

Curs 9  
2019/2020

# Dispozitive și circuite de microunde pentru radiocomunicații

# Disciplina 2019/2020

- 2C/1L, **DCMR (CDM)**
- Minim 7 prezente (curs+laborator)
- Curs - **conf. Radu Damian**
  - Marti 14-16, P7
  - E – **50%** din nota
  - probleme + (2p prez. curs) + (3 teste) + (bonus activitate)
    - primul test L1 (t<sub>2</sub> si t<sub>3</sub> neanuntate)
    - 3pz (C) = +0.5p
  - toate materialele permise

# Disciplina 2019/2020

- 2C/1L, **DCMR (CDM)**
- Laborator – **conf. Radu Damian**
  - Miercuri 10-14 impar II.12 (par eng.)
  - Joi 14- 16 par
  - L – **25%** din nota
    - prezenta + rezultate personale
  - P – **25%** din nota
    - tema personală

# Documentatie

■ <http://rf-opto.etti.tuiasi.ro>

Laboratorul de Microunde si Optică

Not secure | rf-opto.etti.tuiasi.ro/microwave\_cd.php?chg\_lang=1

RF-OPTO

Universitatea Tehnică "Gheorghe Asachi" din Iași

English | Romana |

Start Didactic Master Colectiv Cercetare Studenti Admin

Microunde Comunicatii Optice Optoelectronica Internet Antene Practica Retele Soft didactic

## Dispozitive si circuite de microunde pentru radiocomunicatii

### Disciplina: DCMR (2017-2018)

Coordinator Disciplina: conf. dr. Radu-Florin Damian

Cod: DOS412T

Tip Disciplina: DOS; Disciplina Optionala, Disciplina de Specialitate

Credite: 4

An de Studiu: 4, Sem. 7

### Activitati

Curs: Cadru Didactic: conf. dr. Radu-Florin Damian, 2 Ore/Saptamana, Sectie Specializare, Orar:

Laborator: Cadru Didactic: conf. dr. Radu-Florin Damian, 1 Ore/Saptamana, Grupa, Orar:

### Evaluare

Tip: Examen

A: 50%, (Examen/Colocviu)

B: 25%, (Activitate Seminar/Laborator/Proiect)

D: 25%, (Teme de casa/Lucrari de specialitate)

### Note

[Rezultate totale](#)

### Prezenta

[Curs](#)

[Laborator](#)

### Liste

[Bonus-uri acumulate \(final\)](#)

[Studenti care nu pot intra in examen](#)

# Bibliografie

- <http://rf-opto.eti.tuiasi.ro>
- Irinel Casian-Botez: "Microunde vol. 1: Proiectarea de circuit", Ed. TEHNOPRES, 2008
- David Pozar, Microwave Engineering, Wiley; 4th edition , 2011, ISBN : 978-1-118-29813-8 (E), ISBN : 978-0-470-63155-3 (P)

# Examen: Reprezentare logaritmică

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

$$0 \text{ dB} = 1$$

$$+0.1 \text{ dB} = 1.023 (+2.3\%)$$

$$+3 \text{ dB} = 2$$

$$+5 \text{ dB} = 3$$

$$+10 \text{ dB} = 10$$

$$-3 \text{ dB} = 0.5$$

$$-10 \text{ dB} = 0.1$$

$$-20 \text{ dB} = 0.01$$

$$-30 \text{ dB} = 0.001$$

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

$$0 \text{ dBm} = 1 \text{ mW}$$

$$3 \text{ dBm} = 2 \text{ mW}$$

$$5 \text{ dBm} = 3 \text{ mW}$$

$$10 \text{ dBm} = 10 \text{ mW}$$

$$20 \text{ dBm} = 100 \text{ mW}$$

$$-3 \text{ dBm} = 0.5 \text{ mW}$$

$$-10 \text{ dBm} = 100 \mu\text{W}$$

$$-20 \text{ dBm} = 1 \mu\text{W}$$

$$-30 \text{ dBm} = 1 \text{ nW}$$

$$[\text{dBm}] + [\text{dB}] = [\text{dBm}]$$

$$[\text{dBm}/\text{Hz}] + [\text{dB}] = [\text{dBm}/\text{Hz}]$$

$$[x] + [\text{dB}] = [x]$$

# Examen: Operatii cu numere complexe

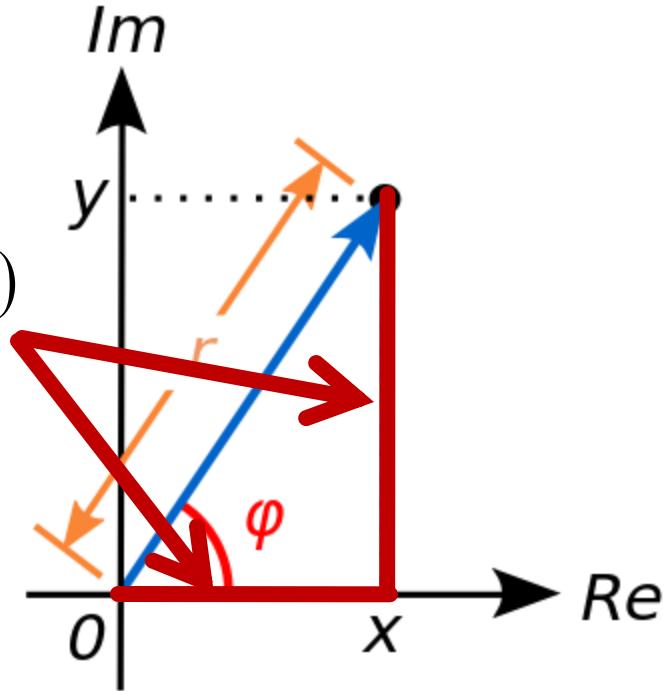
## ■ Reprezentare polară

- modul
- faza

$$z = a + j \cdot b = |z| \cdot (\cos \varphi + j \cdot \sin \varphi)$$

$$|z| = \sqrt{a^2 + b^2}$$

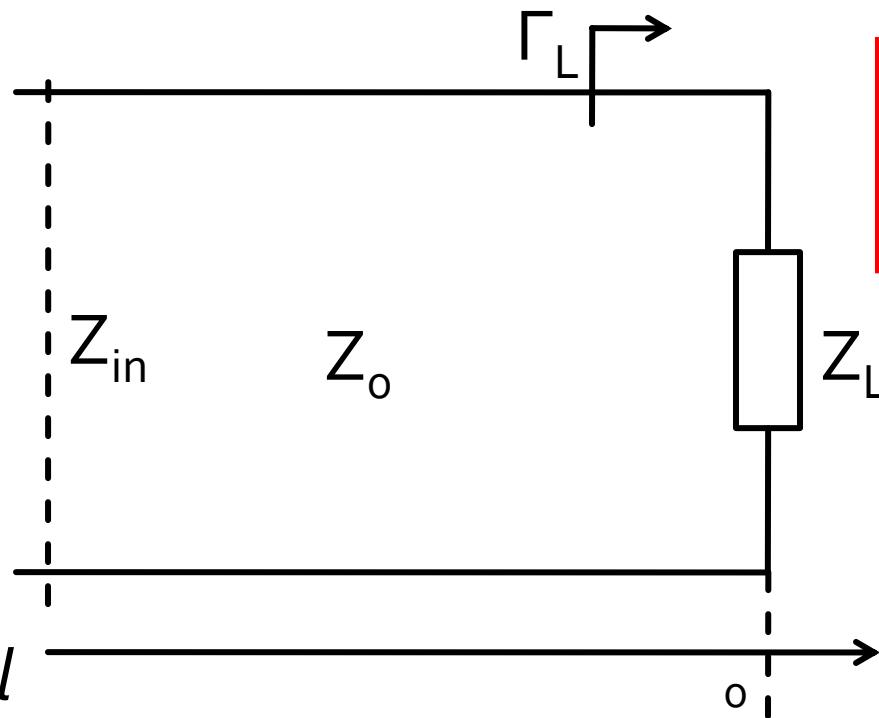
$$\varphi = \arg(z) = \begin{cases} \arctan\left(\frac{b}{a}\right), & a > 0 \\ \arctan\left(\frac{b}{a}\right) + \pi, & a < 0, b \geq 0 \\ \arctan\left(\frac{b}{a}\right) - \pi, & a < 0, b < 0 \\ \frac{\pi}{2}, -\frac{\pi}{2}, \text{nedefinit} & a = 0 \end{cases}$$



# **Linii de transmisie in mod TEM**

# Linie fara pierderi

- impedanta la intrarea liniei de impedanta caracteristica  $Z_0$ , de lungime  $l$ , terminata cu impedanta  $Z_L$

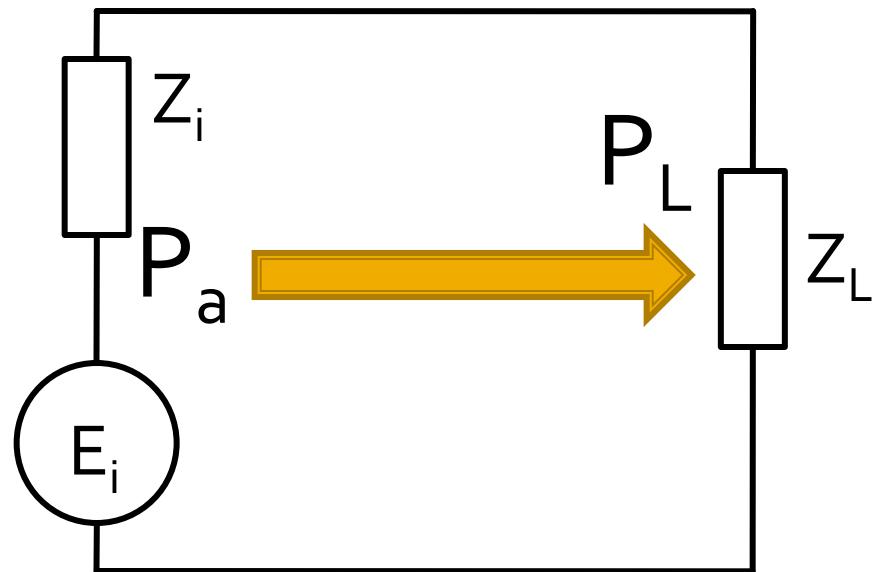
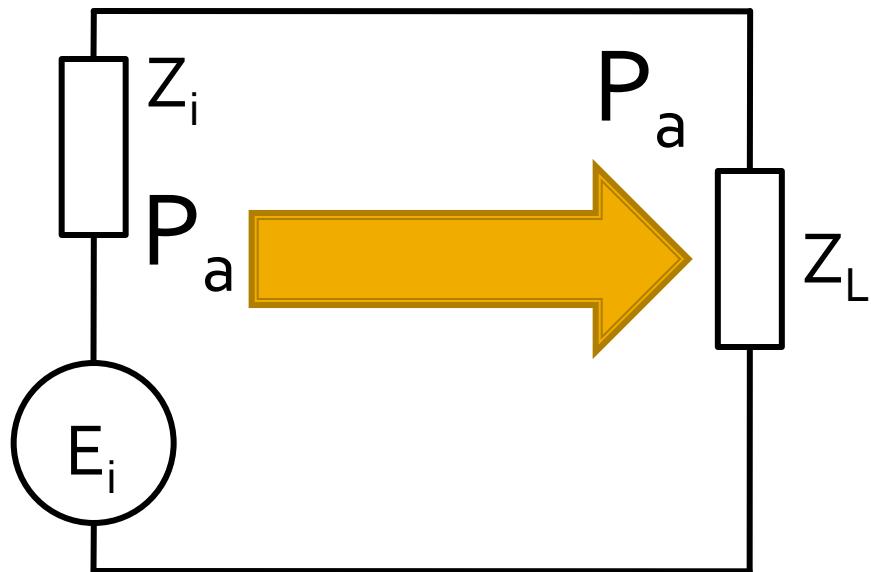


$$Z_{in} = Z_0 \cdot \frac{Z_L + j \cdot Z_0 \cdot \tan \beta \cdot l}{Z_0 + j \cdot Z_L \cdot \tan \beta \cdot l}$$

Transfer de putere

# **Adaptarea de impedanță**

# Reflexie de putere / Model



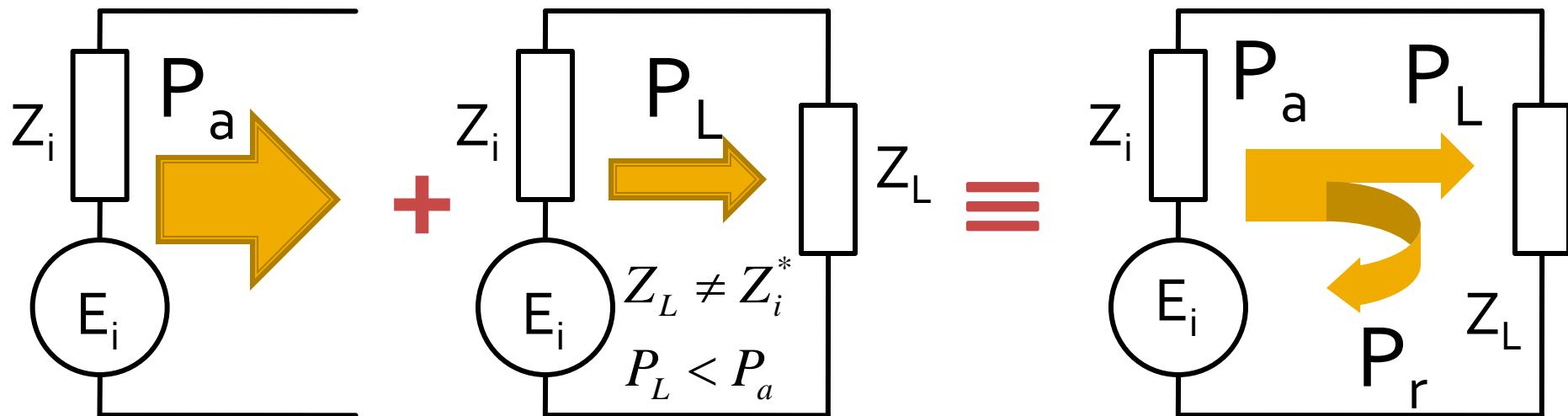
$$Z_L = Z_i^*$$

$$P_L = P_a$$

$$Z_L \neq Z_i^*$$

$$P_L < P_a$$

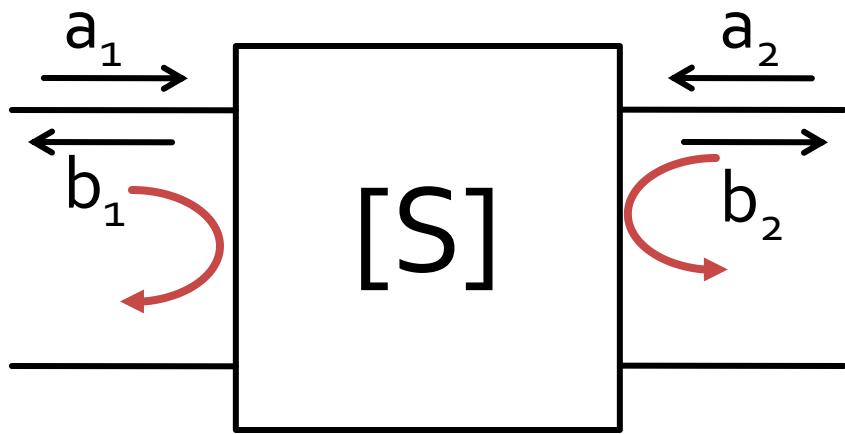
# Reflexie de putere / Model



- Generatorul are posibilitatea de a oferi o anumita putere maxima de semnal  $P_a$
- Pentru o sarcina oarecare, acesteia i se ofera o putere de semnal mai mica  $P_L < P_a$
- Se intampla "**ca si cum**" (model) o parte din putere se reflecta  $P_r = P_a - P_L$
- Puterea este o marime **scalara!**

**Analiza la nivel de rețea a  
circuitelor de microunde**

# Matricea S (repartitie)

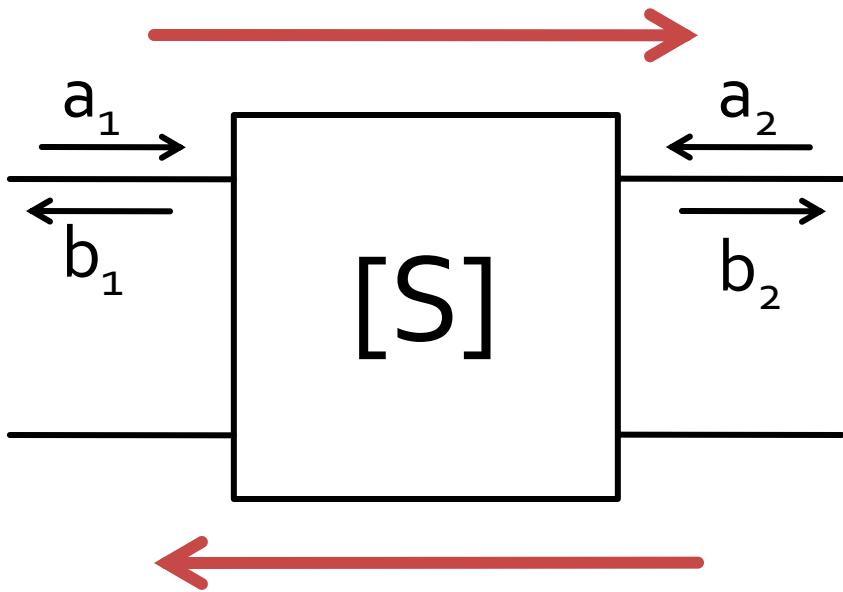


$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

- $S_{11}$  și  $S_{22}$  sunt coeficienti de reflexie la intrare si iesire cand celalalt port este adaptat

# Matricea S (repartitie)



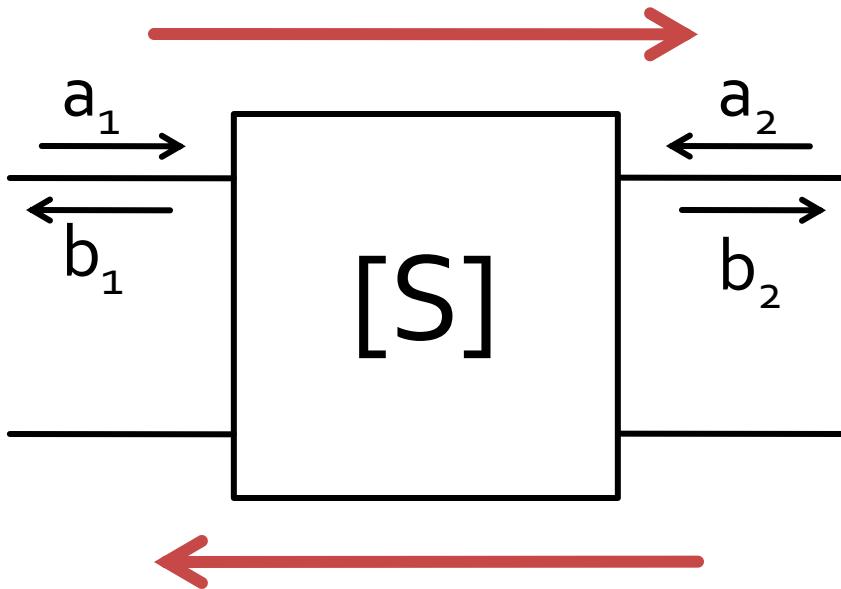
$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{21} = \frac{b_2}{a_1} \Big|_{a_2=0}$$

$$S_{12} = \frac{b_1}{a_2} \Big|_{a_1=0}$$

- $S_{21}$  și  $S_{12}$  sunt amplificări de semnal cand celalalt port este adaptat

# Matricea S (repartitie)



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

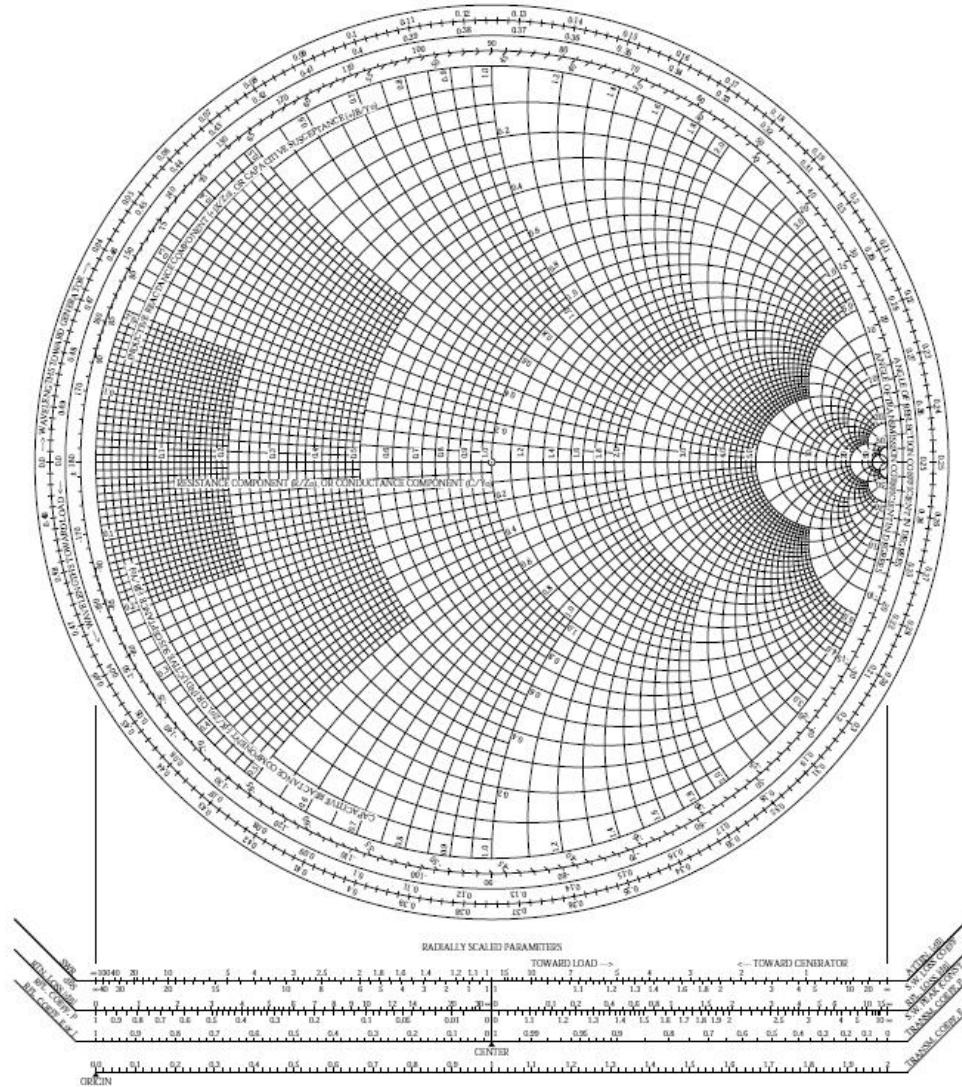
$$|S_{21}|^2 = \frac{\text{Putere sarcina } Z_0}{\text{Putere sursa } Z_0}$$

- a,b
  - informatia despre putere **SI** faza
- $S_{ij}$ 
  - influenta circuitului asupra puterii semnalului incluzand informatiile relativ la faza

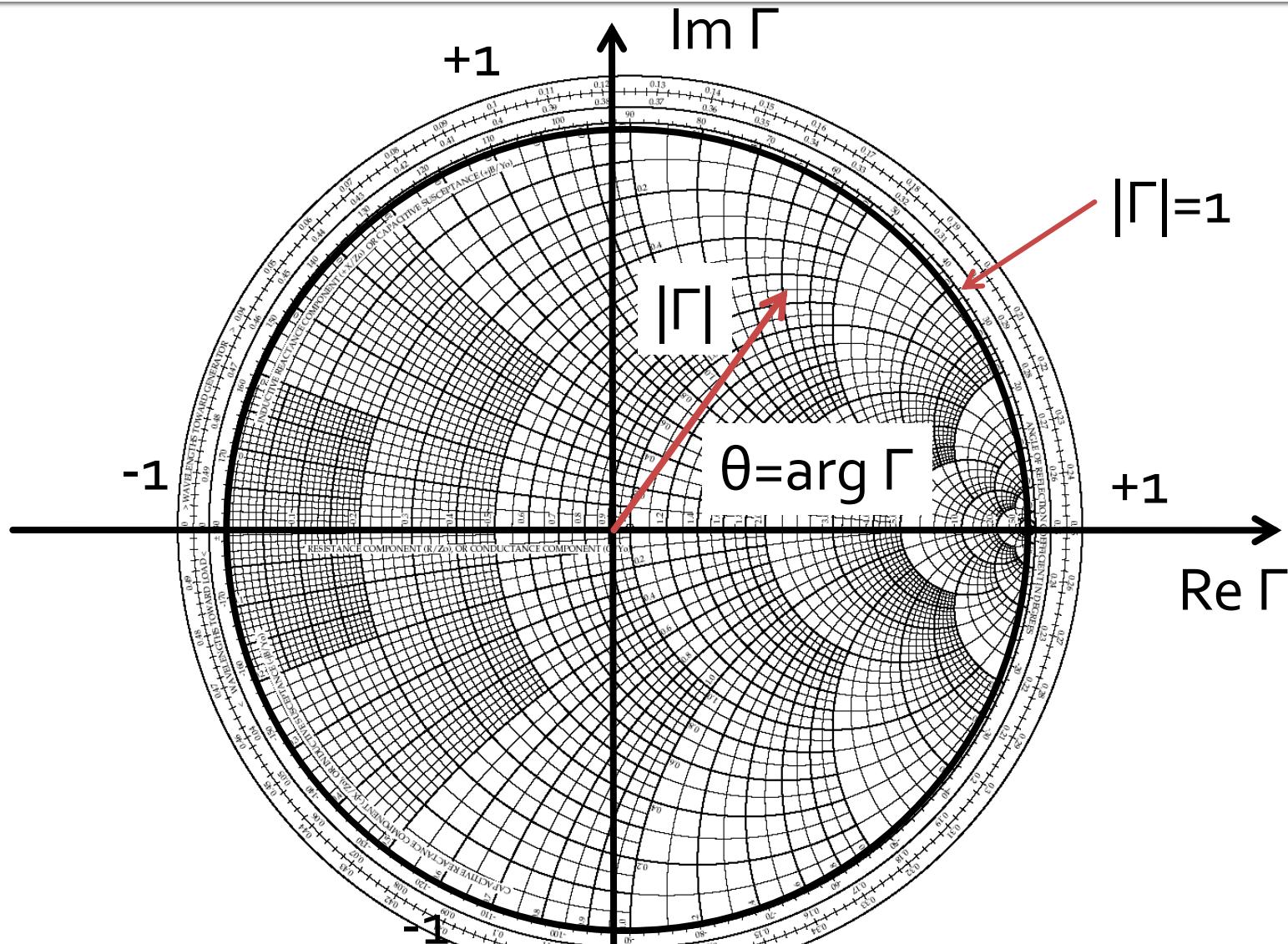
Adaptarea de impedanță

# Diagrama Smith

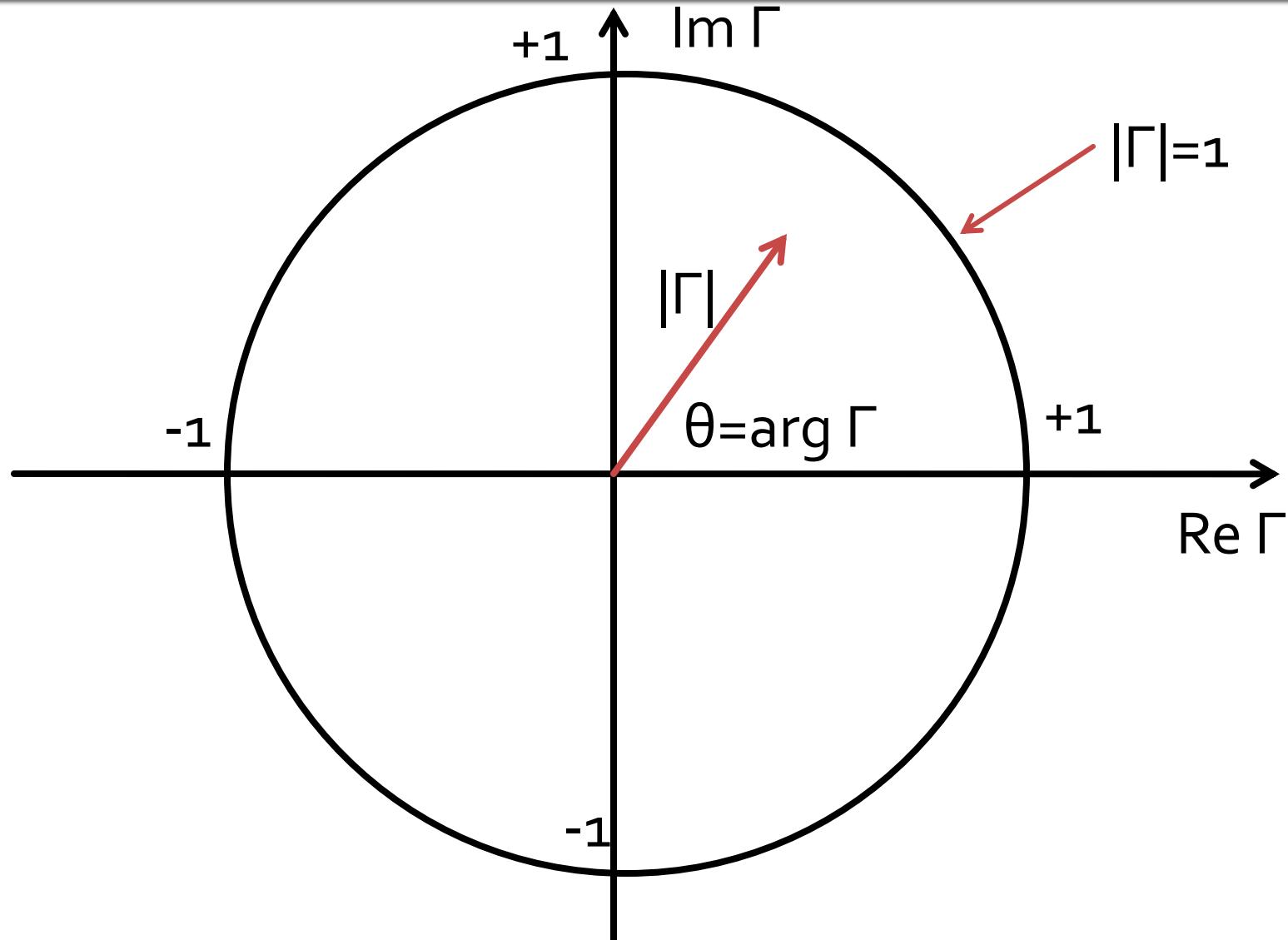
# Diagrama Smith



# Diagrama Smith



# Diagrama Smith

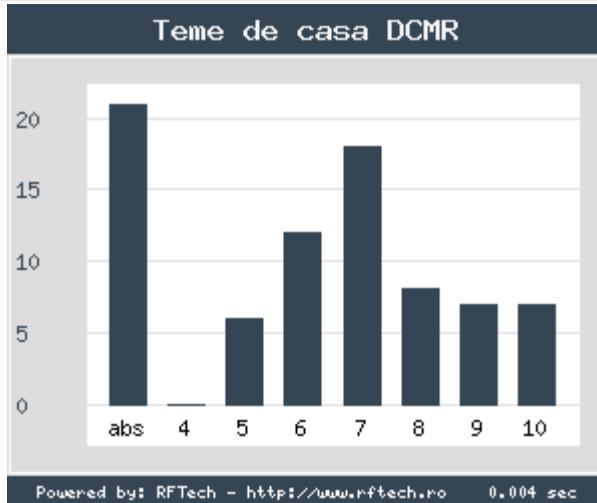


Adaptarea cu sectiuni de linii (stub)

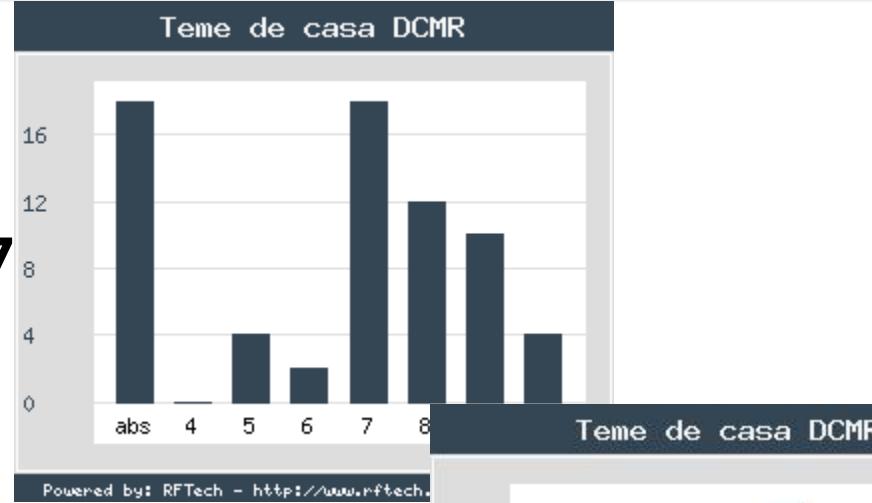
# **Adaptarea de impedanță**

# Efect? – factorul “andrei”

15/6



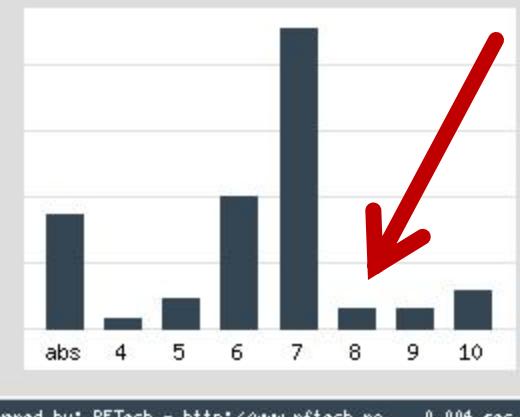
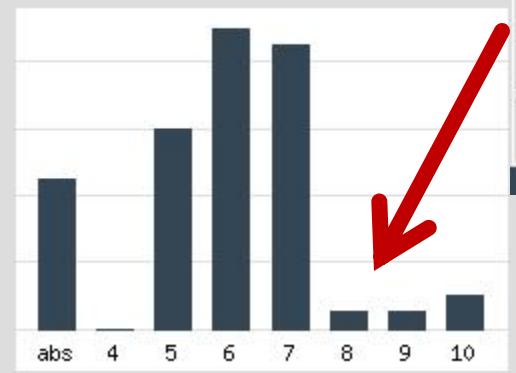
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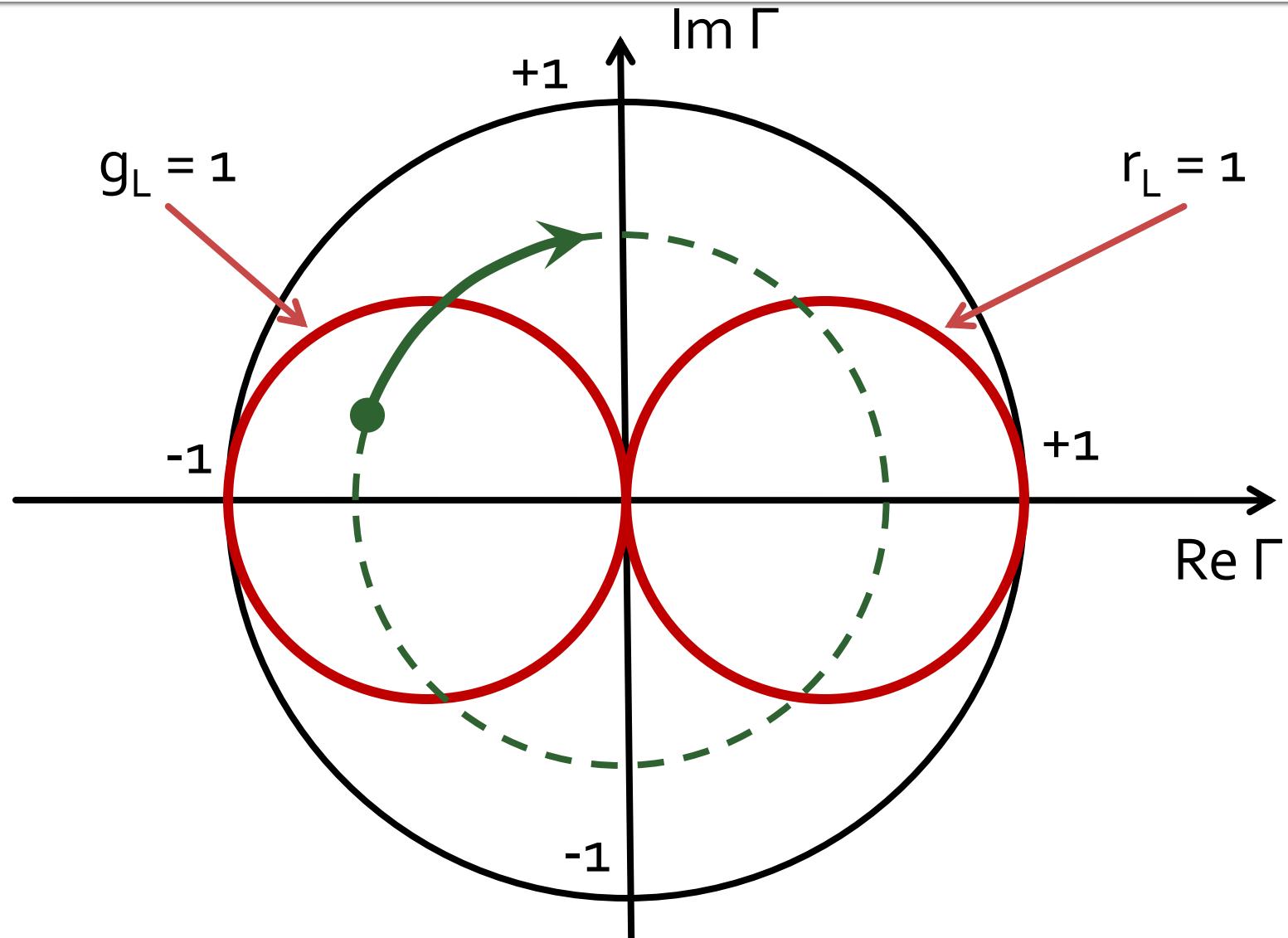
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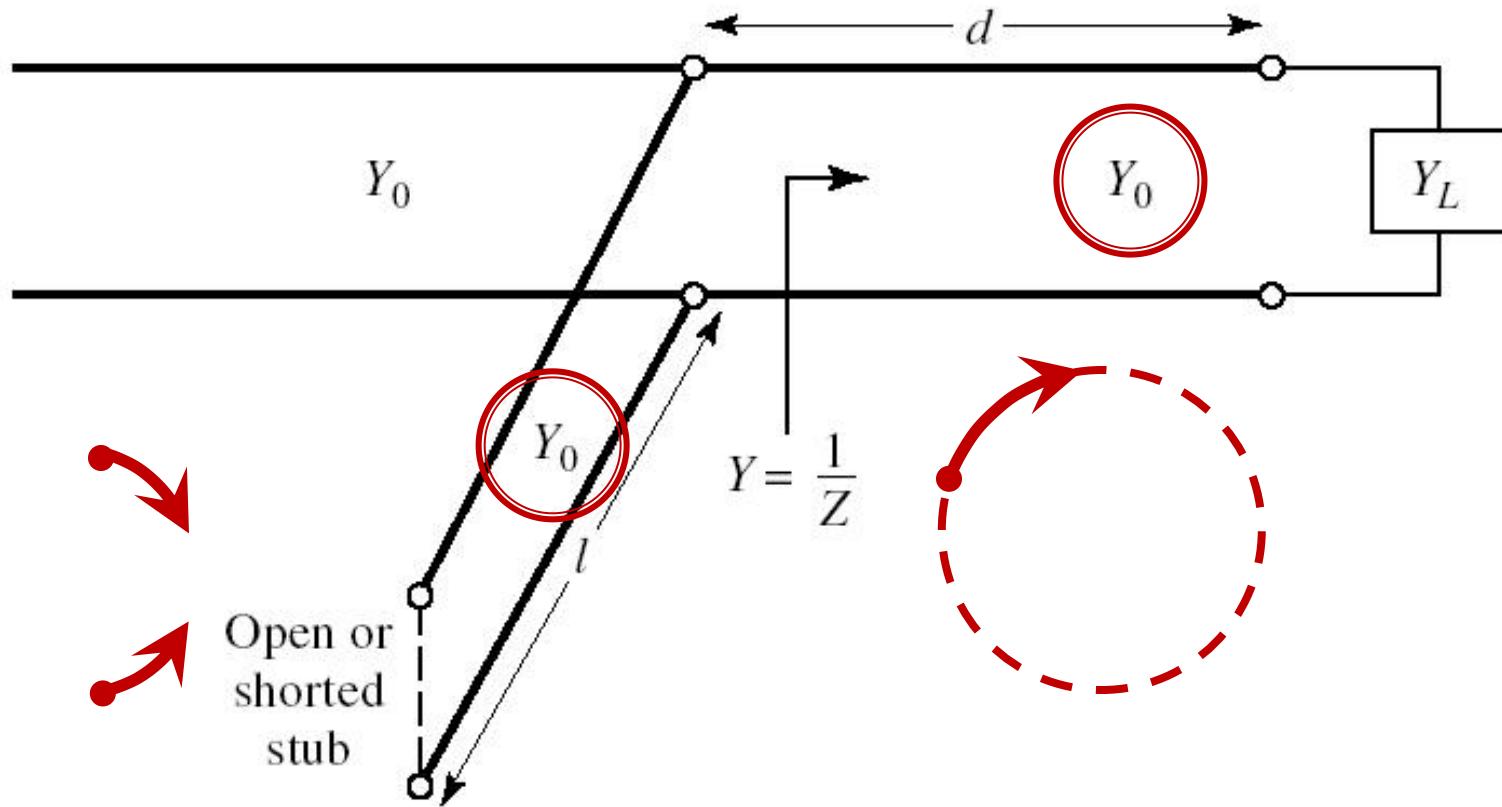


# Diagrama Smith, $r=1$ si $g=1$



# Caz 1, Shunt Stub

- Shunt Stub (secțiune de linie în paralel)



# Calcul analitic (calcul efectiv)

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

$$|\Gamma_S| = 0.593 \angle 46.85^\circ$$

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

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

- **Semnul (+/-) solutiei alese la ecuatia liniei serie impune semnul solutiei utilizate la ecuatia stub-ului paralel**

