

**Curs 10**  
**2015/2016**

# **Dispozitive și circuite de microunde pentru radiocomunicații**

# Disciplina 2015/2016

- 2C/1L, DCMR (CDM)
- **Minim 7 prezente (curs+laborator)**
- Curs - **sl. Radu Damian**
  - Marti 18-20, P2
  - E – 60% din nota
  - probleme + (2p prez. curs)
    - 3p=+0.5p
  - **toate materialele permise**
- Laborator – **sl. Radu Damian**
  - Miercuri 8-14 impar (14.10.2015 – prez. obligatorie)
  - L – 25% din nota
  - P – 15% din nota

# Fotografii +0.5p

Grupa 5403												
Nr.	Student	Prezent		Nr.	Student	Prezent		Nr.	Student	Prezent		
1	ANGHELUS IONUT-MARCUS		<input type="checkbox"/> Prezent		2 ANTIGHIN FLORIN-RAZVAN		<b>Fotografia nu există</b>		3 ANTONICA BIANCA		<b>Fotografia nu există</b>	
4	APOSTOL PAVEL-MANUEL		<b>Fotografia nu există</b>		5 BALASCA TUDIAN-PETRU		<b>Fotografia nu există</b>		6 BOSTAN ANDREI-PETRICA		<b>Fotografia nu există</b>	
7	BOTEZAT EMANUEL		<input type="checkbox"/> Prezent		8 BUTUNOI GEORGE-MADALIN		<b>Fotografia nu există</b>		9 CHILEA SALUCA-MARIA		<b>Fotografia nu există</b>	
10	CHIRITOIU CATERINA		<input type="checkbox"/> Prezent		11 CODOC MARIUS		<input checked="" type="checkbox"/> Prezent		12 COJOCARU AURA-FLORINA		<input type="checkbox"/> Prezent	

Nr. Student

2 ANTIGHIN  
FLORIN-RAZVAN

Prezent

Prezent

Puncte: 0

Nota: 0

Obs:

<b>Fotografia nu există</b>
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# Reprezentare logarithmică

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

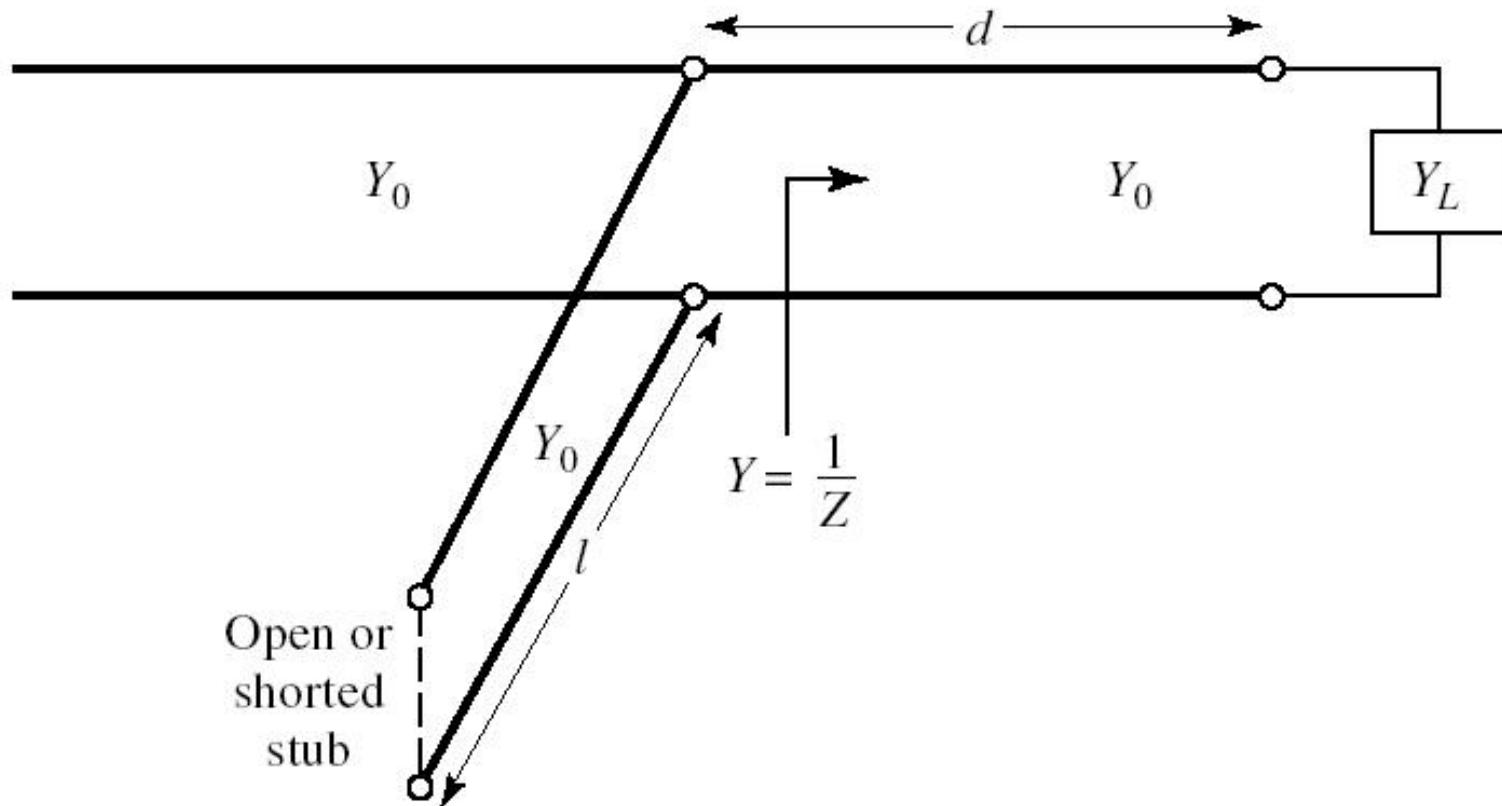
# Recapitulare

Adaptarea cu sectiuni de linii (stub)

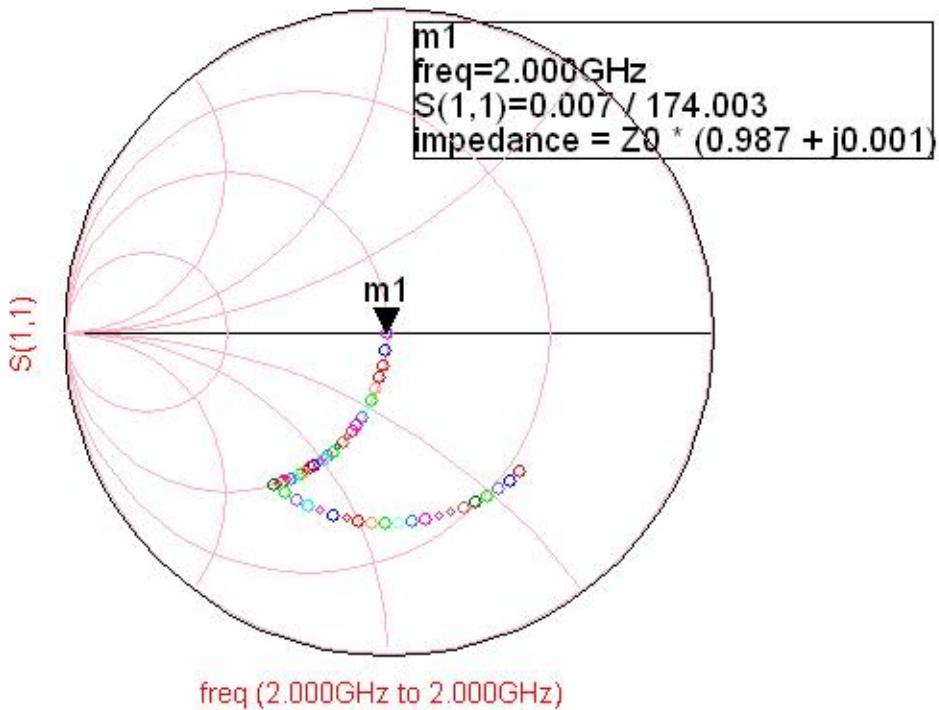
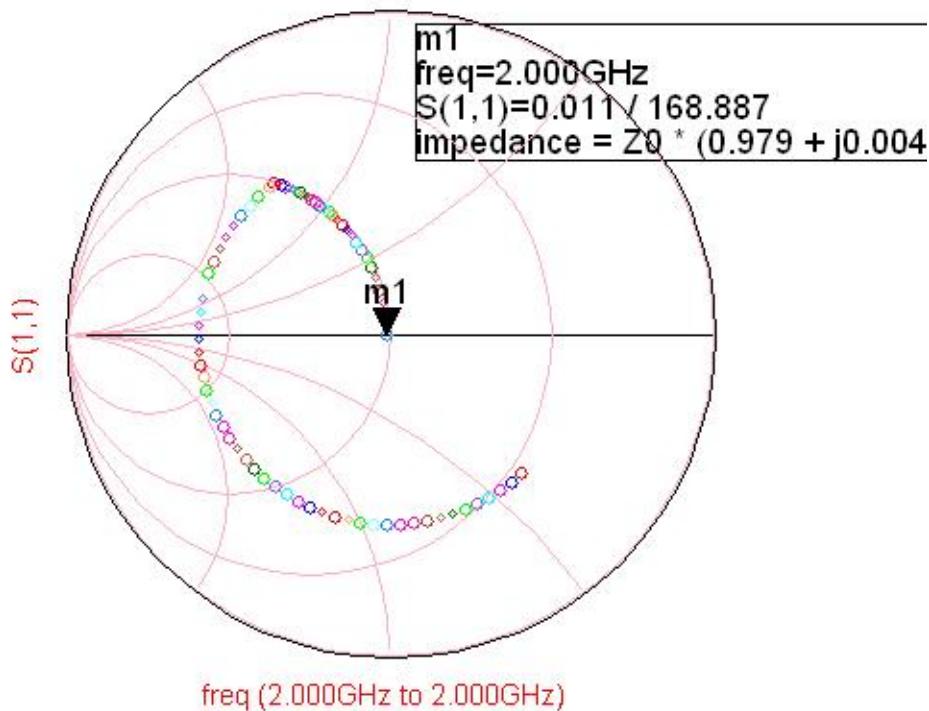
# **Adaptarea de impedanță**

# Single stub tuning

- Shunt Stub (secțiune de linie în paralel)



# Exemplu, Shunt Stub, sc

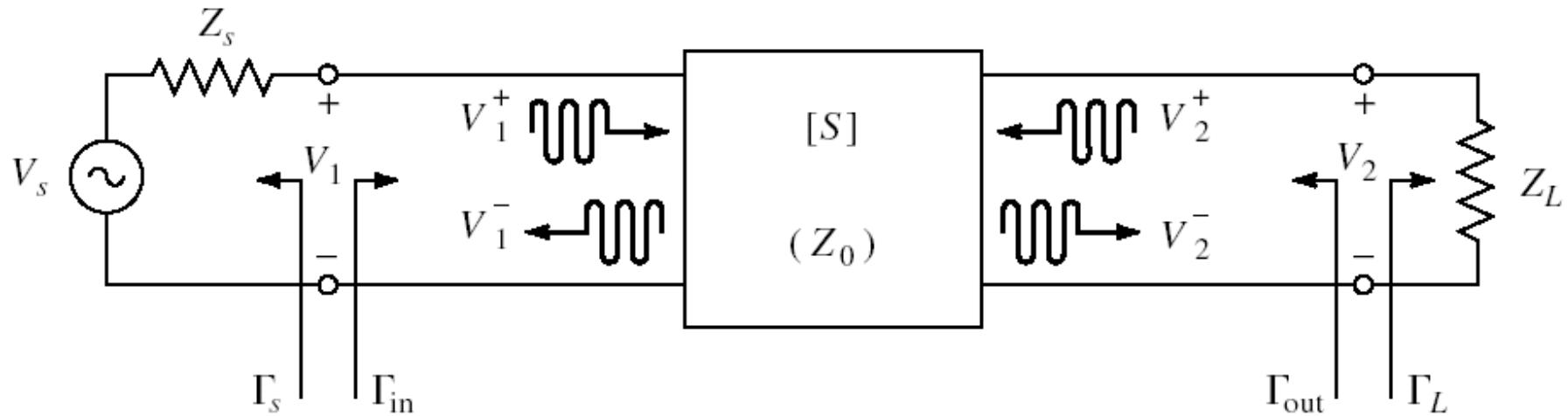


Doua solutii posibile

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

# Catalogage

**NE46100**

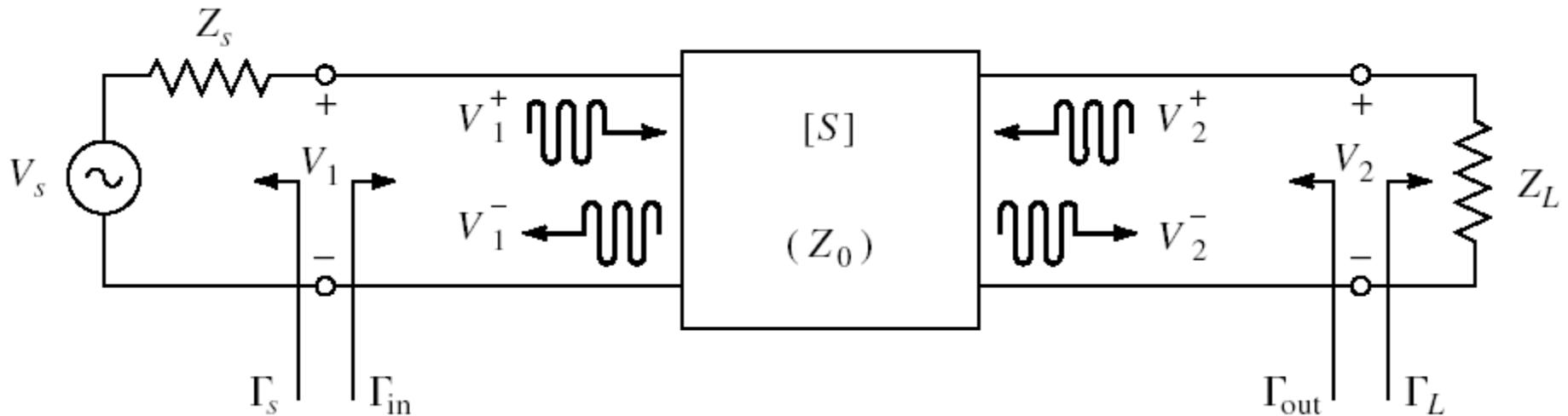
**VCE = 5 V, Ic = 50 mA**

FREQUENCY (MHz)	S <sub>11</sub>		S <sub>21</sub>		S <sub>12</sub>		S <sub>22</sub>		K	MAG <sup>2</sup> (dB)
	MAG	ANG	MAG	ANG	MAG	ANG	MAG	ANG		
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

**VCE = 5 V, Ic = 100 mA**

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

# Dipole amplifier



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

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

# Castig de putere

## ■ Castigul de putere

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

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

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

- Castigul **introdus** efectiv de amplificator este mai putin important deoarece un castig mai mare poate fi insotit de o **scadere** a puterii de intrare (absorbita efectiv de la sursa)
- Se prefera caracterizarea efectului amplificatorului prin analiza puterii **efectiv obtinuta pe sarcina** in raport cu puterea **disponibila de la sursa** (constanta)

# 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**

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

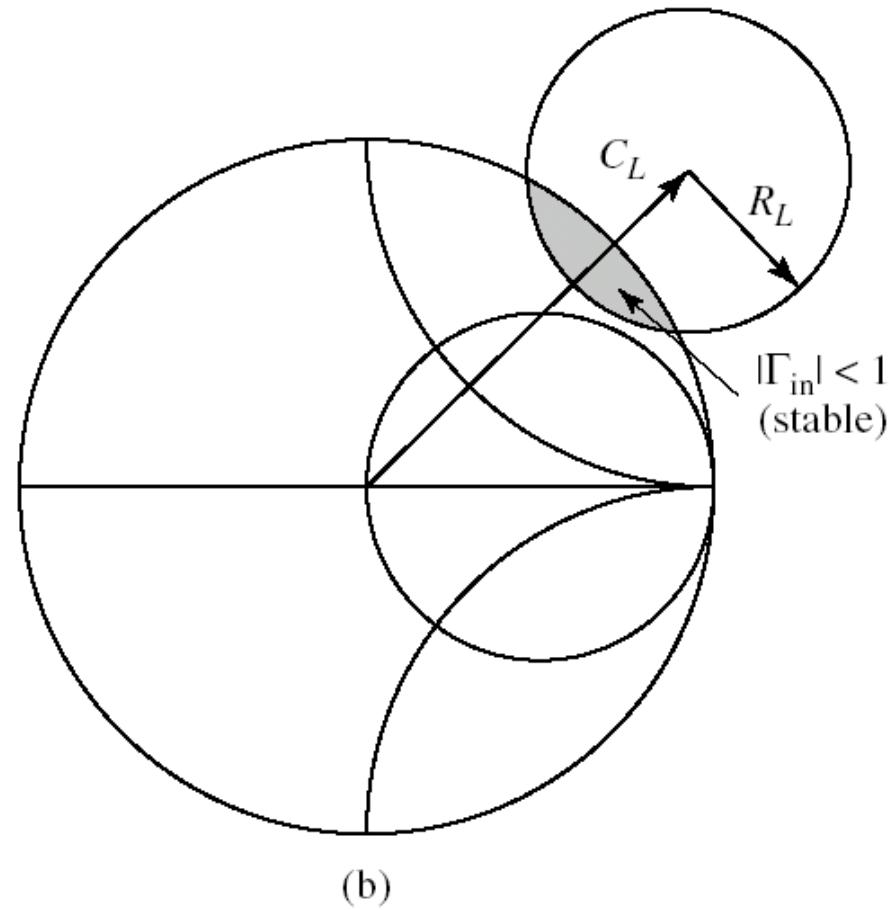
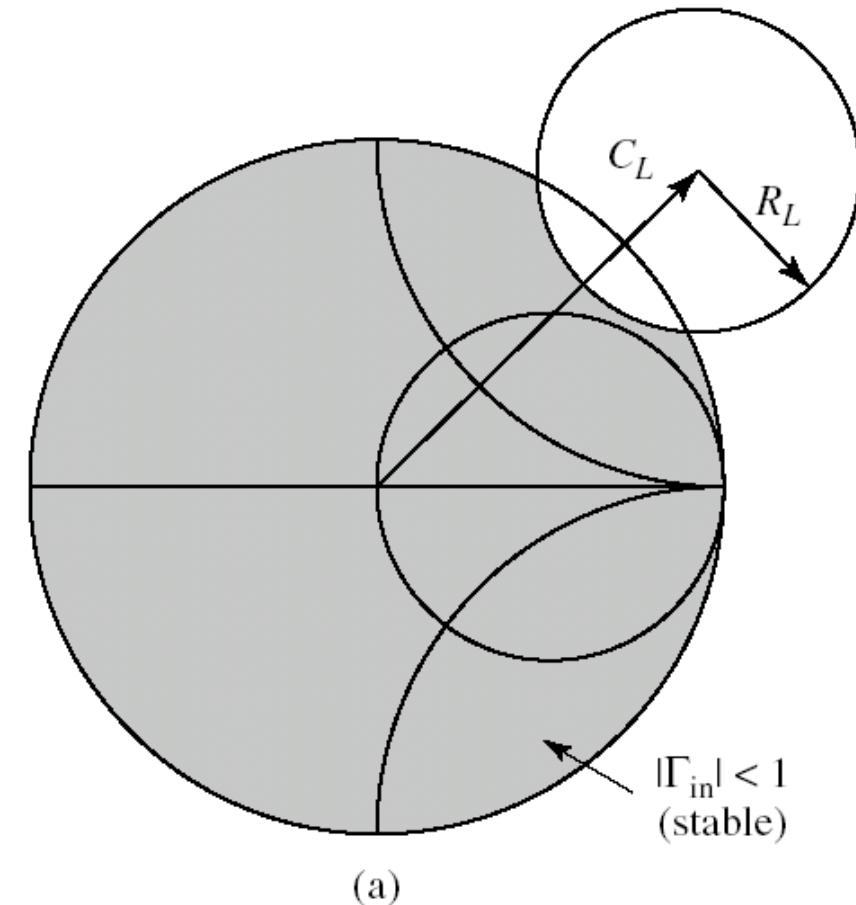
$$S_{12} \cong 0 \quad \Gamma_{in} = S_{11}$$

Permite tratarea separata  
a intrarii si iesirii

# Cerc de stabilitate la ieșire

- **Cercul de stabilitate la ieșire** reprezinta locul geometric al punctelor  $\Gamma_L$  pentru **limita** de stabilitate ( $|\Gamma_{in}|=1$ )
- Cercul imparte planul complex in doua suprafete, **interiorul** si **exteriorul** cercului
- Cele doua suprafete vor reprezenta zonele  $\Gamma_L$  de stabilitate ( $|\Gamma_{in}|<1$ ) / instabilitate ( $|\Gamma_{in}|>1$ )

