Lecture 7

2017/2018

Microwave Devices and Circuits for Radiocommunications

Materials

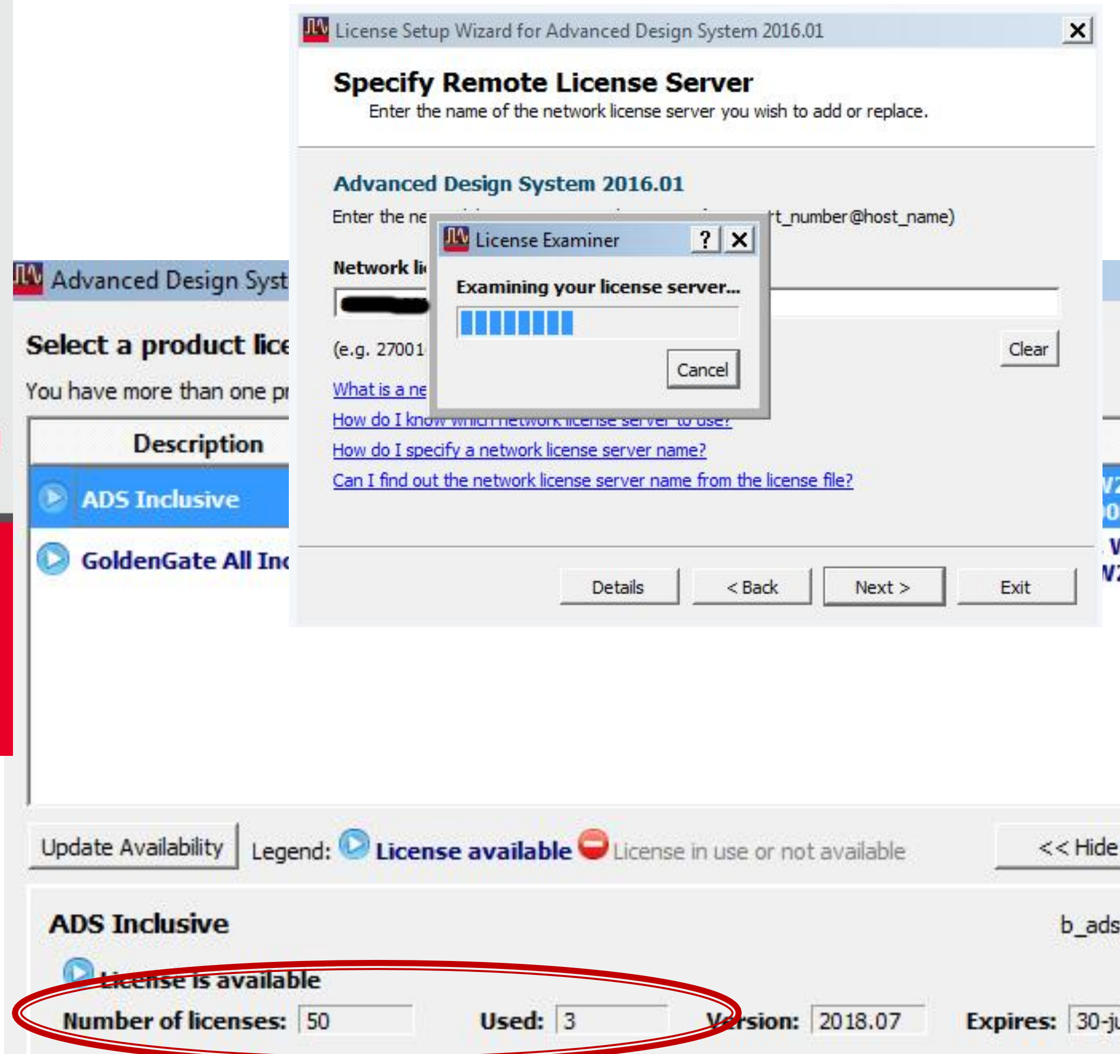
- RF-OPTO
  - **http://rf-opto.etti.tuiasi.ro**
- **David Pozar, “Microwave Engineering”**, Wiley; 4th edition , 2011
  - 1 exam problem ← Pozar
- Photos
  - sent by email: rdamian@etti.tuiasi.ro
  - used at lectures/laboratory

Software

- ADS 2016
- EmPro 2015
- based on IP from outside university or campus

Software

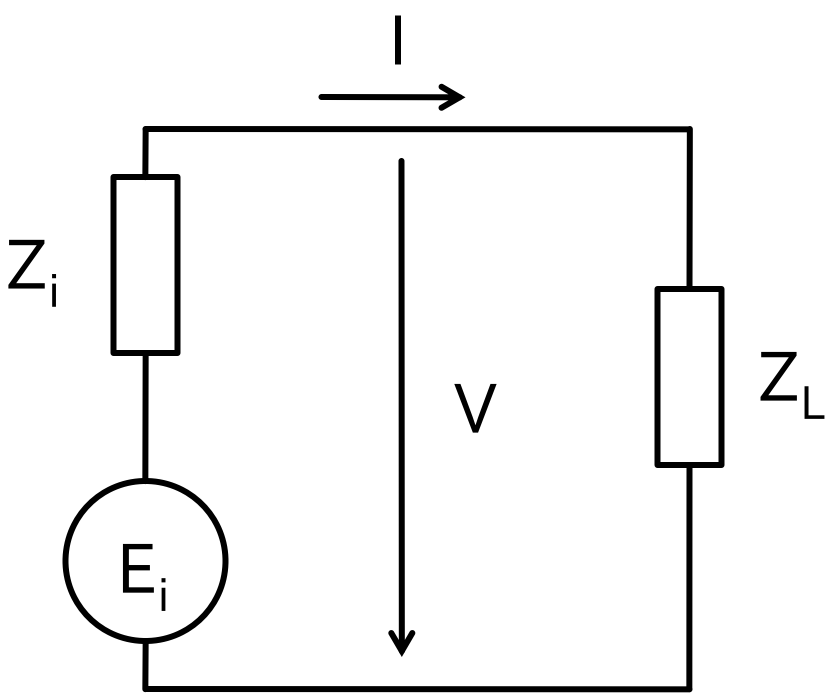
Advanced Design System
Premier High-Frequency and High Speed Design Platform
2016.01
KEYSIGHT TECHNOLOGIES
© Keysight Technologies 1985-2016



License Setup Wizard for Advanced Design System 2016.01
Specify Remote License Server
Enter the name of the network license server you wish to add or replace.
Advanced Design System 2016.01
Enter the ne
rt_number@host_name)
Network li
[redacted]
(e.g. 27001
Clear
What is a ne
How do I know which network license server to use?
How do I specify a network license server name?
Can I find out the network license server name from the license file?
Details
< Back
Next >
Exit
License Examiner
Examining your license server...
Cancel
Advanced Design Syst
Select a product lice
You have more than one pr
Description
ADS Inclusive
GoldenGate All Inc
Update Availability
Legend:
License available
License in use or not available
<< Hide D
ADS Inclusive
b_ads_i
License is available
Number of licenses: 50
Used: 3
Version: 2018.07
Expires: 30-jul-

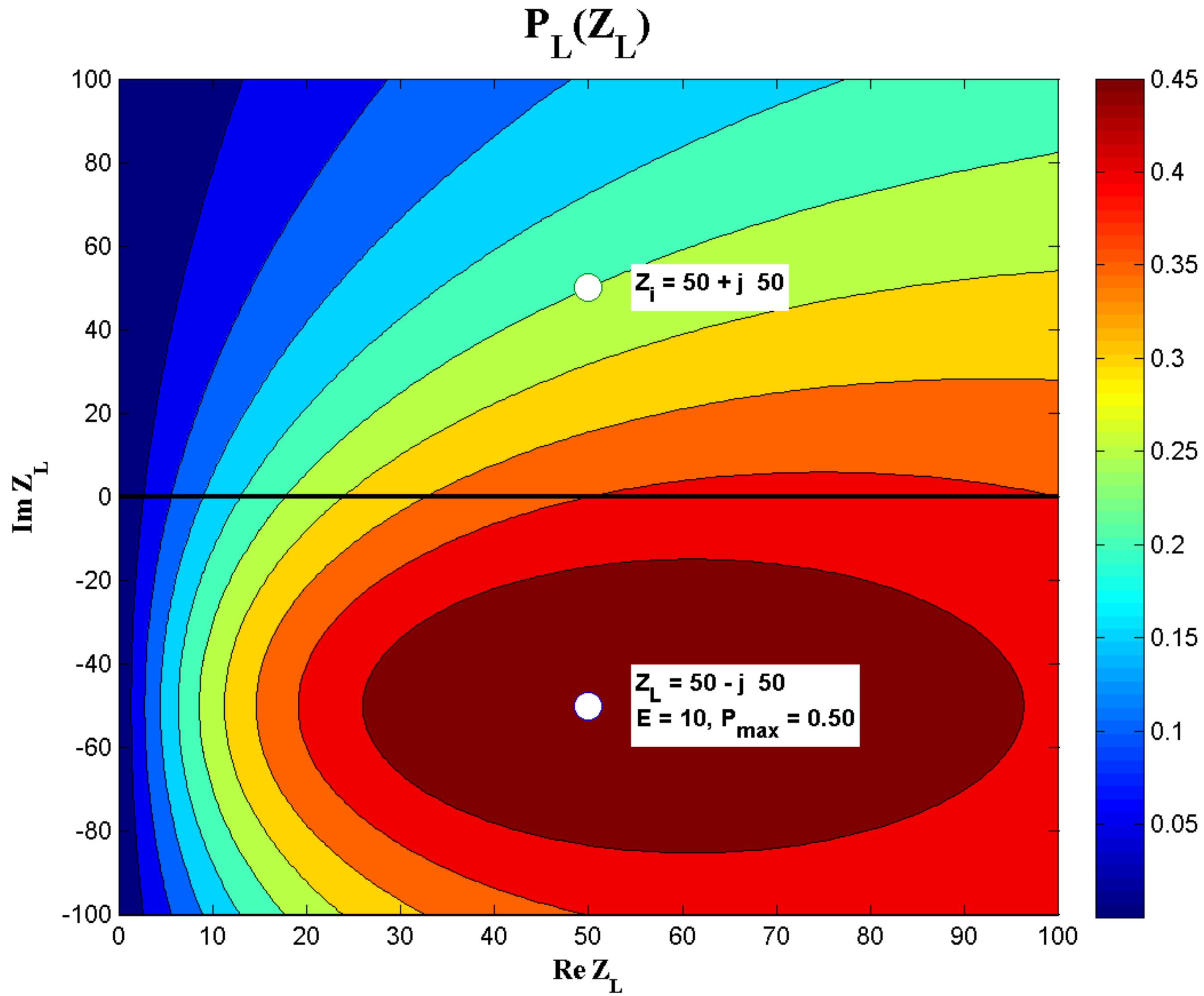
Matching

- Source **matched** to load ?



- impedance values ?
- existence of reflections ?

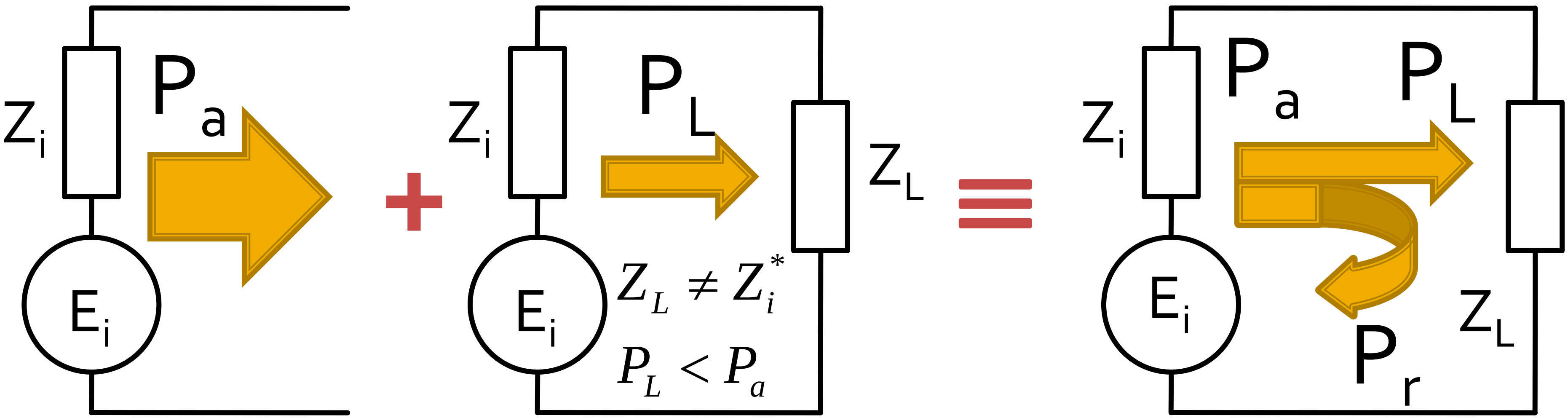
Matching, example



$$Z_L = Z_i^*$$

$$\Gamma_L = \Gamma_i^*$$

Reflection and power / Model

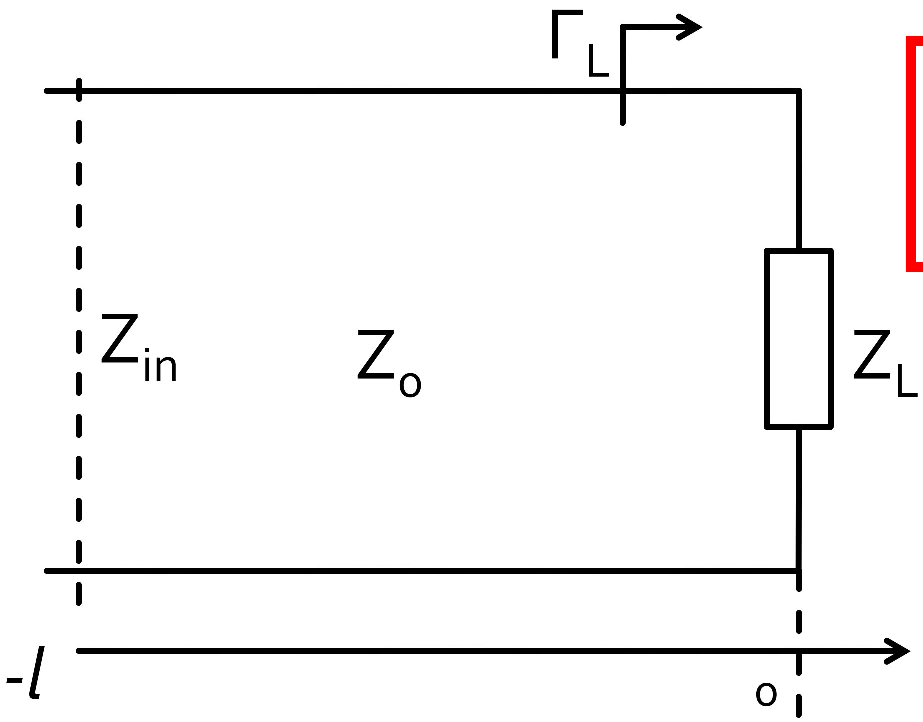


- The source has the ability to sent to the load a certain maximum power (available power) P_a
- For a particular load the power sent to the load is less than the maximum (mismatch) $P_L < P_a$
- The phenomenon is **"as if"** (model) part of the input power is reflected $P_r = P_a - P_L$
- The power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

TEM transmission lines

The lossless line

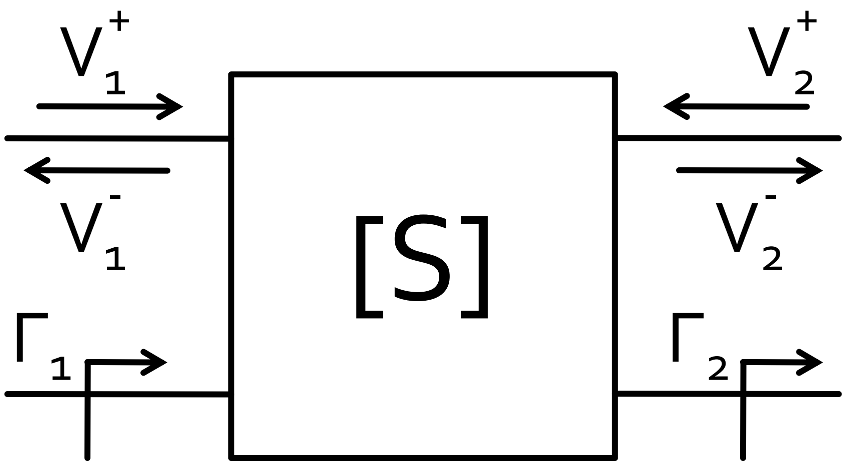
- input impedance of a length ***l*** of transmission line with characteristic impedance $\boldsymbol{Z_o}$, loaded with an arbitrary impedance $\boldsymbol{Z_L}$



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

Microwave Network Analysis

Scattering matrix – S



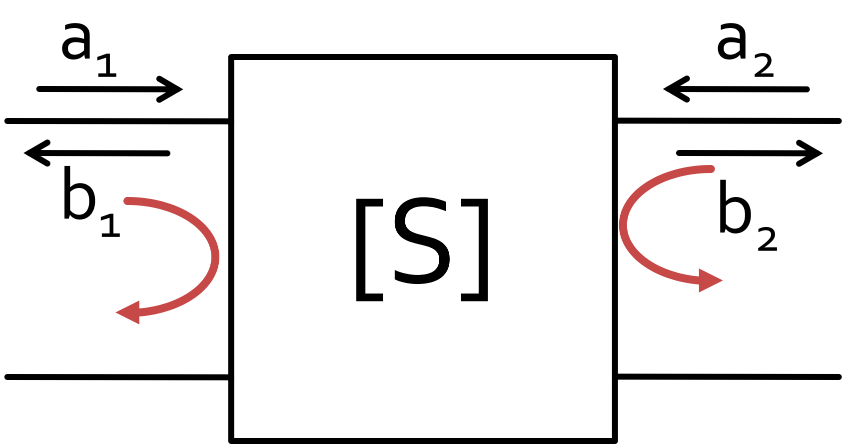
$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

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

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

- 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

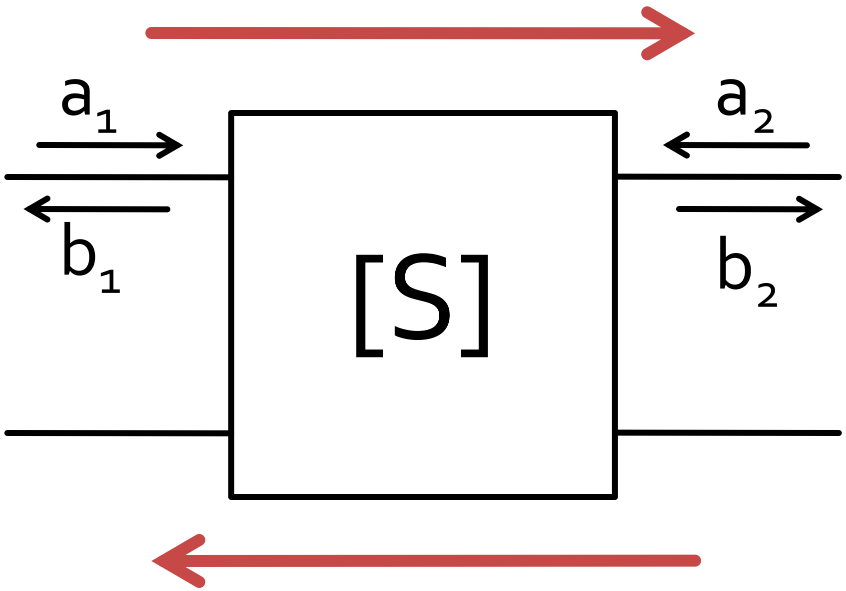


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

Scattering matrix – S

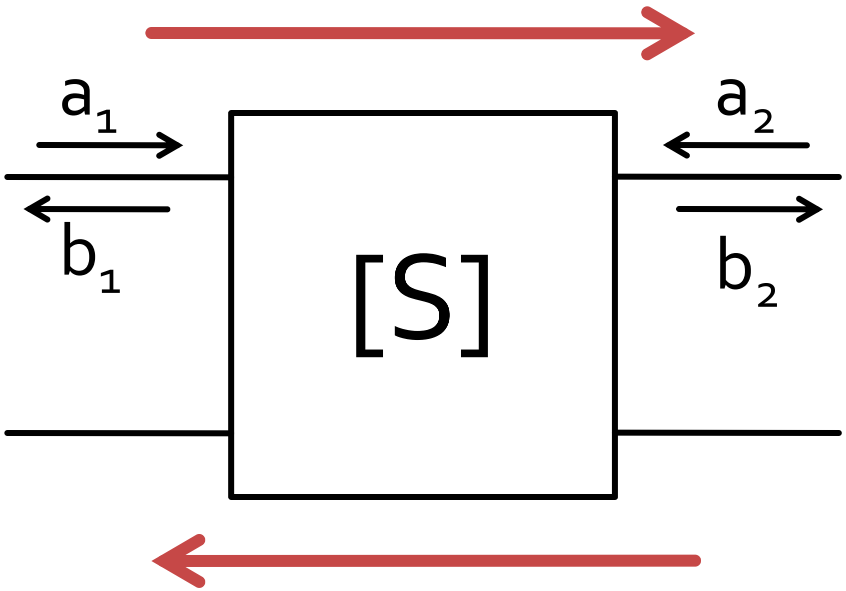


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

Scattering matrix – S



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

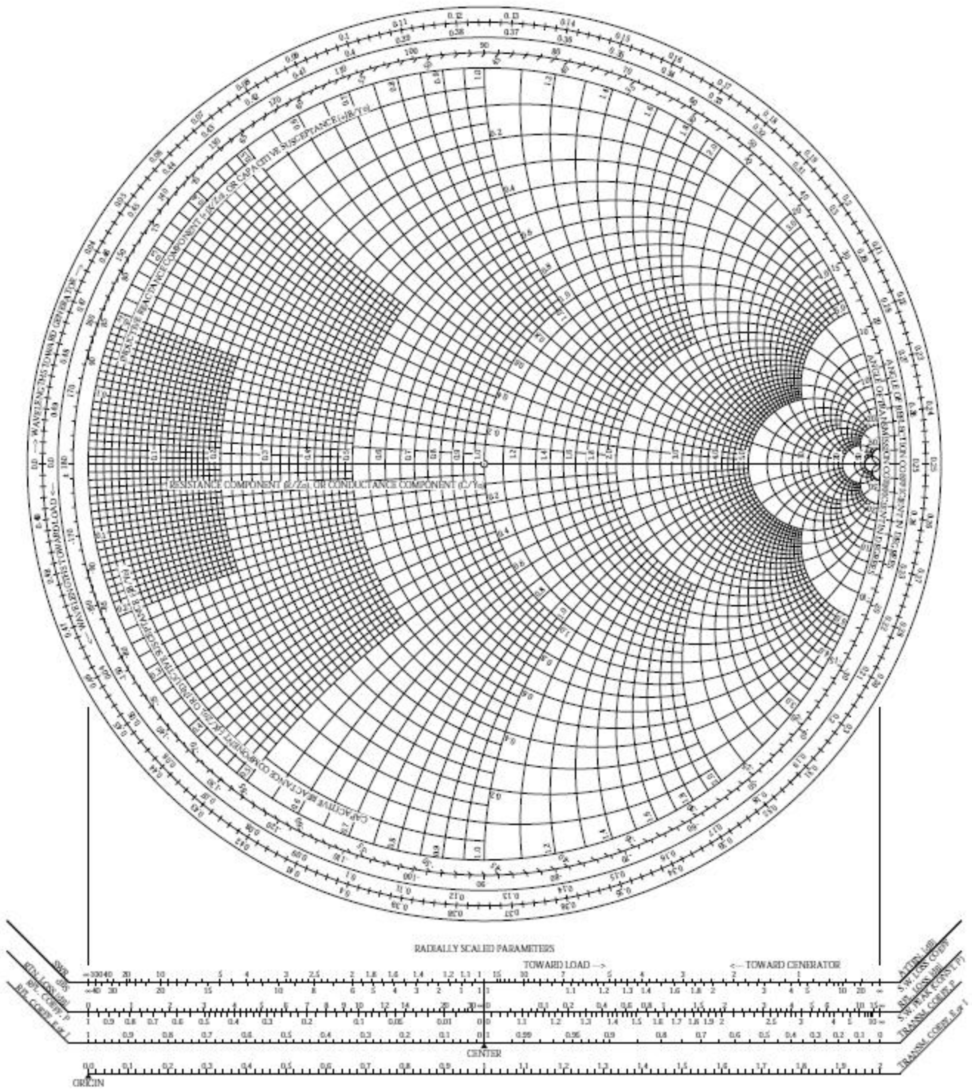
$$|S_{21}|^2 = \frac{Power\ in\ Z_0\ load}{Power\ from\ Z_0\ source}$$