- **solutia "cu +"**

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

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

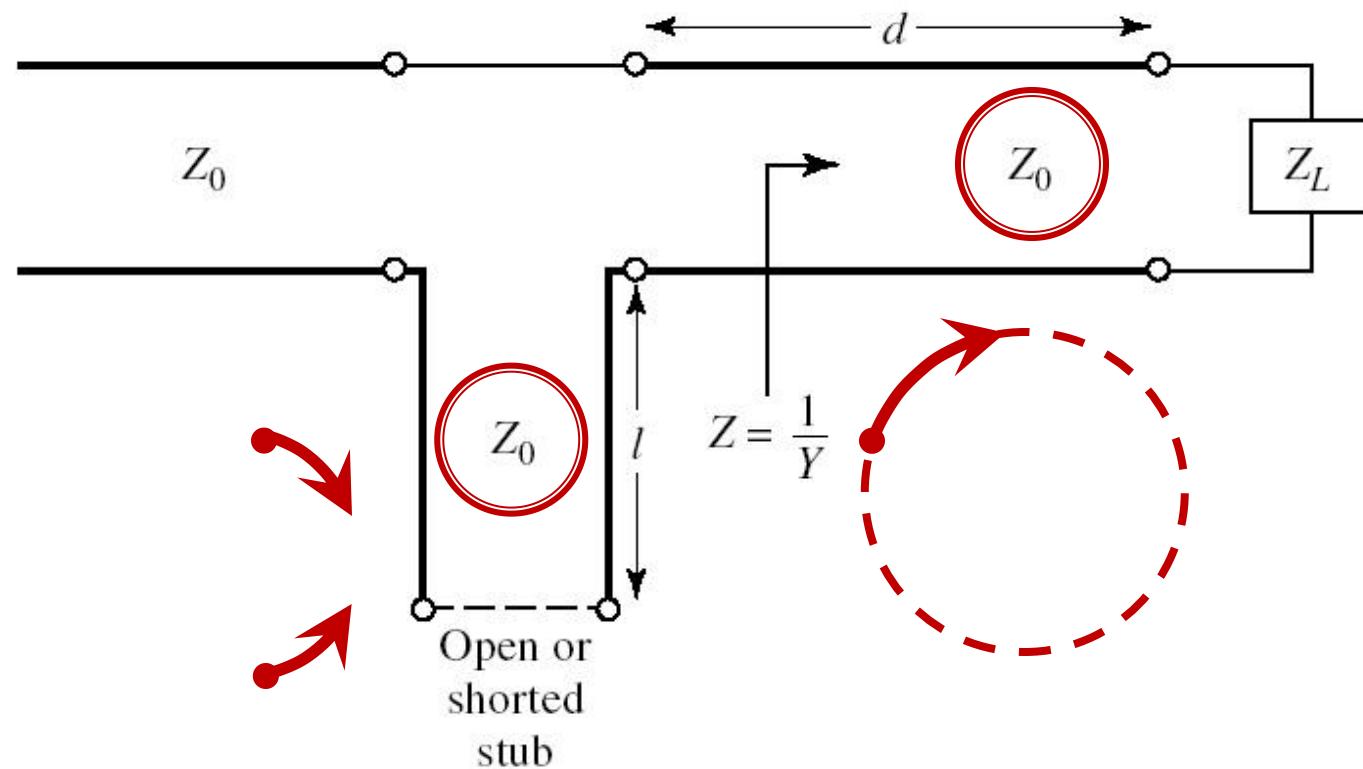
- **solutia "cu -"**

$$(46.85^\circ + 2\theta) = -126.35^\circ \quad \theta = -86.6^\circ (+180^\circ) \rightarrow \theta = 93.4^\circ$$

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

# Caz 2, Series Stub

- Series Stub (secțiune de linie în serie)
- tehnologic mai dificil de realizat la liniile monofilare (microstrip)



# Calcul analitic (calcul efectiv)

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

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

$$|\Gamma_s| = 0.555 \angle -29.92^\circ$$

$$|\Gamma_s| = 0.555; \quad \varphi = -29.92^\circ \quad \cos(\varphi + 2\theta) = 0.555 \Rightarrow (\varphi + 2\theta) = \pm 56.28^\circ$$

- **Semnul (+/-) solutiei alese la ecuatia liniei serie impune semnul solutiei utilizate la ecuatia stub-ului serie**

- **solutia "cu +"**

$$(-29.92^\circ + 2\theta) = +56.28^\circ \quad \theta = 43.1^\circ \quad \text{Im } z_s = \frac{+2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}} = +1.335$$

$$\theta_{ss} = -\cot^{-1}(\text{Im } z_s) = -36.8^\circ (+180^\circ) \rightarrow \theta_{ss} = 143.2^\circ$$

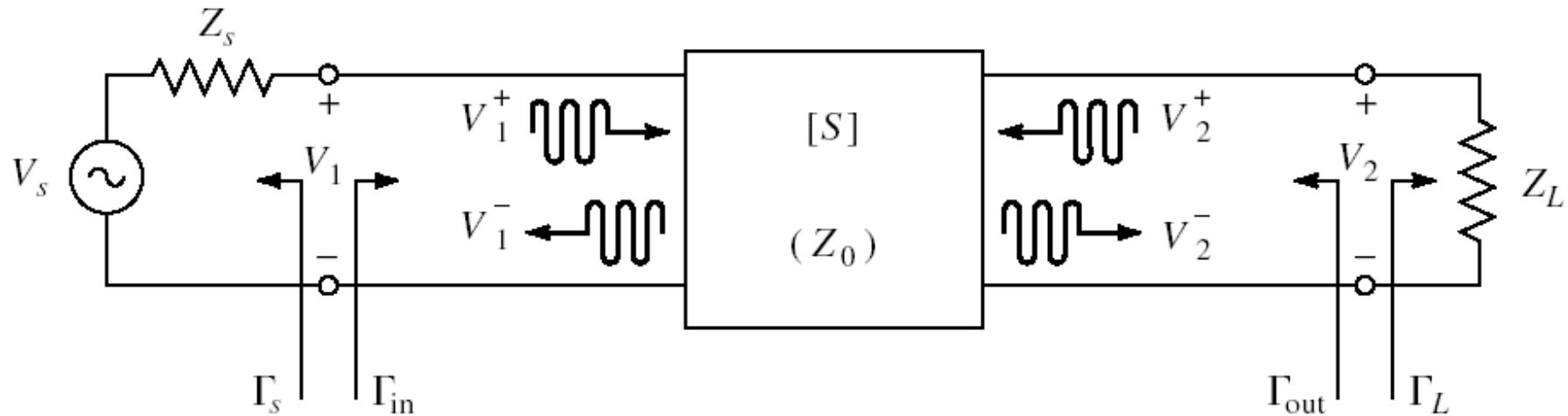
- **solutia "cu -"**

$$(-29.92^\circ + 2\theta) = -56.28^\circ \quad \theta = -13.2^\circ (+180^\circ) \rightarrow \theta = 166.8^\circ$$

$$\text{Im } z_s = \frac{-2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}} = -1.335 \quad \theta_{ss} = -\cot^{-1}(\text{Im } z_s) = 36.8^\circ$$

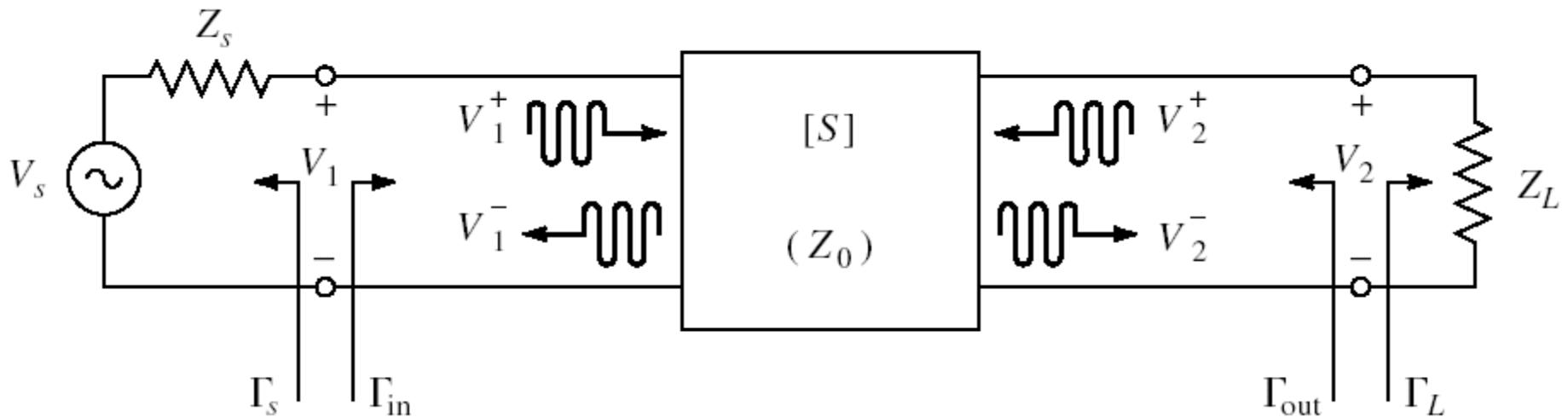
# **Amplificatoare de microunde**

# Cuadripol Amplificator (diport)



- Caracterizare cu parametri S
- Normalizati la  $Z_0$  (implicit  $50\Omega$ )
- Catalogage: parametri S pentru anumite polarizari

# Dipole amplifier

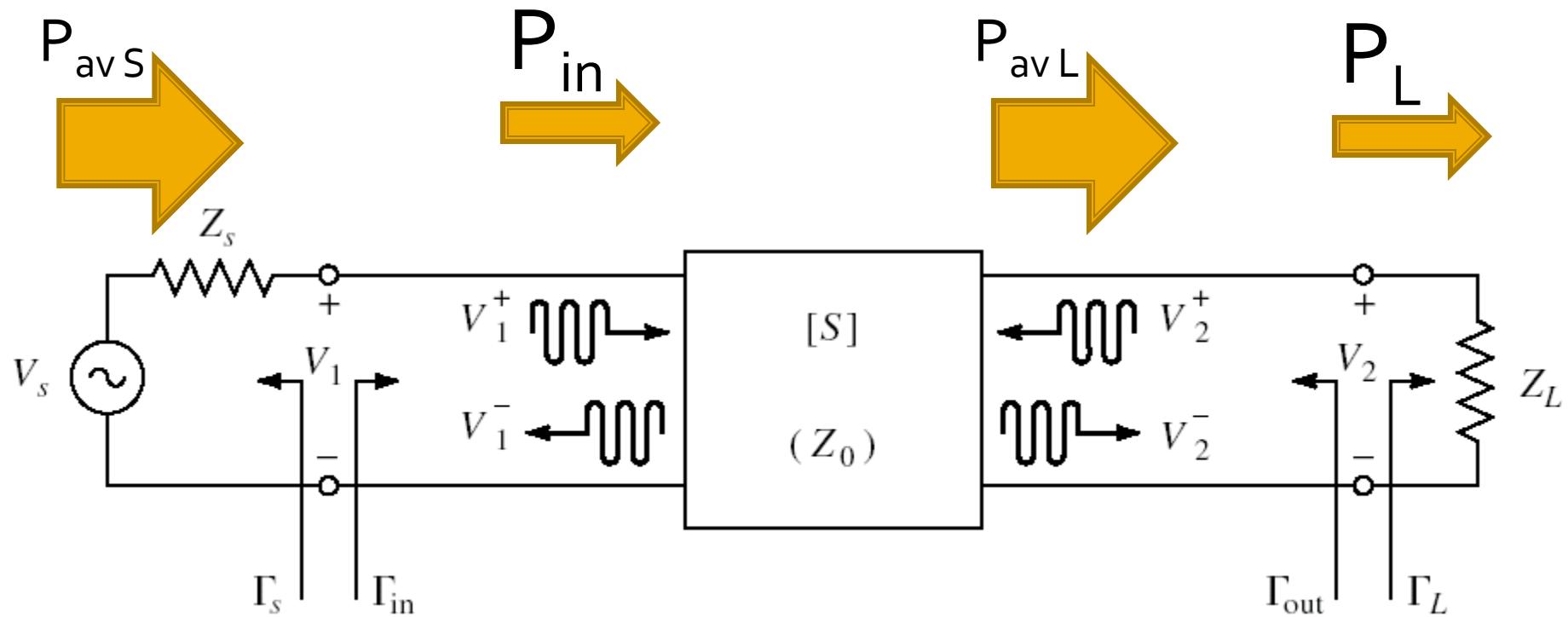


$$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_L}{1 - S_{22} \cdot \Gamma_L}$$

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

# Puteri / Adaptare

- Doua porturi in care adaptarea influenteaza transferul de putere



# Castig de putere

## ■ Castigul de putere **disponibil**

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

## ■ Castigul de putere de **transfer** (transducer power gain)

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

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

## ■ Castigul de putere de **transfer unilateral**

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

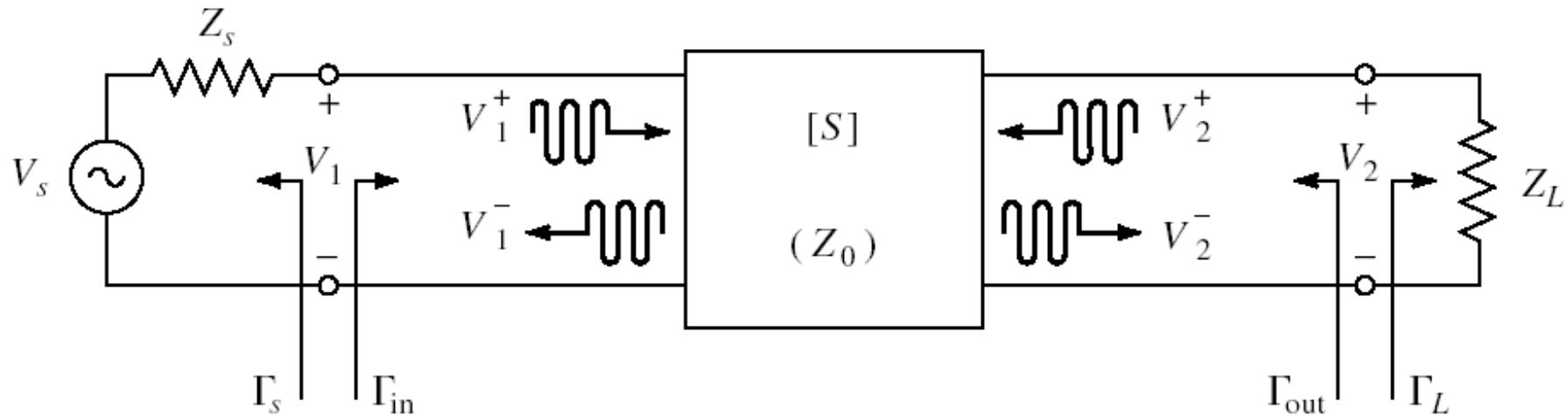
$$S_{12} \cong 0 \quad \Gamma_{in} = S_{11}$$

Permite tratarea separata  
a intrarii si iesirii

Stabilitate

# Amplificatoare de microunde

# Cuadripol Amplifier



- marimi care intereseaza:
  - **stabilitate**
  - castig de putere
  - zgomot (uneori – semnal mic)
  - liniaritate (uneori – semnal mare)

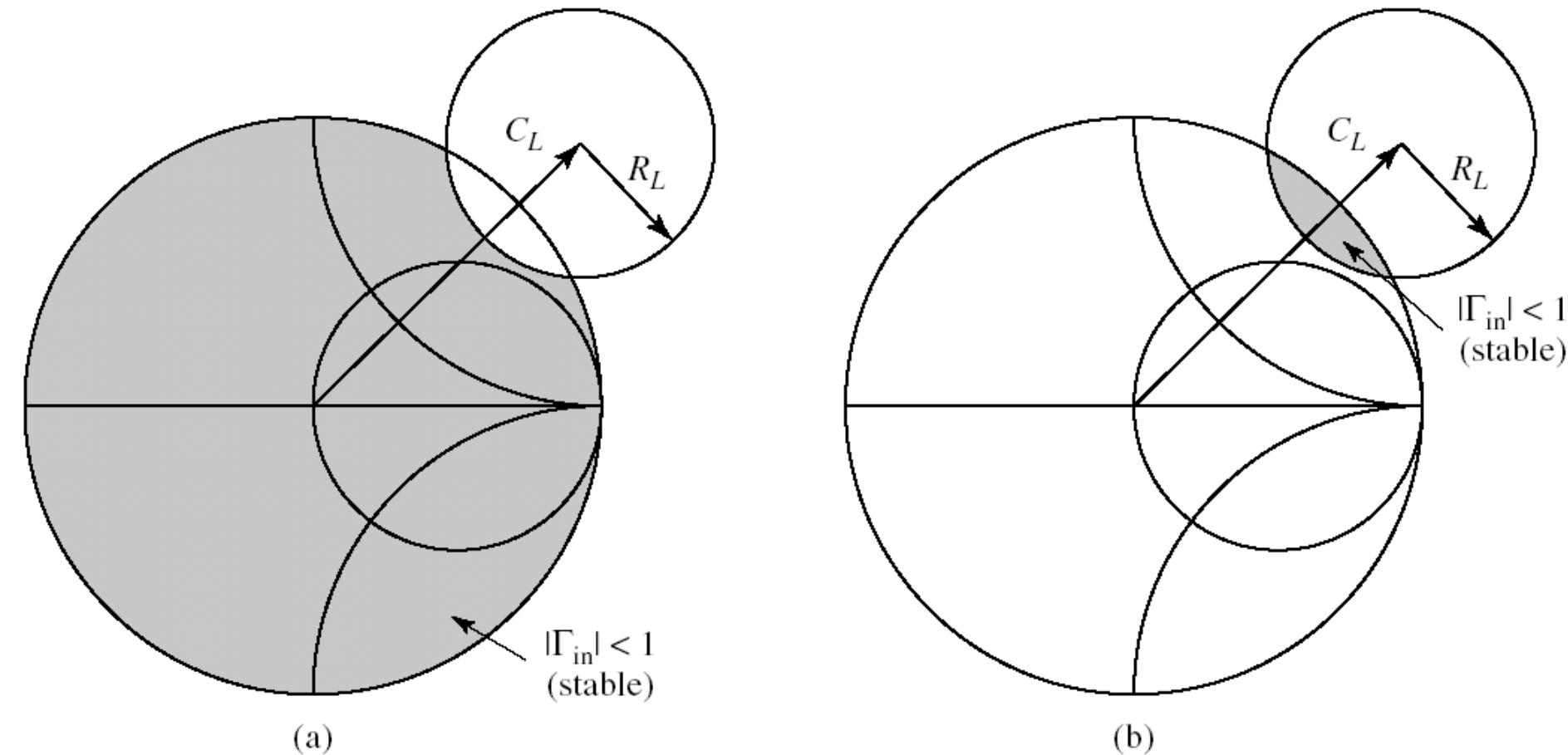
# Cerc de stabilitate la ieșire (CSOUT)

$$\left| \Gamma_L - \frac{(S_{22} - \Delta \cdot S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2} \right| = \left| \frac{S_{12} \cdot S_{21}}{|S_{22}|^2 - |\Delta|^2} \right| \quad |\Gamma_L - C_L| = R_L$$

- Ecuatia unui cerc, care reprezinta locul geometric al punctelor  $\Gamma_L$  pentru **limita** de stabilitate
- Cercul se numeste **cerc de stabilitate la ieșire** ( $\Gamma_L$ )

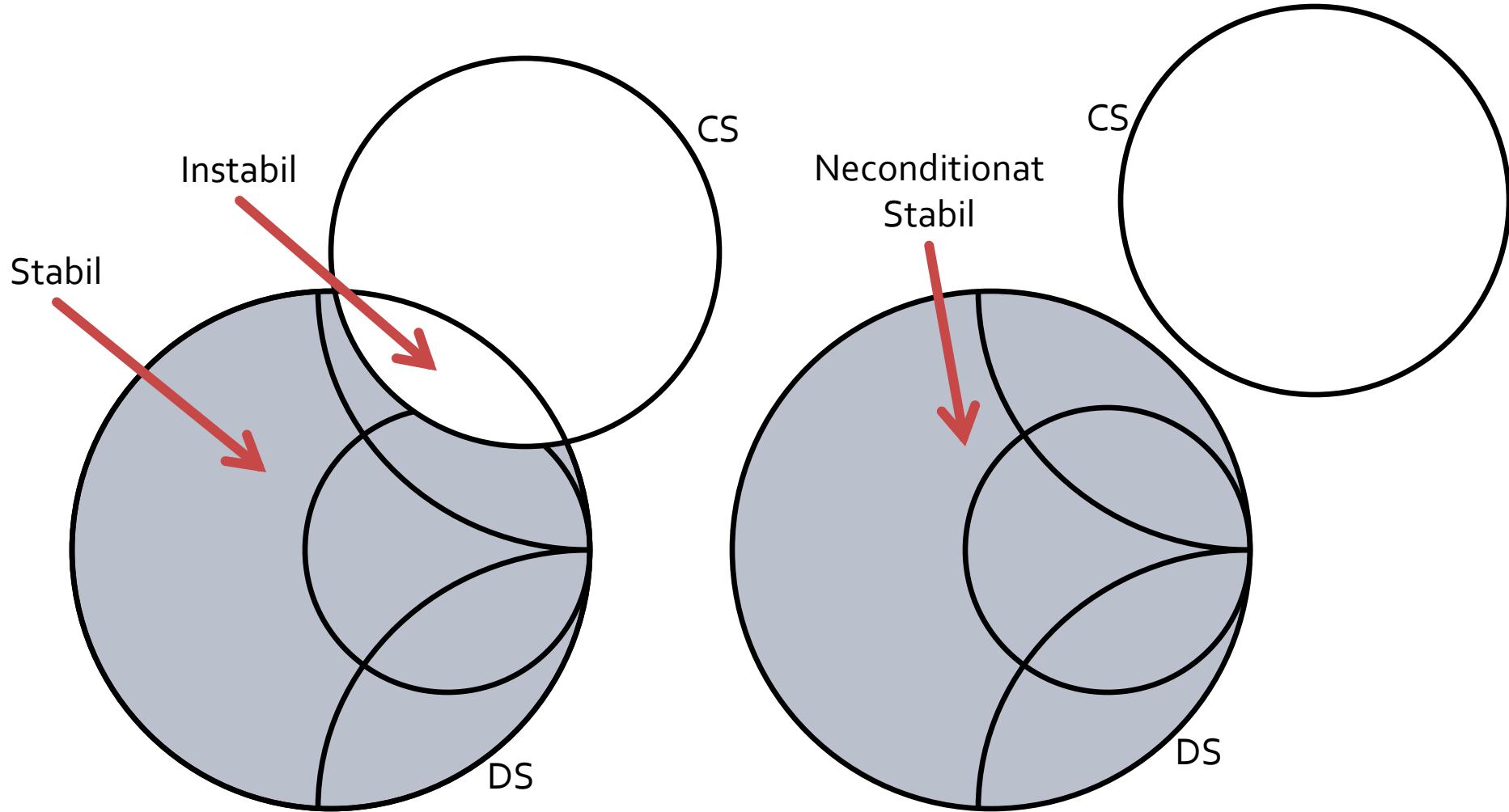
$$C_L = \frac{(S_{22} - \Delta \cdot S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2} \quad R_L = \frac{|S_{12} \cdot S_{21}|}{|S_{22}|^2 - |\Delta|^2}$$

# Cerc de stabilitate la ieșire (CSOUT)

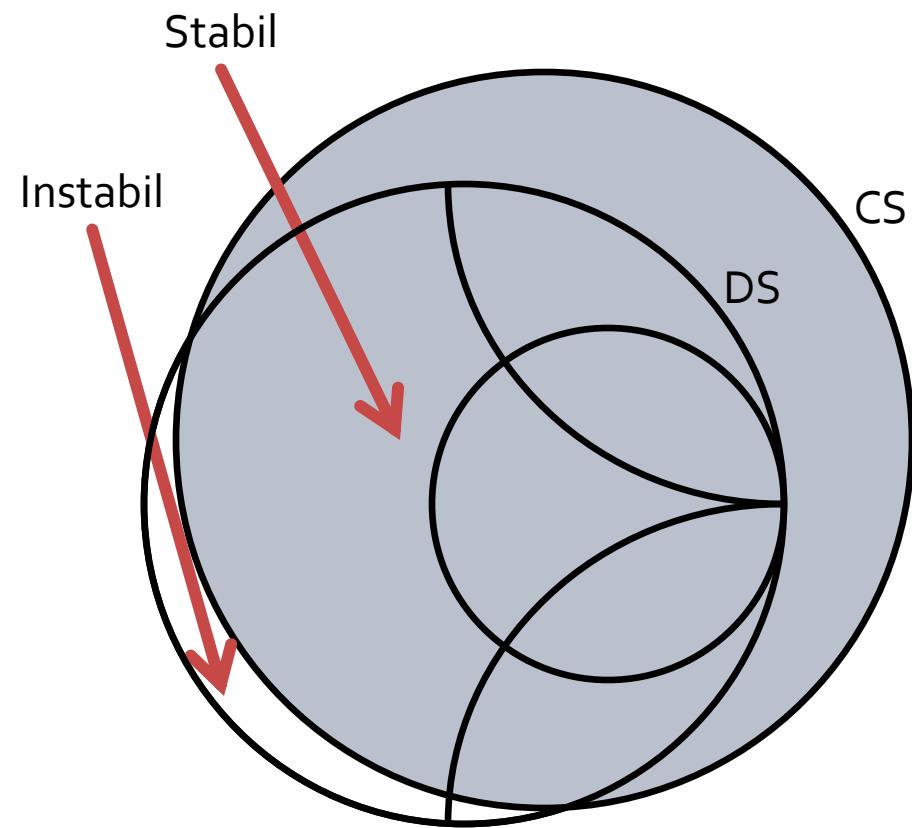


- Doua cazuri: (a) exterior stabil / (b) interior stabil

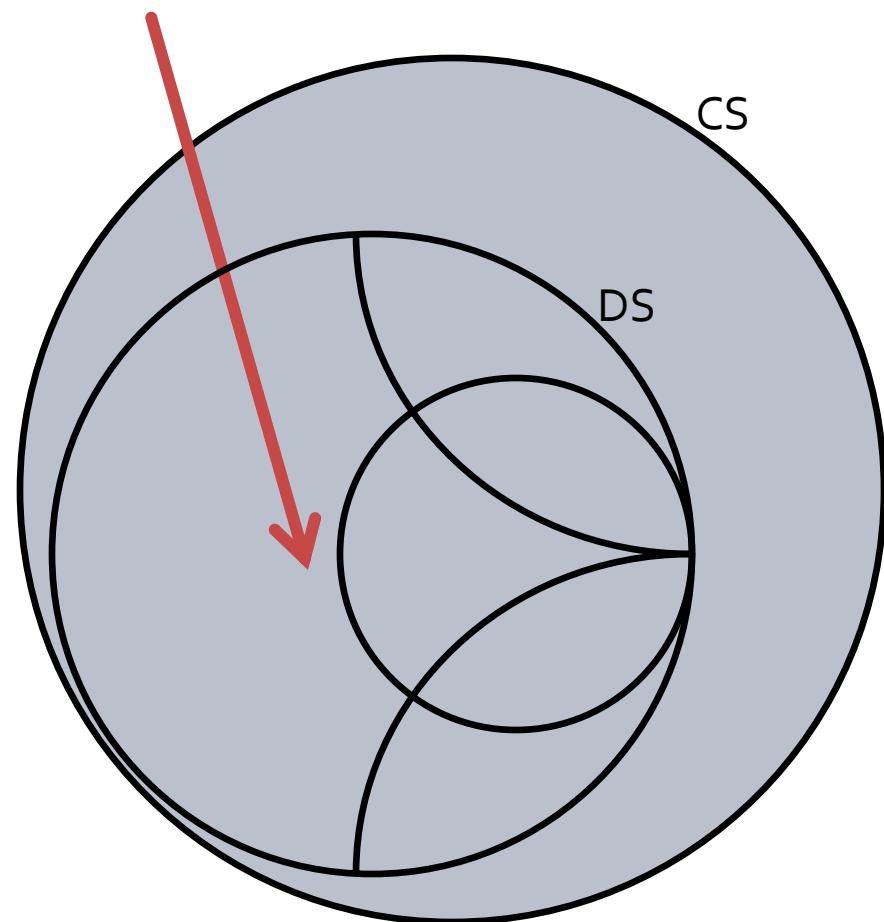
# Mai multe pozitionari posibile



# Mai multe pozitionari posibile



Neconditionat  
Stabil



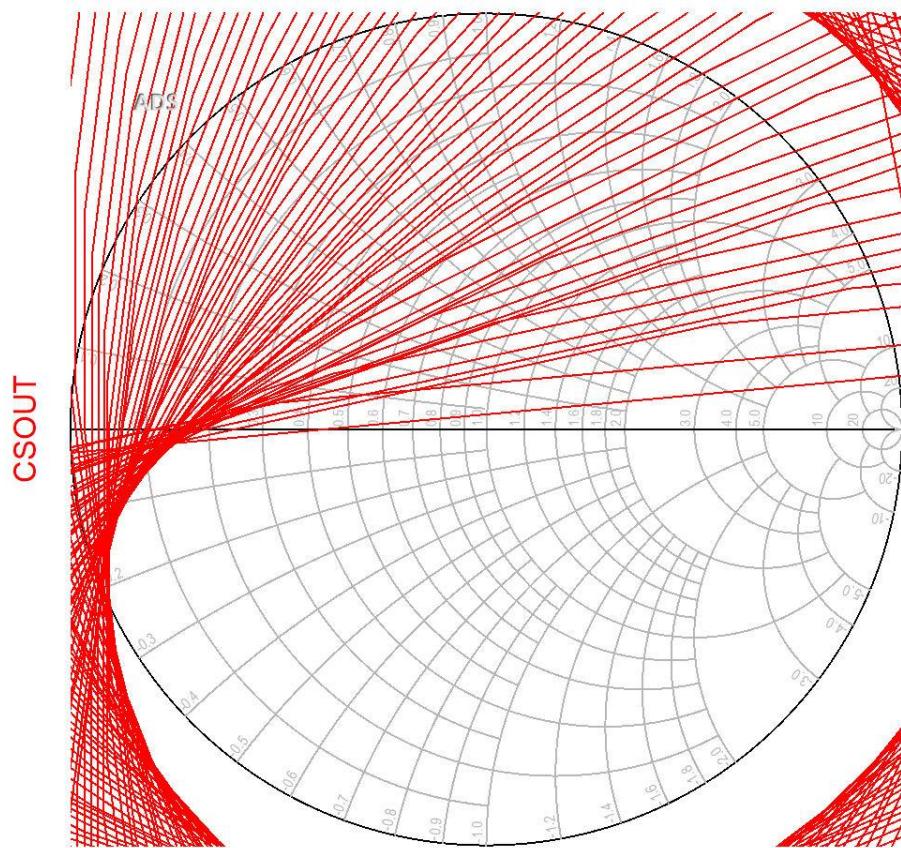
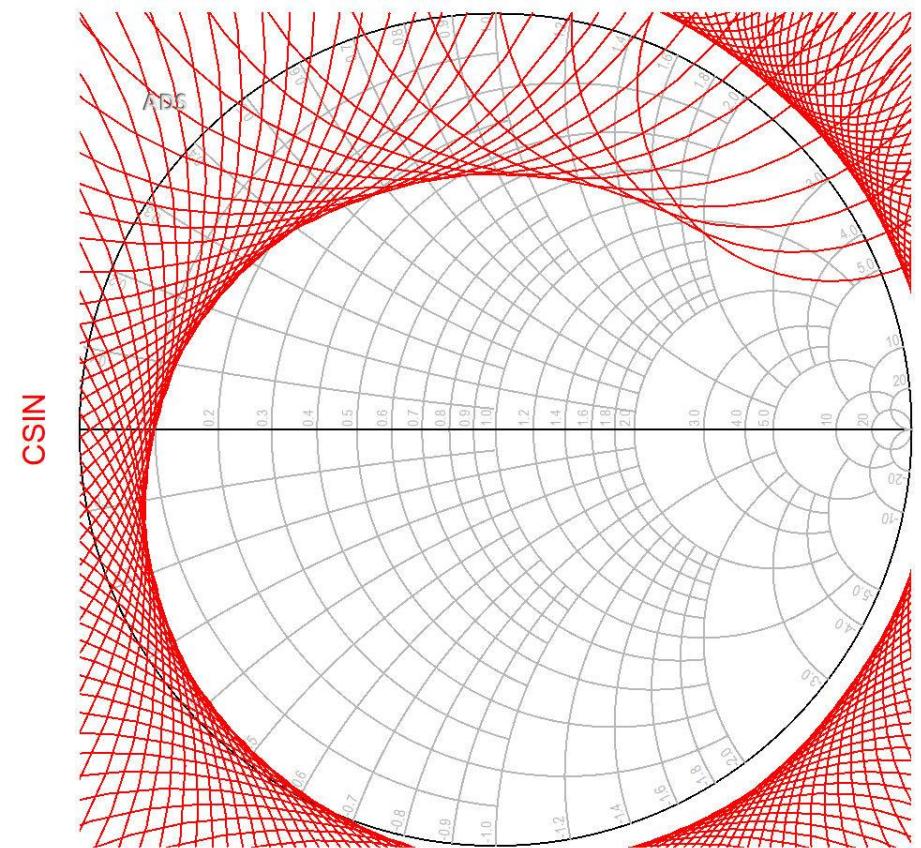
# Stabilitate

- **Stabilitatea necondiționată:** circuitul este necondiționat stabil dacă  $|\Gamma_{in}| < 1$  și  $|\Gamma_{out}| < 1$  pentru **orice** impedanță pasivă a sarcinii și sursei
- **Stabilitatea condiționată:** circuitul este condiționat stabil dacă  $|\Gamma_{in}| < 1$  și  $|\Gamma_{out}| < 1$  doar pentru un anumit interval de valori pentru impedanța pasivă a sarcinii și sursei

# Conditii analitice de stabilitate neconditionata

- Utile pentru analiza de banda larga
- Stabilitatea nu e suficient sa fie apreciata doar la frecventele de lucru
  - e necesar sa avem stabilitate pentru  $\Gamma_L$  si  $\Gamma_S$  alese la **orice** frecventa

# Cercuri in banda larga



# Conditia Rollet

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2 \cdot |S_{12} \cdot S_{21}|}$$
$$\Delta = S_{11} \cdot S_{22} - S_{12} \cdot S_{21}$$

- Diportul este **neconditionat stabil** daca:
  - Sunt indeplinite simultan conditiile
    - $K > 1$
    - $|\Delta| < 1$
  - Sunt valabile si conditiile implice
    - $|S_{11}| < 1$
    - $|S_{22}| < 1$

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2 \cdot |S_{12} \cdot S_{21}|} > 1$$
$$|\Delta| = |S_{11} \cdot S_{22} - S_{12} \cdot S_{21}| < 1$$

# Criteriul $\mu$

- Conditia Rollet depinde de doi parametri,  $K$  si  $\Delta$ , si nu poate fi utilizata pentru compararea stabilitatii a doua scheme

$$\mu = \frac{1 - |S_{11}|^2}{|S_{22} - \Delta \cdot S_{11}^*| + |S_{12} \cdot S_{21}|} > 1$$

- Diportul este **neconditionat stabil** daca:
  - $\mu > 1$
- Sunt valabile si conditiile implicite
  - $|S_{11}| < 1$
  - $|S_{22}| < 1$
- In plus se poate spune ca daca  $\mu$  creste se obtine stabilitate mai buna
  - $\mu$  este distanta de la centrul diagramei Smith la cercul de stabilitate la iesire

# Criteriul $\mu'$

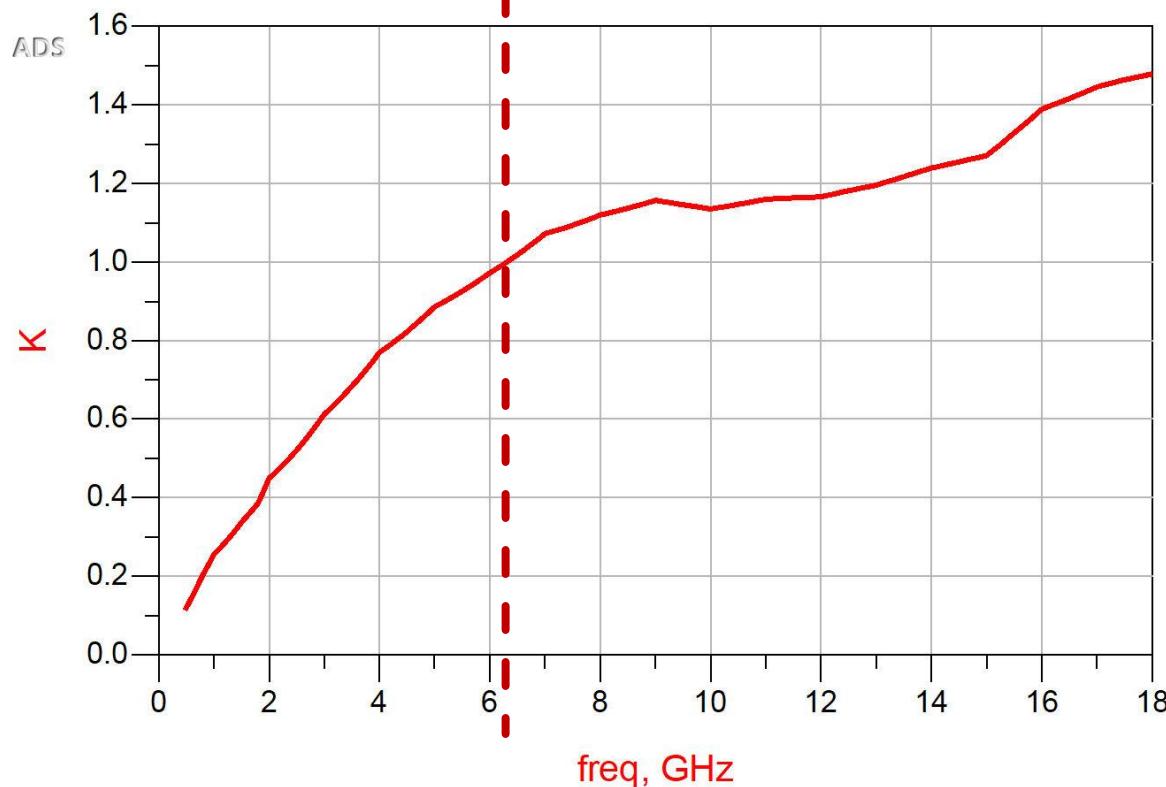
- Parametru dual pentru  $\mu$ , determinat relativ la cercul de stabilitate la intrare

$$\mu' = \frac{1 - |S_{22}|^2}{|S_{11} - \Delta \cdot S_{22}^*| + |S_{12} \cdot S_{21}|} > 1$$

- Diportul este **neconditionat stabil** daca:
  - $\mu' > 1$
- Sunt valabile si conditiile implice
  - $|S_{11}| < 1$
  - $|S_{22}| < 1$
- In plus se poate spune ca daca  $\mu'$  creste se obtine stabilitate mai buna
  - $\mu'$  este distanta de la centrul diagramei Smith la cercul de stabilitate la intrare

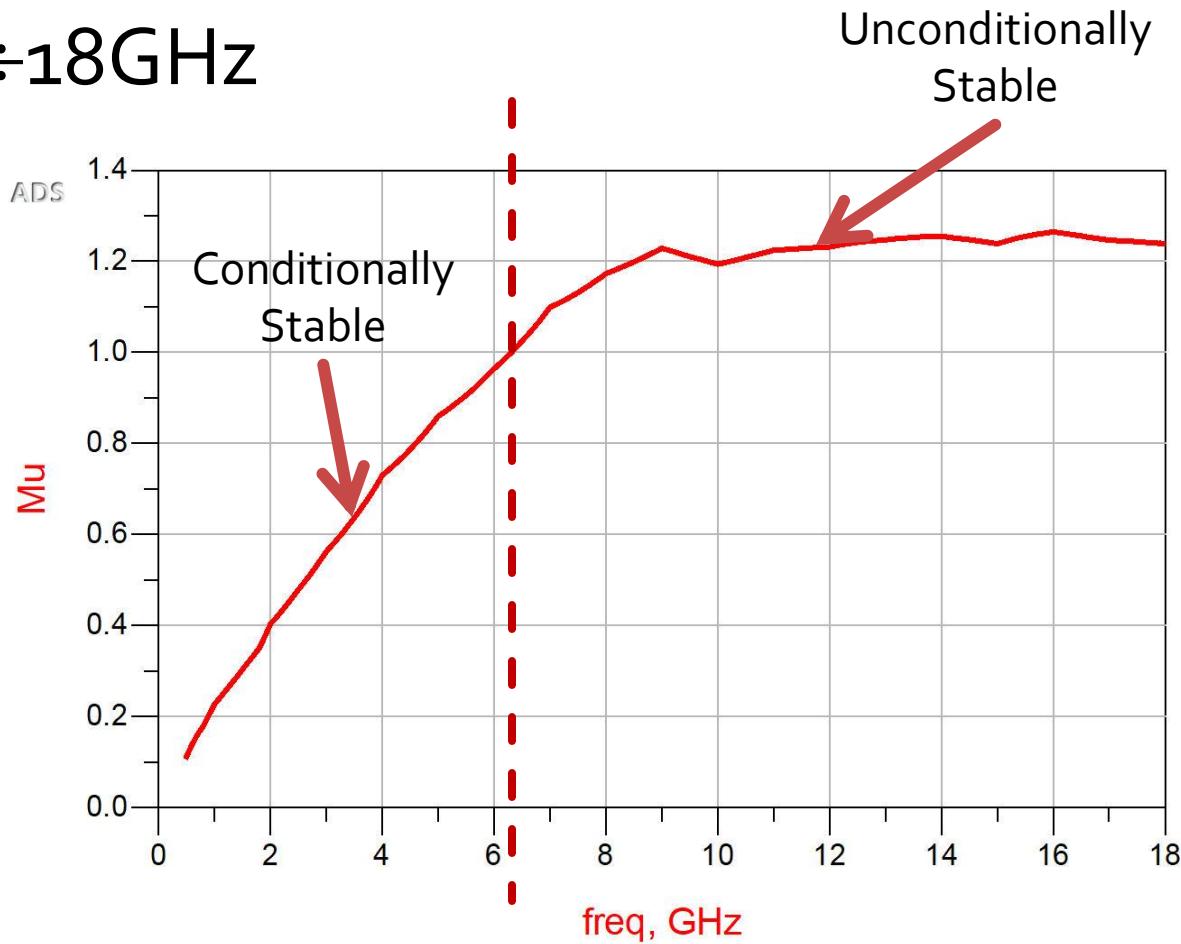
# Conditia Rollet

- ATF-34143 at  $V_{ds}=3V$   $I_d=20mA$ .
- @ $0.5 \div 18GHz$



# Criteriul $\mu$

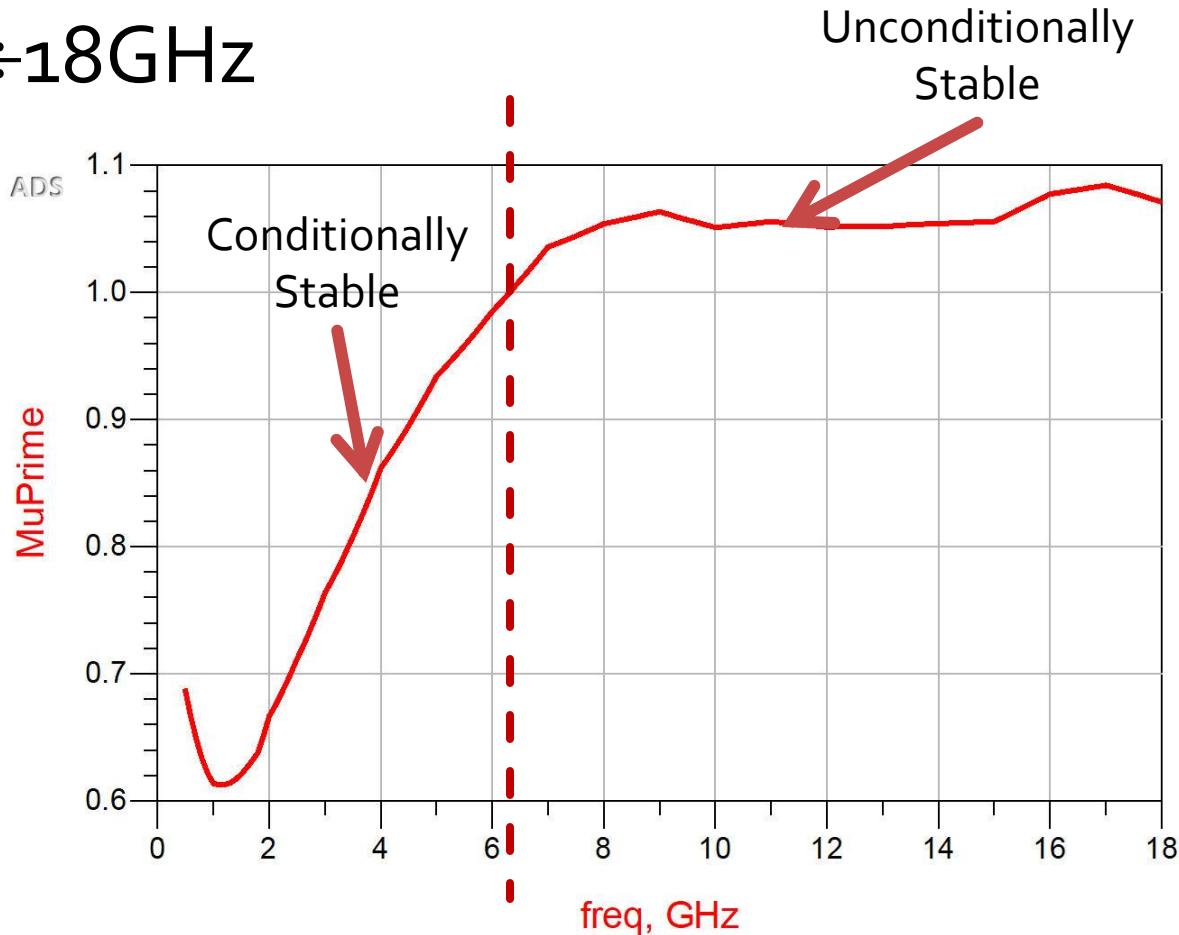
- ATF-34143 at  $V_{ds}=3V$   $I_d=20mA$ .
- @ $0.5 \div 18GHz$



# Criteriul $\mu'$

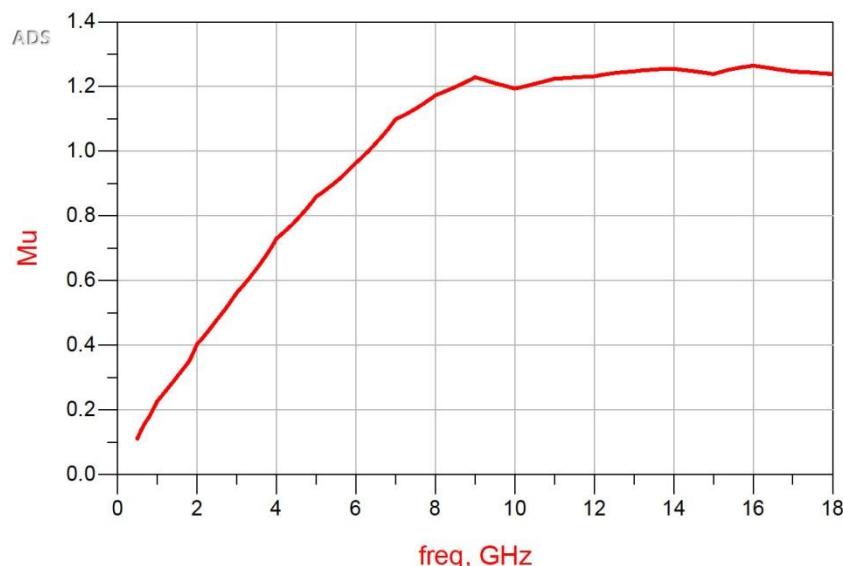
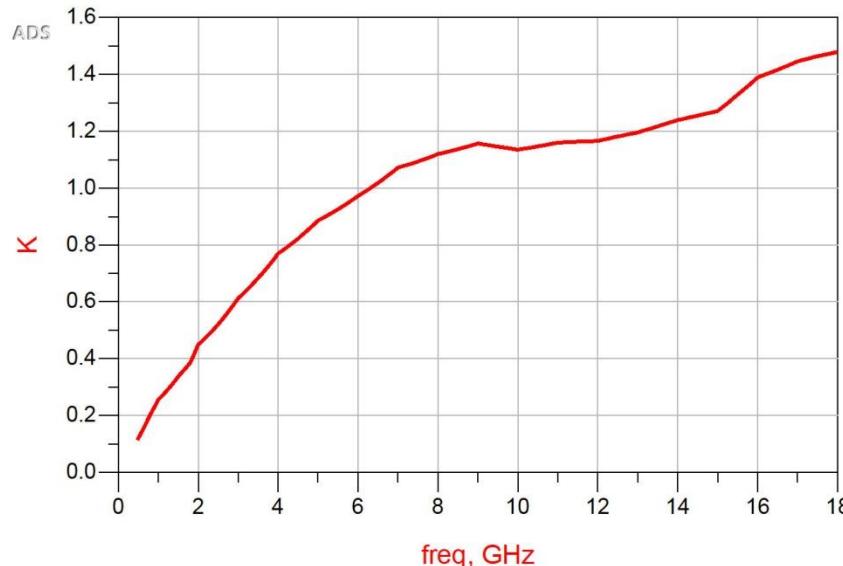
- ATF-34143 at  $V_{ds}=3V$   $I_d=20mA$ .