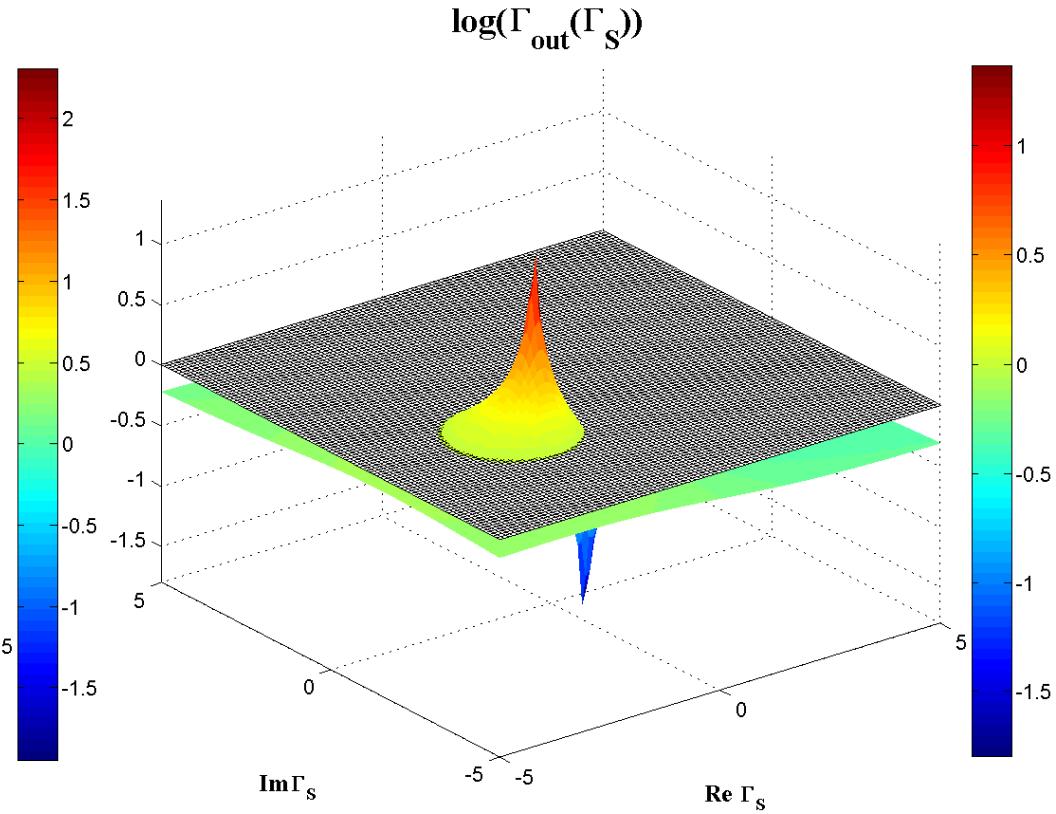
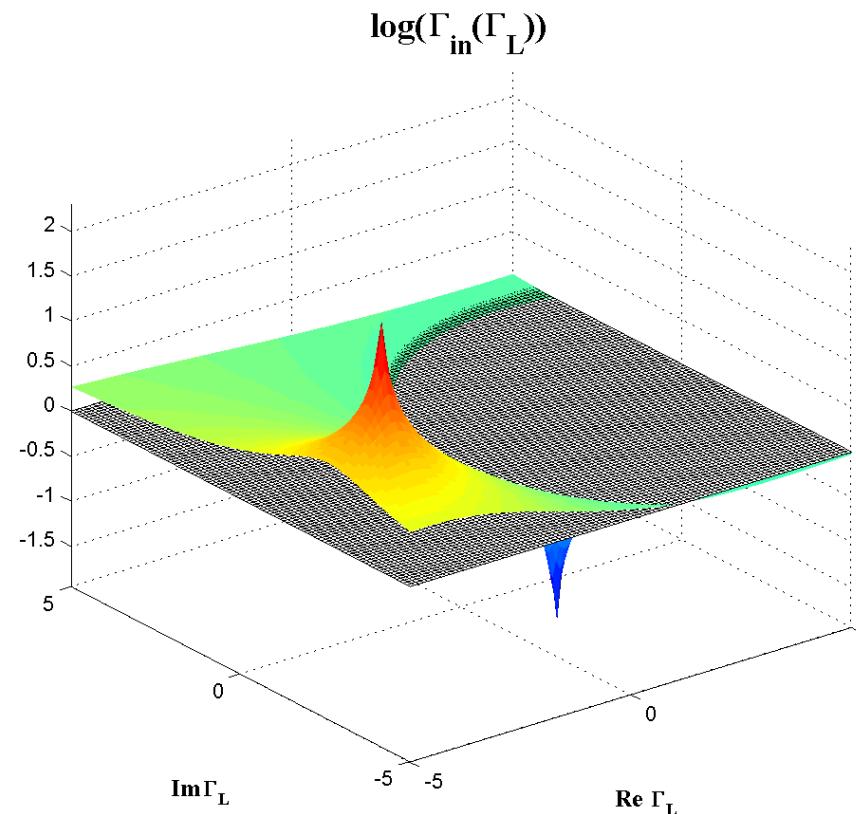
# Cerc de stabilitate la ieșire



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

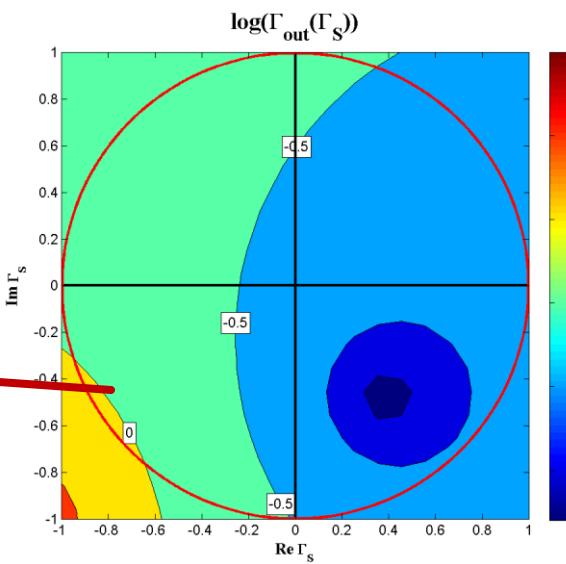
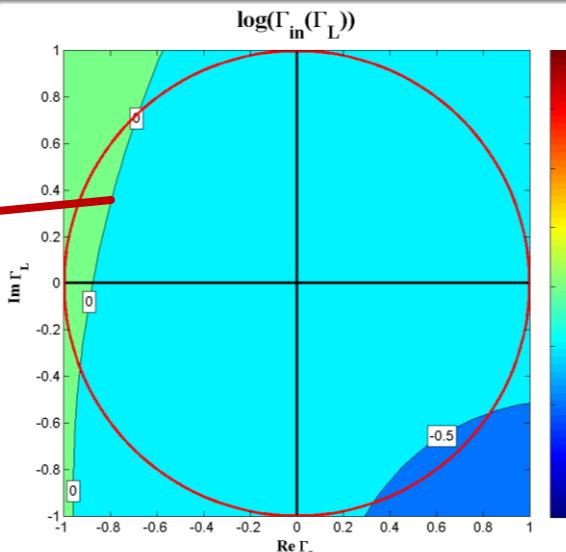
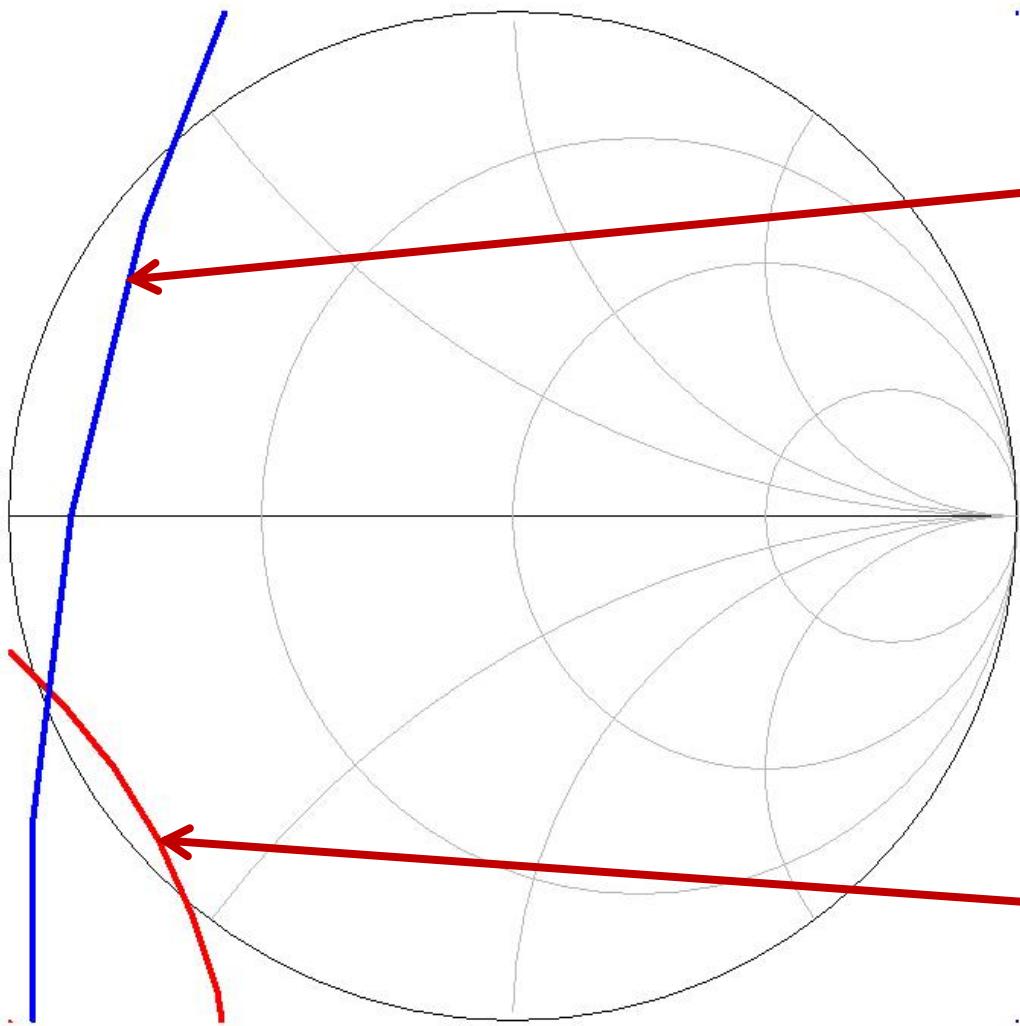
# Reprezentare 3D $|\Gamma_{\text{in}}|, |\Gamma_{\text{out}}|, |\Gamma|=1$

- $|\Gamma| = 1 \rightarrow \log_{10}|\Gamma| = 0$ , intersectia = cerc



# CSIN, CSOUT

CSOUT  
CSIN



# 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

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

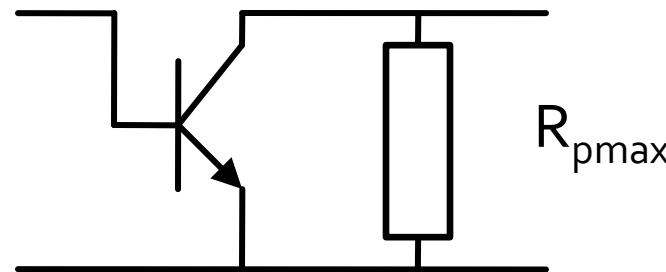
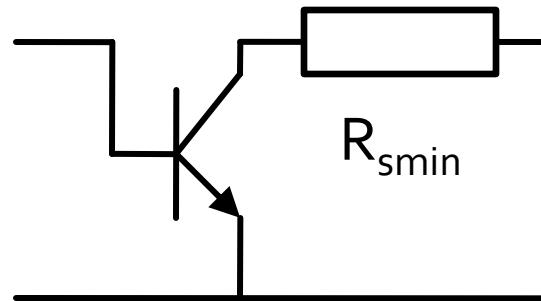
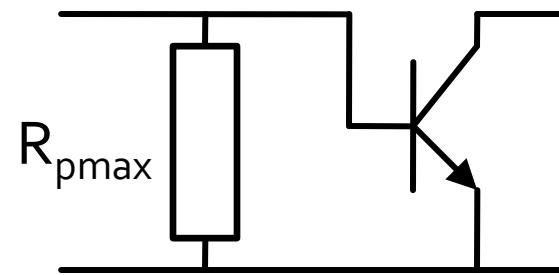
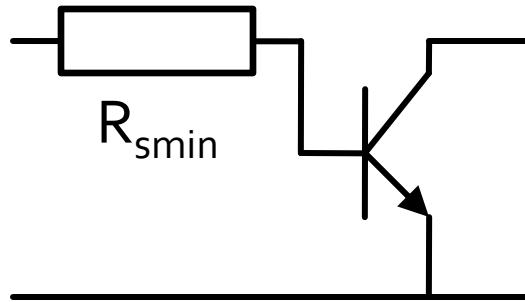
$$|\Delta| = |S_{11} \cdot S_{22} - S_{12} \cdot S_{21}| < 1$$

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

- Sunt valabile si conditiile implicite
  - $|S_{11}| < 1$
  - $|S_{22}| < 1$

# Stabilizarea unui diport

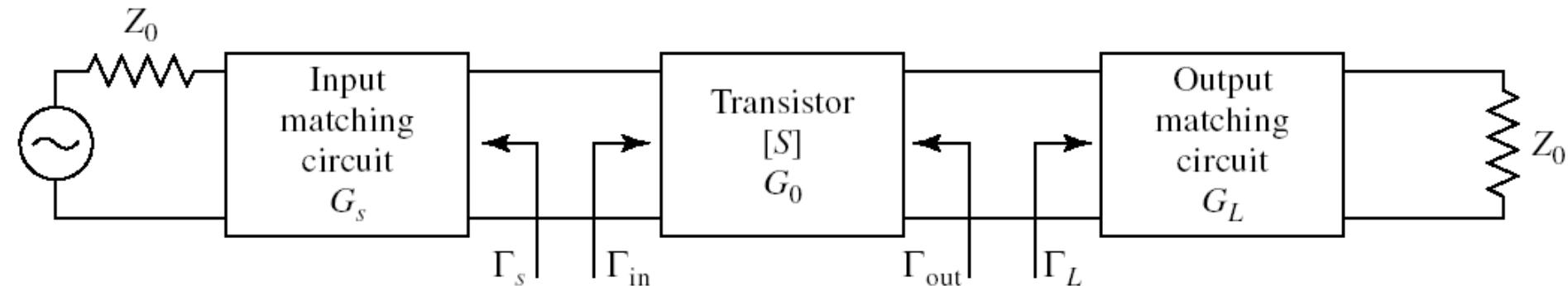
- Stabilitatea neconditionata poate fi fortata prin introducerea de elemente rezistive in serie/paralel la intrare si/sau iesire



Castigul amplificatoarelor de microunde

# **Amplificatoare de microunde**

# 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

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

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

# 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 –

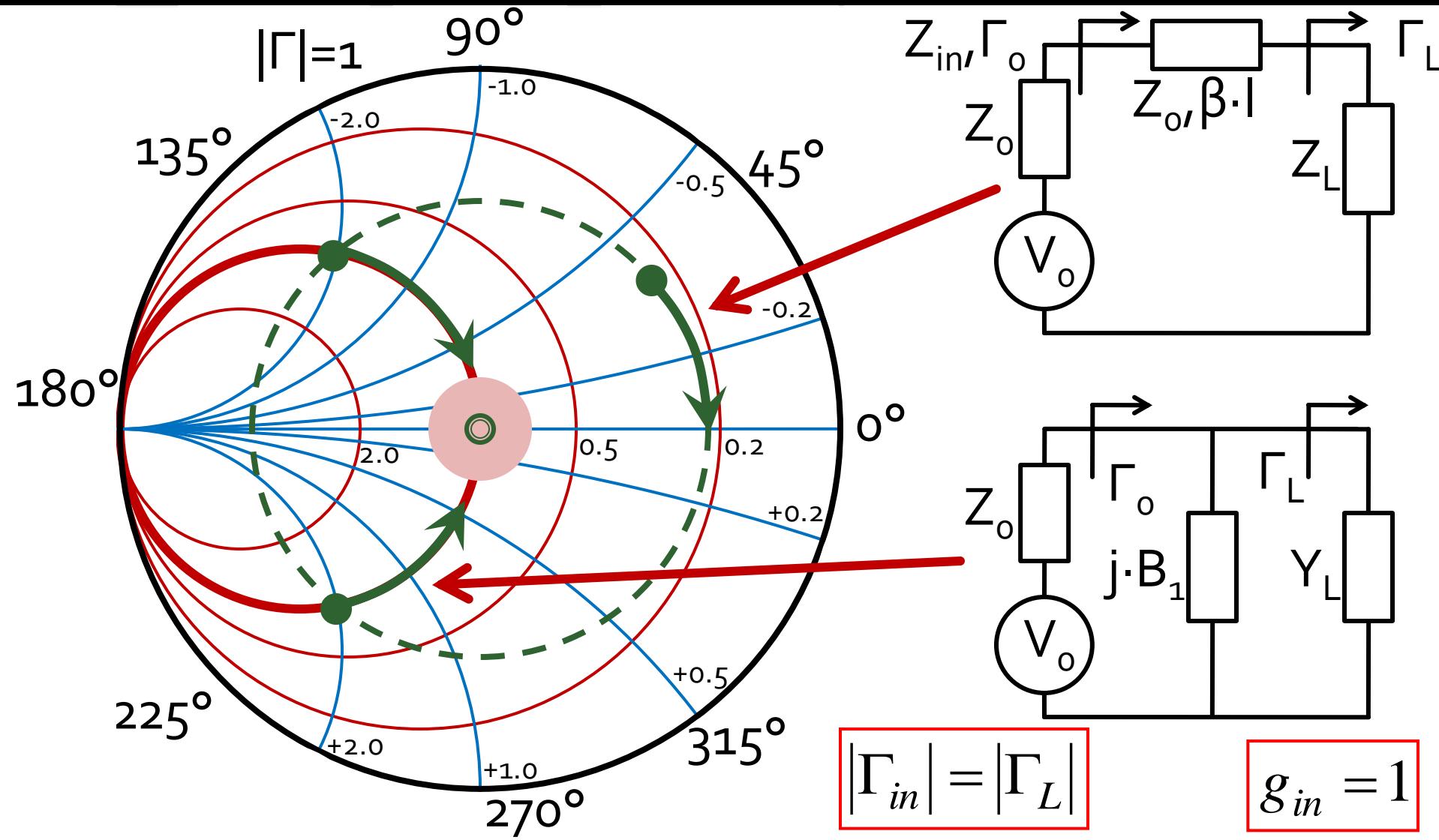
$$\Gamma_S = \frac{B_1 - \sqrt{B_1^2 - 4 \cdot |C_1|^2}}{2 \cdot C_1}$$

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

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

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

# Adaptare cu stub-uri, C8



# Calcul analitic

- Ecuatia pentru calcularea stub-ului paralel

$$\operatorname{Re}[y_s(\theta)] = 1 \Rightarrow \cos(\varphi + 2\theta) = -|\Gamma_s| \Rightarrow \theta_1, \theta_2$$

- Ecuatia pentru calcularea stub-ului paralel

$$\operatorname{Im}[y_s(\theta)] = \frac{\mp 2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}}$$

$$\theta_{sp} = \beta \cdot l = \tan^{-1} \frac{\mp 2 \cdot |\Gamma_s|}{\sqrt{1 - |\Gamma_s|^2}} \Rightarrow \theta_{sp1}(\theta_1), \theta_{sp2}(\theta_2)$$

# Calcul analitic

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

- Se alege **una** din cele două solutii posibile
- Similar pentru adaptarea la ieșire

$$\Gamma_L = 0.686 \angle 176.7^\circ \quad \text{Re}[y_L(\theta)] = 1 \Rightarrow \cos(\varphi + 2\theta) = -|\Gamma_L|$$

$$(176.7^\circ + 2\theta) = \begin{cases} +133.3^\circ \\ -133.3^\circ \end{cases} \quad \theta = \begin{cases} -21.7^\circ + 180^\circ = +158.3^\circ \\ -155^\circ + 180^\circ = +25^\circ \end{cases}$$

$$\text{Im}[y_L(\theta)] = \frac{-2 \cdot |\Gamma_L|}{\sqrt{1 - |\Gamma_L|^2}} = -1.885 \quad \theta_{sp} = \begin{cases} -62.1^\circ + 180^\circ = 117.9^\circ \\ +62.1^\circ \end{cases}$$

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

Proiectare pentru castig impus

# **Amplificatoare de microunde**

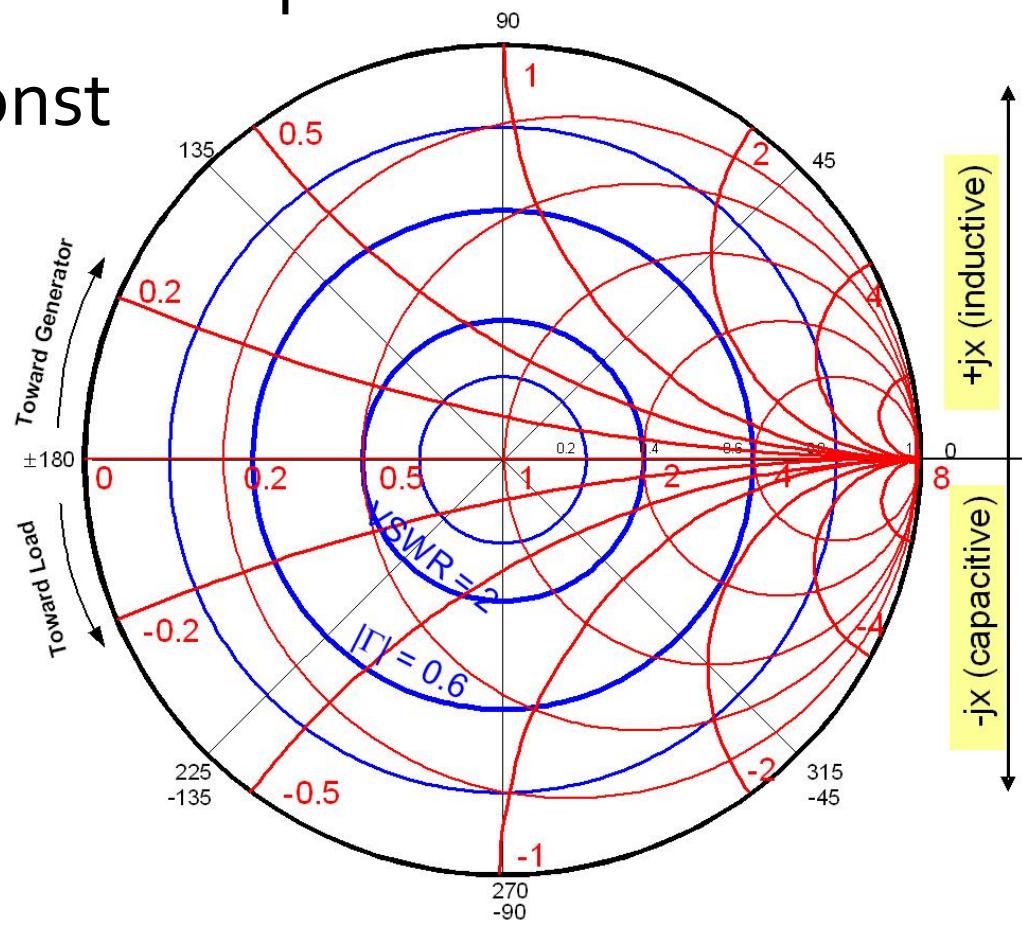
# Proiectare pentru castig impus

- 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
- $VSWR = \text{const} \rightarrow \Gamma = \text{const}$