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

Impedance Matching

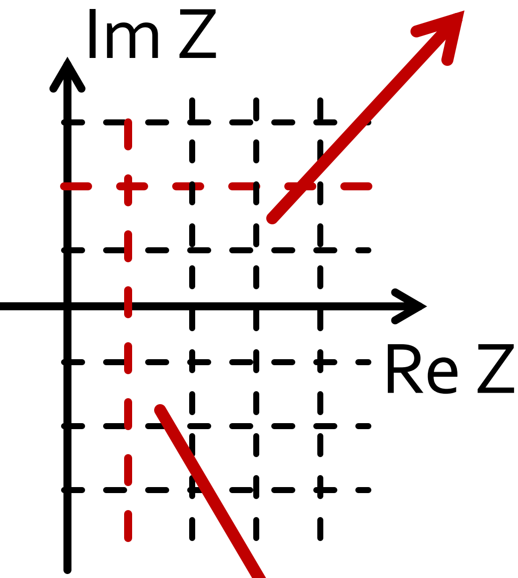
The Smith Chart

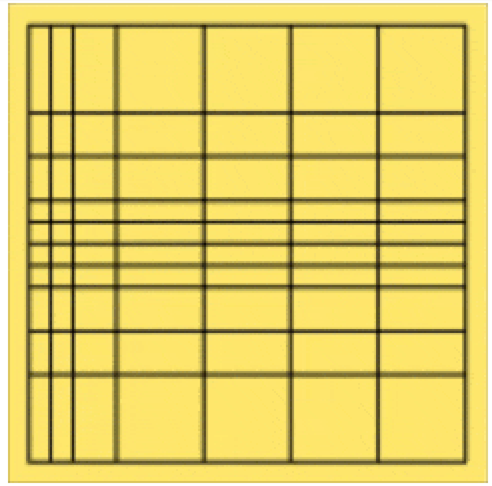
The Smith Chart

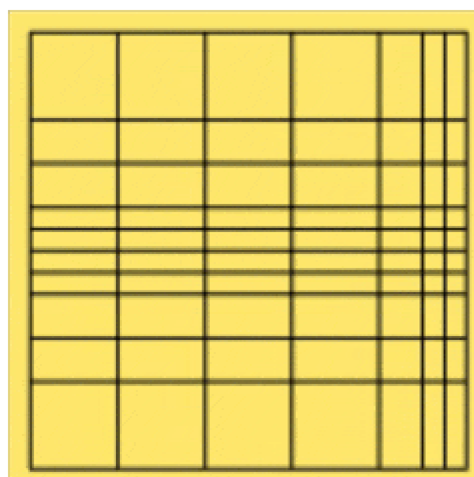


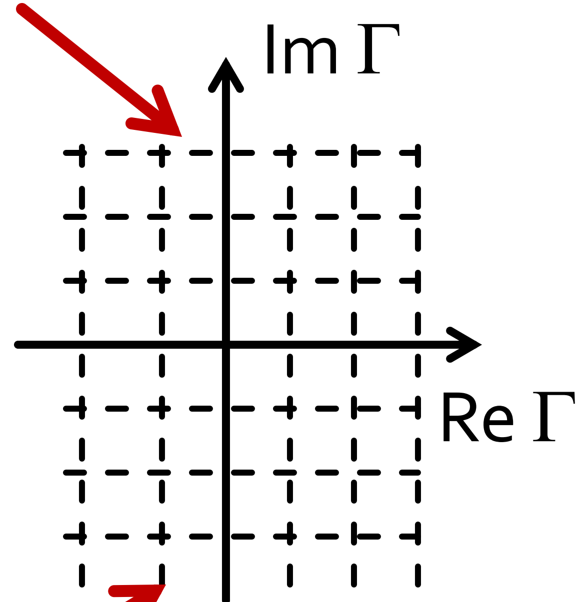
The Smith Chart

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



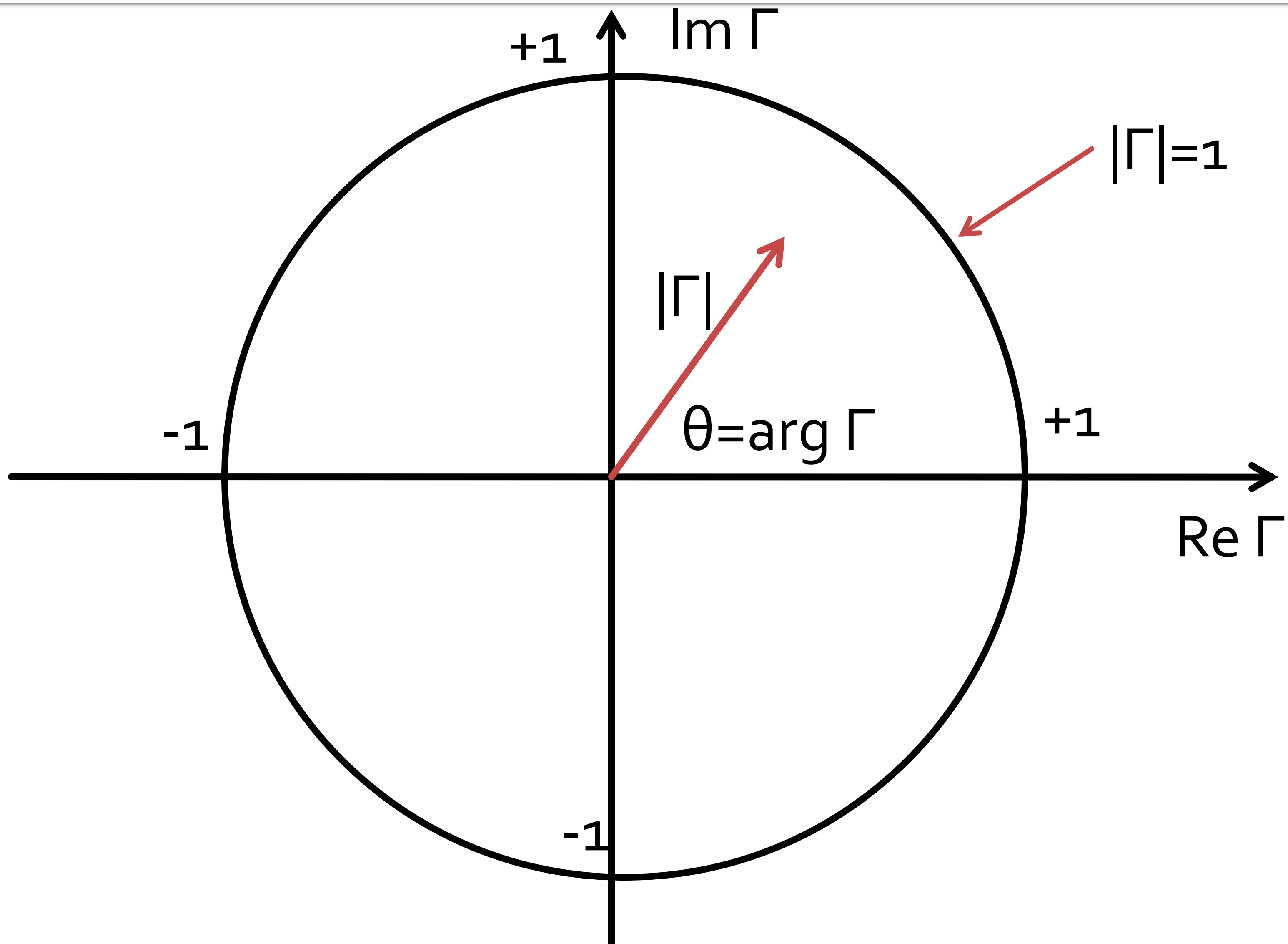






$$\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{Y_0 - Y_L}{Y_0 + Y_L} = \frac{1 - y_L}{1 + y_L}$$

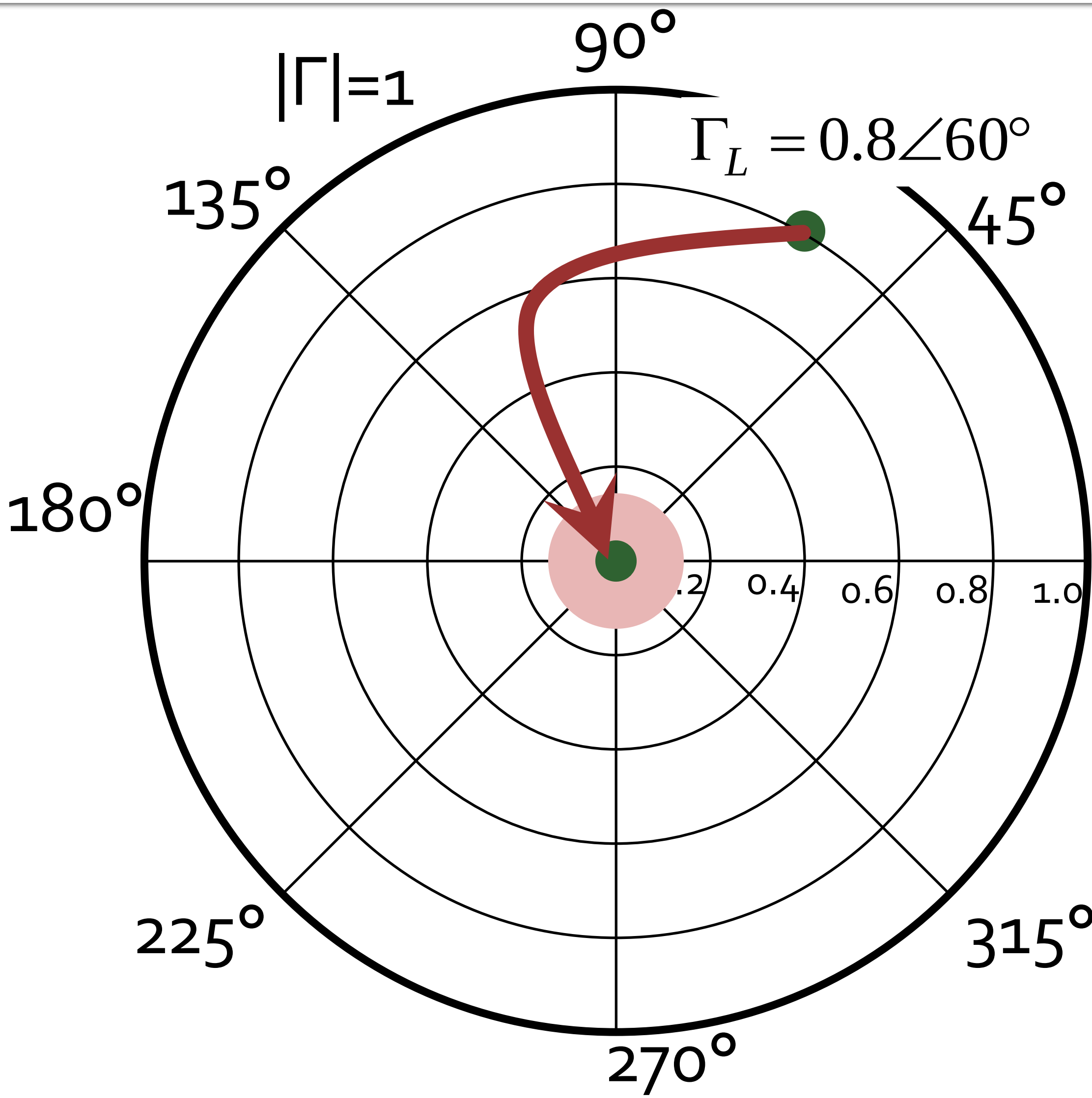
The Smith Chart

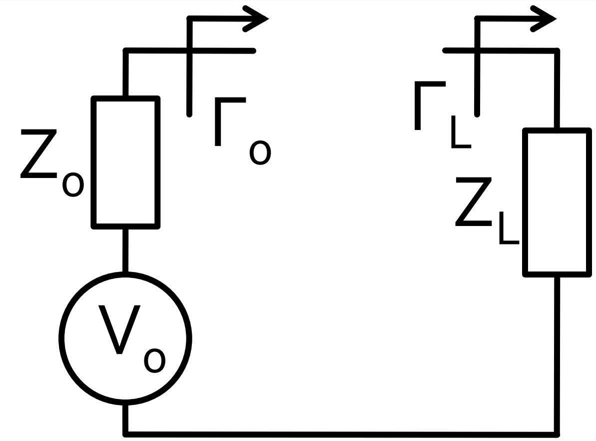


Impedance matching with lumped elements (L Networks)

Impedance Matching

The Smith Chart, reflection coefficient, impedance matching





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

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

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

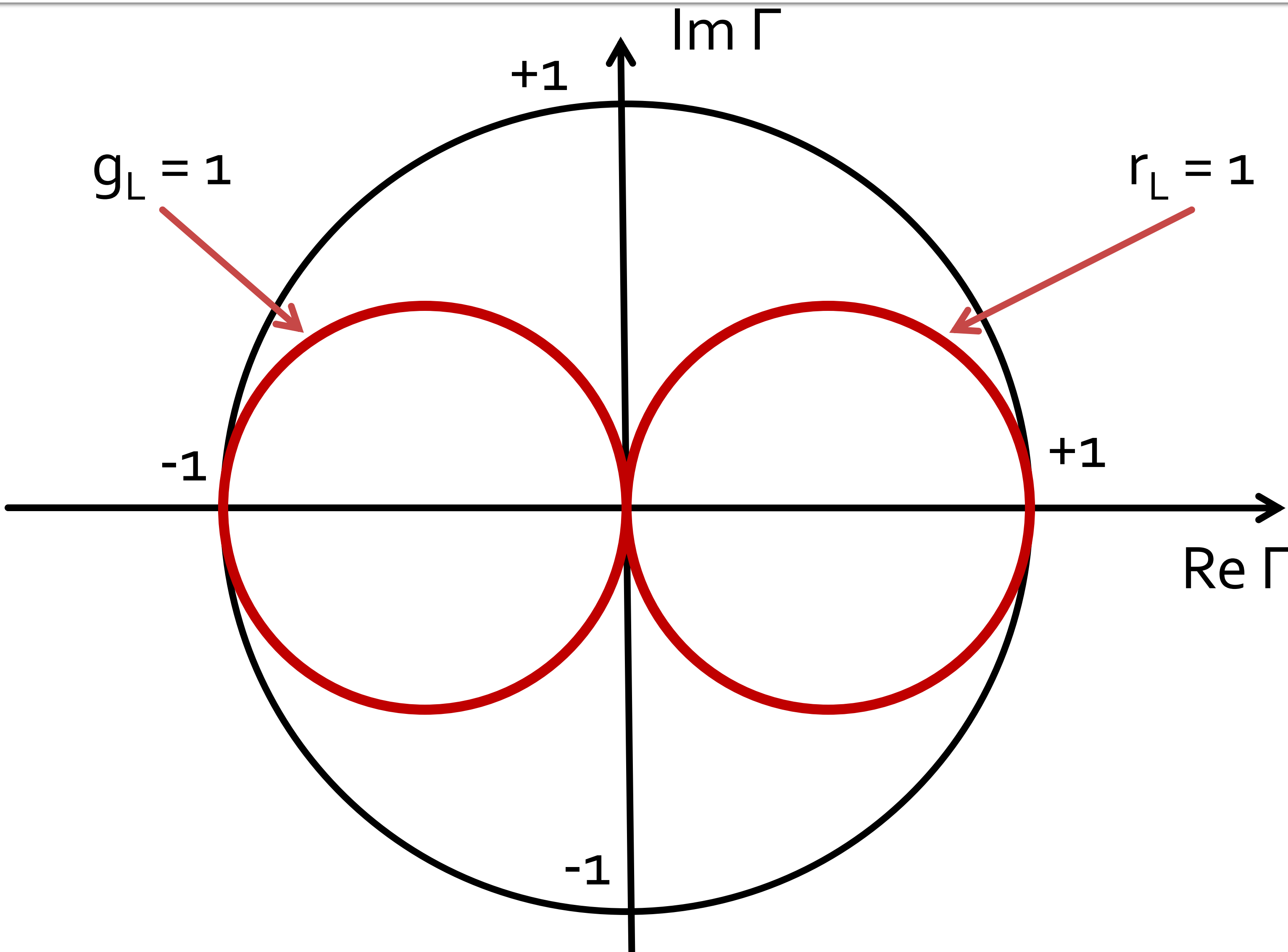
$$\Gamma_L = 0.8\angle 60^\circ$$

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

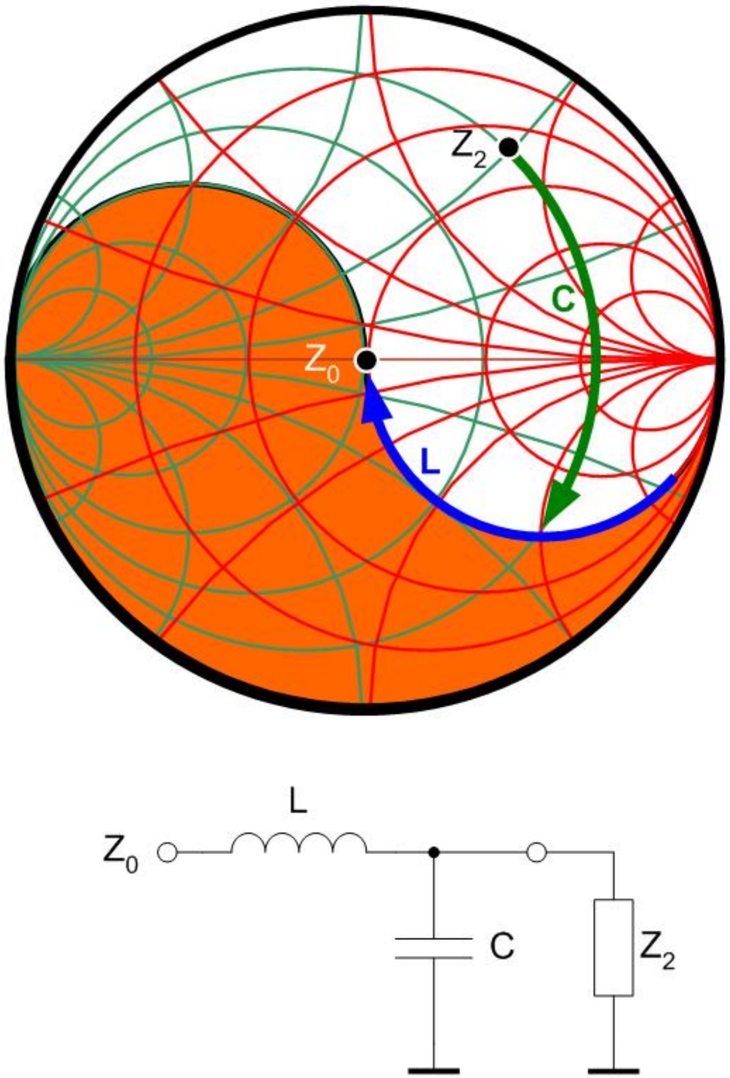
$\Gamma_0 = 0$ perfect match

$|\Gamma_0| \leq \Gamma_m$ “good enough” match

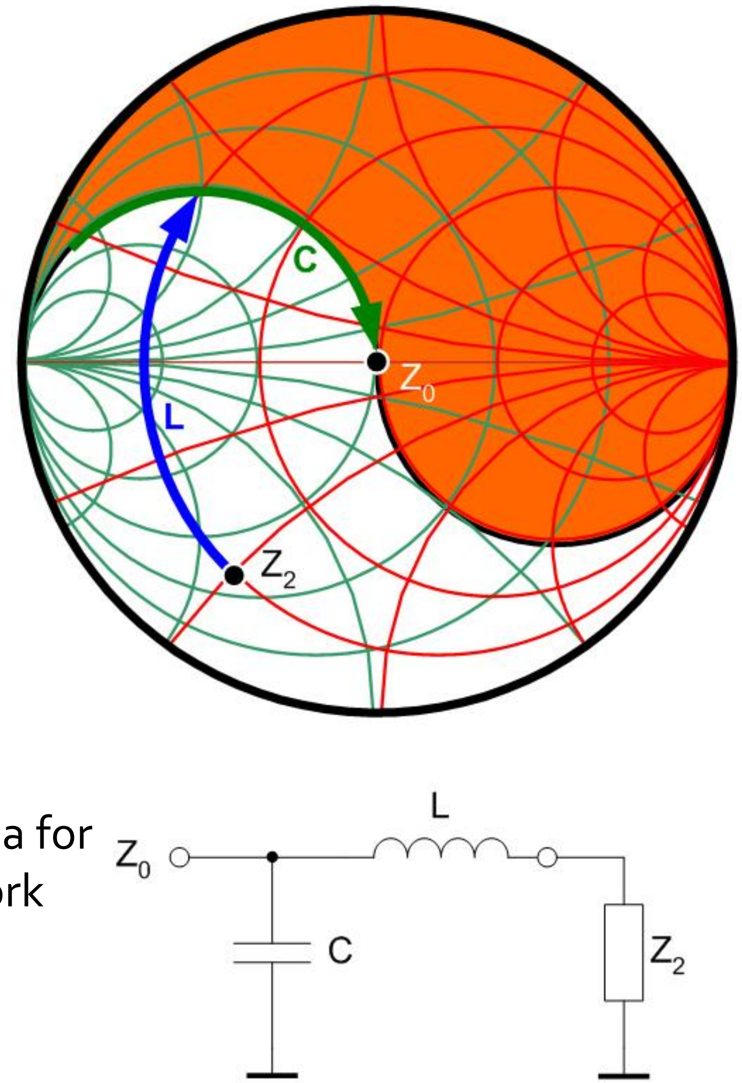
Smith chart, r=1 and g=1



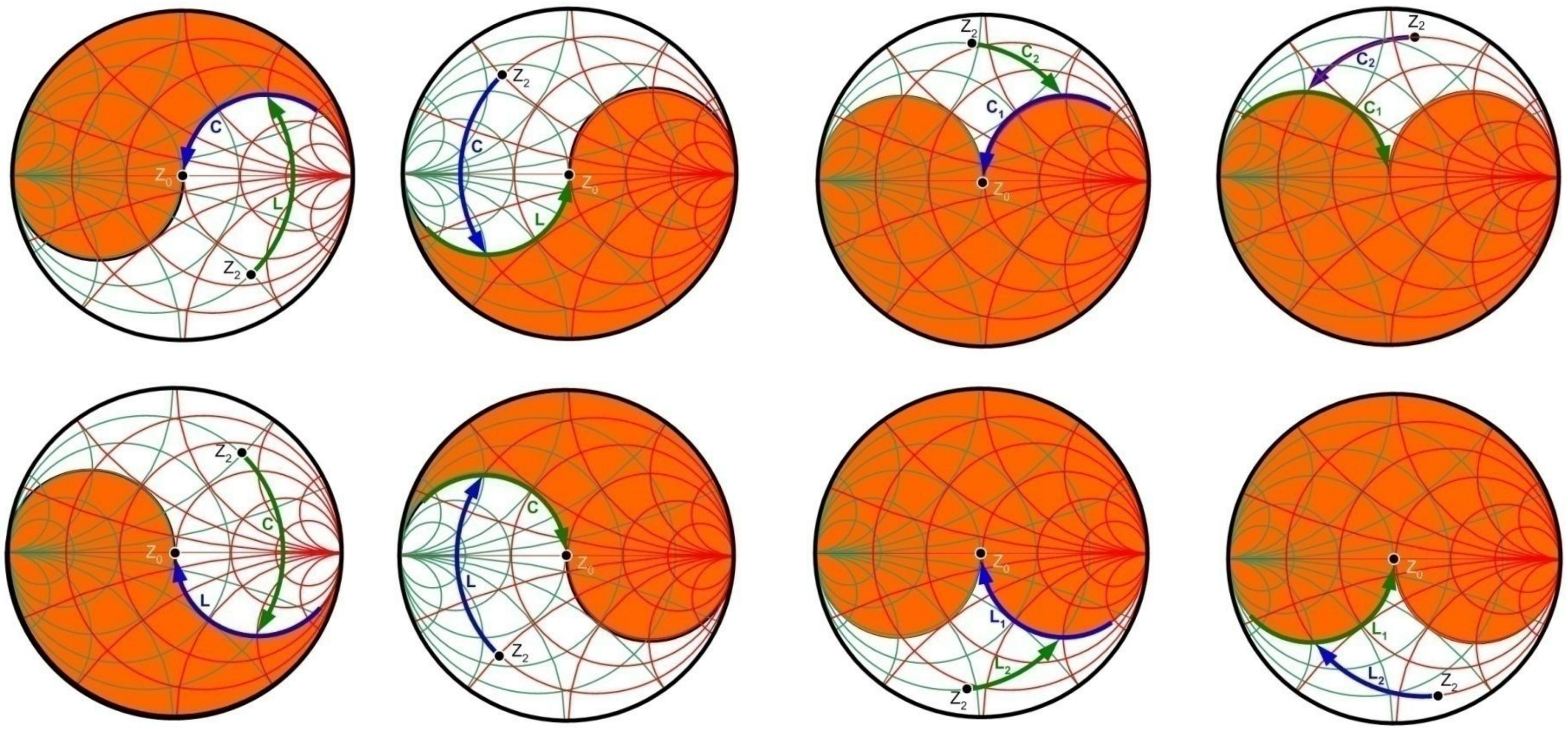
series L, shunt C / shunt C, series L

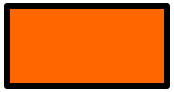


Forbidden area for current network



Matching with 2 reactive elements (L Networks)





