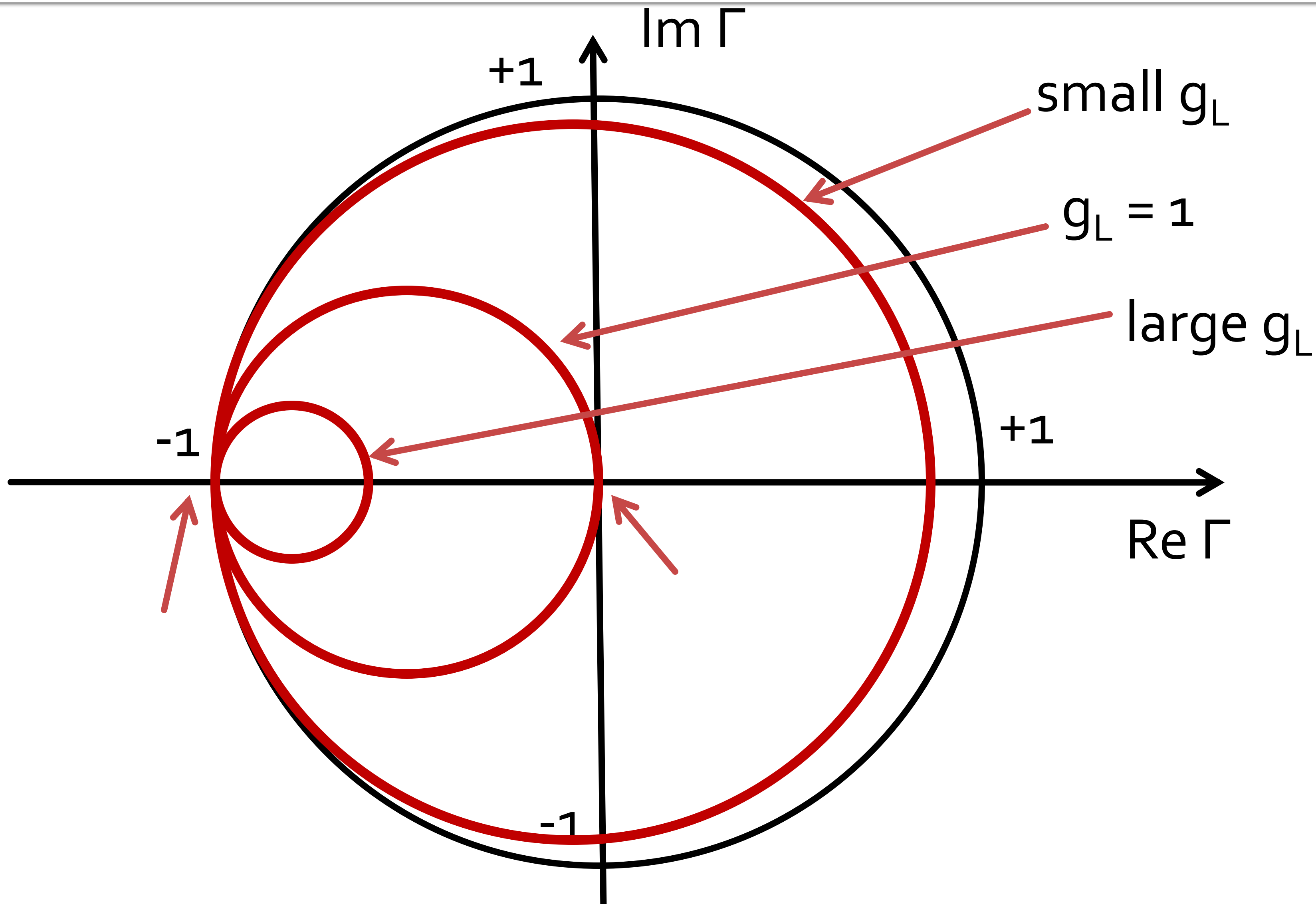
$$\left(\Gamma_r+\frac{g_L}{1+g_L}\right)^2+\Gamma_i^2=\left(\frac{1}{1+g_L}\right)^2$$