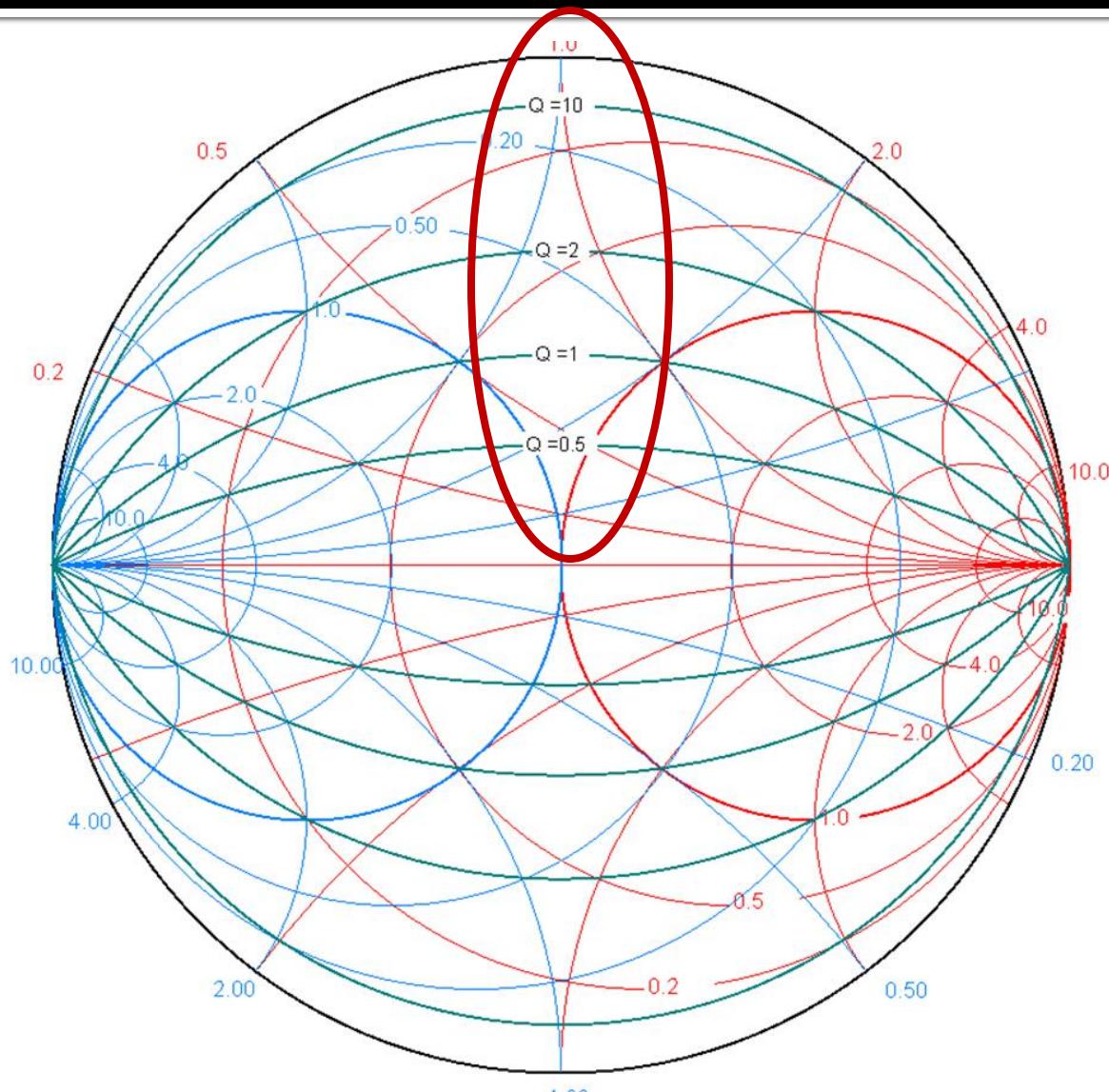
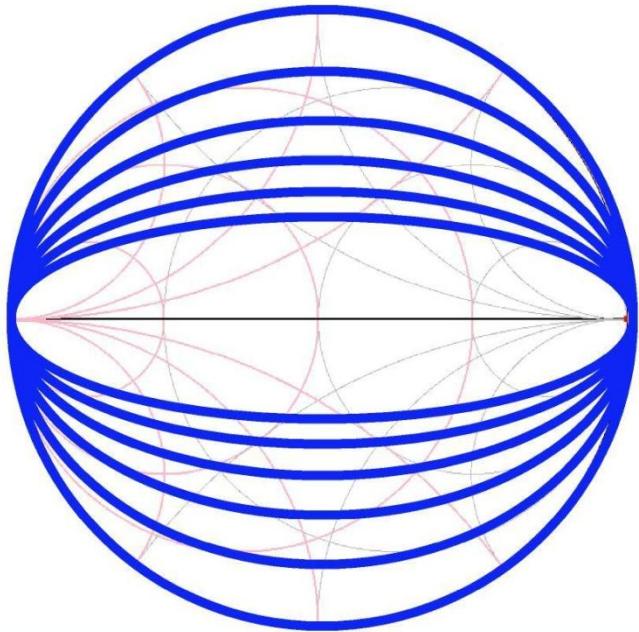
$$VSWR = \frac{V_{\max}}{V_{\min}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$



# Cercuri de factor de calitate constant

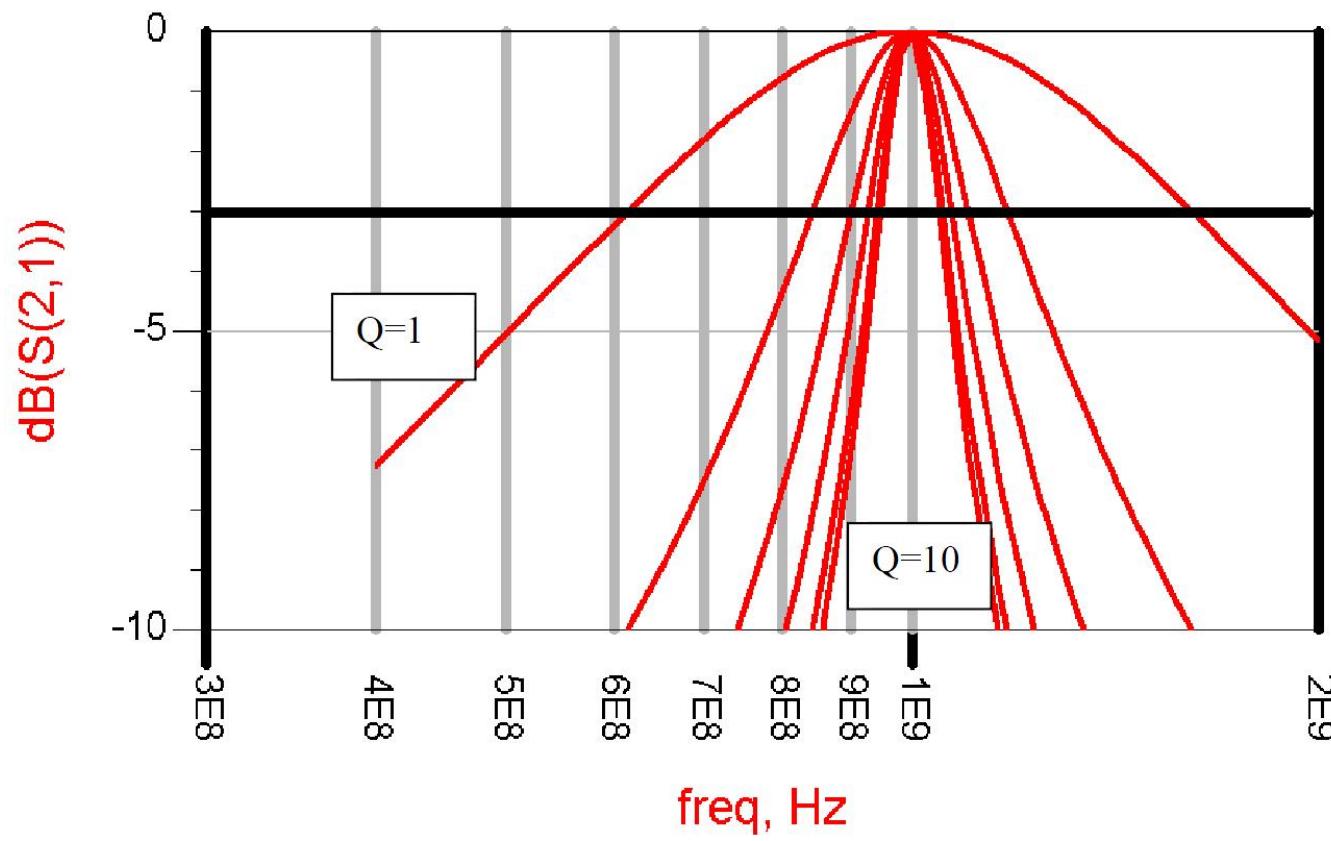
- Diagrama Smith

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

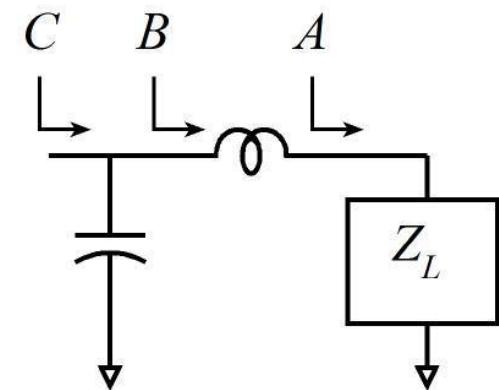
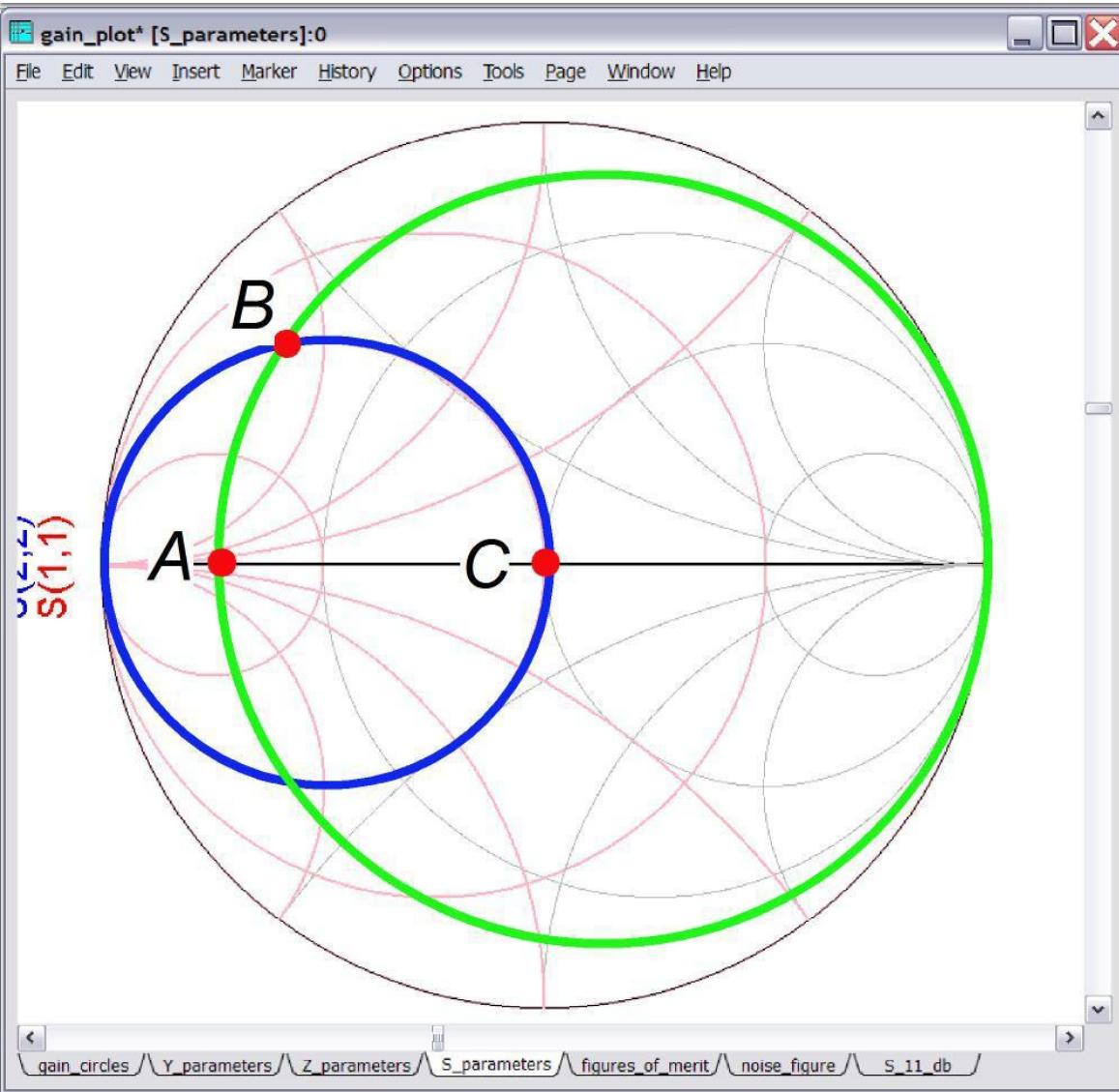


# Factor de calitate - banda

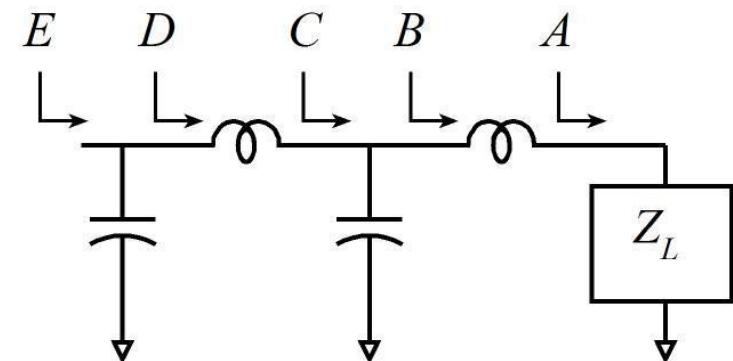
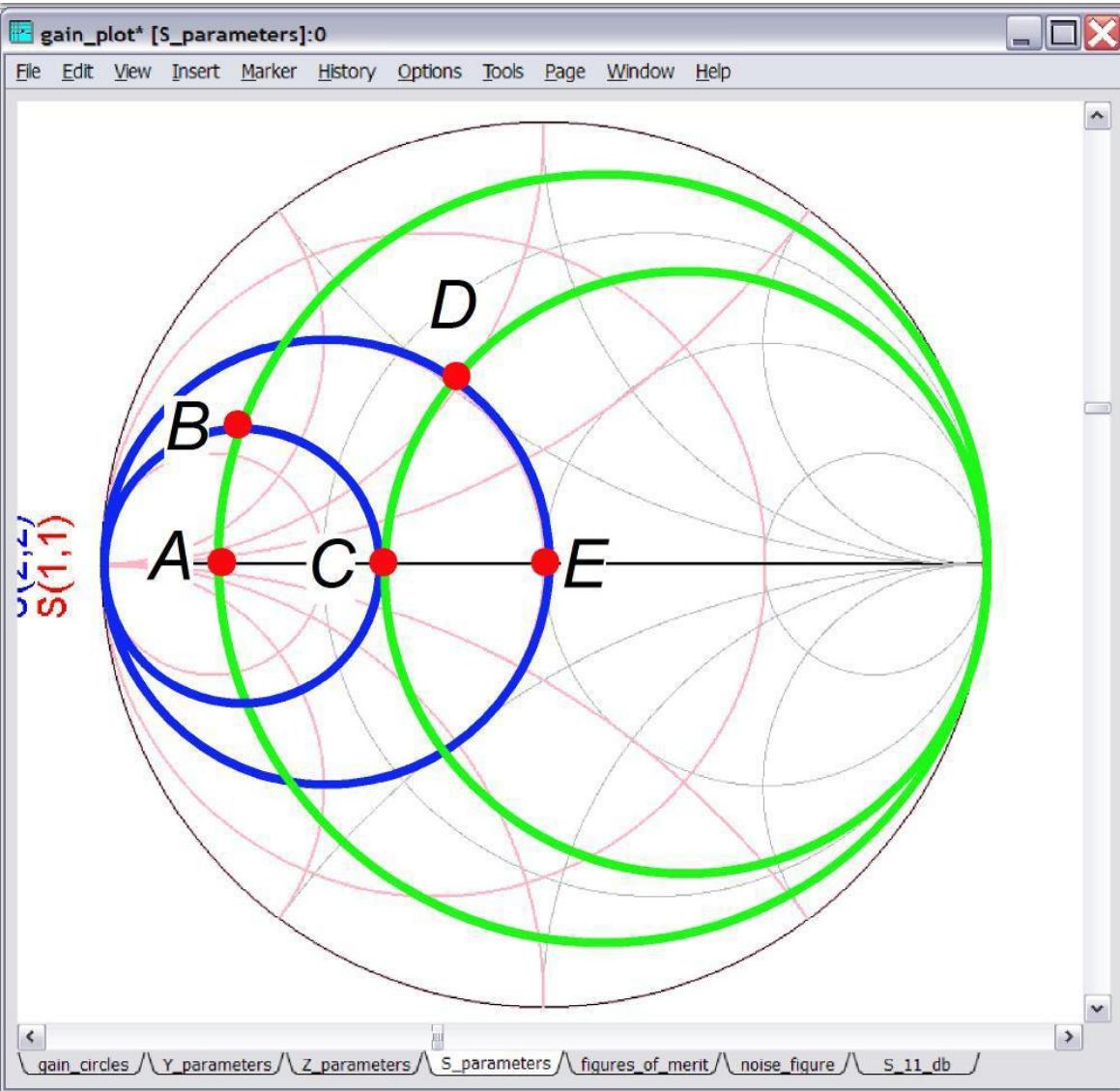
- Factor de calitate ridicat echivalent cu banda ingusta



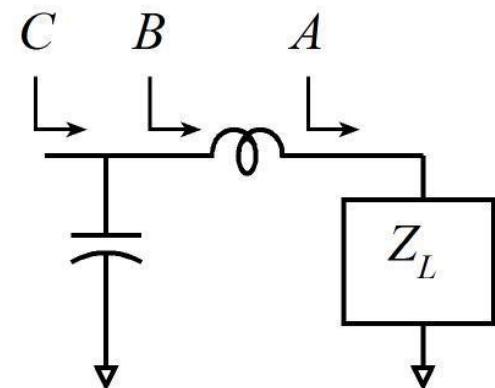
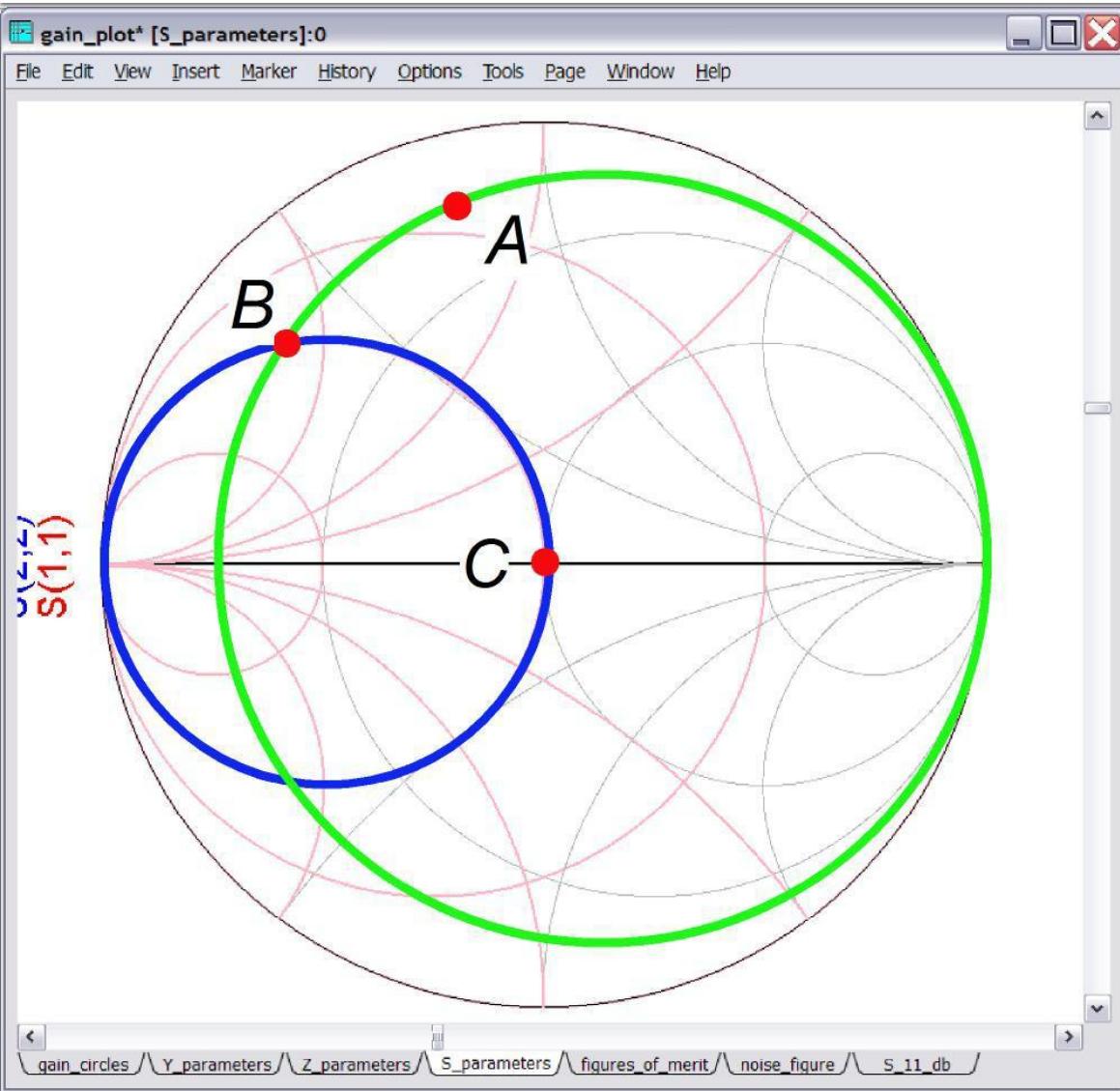
# Adaptare - banda