Forbidden area for current network

Impedance Matching with Stubs

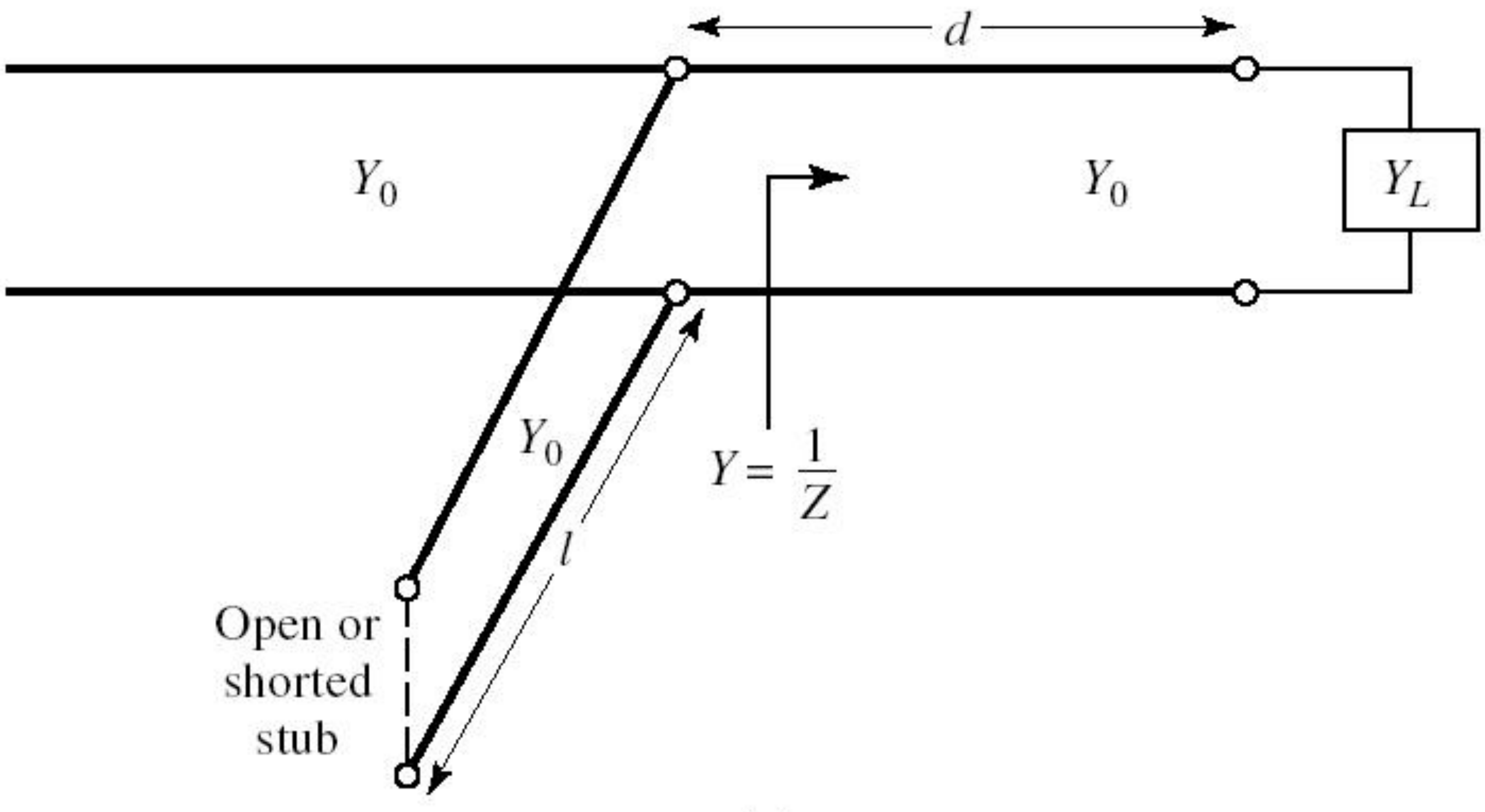
Impedance Matching

Stub

- **Stub** (en)="rest, ciot, cotor, capăt" (ro)
- We avoid the necessity to use lumped elements
- Matching is achieved (with higher accuracy) using usual Zo transmission lines of the circuit
- We use one or more lengths of transmission line (stub) connected either in parallel or in series with the transmission feed line :
  - open-circuited
  - short-circuited
- Usually open-circuited transmission lines are easier to implement and are preferred

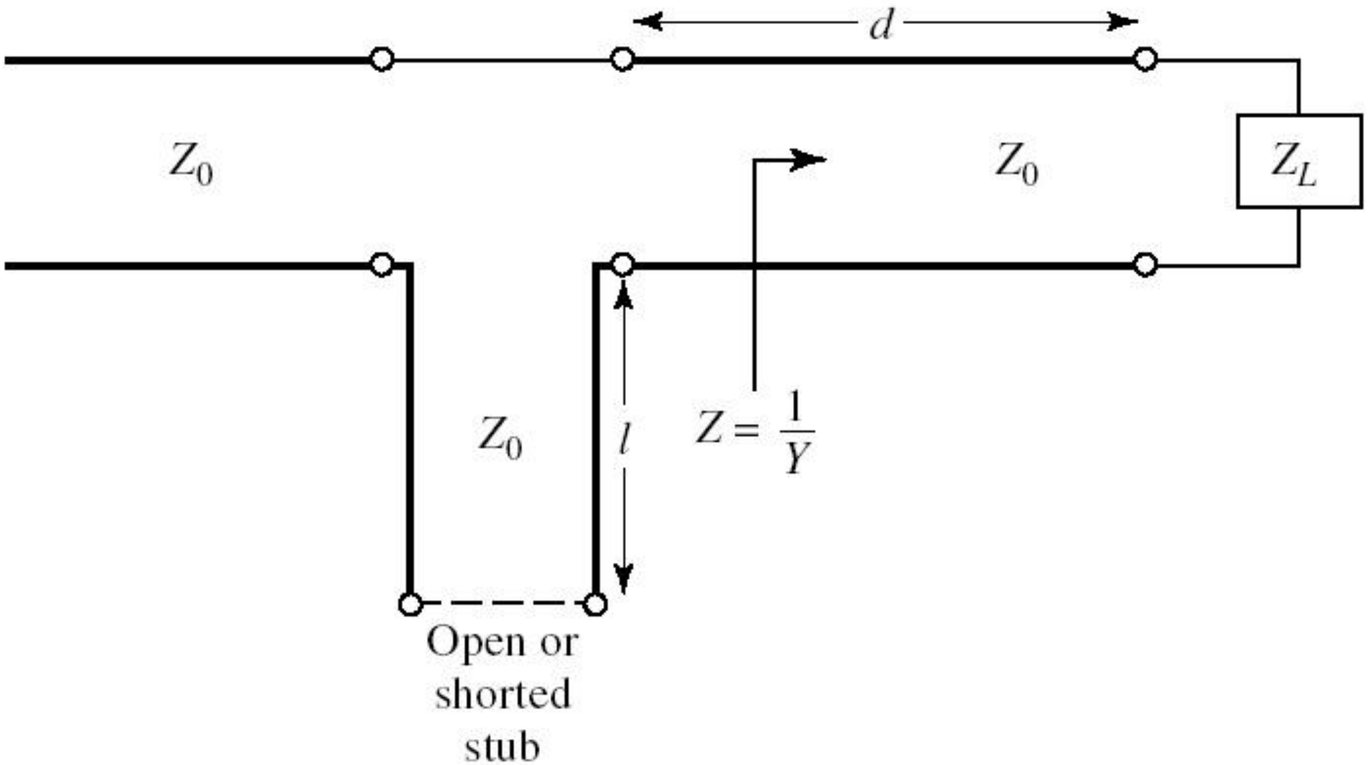
Single stub tuning

- Shunt Stub

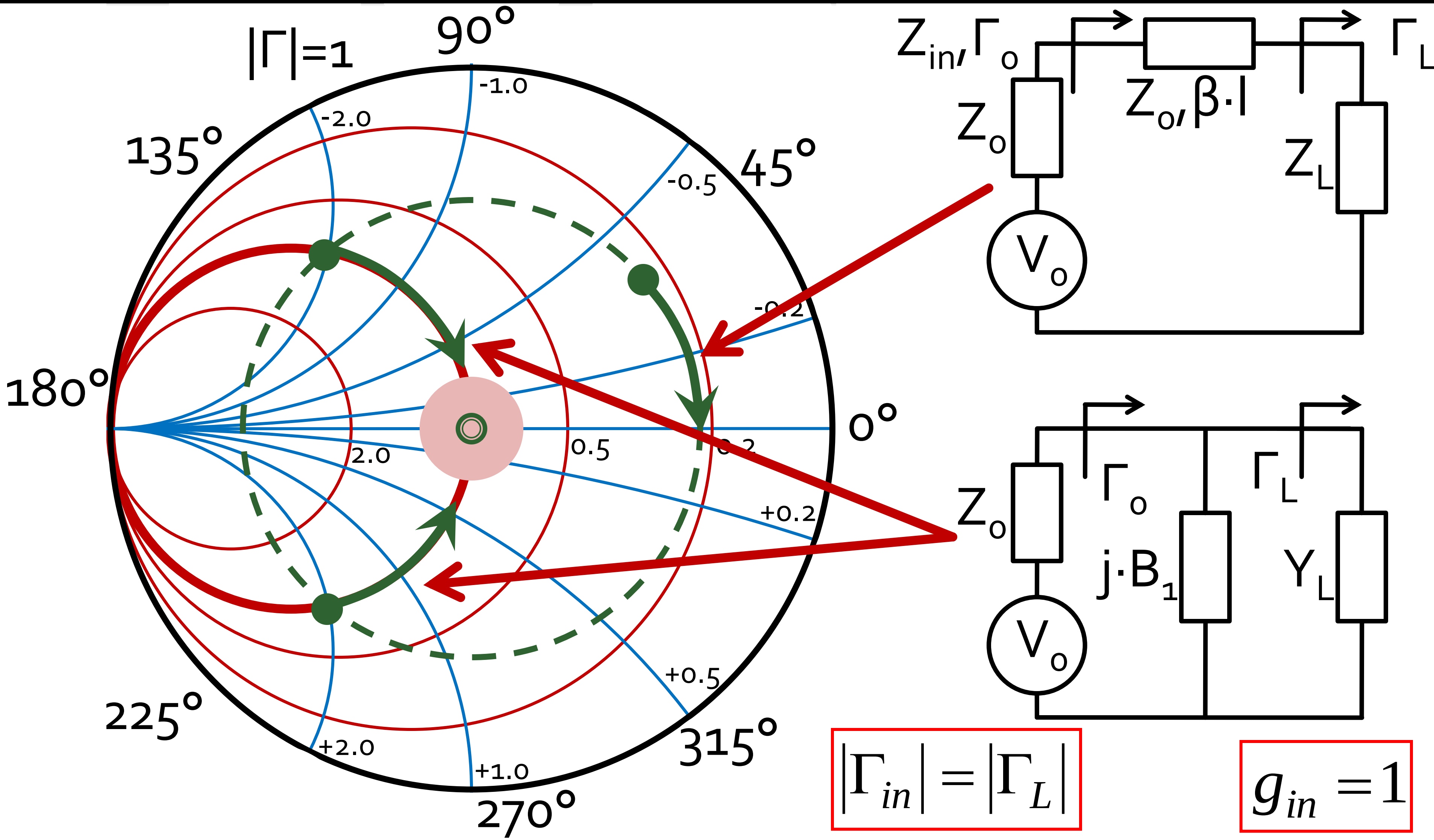


Single stub tuning

- Series Stub
- difficult to realize in single conductor line technologies (microstrip)



Matching, series line + shunt susceptance

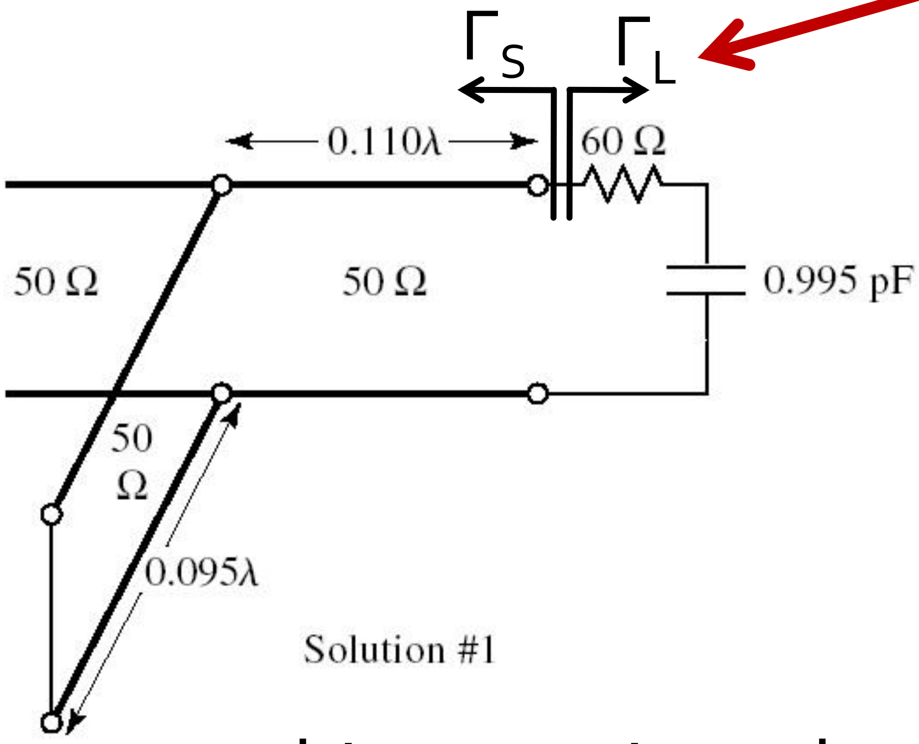


$|\Gamma_{in}| = |\Gamma_L|$

$g_{in} = 1$

Analytical solution, reflection coefficient

- load: 60 Ω series with 0.995 pF at 2GHz



$$Z_L = R_L + \frac{1}{j \cdot \omega \cdot C_L} = 60\Omega - j \cdot 79.977\Omega$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} = 0.405 - j \cdot 0.432$$

$$Y_L = \frac{1}{Z_L} = 0.006S + j \cdot 0.008S$$

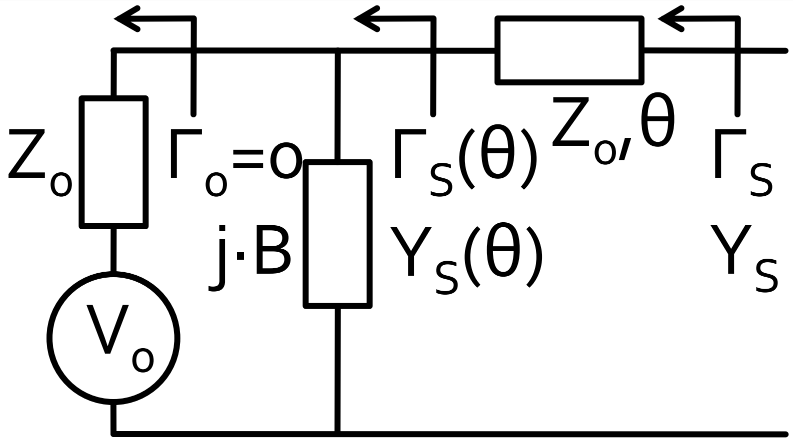
$$y_L = \frac{Y_L}{Y_0} = 0.3 + j \cdot 0.4$$

- matching requires obtaining conjugate value for Γ

$$\Gamma_S = \Gamma_L^* = 0.405 + j \cdot 0.432 \qquad \Gamma_S = 0.593\angle 46.85^\circ \qquad |\Gamma_S| = 0.593; \quad \varphi = 46.85^\circ$$

Analytical solution, Γ

- series line
  - electrical length E= β·l=θ
  - moves the reflection coefficient on the circle g=1
- shunt stub
  - electrical length E= $\beta \cdot l_{sp}=\theta_{sp}$
  - moves the reflection coefficient to the center of the Smith Chart ($\Gamma_o=0$)



$$y_S = \frac{Y_S}{Y_0} = Y_S \cdot Z_0 = Y_S \cdot 50\Omega$$

$$y_S = \frac{1-\Gamma_S}{1+\Gamma_S} = 0.3 - j \cdot 0.4$$

$$\Gamma_S(\theta) = [\Gamma_L(\theta)]^* = \left[\Gamma_L \cdot e^{-2j\theta}\right]^*$$

$$\Gamma_S(\theta) = \Gamma_L^* \cdot e^{2j\theta} = \Gamma_S \cdot e^{2j\theta}$$

$$y_S(\theta) = \frac{1-\Gamma_S(\theta)}{1+\Gamma_S(\theta)} = \frac{1-\Gamma_S \cdot e^{2j\theta}}{1+\Gamma_S \cdot e^{2j\theta}}$$

Analytical solution, Γ, series line

- After the series line with electrical length θ:

$$\mathrm{Re}\left[y_S(\theta)\right] = 1 \qquad \mathrm{Im}\left[y_S(\theta)\right] = B$$

$$\mathrm{Re}\left[y_S(\theta)\right] = \frac{1}{2}\cdot\left[y_S(\theta) + y_S^*(\theta)\right] \qquad \mathrm{Im}\left[y_S(\theta)\right] = \frac{1}{2j}\cdot\left[y_S(\theta) - y_S^*(\theta)\right]$$

$$\mathrm{Re}\left[y_S(\theta)\right] = \frac{1}{2}\cdot\left[\frac{1-\Gamma_S\cdot e^{2j\theta}}{1+\Gamma_S\cdot e^{2j\theta}} + \frac{1-\Gamma_S^*\cdot e^{-2j\theta}}{1+\Gamma_S^*\cdot e^{-2j\theta}}\right] \qquad \Gamma_S = \left|\Gamma_S\right|\cdot e^{j\varphi}$$

$$\mathrm{Re}\left[y_S(\theta)\right] = \frac{1}{2}\cdot\left[\frac{\left(1-\left|\Gamma_S\right|\cdot e^{j\cdot(\varphi+2\theta)}\right)\cdot\left(1+\left|\Gamma_S\right|\cdot e^{-j\cdot(\varphi+2\theta)}\right) + \left(1-\left|\Gamma_S\right|\cdot e^{-j\cdot(\varphi+2\theta)}\right)\cdot\left(1+\left|\Gamma_S\right|\cdot e^{j\cdot(\varphi+2\theta)}\right)}{\left(1+\left|\Gamma_S\right|\cdot e^{-j\cdot(\varphi+2\theta)}\right)\cdot\left(1+\left|\Gamma_S\right|\cdot e^{j\cdot(\varphi+2\theta)}\right)}\right]$$

$$\mathrm{Re}\left[y_S(\theta)\right] = \frac{1}{2}\cdot\left[\frac{2-2\cdot\left|\Gamma_S\right|^2}{1+\left|\Gamma_S\right|^2+2\cdot\left|\Gamma_S\right|\cdot\cos(\varphi+2\theta)}\right] = 1 \quad \Rightarrow \quad \boxed{\cos(\varphi+2\theta) = -\left|\Gamma_S\right|}$$

Analytical solution, Γ, series line

- Equations for computing the series line θ:

$$\mathrm{Re}[y_S(\theta)] = 1 \Rightarrow \qquad \cos(\varphi + 2\theta) = -|\Gamma_S|$$

$$\Gamma_S = |\Gamma_S| \cdot e^{j\varphi} \qquad \Gamma_S = 0.593\angle 46.85° \qquad |\Gamma_S| = 0.593; \quad \varphi = 46.85°$$

- two solutions possible, in the 0÷180° range (add λ/2 ⇔ 180° as needed)

$$\theta = \frac{1}{2} \cdot \left[\pm\cos^{-1}(-|\Gamma_S|) - \varphi + k \cdot 360°\right] = \frac{1}{2} \cdot \left[\pm\cos^{-1}(-|\Gamma_S|) - \varphi\right] + k \cdot 180°$$

$$\forall k \in N$$

$$\cos(\varphi + 2\theta) = -0.593 \Rightarrow \qquad (\varphi + 2\theta) = \pm 126.35°$$

$$(46.85° + 2\theta) = \begin{cases} +126.35° \\ -126.35° \end{cases} \qquad \theta = \begin{cases} +39.7° \\ -86.6° + 180° = +93.4° \end{cases}$$

Analytical solution, Γ, shunt stub

- Equations for computing the shunt stub θ_{sp}:

$$\mathrm{Re}[y_S(\theta)] = 1 \qquad \cos(\varphi + 2\theta) = -|\Gamma_S|$$

$$\mathrm{Im}[y_S(\theta)] = \frac{1}{2j} \cdot \left[\frac{1-\Gamma_S \cdot e^{2j\theta}}{1+\Gamma_S \cdot e^{2j\theta}} - \frac{1-\Gamma_S^* \cdot e^{-2j\theta}}{1+\Gamma_S^* \cdot e^{-2j\theta}} \right] \qquad \Gamma_S = |\Gamma_S| \cdot e^{j\varphi}$$

$$\mathrm{Im}[y_S(\theta)] = \frac{1}{2j} \cdot \left[\frac{\left(1-|\Gamma_S| \cdot e^{j\cdot(\varphi+2\theta)}\right) \cdot \left(1+|\Gamma_S| \cdot e^{-j\cdot(\varphi+2\theta)}\right) - \left(1-|\Gamma_S| \cdot e^{-j\cdot(\varphi+2\theta)}\right) \cdot \left(1+|\Gamma_S| \cdot e^{j\cdot(\varphi+2\theta)}\right)}{\left(1+|\Gamma_S| \cdot e^{-j\cdot(\varphi+2\theta)}\right) \cdot \left(1+|\Gamma_S| \cdot e^{j\cdot(\varphi+2\theta)}\right)} \right]$$

$$\mathrm{Im}[y_S(\theta)] = \frac{1}{2j} \cdot \left[\frac{2 \cdot |\Gamma_S| \cdot e^{-j\cdot(\varphi+2\theta)} - 2 \cdot |\Gamma_S| \cdot e^{+j\cdot(\varphi+2\theta)}}{1+|\Gamma_S|^2 + 2 \cdot |\Gamma_S| \cdot \cos(\varphi+2\theta)} \right] = \frac{-2 \cdot |\Gamma_S| \cdot \sin(\varphi+2\theta)}{1+|\Gamma_S|^2 + 2 \cdot |\Gamma_S| \cdot \cos(\varphi+2\theta)}$$

$$\cos(\varphi + 2\theta) = -|\Gamma_S| \Rightarrow \qquad \mathrm{Im}[y_S(\theta)] = \frac{-2 \cdot |\Gamma_S| \cdot \sin(\varphi+2\theta)}{1-|\Gamma_S|^2}$$

Analytical solution, Γ, shunt stub

- Equations for computing the shunt stub

$$\cos(\varphi+2\theta)=-|\Gamma_S| \Rightarrow \qquad \sin(\varphi+2\theta)=\pm\sqrt{1-|\Gamma_S|^2}$$

$$\operatorname{Im}[y_S(\theta)]=\frac{-2\cdot|\Gamma_S|\cdot\sin(\varphi+2\theta)}{1-|\Gamma_S|^2} \Rightarrow \qquad \operatorname{Im}[y_S(\theta)]=\frac{\mp 2\cdot|\Gamma_S|}{\sqrt{1-|\Gamma_S|^2}}$$

- two cases

$$\varphi+2\theta\in[0°,180°]\Rightarrow\sin(\varphi+2\theta)\geq 0 \quad \begin{cases}\sin(\varphi+2\theta)=\sqrt{1-|\Gamma_S|^2}\\ \operatorname{Im}[y_S(\theta)]=\dfrac{-2\cdot|\Gamma_S|}{\sqrt{1-|\Gamma_S|^2}}\end{cases}$$

$$\varphi+2\theta\in(-180°,0°)\Rightarrow\sin(\varphi+2\theta)<0 \quad \begin{cases}\sin(\varphi+2\theta)=-\sqrt{1-|\Gamma_S|^2}\\ \operatorname{Im}[y_S(\theta)]=\dfrac{2\cdot|\Gamma_S|}{\sqrt{1-|\Gamma_S|^2}}\end{cases}$$

- The **sign** (+/-) chosen for the **series line** equation imposes the **sign** used for the **shunt stub** equation

Analytical solution, Γ, shunt stub

- We prefer (for microstrip) open circuited stub

$$Z_{in,oc} = -j \cdot Z_0 \cdot \cot \beta \cdot l$$

- The normalized susceptance to be introduced to achieve the match
  - Y(θ) is the admittance seen **towards** the source, Zo parallel with j·B

$$b = \mathrm{Im}\left[\frac{Y_{in,oc}}{Y_0}\right] = \mathrm{Im}\left[\frac{Z_0}{Z_{in,oc}}\right] = \tan \beta \cdot l = \mathrm{Im}\left[y_S(\theta)\right]$$

$$\boxed{\theta_{sp} = \beta \cdot l = \tan^{-1} \frac{\mp 2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}}}$$

Analytical solution, Γ

$$\cos(\varphi + 2\theta) = -|\Gamma_S|$$

$$\theta_{sp} = \beta \cdot l = \tan^{-1} \frac{\mp 2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}}$$

$$\Gamma_S = 0.593 \angle 46.85°$$

$$|\Gamma_S| = 0.593; \quad \varphi = 46.85° \qquad \cos(\varphi + 2\theta) = -0.593 \Rightarrow (\varphi + 2\theta) = \pm 126.35°$$

- The **sign** (+/-) chosen for the **series line** equation imposes the **sign** used for the **shunt stub** equation
  - **"+" solution**

$$(46.85° + 2\theta) = +126.35° \qquad \theta = +39.7° \qquad \operatorname{Im} y_S = \frac{-2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = -1.472$$

$$\theta_{sp} = \tan^{-1}(\operatorname{Im} y_S) = -55.8° (+180°) \rightarrow \theta_{sp} = 124.2°$$

  - **"-" solution**

$$(46.85° + 2\theta) = -126.35° \qquad \theta = -86.6° (+180°) \rightarrow \theta = 93.4°$$

$$\operatorname{Im} y_S = \frac{+2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = +1.472 \qquad \theta_{sp} = \tan^{-1}(\operatorname{Im} y_S) = 55.8°$$

Analytical solution, Γ

$$(\varphi+2\theta)=\begin{cases}+126.35^\circ\\-126.35^\circ\end{cases}\quad \theta=\begin{cases}39.7^\circ\\93.4^\circ\end{cases}\quad \mathrm{Im}\left[y_S(\theta)\right]=\begin{cases}-1.472\\+1.472\end{cases}\quad \theta_{sp}=\begin{cases}-55.8^\circ+180^\circ=124.2^\circ\\+55.8^\circ\end{cases}$$