- @ $0.5 \div 18GHz$



# Stabilitate

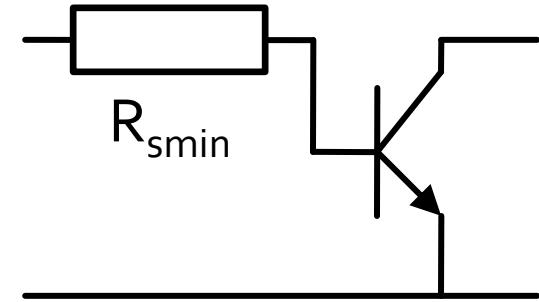
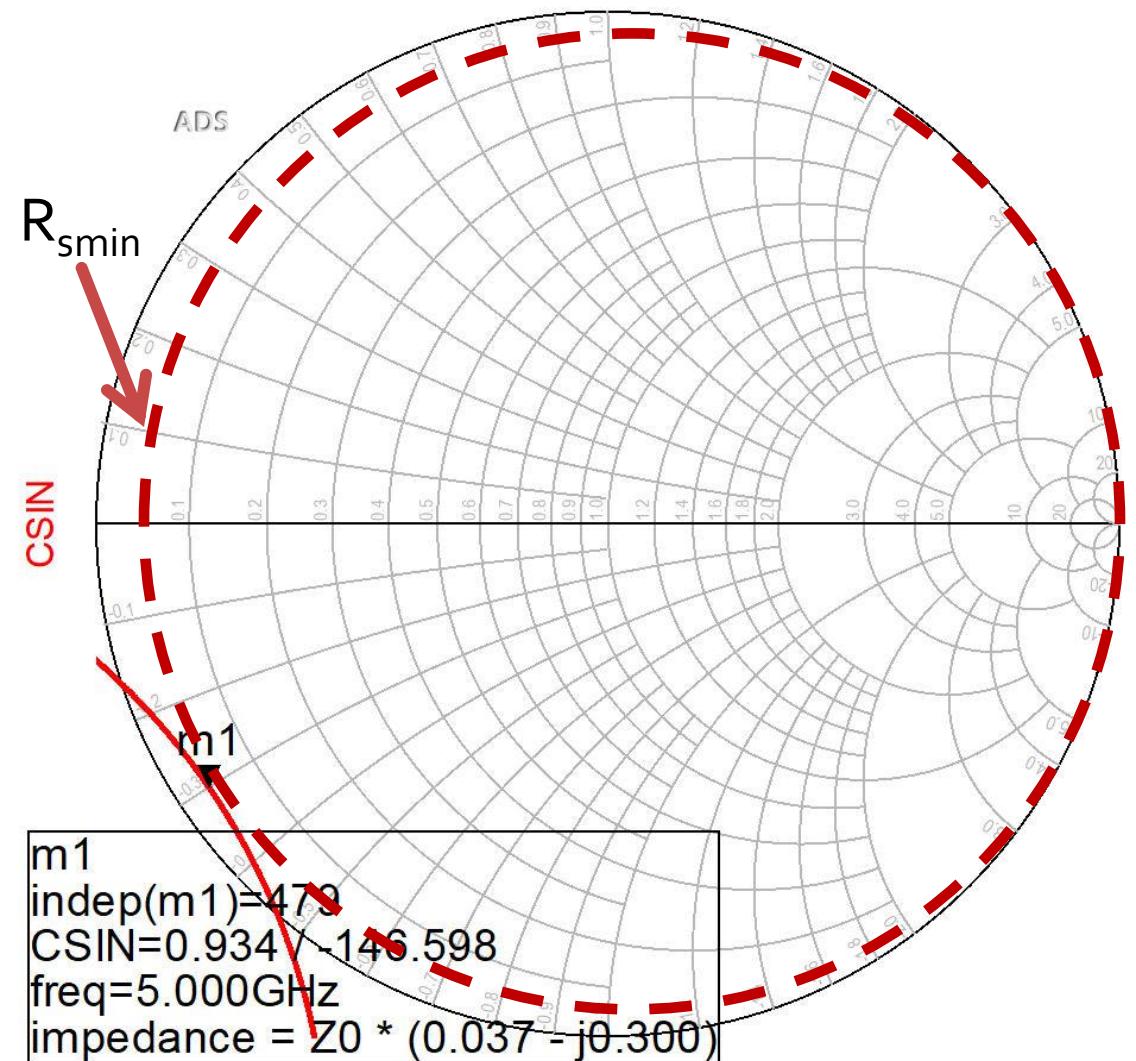
- ATF-34143 at  $V_{ds}=3V$   $I_d=20mA$ .
- @ $0.5 \div 18GHz$
- Neconditionat stabil pentru  $f > 6.31GHz$



# Stabilizarea unui dipozit

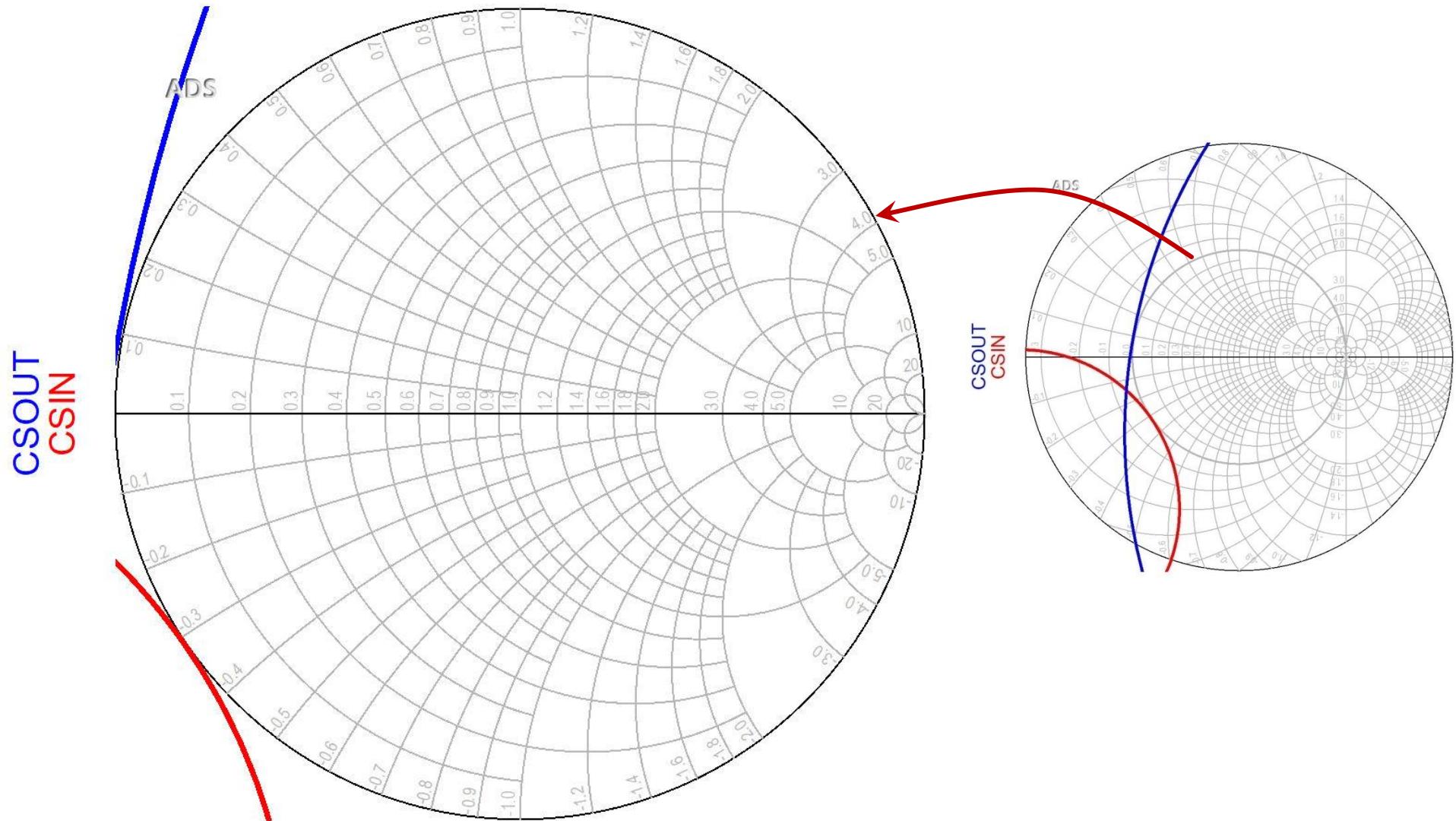
- Stabilitatea neconditionata pentru un interval larg de frecvente are avantaje importante
  - Ex: pot projecata cu ATF 34143 un amplificator stabil (conditionat) la 5GHz, dar acest lucru este inutil daca apar oscilatii la 500MHz ( $\mu \approx 0.1$ )
  - **Minimul necesar** in conditii de lucru cu stabilitate conditionata este **sa se verifice stabilitatea** la frecvente inafara benzii
- Stabilitatea neconditionata poate fi fortata prin introducerea de elemente rezistive in serie/paralel la intrare si/sau iesire

# Rezistenta serie la intrare



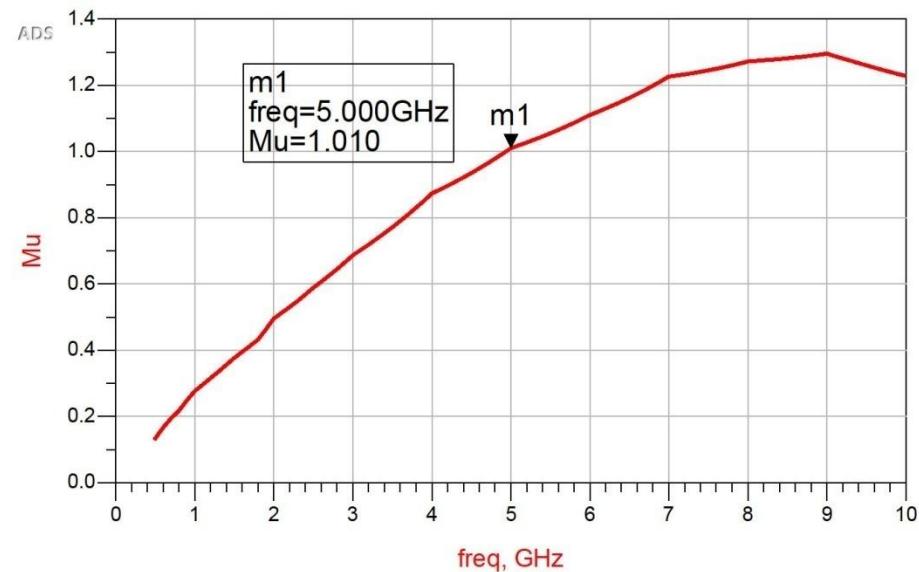
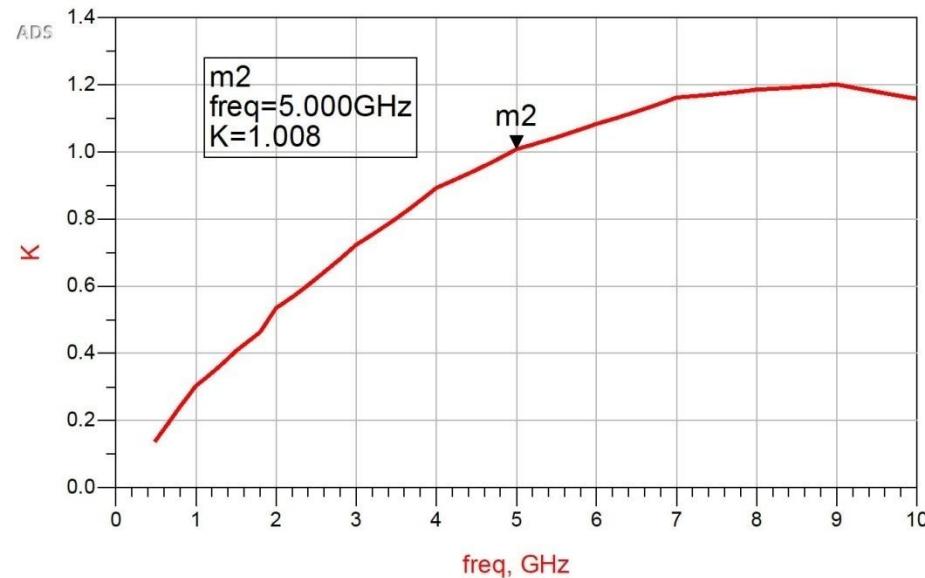
$$R_{smin} = 0.037 \cdot 50\Omega = 1.85\Omega$$

# ADS, $R_s = 2\Omega$

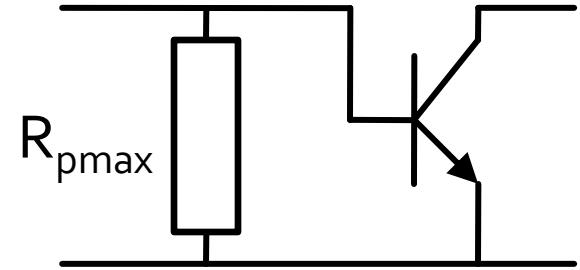
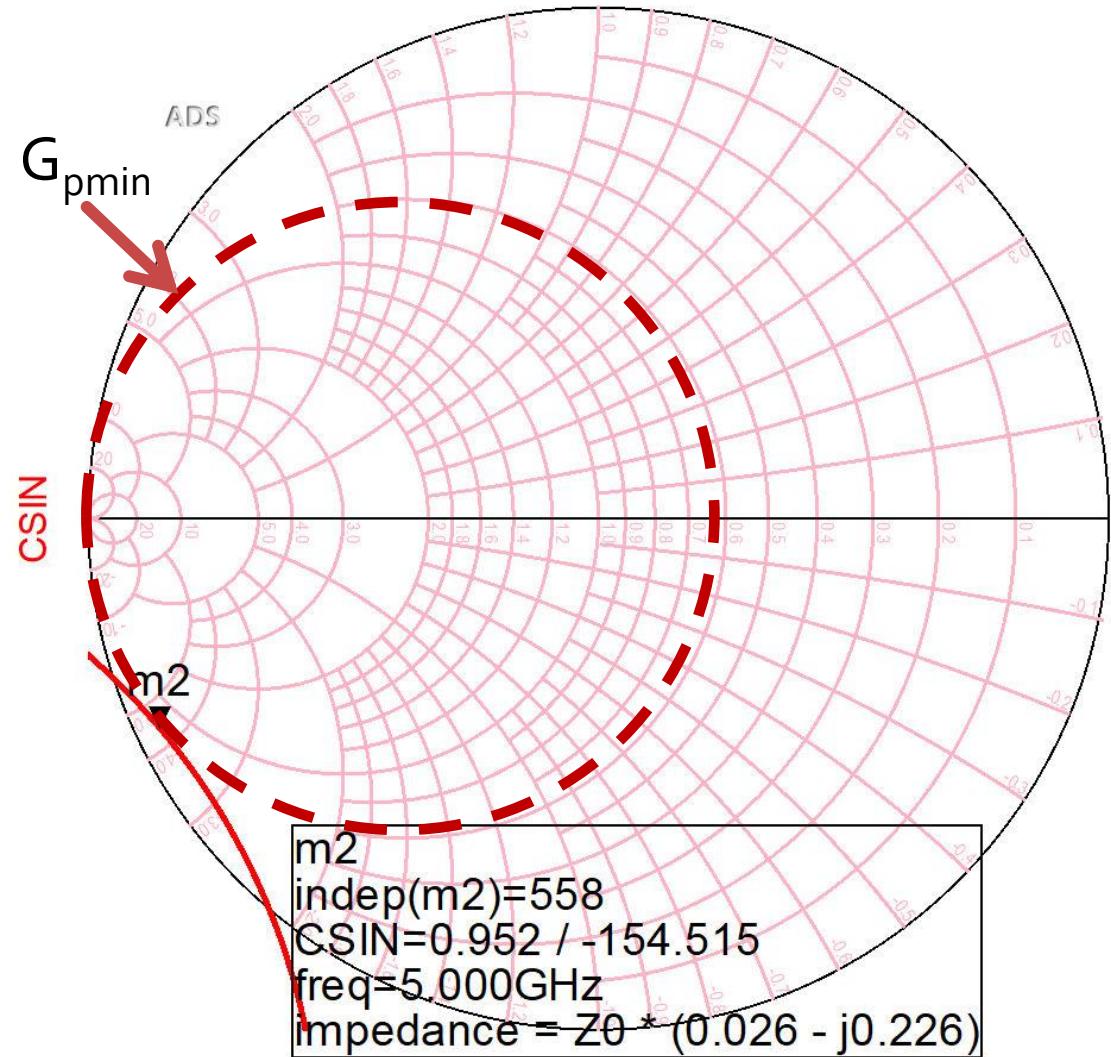


# Rezistenta serie la intrare

- $R_s = 2\Omega$
- $K = 1.008$ , MAG = 13.694dB @ 5GHz
  - fara stabilizare,  $K = 0.886$ , MAG = 14.248dB @ 5GHz



# Rezistenta paralel la intrare



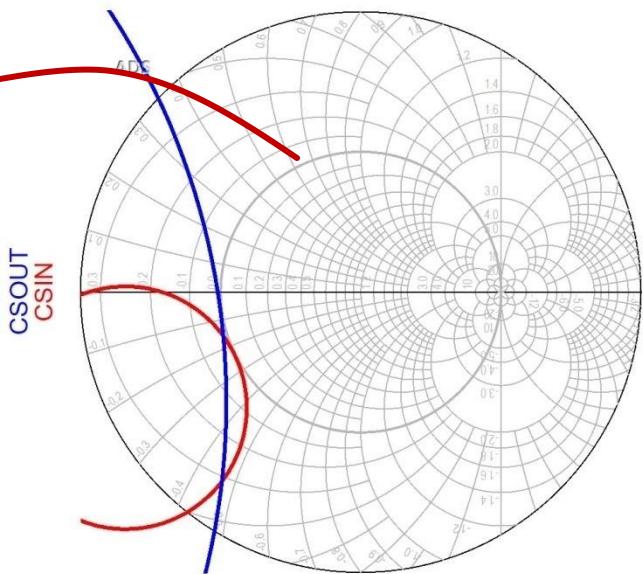
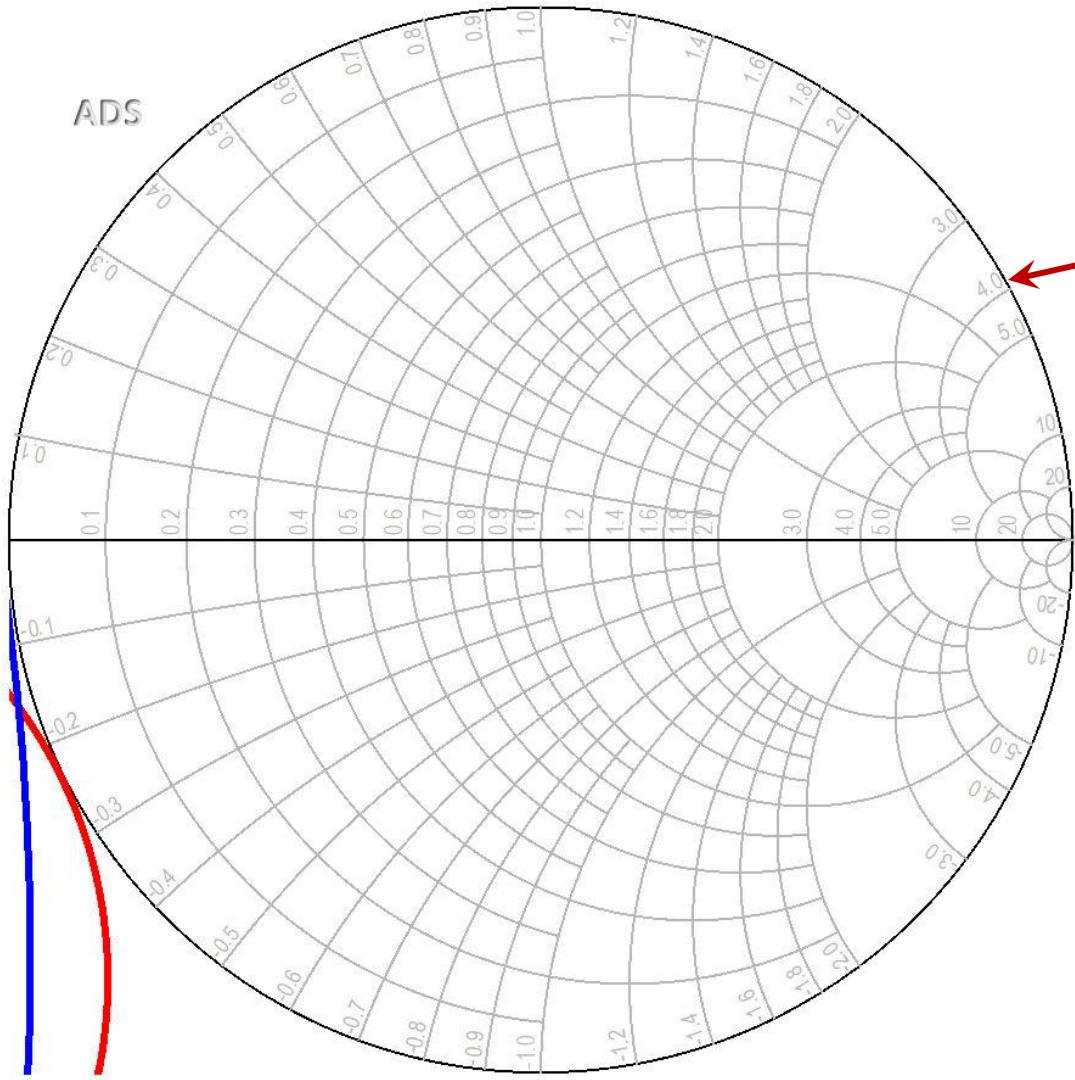
$$R_{pmax} = \frac{1}{G_{pmin}}$$

$$\frac{1}{0.026 - j \cdot 0.226} = 0.502 + j \cdot 4.367$$

$$R_{pmax} = \frac{50\Omega}{0.502} = 99.6\Omega$$

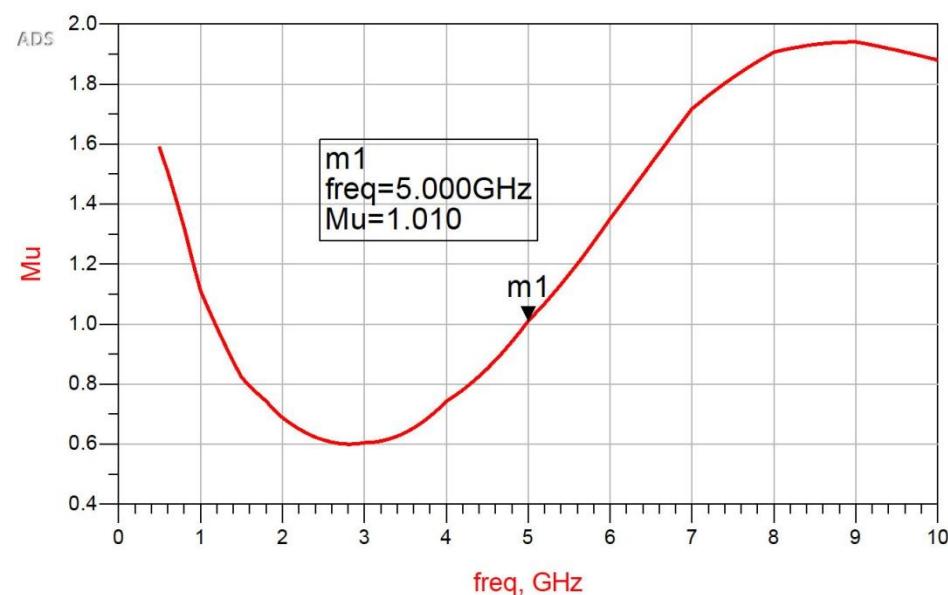
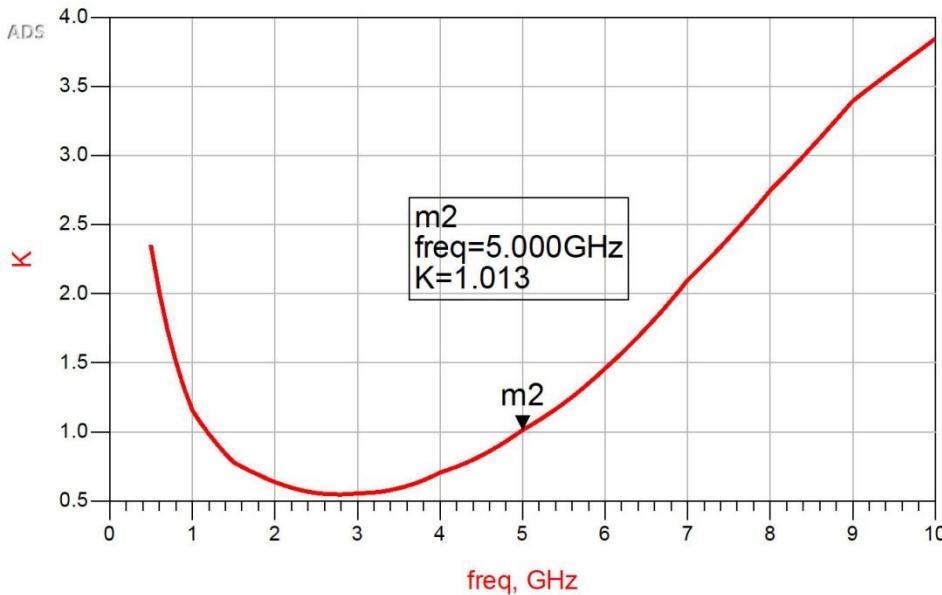
# ADS, $R_p = 90\Omega$

CSOUT  
CSIN



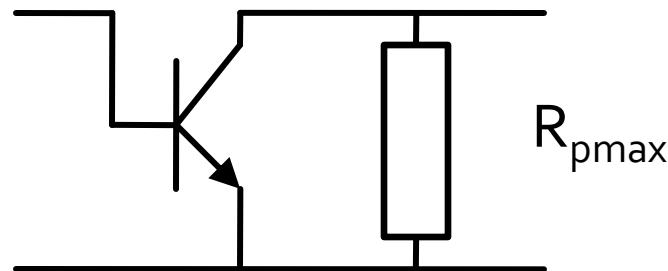
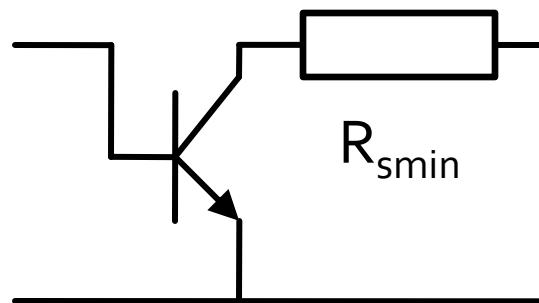
# Rezistenta paralel la intrare

- $R_p = 90\Omega$
- $K = 1.013$ , MAG = 13.561dB @ 5GHz
  - fara stabilizare,  $K = 0.886$ , MAG = 14.248dB @ 5GHz



# Rezistenta serie/paralel la iesire

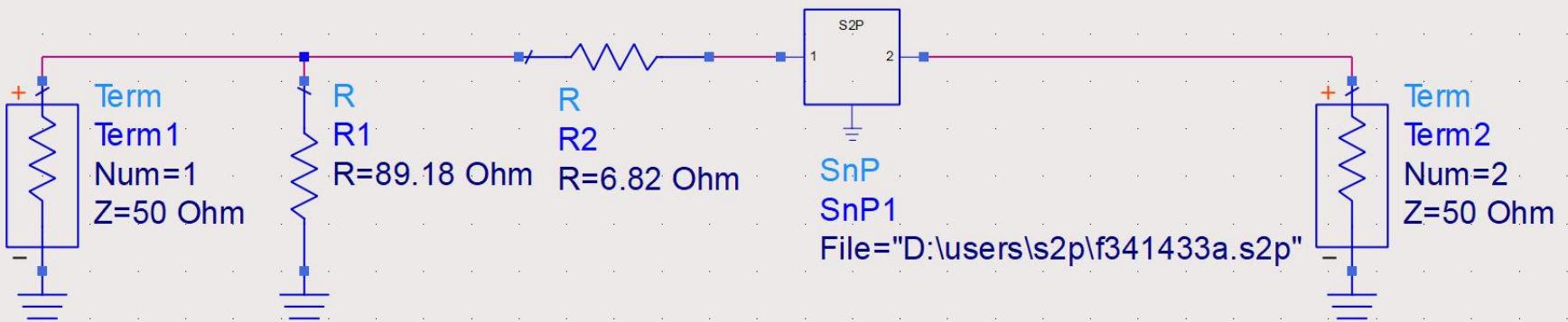
- Procedura se poate aplica similar la iesire (plecand de la CSOUT)
- Din exemplele anterioare, incarcarea rezistiva la intrare are efect pozitiv si asupra stabilitatii la iesire si viceversa (incarcare la iesire efect asupra stabilitatii la intrare)



# Stabilizarea unui dipozit

- Efect negativ asupra castigului
  - trebuie urmarit MAG/MSG in timpul proiectarii
- Efect negativ asupra zgomotului (<sup>va urma</sup>)
- Se poate alege una din cele 4 variante care ofera performante mai bune (in functie de aplicatie)
- Se pot realiza cu elemente de pasivizare selective in frecventa
  - Ex: Circuite RL, RC sacrificia performanta doar unde este necesar sa se imbunatateasca stabilitatea fara afectarea frecventelor la care dispozitivul e deja stabil
- E posibil ca aceste efecte sa apară automat ca urmare a elementelor parazite ale circuitelor de polarizare (capacitati de decuplare, socruri de radiofrecventa)

# Stabilizarea unui diport



**S-PARAMETERS**

**S\_Param**

**SP1**

**Start=0.5 GHz**

**Stop=10.0 GHz**

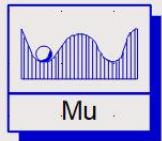
**Step=0.1 GHz**



**MaxGain**

**MAG**

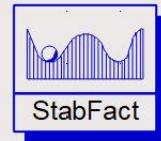
**MAG=max\_gain(S)**



**Mu**

**Mu1**

**Mu=mu(S)**

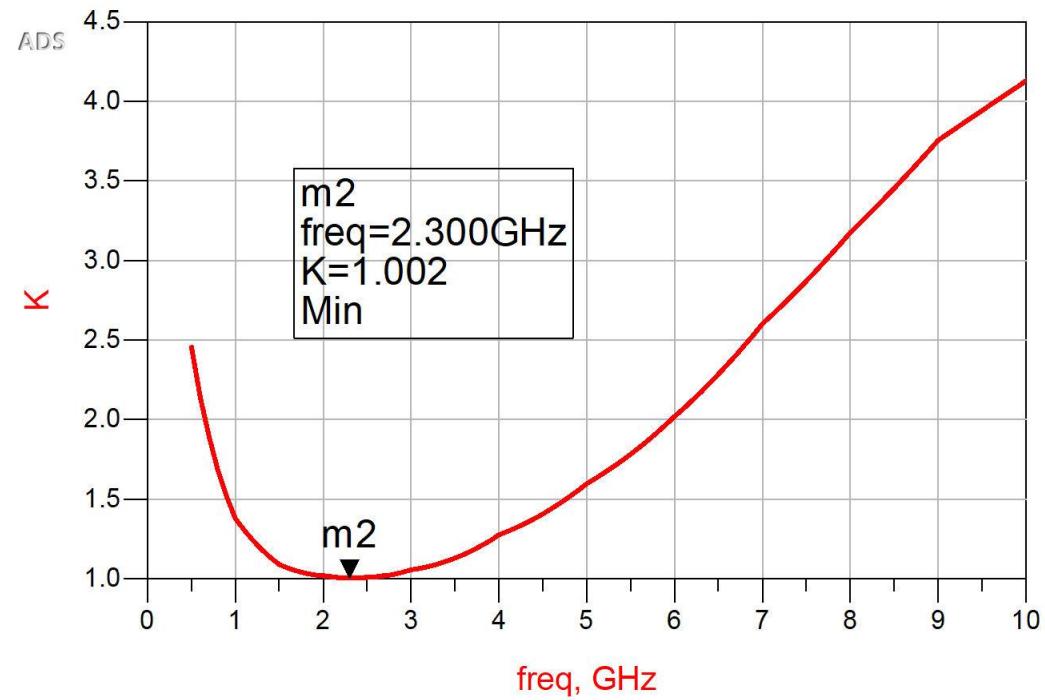
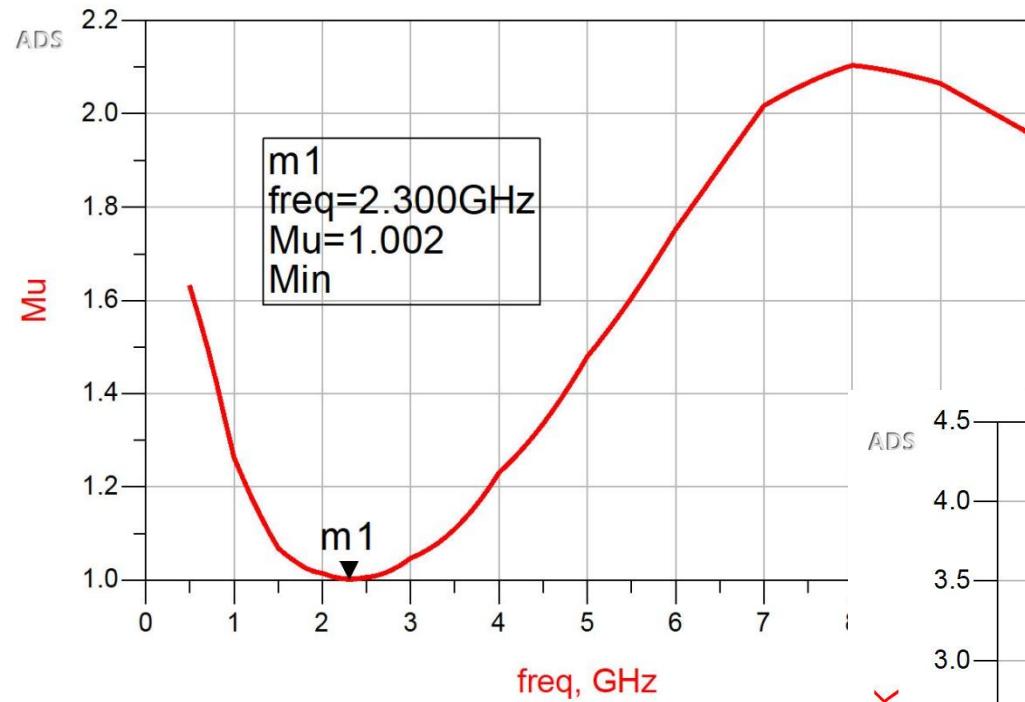