# Adaptare - banda

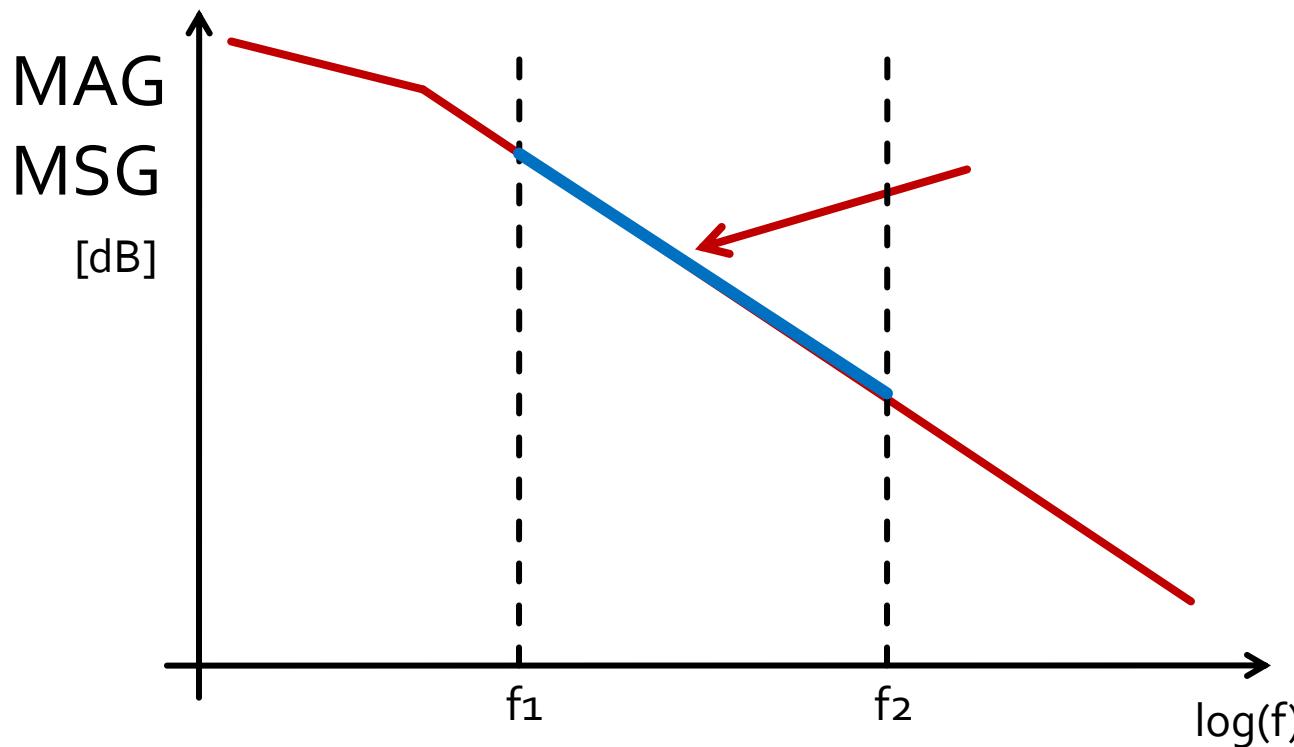


# Adaptare - banda



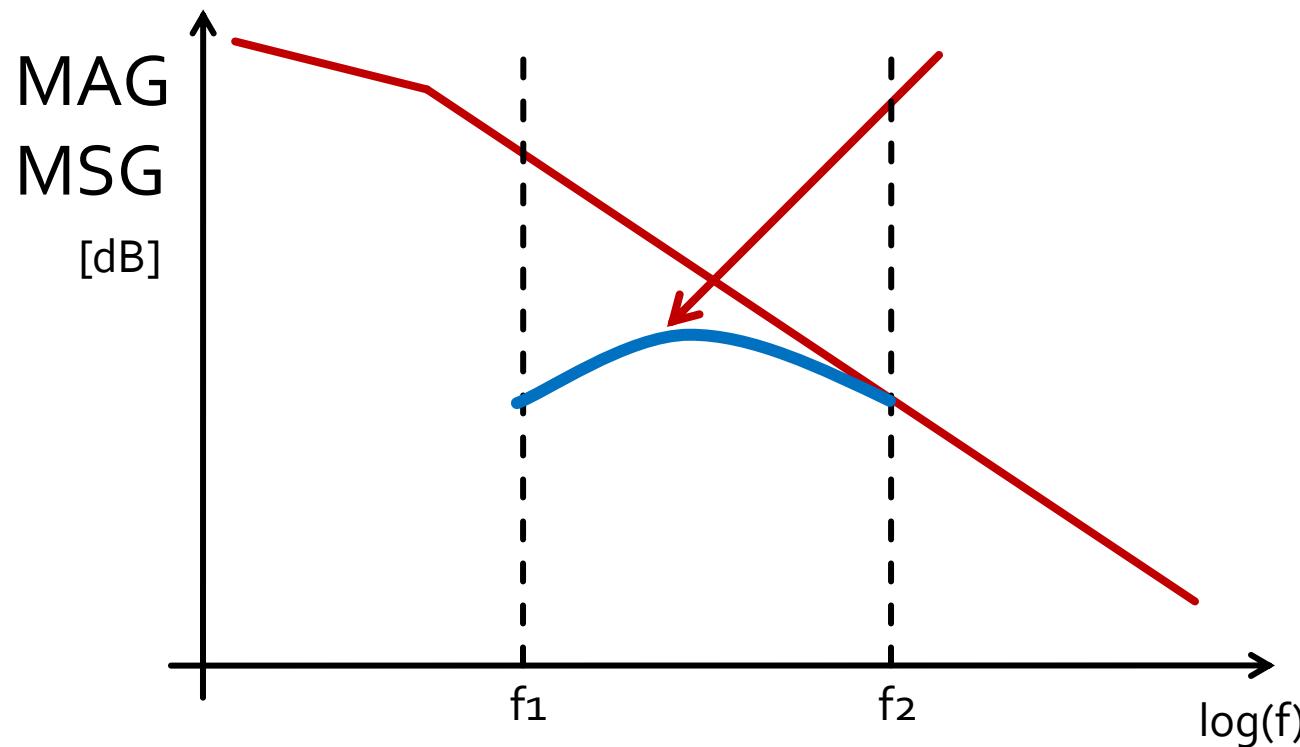
# Amplificator de banda largă

- 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

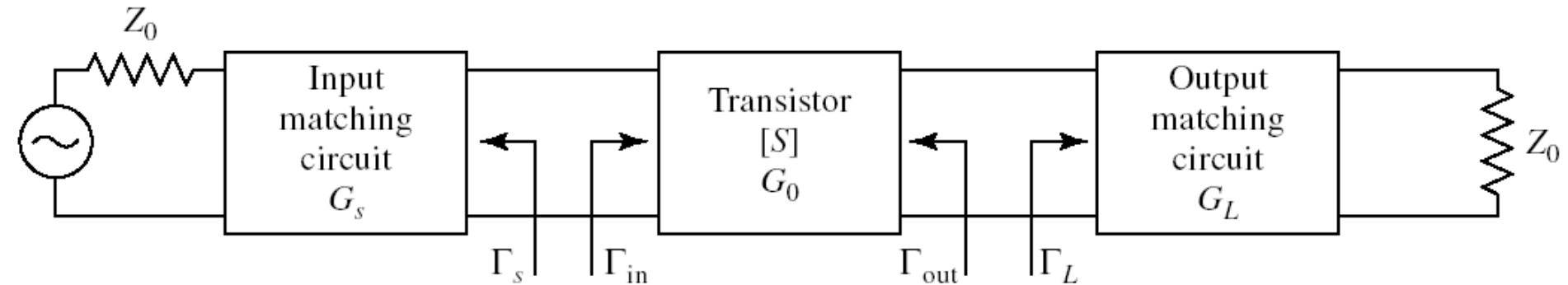
$$\frac{1}{(1+U)^2} < \frac{G_T}{G_{TU}} < \frac{1}{(1-U)^2}$$

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

- Se calculeaza U si abaterea maxima si minima a lui GTU fata de GT
  - aceasta abatere trebuie prevazuta in proiectare ca rezerva pentru castigul maxim

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

# Proiectare pentru castig impus



- Daca ipoteza tranzistorului unilateral este justificata:

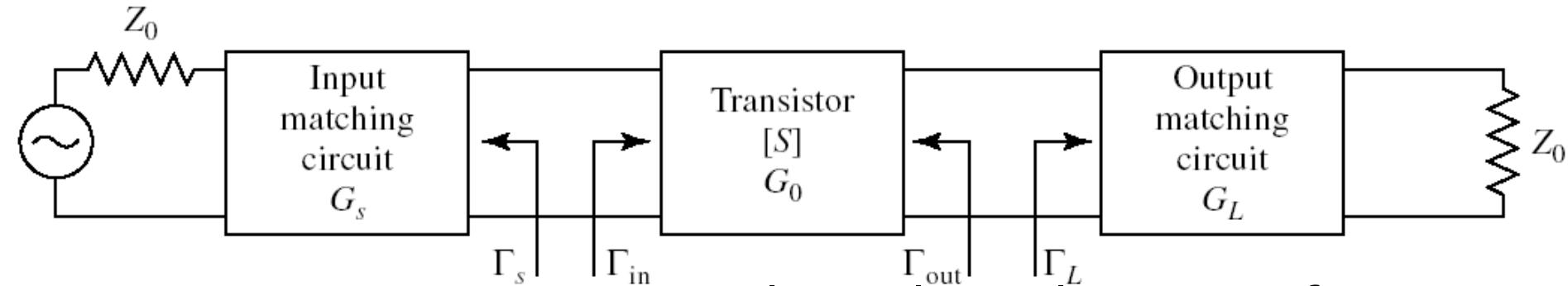
$$G_{TU} = |S_{21}|^2 \cdot \frac{1 - |\Gamma_S|^2}{|1 - S_{11} \cdot \Gamma_S|^2} \cdot \frac{1 - |\Gamma_L|^2}{|1 - S_{22} \cdot \Gamma_L|^2}$$

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

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

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

# Proiectare pentru castig impus

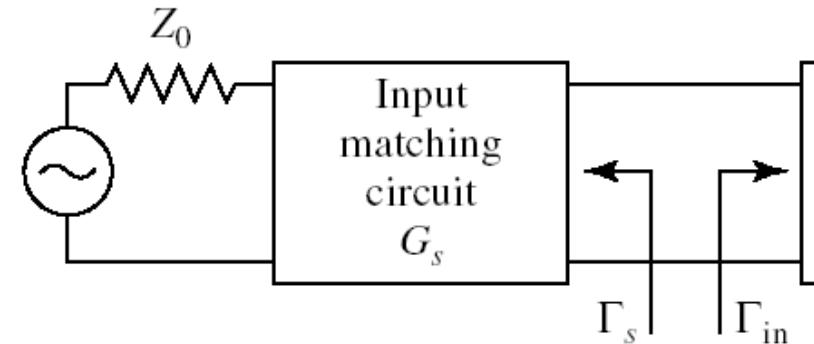


- Daca ipoteza tranzistorului unilateral este justificata:
  - castigul adaugat prin adaptare mai buna la intrare **nu** depinde de adaptarea la iesire
  - castigul adaugat prin adaptare mai buna la iesire **nu** depinde de adaptarea la intrare
- Adaptarile la intrare/iesire pot fi tratate independent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

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

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

# 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

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

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

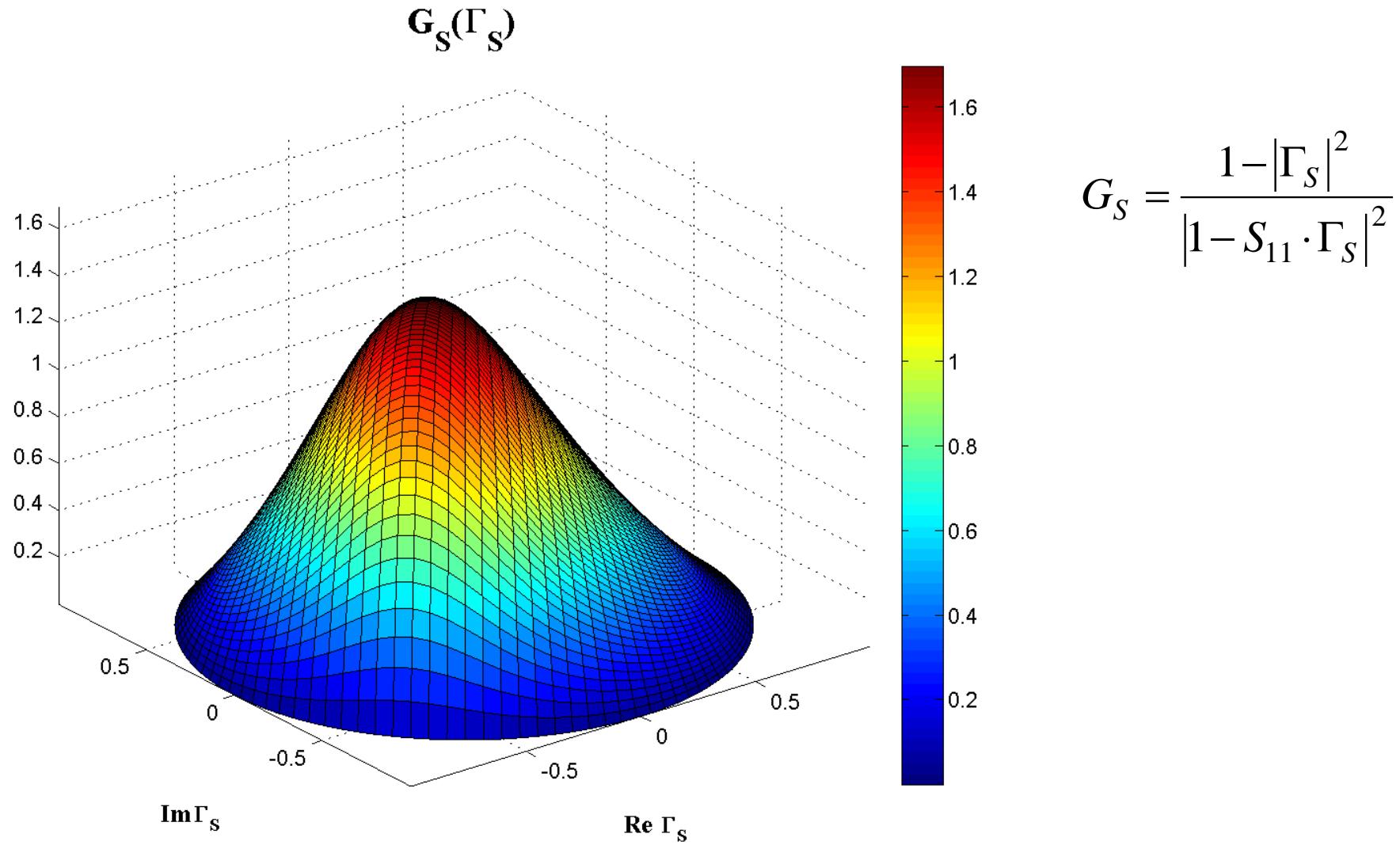
$$-0.783 \text{ dB} < G_T[\text{dB}] - G_{TU}[\text{dB}] < 0.861 \text{ dB}$$

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

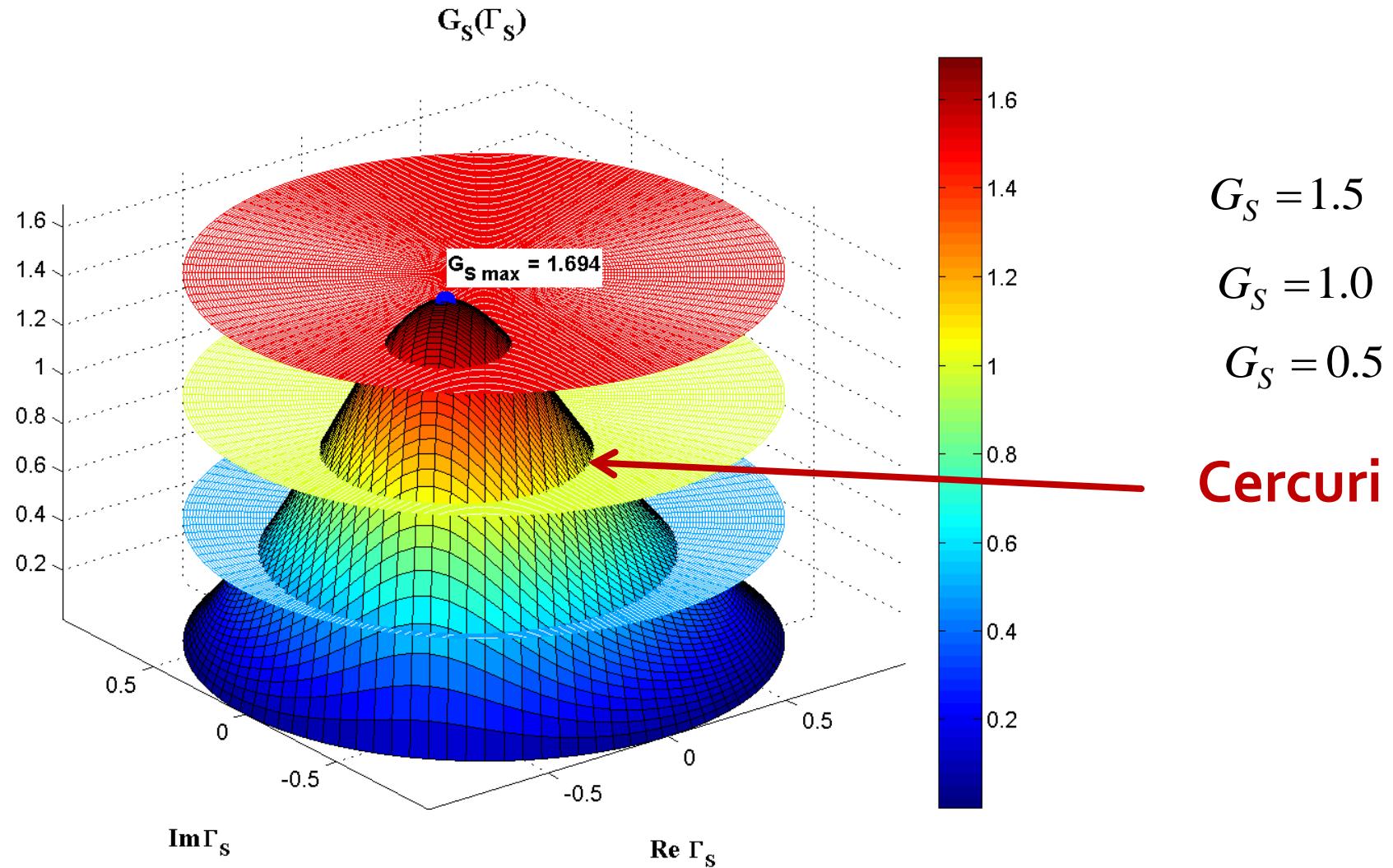
$$G_{TU \max}[\text{dB}] = 12.511 \text{ dB}$$