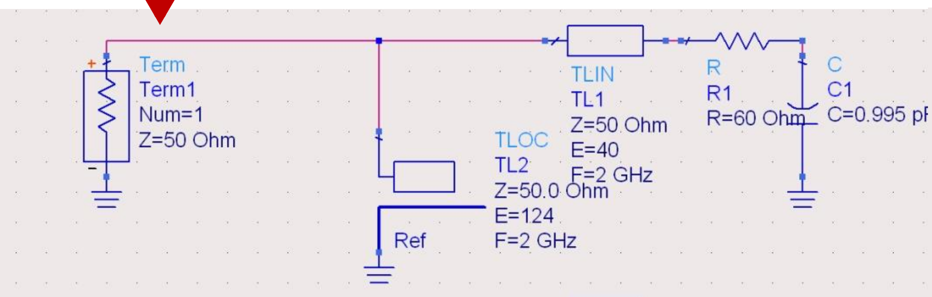
- We choose **one** of the two possible solutions
- The **sign** (+/-) chosen for the **series line** equation imposes the **sign** used for the **shunt stub** equation

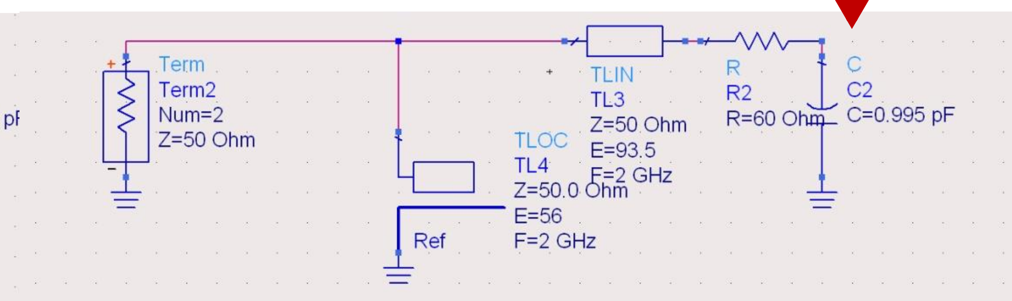
$$l_1=\frac{39.7^\circ}{360^\circ}\cdot\lambda=0.110\cdot\lambda$$

$$l_2=\frac{124.2^\circ}{360^\circ}\cdot\lambda=0.345\cdot\lambda$$

$$l_1=\frac{93.4^\circ}{360^\circ}\cdot\lambda=0.259\cdot\lambda$$

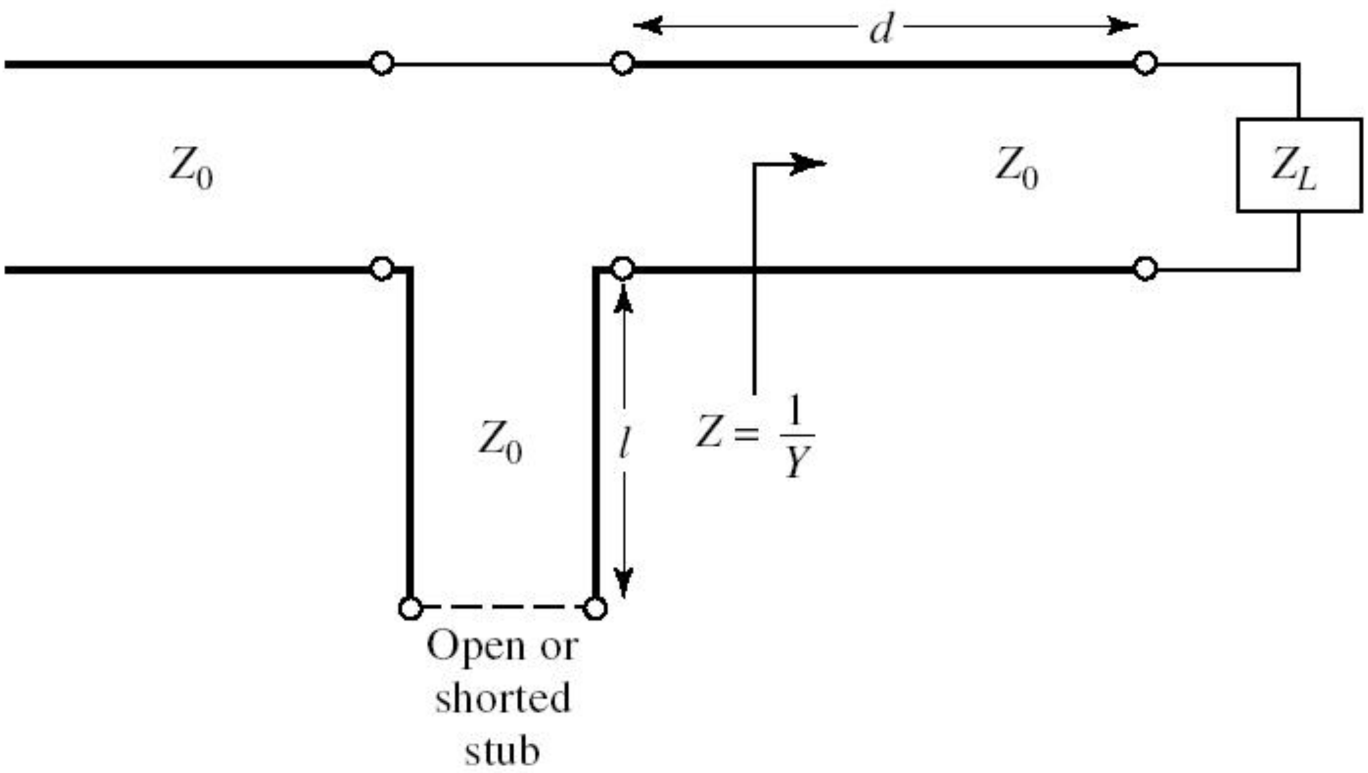
$$l_2=\frac{55.8^\circ}{360^\circ}\cdot\lambda=0.155\cdot\lambda$$



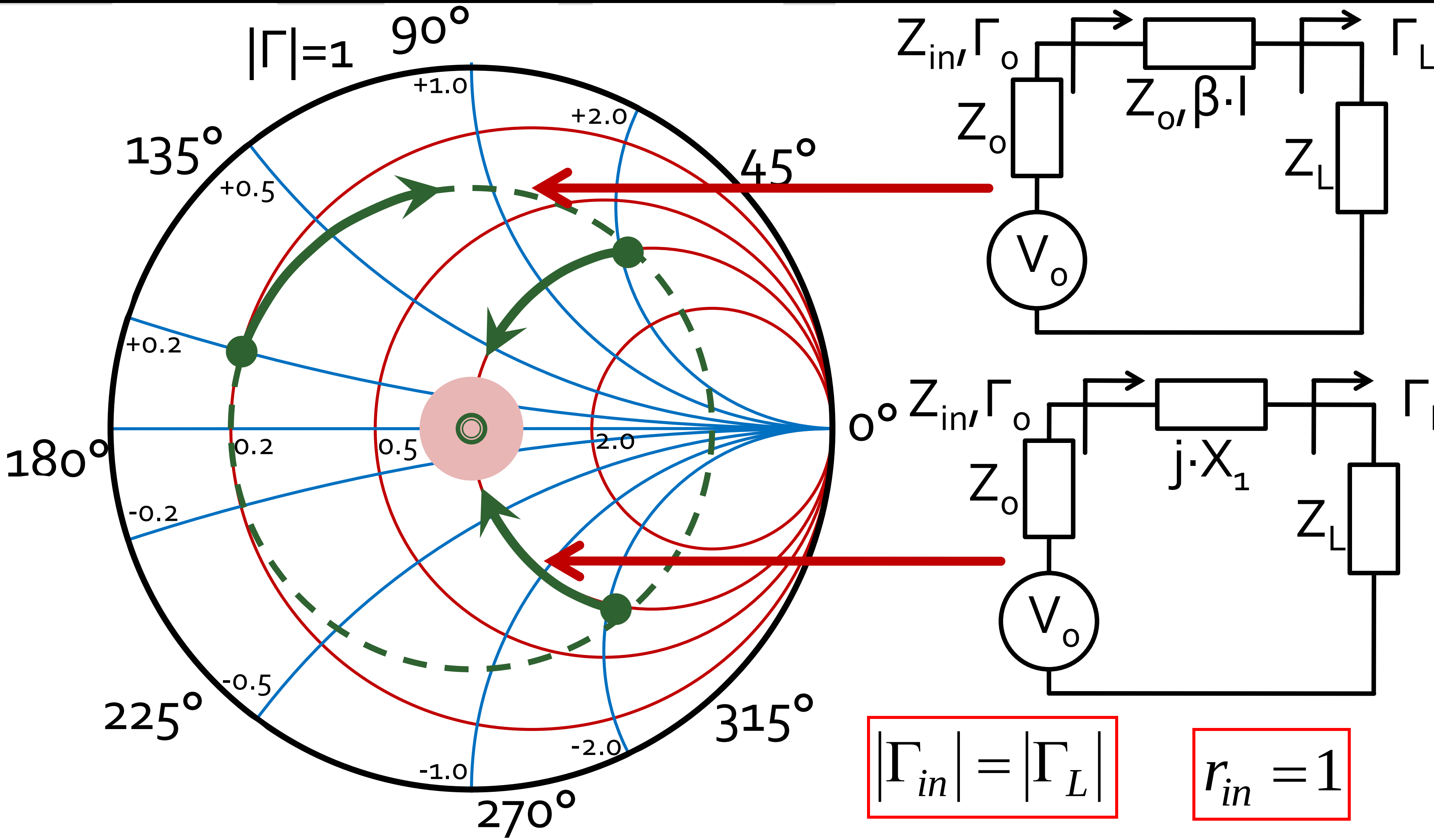


Case 2, Series Stub

- Series Stub
- difficult to realize in single conductor line technologies (microstrip)



Matching, series line + series reactance

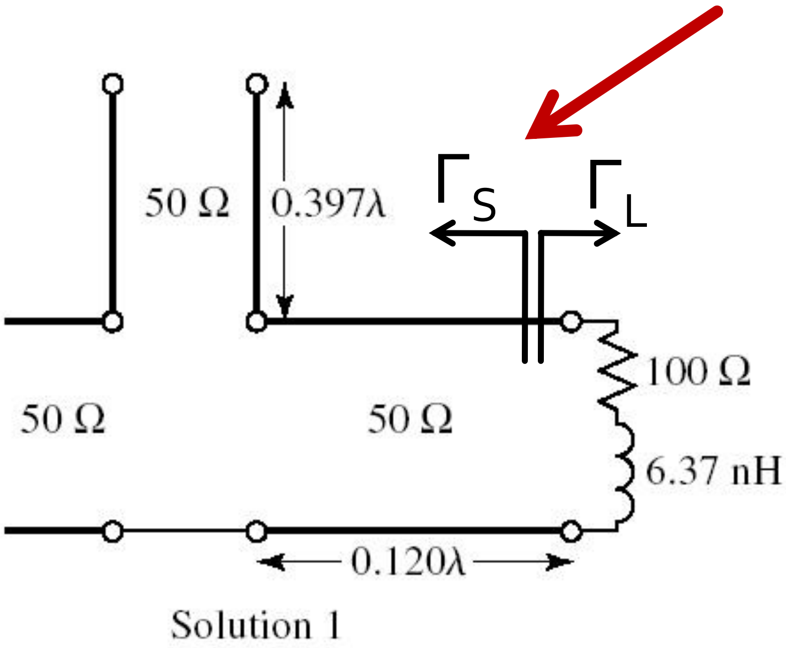


$$\left|\Gamma_{in}\right| = \left|\Gamma_L\right|$$

$$r_{in} = 1$$

Analytical solution, reflection coefficient

- load: 100 Ω series with 6.37 nH at 2 GHz



$$Z_L = R_L + \frac{1}{j \cdot \omega \cdot C_L} = 100\Omega + j \cdot 80.05\Omega$$

$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} = 0.481 + j \cdot 0.277$$

$$z_L = \frac{Z_L}{Z_0} = 2 + j \cdot 1.6$$

- matching requires obtaining conjugate value for Γ

$$\Gamma_S = \Gamma_L^* = 0.481 - j \cdot 0.277$$

$$\Gamma_S = 0.555\angle -29.92^\circ \qquad |\Gamma_S| = 0.555; \quad \varphi = -29.92^\circ$$

Analytical solution, Γ

$$\cos(\varphi + 2\theta) = |\Gamma_S|$$

$$\theta_{ss} = \beta \cdot l = \cot^{-1} \frac{\mp 2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}}$$

$$\Gamma_S = 0.555 \angle -29.92°$$

$$|\Gamma_S| = 0.555; \quad \varphi = -29.92° \qquad \cos(\varphi + 2\theta) = 0.555 \Rightarrow (\varphi + 2\theta) = \pm 56.28°$$

- The **sign** (+/-) chosen for the **series line** equation imposes the **sign** used for the **series stub** equation
  - **"+" solution**

    $$(-29.92° + 2\theta) = +56.28° \qquad \theta = 43.1° \qquad \operatorname{Im} z_S = \frac{+2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = +1.335$$

    $$\theta_{ss} = -\cot^{-1}(\operatorname{Im} z_S) = -36.8°(+180°) \rightarrow \theta_{ss} = 143.2°$$

  - **"-" solution**

    $$(-29.92° + 2\theta) = -56.28° \qquad \theta = -13.2°(+180°) \rightarrow \theta = 166.8°$$

    $$\operatorname{Im} z_S = \frac{-2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = -1.335 \qquad \theta_{ss} = -\cot^{-1}(\operatorname{Im} z_S) = 36.8°$$

Analytical solution, Γ

$$(\varphi + 2\theta) = \begin{cases} +56.28^\circ \\ -56.28^\circ \end{cases} \quad \theta = \begin{cases} 43.1^\circ \\ 166.8^\circ \end{cases} \quad \mathrm{Im}[z_S(\theta)] = \begin{cases} +1.335 \\ -1.335 \end{cases} \quad \theta_{ss} = \begin{cases} -36.8^\circ + 180^\circ = 143.2^\circ \\ +36.8^\circ \end{cases}$$

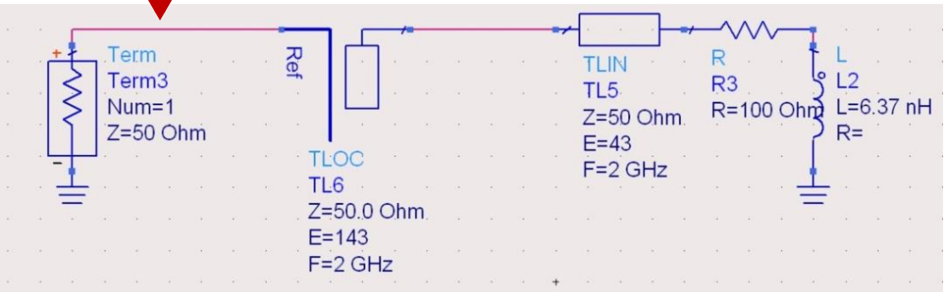
- We choose **one** of the two possible solutions
- The **sign** (+/-) chosen for the **series line** equation imposes the **sign** used for the **series stub** equation

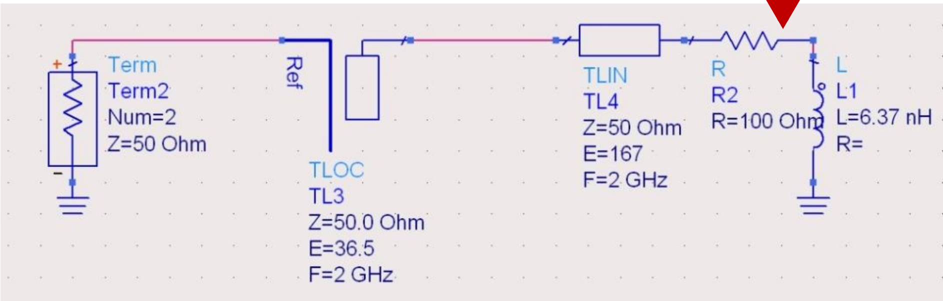
$$l_1 = \frac{43.1^\circ}{360^\circ} \cdot \lambda = 0.120 \cdot \lambda$$

$$l_2 = \frac{143.2^\circ}{360^\circ} \cdot \lambda = 0.398 \cdot \lambda$$

$$l_1 = \frac{166.8^\circ}{360^\circ} \cdot \lambda = 0.463 \cdot \lambda$$

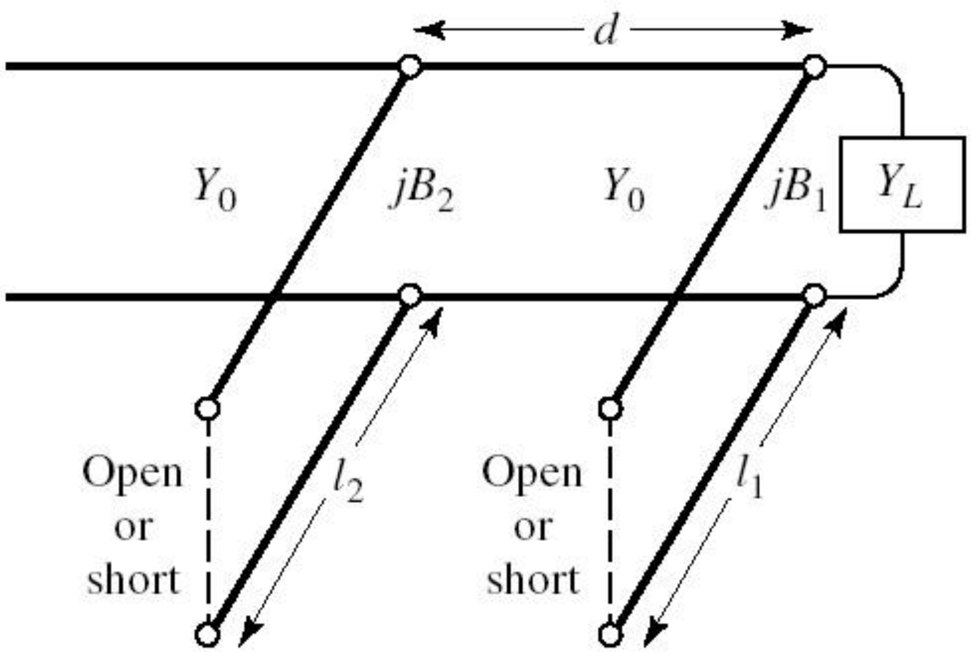
$$l_2 = \frac{36.8^\circ}{360^\circ} \cdot \lambda = 0.102 \cdot \lambda$$





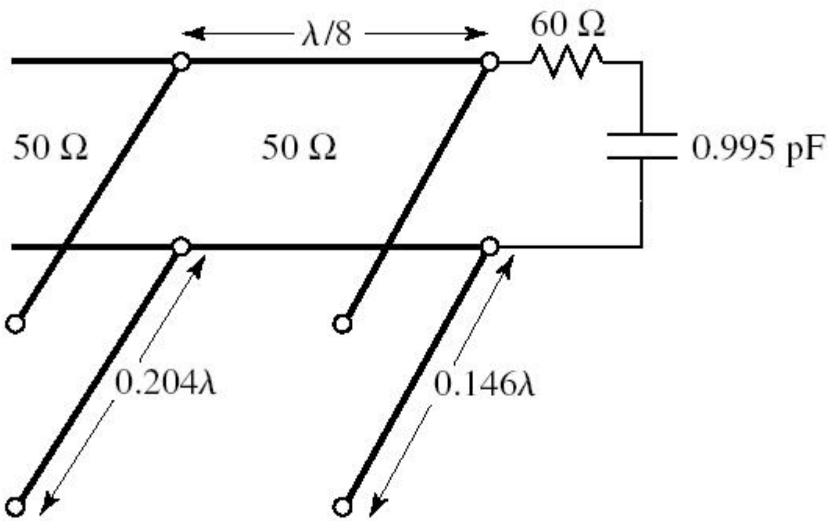
Double stub tuning

- Double stub tuning
- uses two tuning stubs in fixed positions (a fixed length of line between the stubs)