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

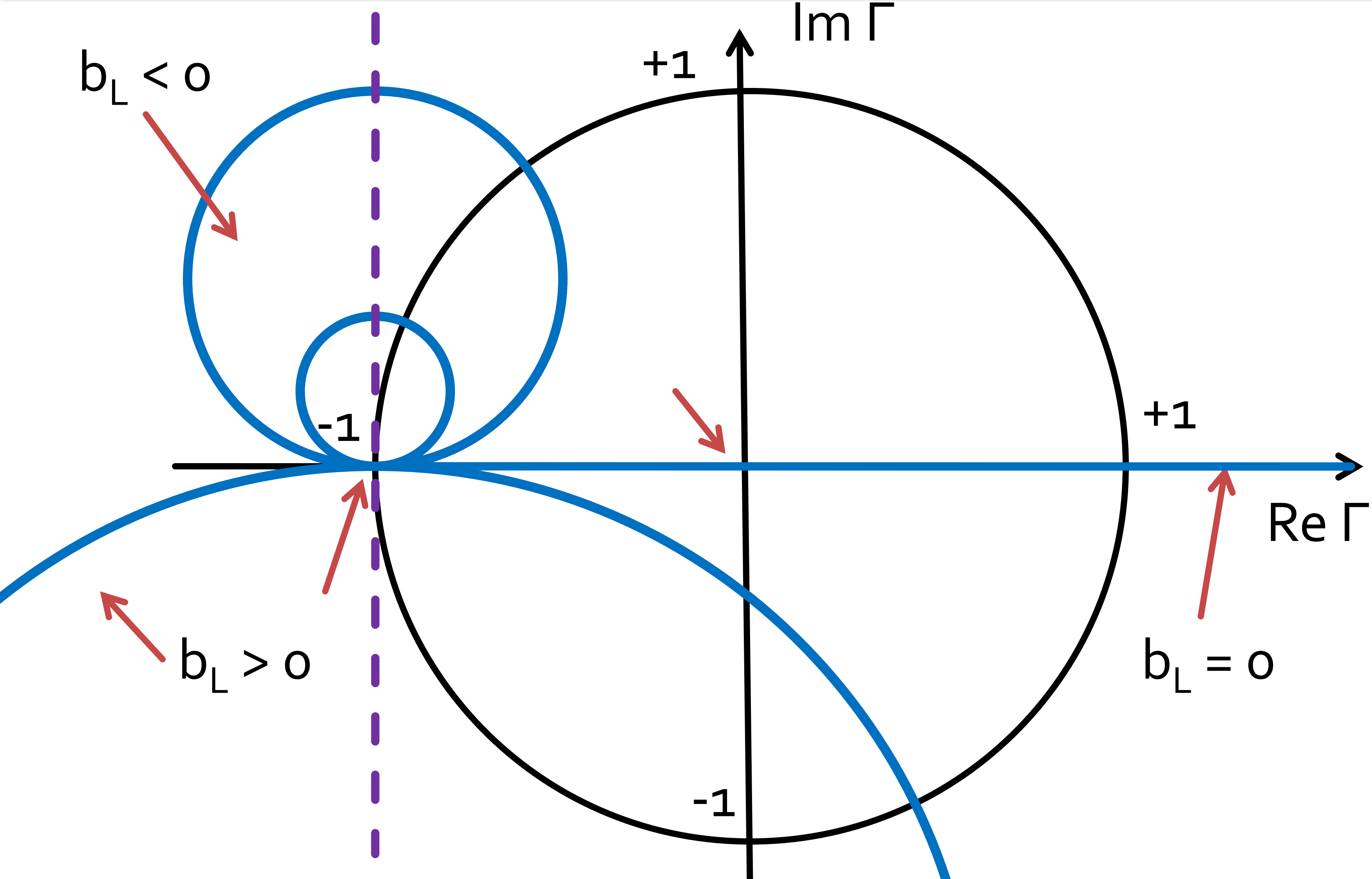
- Circles in the (Γ_r, Γ_i) complex plane