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

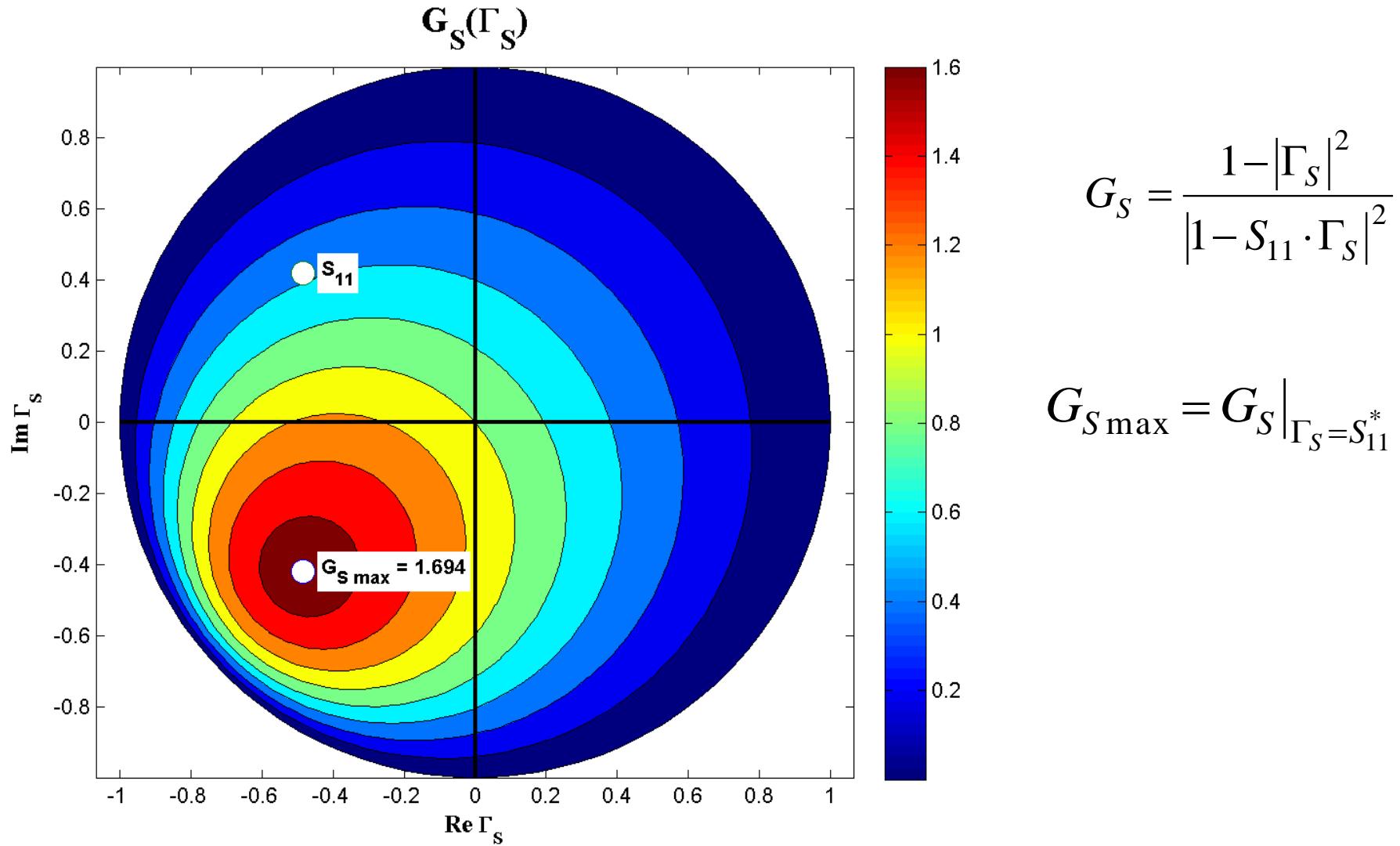
# $\mathbf{G}_S(\Gamma_S)$



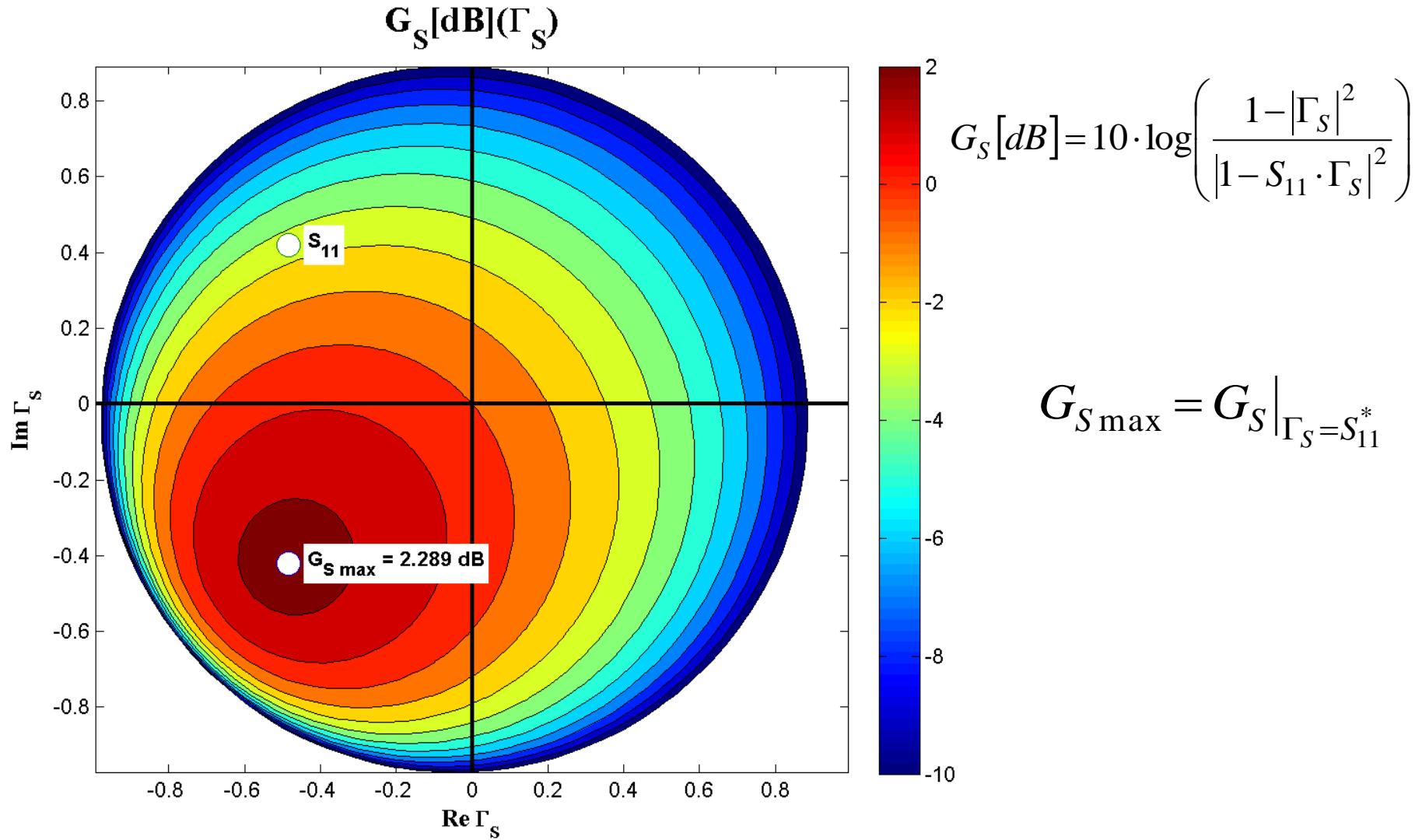
# $G_S(\Gamma_S)$ , nivel constant



# $G_S(\Gamma_S)$ , 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  $G_S > G_{\text{cerc}}$

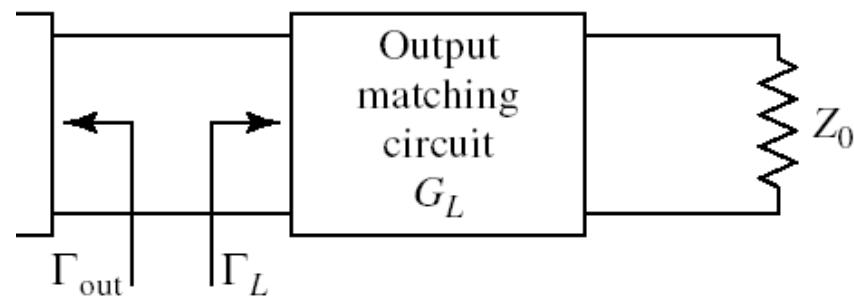
# Cercuri de castig constant la intrare

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

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

- 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

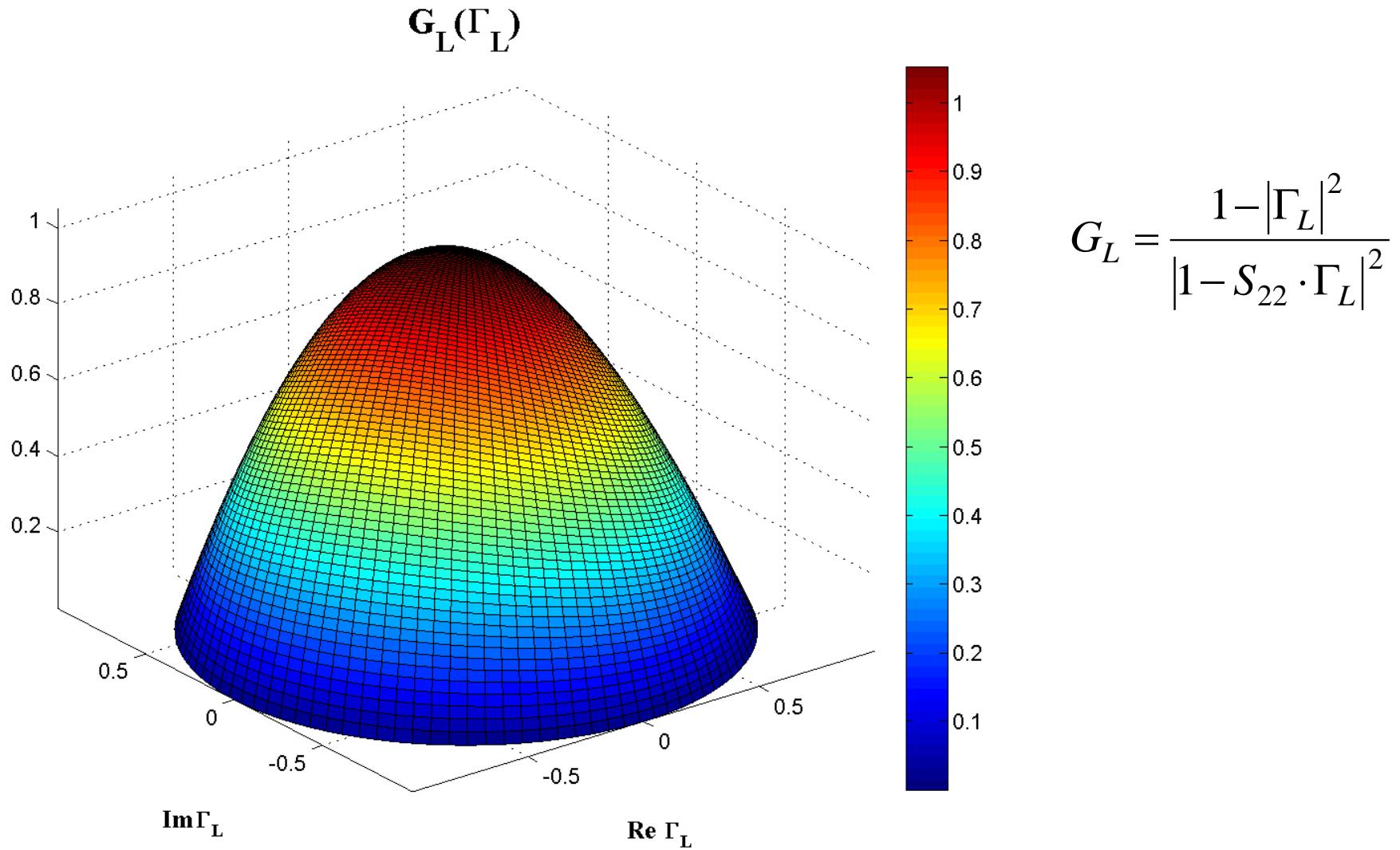
$$C_L = \frac{g_L \cdot S_{22}^*}{1 - (1 - g_L) \cdot |S_{22}|^2}$$

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

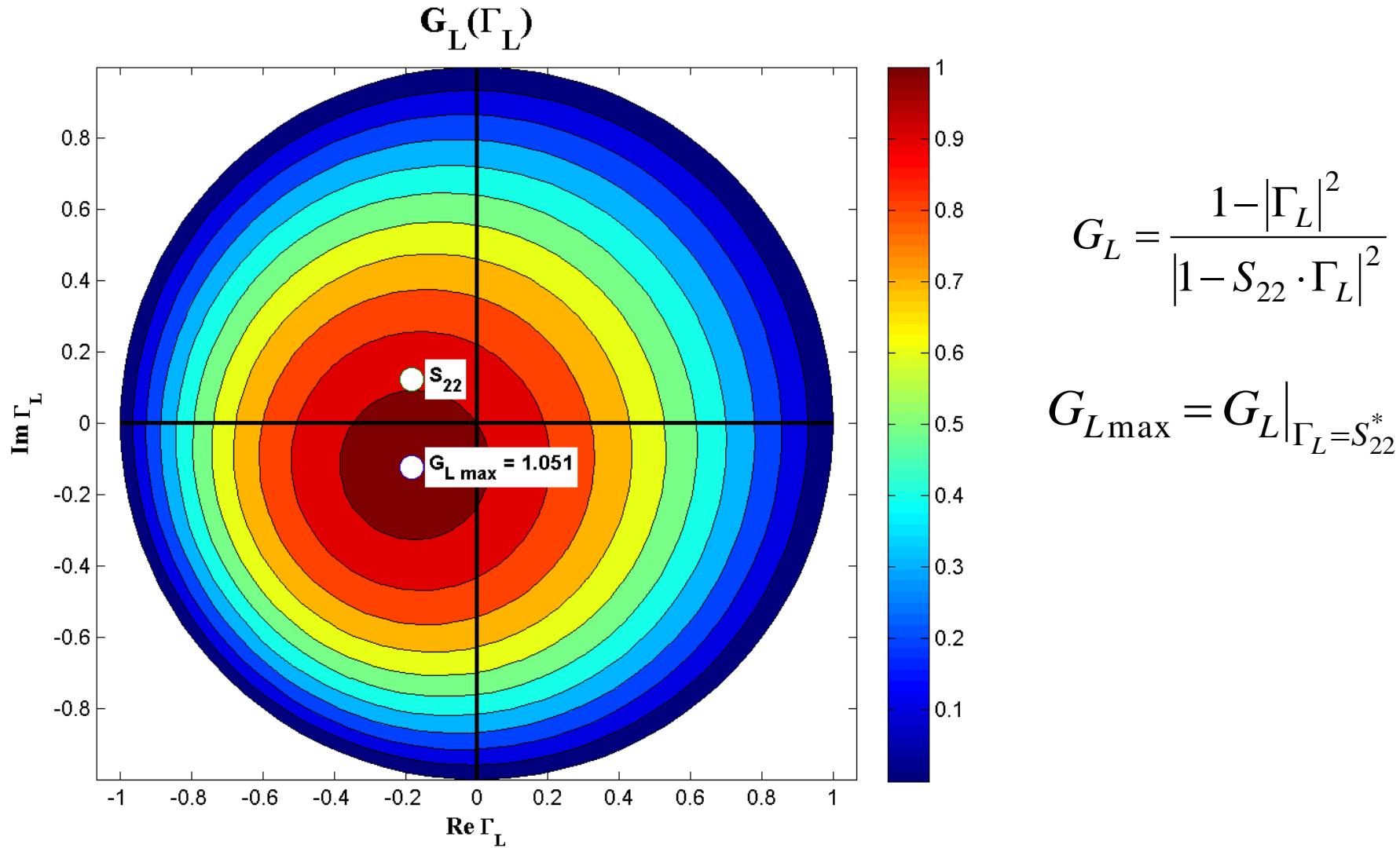
- Exemplu

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

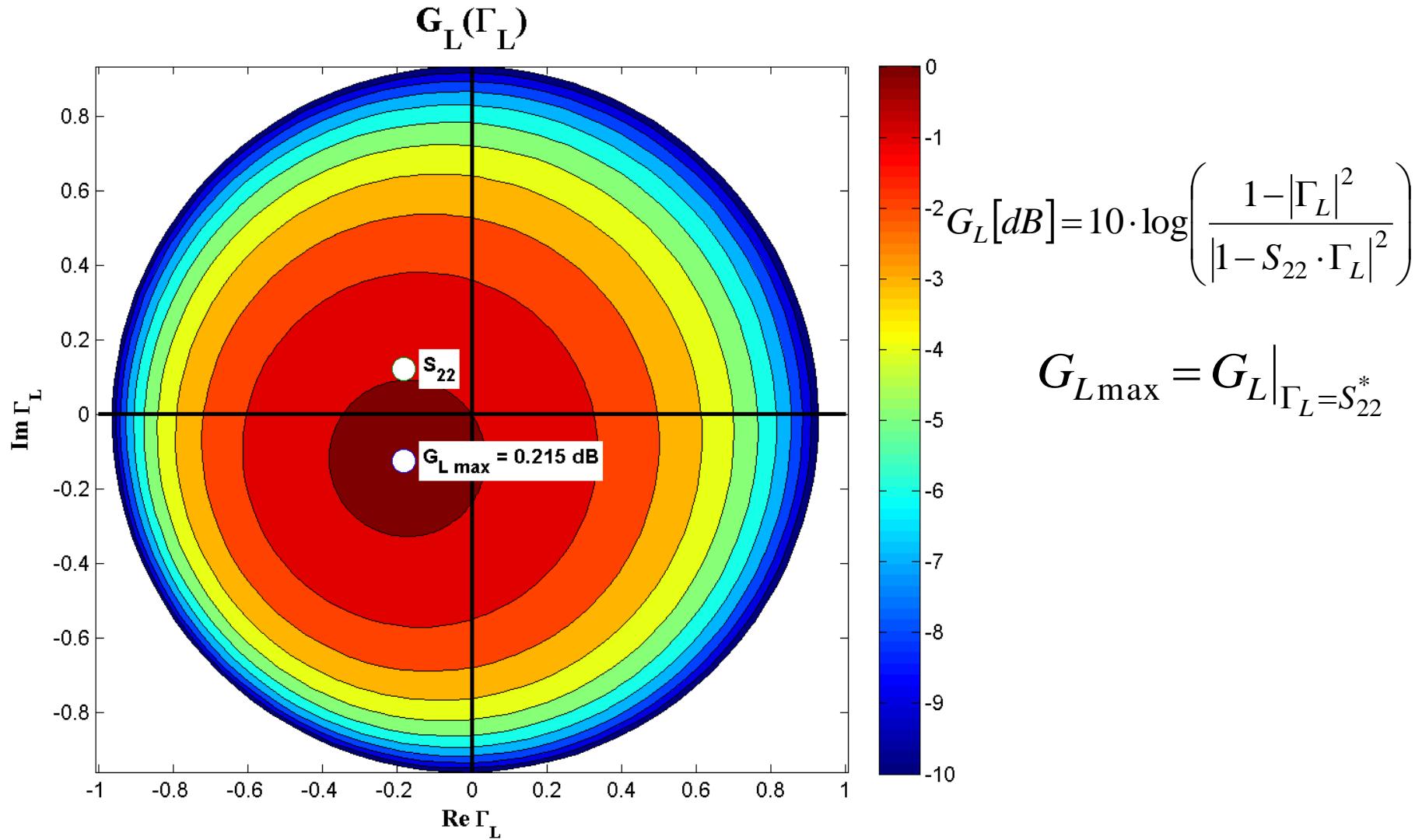
# $\mathbf{G}_L(\Gamma_L)$



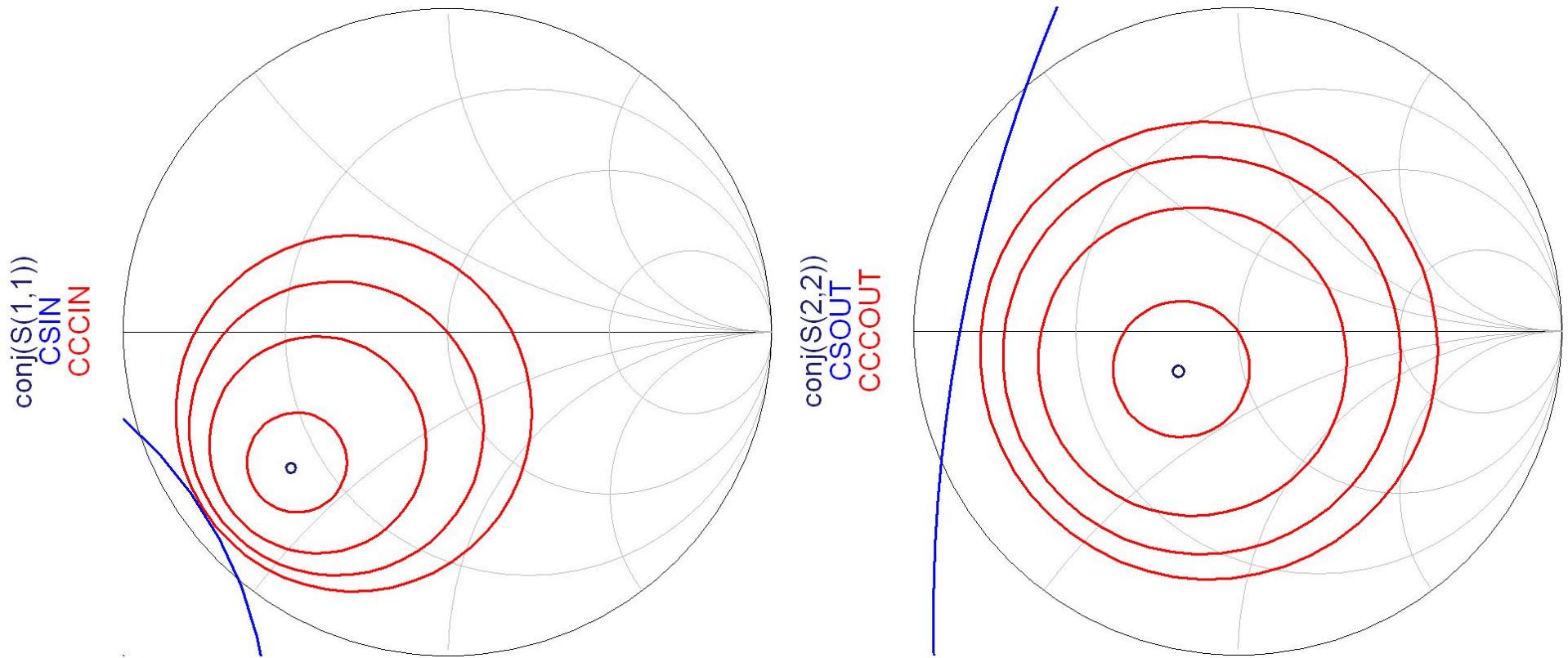
# $G_L(\Gamma_L)$ , diagrama de nível



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



# ADS



- 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

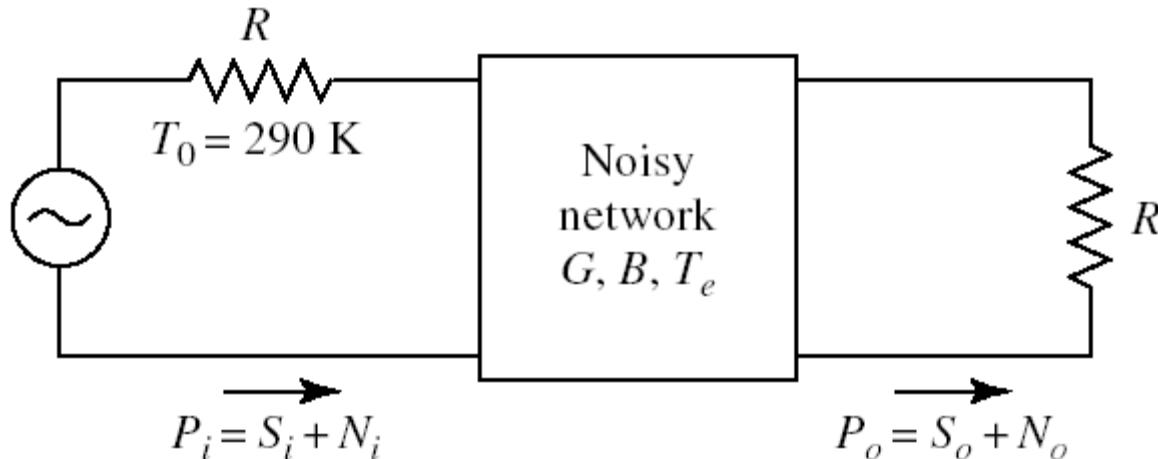
$$G_{dorit} [dB] = G_{S\_dor} [dB] + G_0 [dB] + G_{L\_dor} [dB]$$

- 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)

Proiectare pentru zgomot redus

# **Amplificatoare de microunde**

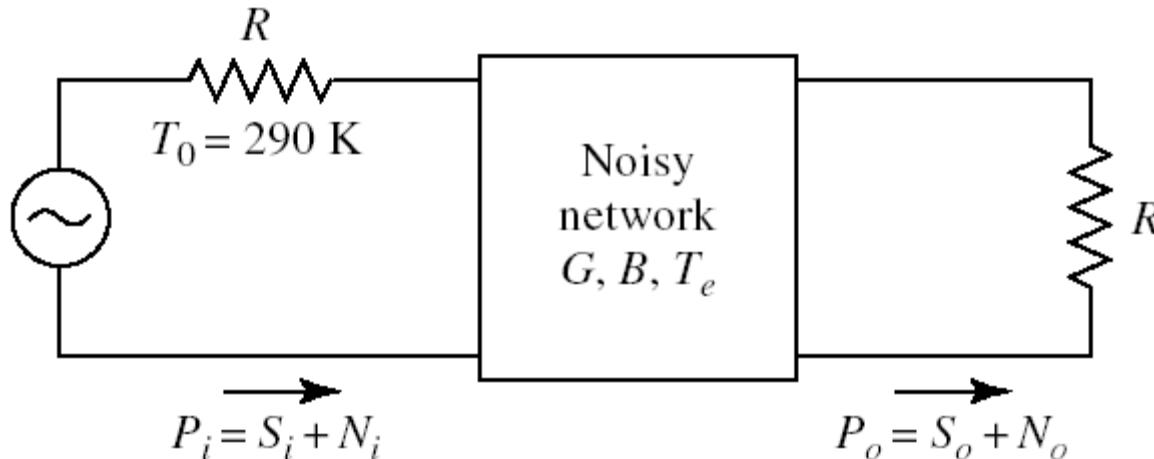
# Factor de zgomot



- Factorul de zgomot  $F$  caracterizeaza degradarea raportului semnal/zgomot intre intrarea si iesirea unei componente, cand la intrare se aplica o putere de zgomot de referinta ( $T_0 = 290\text{K}$ )

$$F = \left. \frac{S_i/N_i}{S_o/N_o} \right|_{T_0=290K}$$

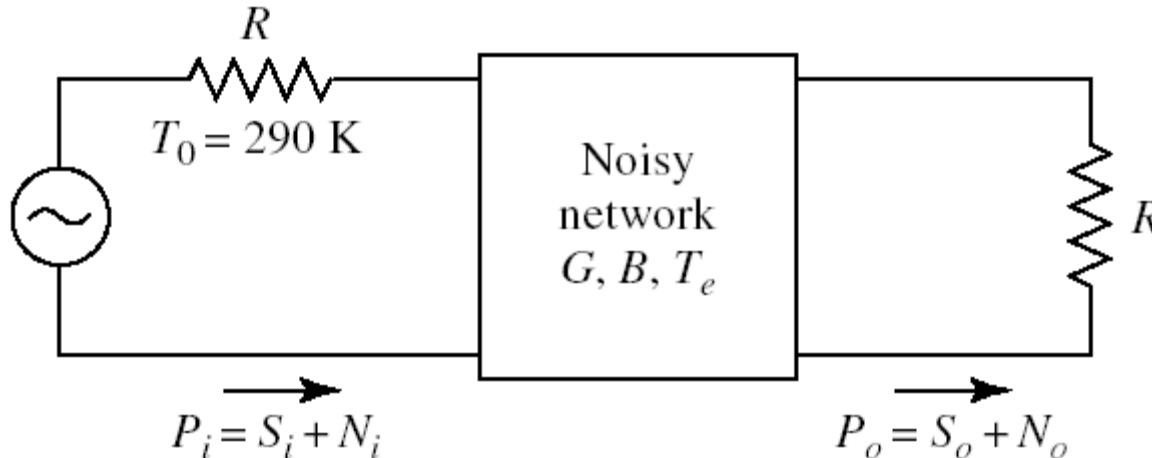
# Factor de zgomot



- Factorul de zgomot  $F$  **nu** caracterizeaza direct degradarea raportului semnal/zgomot intre intrarea si iesirea unei componente, cand la intrare se aplica o putere de zgomot diferita de cea de referinta