**StabFact**

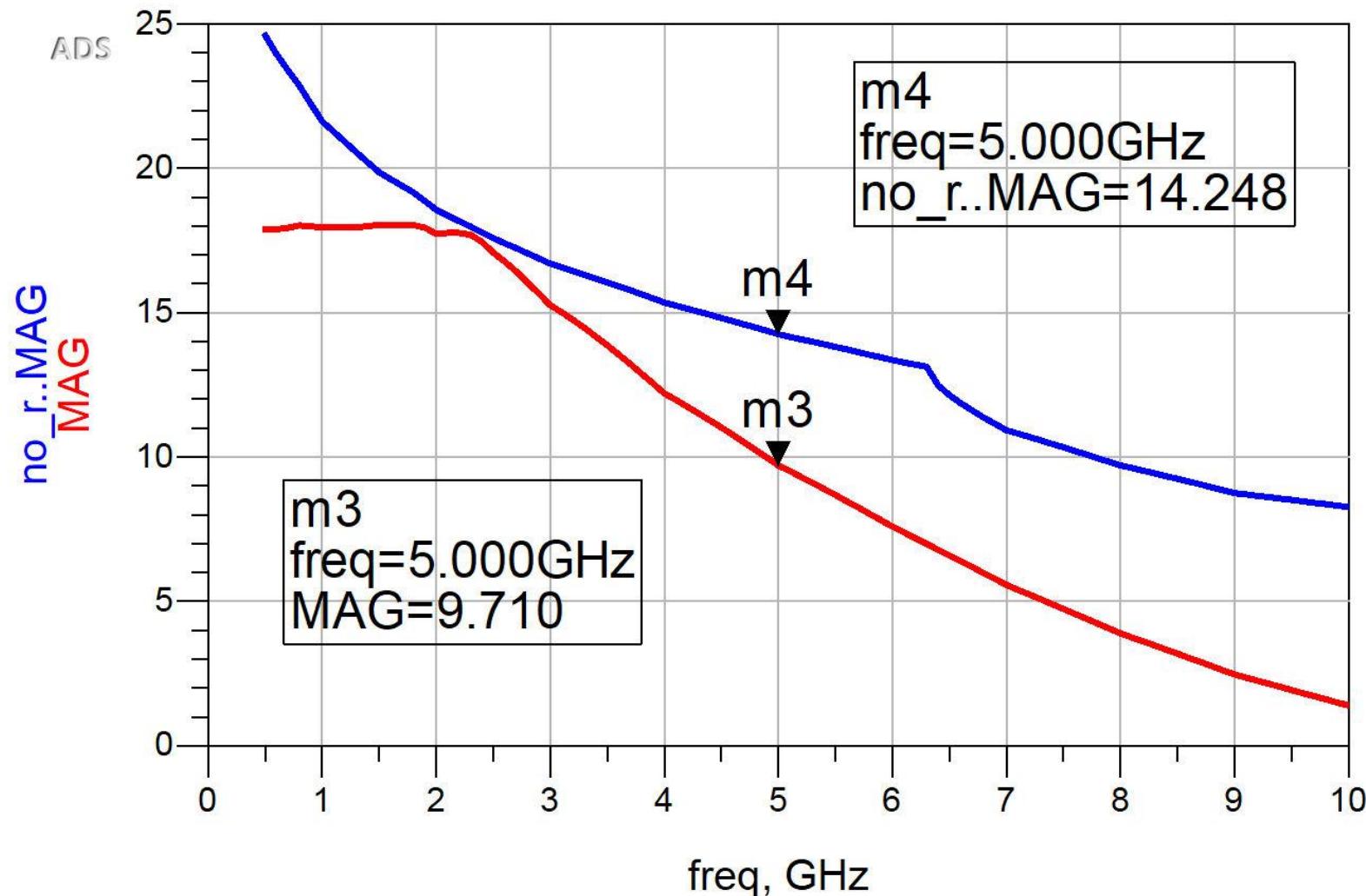
**K**

**K=stab\_fact(S)**

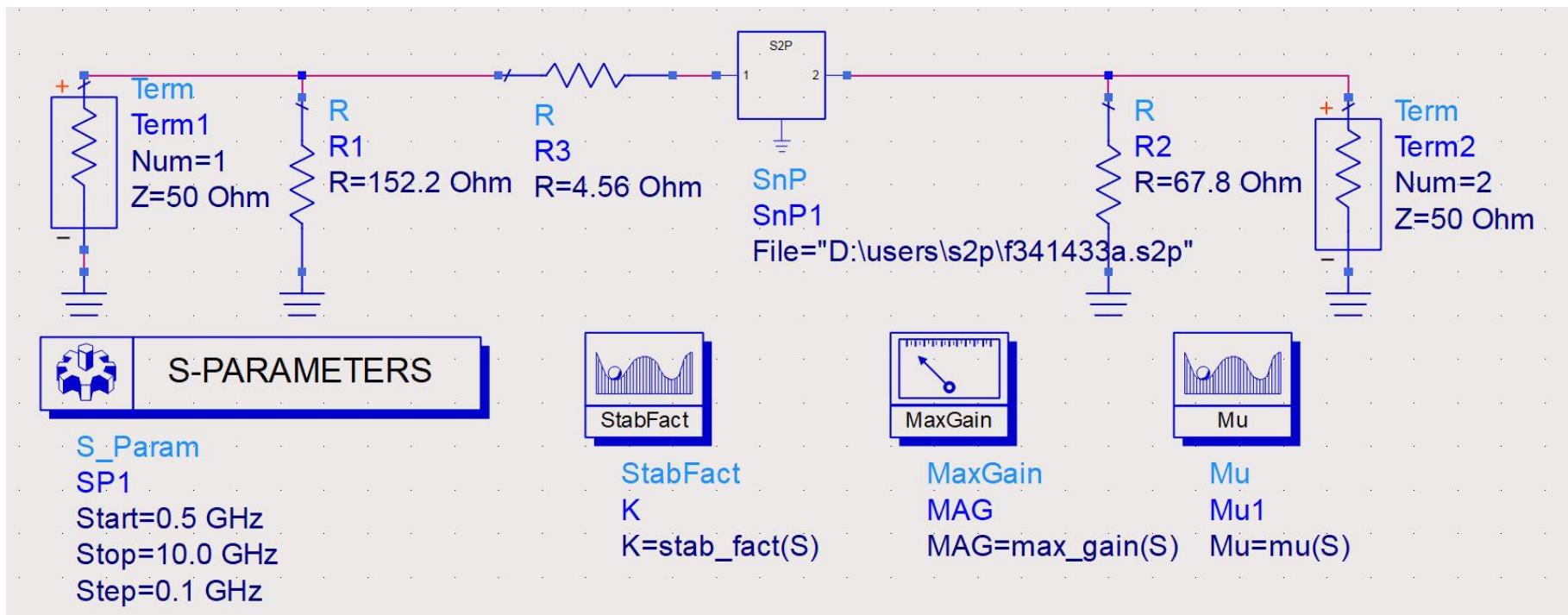
# Stabilizarea unui dipoz



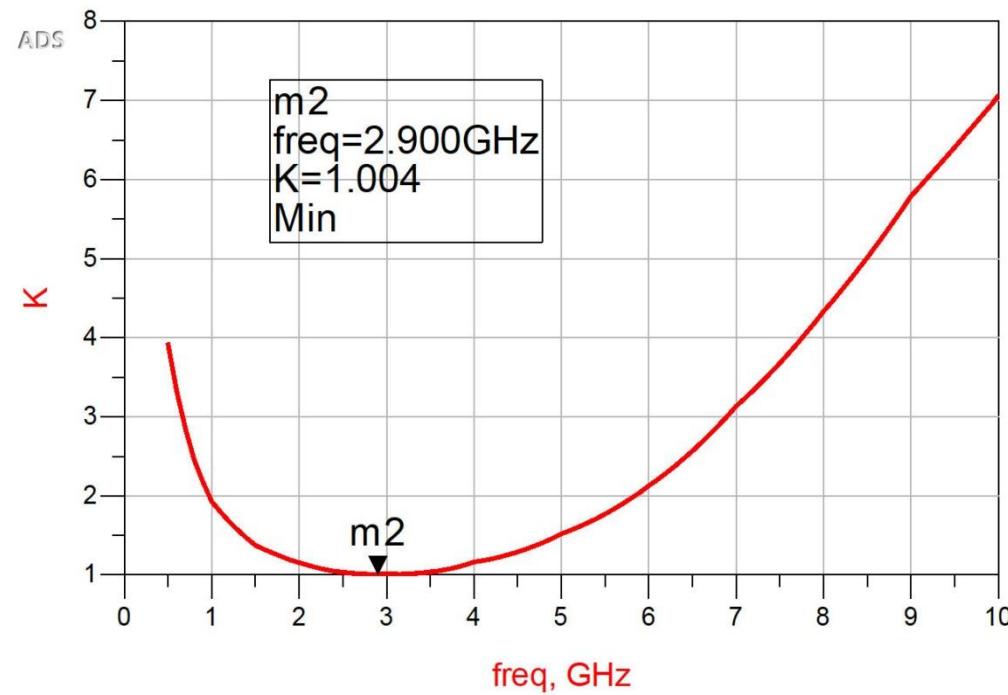
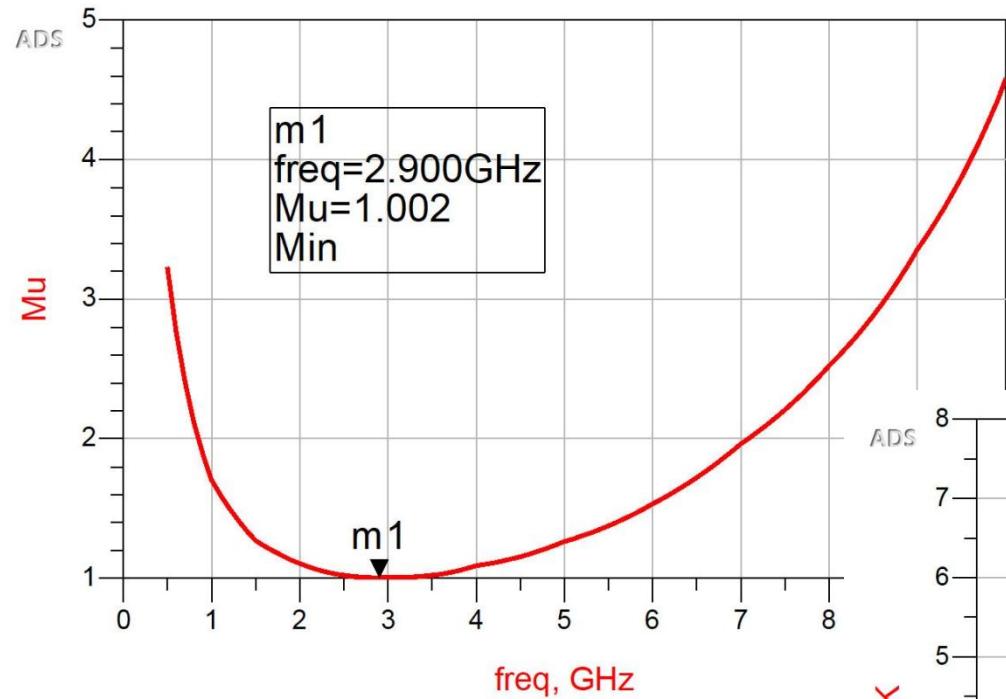
# Stabilizarea unui dipoz



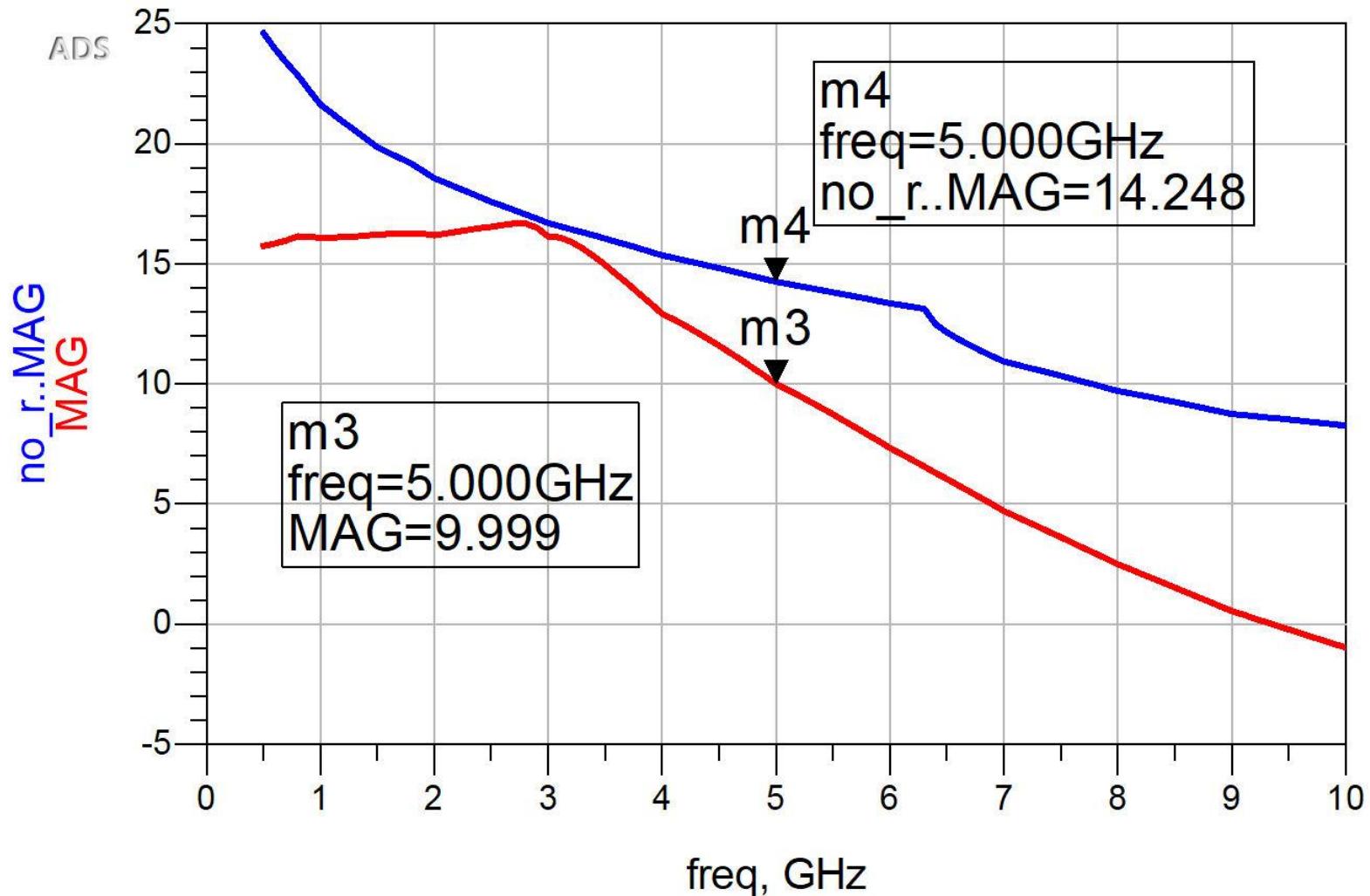
# Stabilizarea unui diport



# Stabilizarea unui dipoz



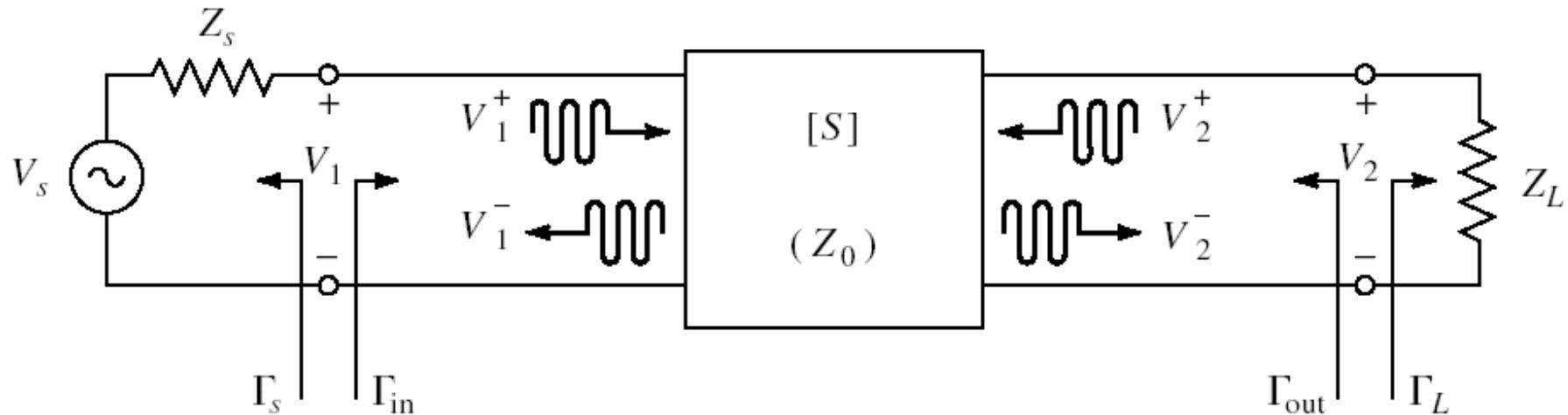
# Stabilizarea unui dipoz



Castigul amplificatoarelor de microunde

# **Amplificatoare de microunde**

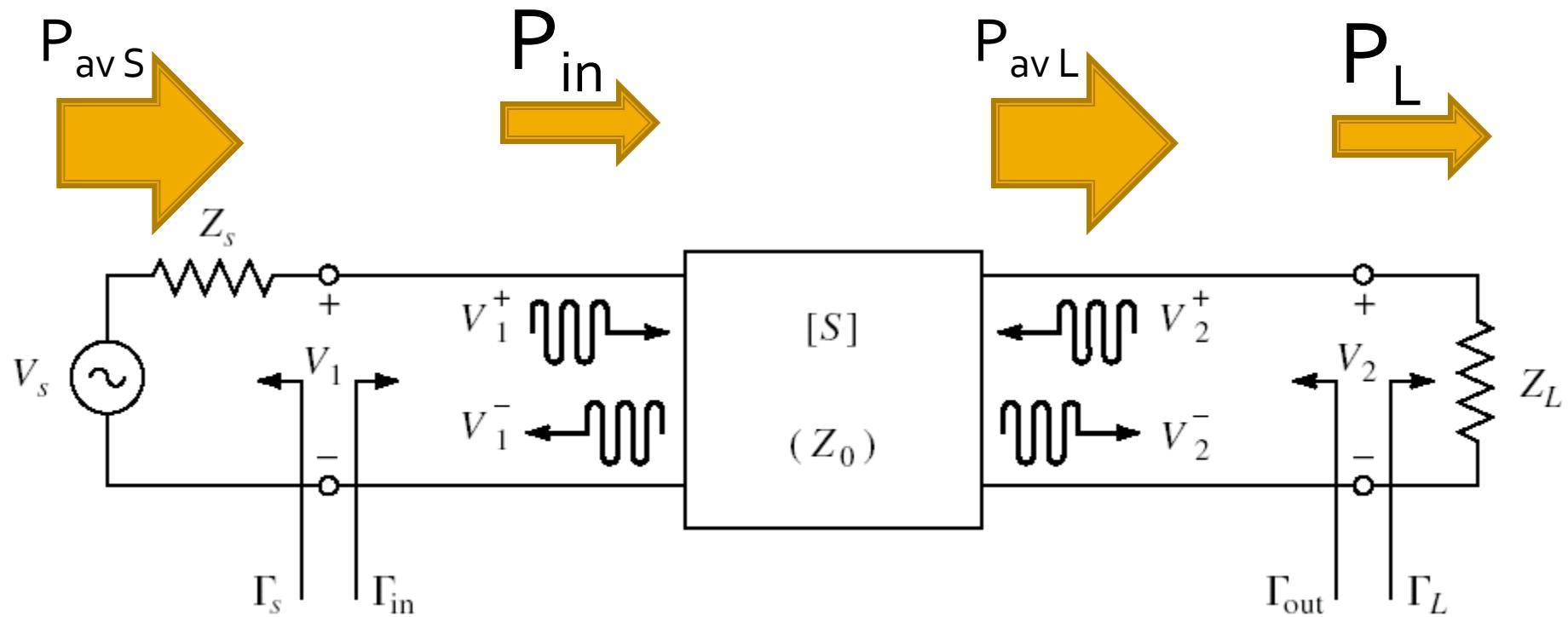
# Cuadripol Amplifier



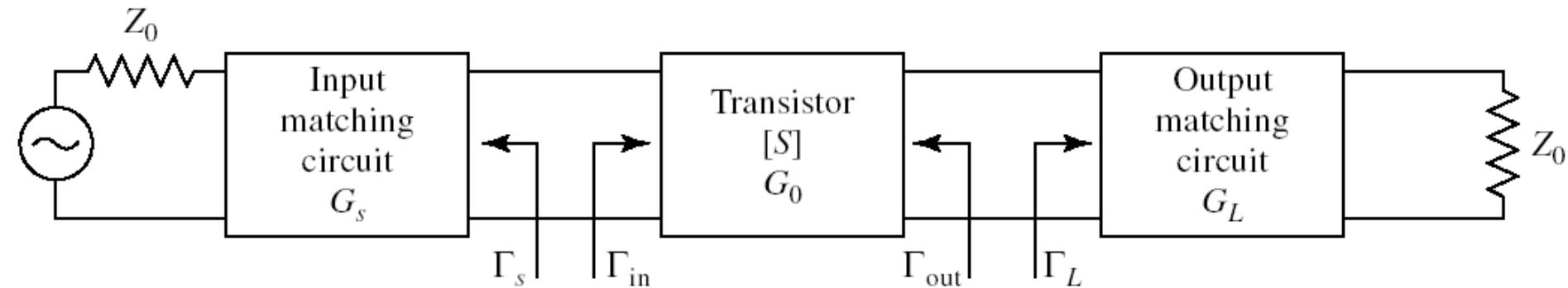
- marimi care intereseaza:
  - stabilitate
  - **castig de putere**
  - zgomot (uneori – semnal mic)
  - liniaritate (uneori – semnal mare)

# Puteri / Adaptare

- Doua porturi in care adaptarea influenteaza transferul de putere



# Proiectare pentru castig maxim



- Castig maxim de putere se obtine cand

$$\Gamma_{in} = \Gamma_s^* \quad \Gamma_{out} = \Gamma_L^*$$

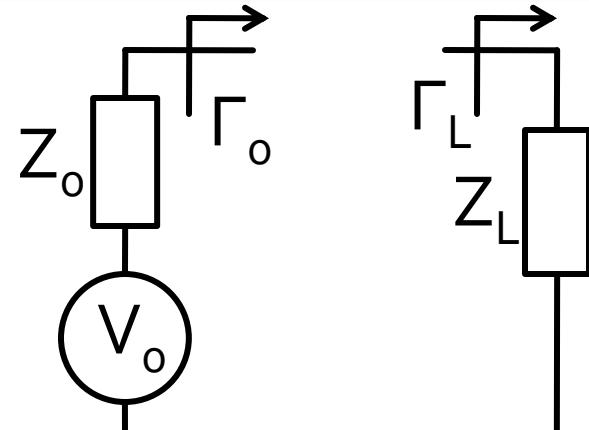
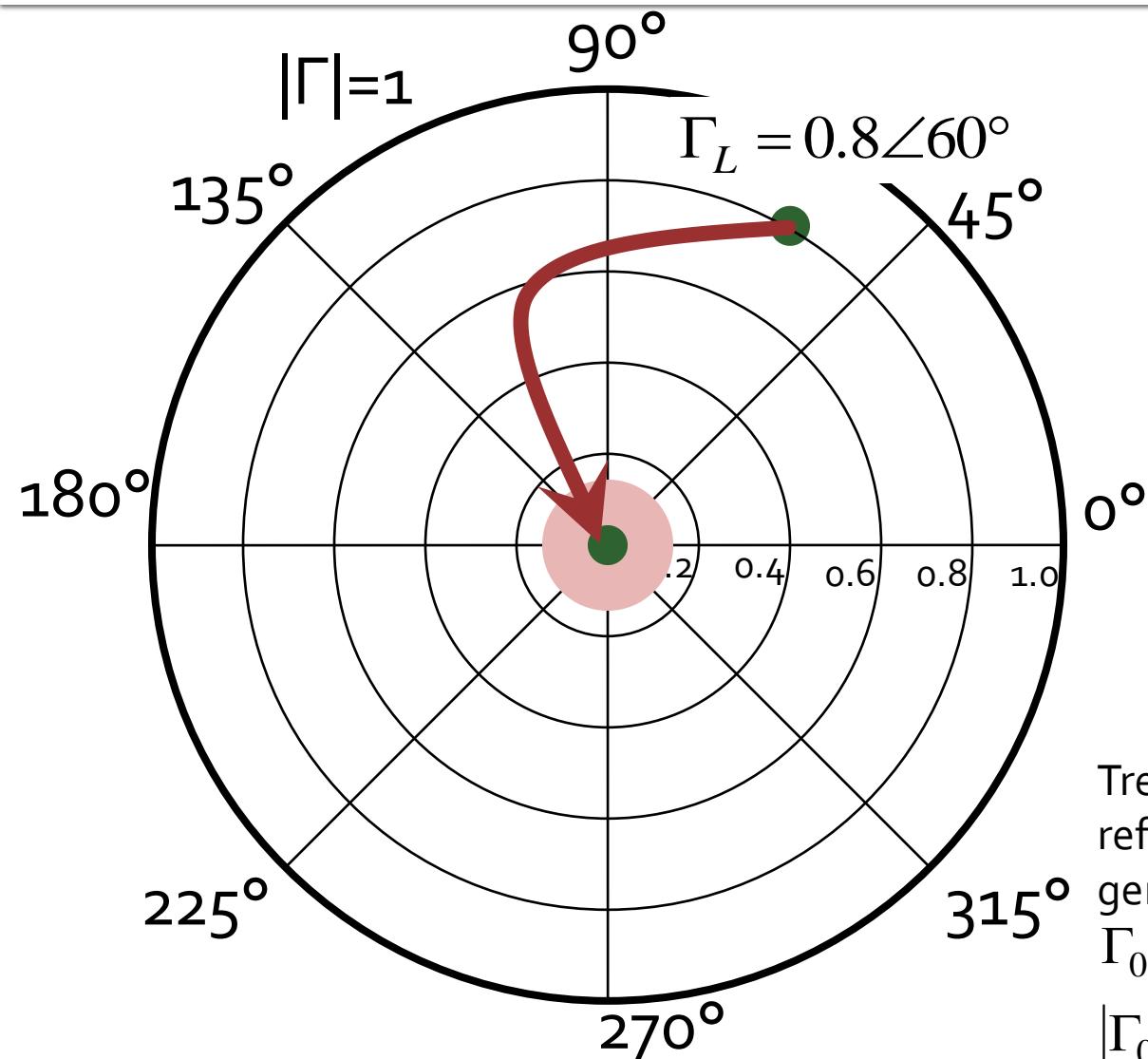
- Pentru retelele de adaptare fara pierderi

$$G_{T\max} = \frac{|S_{21}|^2 \cdot (1 - |\Gamma_s|^2) \cdot (1 - |\Gamma_L|^2)}{|1 - \Gamma_s \cdot \Gamma_{in}|^2 \cdot |1 - S_{22} \cdot \Gamma_L|^2}$$

$$G_{T\max} = \frac{1}{1 - |\Gamma_s|^2} \cdot |S_{21}|^2 \cdot \frac{1 - |\Gamma_L|^2}{|1 - S_{22} \cdot \Gamma_L|^2}$$

- Pentru tranzistor bilateral ( $S_{12} \neq 0$ )  $\Gamma_{in}$  si  $\Gamma_{out}$  se influenteaza reciproc deci adaptarea trebuie sa fie simultana

# Diagrama Smith, adaptare, $Z_L \neq Z_o$



Adaptare  $Z_L$  la  $Z_o$ . Se raporteaza  $Z_L$  la  $Z_o$

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

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

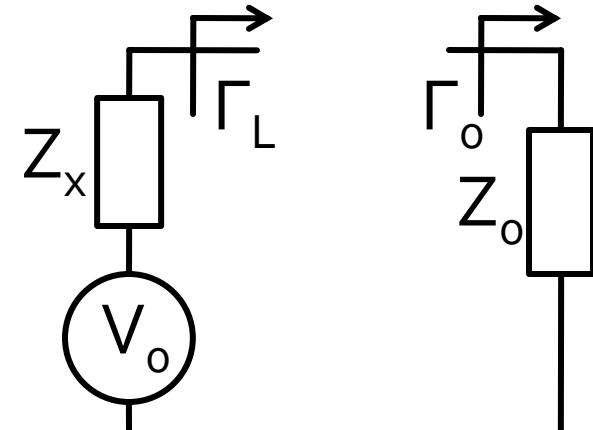
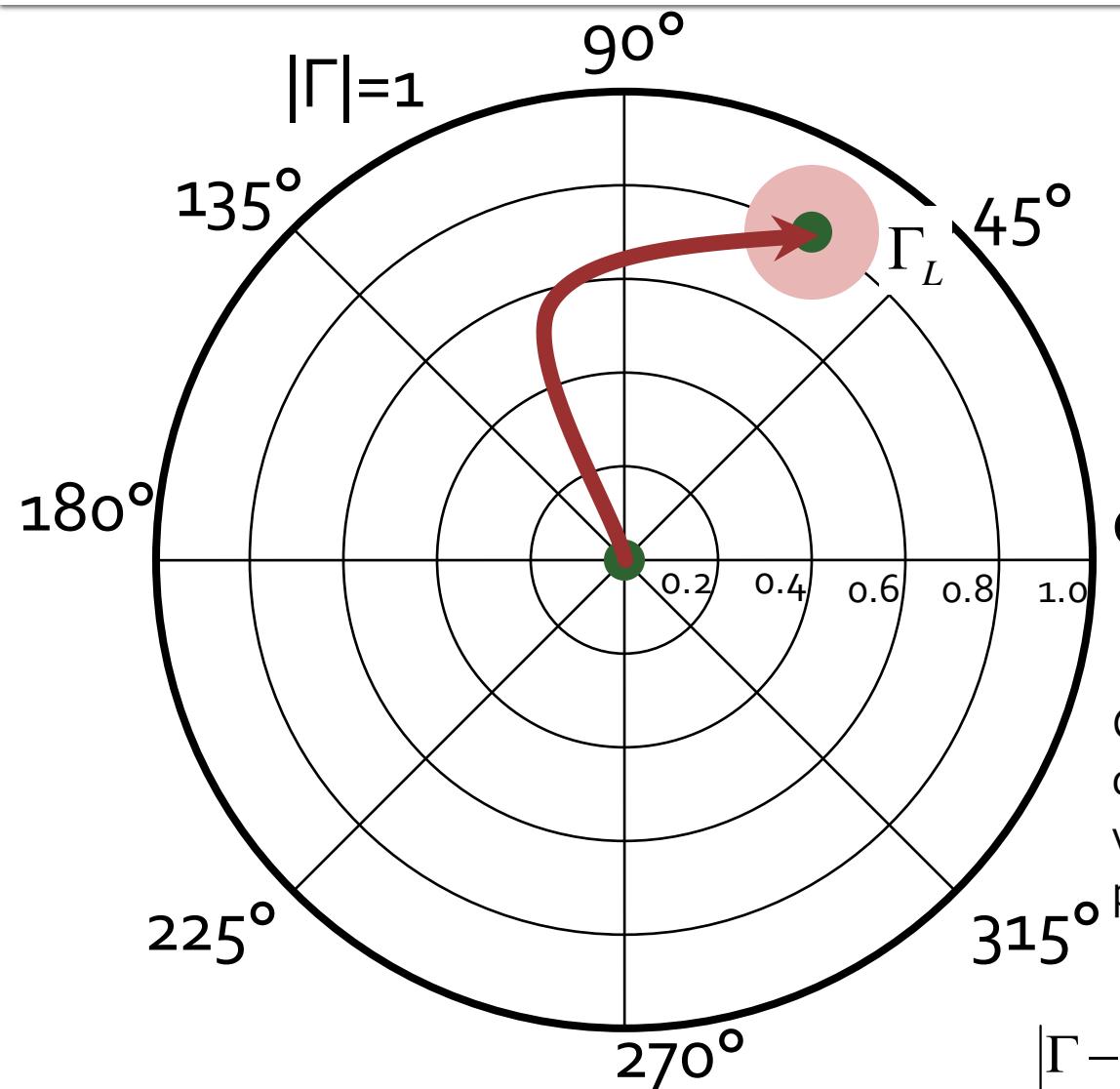
$$\Gamma_L = 0.8\angle 60^\circ$$

Trebuie sa deplasez coeficientul de reflexie in zona in care pentru generator cu  $Z_o$  am:

$$\Gamma_0 = 0 \text{ adaptare perfecta} \bullet$$

$|\Gamma_0| \leq \Gamma_m$  adaptare "suficienta" ●

# Diagrama Smith, adaptare, $Z_L = Z_o$



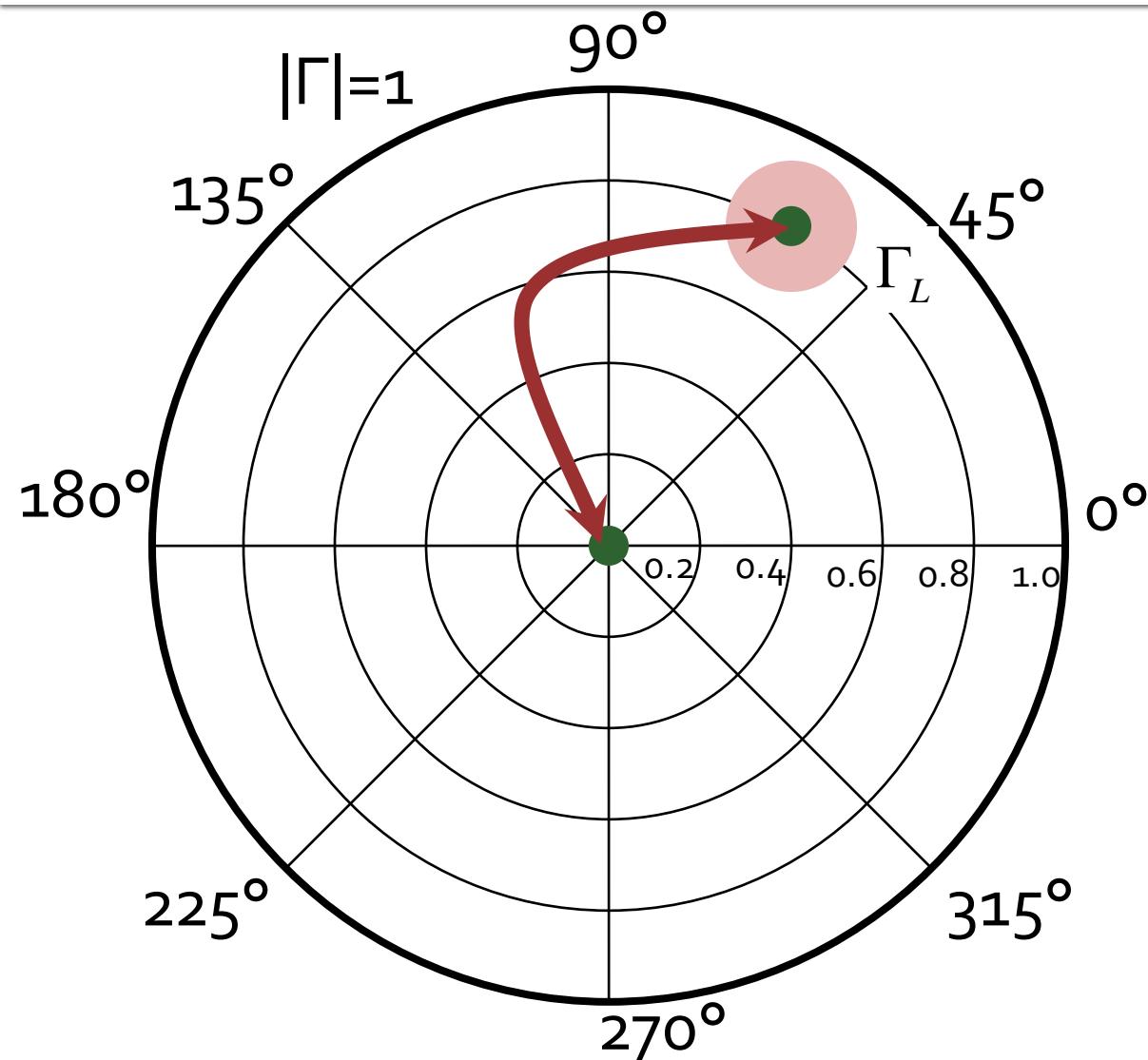
Sursa (de ex. tranzistorul) cu  $Z_x$  are nevoie de un anumit coeficient de reflexie  $\Gamma_L$  pentru a functiona corect

Circuitul de adaptare trebuie sa deplaseze coeficientul de reflexie vazut spre sarcina in zona in care pentru sarcina  $Z_o$  ( $\Gamma_o=0$ ) am:

$\Gamma = \Gamma_L$  adaptare perfecta ●

$|\Gamma - \Gamma_L| \leq \Gamma_m$  adaptare "suficientă" ●

# Diagrama Smith, adaptare, $Z_L = Z_o$



- Circuitele de adaptare care mută
  - $\Gamma_L$  în  $\Gamma_o$
  - $\Gamma_o$  în  $\Gamma_L$
- sunt **identice** ca realizare. Difera doar prin **ordinea** în care se introduc elementele în circuitul de adaptare
- Ca urmare se pot folosi în proiectarea circuitelor de adaptare aceleasi:
  - **metode**
  - **relatii**

# Adaptare simultana

$$\Gamma_{in} = \Gamma_S^*$$

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

$$\Gamma_S^* = S_{11} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_L}{1 - S_{22} \cdot \Gamma_L}$$

$$\Gamma_{out} = \Gamma_L^*$$

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

$$\Gamma_L^* = S_{22} + \frac{S_{12} \cdot S_{21} \cdot \Gamma_S}{1 - S_{11} \cdot \Gamma_S}$$

- Aflam  $\Gamma_S$

$$\Gamma_S = S_{11}^* + \frac{S_{12}^* \cdot S_{21}^*}{1/\Gamma_L^* - S_{22}^*}$$

$$\Gamma_L^* = \frac{S_{22} - \Delta \cdot \Gamma_S}{1 - S_{11} \cdot \Gamma_S}$$

$$\Gamma_S \cdot (1 - |S_{22}|^2) + \Gamma_S^2 \cdot (\Delta \cdot S_{22}^* - S_{11}) = \Gamma_S \cdot (\Delta \cdot S_{11}^* \cdot S_{22}^* - |S_{22}|^2 - \Delta \cdot S_{12}^* \cdot S_{21}^*) + S_{11}^* \cdot (1 - |S_{22}|^2) + S_{12}^* \cdot S_{21}^* \cdot S_{22}$$

# Adaptare simultana

$$\Delta \cdot (S_{11}^* \cdot S_{22}^* - S_{12}^* \cdot S_{21}^*) = |\Delta|^2$$

$$\Gamma_S^2 \cdot (S_{11} - \Delta \cdot S_{22}^*) + \Gamma_S \cdot (|\Delta|^2 - |S_{11}|^2 + |S_{22}|^2 - 1) + (S_{11}^* - \Delta^* \cdot S_{22}) = 0$$

- Ecuatie de gradul 2

$$\Gamma_S = \frac{B_1 \pm \sqrt{B_1^2 - 4 \cdot |C_1|^2}}{2 \cdot C_1}$$

- Similar

$$\Gamma_L = \frac{B_2 \pm \sqrt{B_2^2 - 4 \cdot |C_2|^2}}{2 \cdot C_2}$$

- Cu variabilele

$$\begin{cases} B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \\ C_1 = S_{11} - \Delta \cdot S_{22}^* \end{cases}$$

$$\begin{cases} B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \\ C_2 = S_{22} - \Delta \cdot S_{11}^* \end{cases}$$

# Adaptare simultana

- Este posibila daca

$$B_1^2 - 4 \cdot |C_1|^2 > 0 \quad B_2^2 - 4 \cdot |C_2|^2 > 0$$

$$\Delta \cdot (S_{11}^* \cdot S_{22}^* - S_{12}^* \cdot S_{21}^*) = |\Delta|^2$$

$$|C_1|^2 = |S_{11} - \Delta \cdot S_{22}^*|^2 = |S_{12}|^2 \cdot |S_{21}|^2 + (1 - |S_{22}|^2) \cdot (|S_{11}|^2 - |\Delta|^2)$$

$$\begin{aligned} B_1^2 - 4 \cdot |C_1|^2 &= (1 + |S_{11}|^2)^2 + (|S_{22}|^2 + |\Delta|^2)^2 - \\ &\quad - 2 \cdot (1 + |S_{11}|^2) \cdot (|S_{22}|^2 + |\Delta|^2) - 4 \cdot |S_{12} \cdot S_{21}|^2 - 4 \cdot (1 - |S_{22}|^2) \cdot (|S_{22}|^2 - |\Delta|^2) \end{aligned}$$

$$\begin{aligned} B_1^2 - 4 \cdot |C_1|^2 &= (1 + |S_{11}|^2)^2 + (|S_{22}|^2 + |\Delta|^2)^2 - \\ &\quad - 4 \cdot |S_{11}|^2 - 4 \cdot |S_{22}|^2 \cdot |\Delta|^2 - 2 \cdot (1 - |S_{11}|^2) \cdot (|S_{22}|^2 - |\Delta|^2) - 4 \cdot |S_{12} \cdot S_{21}|^2 \end{aligned}$$

# Adaptare simultana

$$B_1^2 - 4 \cdot |C_1|^2 = \left(1 + |S_{11}|^2\right)^2 + \left(|S_{22}|^2 + |\Delta|^2\right)^2 - \\ - 4 \cdot |S_{11}|^2 - 4 \cdot |S_{22}|^2 \cdot |\Delta|^2 - 2 \cdot \left(1 - |S_{11}|^2\right) \cdot \left(|S_{22}|^2 - |\Delta|^2\right) - 4 \cdot |S_{12} \cdot S_{21}|^2$$

$$B_1^2 - 4 \cdot |C_1|^2 = \left(1 - |S_{11}|^2\right)^2 + \left(|S_{22}|^2 - |\Delta|^2\right)^2 - 2 \cdot \left(1 - |S_{11}|^2\right) \cdot \left(|S_{22}|^2 - |\Delta|^2\right) - 4 \cdot |S_{12} \cdot S_{21}|^2$$

$$B_1^2 - 4 \cdot |C_1|^2 = \left(1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2\right)^2 - 4 \cdot |S_{12} \cdot S_{21}|^2$$

$$B_1^2 - 4 \cdot |C_1|^2 = (K \cdot 2 \cdot |S_{12} \cdot S_{21}|)^2 - 4 \cdot |S_{12} \cdot S_{21}|^2$$

$$B_1^2 - 4 \cdot |C_1|^2 = 4 \cdot |S_{12}|^2 \cdot |S_{21}|^2 \cdot (K^2 - 1)$$

## ■ Similar

$$B_2^2 - 4 \cdot |C_2|^2 = 4 \cdot |S_{12}|^2 \cdot |S_{21}|^2 \cdot (K^2 - 1)$$

# Adaptare simultana

$$\Gamma_S = \frac{B_1 \pm \sqrt{B_1^2 - 4 \cdot |C_1|^2}}{2 \cdot C_1}$$

$$\Gamma_L = \frac{B_2 \pm \sqrt{B_2^2 - 4 \cdot |C_2|^2}}{2 \cdot C_2}$$

## ■ Necesar pentru solutii

$$|\Gamma_S| < 1 \quad |\Gamma_L| < 1$$

$$|\Delta| = |S_{11} \cdot S_{22} - S_{12} \cdot S_{21}| < 1 \quad \begin{cases} B_1 > 0 \\ B_2 > 0 \end{cases}$$

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2 \cdot |S_{12} \cdot S_{21}|} > 1 \quad \begin{cases} B_1^2 - 4 \cdot |C_1|^2 = 4 \cdot |S_{12}|^2 \cdot |S_{21}|^2 \cdot (K^2 - 1) > 0 \\ B_2^2 - 4 \cdot |C_2|^2 = 4 \cdot |S_{12}|^2 \cdot |S_{21}|^2 \cdot (K^2 - 1) > 0 \end{cases}$$

# Adaptare simultana

- Adaptarea simultana se poate realiza **numai** pentru amplificatoarele **neconditionat stabile** la frecventa de lucru, si solutia cu  $|\Gamma| < 1$  se obtine cu semnul “-”

$$\Gamma_S = \frac{B_1 - \sqrt{B_1^2 - 4 \cdot |C_1|^2}}{2 \cdot C_1}$$

$$\begin{cases} B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \\ C_1 = S_{11} - \Delta \cdot S_{22}^* \end{cases}$$

$$\Gamma_L = \frac{B_2 - \sqrt{B_2^2 - 4 \cdot |C_2|^2}}{2 \cdot C_2}$$

$$\begin{cases} B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \\ C_2 = S_{22} - \Delta \cdot S_{11}^* \end{cases}$$

# Adaptare simultana

- În condițiile adaptării simultane se obține castigul de transfer maxim pentru tranzistorul bilateral

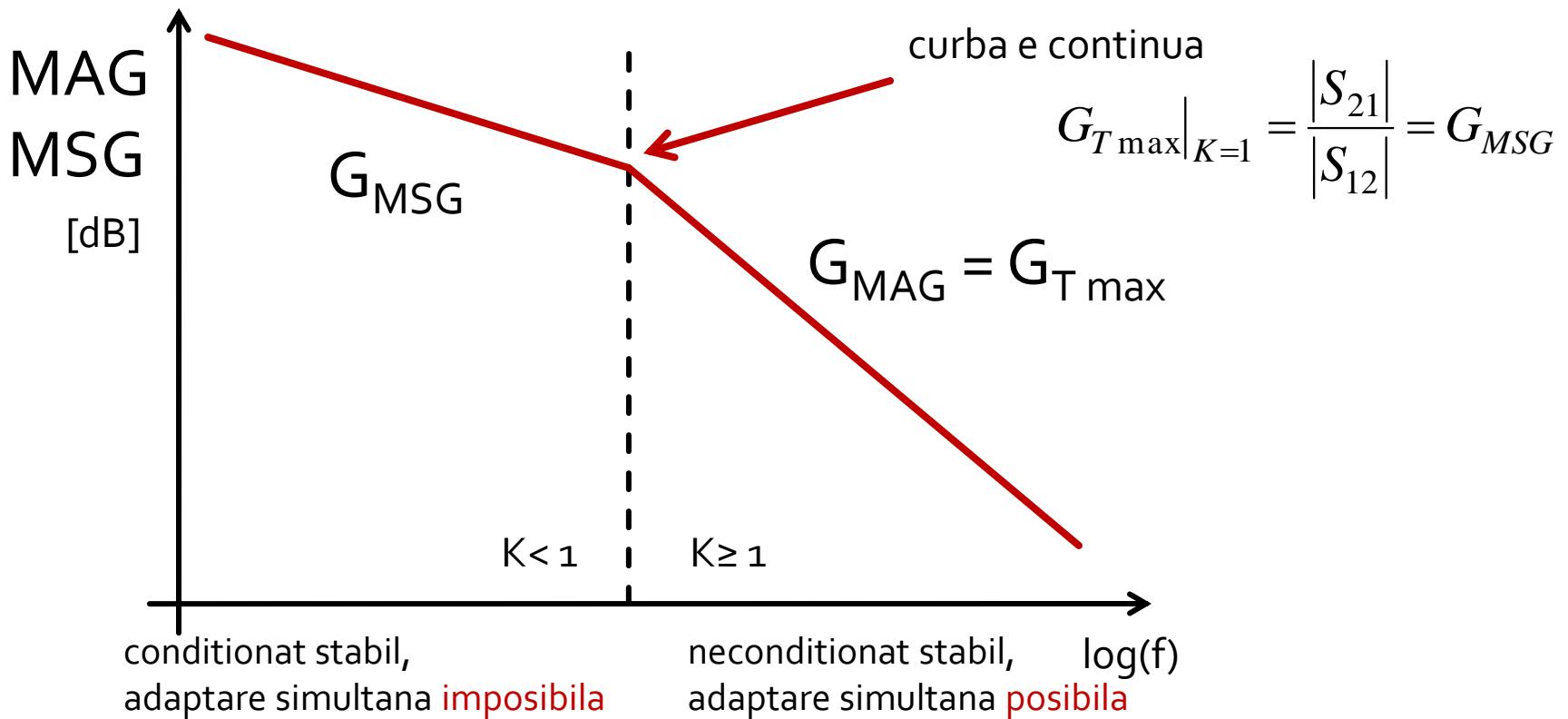
$$G_{T\max} = \frac{|S_{21}|}{|S_{12}|} \cdot \left( K - \sqrt{K^2 - 1} \right)$$