$$(x-x_0)^2+(y-y_0)^2=R^2$$

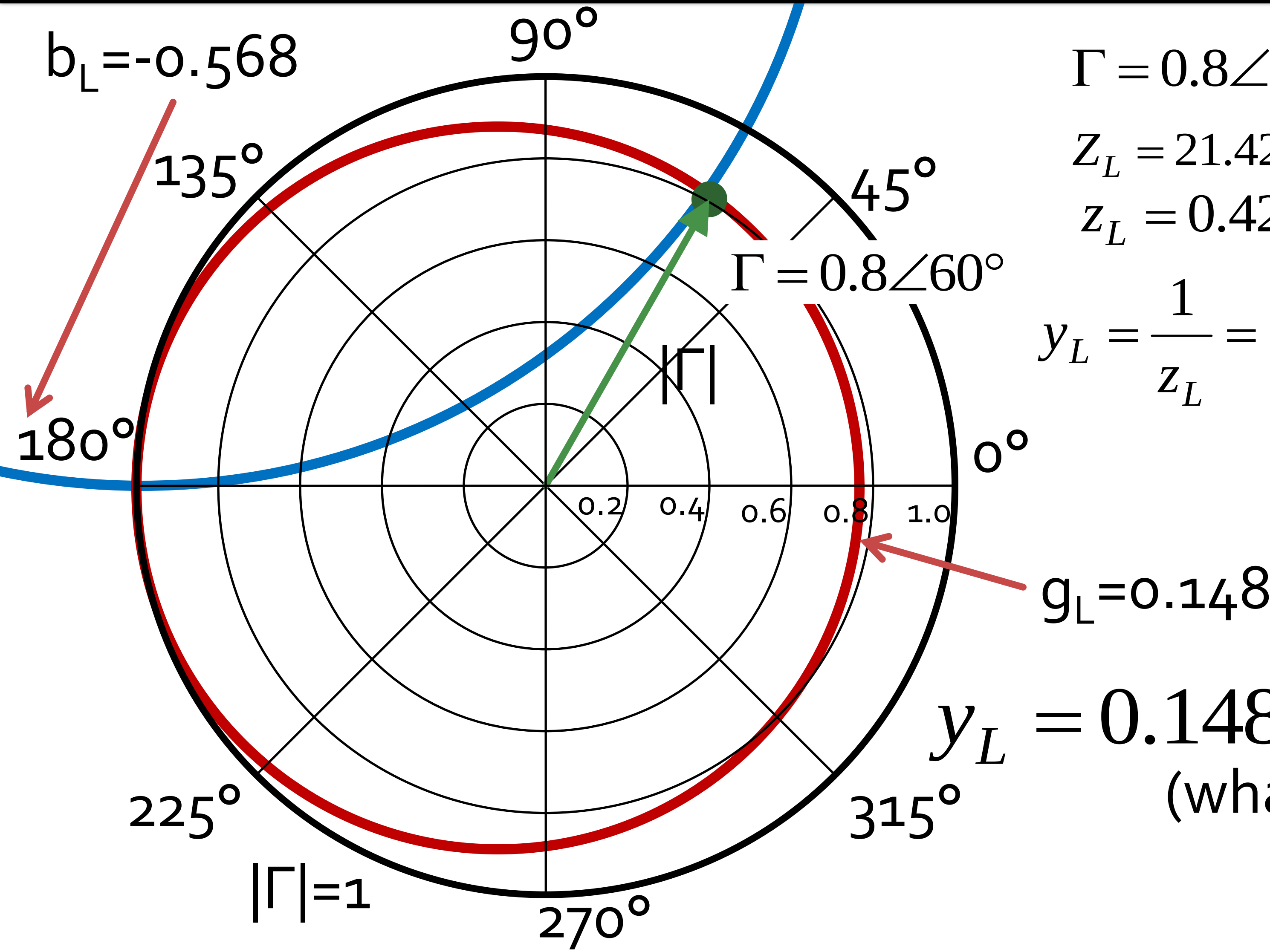
The Smith Chart, conductance



The Smith Chart, susceptance



The Smith Chart, reflection coefficient ⇔ admittance



$$\Gamma = 0.8\angle 60^\circ$$