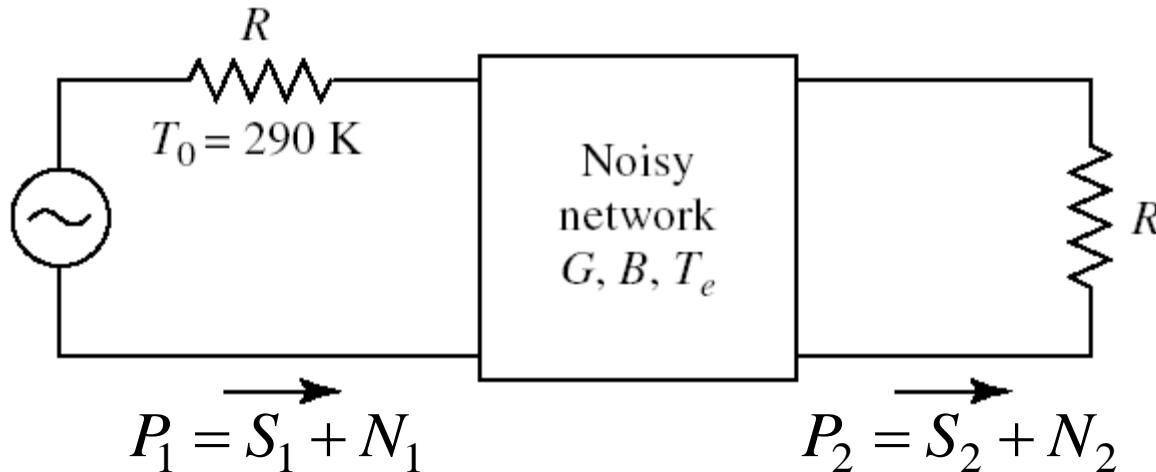
$$F \neq \left. \frac{S_i/N_i}{S_o/N_o} \right|_{T_0 \neq 290K}$$

# Factor de zgomot



- În general, puterea de zgomot la ieșire se obtine cu două componente:
  - o putere datorată zgomotului de intrare amplificat cu castigul  $G$  (depinde de puterea de zgomot de la intrare)
  - o putere de zgomot generată intern de dispozitiv (care **nu** depinde de puterea de zgomot de la intrare)

# Factor de zgomot



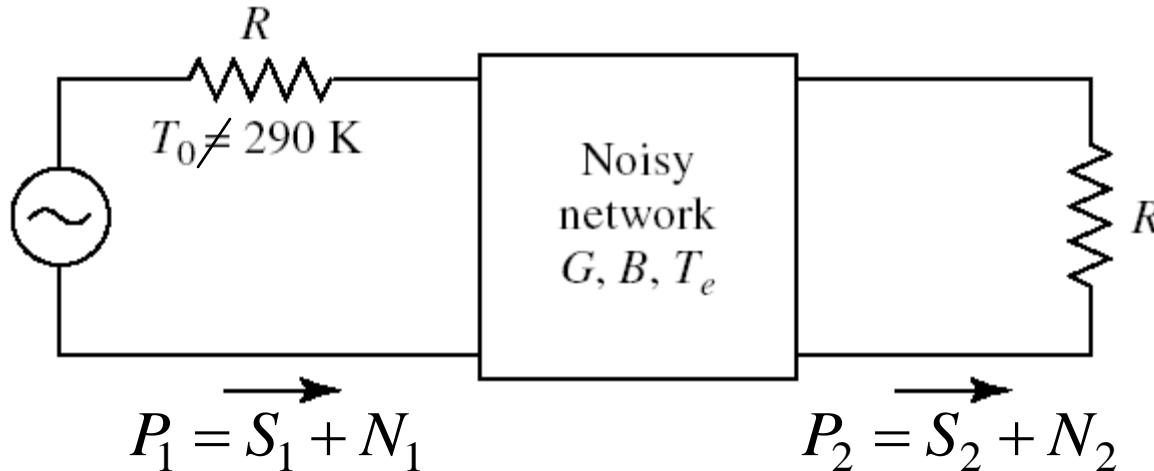
- Estimarea puterii de zgomot adaugate se poate face plecand de la definitia factorului de zgomot:

$$F = \left. \frac{S_1/N_1}{S_2/N_2} \right|_{T_0=290K, N_1=N_0}$$

$$N_2 = F \cdot N_0 \cdot \frac{S_2}{S_1} = F \cdot N_0 \cdot G$$

$$N_2 = N_0 \cdot G + (F - 1) \cdot N_0 \cdot G$$

# Factor de zgomot

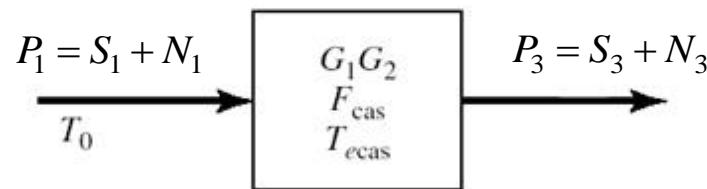
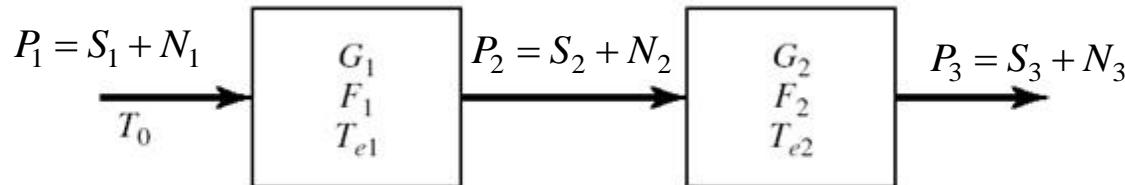


- Se identifica cele două termeni:
  - zgomotul de intrare amplificat
  - zgomotul adăugat intern
- Pentru o situație în care la intrare nu am zgomotul de referință ( $N_1 \neq N_0$ )

$$N_2 = N_0 \cdot G + (F - 1) \cdot N_0 \cdot G$$

$$N_2 = N_1 \cdot G + (F - 1) \cdot N_0 \cdot G$$

# Factor de zgomot al circuitelor cascade



$$N_2 = N_1 \cdot G_1 + (F_1 - 1) \cdot N_0 \cdot G_1$$

$$G_{cas} = G_1 \cdot G_2$$

$$N_3 = N_2 \cdot G_2 + (F_2 - 1) \cdot N_0 \cdot G_2$$

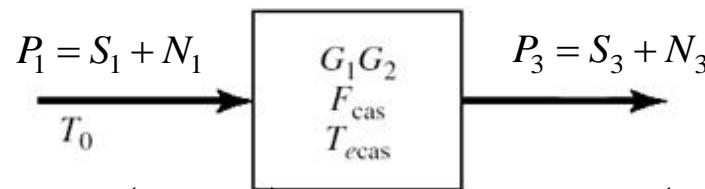
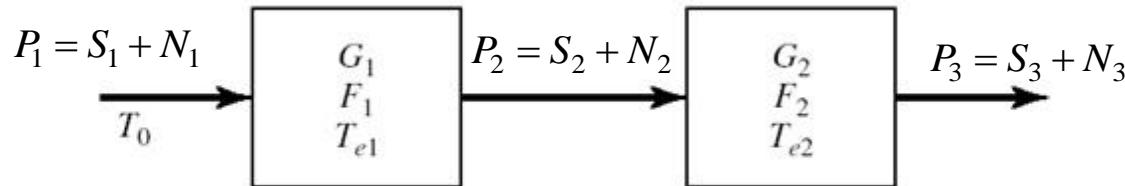
$$N_3 = N_1 \cdot G_{cas} + (F_{cas} - 1) \cdot N_0 \cdot G_{cas}$$



$$N_3 = [N_1 \cdot G_1 + (F_1 - 1) \cdot N_0 \cdot G_1] \cdot G_2 + (F_2 - 1) \cdot N_0 \cdot G_2$$

$$N_3 = N_1 \cdot G_1 \cdot G_2 + (F_1 - 1) \cdot N_0 \cdot G_1 \cdot G_2 + (F_2 - 1) \cdot N_0 \cdot G_2$$

# Factor de zgomot al circuitelor cascade



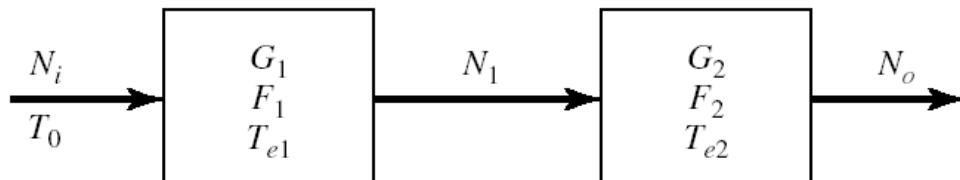
$$N_3 = N_1 \cdot G_1 \cdot G_2 + (F_1 - 1) \cdot N_0 \cdot G_1 \cdot G_2 + (F_2 - 1) \cdot N_0 \cdot G_2$$

$$G_{cas} = G_1 \cdot G_2 \quad N_3 = N_1 \cdot G_{cas} + (F_{cas} - 1) \cdot N_0 \cdot G_{cas}$$

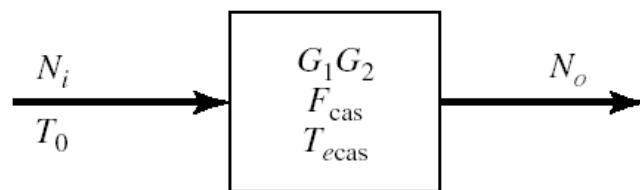
$$(F_1 - 1) \cdot N_0 \cdot G_1 \cdot G_2 + (F_2 - 1) \cdot N_0 \cdot G_2 = (F_{cas} - 1) \cdot N_0 \cdot G_1 \cdot G_2$$

$$F_{cas} = F_1 + \frac{1}{G_1} (F_2 - 1)$$

# Factor de zgomot al circuitelor cascade



(a)



(b)

$$G_{cas} = G_1 \cdot G_2$$

$$F_{cas} = F_1 + \frac{1}{G_1} (F_2 - 1)$$

- Ecuatia Friis (**!coordonate liniare**)

$$F_{cas} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \frac{F_4 - 1}{G_1 \cdot G_2 \cdot G_3} + \dots$$

# Formula lui Friis (zgomot)

$$F_{cas} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \frac{F_4 - 1}{G_1 \cdot G_2 \cdot G_3} + \dots$$

- Formula lui Friis arata ca
  - zgomotul unor circuite in cascada este in mare parte determinat de circuitul de la intrare
  - zgomotul introdus de celelalte circuite este redus
    - $-1$
    - impartire la  $G$  (de obicei supraunitar)

# Formula lui Friis (zgomot)

$$F_{cas} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 \cdot G_2} + \frac{F_4 - 1}{G_1 \cdot G_2 \cdot G_3} + \dots$$

- Formula lui Friis, efecte:
  - in amplificatoare multietaj:
    - e esential ca primul etaj de amplificare sa fie nezgomotos, chiar cu sacrificarea in parte a castigului
    - urmatoarele etaje pot fi optimizate pentru castig
  - pentru un singur amplificator:
    - la intrare e important sa introducem elemente nezgomotoase (reactive, linii fara pierderi)
    - circuitul de adaptare la iesire are o influenta mai mica (zgomotul este generat intr-un punct in care semnalul este deja amplificat de tranzistor)

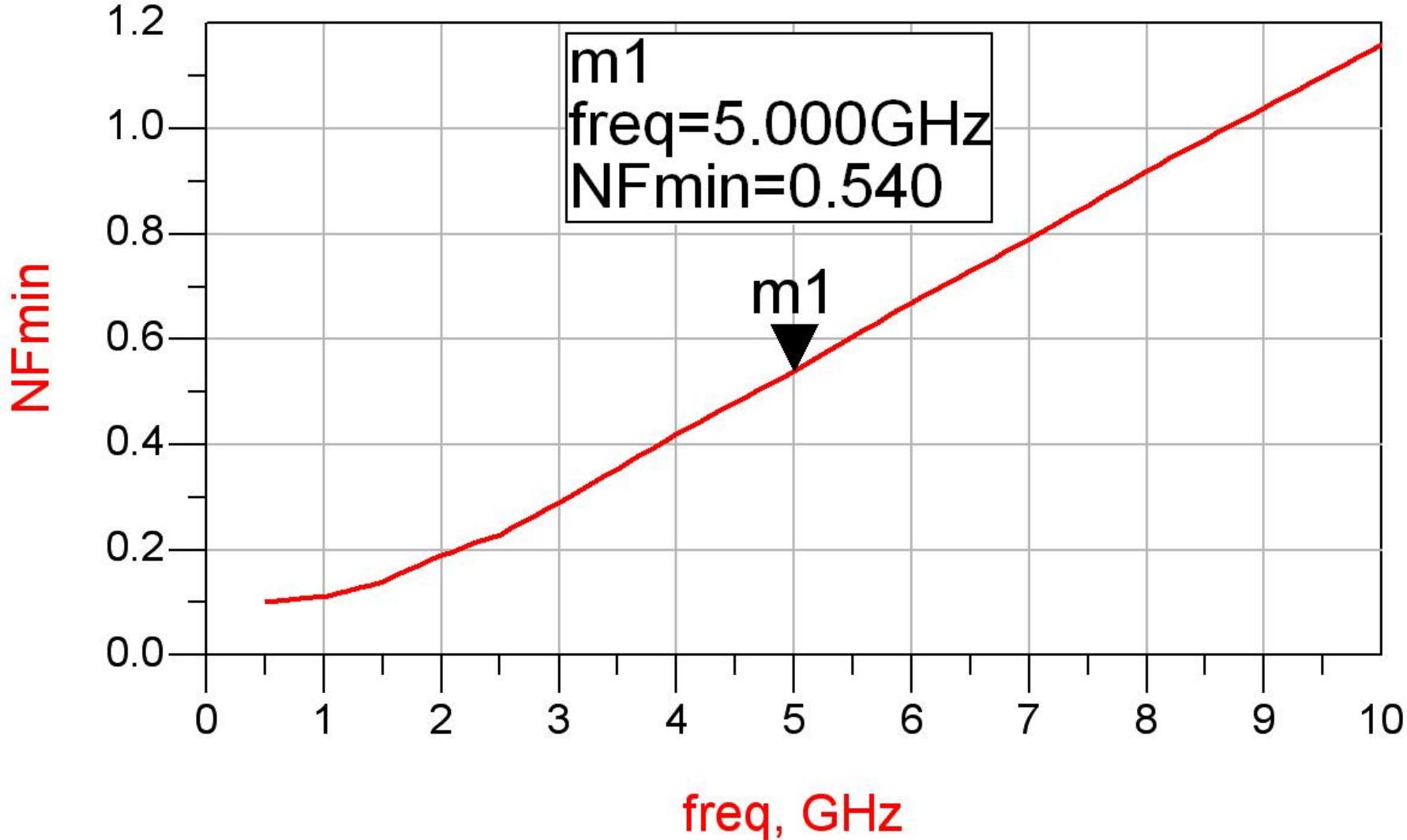
$$V_{n(ef)} = \sqrt{4kTBR}$$

$$P_n = kTB$$

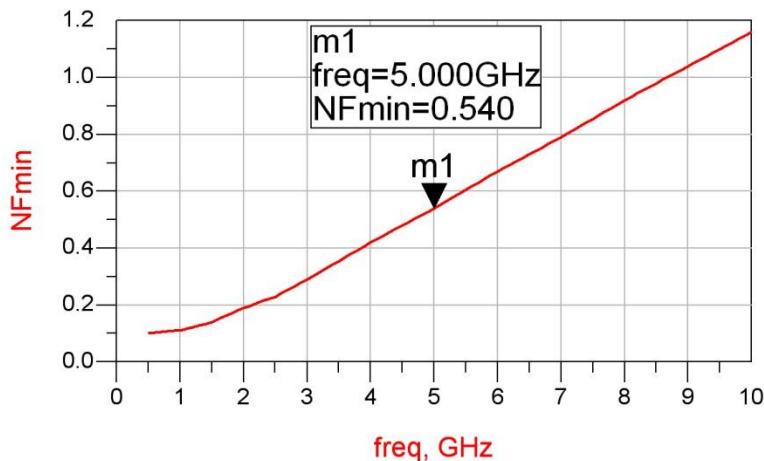
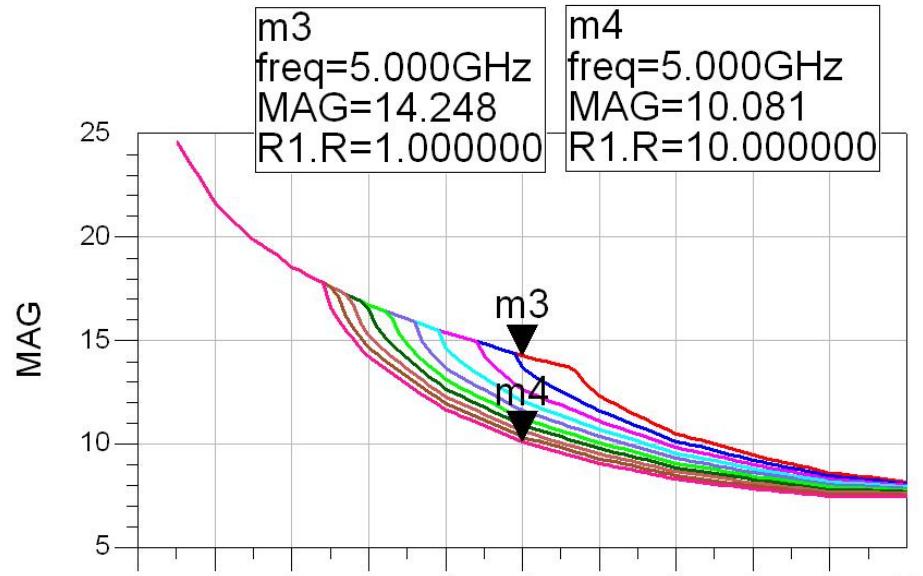
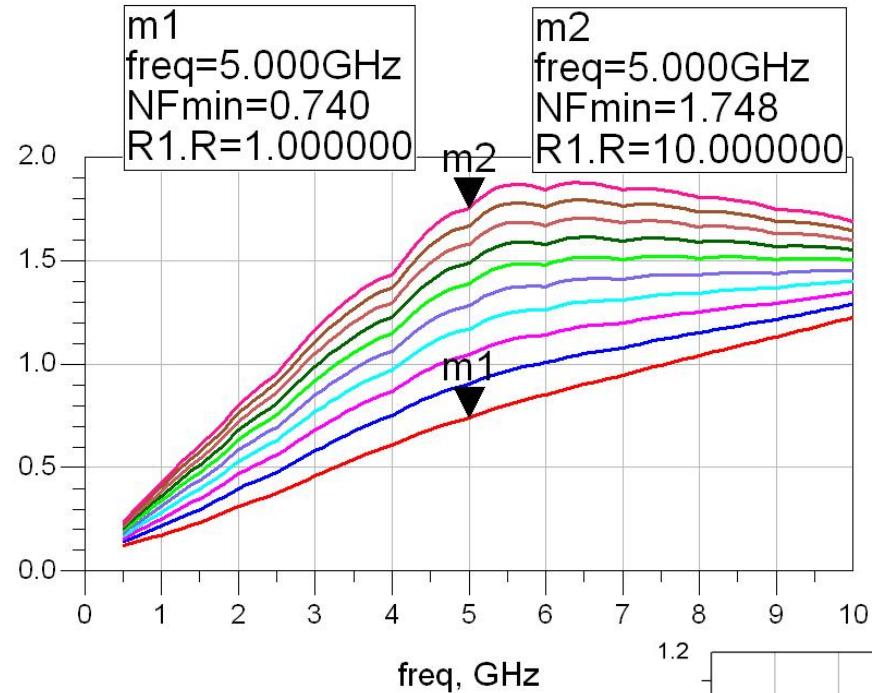
# Exemplu

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- @5GHz
  - $S_{11} = 0.64 \angle 139^\circ$
  - $S_{12} = 0.119 \angle -21^\circ$
  - $S_{21} = 3.165 \angle 16^\circ$
  - $S_{22} = 0.22 \angle 146^\circ$
  - $F_{min} = 0.54$  (**tipic [dB] !**)
  - $\Gamma_{opt} = 0.45 \angle 174^\circ$
  - $r_n = 0.03$