- Dacă dispozitivul **nu** este **neconditionat stabil** se poate folosi ca o indicatie a capacitatii de amplificare castigul maxim stabil (Maximum Stable Gain)

$$G_{MSG} = \frac{|S_{21}|}{|S_{12}|}$$

# Maximum Available Gain

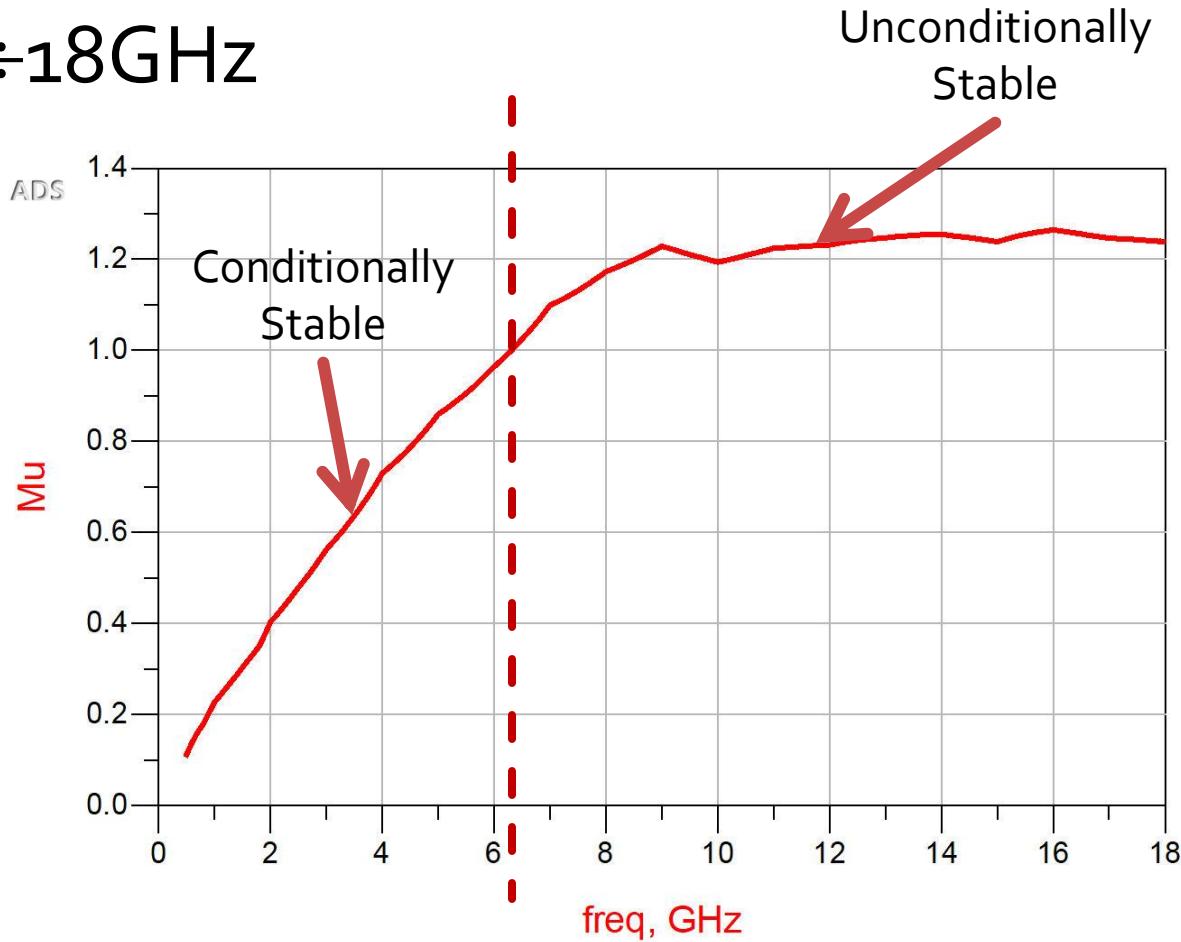
- Indicator in intreaga gama de frecventa a capacitatii de a obtine castig



# Stabilitate

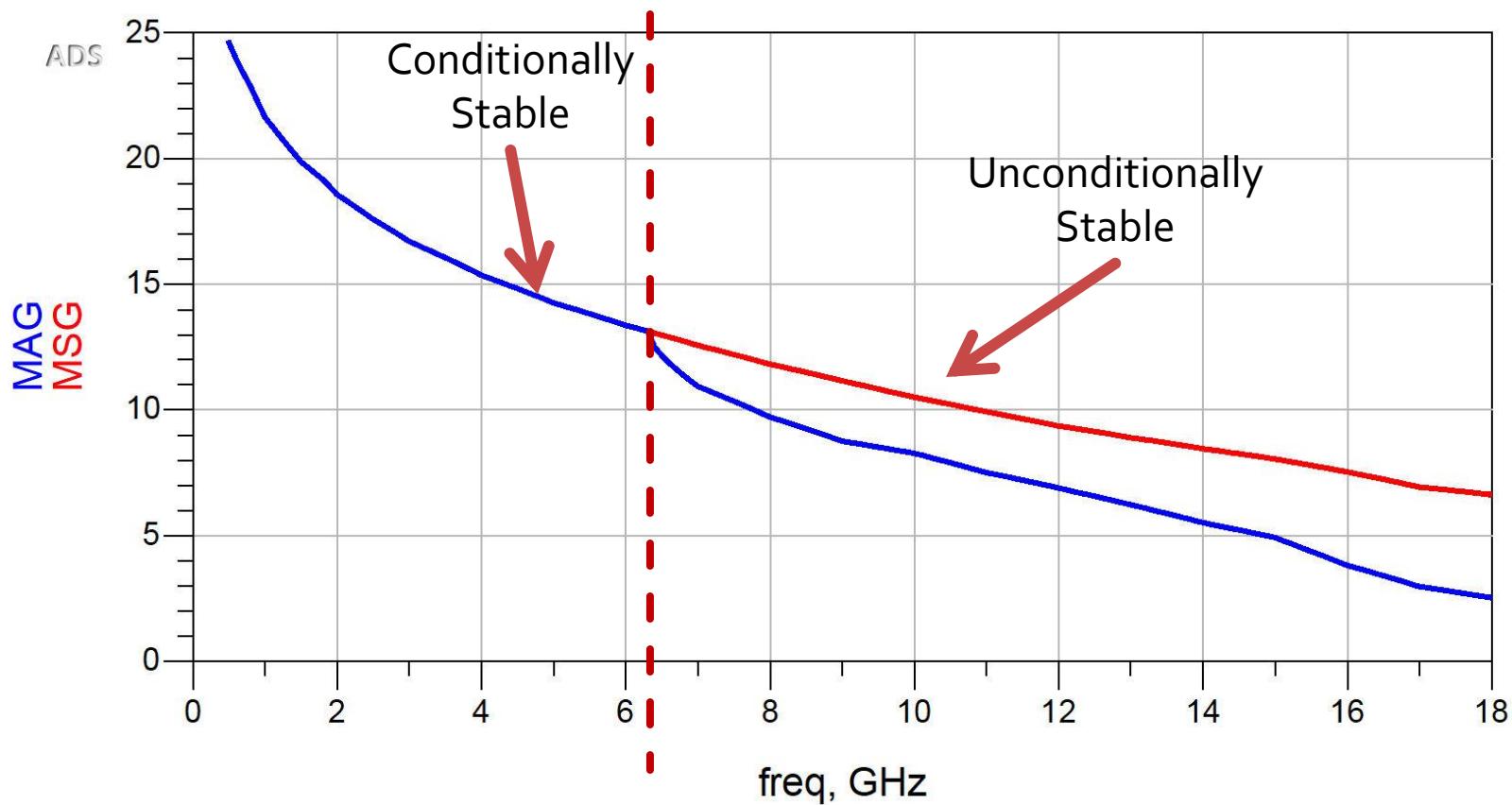
- ATF-34143 at  $V_{ds}=3V$   $I_d=20mA$ .

- @ $0.5 \div 18GHz$



# Castig

- ATF-34143 at  $V_{ds}=3V$   $I_d=20mA$ .
- @ $0.5\div18GHz$



# Adaptare simultana, tranzistor unilateral

- Daca amplificatorul/tranzistorul este **unilateral** ( $S_{12} = 0$ ) adaptarea simultana implica:

$$\Gamma_{in} = S_{11}$$

$$\Gamma_{out} = S_{22}$$

$$\Gamma_S = S_{11}^*$$

$$\Gamma_L = S_{22}^*$$

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

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

# Exemplu

- ATF-34143 **at  $V_{ds}=3V$   $I_d=20mA$ .**
  - fara stabilizare  $K = 0.886$ , MAG = 14.248dB @ 5GHz
  - nu poate fi folosit in aceasta polarizare
- ATF-34143 **at  $V_{ds}=4V$   $I_d=40mA$** 
  - fara stabilizare  $K = 1.031$ , MAG = 12.9dB @ 5GHz
  - utilizam aceasta polarizare pentru a implementa un amplificator

# Exemplu

- ATF-34143 at  $V_{ds}=4V$   $I_d=40mA$ .
- @5GHz
  - $S_{11} = 0.64 \angle 111^\circ$
  - $S_{12} = 0.117 \angle -27^\circ$
  - $S_{21} = 2.923 \angle -6^\circ$
  - $S_{22} = 0.21 \angle 111^\circ$

# Calcul

## ■ Parametri S

- $S_{11} = -0.229 + 0.597 \cdot j$
- $S_{12} = 0.104 - 0.053 \cdot j$
- $S_{21} = 2.907 - 0.306 \cdot j$
- $S_{22} = -0.075 + 0.196 \cdot j$

$$G_{T\max} = \frac{|S_{21}|}{|S_{12}|} \cdot \left( K - \sqrt{K^2 - 1} \right) = 19.497 = 12.9 \text{ dB}$$

$$G_{TU\max} = \frac{1}{1 - |S_{11}|^2} \cdot |S_{21}|^2 \cdot \frac{1}{1 - |S_{22}|^2} = 15.139 = 11.8 \text{ dB}$$

# Calcul

$$\begin{cases} B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \\ C_1 = S_{11} - \Delta \cdot S_{22}^* \end{cases}$$

$$\begin{cases} B_1 = ? \\ C_1 = ? \end{cases}$$

$$\Gamma_S = \frac{B_1 - \sqrt{B_1^2 - 4 \cdot |C_1|^2}}{2 \cdot C_1}$$

$$\Gamma_S = ?$$

$$\begin{cases} B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \\ C_2 = S_{22} - \Delta \cdot S_{11}^* \end{cases}$$

$$\begin{cases} B_2 = ? \\ C_2 = ? \end{cases}$$

$$\Gamma_L = \frac{B_2 - \sqrt{B_2^2 - 4 \cdot |C_2|^2}}{2 \cdot C_2}$$

$$\Gamma_L = ?$$

# Calcul

$$\begin{cases} B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \\ C_1 = S_{11} - \Delta \cdot S_{22}^* \end{cases}$$

$$\begin{cases} B_1 = 1.207 \\ C_1 = -0.277 + j \cdot 0.529 \end{cases}$$

$$\Gamma_S = \frac{B_1 - \sqrt{B_1^2 - 4 \cdot |C_1|^2}}{2 \cdot C_1}$$

$$\Gamma_S = -0.403 - j \cdot 0.768$$

$$|\Gamma_S| = 0.867 < 1$$

$$\Gamma_S = 0.867 \angle -117.7^\circ$$

$$\begin{cases} B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \\ C_2 = S_{22} - \Delta \cdot S_{11}^* \end{cases}$$

$$\begin{cases} B_2 = 0.476 \\ C_2 = -0.222 - j \cdot 0.013 \end{cases}$$

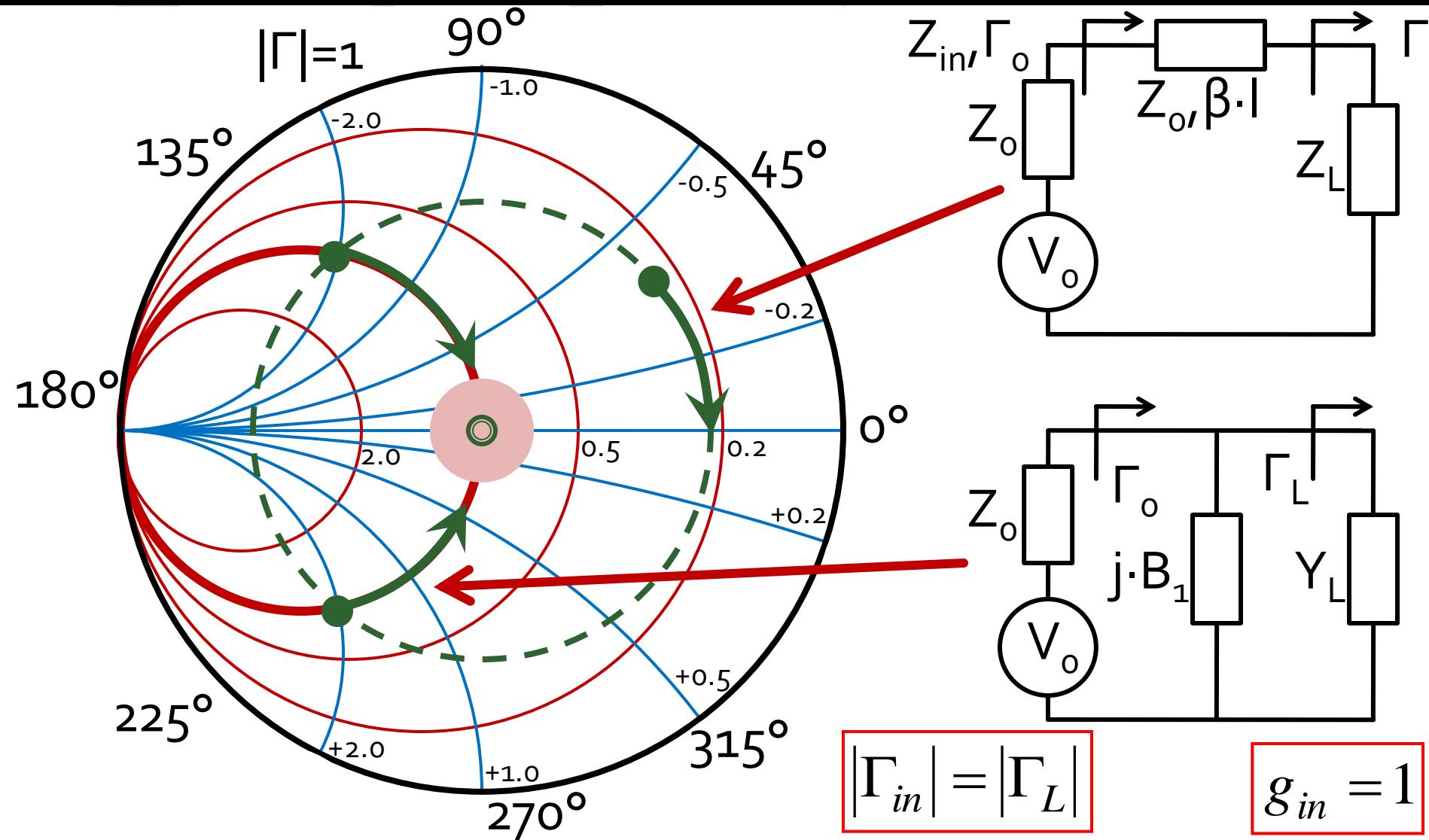
$$\Gamma_L = \frac{B_2 - \sqrt{B_2^2 - 4 \cdot |C_2|^2}}{2 \cdot C_2}$$

$$\Gamma_L = -0.685 + j \cdot 0.04$$

$$|\Gamma_L| = 0.686 < 1$$

$$\Gamma_L = 0.686 \angle 176.7^\circ$$

# Adaptare cu stub-uri, C<sub>7</sub>



# Calcul analitic ( $\Gamma_S$ )

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

$$|\Gamma_S| = 0.867 \angle -117.7^\circ$$

$$|\Gamma_S| = 0.867; \quad \varphi = -117.7^\circ \quad \cos(\varphi + 2\theta) = -0.867 \Rightarrow (\varphi + 2\theta) = \pm 150.1^\circ$$

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

- **Semnul (+/-)** solutiei alese la ecuatia **liniei serie** impune **semnul** solutiei utilizate la ecuatia **stub-ului paralel**

- **solutia "cu +"**

$$(-117.7^\circ + 2\theta) = +150.1^\circ \quad \theta = 133.9^\circ \quad \text{Im } y_S = \frac{-2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = -3.477$$
$$\theta_{sp} = \tan^{-1}(\text{Im } y_S) = -74^\circ (+180^\circ) \rightarrow \theta_{sp} = 106^\circ$$

- **solutia "cu -"**

$$(-117.7^\circ + 2\theta) = -150.1^\circ \quad \theta = -16.2^\circ (+180^\circ) \rightarrow \theta = 163.8^\circ$$
$$\text{Im } y_S = \frac{+2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}} = +3.477 \quad \theta_{sp} = \tan^{-1}(\text{Im } y_S) = 74^\circ$$

# Calcul analitic ( $\Gamma_L$ )

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

$$|\Gamma_L| = 0.686 \angle 176.7^\circ$$

$$|\Gamma_L| = 0.686; \quad \varphi = 176.7^\circ$$

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

- **Semnul (+/-)** solutiei alese la ecuatia **liniei serie** impune **semnul** solutiei utilizate la ecuatia **stub-ului paralel**
  - **solutia “cu +”**
  - **solutia “cu -”**

# Calcul analitic ( $\Gamma_L$ )

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

$$|\Gamma_L| = 0.686 \angle 176.7^\circ$$

$$|\Gamma_L| = 0.686; \quad \varphi = 176.7^\circ \quad \cos(\varphi + 2\theta) = -0.686 \Rightarrow (\varphi + 2\theta) = \pm 133.3^\circ$$

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

- **Semnul (+/-) solutiei alese la ecuatia liniei serie impune semnul solutiei utilizate la ecuatia stub-ului paralel**

- **solutia "cu +"**

$$(176.7^\circ + 2\theta) = +133.3^\circ \quad \theta = -21.7^\circ (+180^\circ) \rightarrow \theta = 158.3^\circ$$
$$\theta_{sp} = \tan^{-1}(\text{Im } y_L) = -62.1^\circ (+180^\circ) \rightarrow \theta_{sp} = 117.9^\circ \quad \text{Im } y_L = \frac{-2 \cdot |\Gamma_L|}{\sqrt{1 - |\Gamma_L|^2}} = -1.885$$

- **solutia "cu -"**

$$(176.7^\circ + 2\theta) = -133.3^\circ \quad \theta = -155^\circ (+180^\circ) \rightarrow \theta = 25^\circ$$

$$\text{Im } y_L = \frac{+2 \cdot |\Gamma_L|}{\sqrt{1 - |\Gamma_L|^2}} = +1.885 \quad \theta_{sp} = \tan^{-1}(\text{Im } y_L) = 62.1^\circ$$

# Calcul analitic

- Se alege **una** din cele două solutii posibile la intrare

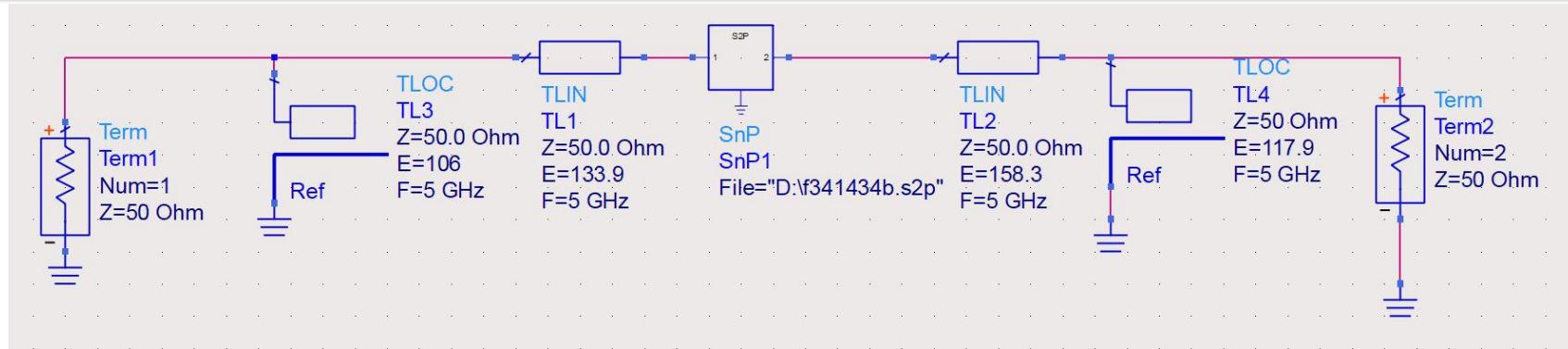
$$(\varphi + 2\theta) = \begin{cases} +150.1^\circ \\ -150.1^\circ \end{cases} \quad \theta = \begin{cases} 133.9^\circ \\ 163.8^\circ \end{cases} \quad \text{Im}[y_s(\theta)] = \begin{cases} -3.477 \\ +3.477 \end{cases} \quad \theta_{sp} = \begin{cases} -74^\circ + 180^\circ = 106^\circ \\ +74^\circ \end{cases}$$

- Similar pentru adaptarea la ieșire

$$(\varphi + 2\theta) = \begin{cases} +133.3^\circ \\ -133.3^\circ \end{cases} \quad \theta = \begin{cases} 158.3^\circ \\ 25.0^\circ \end{cases} \quad \text{Im}[y_s(\theta)] = \begin{cases} -1.885 \\ +1.885 \end{cases} \quad \theta_{sp} = \begin{cases} 117.9^\circ \\ 62.1^\circ \end{cases}$$

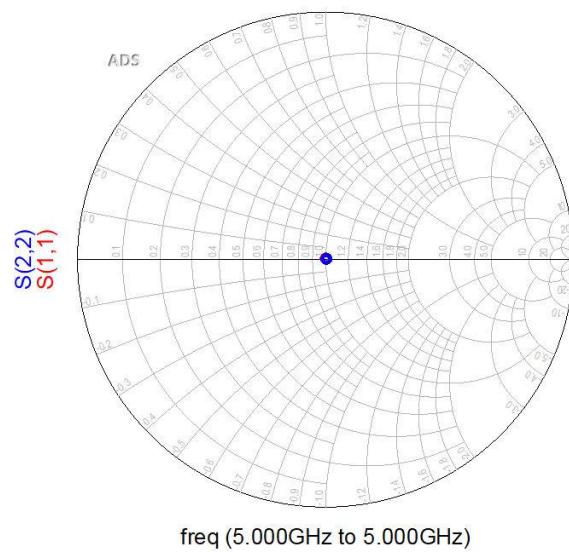
- În total există **4** posibilități de adaptare intrare/ieșire

# ADS

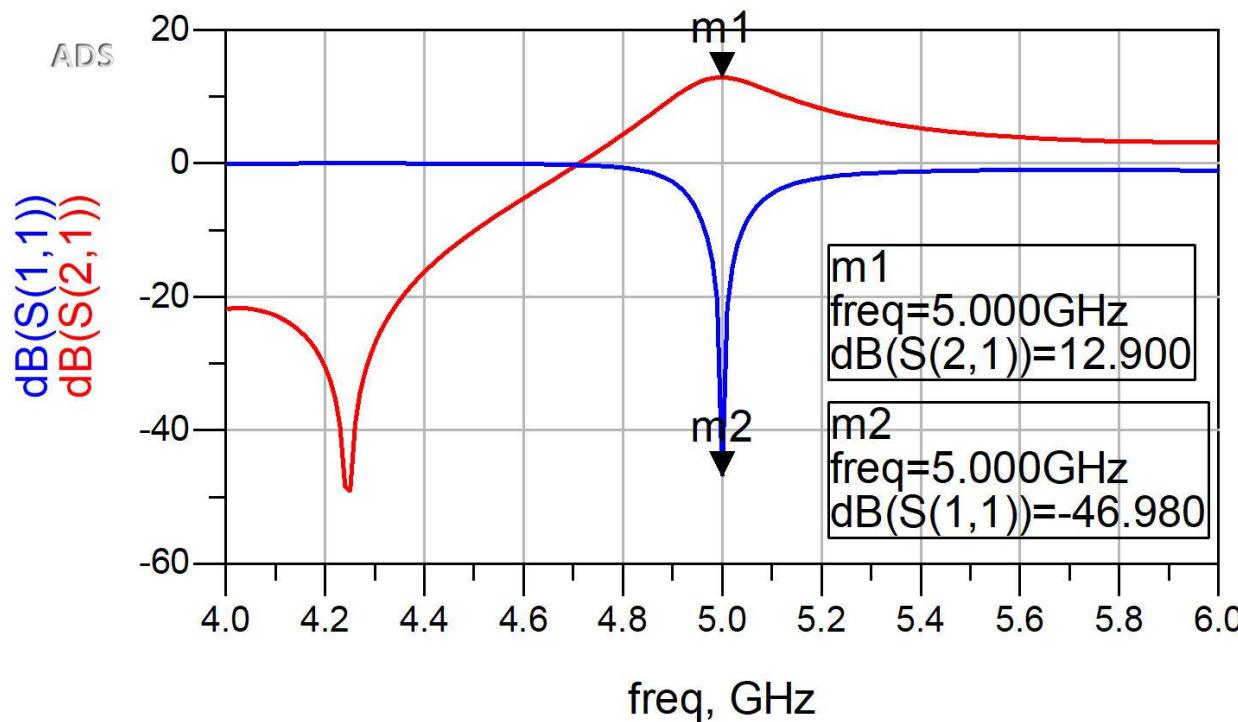
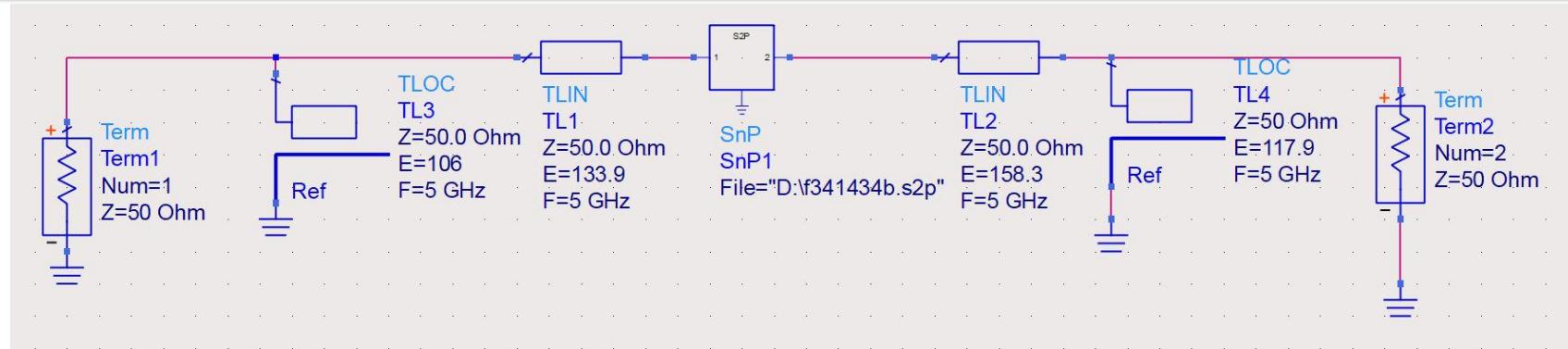


$$\text{Eqn GT} = 10 * \log(\text{mag}(S(2,1))^{\star 2})$$

freq	S(2,1)	GT	S(1,1)	S(2,2)
5.000 GHz	4.415 / 157.353	12.900	0.004 / 86.088	0.004 / 37.766



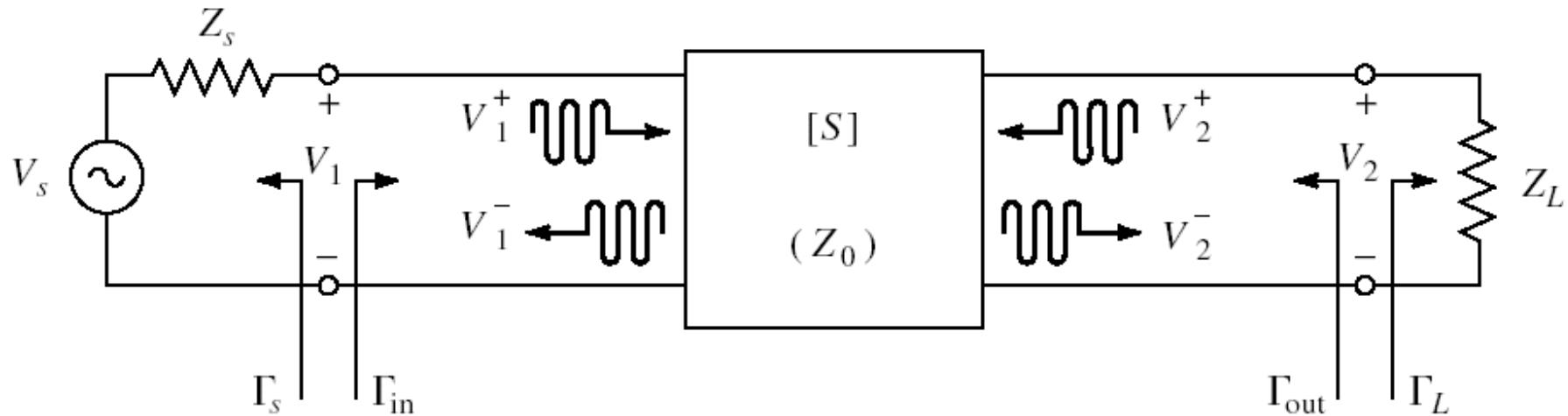
# ADS



Proiectare pentru castig impus

# **Amplificatoare de microunde**

# Cuadripol Amplifier



- marimi care intereseaza:
  - stabilitate
  - **castig de putere**
  - zgomot (uneori – semnal mic)
  - liniaritate (uneori – semnal mare)

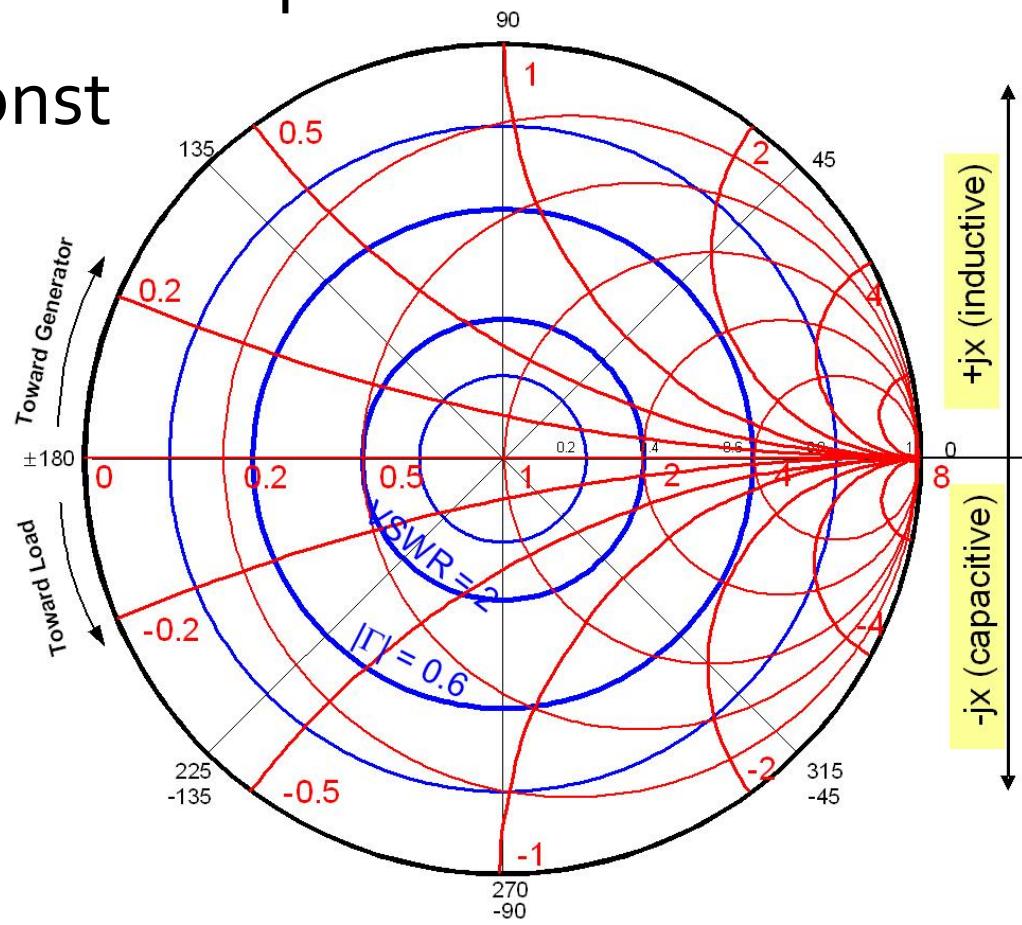
# Proiectare pentru castig impus

- Deseori este necesara o alta abordare decat "forta bruta" si se prefera obtinerea unui **castig mai mic** decat cel maxim posibil pentru:
  - conditii de zgomot avantajoase ( $L_3 + C_9$ )
  - conditii de stabilitate mai bune
  - obtinerea unui VSWR mai mic
  - controlul performantelor la mai multe frecvente
  - banda de functionare a amplificatorului

# VSWR

- Anumite aplicatii pot impune un raport intre tensiunile maxime/minime pe linii
- $VSWR = \text{const} \rightarrow \Gamma = \text{const}$

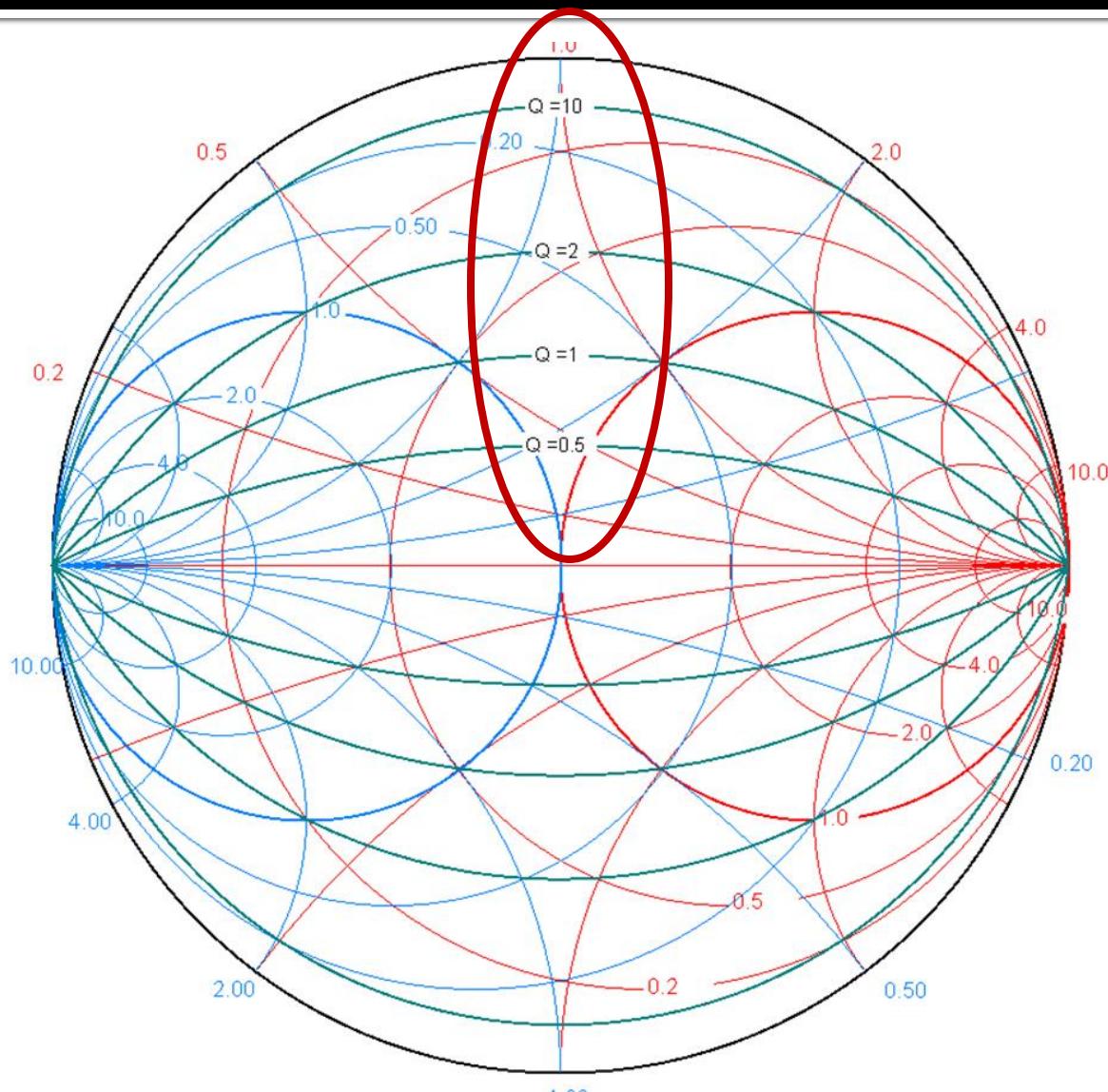
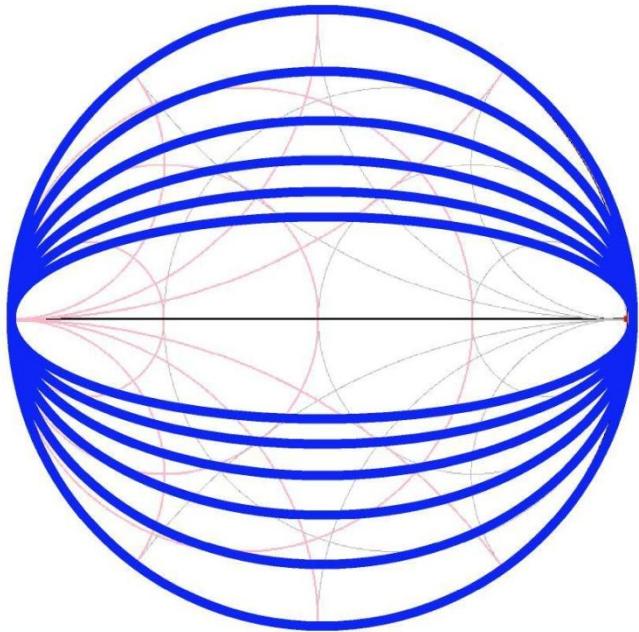
$$VSWR = \frac{V_{\max}}{V_{\min}} = \frac{1+|\Gamma|}{1-|\Gamma|}$$