$$Z_L = 21.429\Omega + j\cdot 82.479\Omega$$

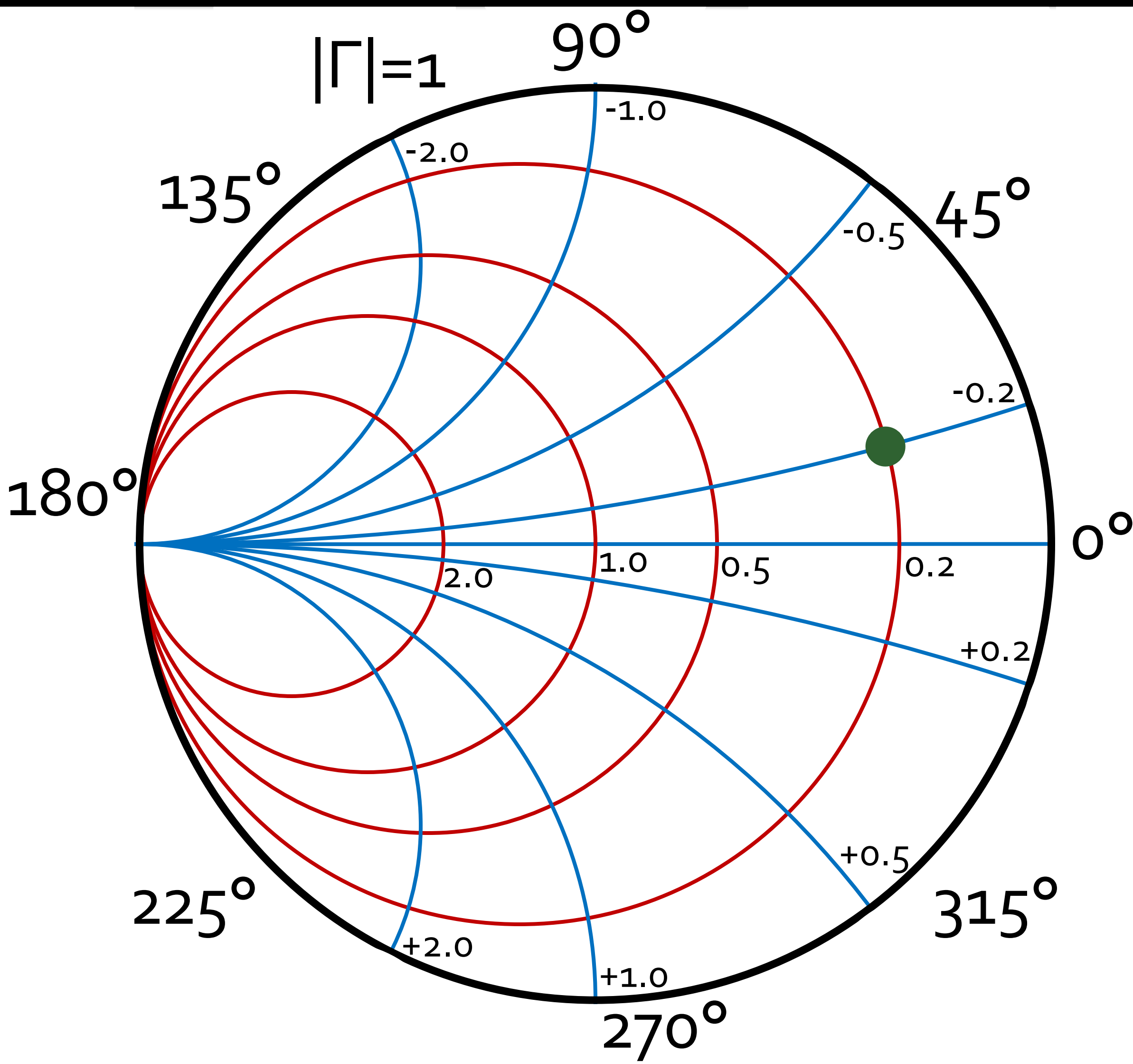
$$z_L = 0.429 + j\cdot 1.65$$

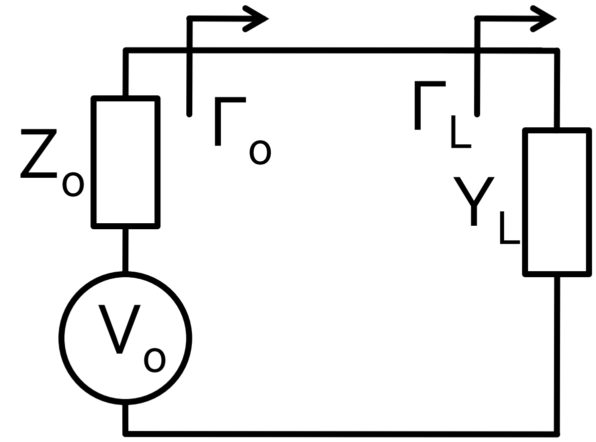
$$y_L = \frac{1}{z_L} = 0.148 - j\cdot 0.568$$

$$y_L = 0.148 + j\cdot 0.568$$

(whatever Z_o)