# Exemplu

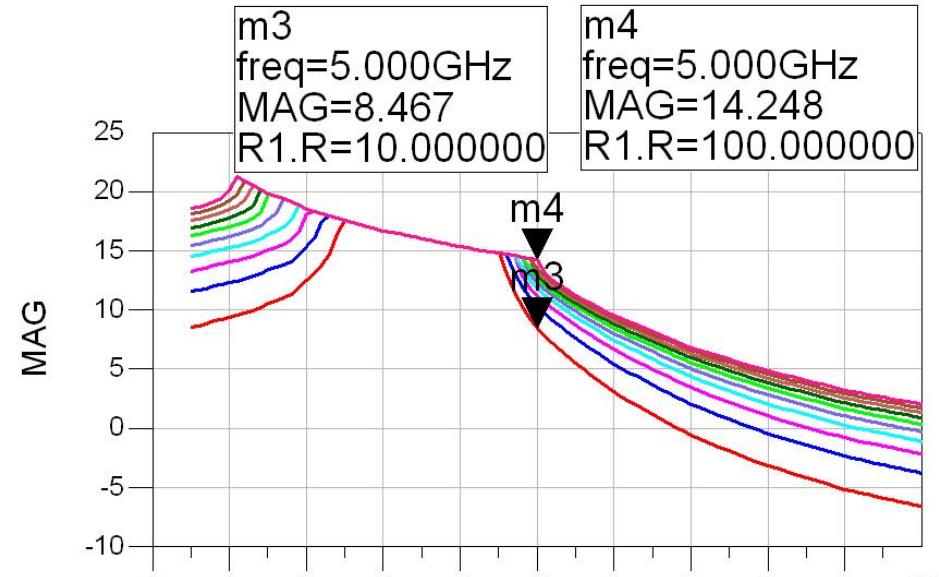
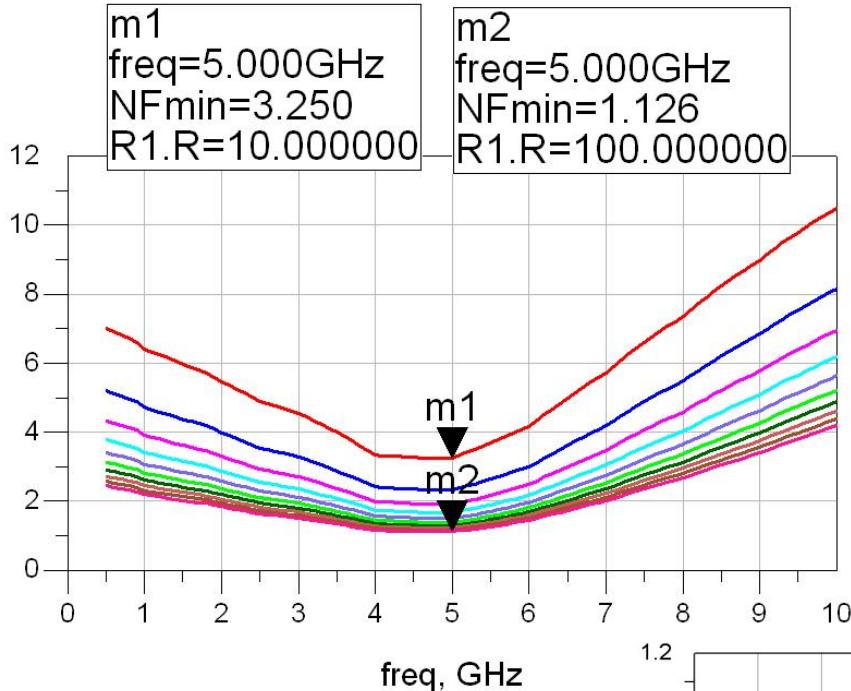


# Stabilizare R serie la intrare

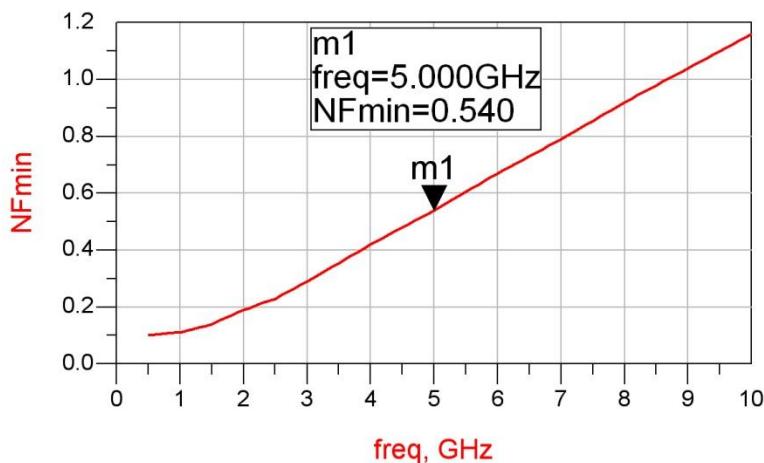


$$R_{SS} = 1 \div 10 \Omega$$

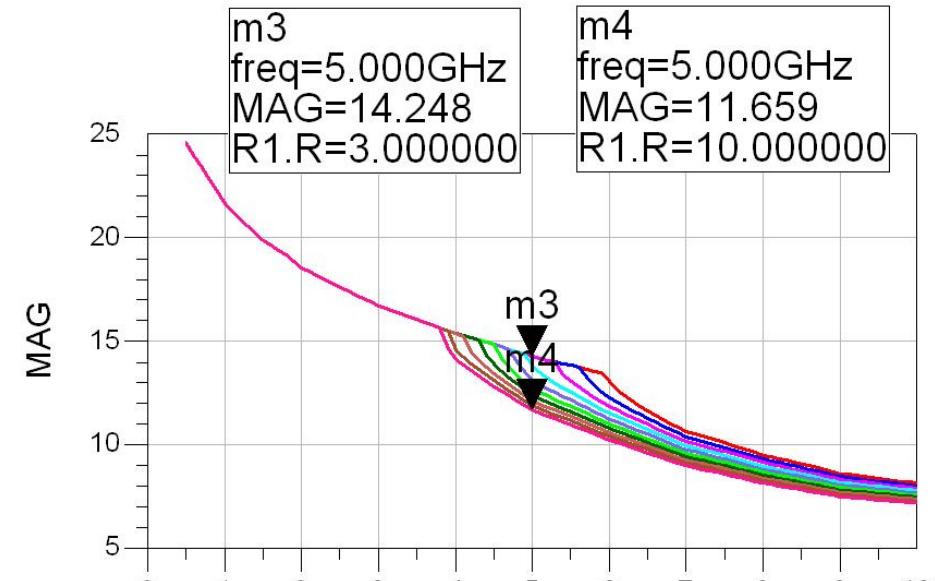
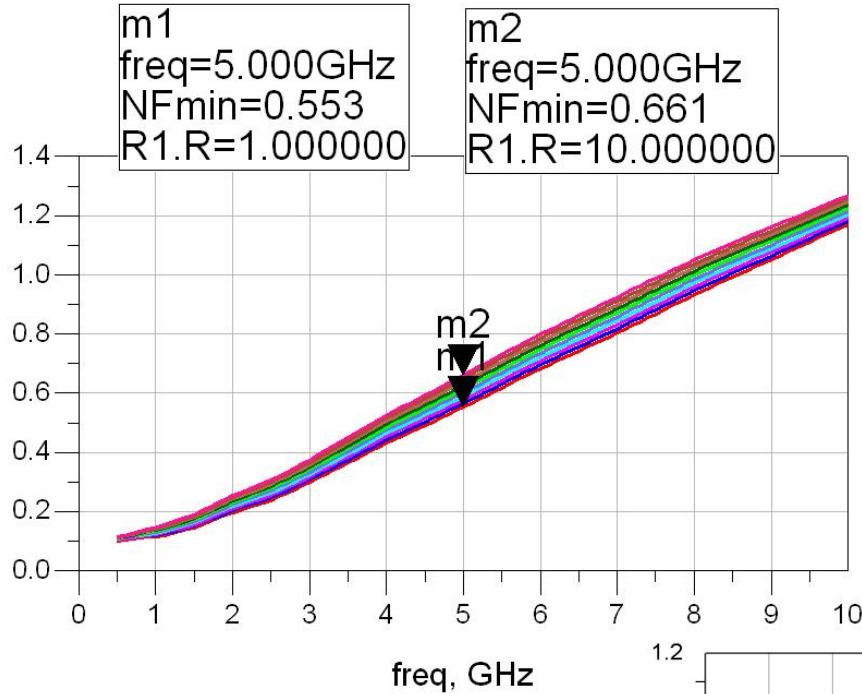
# Stabilizare R paralel la intrare



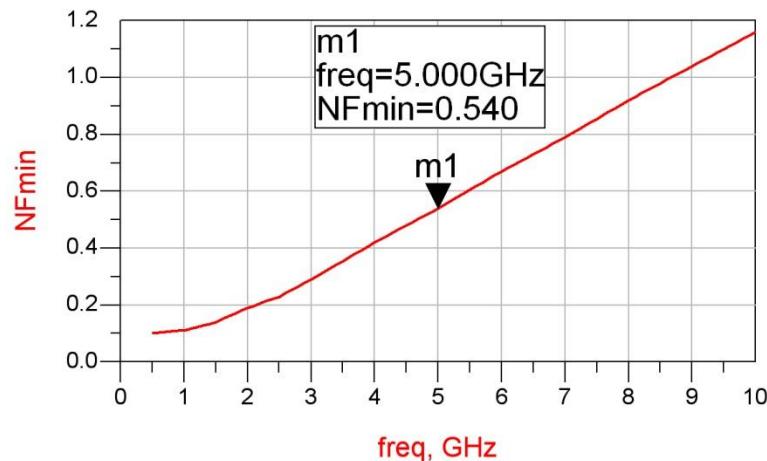
$$R_{PS} = 10 \div 100 \Omega$$



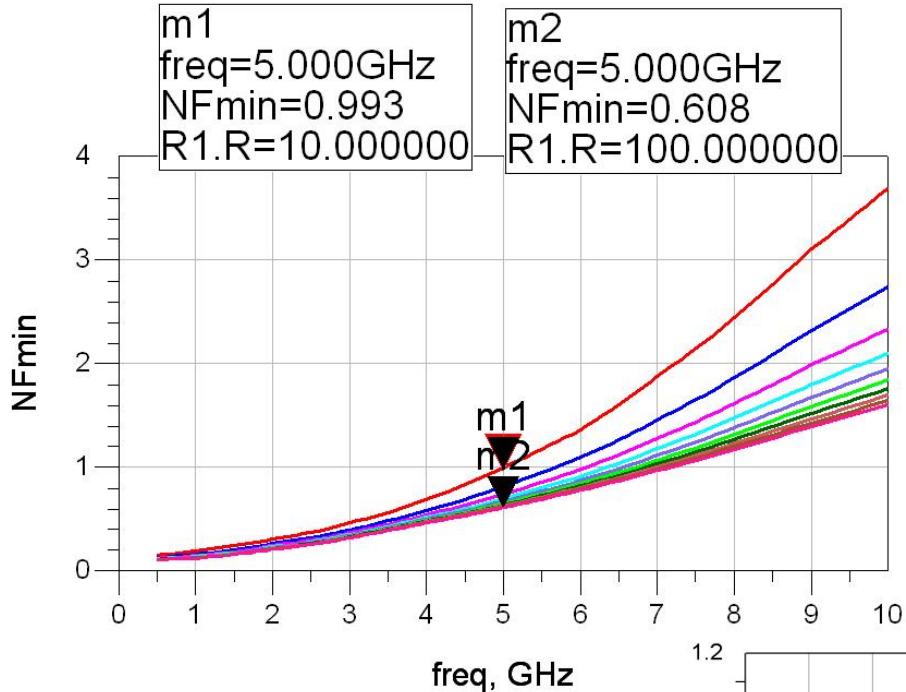
# Stabilizare R serie la ieșire



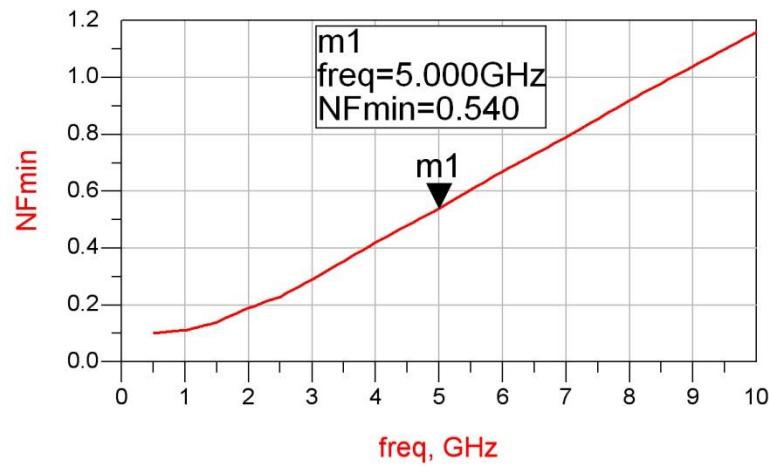
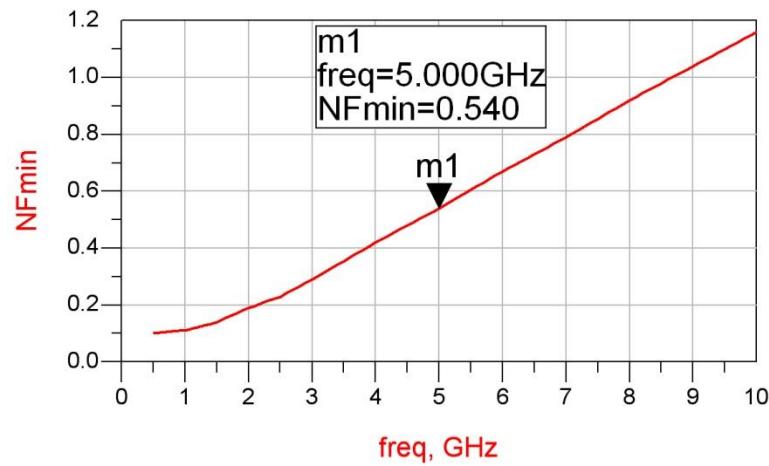
$$R_{SL} = 1 \div 10 \Omega$$



# Stabilizare R paralel la ieșire



$$R_{PL} = 10 \div 100 \Omega$$



# Zgomotul unui amplificator

- Caracterizat de 3 parametri (2 reali + 1 complex):

$$F_{\min}, r_n = \frac{R_N}{Z_0}, \Gamma_{opt}$$

$$F = F_{\min} + \frac{R_N}{G_S} \cdot |Y_S - Y_{opt}|^2 \quad Y_S = \frac{1}{Z_0} \cdot \frac{1 - \Gamma_S}{1 + \Gamma_S} \quad Y_{opt} = \frac{1}{Z_0} \cdot \frac{1 - \Gamma_{opt}}{1 + \Gamma_{opt}}$$

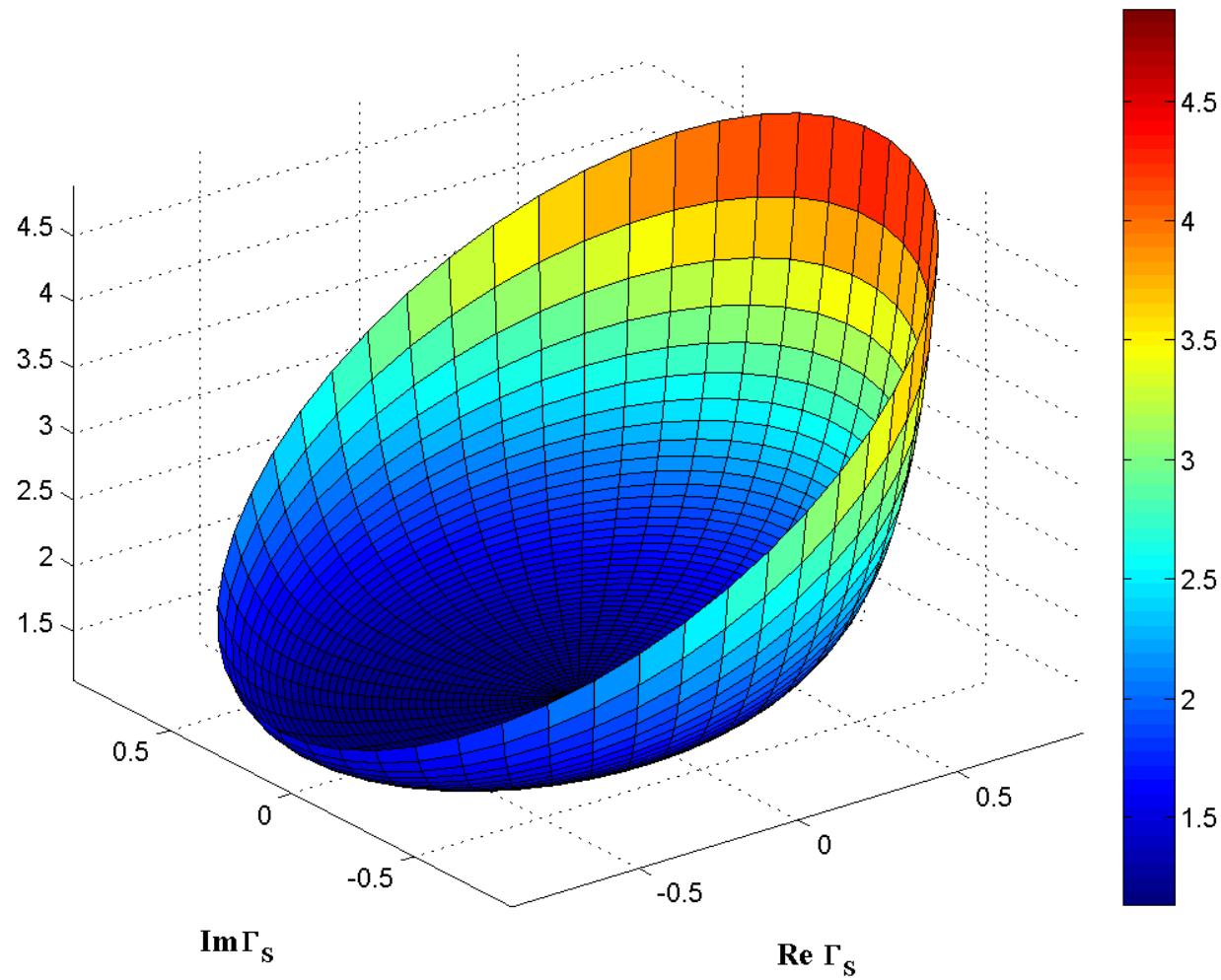
$$F = F_{\min} + 4 \cdot r_n \cdot \frac{|\Gamma_S - \Gamma_{opt}|^2}{(1 - |\Gamma_S|^2) \cdot |1 + \Gamma_{opt}|^2}$$