# Cercuri de factor de calitate constant

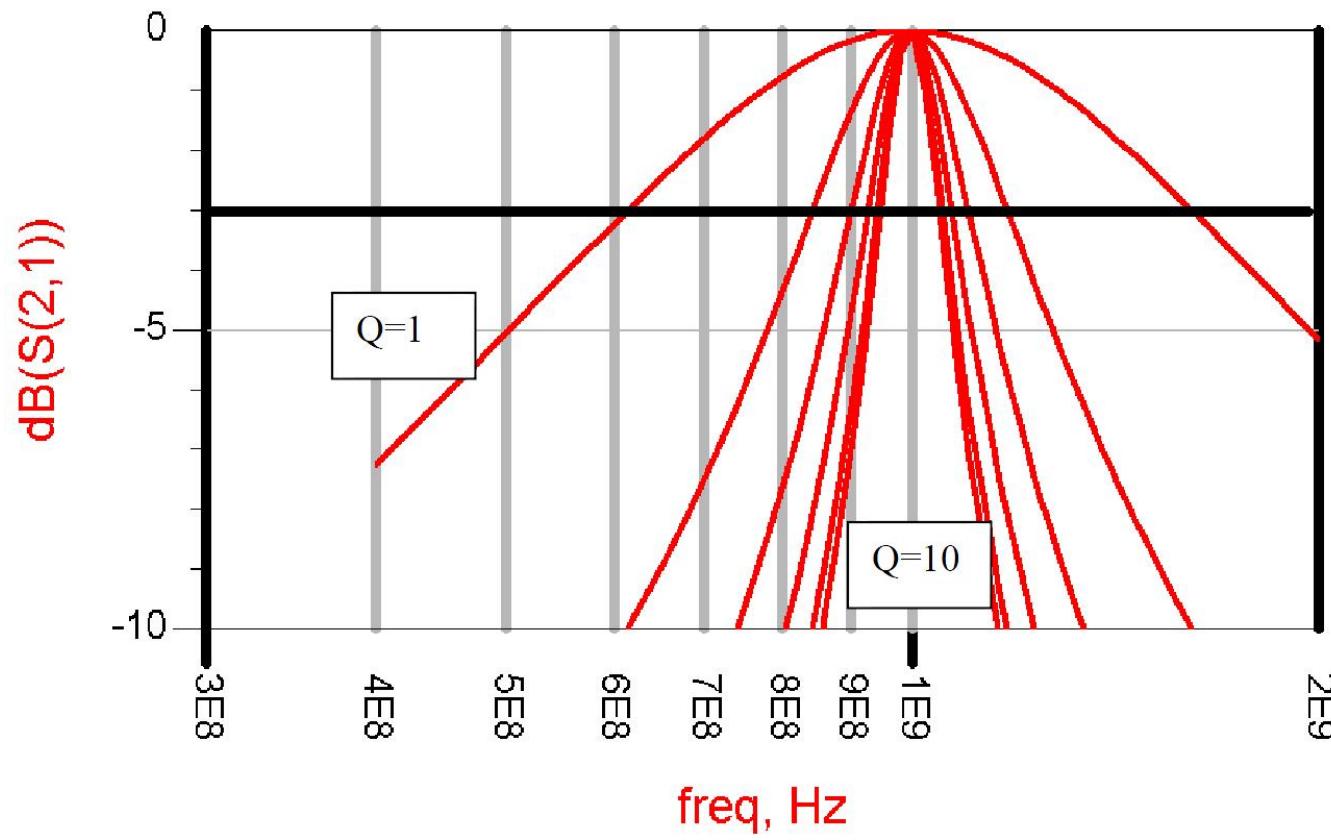
- Diagrama Smith

$$Q = \frac{X}{R} = \frac{G}{B} = const$$



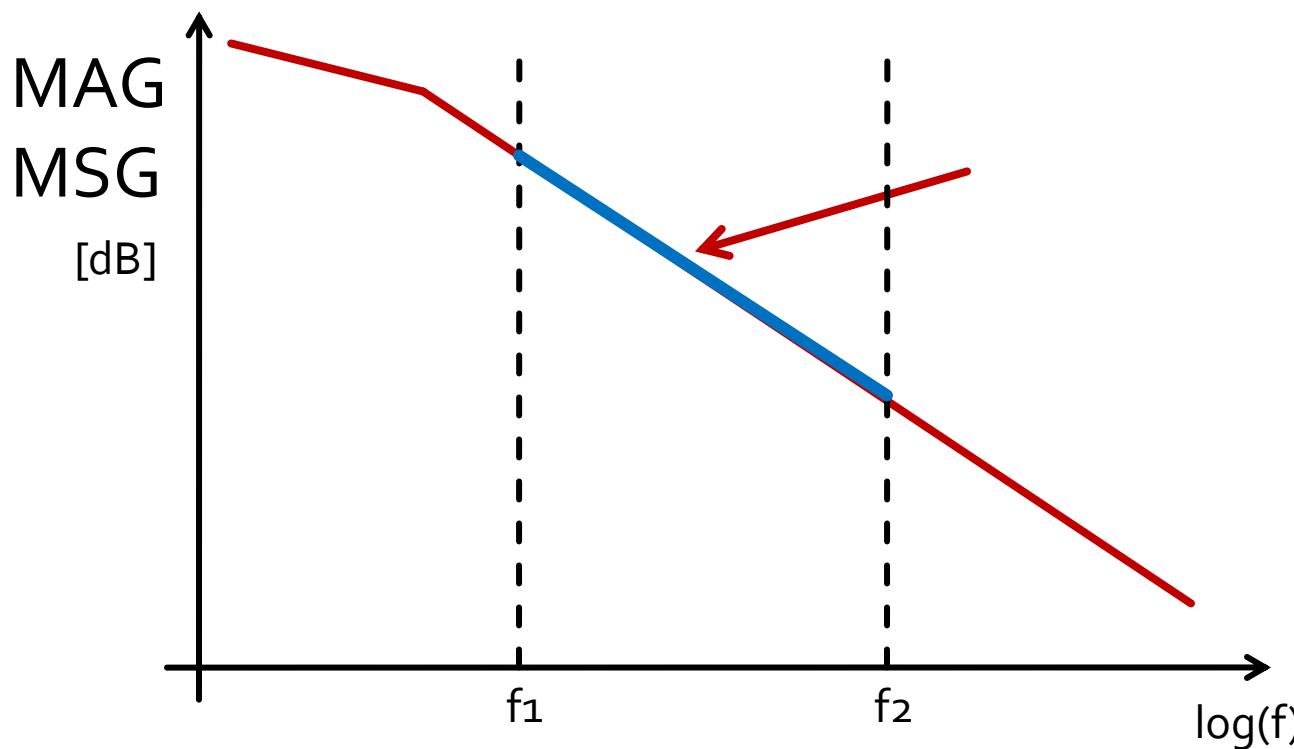
# Factor de calitate - banda

- Factor de calitate ridicat echivalent cu banda ingusta



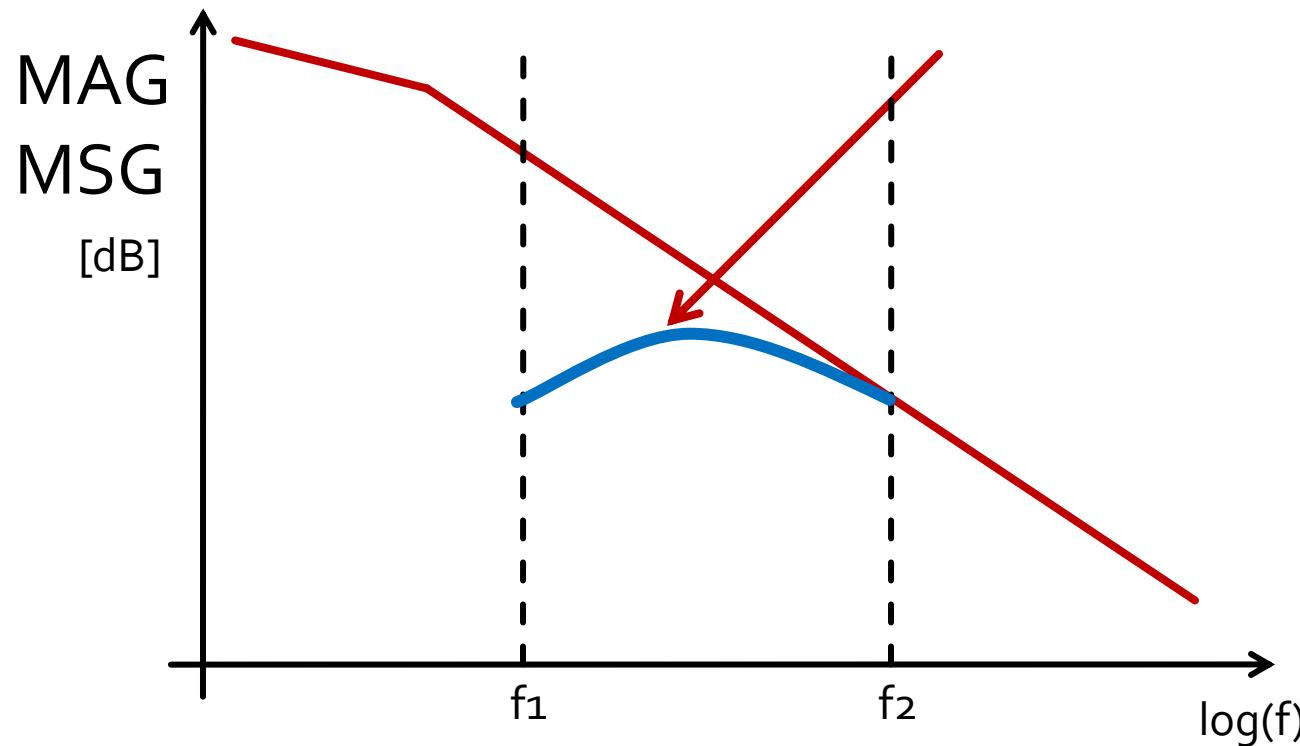
# Amplificator de banda largă

- Adaptarea pentru castig maxim la doua frecvente genereaza o comportare dezechilibrata



# Amplificator de banda largă

- Adaptare pentru castig maxim la frecventa maxima
- Dezadaptare controlata la frecventa minima
  - eventual la mai multe frecvente din banda



# Proiectare pentru castig impus

- Se realizeaza cu asumarea unilaterală a amplificatorului



Permite tratarea separată  
a intrării și ieșirii

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

$$S_{12} \approx 0 \quad \Gamma_{in} = S_{11}$$

- Castig maxim

$$\Gamma_S = S_{11}^*$$

$$\Gamma_L = S_{22}^*$$

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

# Factor de merit unilateral

- Permite estimarea erorii induse de ipoteza tranzistorului unilateral

$$\frac{1}{(1+U)^2} < \frac{G_T}{G_{TU}} < \frac{1}{(1-U)^2}$$

$$U = \frac{|S_{12}| \cdot |S_{21}| \cdot |S_{11}| \cdot |S_{22}|}{\left(1 - |S_{11}|^2\right) \cdot \left(1 - |S_{22}|^2\right)}$$

- Se calculeaza U si abaterea maxima si minima a lui  $G_{TU}$  fata de  $G_T$ 
  - aceasta abatere trebuie prevazuta in proiectare ca rezerva pentru castigul maxim

$$-20 \cdot \log(1+U) < G_T [dB] - G_{TU} [dB] < -20 \cdot \log(1-U)$$

# Exemplu

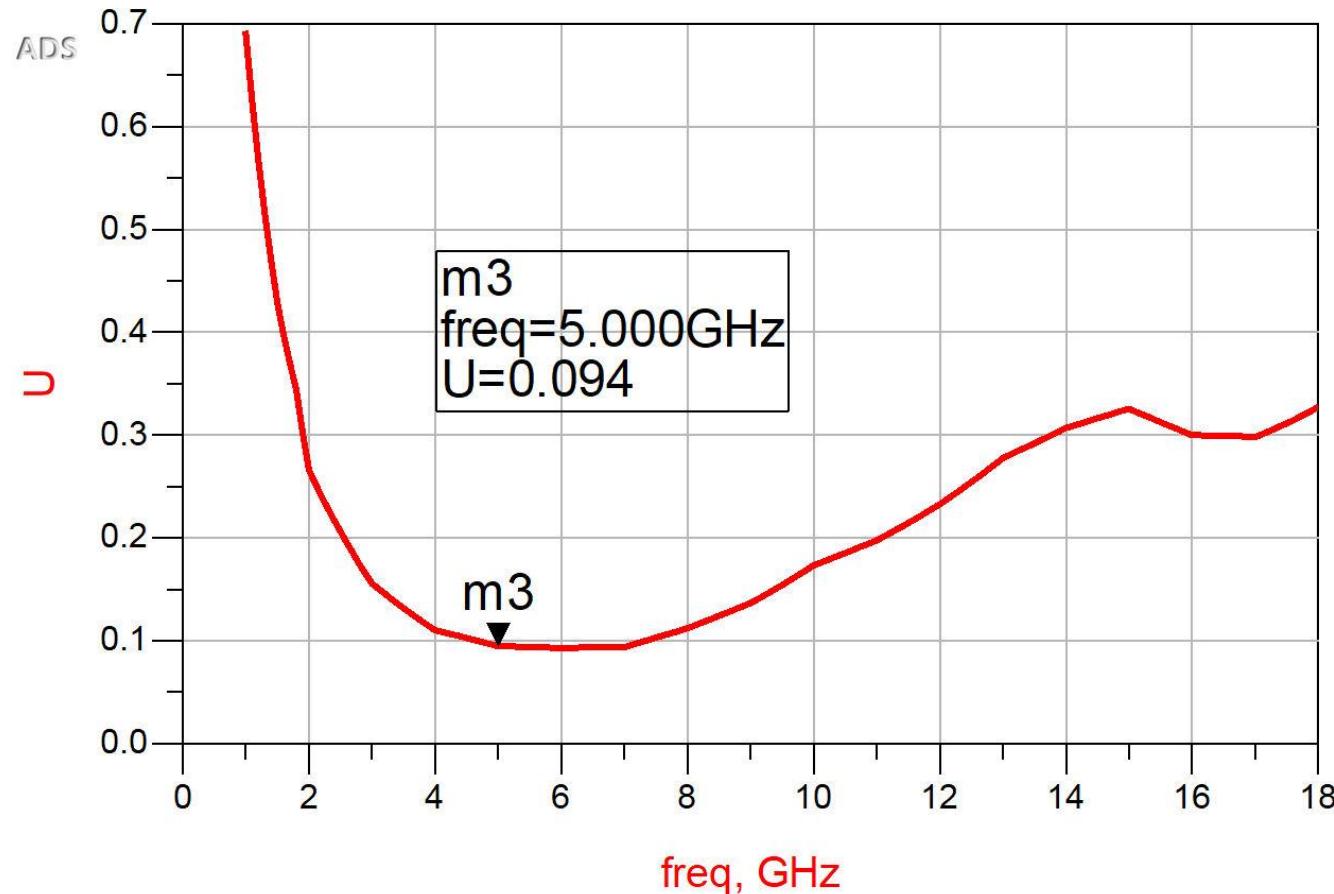
- ATF-34143 at  $V_{ds}=3V$   $I_d=20mA$ .
- @5GHz
  - $S_{11} = 0.64 \angle 139^\circ$
  - $S_{12} = 0.119 \angle -21^\circ$
  - $S_{21} = 3.165 \angle 16^\circ$
  - $S_{22} = 0.22 \angle 146^\circ$

$$U = \frac{|S_{12}| \cdot |S_{21}| \cdot |S_{11}| \cdot |S_{22}|}{\left(1 - |S_{11}|^2\right) \cdot \left(1 - |S_{22}|^2\right)} = 0.094$$

$$-0.783 \text{ dB} < G_T[\text{dB}] - G_{TU}[\text{dB}] < 0.861 \text{ dB}$$

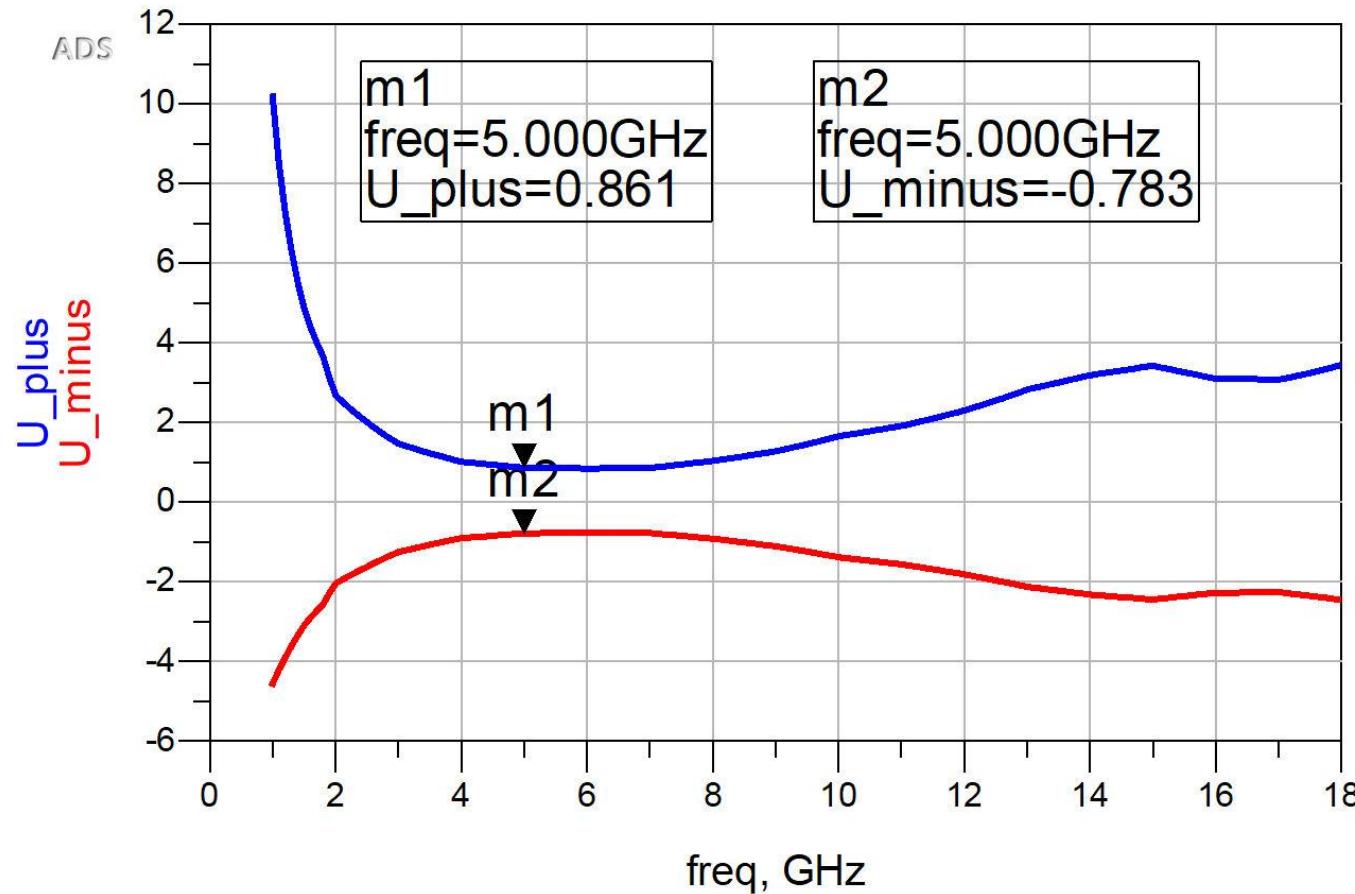
# Exemplu

- ATF-34143 at  $V_{ds}=3V$   $I_d=20mA$ .
- @5GHz

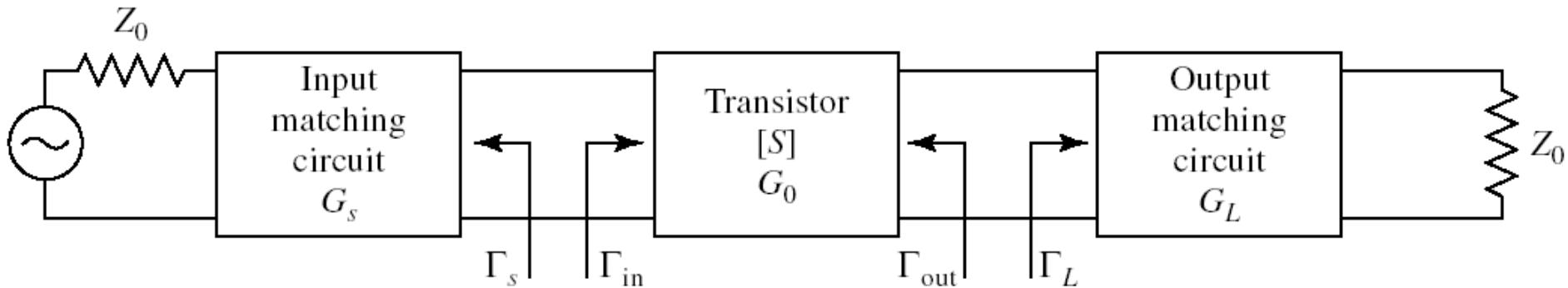


# Exemplu

- ATF-34143 at  $V_{ds}=3V$   $I_d=20mA$ .
- @5GHz



# Proiectare pentru castig impus



- Daca ipoteza tranzistorului unilateral este justificata:

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

$$G_s = \frac{1 - |\Gamma_s|^2}{|1 - S_{11} \cdot \Gamma_s|^2}$$

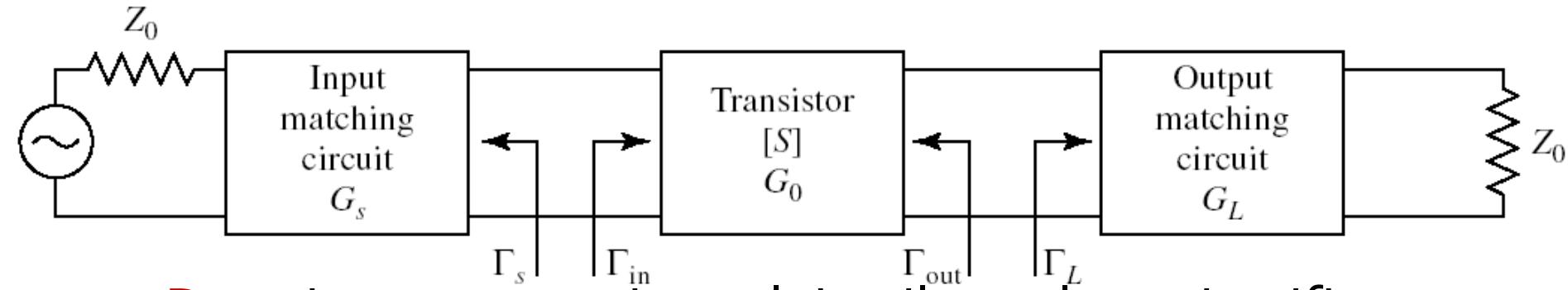
$$G_s = G_s(\Gamma_s)$$

$$G_0 = |S_{21}|^2$$

$$G_L = \frac{1 - |\Gamma_L|^2}{|1 - S_{22} \cdot \Gamma_L|^2}$$

$$G_L = G_L(\Gamma_L)$$

# Proiectare pentru castig impus

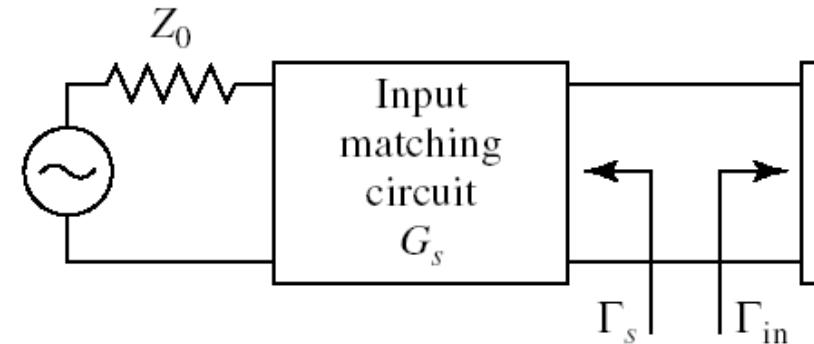


- **Daca** ipoteza tranzistorului unilateral este justificata:
  - castigul adaugat prin adaptare mai buna la intrare **nu** depinde de adaptarea la iesire  $G_s = G_s(\Gamma_s)$
  - castigul adaugat prin adaptare mai buna la iesire **nu** depinde de adaptarea la intrare  $G_L = G_L(\Gamma_L)$
- Adaptarile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

$$G_T = G_s \cdot G_0 \cdot G_L$$

$$G_T [dB] = G_s [dB] + G_0 [dB] + G_L [dB]$$

# Adaptarea la intrare



$$G_s = \frac{1 - |\Gamma_s|^2}{|1 - S_{11} \cdot \Gamma_s|^2}$$

- Castig maxim pentru adaptare complex conjugata (putere) la intrare

$$\Gamma_s = S_{11}^* \Rightarrow G_{s\max} = \frac{1}{1 - |S_{11}|^2}$$

- Pentru oricare alta retea de adaptare

$$G_s = \frac{1 - |\Gamma_s|^2}{|1 - S_{11} \cdot \Gamma_s|^2} < G_{s\max} = \frac{1}{1 - |S_{11}|^2}$$

# Exemplu

- ATF-34143 at  $V_{ds}=3V$   $I_d=20mA$ .

- @5GHz

- $S_{11} = 0.64 \angle 139^\circ$
- $S_{12} = 0.119 \angle -21^\circ$
- $S_{21} = 3.165 \angle 16^\circ$
- $S_{22} = 0.22 \angle 146^\circ$

$$U = \frac{|S_{12}| \cdot |S_{21}| \cdot |S_{11}| \cdot |S_{22}|}{\left(1 - |S_{11}|^2\right) \cdot \left(1 - |S_{22}|^2\right)} = 0.094$$

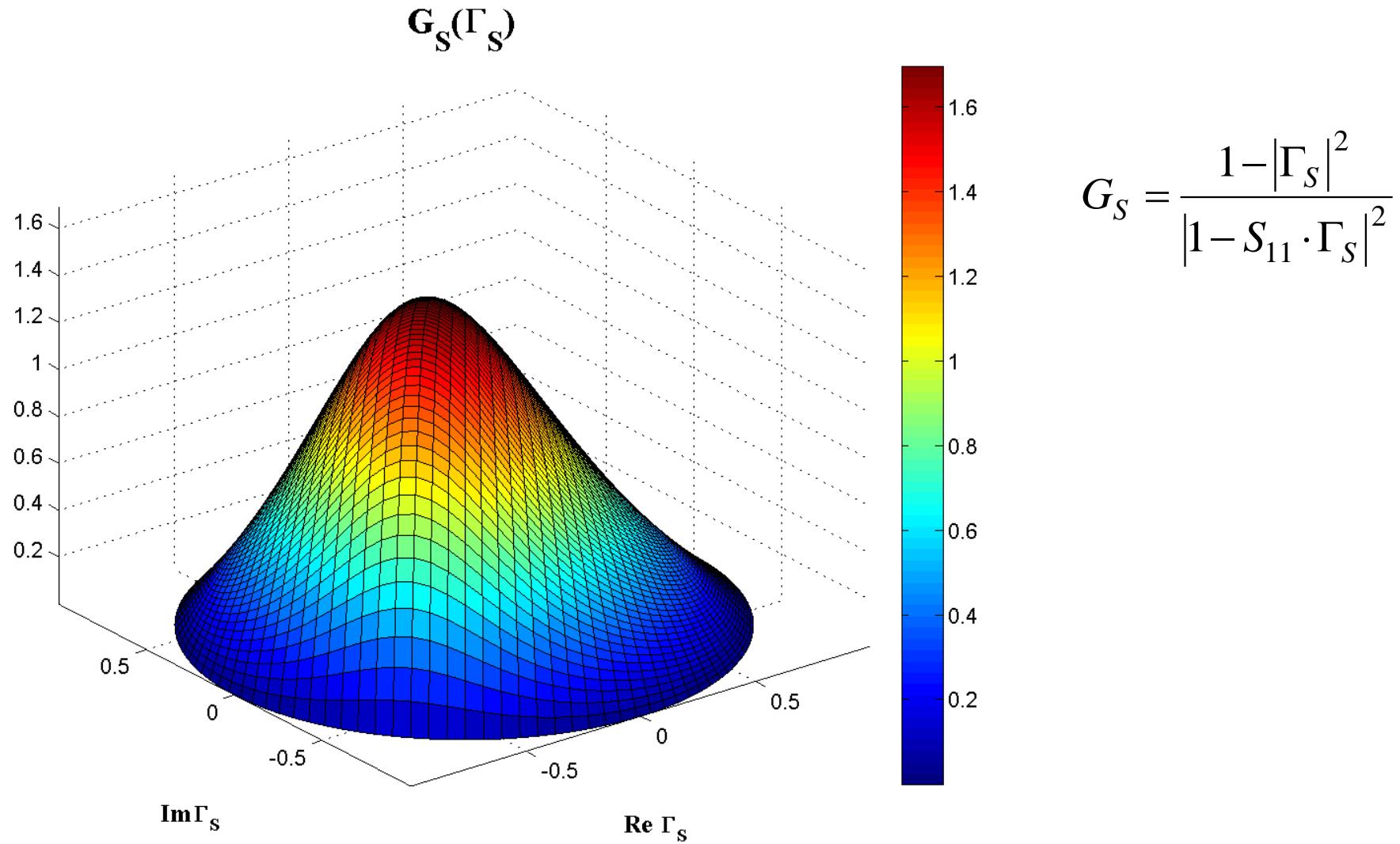
$$-0.783 \text{ dB} < G_T[\text{dB}] - G_{TU}[\text{dB}] < 0.861 \text{ dB}$$

$$G_{TU \max} = \frac{1}{1 - |S_{11}|^2} \cdot |S_{21}|^2 \cdot \frac{1}{1 - |S_{22}|^2} = 17.83$$

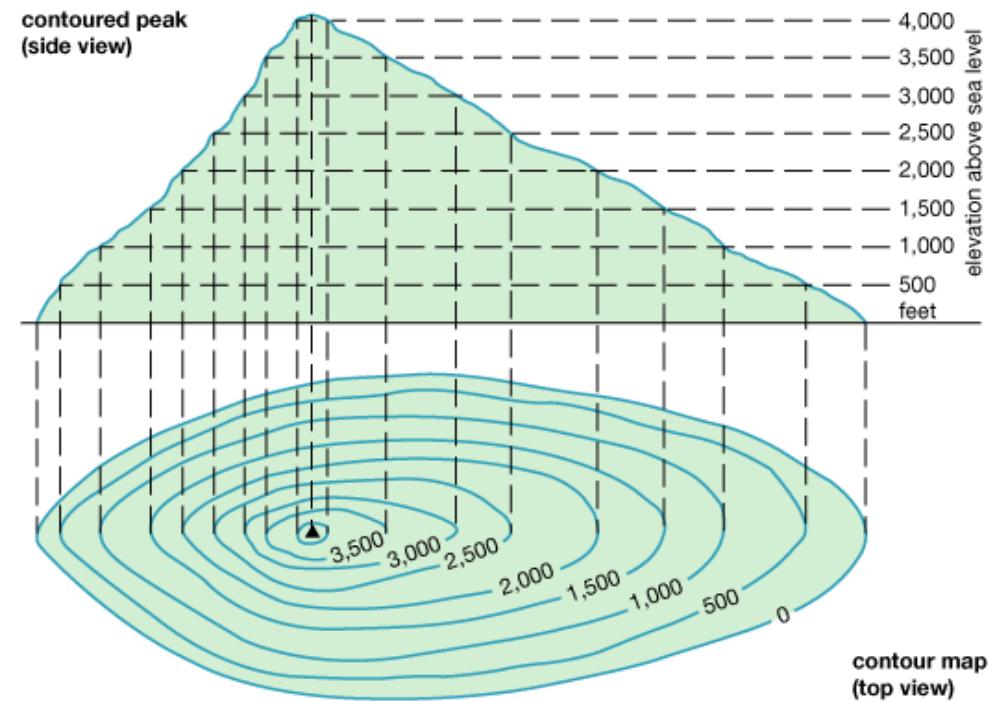
$$G_{TU \max}[\text{dB}] = 12.511 \text{ dB}$$

$$G_{S \max} = \frac{1}{1 - |S_{11}|^2} = 1.694 = 2.289 \text{ dB}$$

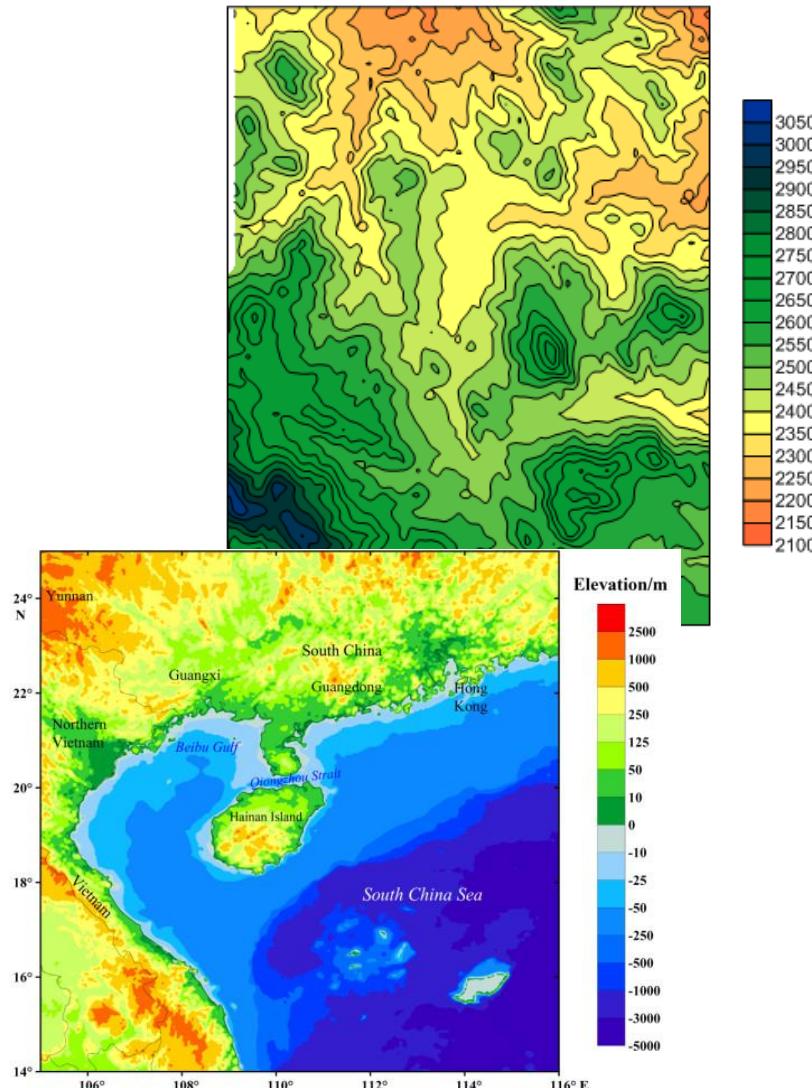
# $\mathbf{G}_S(\Gamma_S)$



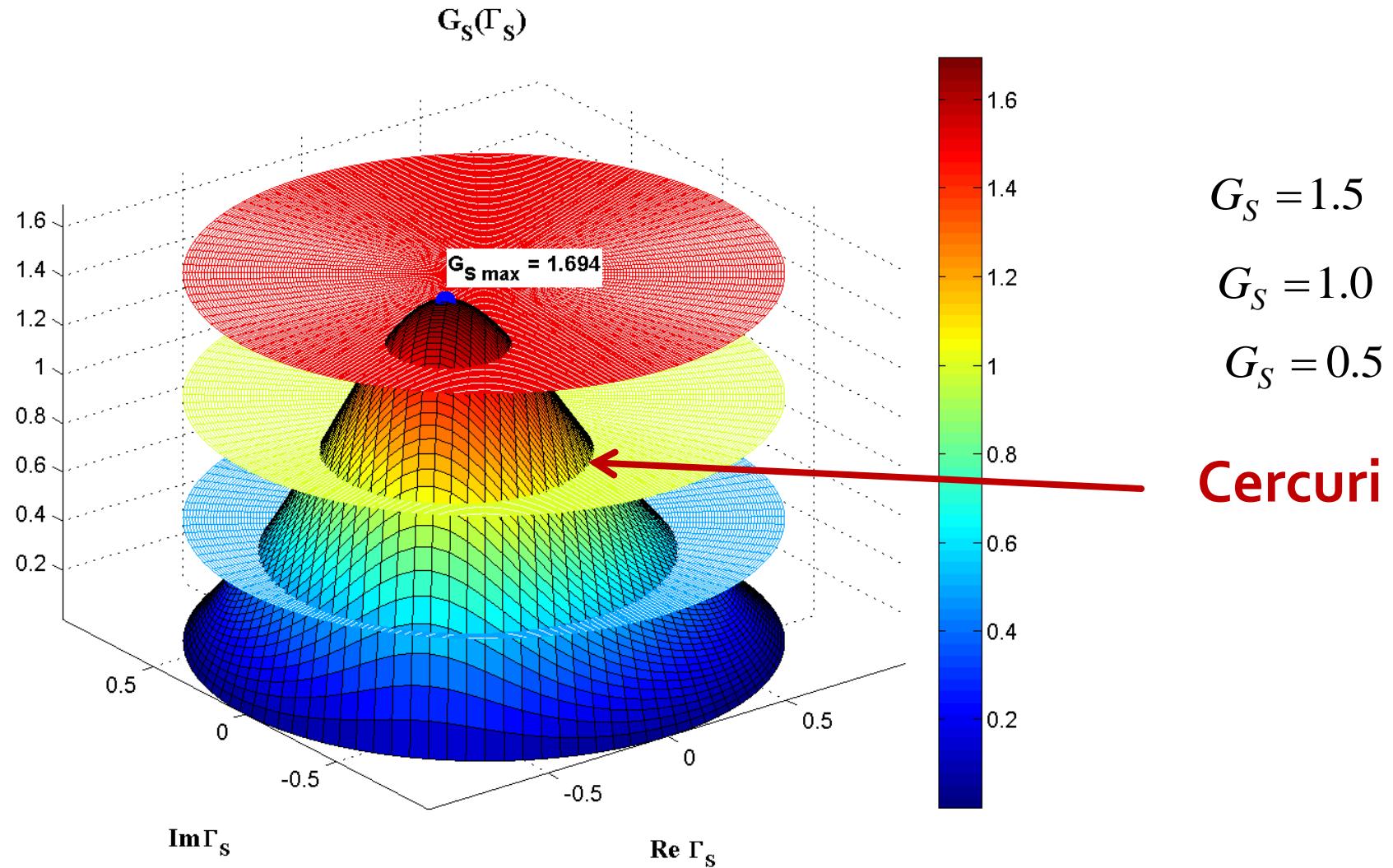
# Contour map/lines



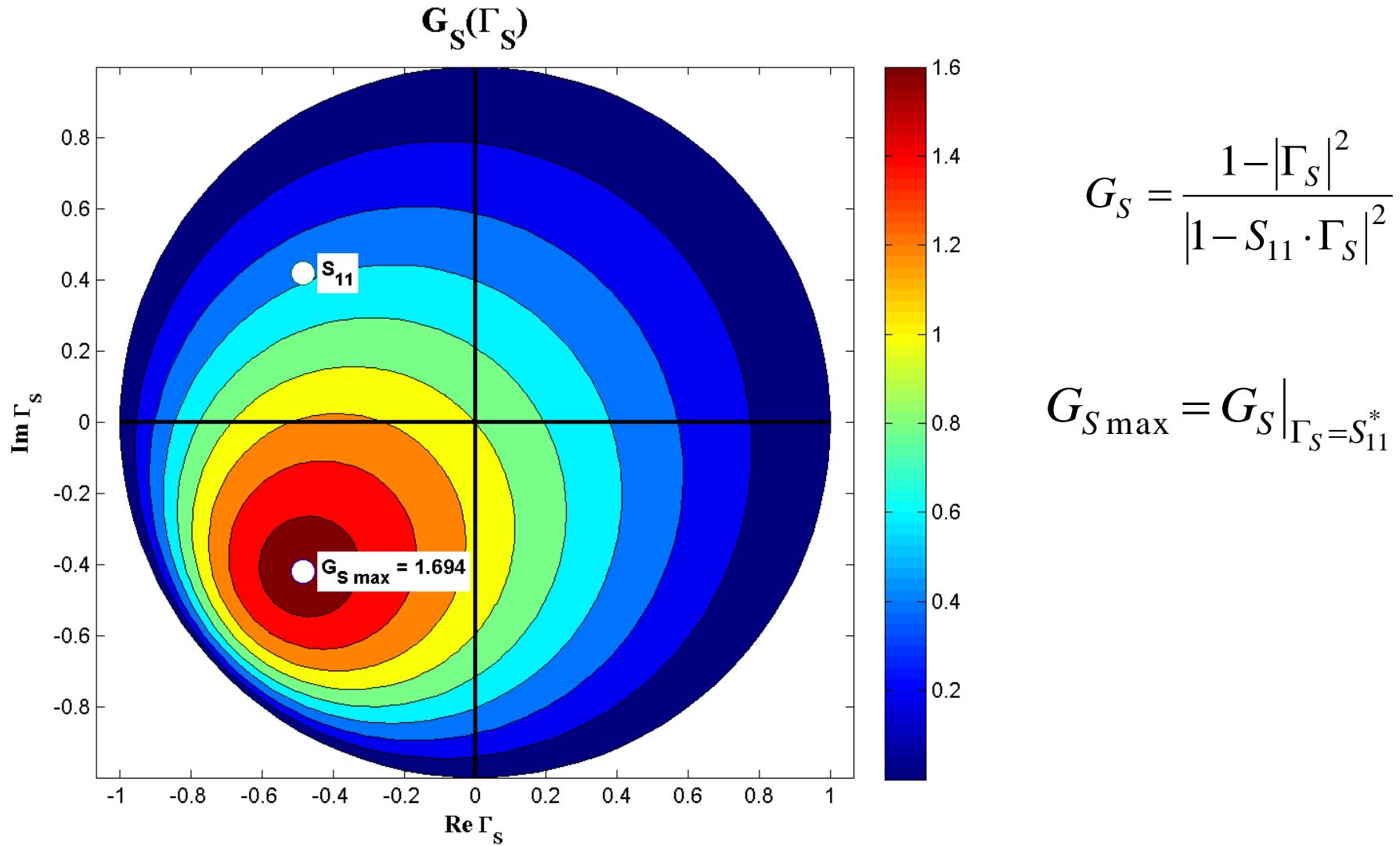
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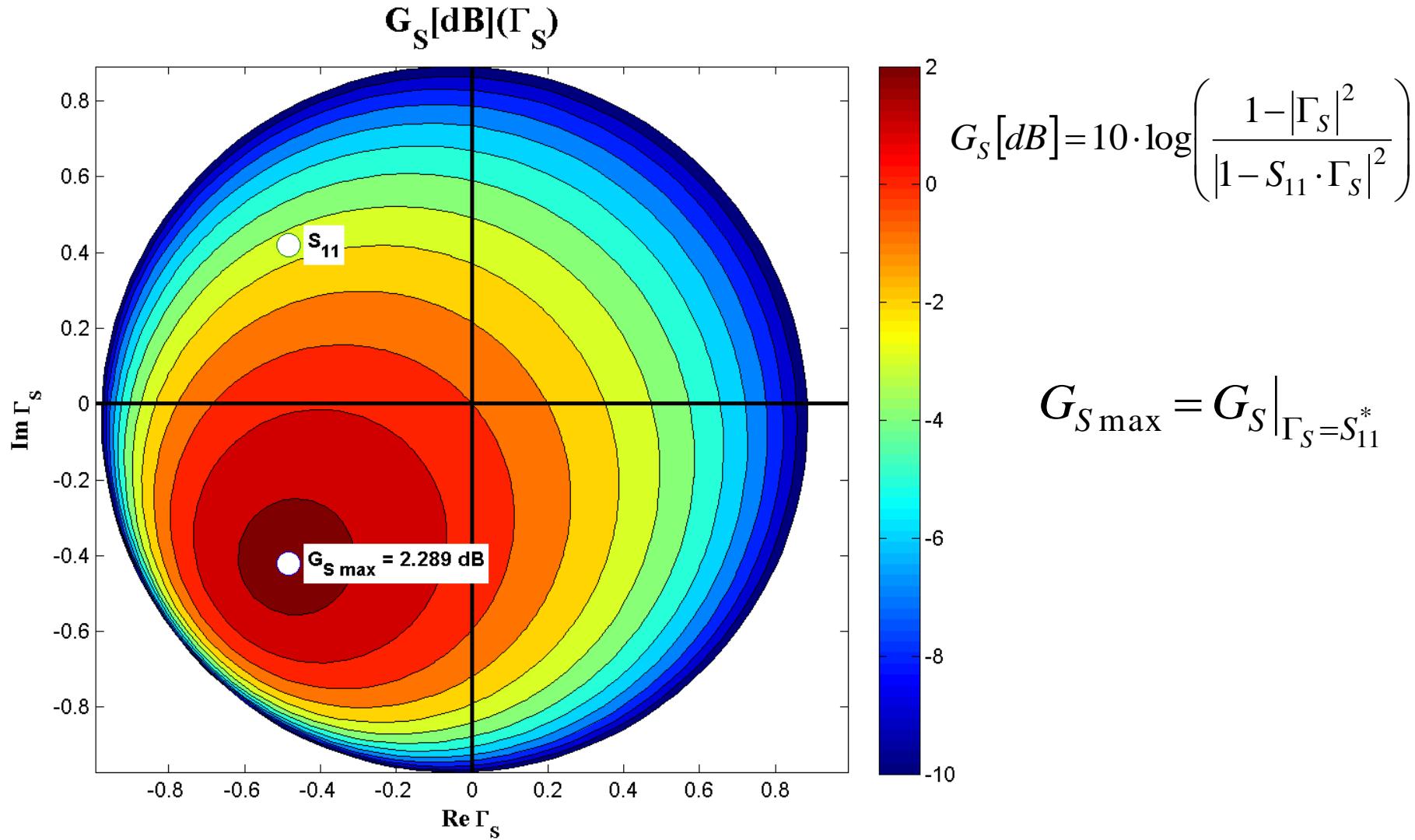
# $G_S(\Gamma_S)$ , nivel constant



# $G_S(\Gamma_S)$ , diagrama de nível



# $G_S[\text{dB}](\Gamma_S)$ , diagrama de nível



# Cercuri de castig constant la intrare

- Castig normat (coordonate liniare)

$$g_S = \frac{G_S}{G_{S\max}} = \frac{1 - |\Gamma_S|^2}{|1 - S_{11} \cdot \Gamma_S|^2} \cdot (1 - |S_{11}|^2) < 1$$