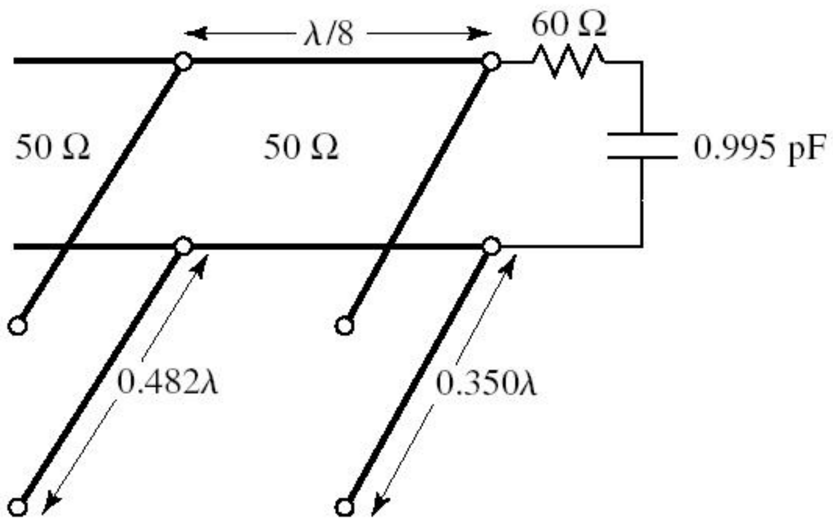


Double stub tuning

- same load: 60 Ω series with 0.995 pF at 2GHz
- two possible solutions



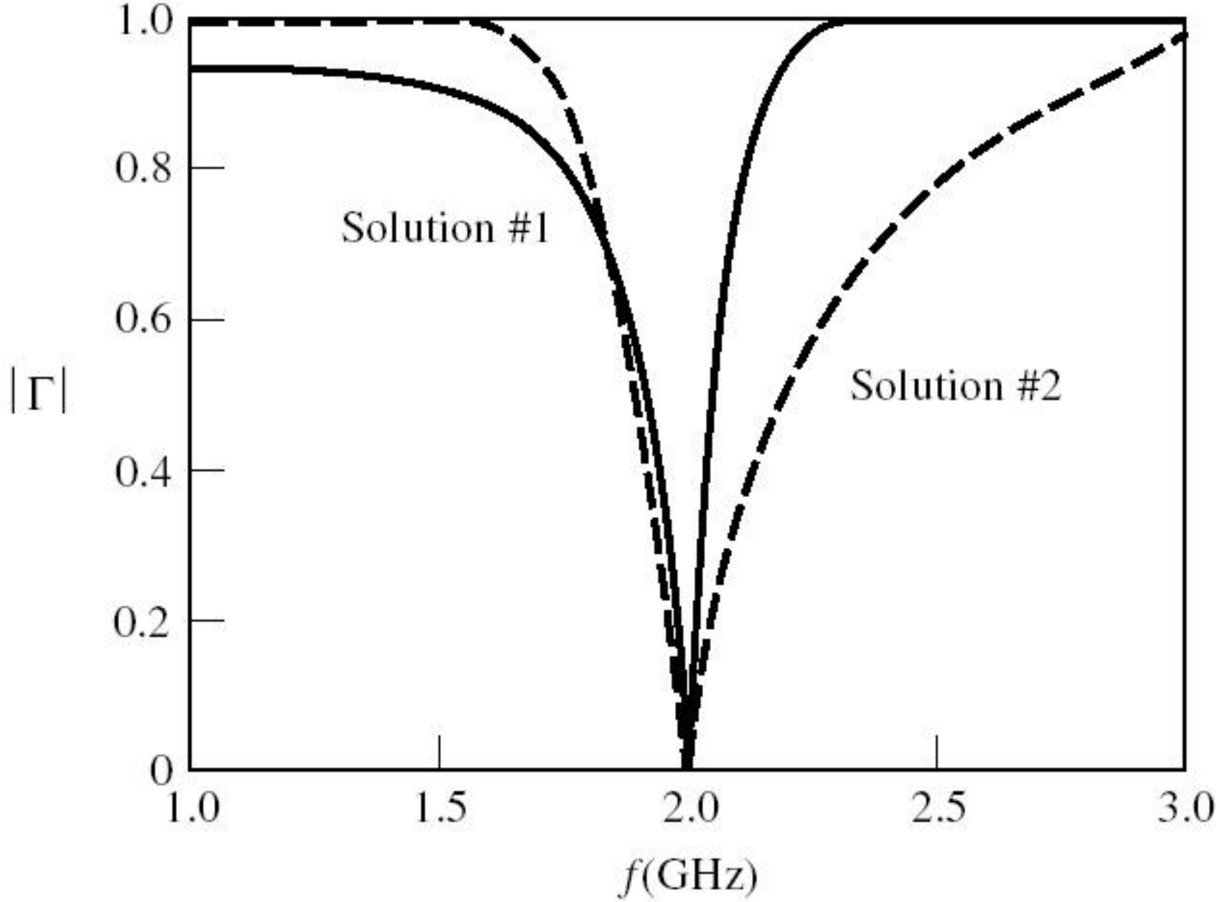
Solution 1



Solution 2

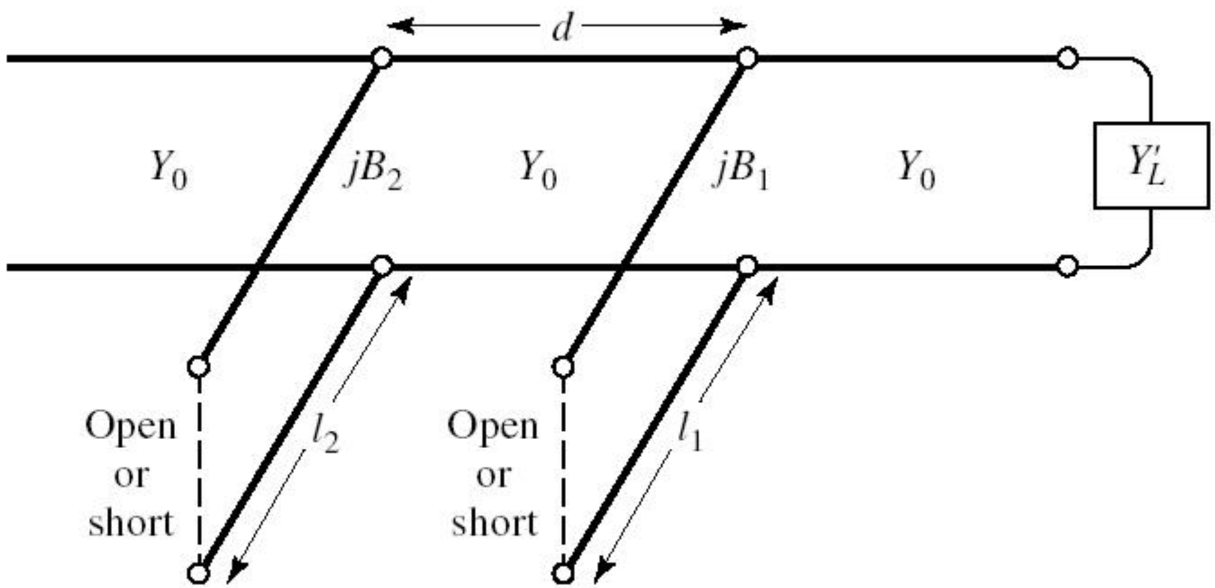
Double stub tuning

- two possible solutions

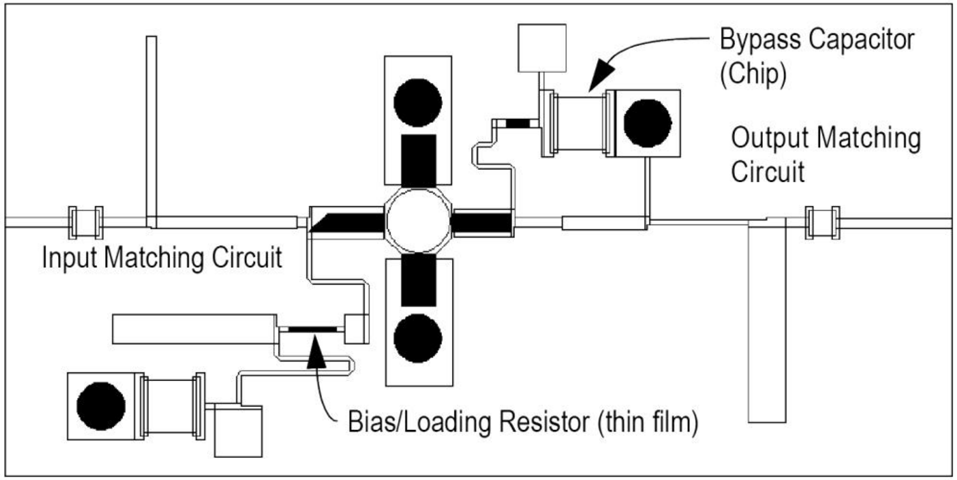


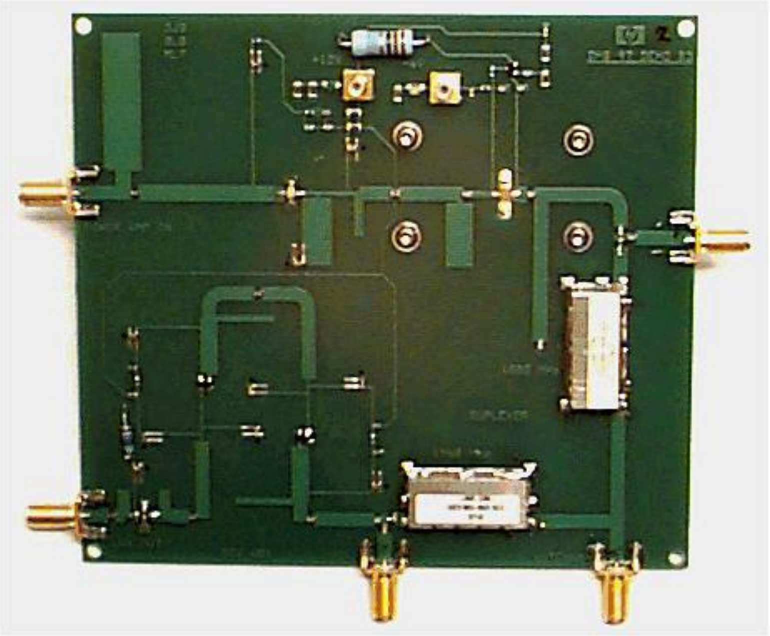
Double stub tuning

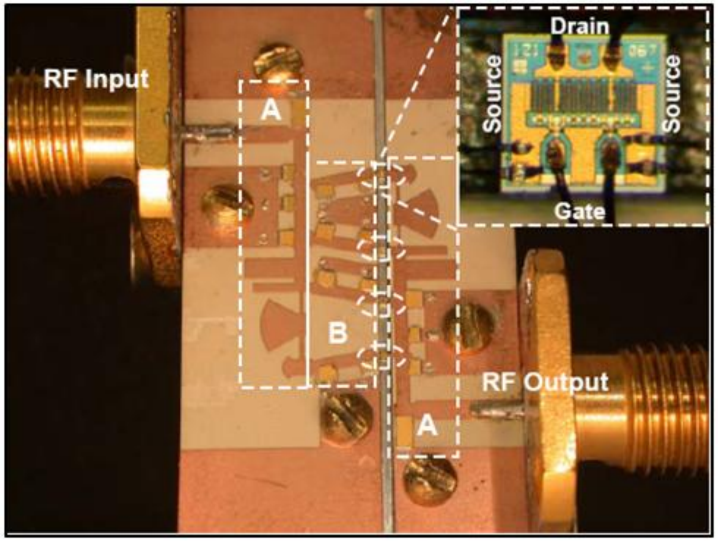
- Typically d=λ/8 or d=3λ/8
- **Not possible** for every load
  - unless we can add a specific length of line between the load and the first stub

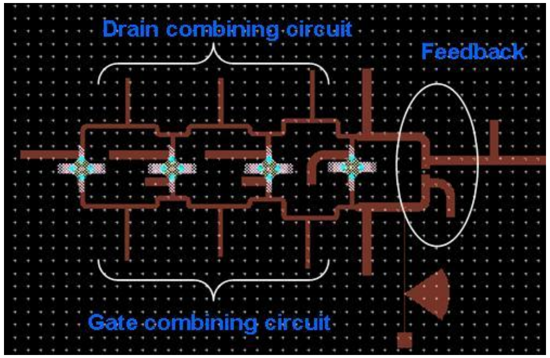


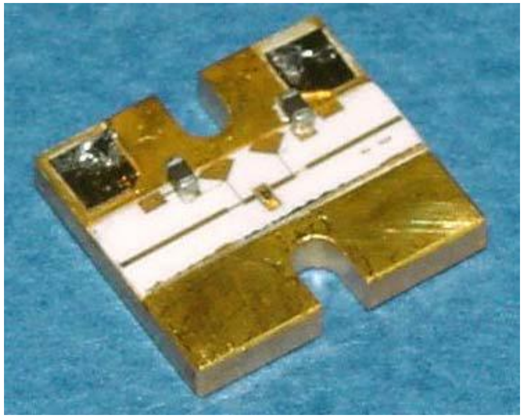
Impedance Matching with Stubs





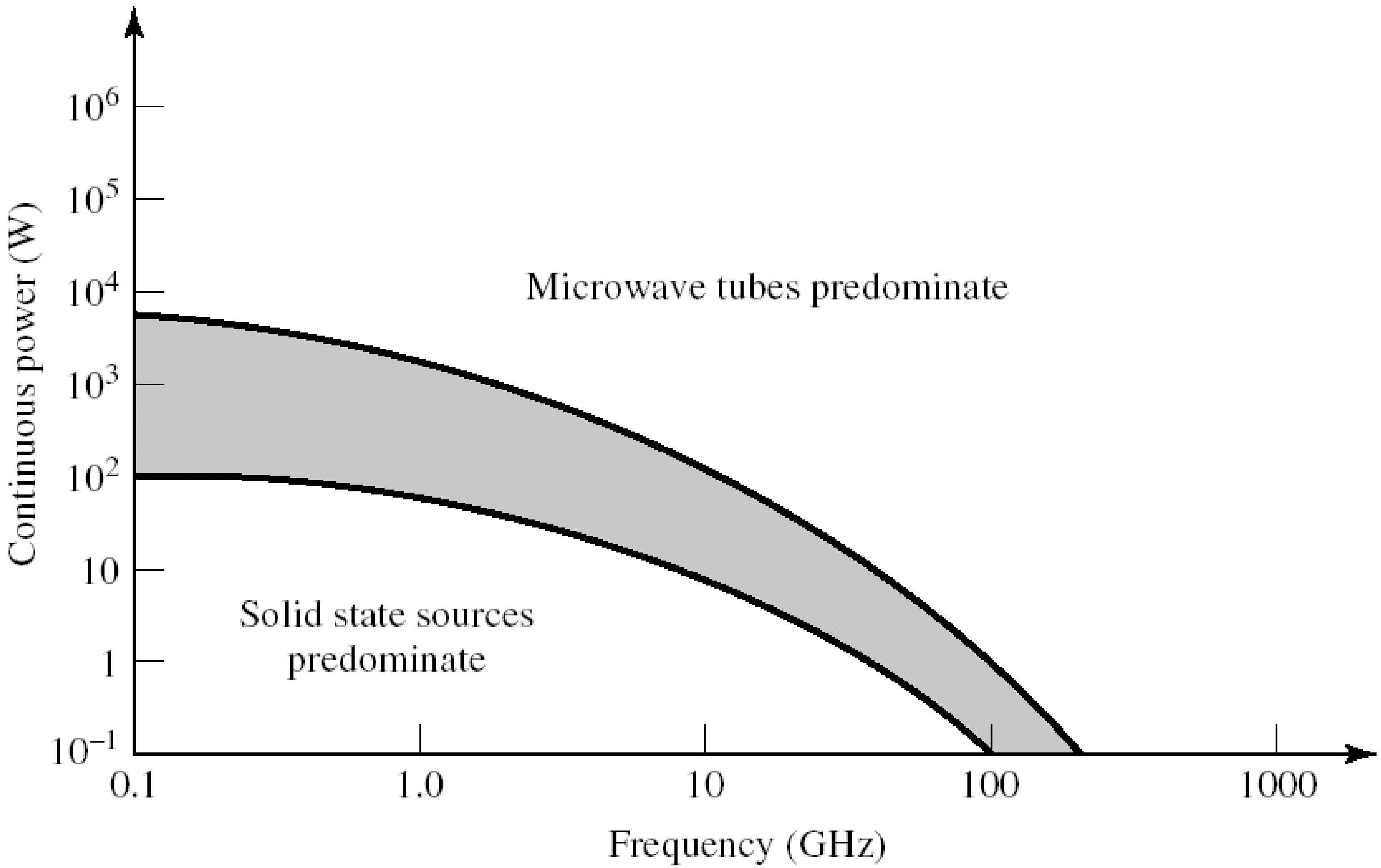




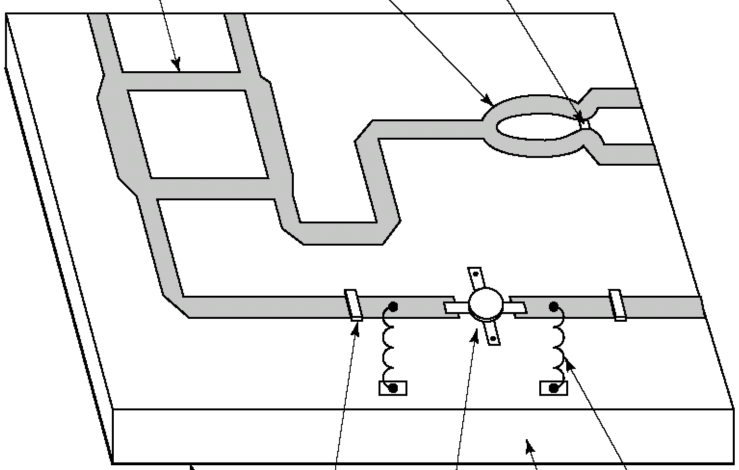


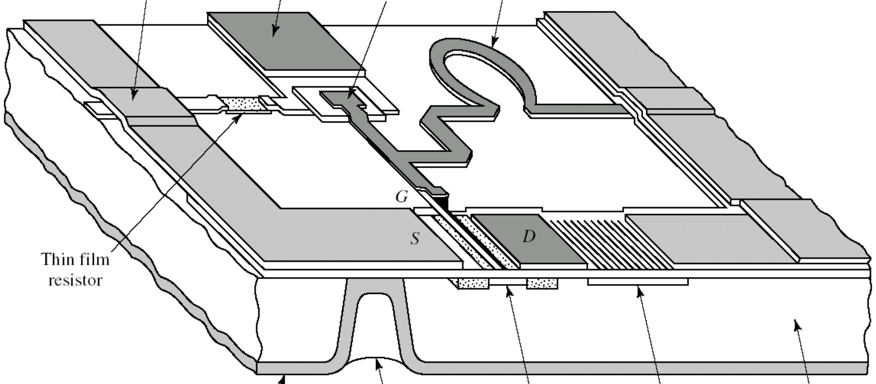
Microwave Amplifiers

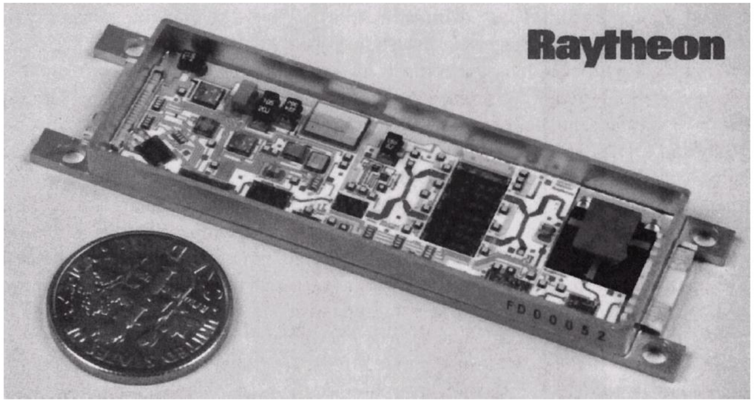
Microwave Amplifiers

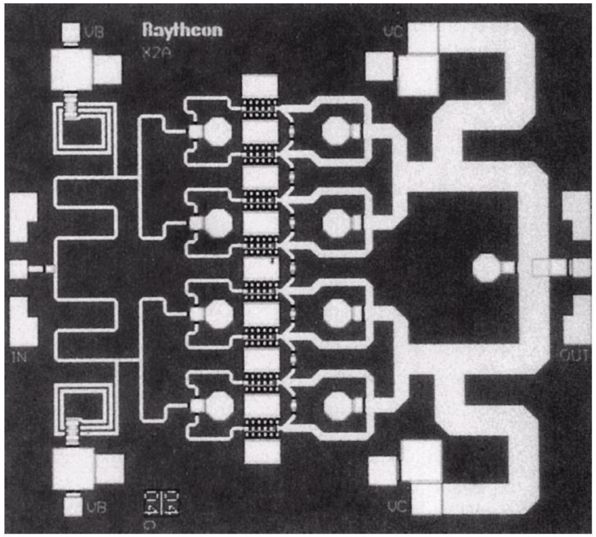


Microwave Integrated Circuits

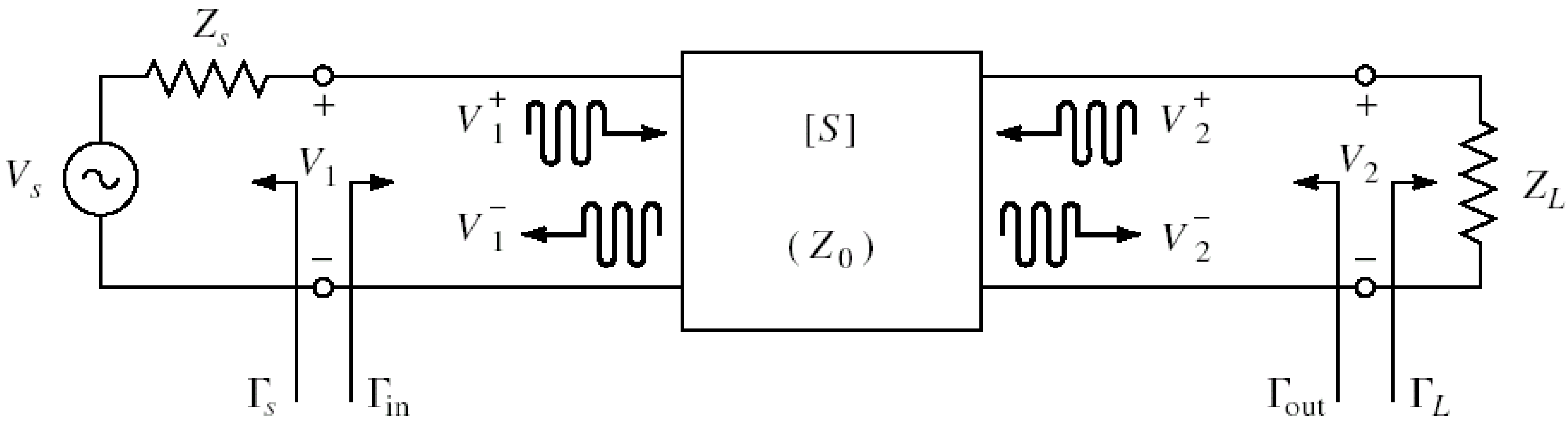








Amplifier as two-port



- Charaterized with S parameters
- normalized at Zo (implicit 50Ω)
- Datasheets: S parameters for specific bias conditions

Datasheets

CEL

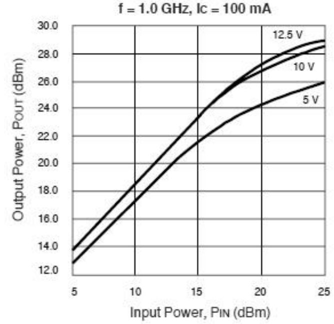
NE46100 / NE46134

NPN MEDIUM POWER MICROWAVE TRANSISTOR

FEATURES

- **HIGH DYNAMIC RANGE**
- **LOW IM DISTORTION:** -40 dBc
- **HIGH OUTPUT POWER :** 27.5 dBm at TYP
- **LOW NOISE:** 1.5 dB TYP at 500 MHz
- **LOW COST**

NE46134
TYPICAL OUTPUT POWER
vs. INPUT POWER
f = 1.0 GHz, Ic = 100 mA



DESCRIPTION

The NE461 series of NPN silicon epitaxial bipolar transistors is designed for medium power applications requiring high dynamic range. This device exhibits an outstanding combination of high gain and low intermodulation distortion, as well as low noise figure. The NE461 series offers excellent performance and reliability at low cost through titanium, platinum, gold metallization system and direct nitride passivation of the surface of the chip. Devices are available in a low cost surface mount package (SOT-89) as well as in chip form.

ELECTRICAL CHARACTERISTICS (T_A = 25°C)

PART NUMBER EIAJ[1] REGISTERED NUMBER PACKAGE OUTLINE			NE46100 00 (CHIP)			NE46134 2SC4536 34		
SYMBOLS	PARAMETERS AND CONDITIONS	UNITS	MIN	TYP	MAX	MIN	TYP	MAX
f_T	Gain Bandwidth Product at V_{CE} = 10 V, I_C = 100 mA	GHz		5.5			5.5	
NF_{MIN}	Minimum Noise Figure[3] at V_{CE} = 10 V, I_C = 50 mA, 500 MHz V_{CE} = 10 V, I_C = 50 mA, 1 GHz	dB dB		1.5 2.0			1.5 2.0	
G_L	Linear Gain, V_{CE} = 12.5 V, I_C = 100 mA, 2.0 GHz V_{CE} = 12.5 V, I_C = 100 mA, 1.0 GHz	dB dB		9.0			 8.0	
$\|S_{21E}\|^2$	Insertion Power Gain at 10 V, 50 mA, f = 1.0 GHz	dB		10.0		5.5	7.0	
h_{FE}	DC Current Gain[2] at V_{CE} = 10 V, I_C = 50 mA		40		200	40		200
I_{CBO}	Collector Cutoff Current at V_{CB} = 20 V, I_E = 0 mA .	μA			5.0			5.0
I_{EBO}	Emitter Cutoff Current at V_{EB} = 2 V, I_C = 0 mA	μA			5.0			5.0
P_{1dB}	Output Power at 1 dB Compression, V_{CE} = 12.5 V, I_C = 100 mA, 2.0 GHz V_{CE} = 12.5 V, I_C = 100 mA, 1.0 GHz	dBm dBm	27.0				 27.5	
IM_3	Intermodulation Distortion, 10 V, 100 mA, F1 = 1.0 GHz, F2 = 0.99 GHz,							

Datasheets

NE46100

V_{CE} = 5 V, I_C = 50 mA

FREQUENCY (MHz)	S_{11} MAG	S_{11} ANG	S_{21} MAG	S_{21} ANG	S_{12} MAG	S_{12} ANG	S_{22} MAG	S_{22} ANG	K	MAG[2] (dB)
100	0.778	-137	26.776	114	0.028	30	0.555	-102	0.16	29.8
200	0.815	-159	14.407	100	0.035	29	0.434	-135	0.36	26.2
500	0.826	-177	5.855	84	0.040	38	0.400	-162	0.75	21.7
800	0.827	176	3.682	76	0.052	43	0.402	-169	0.91	18.5
1000	0.826	173	2.963	71	0.058	47	0.405	-172	1.02	16.3
1200	0.825	170	2.441	66	0.064	47	0.412	-174	1.08	14.0
1400	0.820	167	2.111	61	0.069	47	0.413	-176	1.17	12.4
1600	0.828	165	1.863	57	0.078	54	0.426	-177	1.15	11.4
1800	0.827	162	1.671	53	0.087	50	0.432	-178	1.14	10.6
2000	0.828	159	1.484	49	0.093	50	0.431	-180	1.17	9.5
2500	0.822	153	1.218	39	0.11	48	0.462	177	1.18	7.8
3000	0.818	148	1.010	30	0.135	46	0.490	174	1.16	6.3
3500	0.824	142	0.876	21	0.147	44	0.507	170	1.16	5.3
4000	0.812	137	0.762	13	0.168	38	0.535	167	1.14	4.3

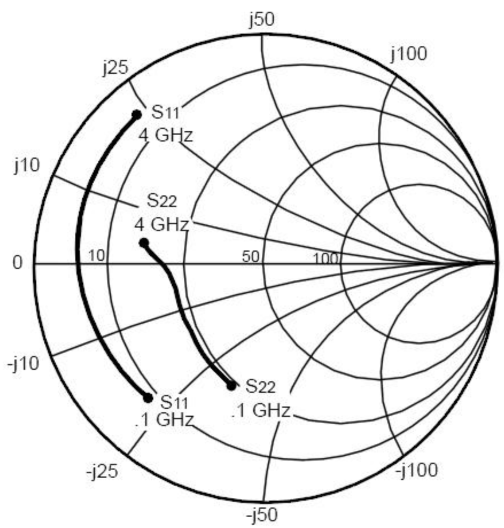
V_{CE} = 5 V, I_C = 100 mA

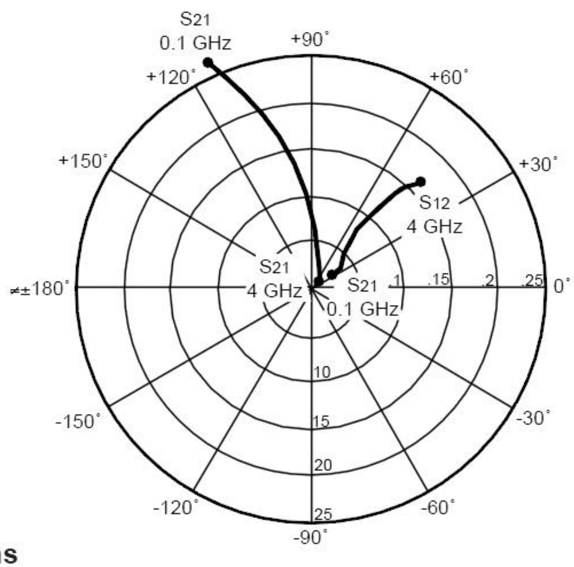
FREQUENCY (MHz)	S_{11} MAG	S_{11} ANG	S_{21} MAG	S_{21} ANG	S_{12} MAG	S_{12} ANG	S_{22} MAG	S_{22} ANG	K	MAG[2] (dB)
100	0.778	-144	27.669	111	0.027	35	0.523	-114	0.27	30.2
200	0.820	-164	14.559	97	0.029	29	0.445	-144	0.42	27.0
500	0.832	-179	5.885	84	0.035	38	0.435	-166	0.81	22.2
800	0.833	175	3.691	76	0.048	45	0.435	-173	0.95	18.8
1000	0.831	172	2.980	71	0.056	51	0.437	-176	1.05	16.0
1200	0.836	169	2.464	67	0.061	52	0.432	-178	1.11	14.0
1400	0.829	166	2.121	61	0.072	53	0.447	-180	1.12	12.6
1600	0.831	164	1.867	58	0.080	54	0.445	179	1.14	11.4