The Smith Chart, reflection coefficient ⇔ admittance





$$Z_0 = 50\Omega, Y_0 = 0.02S$$

$$Z_L = 125\Omega + j \cdot 125\Omega$$

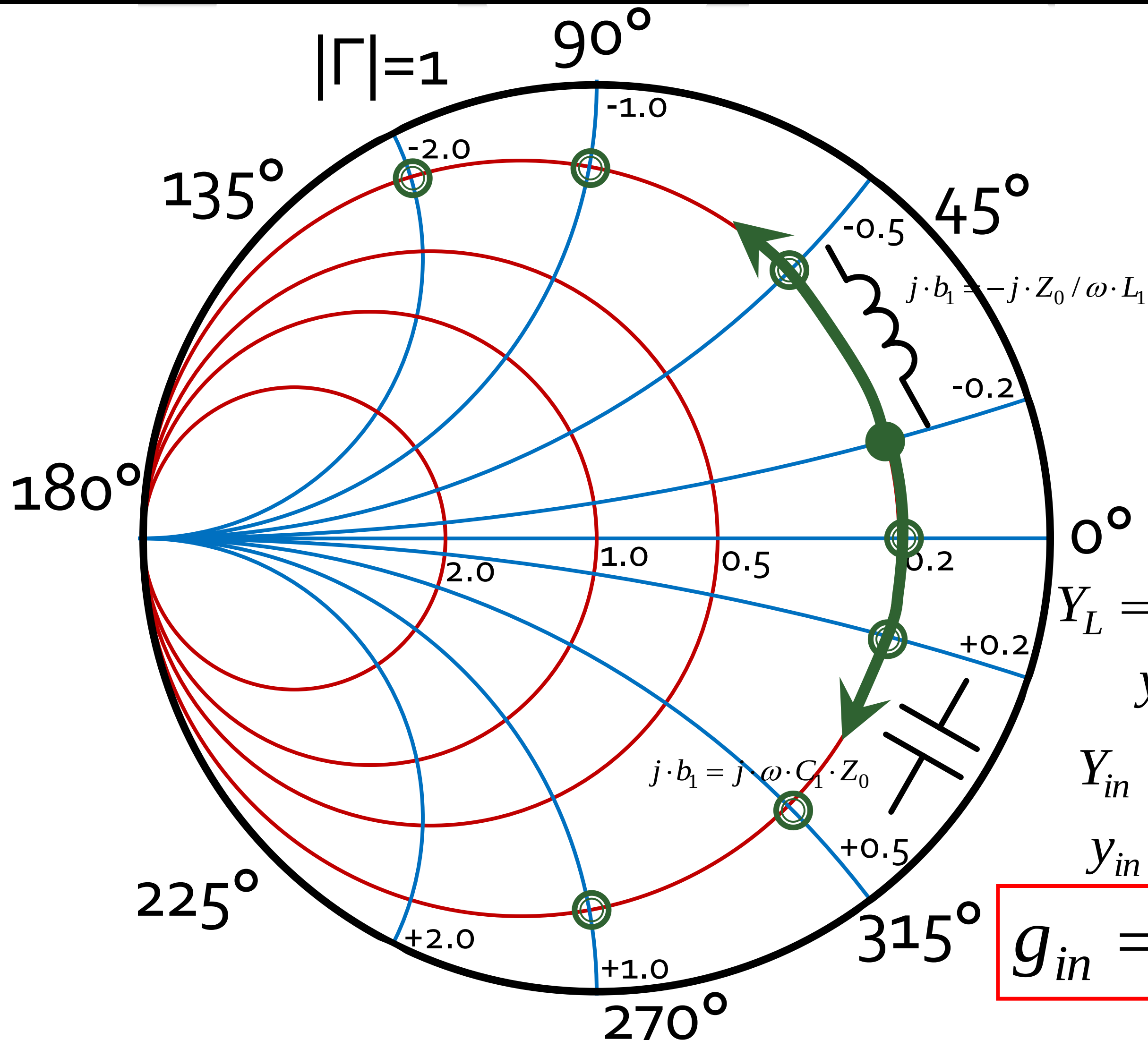
$$z_L = 2.5 + j \cdot 2.5$$

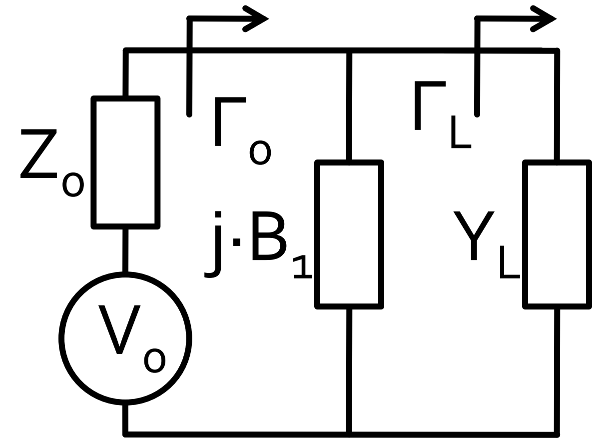
$$\Gamma_L = \Gamma_0 = 0.678\angle 23.5°$$