- Punctele de nivel constant, pentru un  $g_s < 1$  fixat

$$\begin{aligned} g_S \cdot |1 - S_{11} \cdot \Gamma_S|^2 &= (1 - |\Gamma_S|^2) \cdot (1 - |S_{11}|^2) \\ (g_S \cdot |S_{11}|^2 + 1 - |S_{11}|^2) \cdot |\Gamma_S|^2 - g_S \cdot (S_{11} \cdot \Gamma_S + S_{11}^* \cdot \Gamma_S^*) &= 1 - |S_{11}|^2 - g_S \\ \Gamma_S \cdot \Gamma_S^* - \frac{g_S \cdot (S_{11} \cdot \Gamma_S + S_{11}^* \cdot \Gamma_S^*)}{1 - (1 - g_S) \cdot |S_{11}|^2} &= \frac{1 - |S_{11}|^2 - g_S}{1 - (1 - g_S) \cdot |S_{11}|^2} \quad \leftarrow + \frac{g_S^2 \cdot |S_{11}|^2}{[1 - (1 - g_S) \cdot |S_{11}|^2]^2} \end{aligned}$$

# Cercuri de castig constant la intrare

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

- Ecuatia unui cerc in planul complex in care reprezint  $\Gamma_S$
- **Interpretare:** Orice punct  $\Gamma_S$  care reprezentat in planul complex se gaseste **pe** cercul desenat pentru  $g_{\text{cerc}} = G_{\text{cerc}}/G_{S\max}$  va conduce la obtinerea castigului  $G_S = G_{\text{cerc}}$ 
  - Orice punct **in exteriorul** acestui cerc va genera un castig  $G_S < G_{\text{cerc}}$
  - Orice punct **in interiorul** acestui cerc va genera un castig  $G_S > G_{\text{cerc}}$

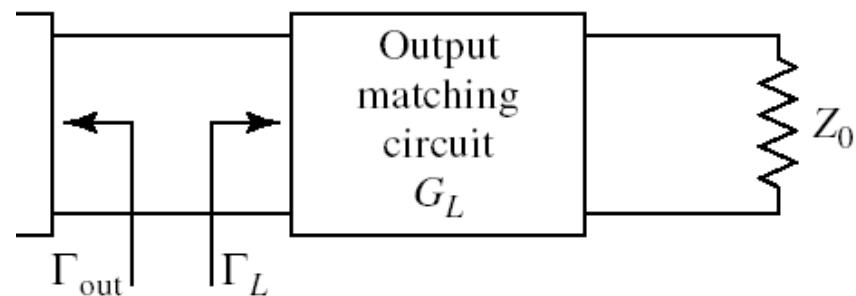
# Cercuri de castig constant la intrare

$$C_S = \frac{g_S \cdot S_{11}^*}{1 - (1 - g_S) \cdot |S_{11}|^2}$$

$$R_S = \frac{\sqrt{1 - g_S} \cdot (1 - |S_{11}|^2)}{1 - (1 - g_S) \cdot |S_{11}|^2}$$

- Centrele cercurilor se gasesc pe segmentul care unește  $\Gamma_S = S_{11}^*$  cu centrul diagramei Smith
- Cercurile se traseaza (traditional, CAD) in **coordonate logaritmice** ([dB])
  - relatiile de calcul sunt in coordonate **liniare** !
- Cercul corespunzator lui  $g_S = 0$  dB trece prin origine

# Cercuri de castig constant la iesire



$$G_L = \frac{1 - |\Gamma_L|^2}{|1 - S_{22} \cdot \Gamma_L|^2}$$

- Castig maxim  $\Gamma_L = S_{22}^* \Rightarrow G_{L\max} = \frac{1}{1 - |S_{22}|^2}$

$$g_L = \frac{G_L}{G_{L\max}} = \frac{1 - |\Gamma_L|^2}{|1 - S_{22} \cdot \Gamma_L|^2} \cdot (1 - |S_{22}|^2) < 1$$

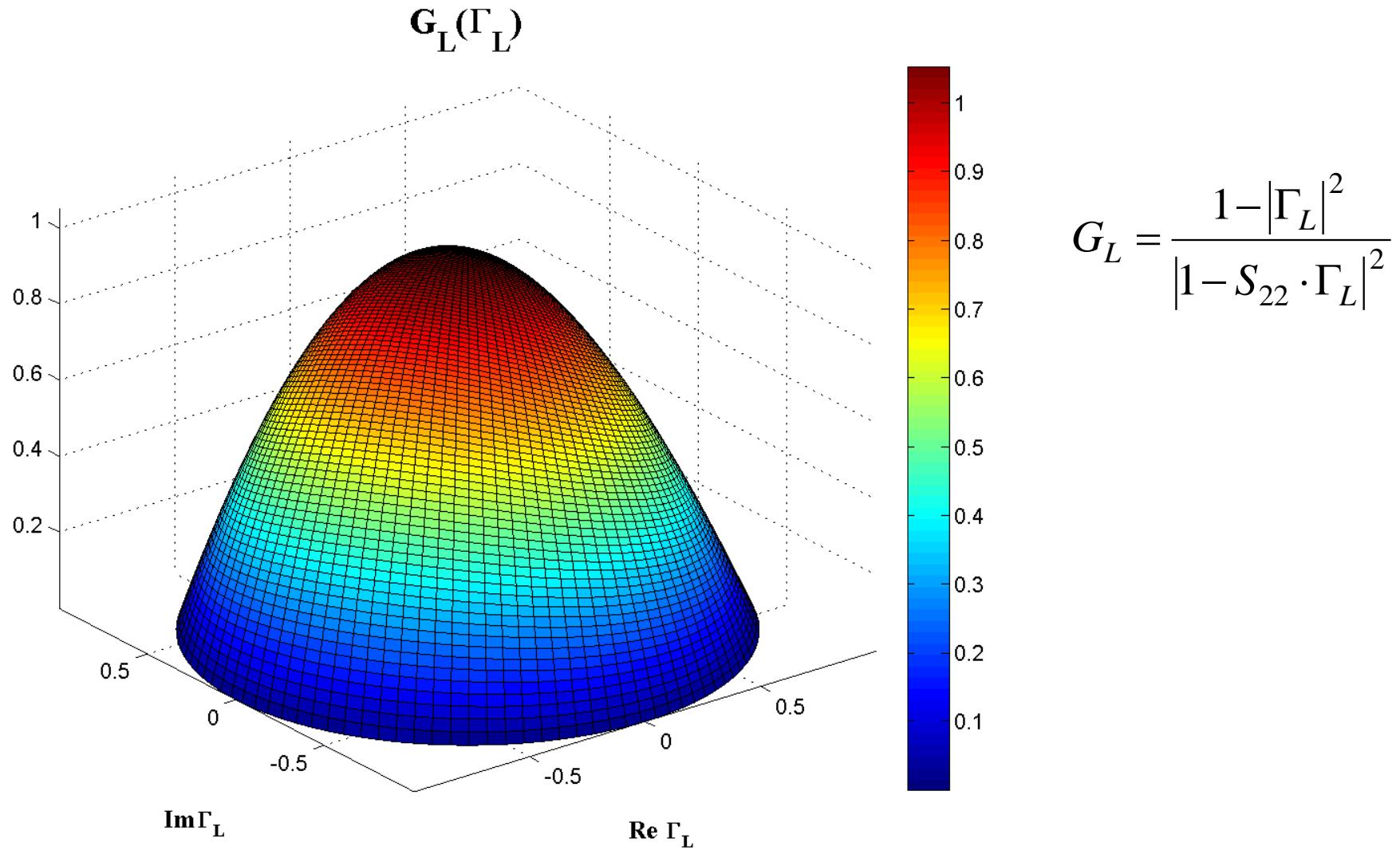
- Calcul similar

$$C_L = \frac{g_L \cdot S_{22}^*}{1 - (1 - g_L) \cdot |S_{22}|^2}$$

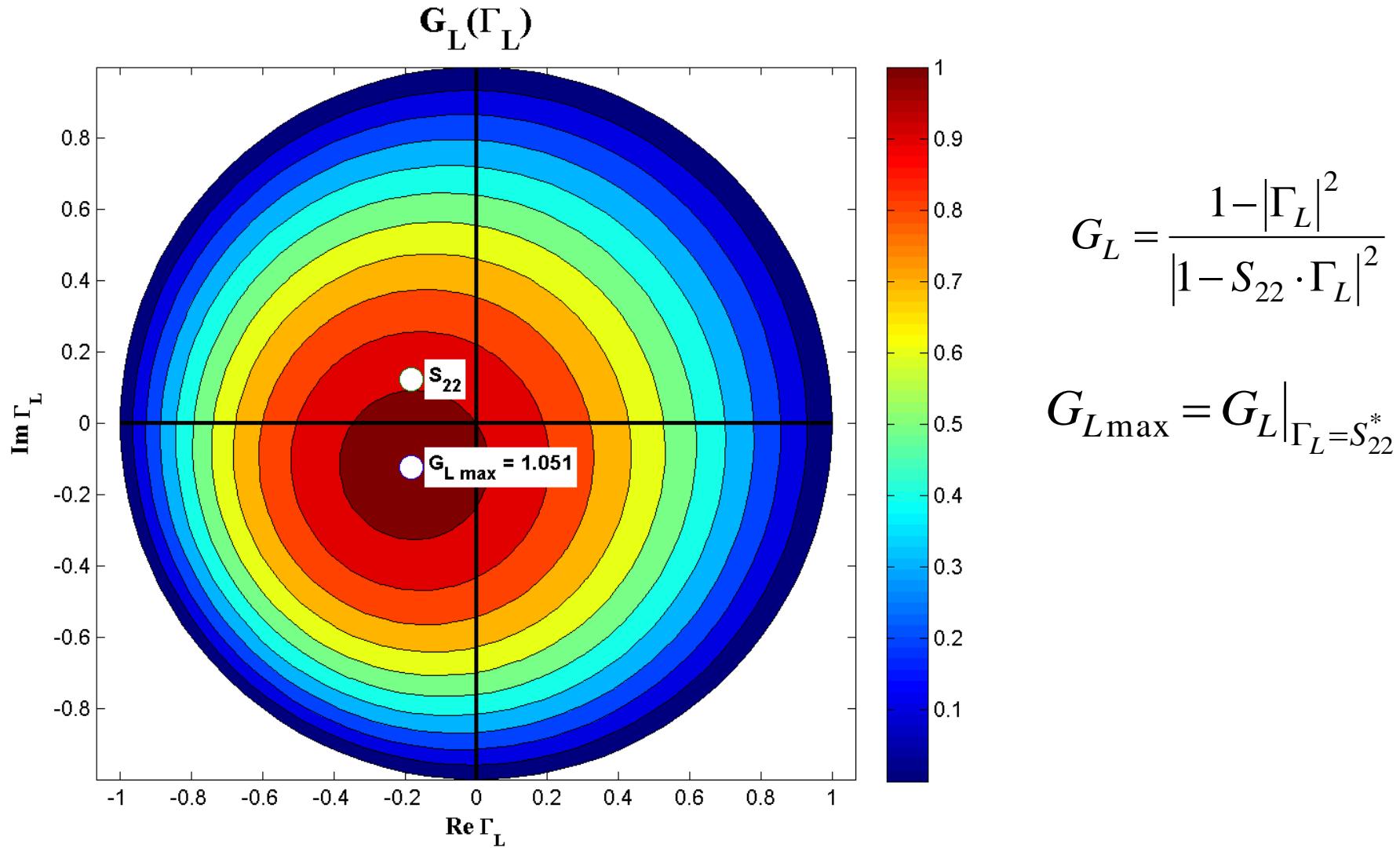
$$R_L = \frac{\sqrt{1 - g_L} \cdot (1 - |S_{22}|^2)}{1 - (1 - g_L) \cdot |S_{22}|^2}$$

- Exemplu  $G_{L\max} = \frac{1}{1 - |S_{22}|^2} = 1.051 = 0.215 \text{ dB}$

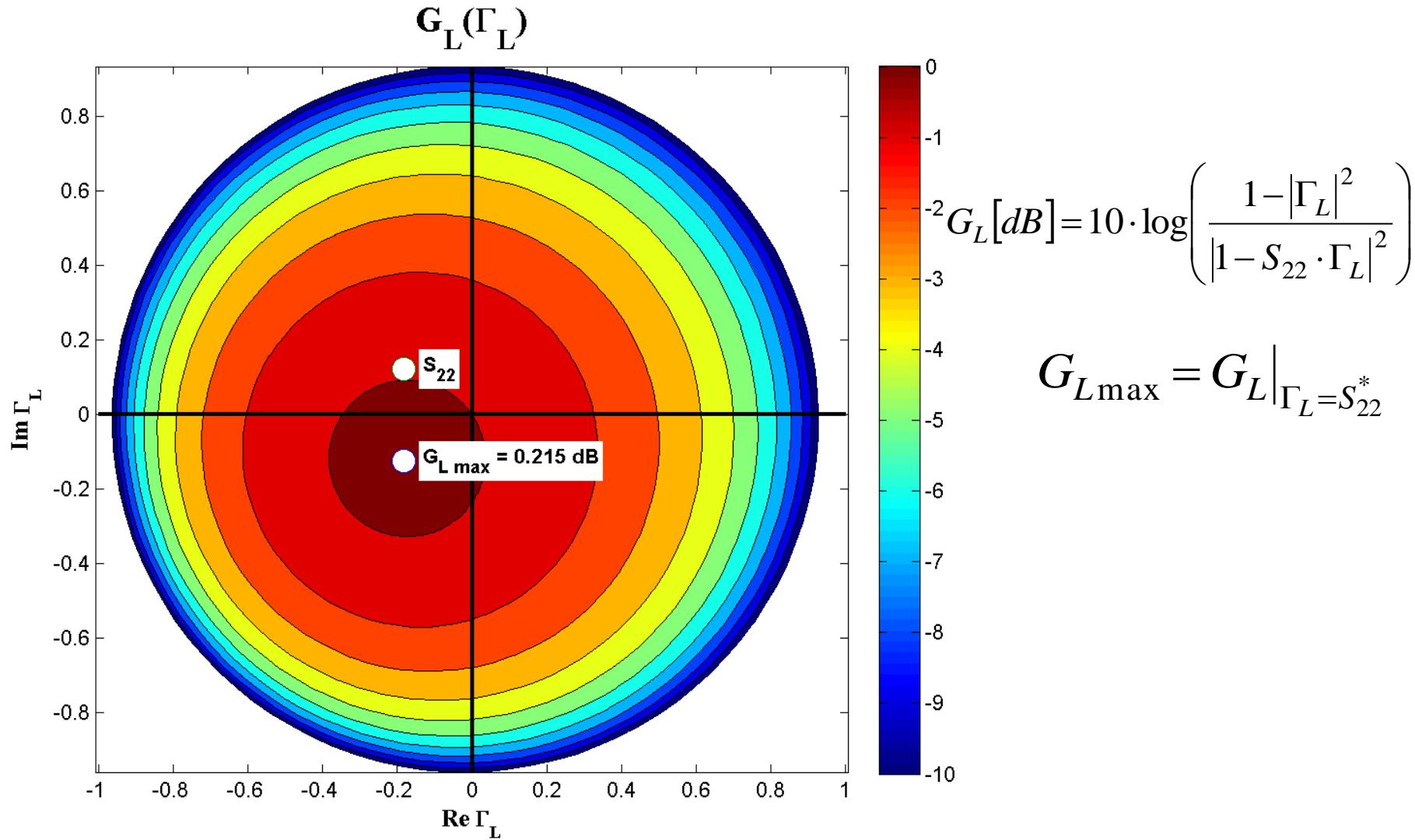
# $\mathbf{G}_L(\Gamma_L)$



# $G_L(\Gamma_L)$ , diagrama de nível

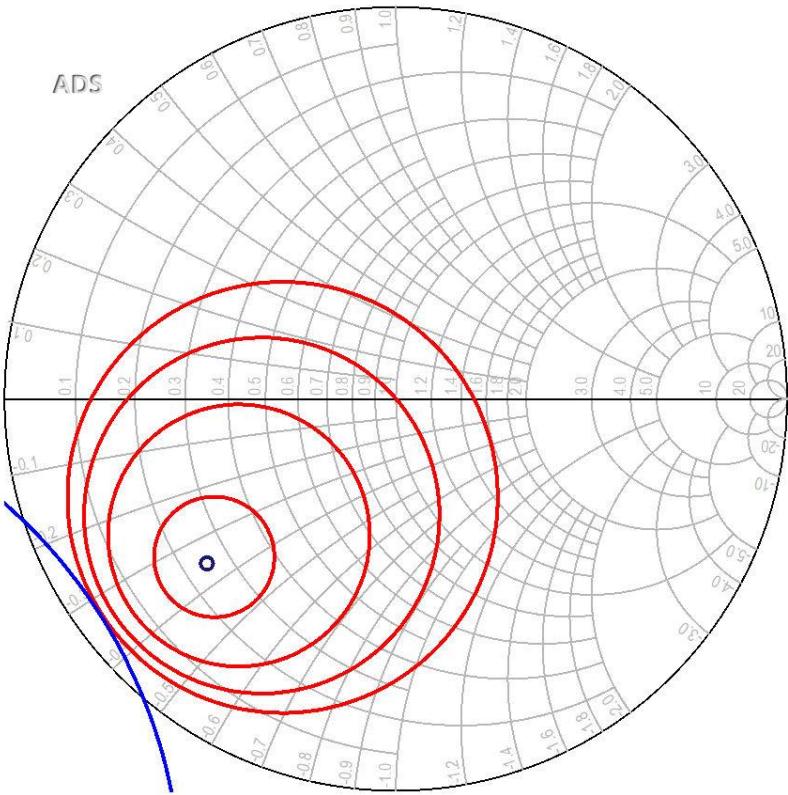


# $G_L[\text{dB}](\Gamma_L)$ , diagrama de nível

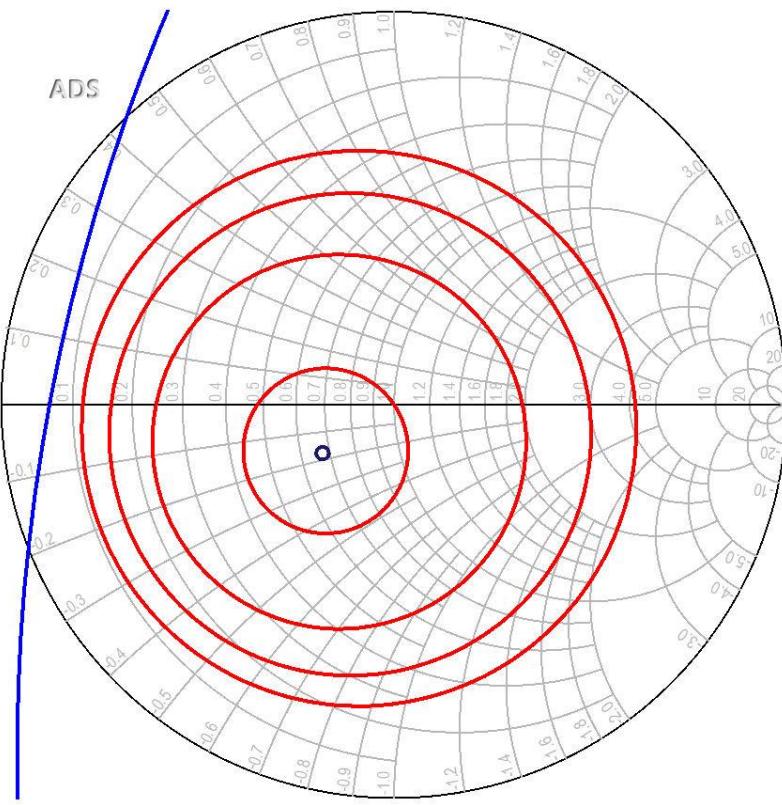


# ADS

conj(S(1,1))  
CSIN  
CCCIN



conj(S(2,2))  
CSOUT  
CCCOUT



- Cerculile se reprezinta pentru valorile cerute in dB
- Este utila calcularea  $G_{S_{max}}$  si  $G_{L_{max}}$  anterior

# Proiectare pentru castig impus

- Se calculeaza  $G_o$ ,  $G_{S_{max}}$ ,  $G_{L_{max}}$
- Pentru obtinerea castigului impus se **aleg** valorile suplimentare necesare (suplimentar la  $G_o$ )
  - se tine cont de abaterea caracterizata de factorul de merit U

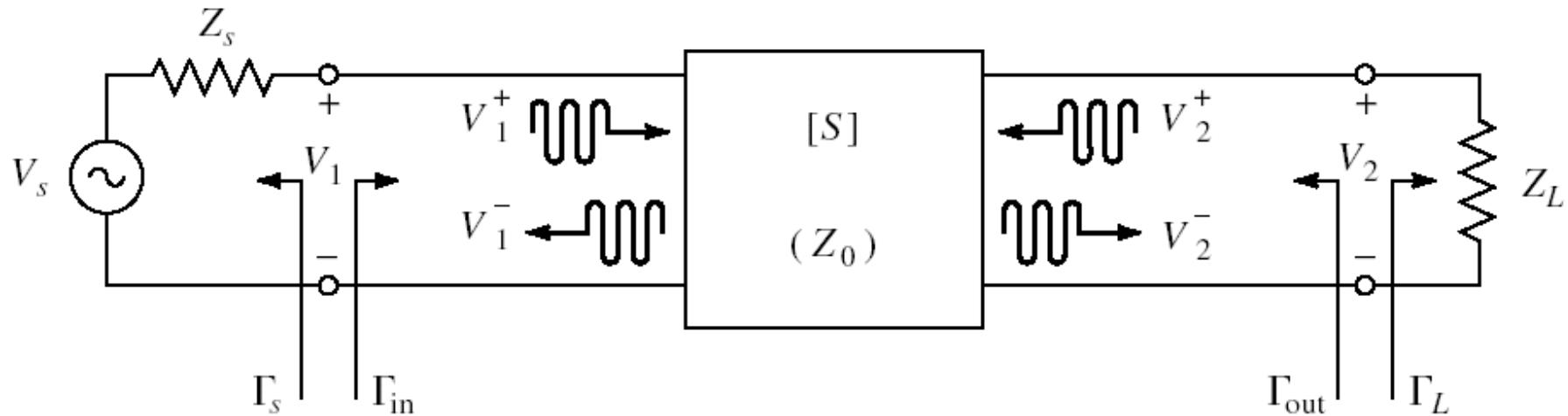
$$G_{dorit} [dB] = G_{S\_dor} [dB] + G_0 [dB] + G_{L\_dor} [dB]$$

- Se reprezinta cercurile de castig pentru valorile alese  $G_{S\_dor}$ ,  $G_{L\_dor}$
- Se proiecteaza retelele de adaptare care muta coeficientul de reflexie **pe** sau **in interiorul** cercurilor dorite (in functie de aplicatie)

Preview (pentru laborator 3-4)

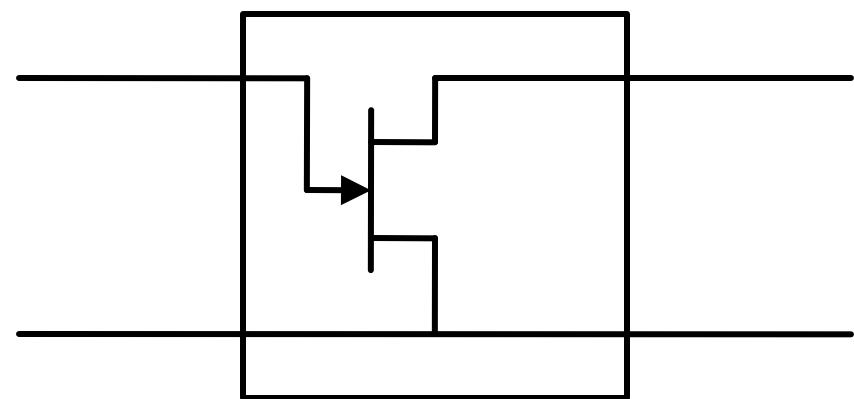
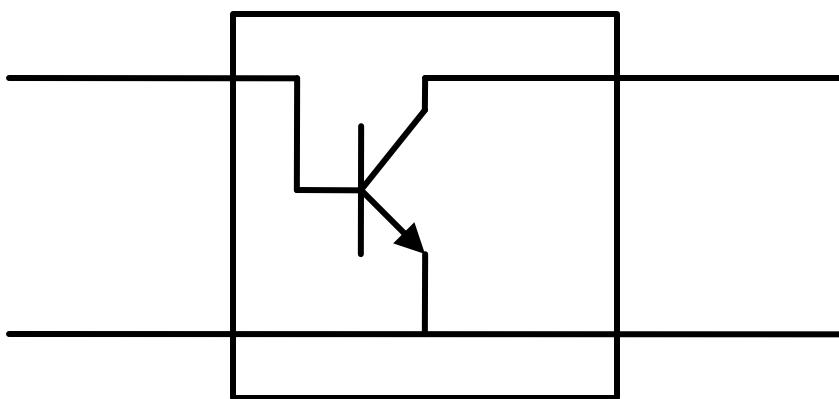
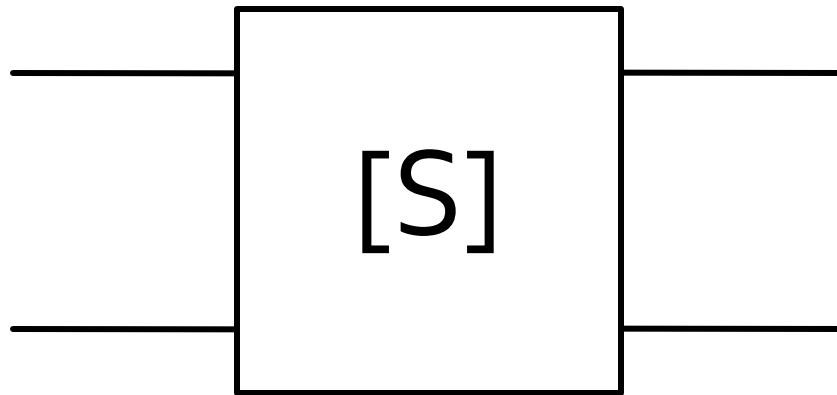
# **Amplificatoare de microunde**

# Cuadripol Amplificator (diport)



- Caracterizare cu parametri S
- Normalizati la  $Z_0$  (implicit  $50\Omega$ )
- Catalogage: parametri S pentru anumite polarizari

# Parametri S

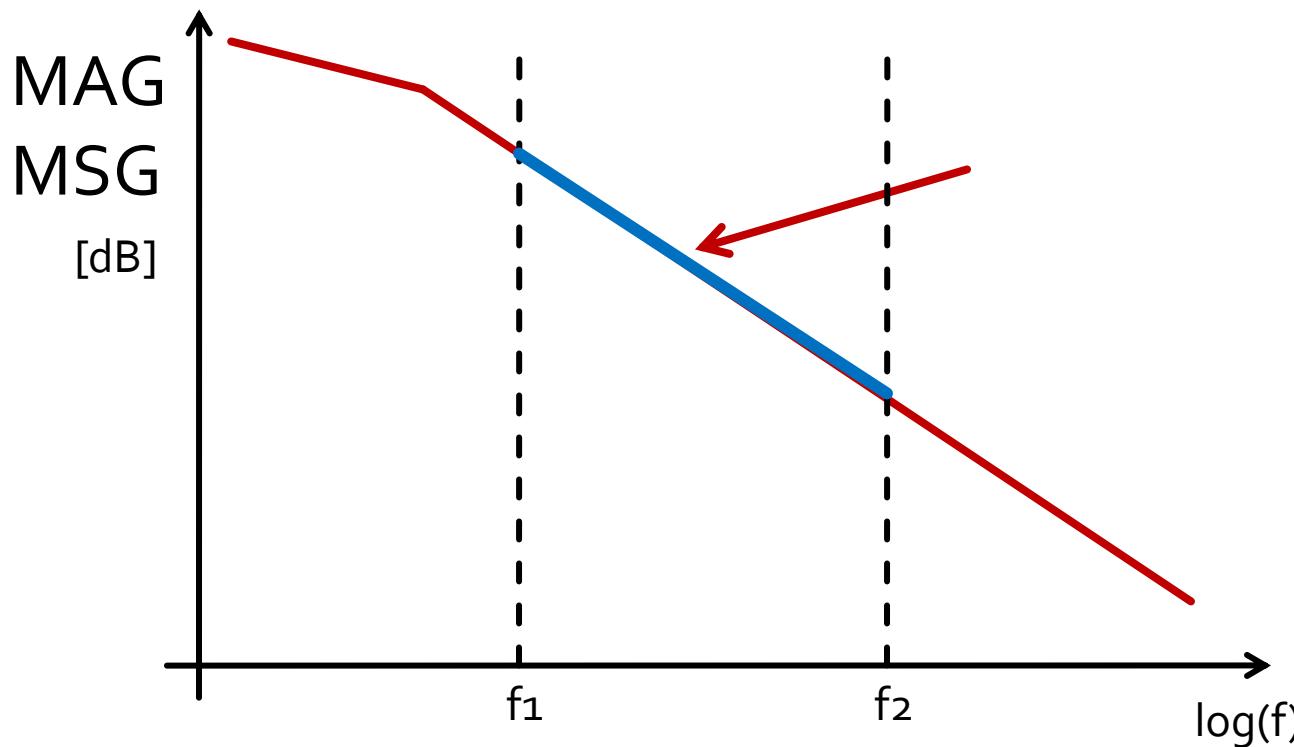


# Proiectare pentru castig impus

- Deseori este necesara o alta abordare decat "forta bruta" si se prefera obtinerea unui **castig mai mic** decat cel maxim posibil pentru:
  - conditii de zgomot avantajoase ( $L_3$ )
  - conditii de stabilitate mai bune
  - obtinerea unui VSWR mai mic
  - controlul performantelor la mai multe frecvente
  - banda de functionare a amplificatorului

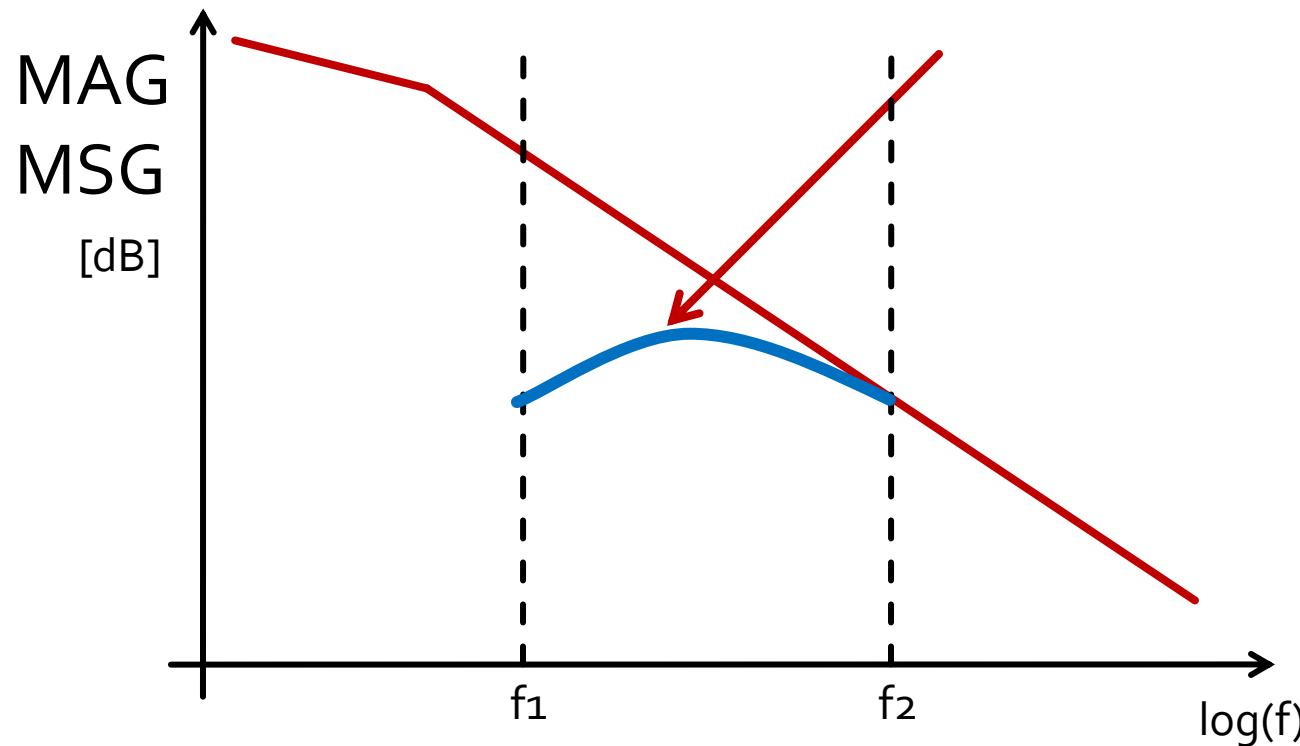
# Amplificator de banda largă

- Adaptarea pentru castig maxim la doua frecvente genereaza o comportare dezechilibrata

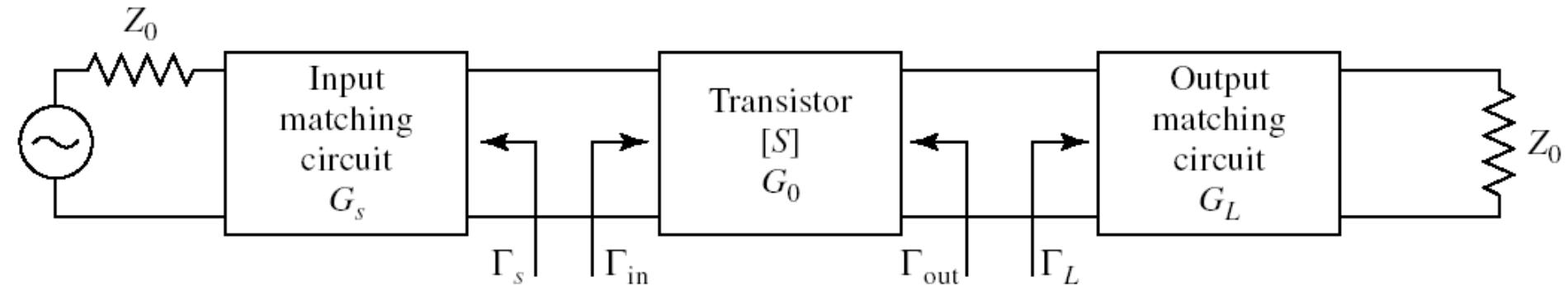


# Amplificator de banda largă

- Adaptare pentru castig maxim la frecventa maxima
- Dezadaptare controlata la frecventa minima
  - eventual la mai multe frecvente din banda



# Proiectare pentru castig impus



- Daca ipoteza tranzistorului unilateral este justificata:

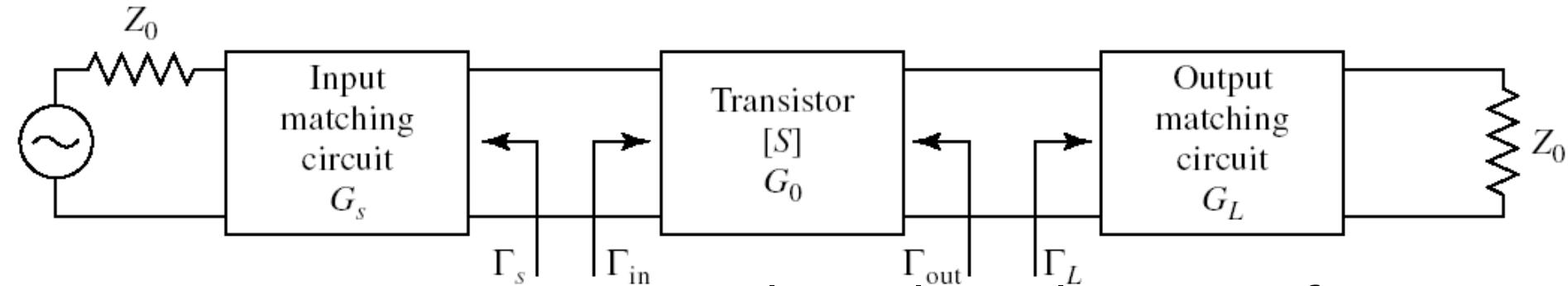
$$G_{TU} = |S_{21}|^2 \cdot \frac{1 - |\Gamma_S|^2}{|1 - S_{11} \cdot \Gamma_S|^2} \cdot \frac{1 - |\Gamma_L|^2}{|1 - S_{22} \cdot \Gamma_L|^2}$$

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

$$G_0 = |S_{21}|^2$$

$$G_L = \frac{1 - |\Gamma_L|^2}{|1 - S_{22} \cdot \Gamma_L|^2}$$

# Proiectare pentru castig impus

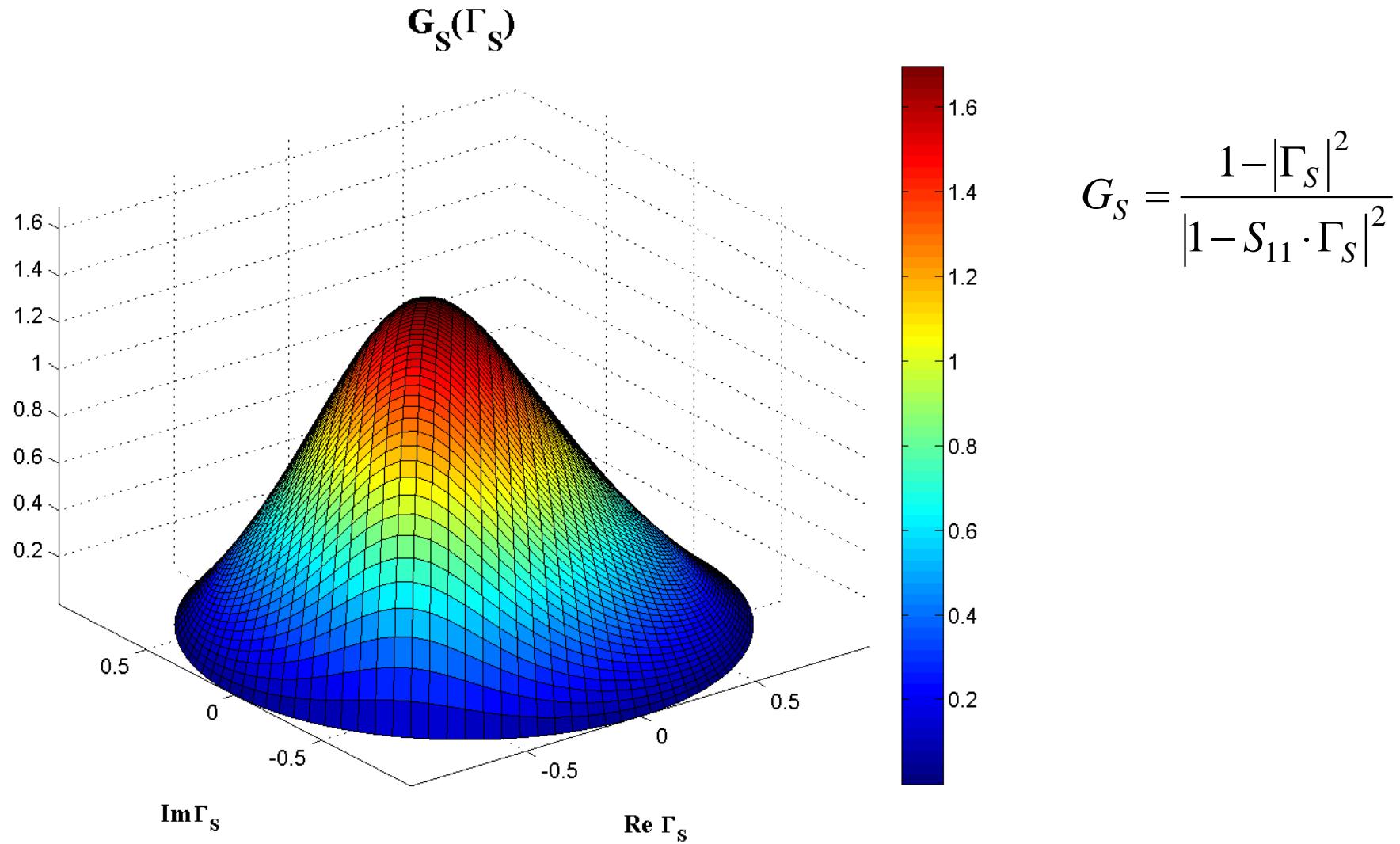


- Daca ipoteza tranzistorului unilateral este justificata:
  - castigul adaugat prin adaptare mai buna la intrare **nu** depinde de adaptarea la iesire
  - castigul adaugat prin adaptare mai buna la iesire **nu** depinde de adaptarea la intrare
- Adaptarile la intrare/iesire pot fi tratate independent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