Datasheets

NE46100, NE46134

TYPICAL COMMON EMITTER SCATTERING PARAMETERS[1] (TA = 25°C)





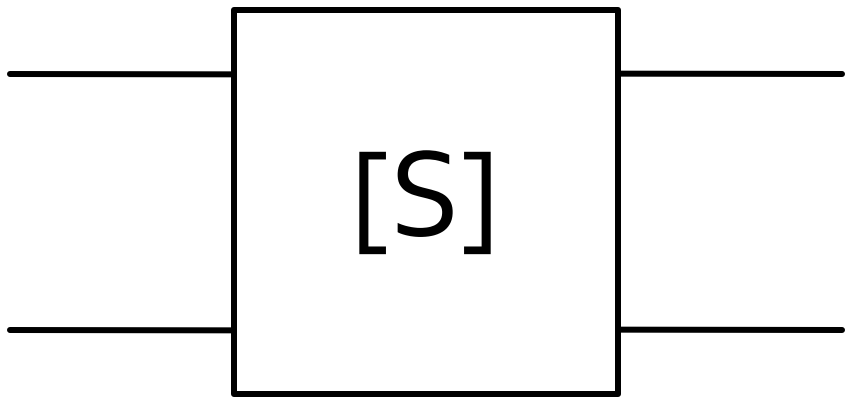
Coordinates in Ohms
Frequency in GHz
VCE = 5 V, Ic = 50 mA

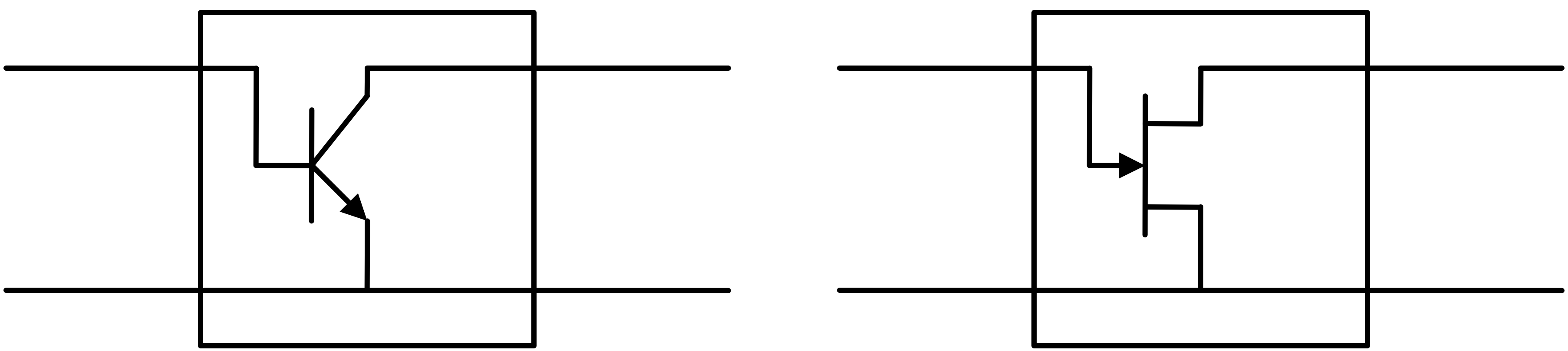
S2P - Touchstone

- Touchstone file format (*.s2p)

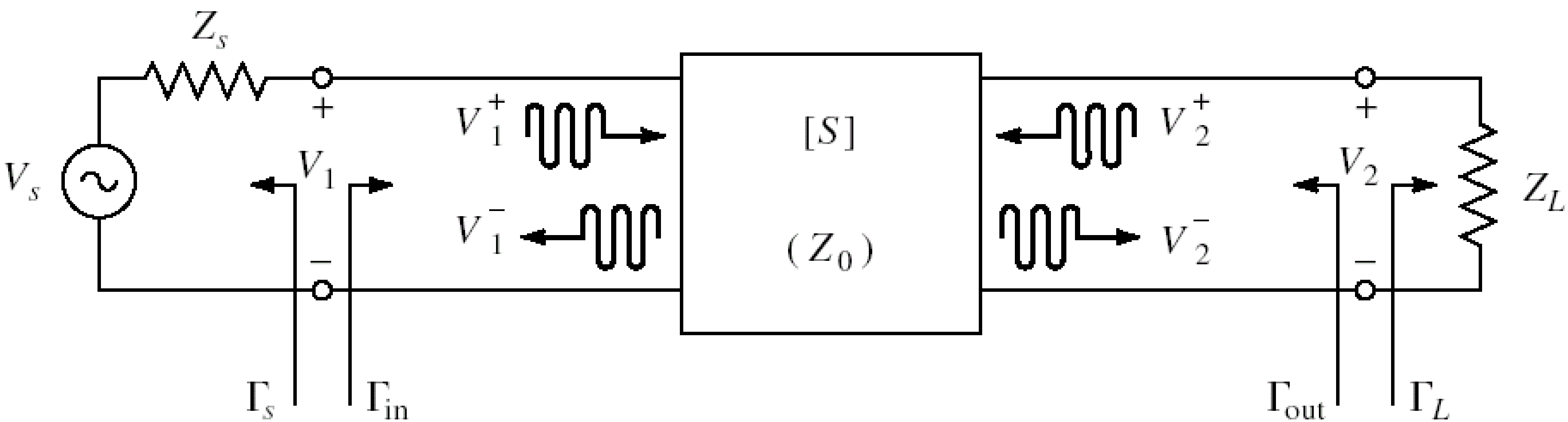
```
! SIEMENS Small Signal Semiconductors
! VDS = 3.5 V     ID = 15 mA
# GHz  S  MA  R  50
!  f        S11          S21          S12          S22
! GHz     MAG   ANG     MAG   ANG     MAG   ANG     MAG   ANG
 1.000 0.9800  -18.0   2.230  157.0  0.0240   74.0  0.6900  -15.0
 2.000 0.9500  -39.0   2.220  136.0  0.0450   57.0  0.6600  -30.0
 3.000 0.8900  -64.0   2.210  110.0  0.0680   40.0  0.6100  -45.0
 4.000 0.8200  -89.0   2.230   86.0  0.0850   23.0  0.5600  -62.0
 5.000 0.7400 -115.0   2.190   61.0  0.0990    7.0  0.4900  -80.0
 6.000 0.6500 -142.0   2.110   36.0  0.1070  -10.0  0.4100  -98.0
!
!  f      Fmin   Gammaopt  rn/50
! GHz      dB    MAG  ANG    -
 2.000     1.00  0.72   27   0.84
 4.000     1.40  0.64   61   0.58
```

S parameters for transistors





Amplifier as two-port



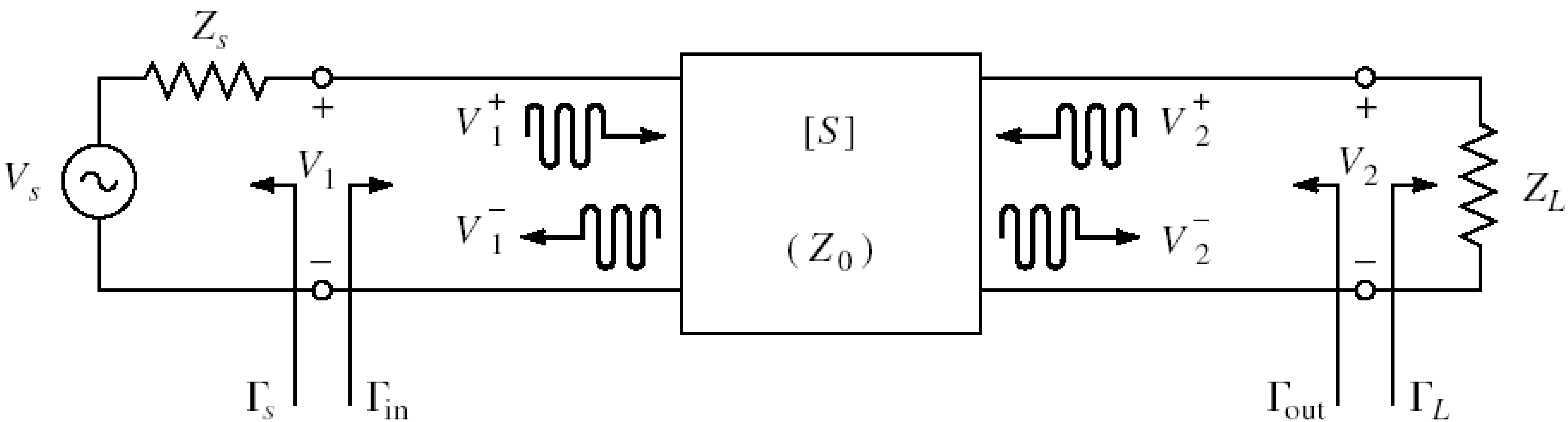
$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \qquad \Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0} \qquad \begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$\Gamma_L = \frac{V_2^+}{V_2^-}$$

$$V_1^- = S_{11} \cdot V_1^+ + S_{12} \cdot V_2^+ = S_{11} \cdot V_1^+ + S_{12} \cdot \Gamma_L \cdot V_2^-$$

$$V_2^- = S_{21} \cdot V_1^+ + S_{22} \cdot V_2^+ = S_{21} \cdot V_1^+ + S_{22} \cdot \Gamma_L \cdot V_2^-$$

Amplifier as two-port



$$V_1^- = S_{11} \cdot V_1^+ + S_{12} \cdot V_2^+ = S_{11} \cdot V_1^+ + S_{12} \cdot \Gamma_L \cdot V_2^-$$

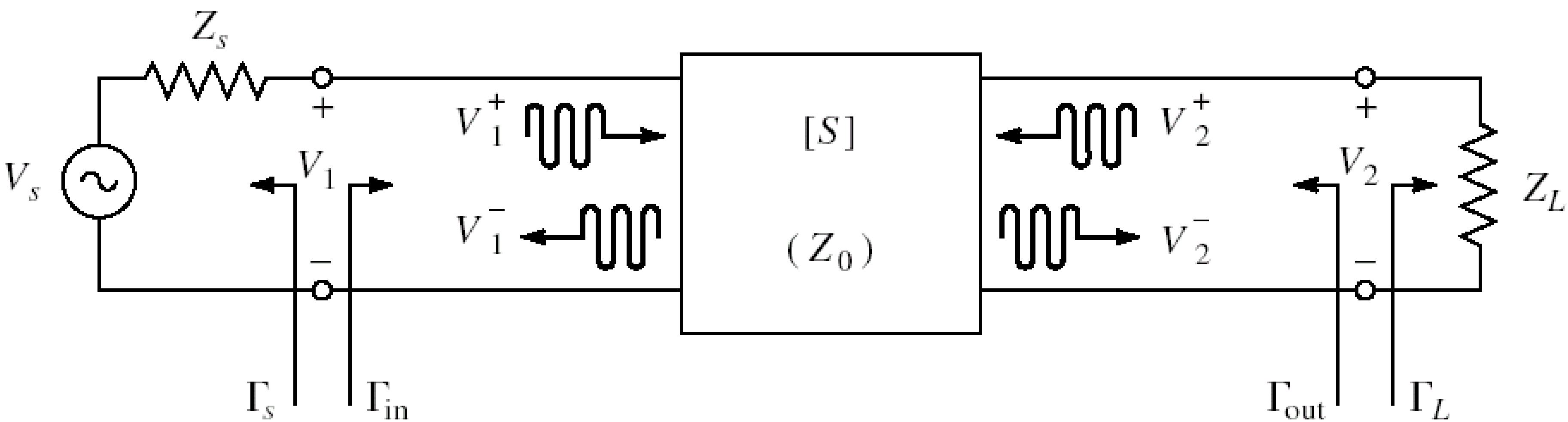
$$V_2^- = S_{21} \cdot V_1^+ + S_{22} \cdot V_2^+ = S_{21} \cdot V_1^+ + S_{22} \cdot \Gamma_L \cdot V_2^-$$

$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_L}{1 - S_{22} \cdot \Gamma_L}$$

- similarly

$$\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_S}{1 - S_{11} \cdot \Gamma_S}$$

Amplifier as two-port



$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_L}{1 - S_{22} \cdot \Gamma_L}$$

$$\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_S}{1 - S_{11} \cdot \Gamma_S}$$

Signal power

$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_L}{1 - S_{22} \cdot \Gamma_L}$$

$$\Gamma_{in} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0}$$

$$V_1 = \frac{V_S \cdot Z_{in}}{Z_S + Z_{in}} = V_1^+ + V_1^- = V_1^+ \cdot (1 + \Gamma_{in})$$

$$V_1^+ = \frac{V_S}{2} \frac{(1 - \Gamma_S)}{(1 - \Gamma_S \cdot \Gamma_{in})}$$

- C3 $$P_{in} = \frac{1}{2 \cdot Z_0} \cdot \left|V_1^+\right|^2 \cdot \left(1 - \left|\Gamma_{in}\right|^2\right)$$ $$P_L = \frac{1}{2 \cdot Z_0} \cdot \left|V_2^-\right|^2 \cdot \left(1 - \left|\Gamma_L\right|^2\right)$$

$$P_{in} = \frac{\left|V_S\right|^2}{8 \cdot Z_0} \cdot \frac{\left|1 - \Gamma_S\right|^2}{\left|1 - \Gamma_S \cdot \Gamma_{in}\right|^2} \left(1 - \left|\Gamma_{in}\right|^2\right)$$

$$V_2^- = S_{21} \cdot V_1^+ + S_{22} \cdot V_2^+ = S_{21} \cdot V_1^+ + S_{22} \cdot \Gamma_L \cdot V_2^-$$

$$V_2^- = \frac{S_{21} \cdot V_1^+}{1 - S_{22} \cdot \Gamma_L}$$

$$P_L = \frac{\left|V_1^+\right|^2}{2 \cdot Z_0} \cdot \frac{\left|S_{21}\right|^2}{\left|1 - S_{22} \cdot \Gamma_L\right|^2} \left(1 - \left|\Gamma_L\right|^2\right)$$

$$P_L = \frac{\left|V_S\right|^2}{8 \cdot Z_0} \cdot \frac{\left|S_{21}\right|^2 \cdot \left(1 - \left|\Gamma_L\right|^2\right)}{\left|1 - S_{22} \cdot \Gamma_L\right|^2} \cdot \frac{\left|1 - \Gamma_S\right|^2}{\left|1 - \Gamma_S \cdot \Gamma_{in}\right|^2}$$

Signal power

- Signal power

$$P_{in} = \frac{|V_S|^2}{8 \cdot Z_0} \cdot \frac{|1-\Gamma_S|^2}{|1-\Gamma_S \cdot \Gamma_{in}|^2} \left(1-|\Gamma_{in}|^2\right)$$

$$P_L = \frac{|V_S|^2}{8 \cdot Z_0} \cdot \frac{|S_{21}|^2 \cdot \left(1-|\Gamma_L|^2\right)}{|1-S_{22} \cdot \Gamma_L|^2} \cdot \frac{|1-\Gamma_S|^2}{|1-\Gamma_S \cdot \Gamma_{in}|^2}$$

- Power available from the source

$$P_{av\,S} = P_{in}\Big|_{\Gamma_{in}=\Gamma_S^*} = \frac{|V_S|^2}{8 \cdot Z_0} \cdot \frac{|1-\Gamma_S|^2}{\left(1-|\Gamma_S|^2\right)}$$

- Power available on the load (from the network)

$$P_{av\,L} = P_L\Big|_{\Gamma_L=\Gamma_{out}^*} = \frac{|V_S|^2}{8 \cdot Z_0} \cdot \frac{|S_{21}|^2 \cdot |1-\Gamma_S|^2}{|1-S_{11} \cdot \Gamma_S|^2 \cdot \left(1-|\Gamma_{out}|^2\right)}$$

Two-Port Power Gains

- Power Gain

$$G = \frac{P_L}{P_{in}} = \frac{|S_{21}|^2 \cdot \left(1 - |\Gamma_L|^2\right)}{\left(1 - |\Gamma_{in}|^2\right) \cdot |1 - S_{22} \cdot \Gamma_L|^2}$$

$$P_{in} = P_{in}\left(\Gamma_S, \Gamma_{in}(\Gamma_L), S\right)$$

$$P_L = P_L\left(\Gamma_S, \Gamma_{in}(\Gamma_L), S\right)$$

- The **actual** power gain **introduced** by the amplifier is less important because a higher gain may be accompanied by a **decrease** in input power (power actually drained from the source)
- We prefer to characterize the amplifier effect looking to the **power actually delivered to the load** in relation to the power **available from the source** (which is a constant)

Two-Port Power Gains

- **Available** power gain

$$G_A = \frac{P_{av\,L}}{P_{av\,S}} = \frac{|S_{21}|^2 \cdot \left(1 - |\Gamma_S|^2\right)}{|1 - S_{22} \cdot \Gamma_L|^2 \cdot \left(1 - |\Gamma_{out}|^2\right)}$$

- **Transducer** power gain

$$G_T = \frac{P_L}{P_{av\,S}} = \frac{|S_{21}|^2 \cdot \left(1 - |\Gamma_S|^2\right) \cdot \left(1 - |\Gamma_L|^2\right)}{|1 - \Gamma_S \cdot \Gamma_{in}|^2 \cdot |1 - S_{22} \cdot \Gamma_L|^2}$$

$$\Gamma_{in} = \Gamma_{in}(\Gamma_L)$$

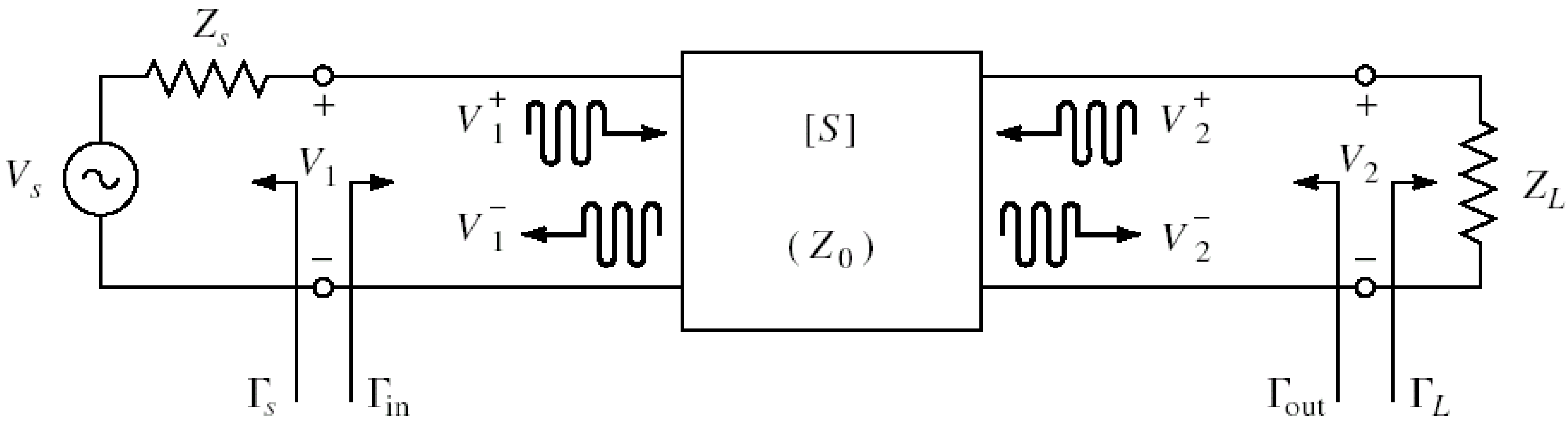
- **Unilateral transducer** power gain

$$G_{TU} = |S_{21}|^2 \cdot \frac{1 - |\Gamma_S|^2}{|1 - S_{11} \cdot \Gamma_S|^2} \cdot \frac{1 - |\Gamma_L|^2}{|1 - S_{22} \cdot \Gamma_L|^2}$$

$$S_{12} \cong 0 \qquad \Gamma_{in} = S_{11}$$

Input and output can be treated independently

Amplifier as two-port

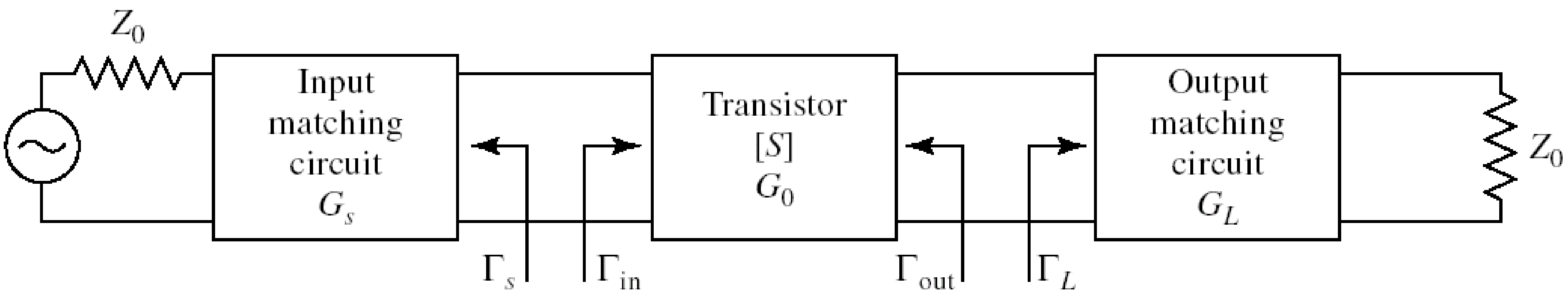


- For an amplifier two-port we are interested in:
  - stability
  - power gain
  - noise (sometimes – small signals)
  - linearity (sometimes – large signals)

Preview (pentru laborator 3-4)

Amplificatoare de microunde

Proiectare pentru castig impus

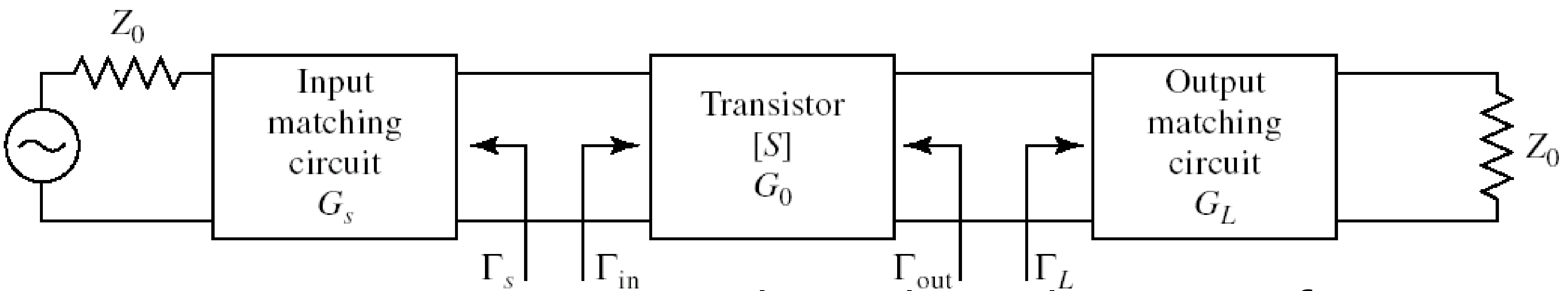


- Daca ipoteza tranzistorului unilateral este justificata:

$$G_{TU} = |S_{21}|^2 \cdot \frac{1-|\Gamma_S|^2}{|1-S_{11}\cdot\Gamma_S|^2} \cdot \frac{1-|\Gamma_L|^2}{|1-S_{22}\cdot\Gamma_L|^2}$$

$$G_S = \frac{1-|\Gamma_S|^2}{|1-S_{11}\cdot\Gamma_S|^2} \qquad G_0 = |S_{21}|^2 \qquad G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\cdot\Gamma_L|^2}$$