$$Y_L = \frac{1}{Z_L} = 0.004S - j \cdot 0.004S$$

$$y_L = \frac{1}{z_L} = \frac{Y_L}{Y_0} = 0.2 - j \cdot 0.2$$

The Smith Chart, shunt susceptance





$Z_0 = 50\Omega, Y_0 = 0.02S$

$\Gamma_L = 0.678\angle 23.5°$

$Y_L = G_L + j \cdot B_L = 0.004S + j \cdot 0.004$

$y_L = g_L + j \cdot b_L = 0.2 - j \cdot 0.2$

$Y_{in} = Y_L + j \cdot B_1 = G_L + j \cdot (B_L + B_1)$

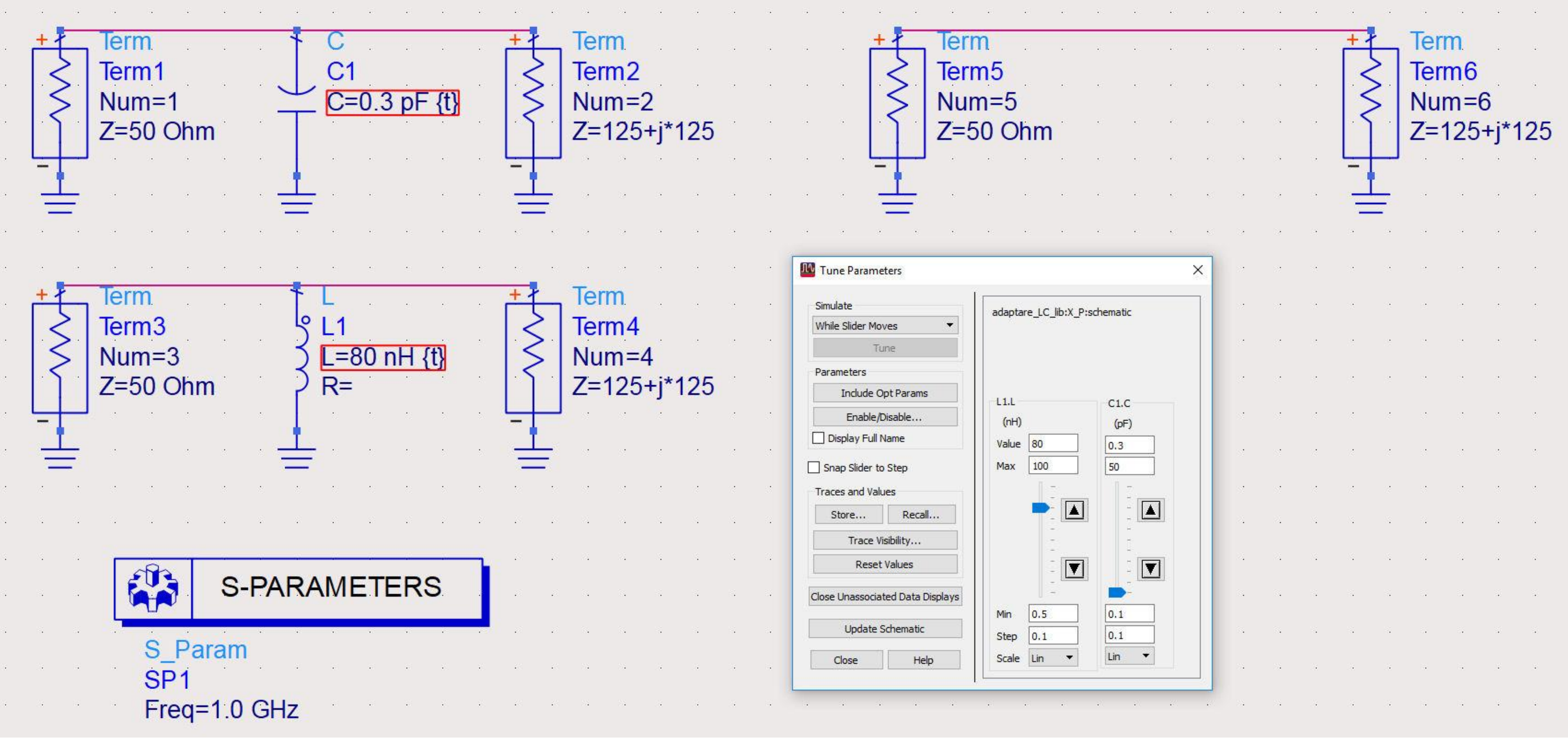
$y_{in} = g_L + j \cdot (b_L + b_1)$

$g_{in} = g_L$

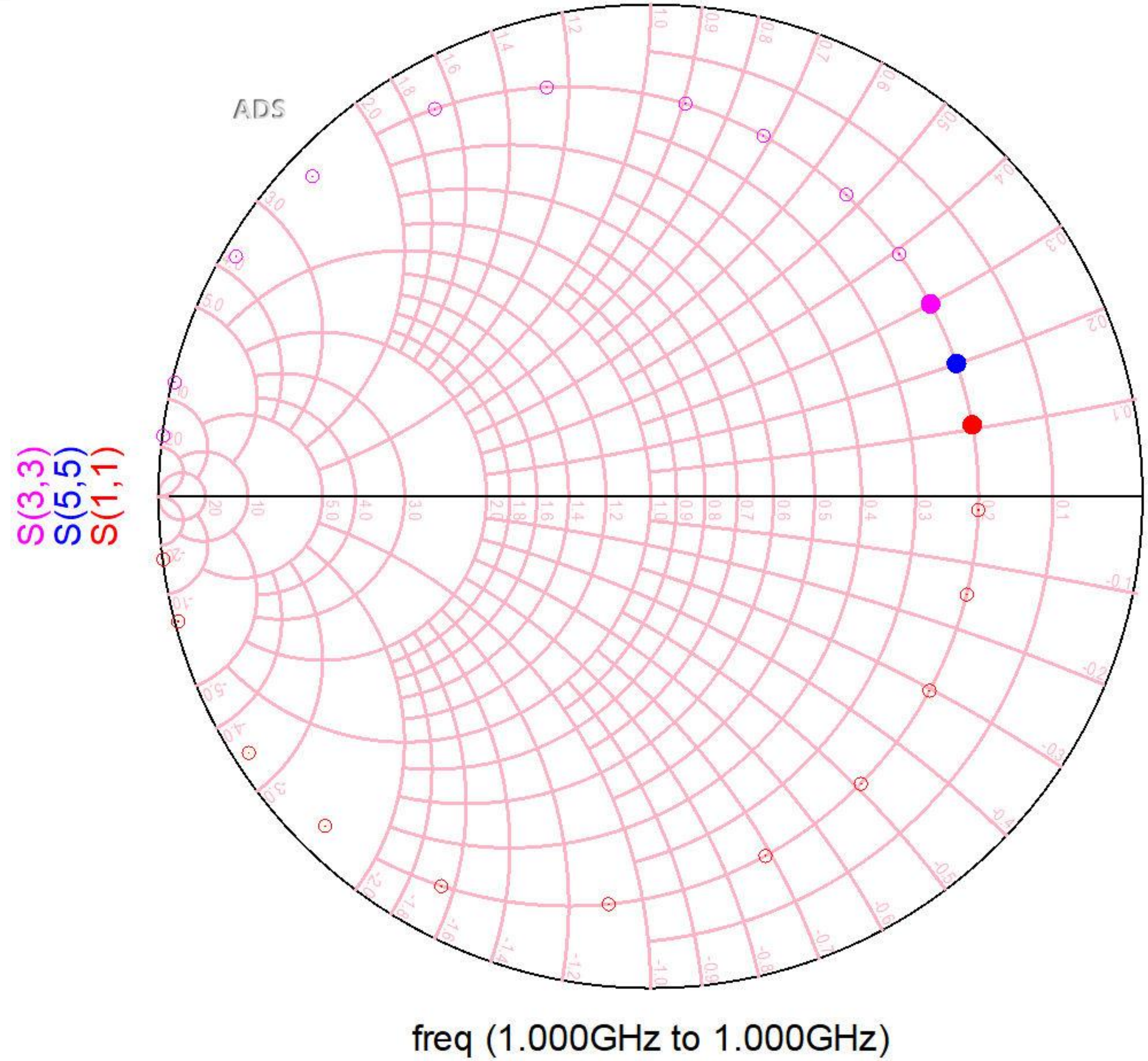
$j \cdot b_1 = j \cdot \omega \cdot C_1 \cdot Z_0 > 0$