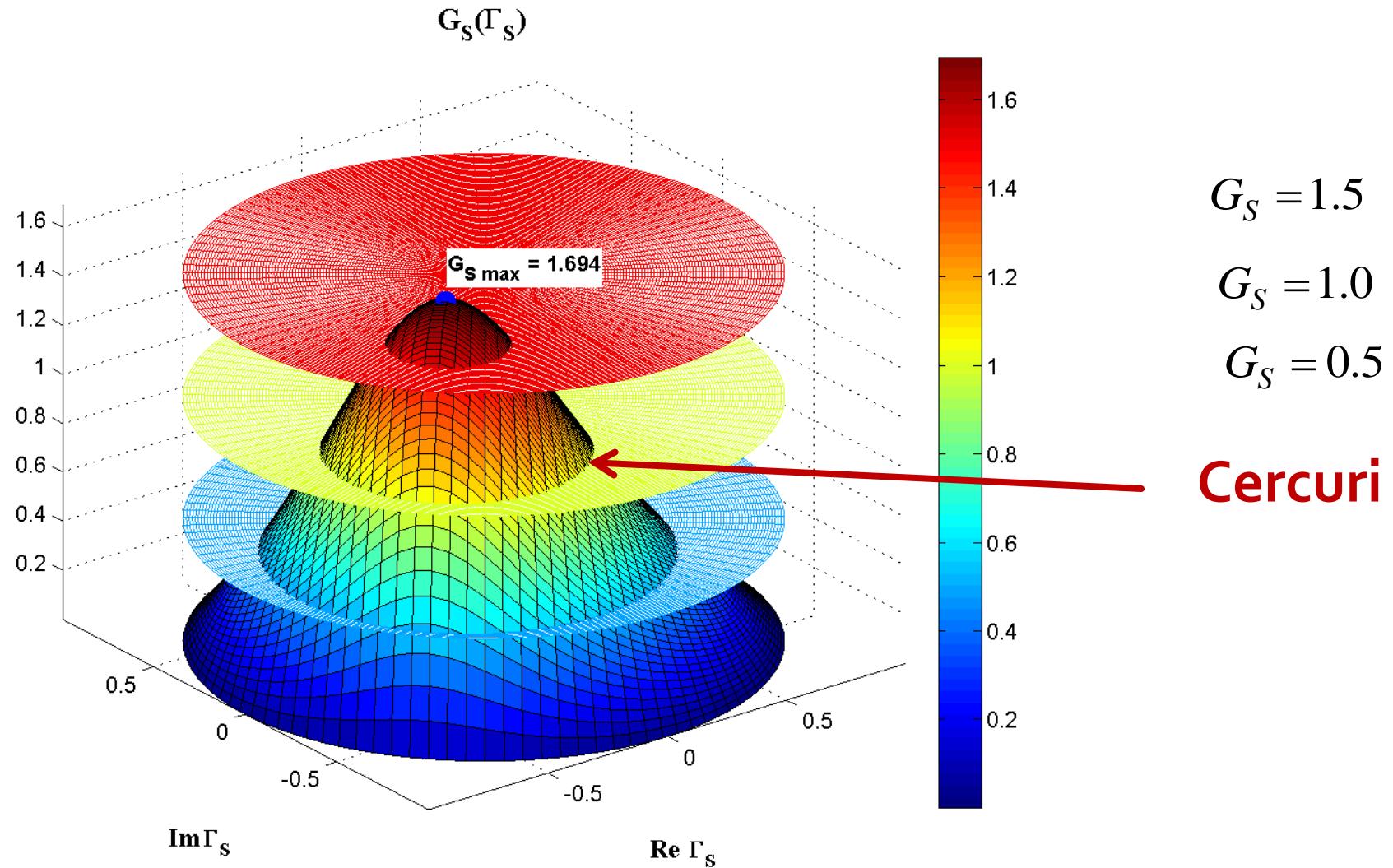
$$G_T = G_S \cdot G_0 \cdot G_L$$

$$G_T [dB] = G_S [dB] + G_0 [dB] + G_L [dB]$$

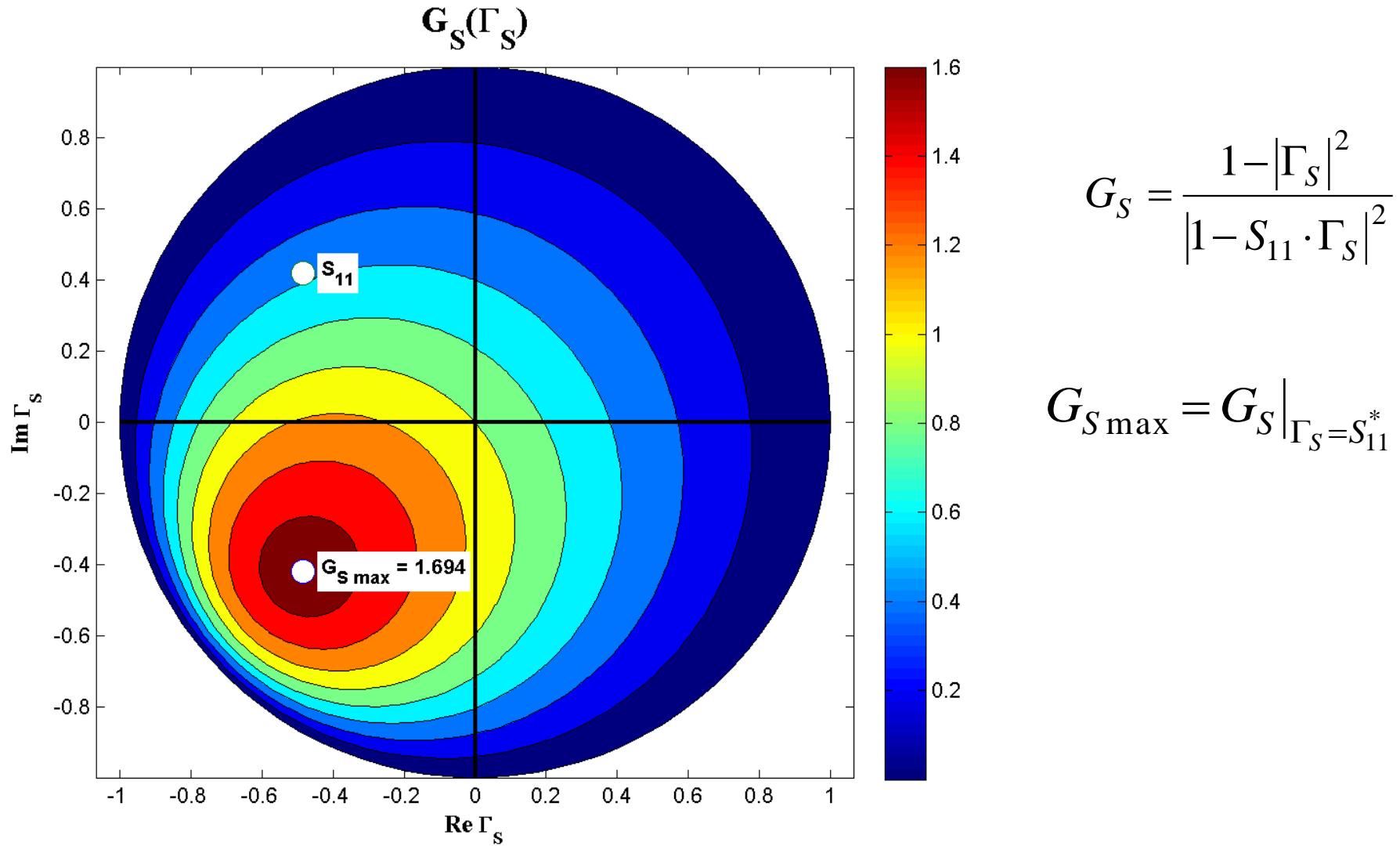
# $\mathbf{G}_S(\Gamma_S)$



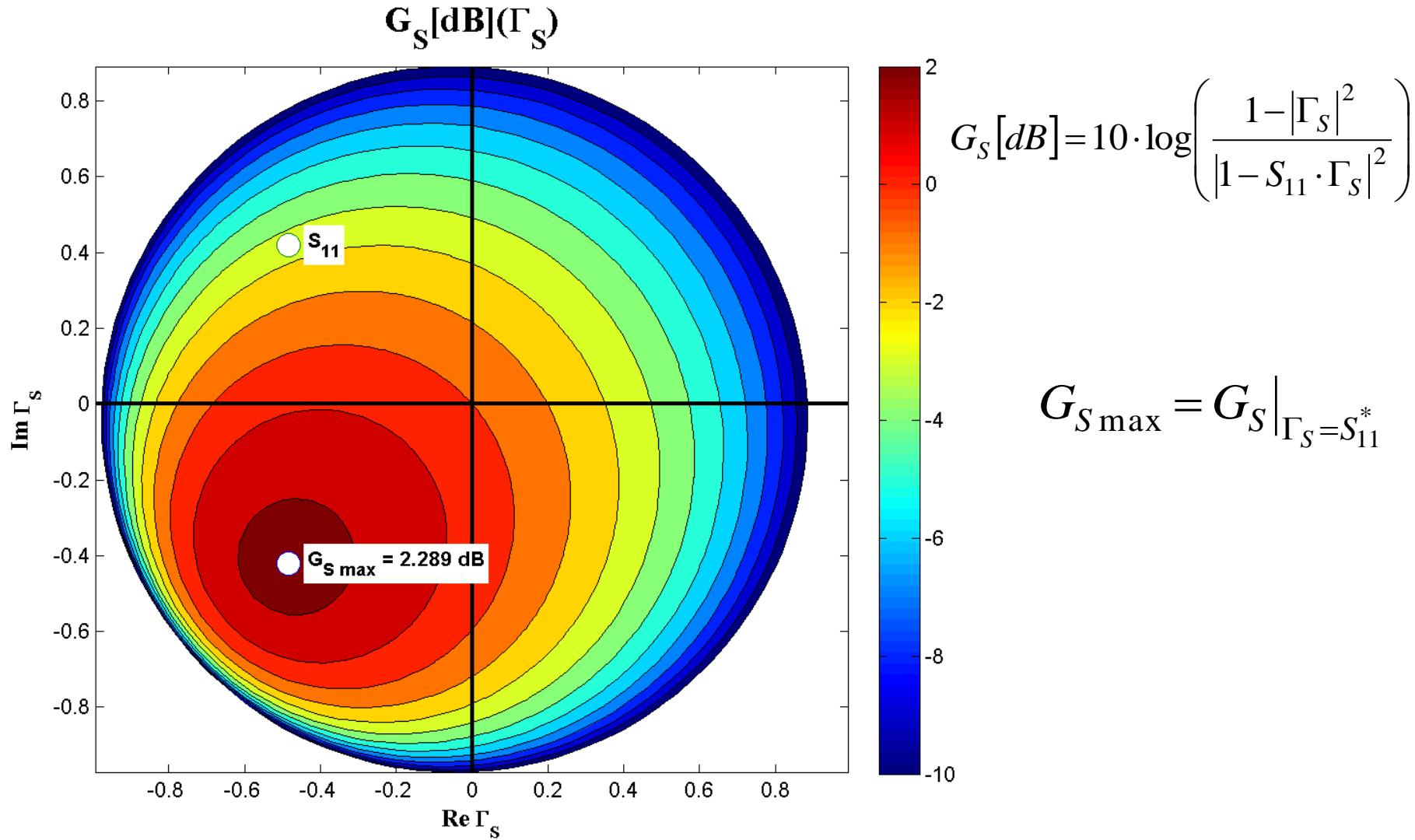
# $G_S(\Gamma_S)$ , nivel constant



# $G_S(\Gamma_S)$ , diagrama de nível



# $G_S[\text{dB}](\Gamma_S)$ , diagrama de nível

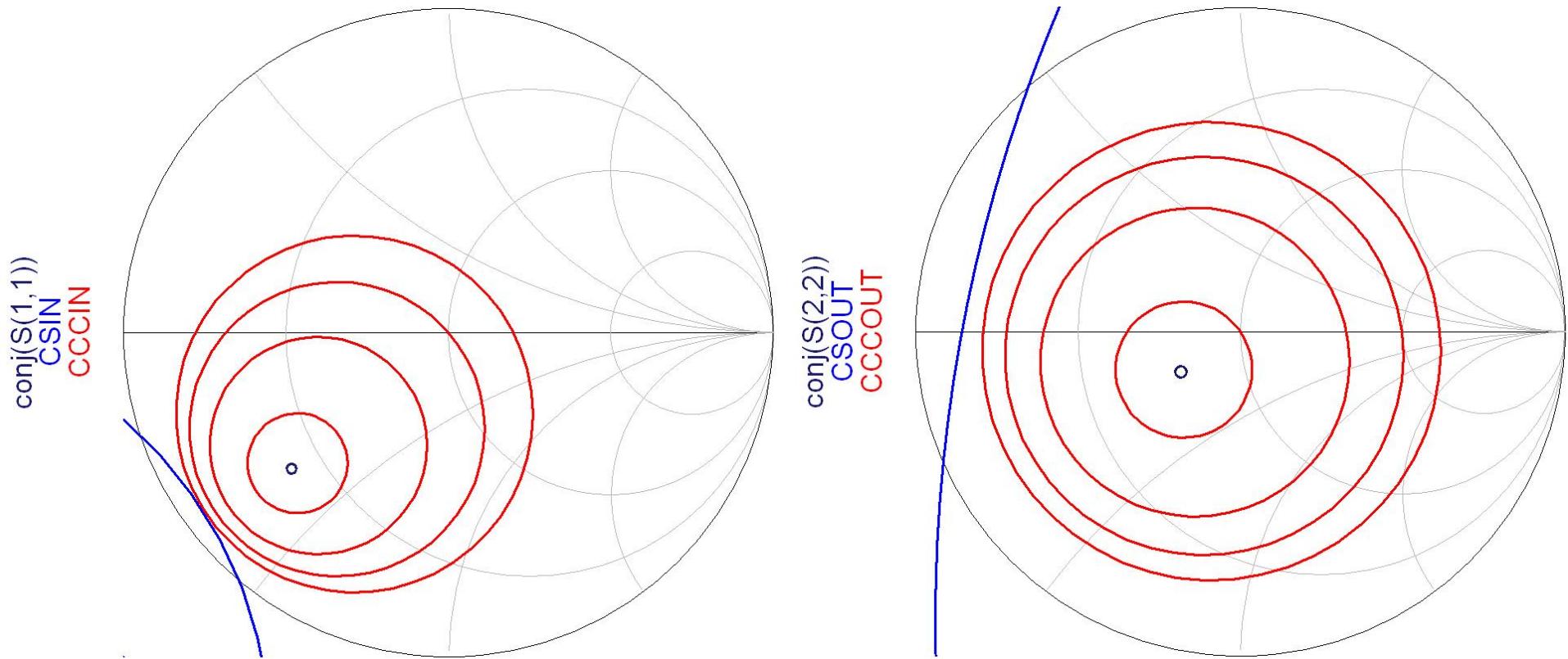


# Cercuri de castig constant la intrare

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

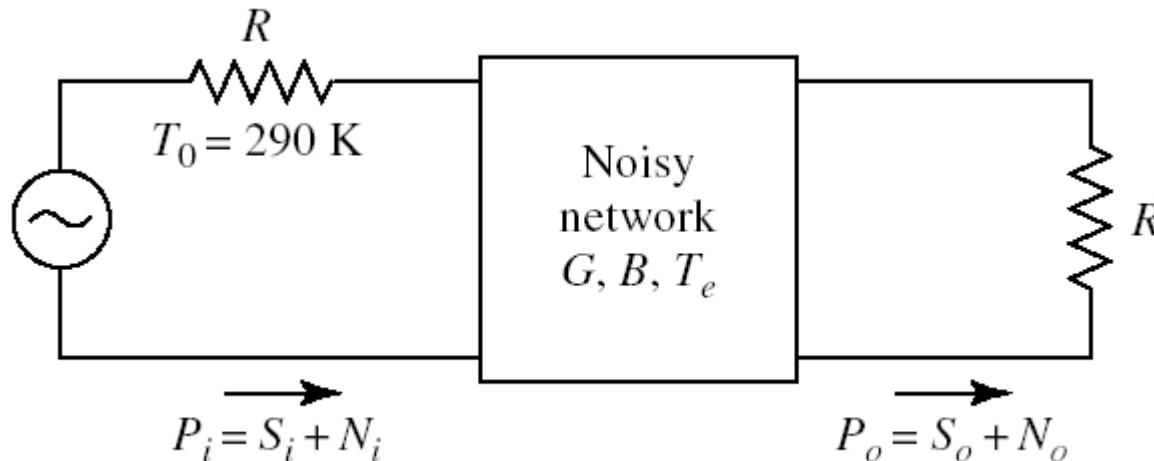
- Ecuatia unui cerc in planul complex in care reprezint  $\Gamma_S$
- Interpretare:** Orice punct  $\Gamma_S$  care reprezentat in planul complex se gaseste **pe** cercul desenat pentru  $g_{\text{cerc}} = G_{\text{cerc}} / G_{\text{Smax}}$  va conduce la obtinerea castigului  $G_S = G_{\text{cerc}}$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

# CCCIN, CCCOUT



- Cerculile se reprezinta pentru valorile cerute in dB
- Este utila calcularea  $G_{S_{max}}$  si  $G_{L_{max}}$  anterior

# Factor de zgomot

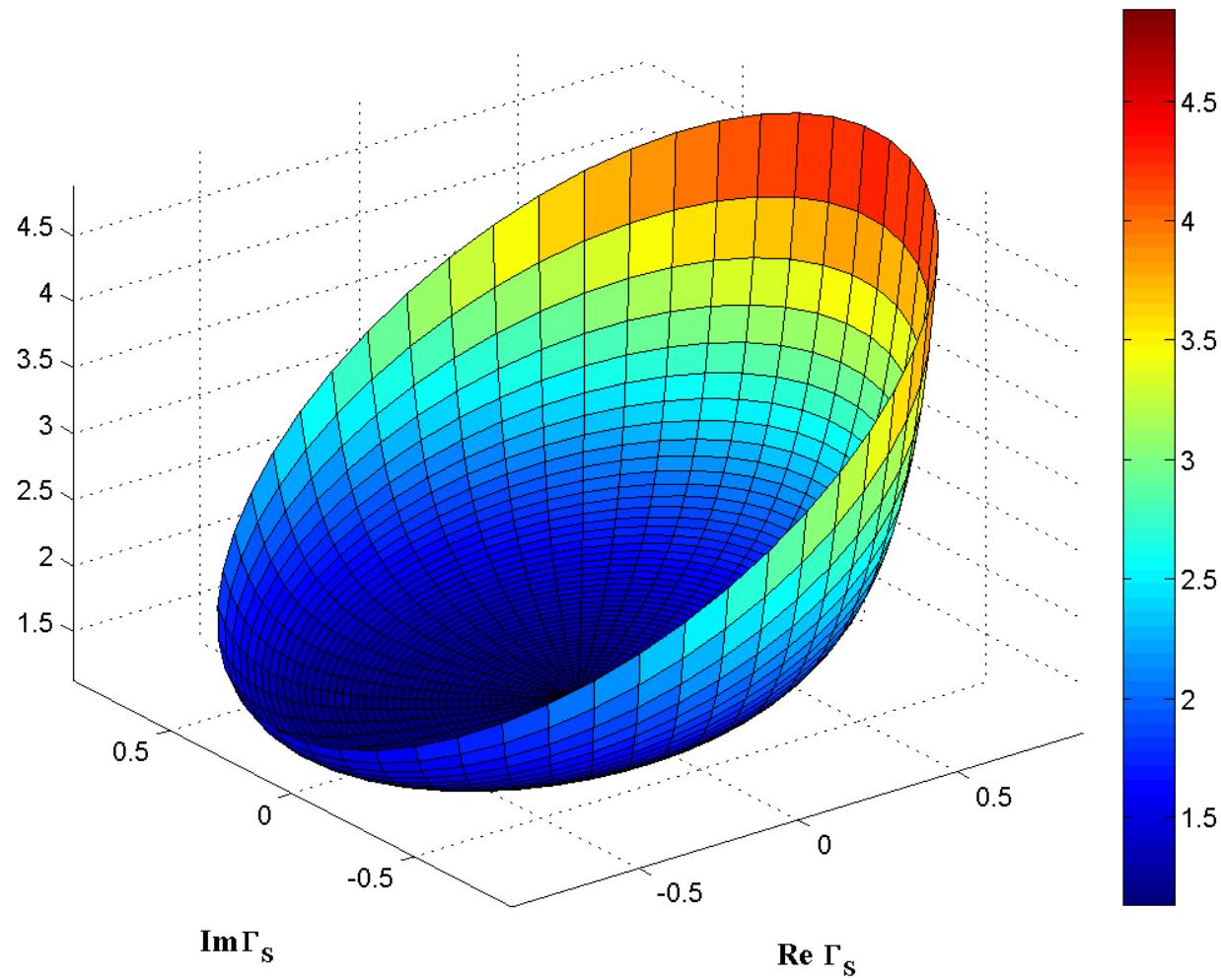


- Factorul de zgomot  $F$  caracterizeaza degradarea raportului semnal/zgomot intre intrarea si iesirea unei componente

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

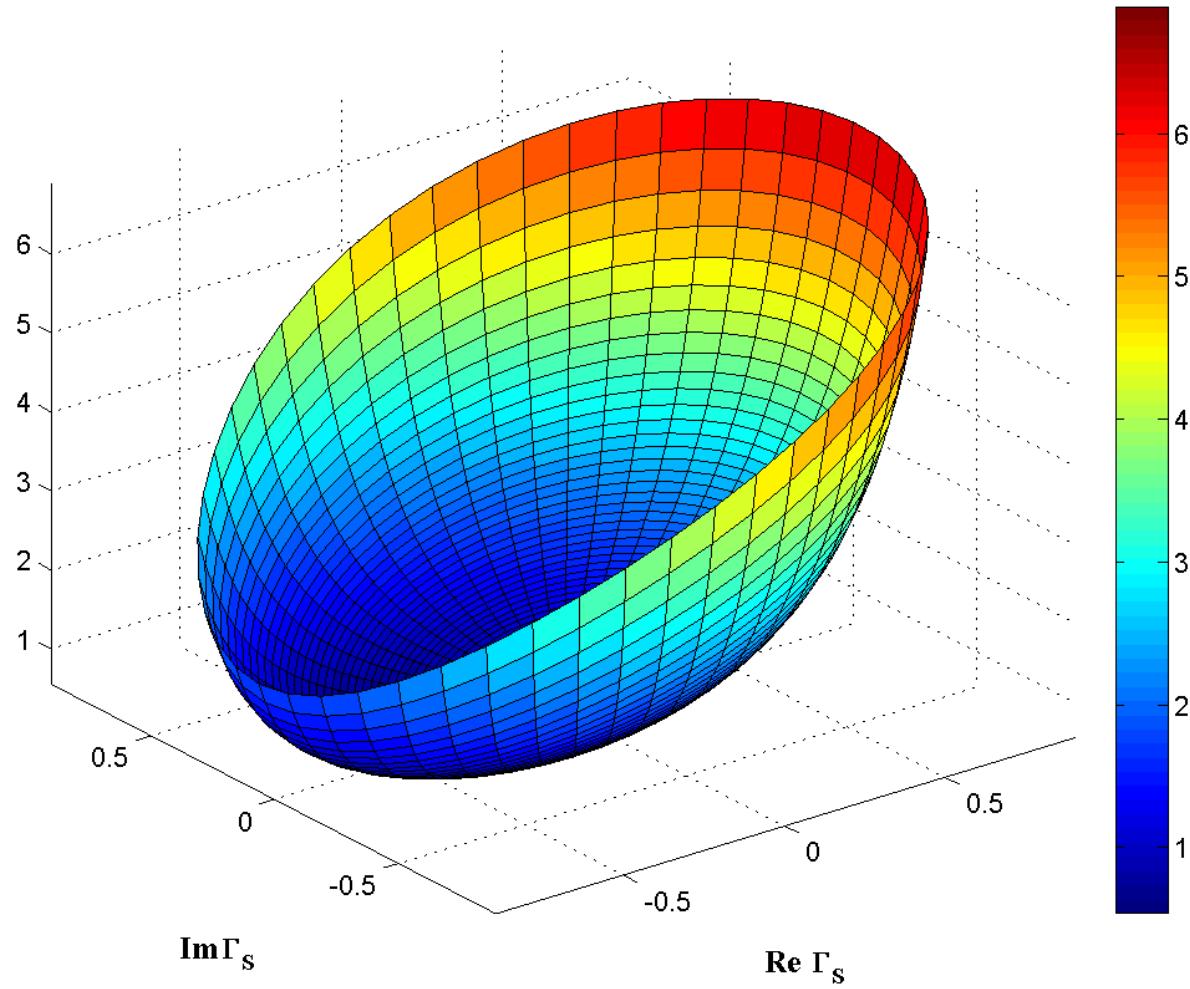
# $F(\Gamma_s)$

$F(\Gamma_s)$

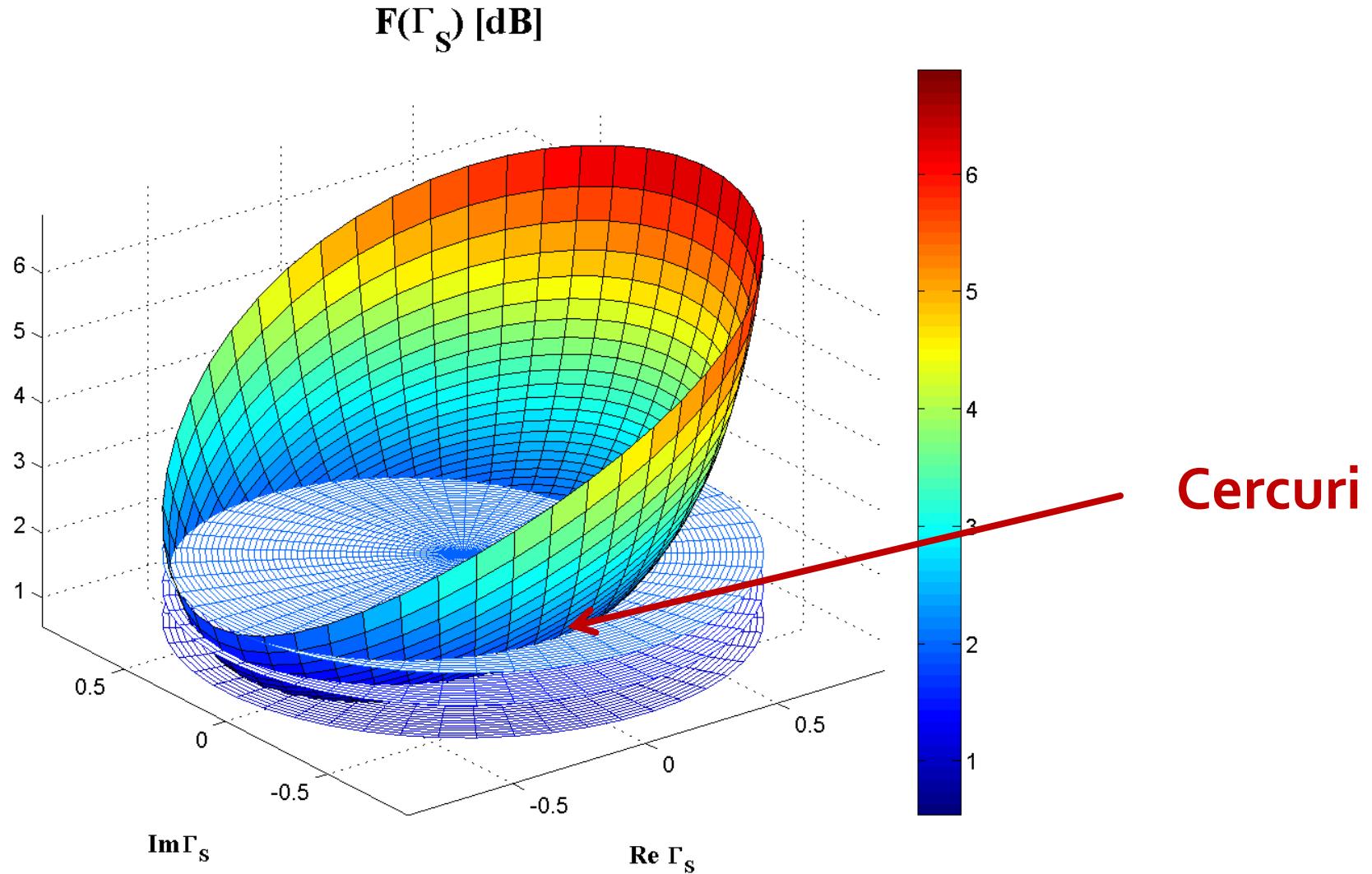


# $F[dB](\Gamma_S)$

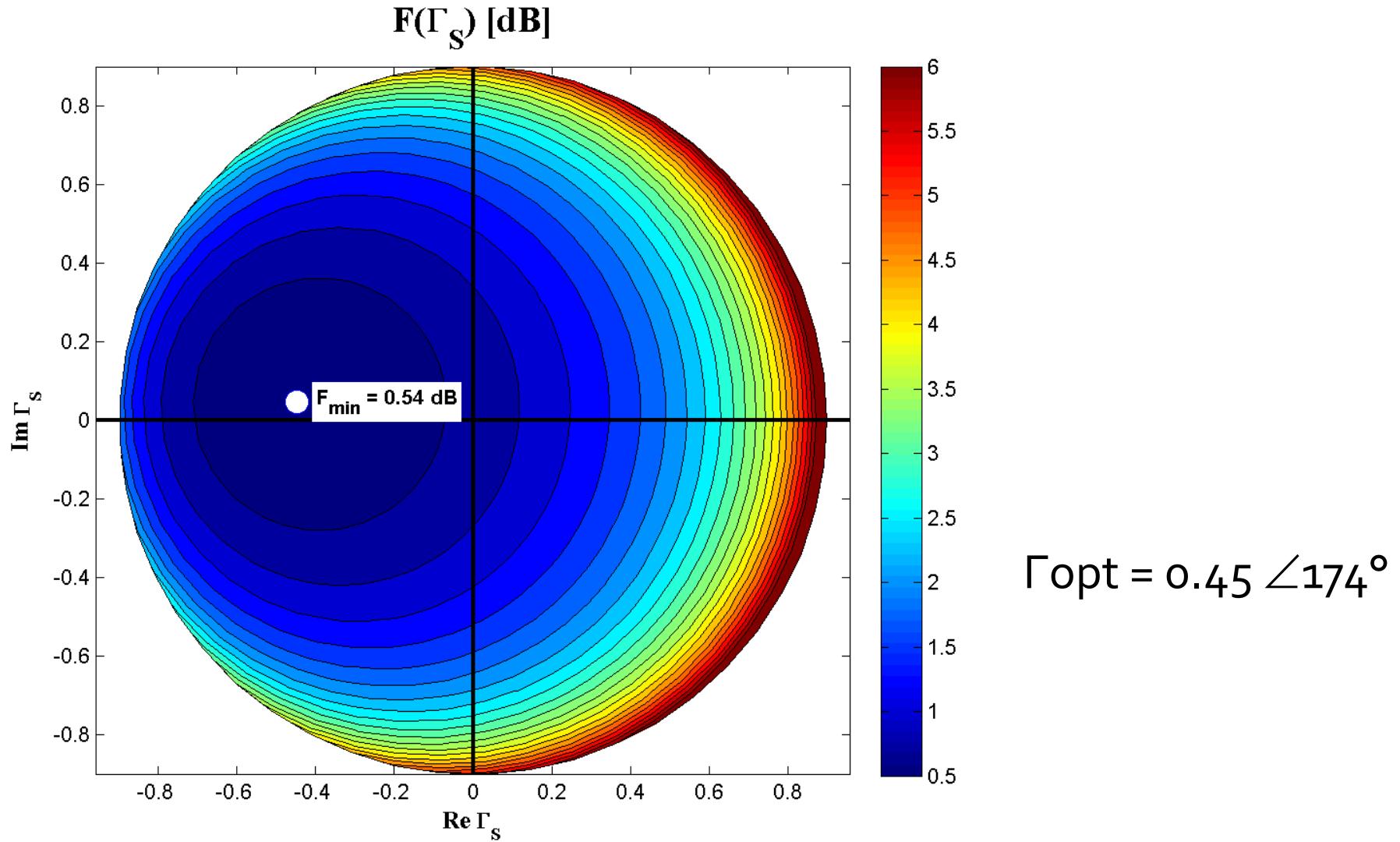
$F(\Gamma_S) [dB]$



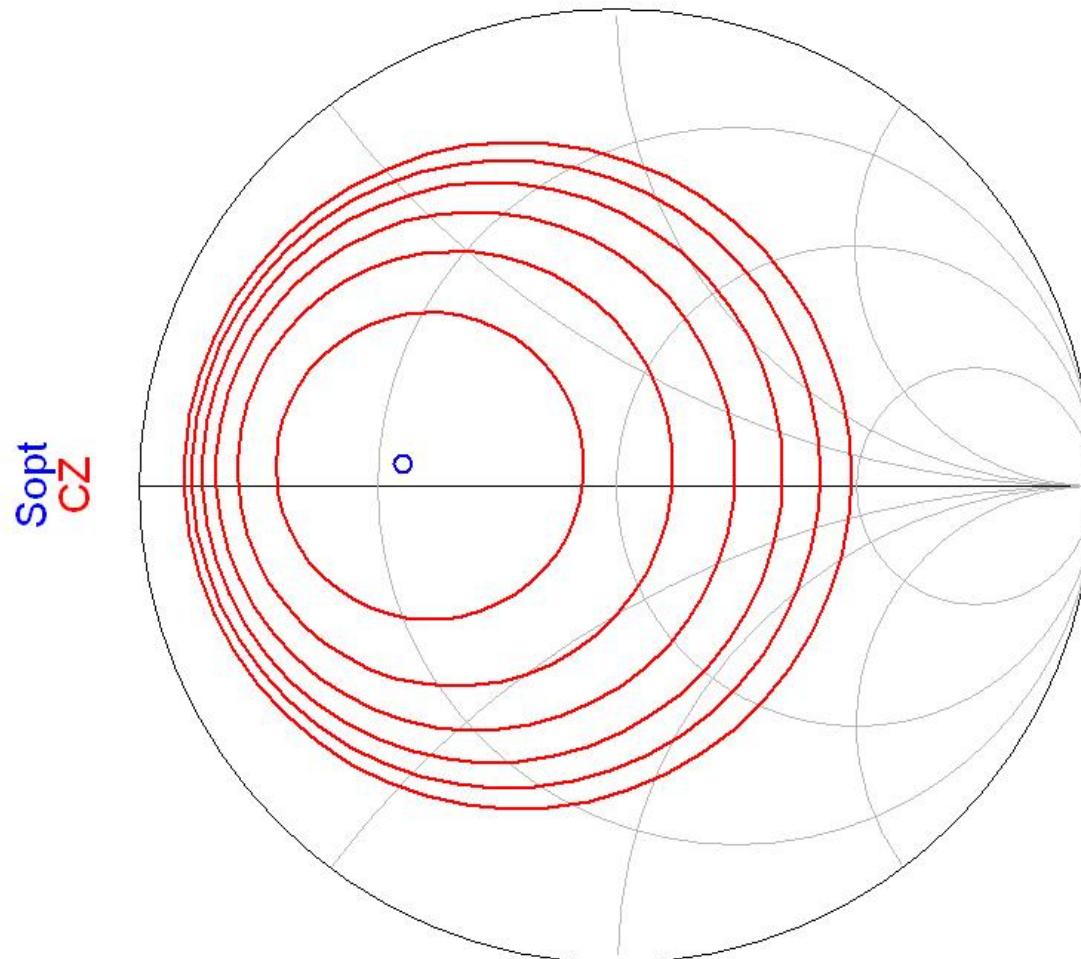
# $F[dB](\Gamma_s)$ , diagrama de nivel



# $G_S[\text{dB}](\Gamma_S)$ , diagrama de nível



# CZ – numai la intrare !



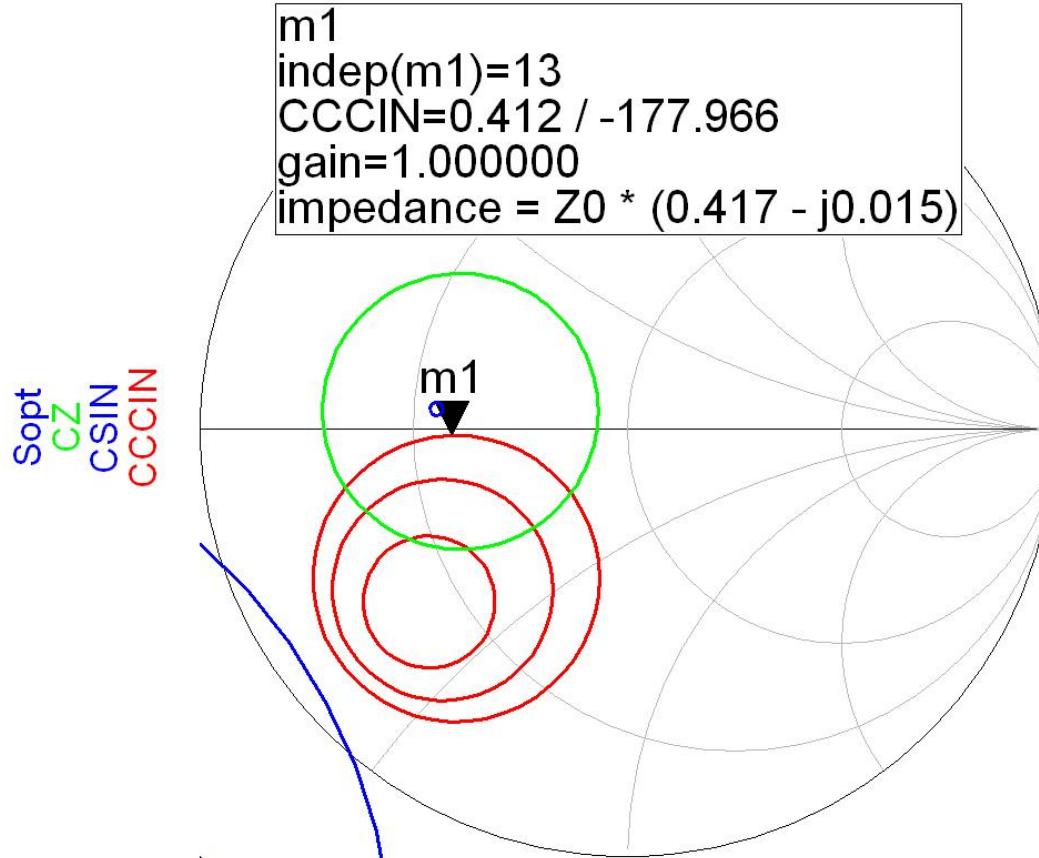
$S_{CZ}^{\text{opt}}$

cir\_pts (0.000 to 51.000)  
freq (5.000GHz to 5.000GHz)

# Exemplu, LNA @ 5 GHz

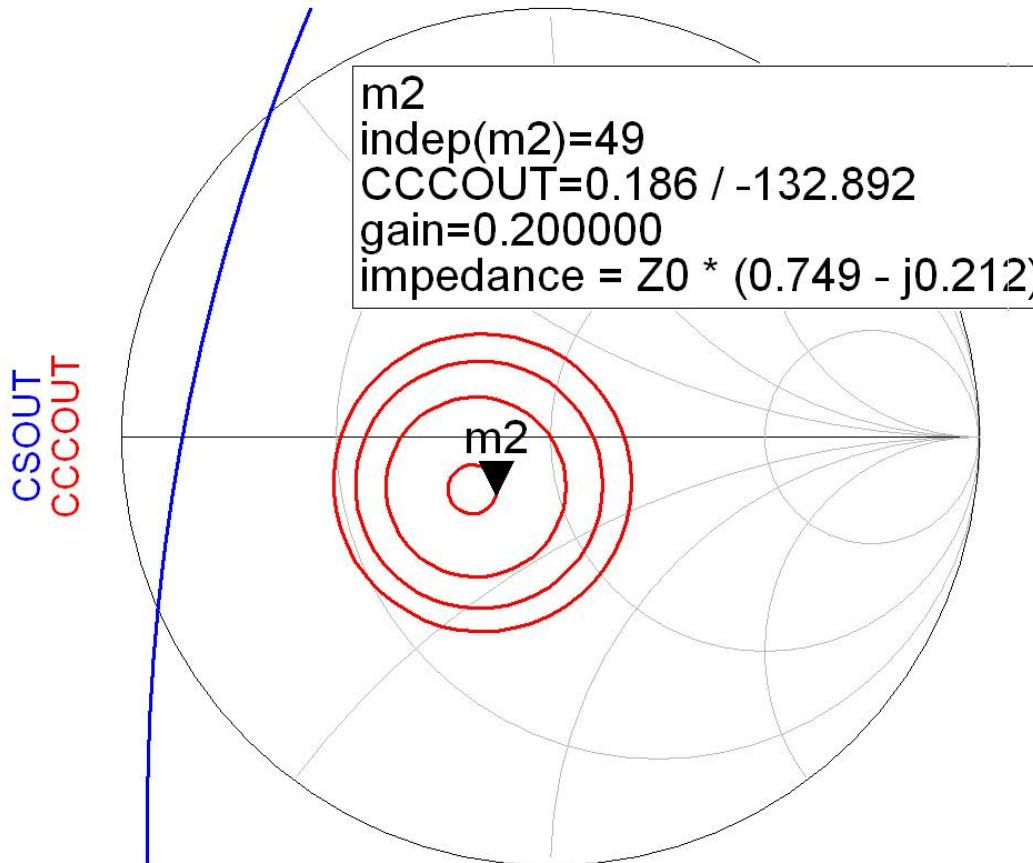
- Amplificator de zgomot redus
- La intrare e necesar un compromis intre
  - zgomot (cerc de zgomot constant ~~la intrare~~)
  - castig (cerc de castig constant la intrare)
  - stabilitate (cerc de stabilitate la intrare)
- La iesire zgomotul **nu intervine** (nu exista influenta). Compromis intre:
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

# Adaptare la intrare



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

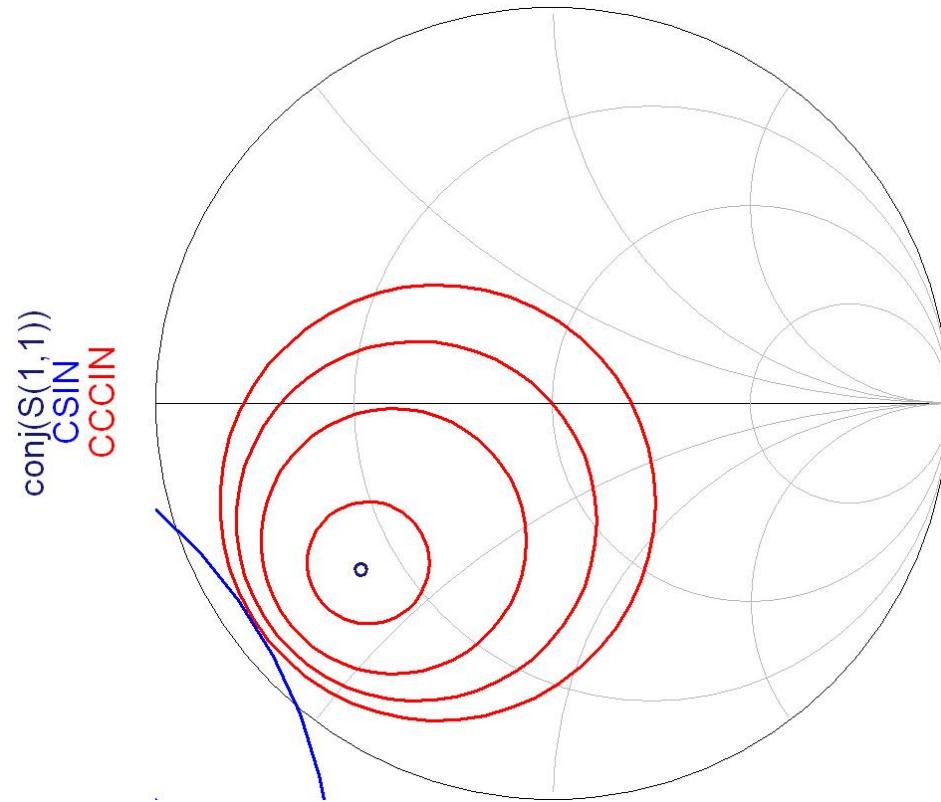
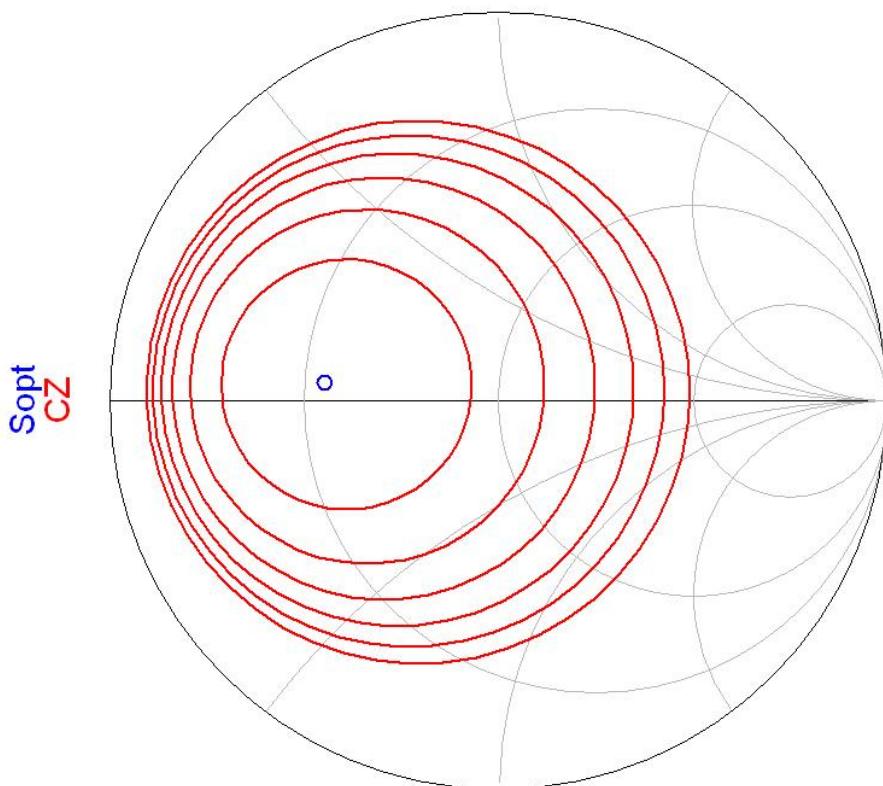
# Adaptare la ieșire



- 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  $\Gamma_s$



# Contact

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- [rdamian@etti.tuiasi.ro](mailto:rdamian@etti.tuiasi.ro)