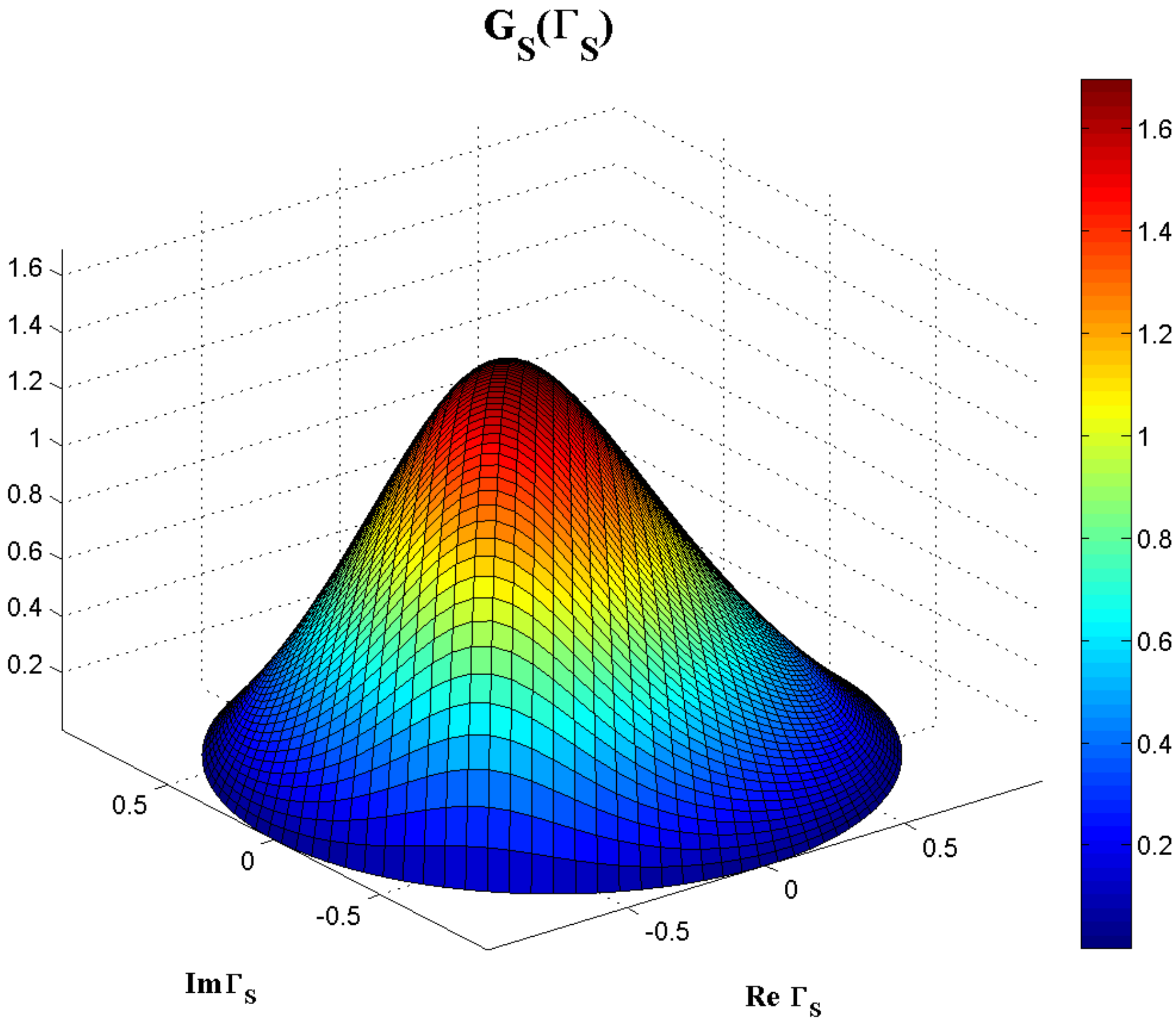
Proiectare pentru castig impus



- Daca ipoteza tranzistorului unilateral este justificata:
  - castigul adaugat prin adaptare mai buna la intrare **nu** depinde de adaptarea la iesire
  - castigul adaugat prin adaptare mai buna la iesire **nu** depinde de adaptarea la intrare
- Adaptarile la intrare/iesire pot fi tratate independent
  - Se pot impune cerinte diferite intrare/iesire
  - se tine cont de compunerea castigurilor generate

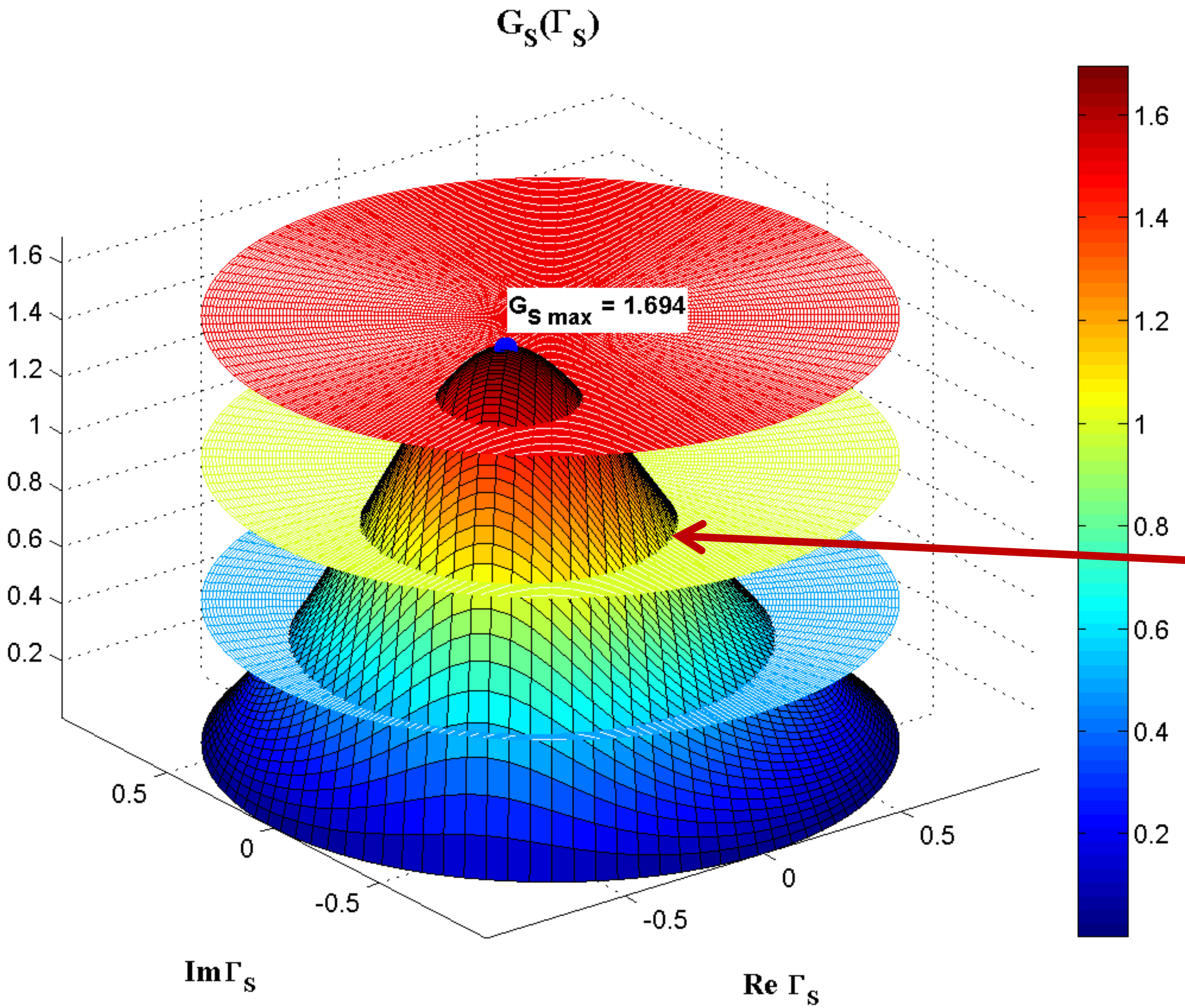
$$G_T = G_S \cdot G_0 \cdot G_L \qquad G_T[dB] = G_S[dB] + G_0[dB] + G_L[dB]$$

$G_S(\Gamma_S)$



$$G_S = \frac{1 - |\Gamma_S|^2}{|1 - S_{11} \cdot \Gamma_S|^2}$$

$G_S(\Gamma_S)$, nivel constant



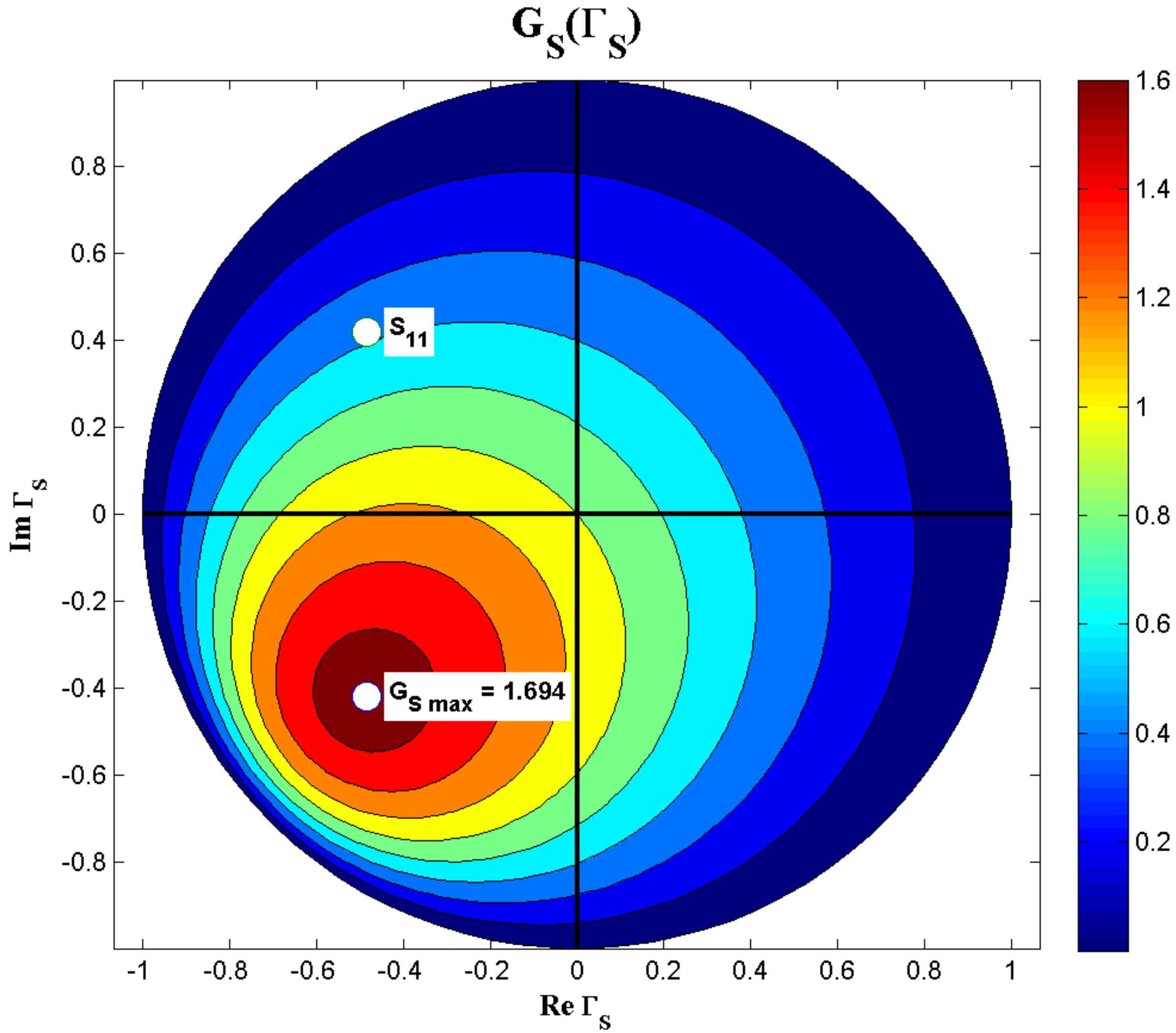
$G_S = 1.5$

$G_S = 1.0$

$G_S = 0.5$

Cercuri

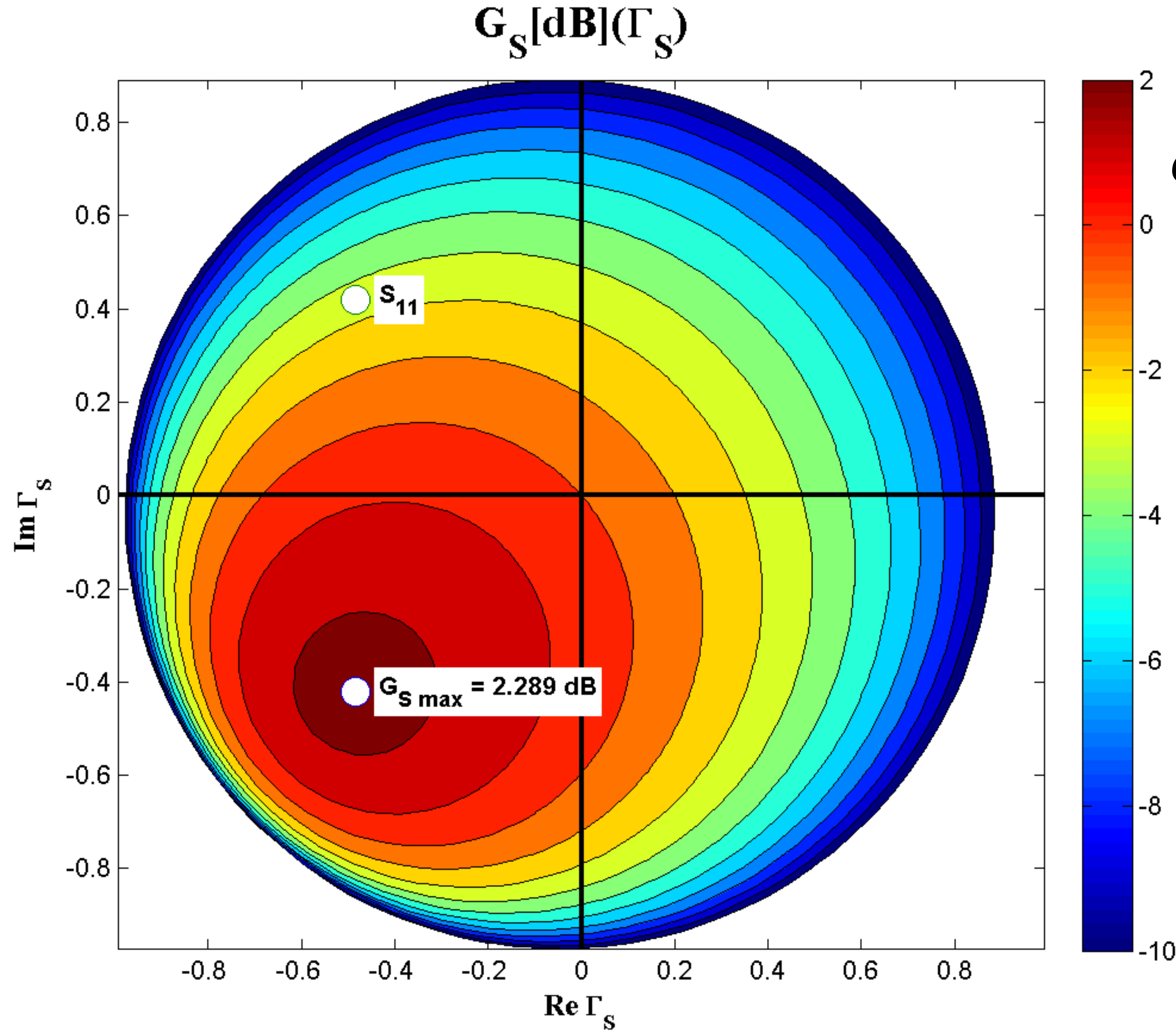
$G_S(\Gamma_S)$, diagrama de nivel



$$G_S = \frac{1 - |\Gamma_S|^2}{|1 - S_{11} \cdot \Gamma_S|^2}$$

$$G_{S\,\max} = G_S\big|_{\Gamma_S = S_{11}^*}$$

$G_S[dB](\Gamma_S)$, diagrama de nivel



$$G_S[dB] = 10 \cdot \log\left(\frac{1-|\Gamma_S|^2}{|1-S_{11}\cdot\Gamma_S|^2}\right)$$

$$G_{S\max} = G_S\big|_{\Gamma_S = S_{11}^*}$$

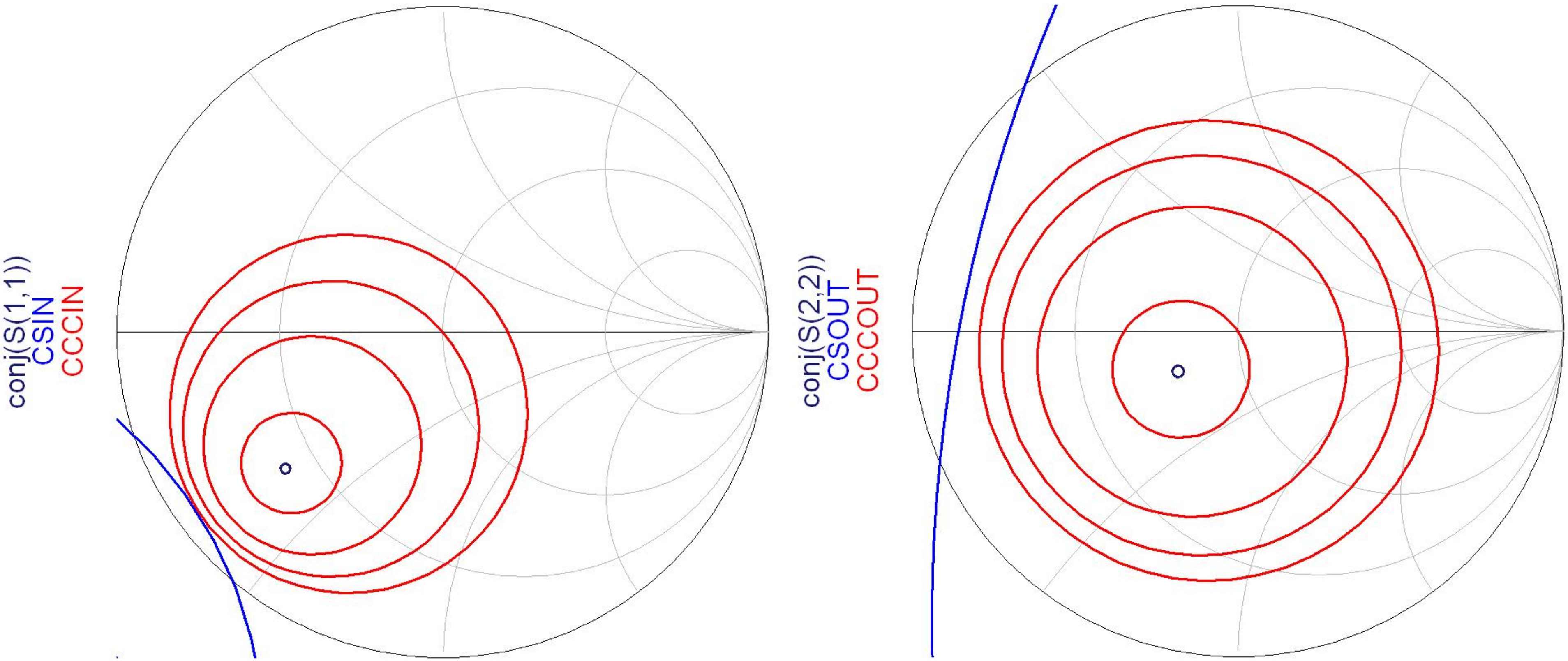
Cercuri de castig constant la intrare

$$\left|\Gamma_S - \frac{g_S \cdot S_{11}^*}{1-(1-g_S)\cdot|S_{11}|^2}\right| = \frac{\sqrt{1-g_S}\cdot\left(1-|S_{11}|^2\right)}{1-(1-g_S)\cdot|S_{11}|^2} \qquad |\Gamma_S - C_S| = R_S$$

$$C_S = \frac{g_S \cdot S_{11}^*}{1-(1-g_S)\cdot|S_{11}|^2} \qquad R_S = \frac{\sqrt{1-g_S}\cdot\left(1-|S_{11}|^2\right)}{1-(1-g_S)\cdot|S_{11}|^2}$$

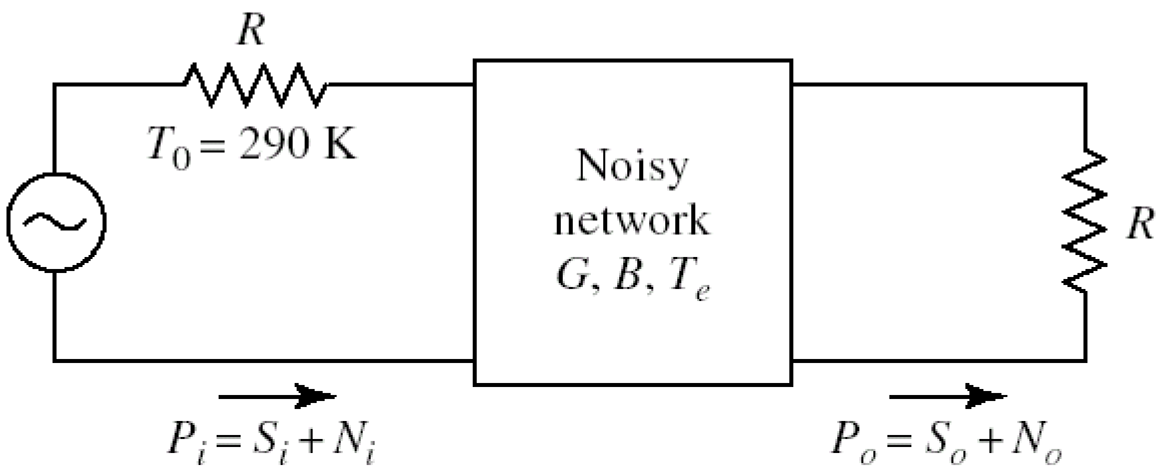
- Ecuatia unui cerc in planul complex in care reprezint Γ_S
- **Interpretare**: Orice punct Γ_S care reprezentat in planul complex se gaseste **pe** cercul desenat pentru $g_{cerc} = G_{cerc}/G_{Smax}$ va conduce la obtinerea castigului $G_S = G_{cerc}$
  - Orice punct **in exteriorul** acestui cerc va genera un castig $G_S < G_{cerc}$
  - Orice punct **in interiorul** acestui cerc va genera un castig $G_S > G_{cerc}$
- Discutie similara la iesire **CCCIN, CCCOUT**

CCCIN, CCCOUT



- Cercurile se reprezinta pentru valorile cerute in dB
- Este utila calcularea G_{Smax} si G_{Lmax} anterior

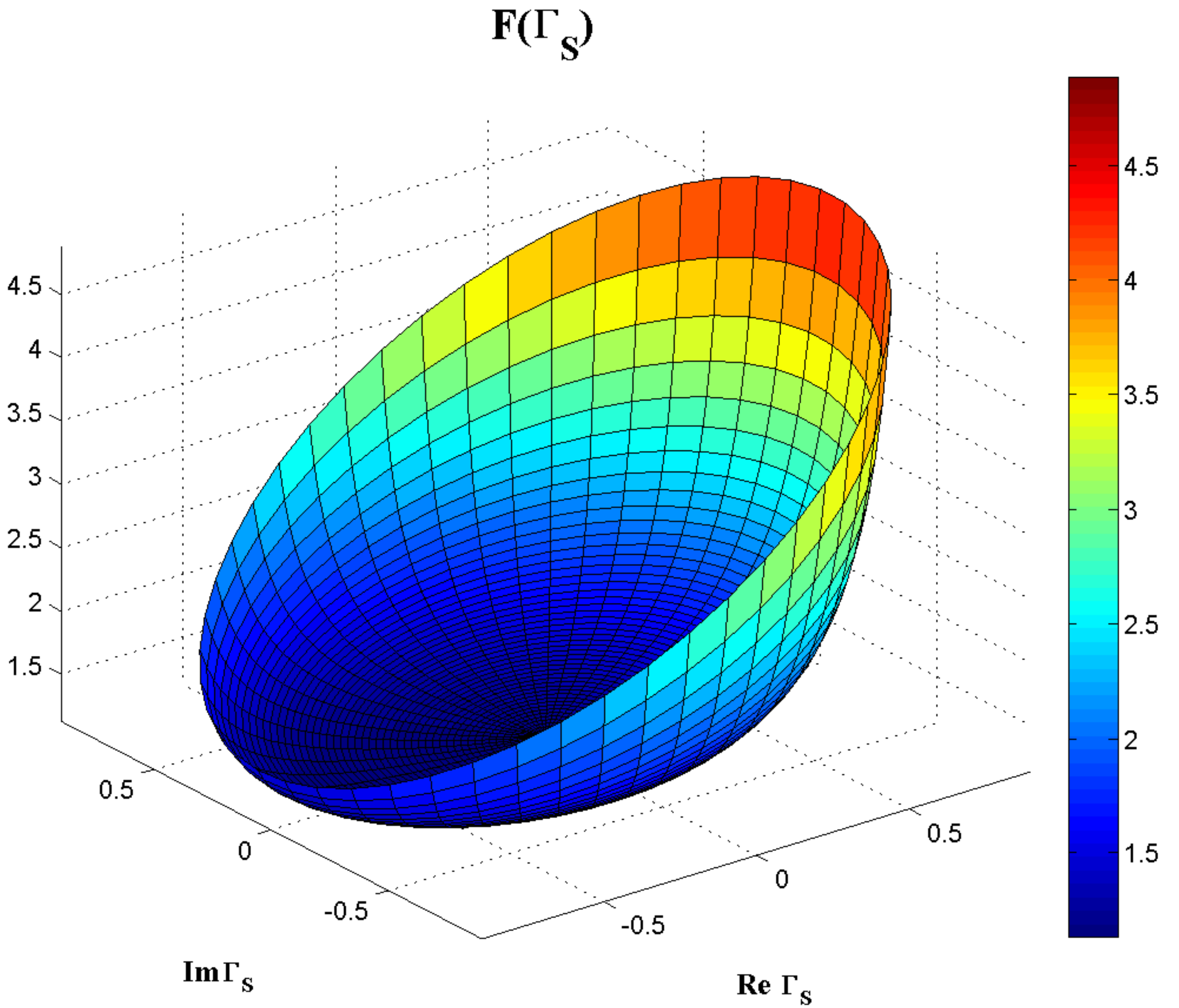
Factor de zgomot



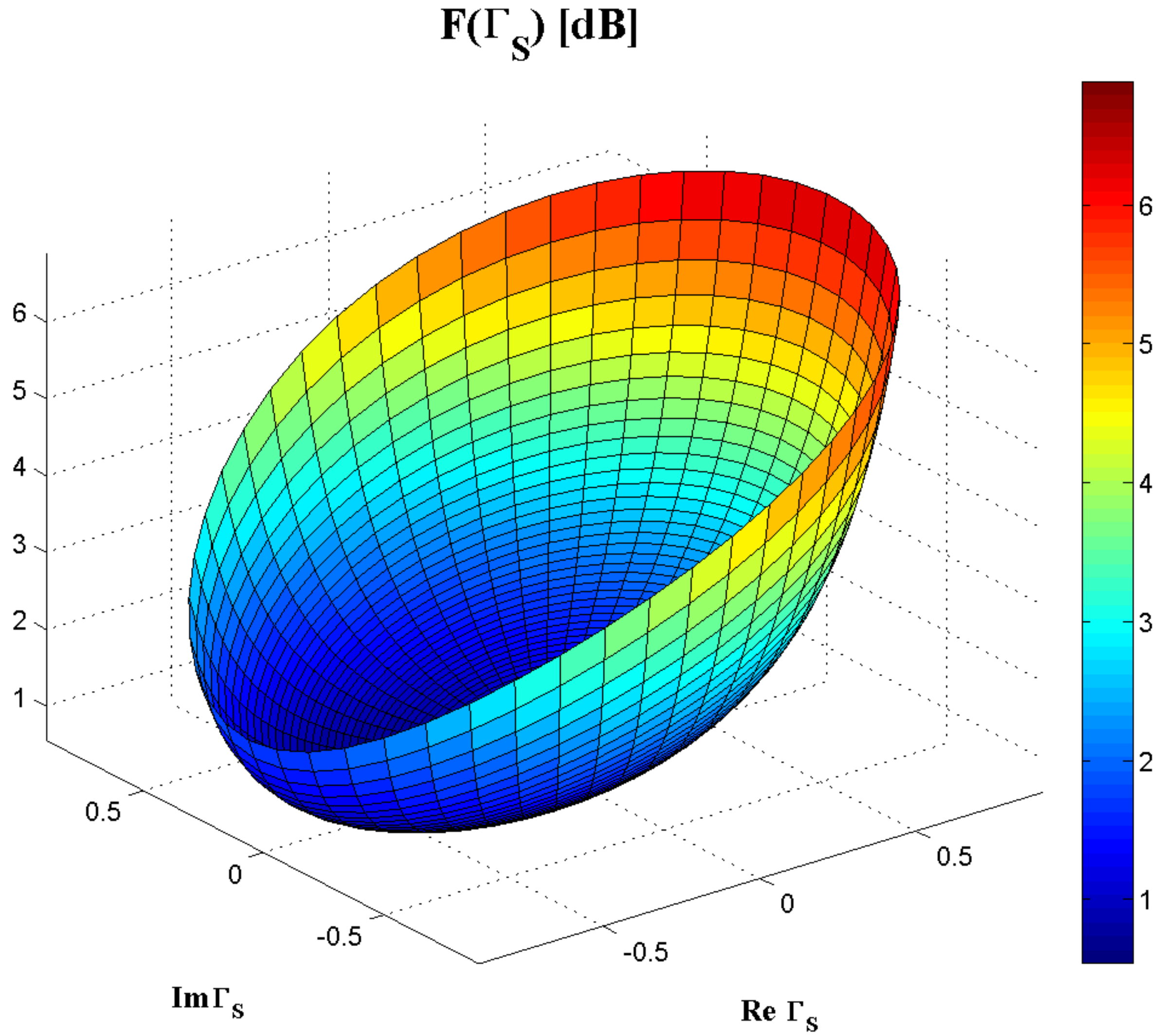
- Factorul de zgomot F caracterizeaza degradarea raportului semnal/zgomot intre intrarea si iesirea unei componente