$j \cdot b_1 = -j \cdot Z_0 / \omega \cdot L_1 < 0$

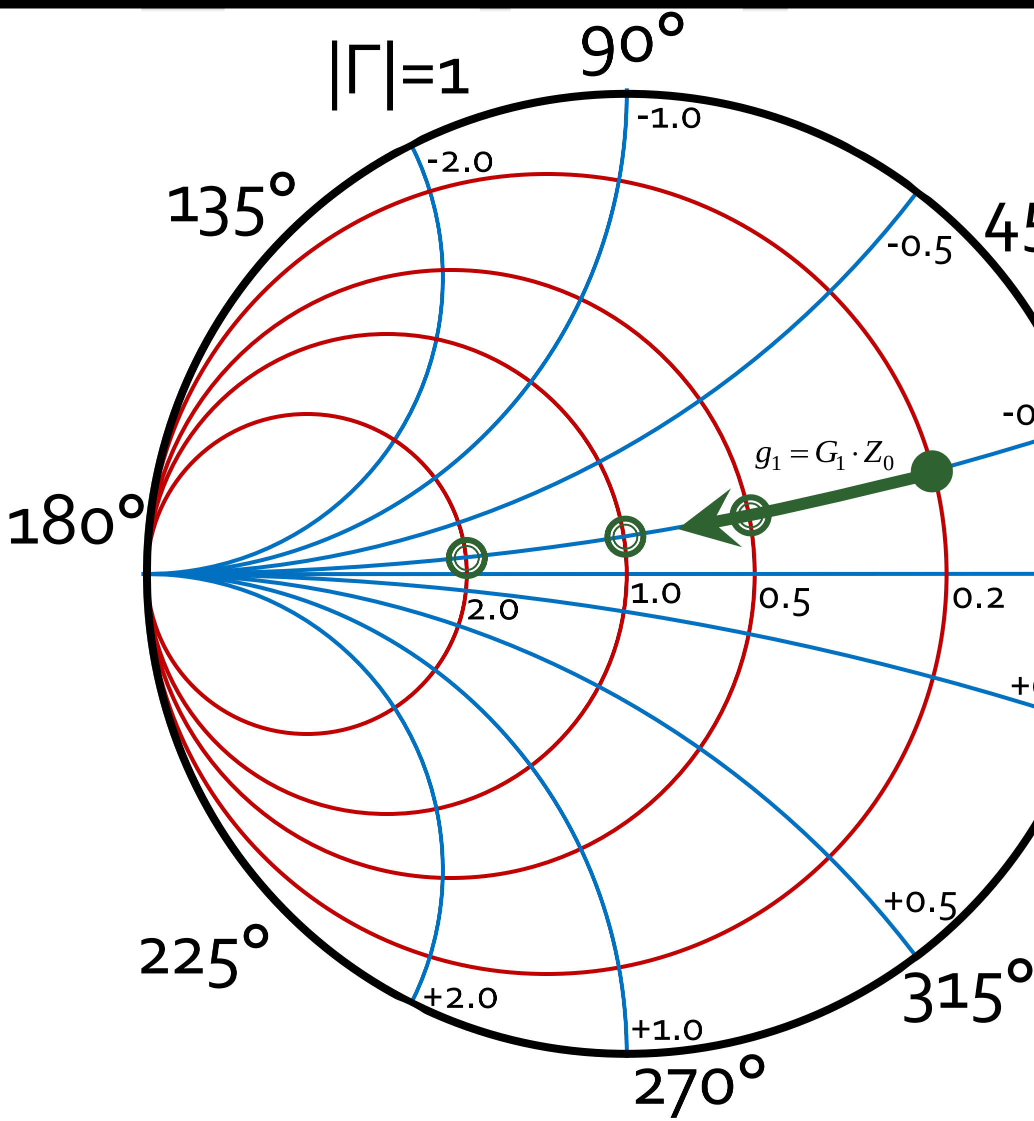
ADS, shunt susceptance

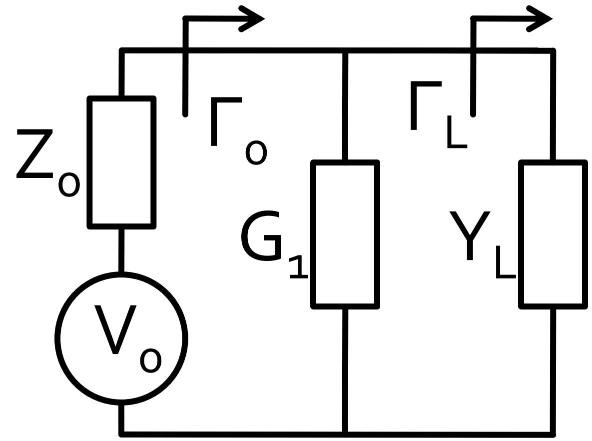


ADS, shunt susceptance



The Smith Chart, shunt conductance





$$Z_0 = 50\Omega, Y_0 = 0.02S$$

$$\Gamma_L = 0.678\angle 23.5°$$

$$Y_L = G_L + j \cdot B_L = 0.004S + j \cdot 0.004$$