$$F = \frac{S_i / N_i}{S_o / N_o}$$

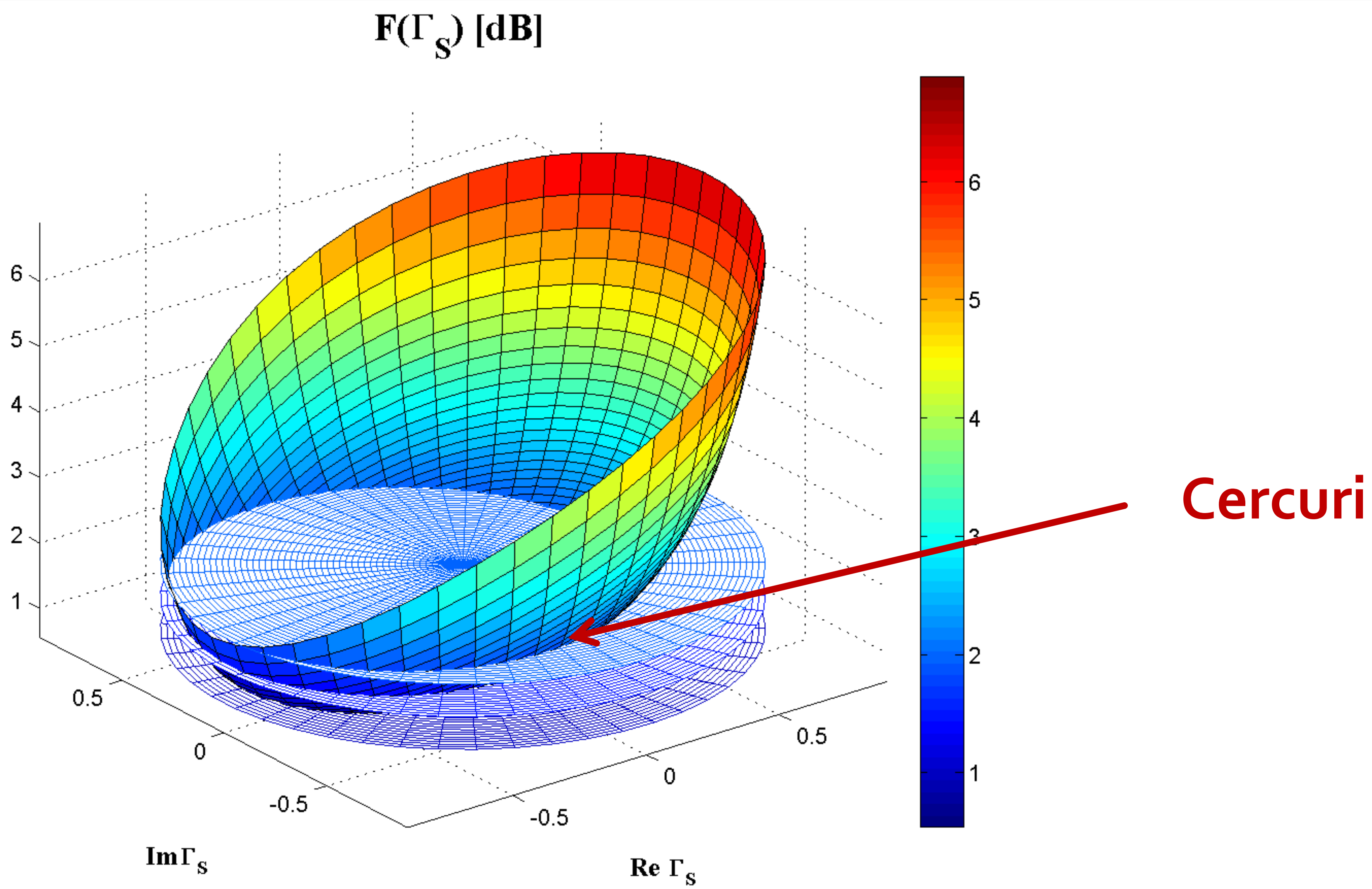
$F(\Gamma_S)$



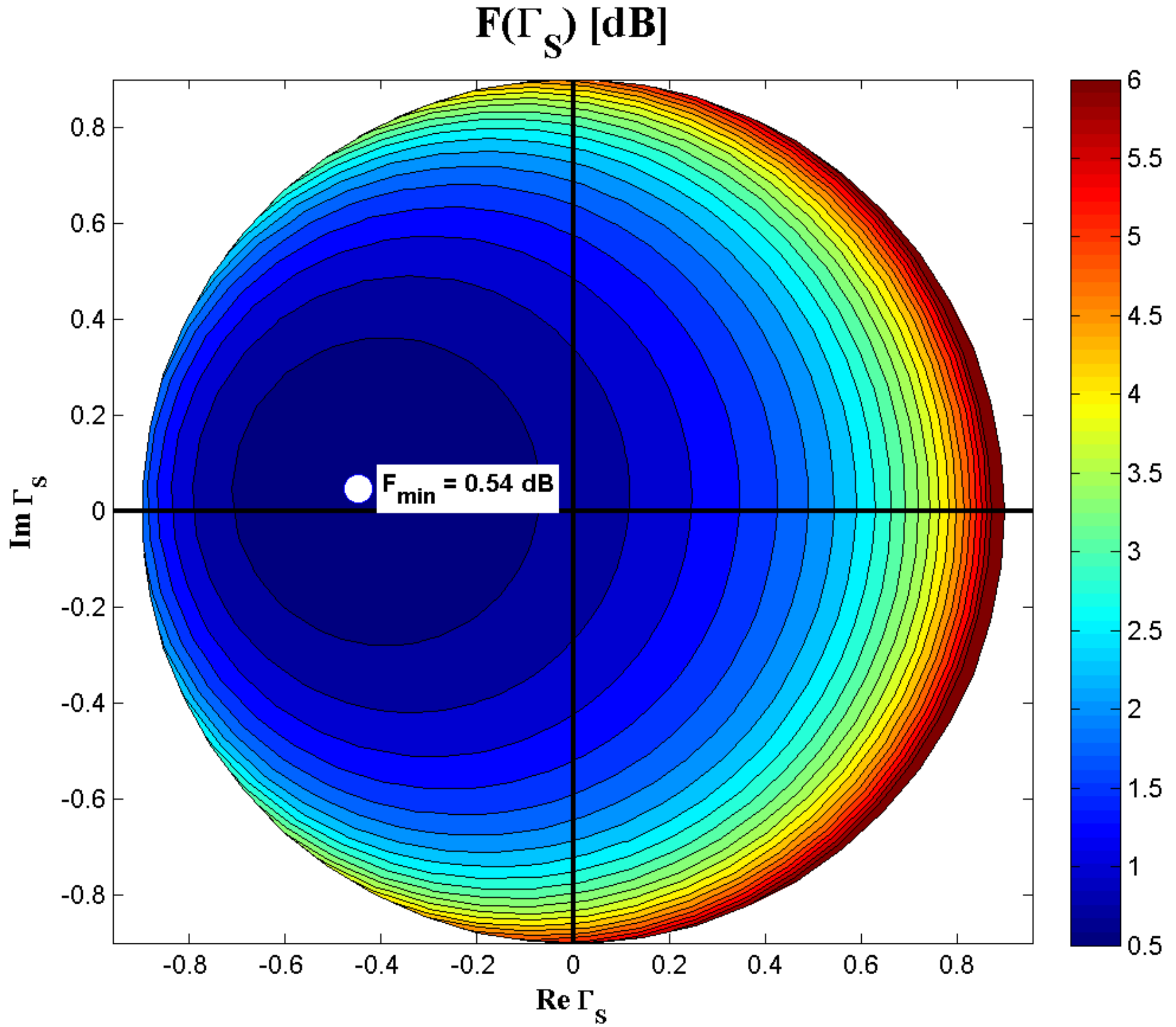
F[dB](Γ_S)



F[dB](Γ_S), diagrama de nivel

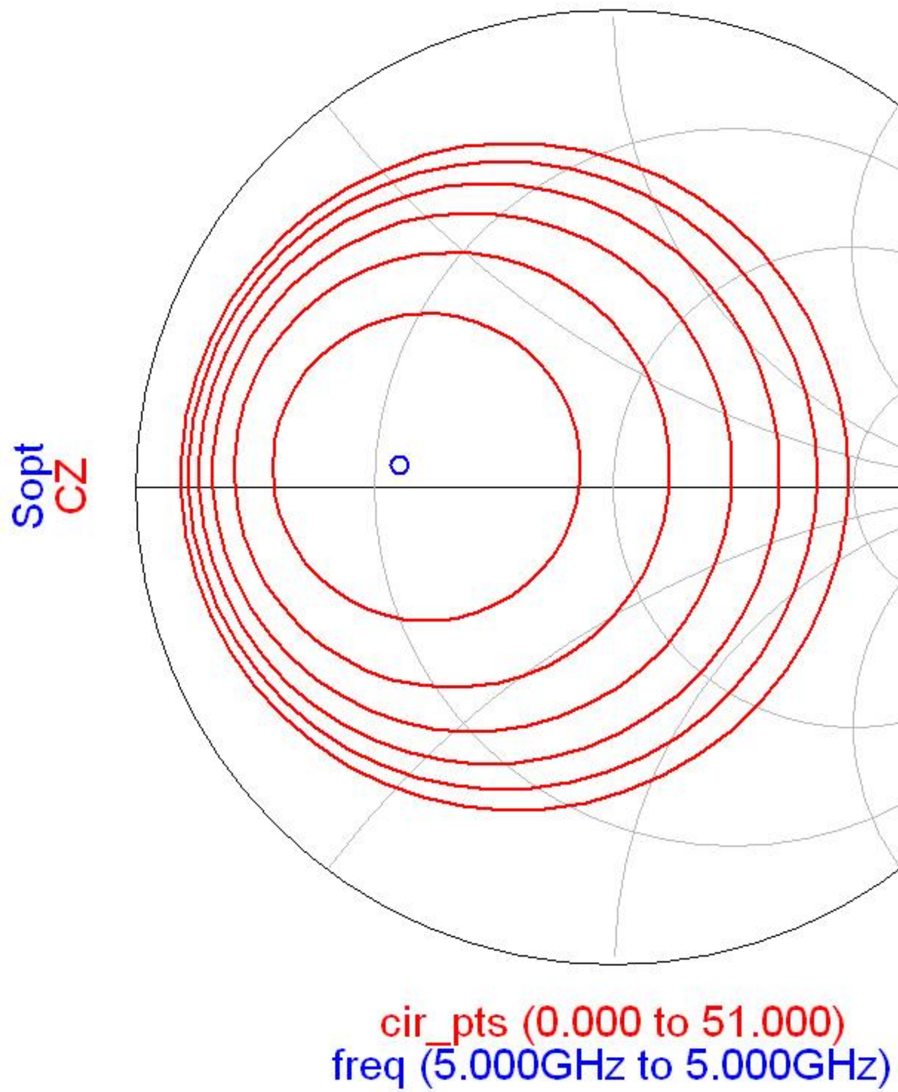


$G_S[dB](\Gamma_S)$, diagrama de nivel



$\Gamma opt = 0.45 \angle 174°$

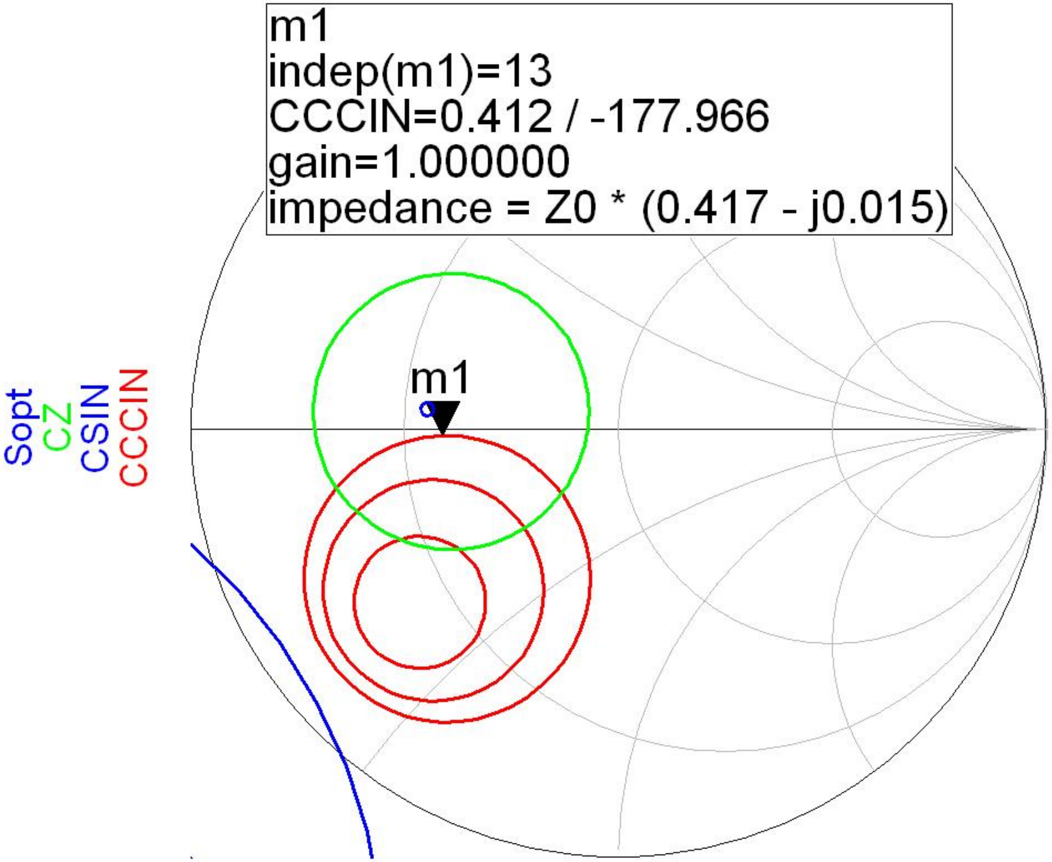
CZ – numai la intrare !



Exemplu, LNA @ 5 GHz

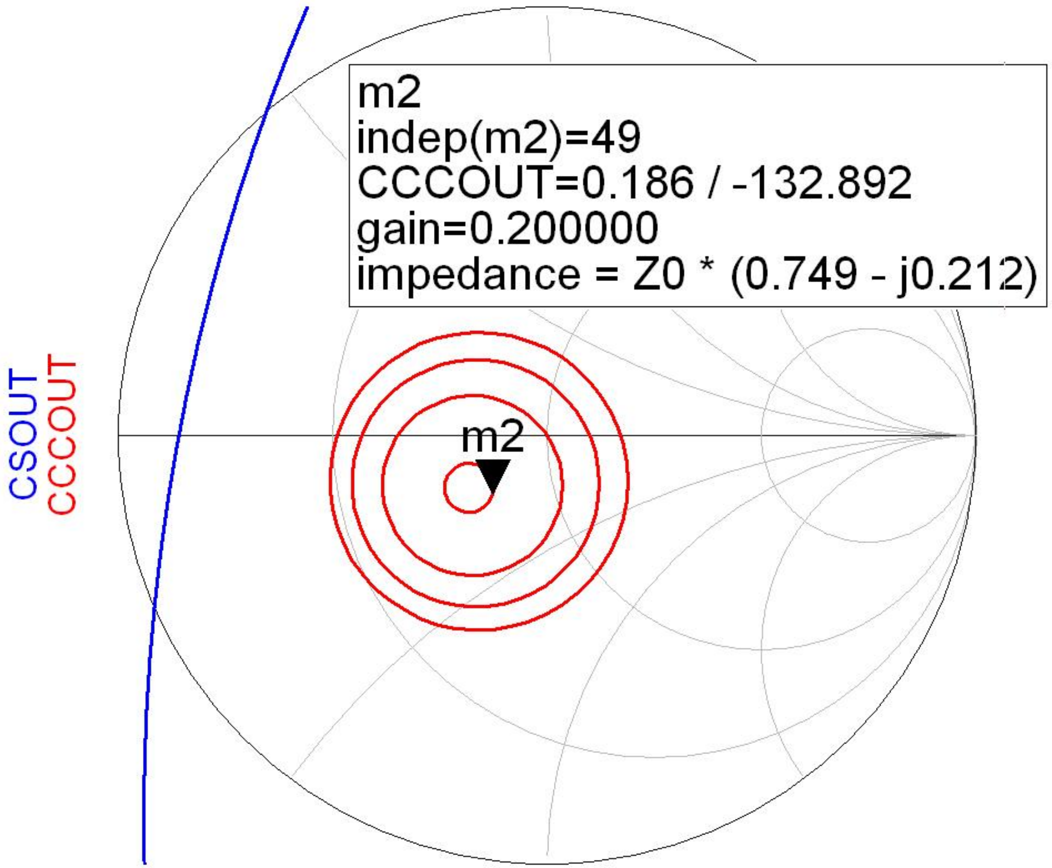
- Amplificator de zgomot redus
- La intrare e necesar un compromis intre
  - zgomot (cerc de zgomot constant ~~la intrare~~)
  - castig (cerc de castig constant la intrare)
  - stabilitate (cerc de stabilitate la intrare)
- La iesire zgomotul **nu intervine** (nu exista influenta). Compromis intre:
  - castig (cerc de castig constant la iesire)
  - stabilitate (cerc de stabilitate la iesire)

Adaptare la intrare



- Daca se sacrifica 1.2dB castig la intrare pentru conditii convenabile F,Q (Gs = 1 dB)
- Se prefera obtinerea unui zgomot mai mic

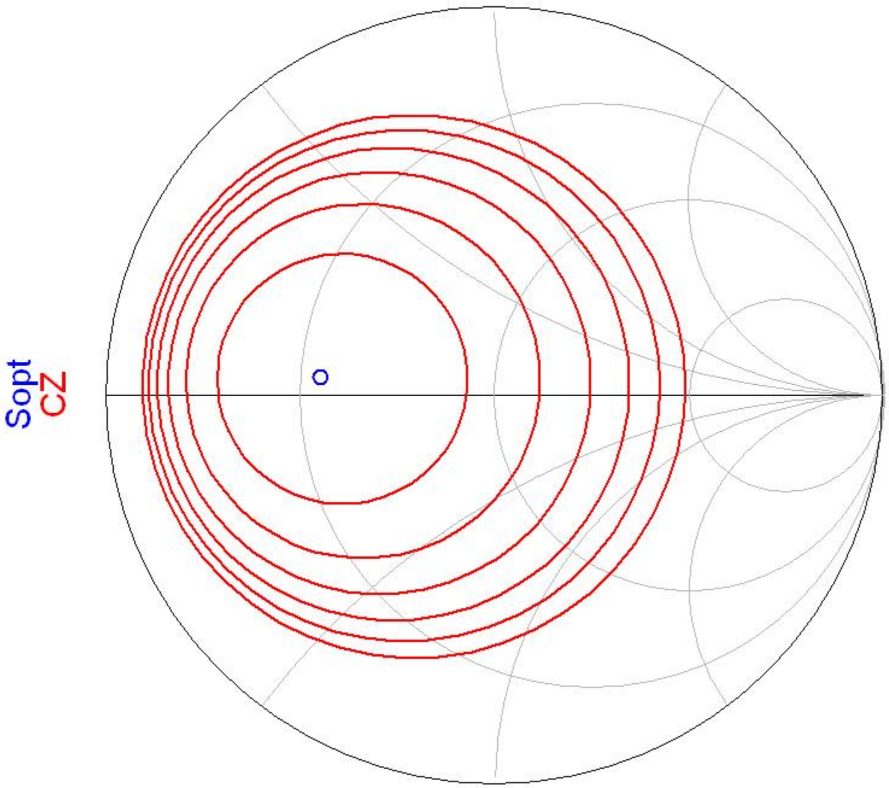
Adaptare la iesire

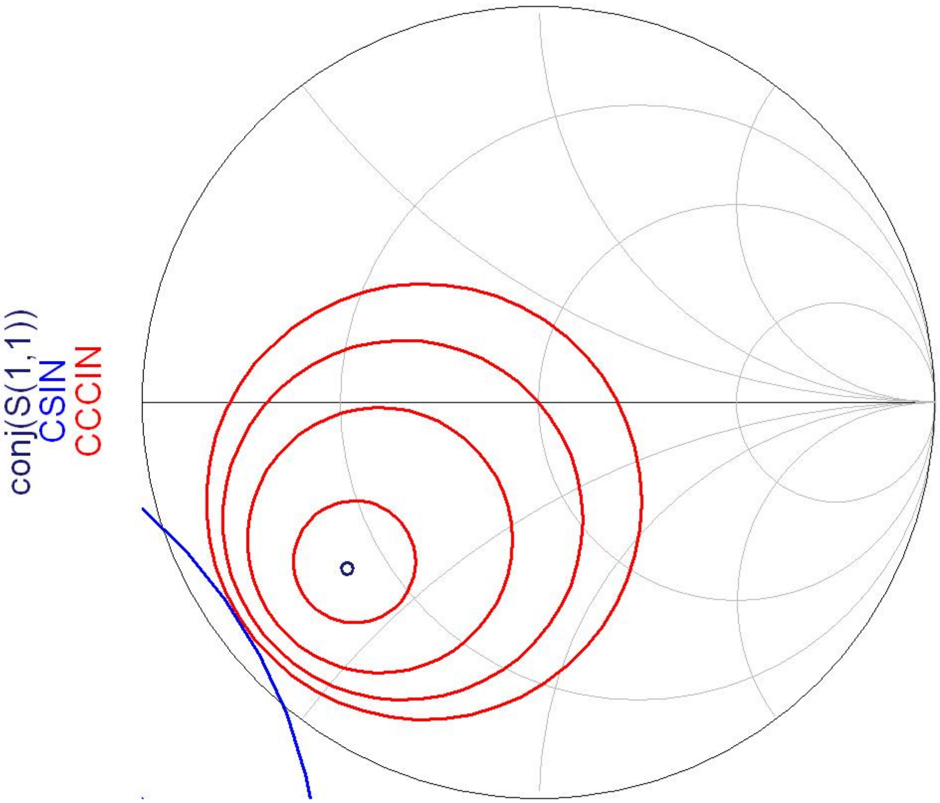


- CCCOUT: -0.4dB, -0.2dB, 0dB, +0.2dB
- Lipsa conditiilor privitoare la zgomot ofera posibilitatea obtinerii unui castig mai mare (spre maxim)

LNA

- De obicei un tranzistor potrivit pentru implementarea unui LNA la o anumita frecventa va avea cercurile de castig la intrare si cercurile de zgomot in aceeasi zona pentru Γ_S





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