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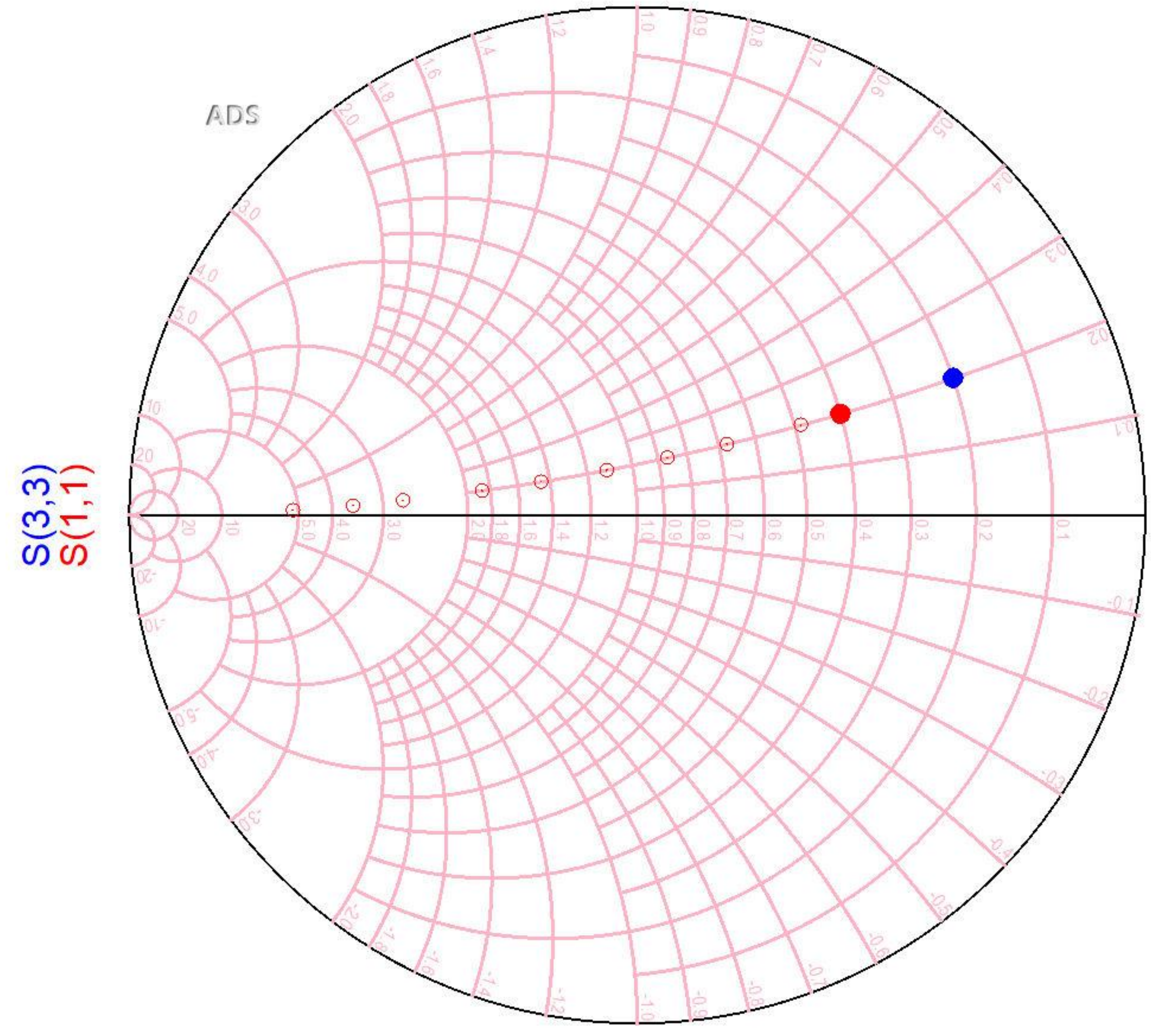
$$Y_{in} = Y_L + G_1 = (G_L + G_1) + j \cdot B_L$$

$$y_{in} = (g_L + g_1) + j \cdot b_L$$

$$b_{in} = b_L$$

$$g_{in} = g_L + G_1 \cdot Z_0$$

ADS, shunt conductance



freq (1.000GHz to 1.000GHz)

Contact

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