- $\Gamma_{opt}$  reprezinta coeficientul optim de reflexie la intrare

$$\Gamma_S = \Gamma_{opt} \Rightarrow F = F_{\min}$$

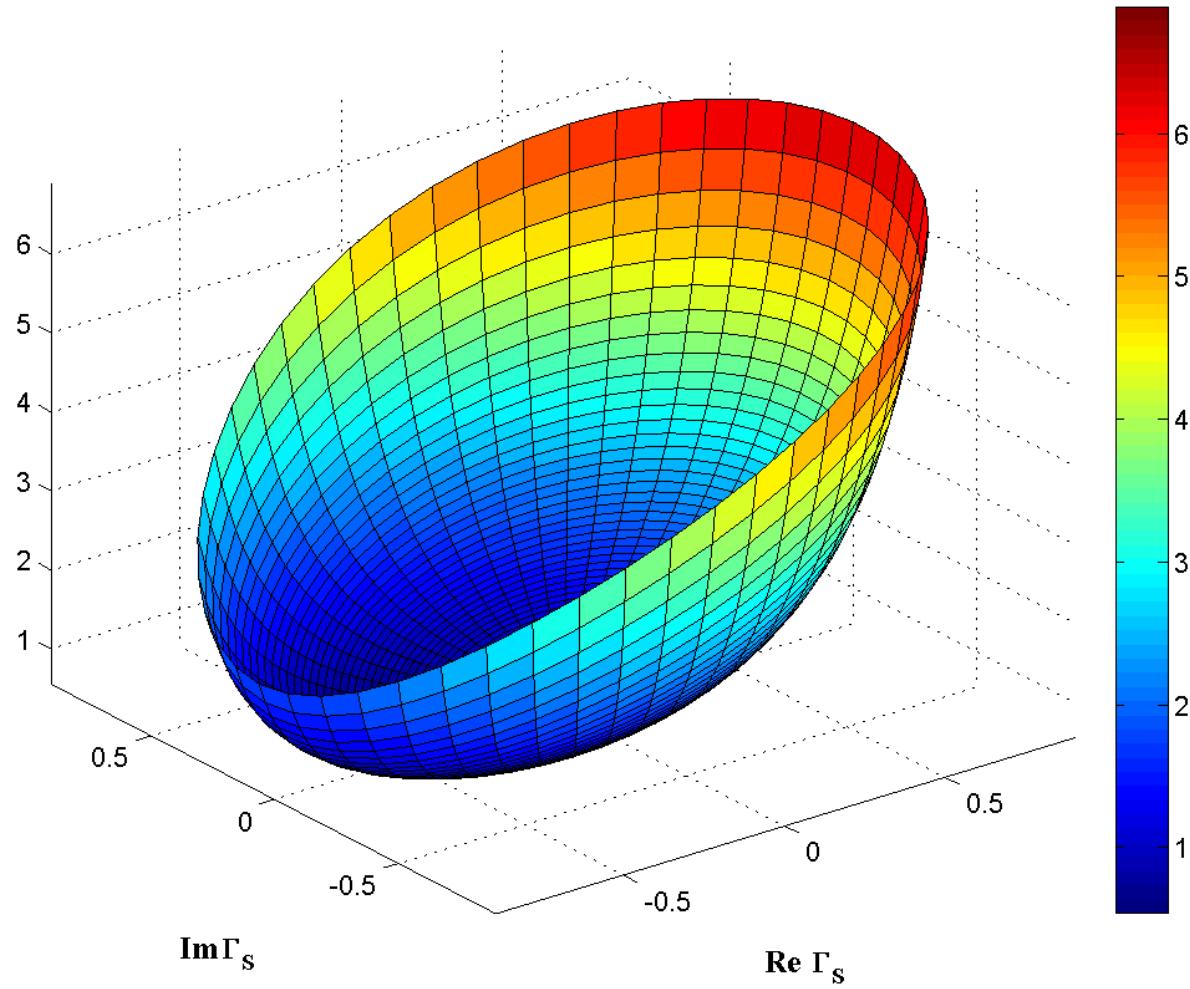
# $F(\Gamma_s)$

$F(\Gamma_s)$

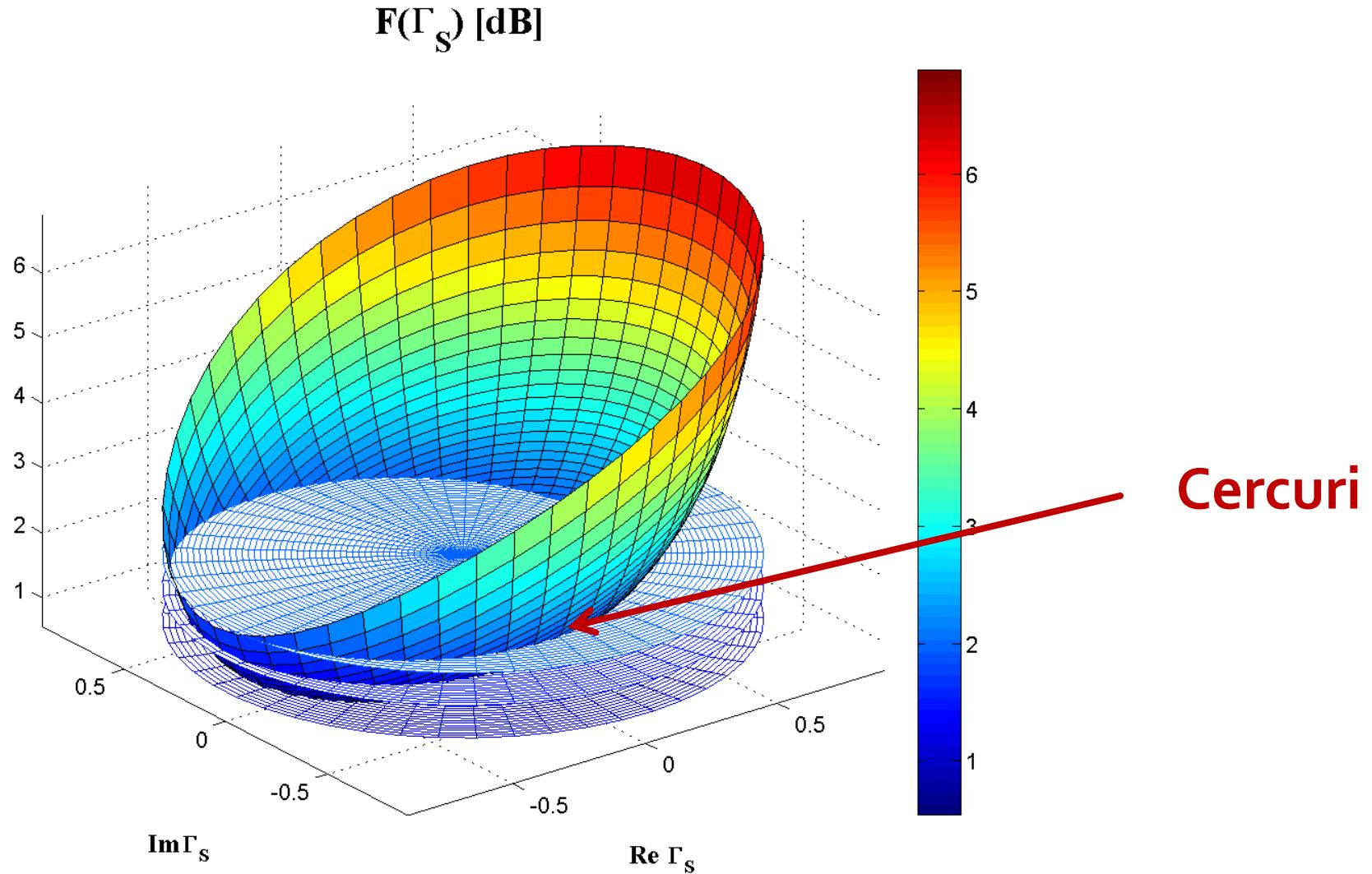


# $F[dB](\Gamma_S)$

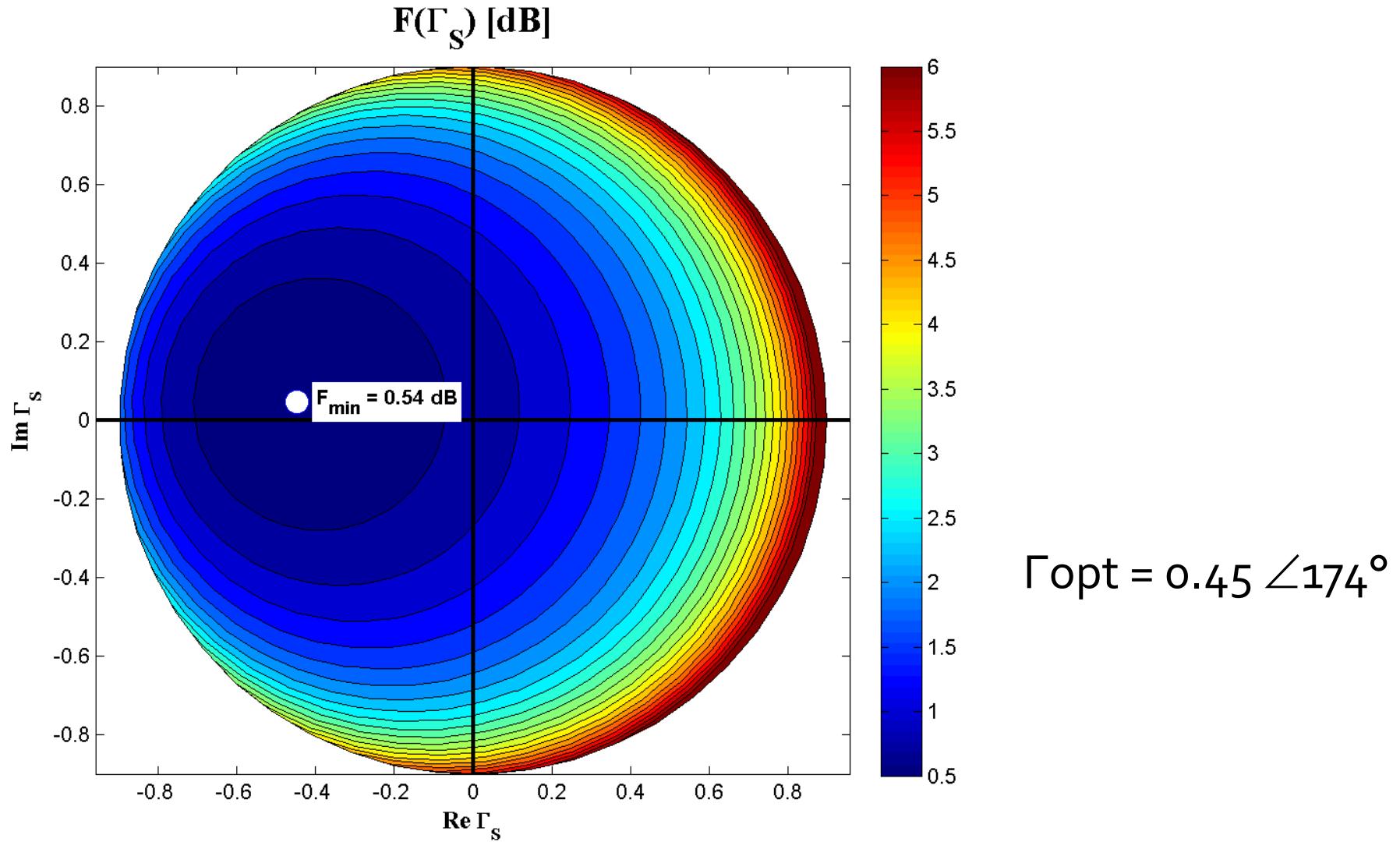
$F(\Gamma_S) [dB]$



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



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



# Cercuri de zgromot constant

- Se noteaza cu  $N$  (parametru de zgromot)
  - $N$  constant pentru  $F$  constant

$$N = \frac{|\Gamma_S - \Gamma_{opt}|^2}{1 - |\Gamma_S|^2} = \frac{F - F_{\min}}{4 \cdot r_n} \cdot \left|1 + \Gamma_{opt}\right|^2$$

$$(\Gamma_S - \Gamma_{opt}) \cdot (\Gamma_S^* - \Gamma_{opt}^*) = N \cdot (1 - |\Gamma_S|^2)$$

$$\Gamma_S \cdot \Gamma_S^* + N \cdot |\Gamma_S|^2 - (\Gamma_S \cdot \Gamma_{opt}^* - \Gamma_S^* \cdot \Gamma_{opt}) + \Gamma_{opt} \cdot \Gamma_{opt}^* = N$$

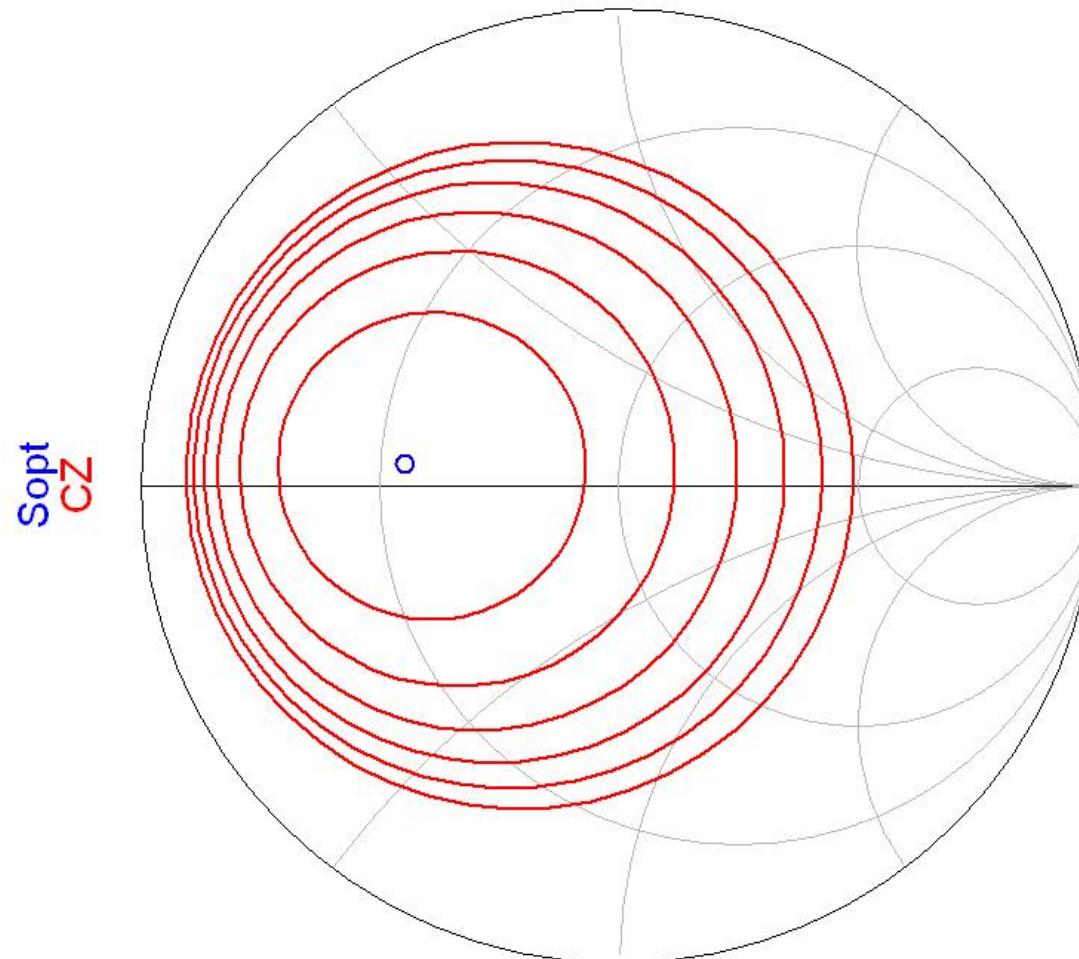
$$\Gamma_S \cdot \Gamma_S^* - \frac{\Gamma_S \cdot \Gamma_{opt}^* - \Gamma_S^* \cdot \Gamma_{opt}}{N+1} + \Gamma_{opt} \cdot \Gamma_{opt}^* = \frac{N - |\Gamma_{opt}|^2}{N+1} \quad \left. + \frac{|\Gamma_{opt}|^2}{(N+1)^2} \right.$$

# Cercuri de zgomot constant

$$\left| \Gamma_S - \frac{\Gamma_{opt}}{N+1} \right| = \frac{\sqrt{N \cdot (N+1 - |\Gamma_{opt}|^2)}}{N+1}$$
$$|\Gamma_S - C_F| = R_F$$
$$C_F = \frac{\Gamma_{opt}}{N+1}$$
$$R_F = \frac{\sqrt{N \cdot (N+1 - |\Gamma_{opt}|^2)}}{N+1}$$

- Locul geometric al punctelor caracterizate de factor de zgomot constant este un cerc
- **Interpretare:** Orice punct  $\Gamma_S$  care reprezentat in planul complex se gaseste **pe** cercul desenat pentru  $F_{cerc}$  va conduce la obtinerea factorului de zgomot  $F = F_{cerc}$ 
  - Orice punct **in exteriorul** acestui cerc va genera un factor de zgomot  $F > F_{cerc}$
  - Orice punct **in interiorul** acestui cerc va genera un factor de zgomot  $F < F_{cerc}$

# ADS



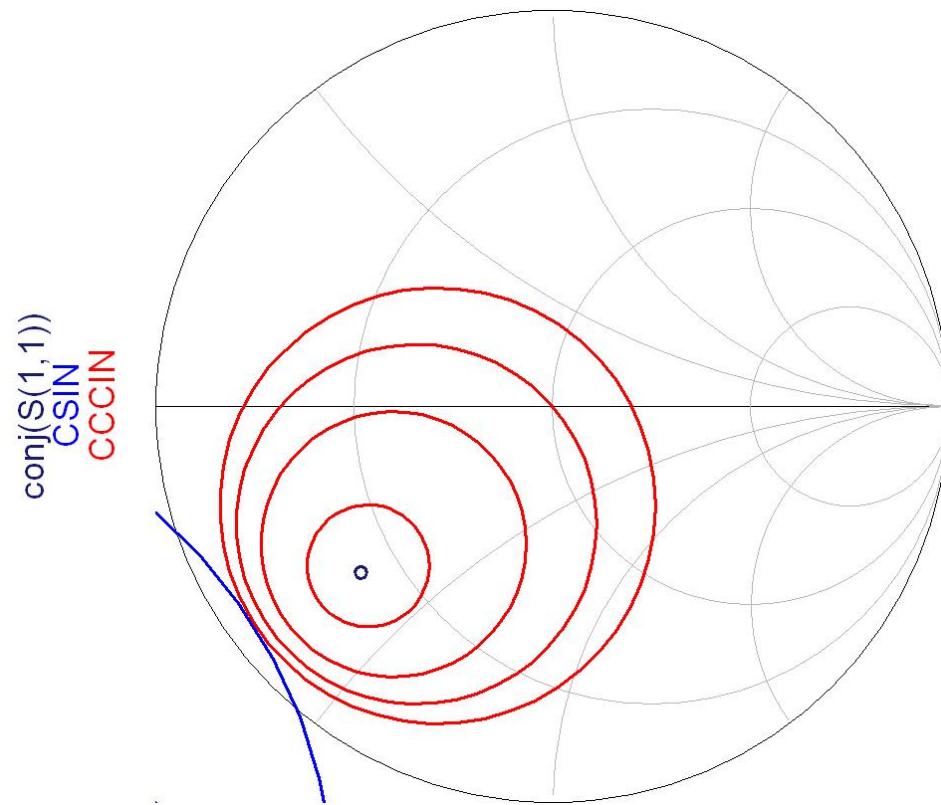
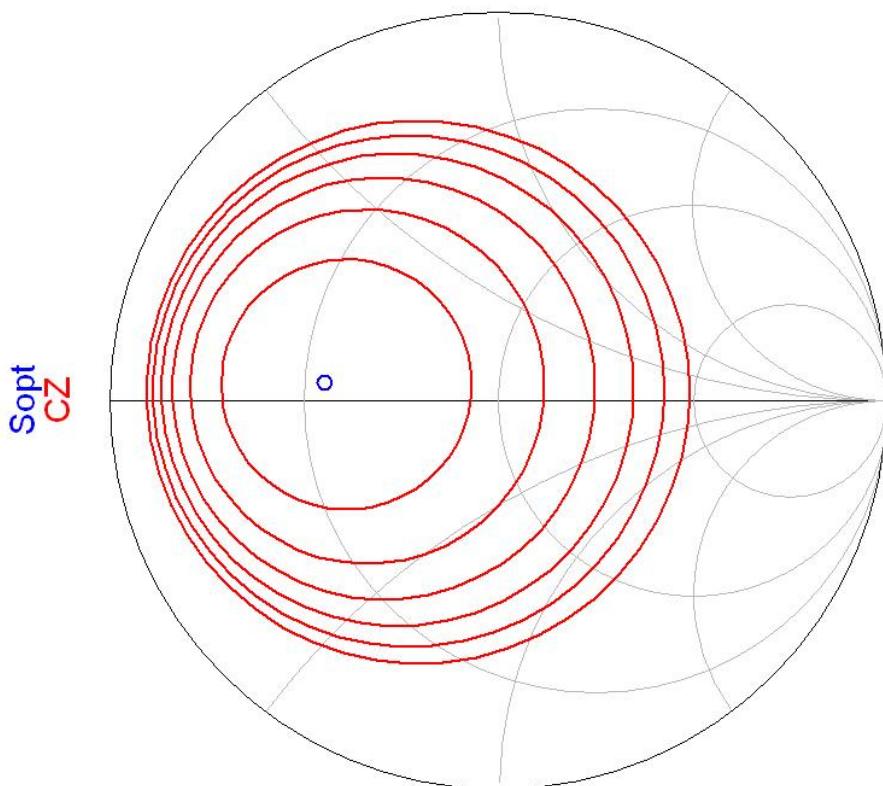
cir\_pts (0.000 to 51.000)  
freq (5.000GHz to 5.000GHz)

# Cercuri de zgomot constant

- Se observa ca zgomotul generat de tranzistor depinde numai de modul in care se realizeaza adaptarea la intrare
- Se poate obtine un minim ( $F_{\min}$  care este parametru de catalog pentru tranzistor)
- Daca se urmareste realizarea unui amplificator de zgomot redus (LNA) o metoda uzuala este:
  - adaptarea la intrare a tranzistorului din considerente de zgomot
  - adaptarea la iesire utilizata pentru compensarea castigului (daca sunt elemente cu pierderi adaptarea la iesire poate adauga zgomot propriu, dar nu se influenteaza in nici un fel zgomotul generat de tranzistor)

# 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  $\Gamma_s$



# Exemplu, LNA @ 5 GHz

- ATF-34143 **at Vds=3V Id=20mA.**
- @5GHz
  - $S_{11} = 0.64 \angle 139^\circ$
  - $S_{12} = 0.119 \angle -21^\circ$
  - $S_{21} = 3.165 \angle 16^\circ$
  - $S_{22} = 0.22 \angle 146^\circ$
  - $F_{min} = 0.54$  (**tipic [dB] !**)
  - $\Gamma_{opt} = 0.45 \angle 174^\circ$
  - $r_n = 0.03$

# 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)

# Exemplu, LNA @ 5 GHz

$$U = \frac{|S_{12}| \cdot |S_{21}| \cdot |S_{11}| \cdot |S_{22}|}{(1 - |S_{11}|^2) \cdot (1 - |S_{22}|^2)} = 0.094 \quad -0.783 \text{ dB} < G_T[\text{dB}] - G_{TU}[\text{dB}] < 0.861 \text{ dB}$$

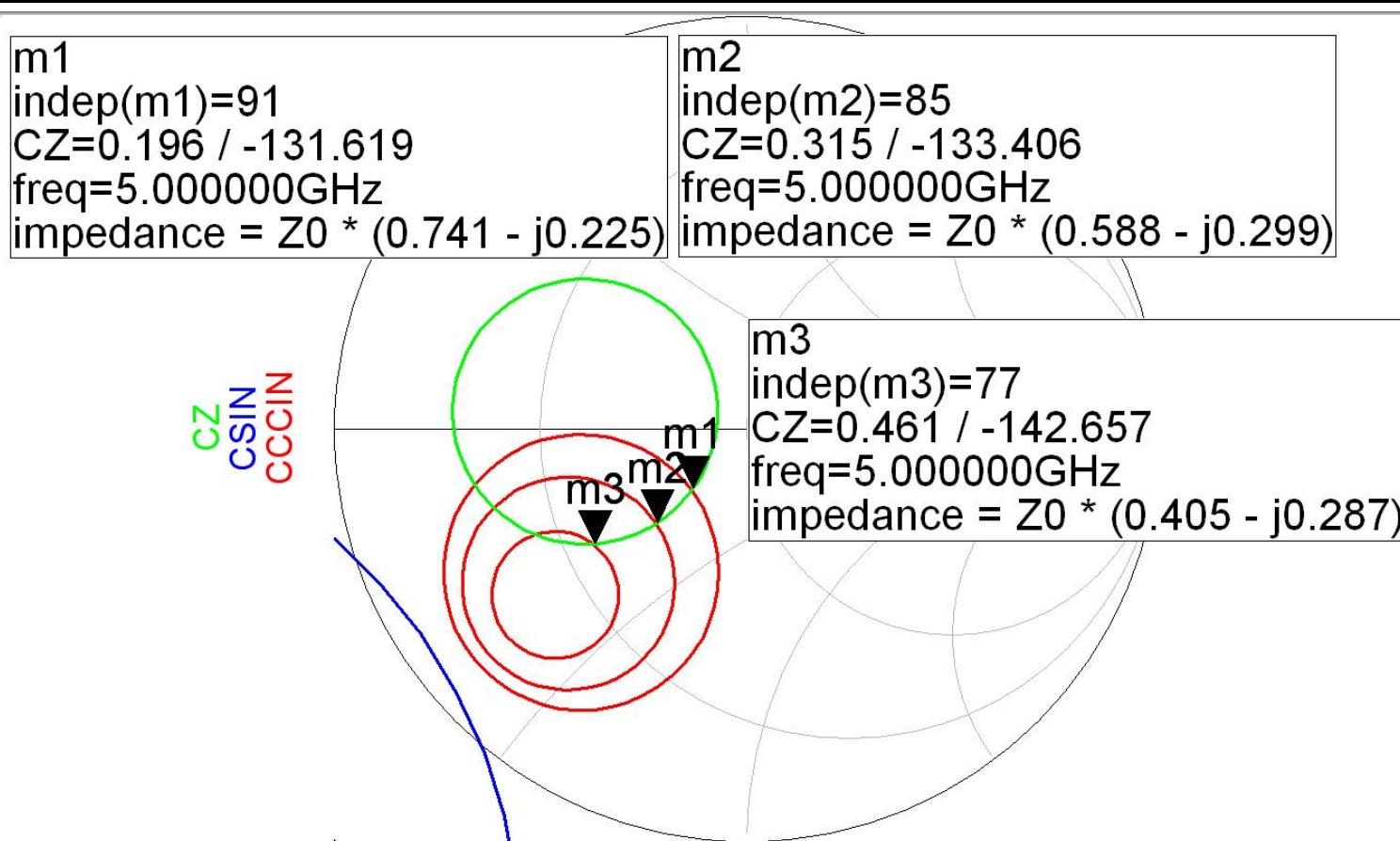
$$G_{TU\max} = \frac{1}{1 - |S_{11}|^2} \cdot |S_{21}|^2 \cdot \frac{1}{1 - |S_{22}|^2} = 17.83 \quad G_{TU\max}[\text{dB}] = 12.511 \text{ dB}$$

$$G_0 = |S_{21}|^2 = 10.017 = 10.007 \text{ dB}$$

$$G_{S\max} = \frac{1}{1 - |S_{11}|^2} = 1.694 = 2.289 \text{ dB} \quad G_{L\max} = \frac{1}{1 - |S_{22}|^2} = 1.051 = 0.215 \text{ dB}$$

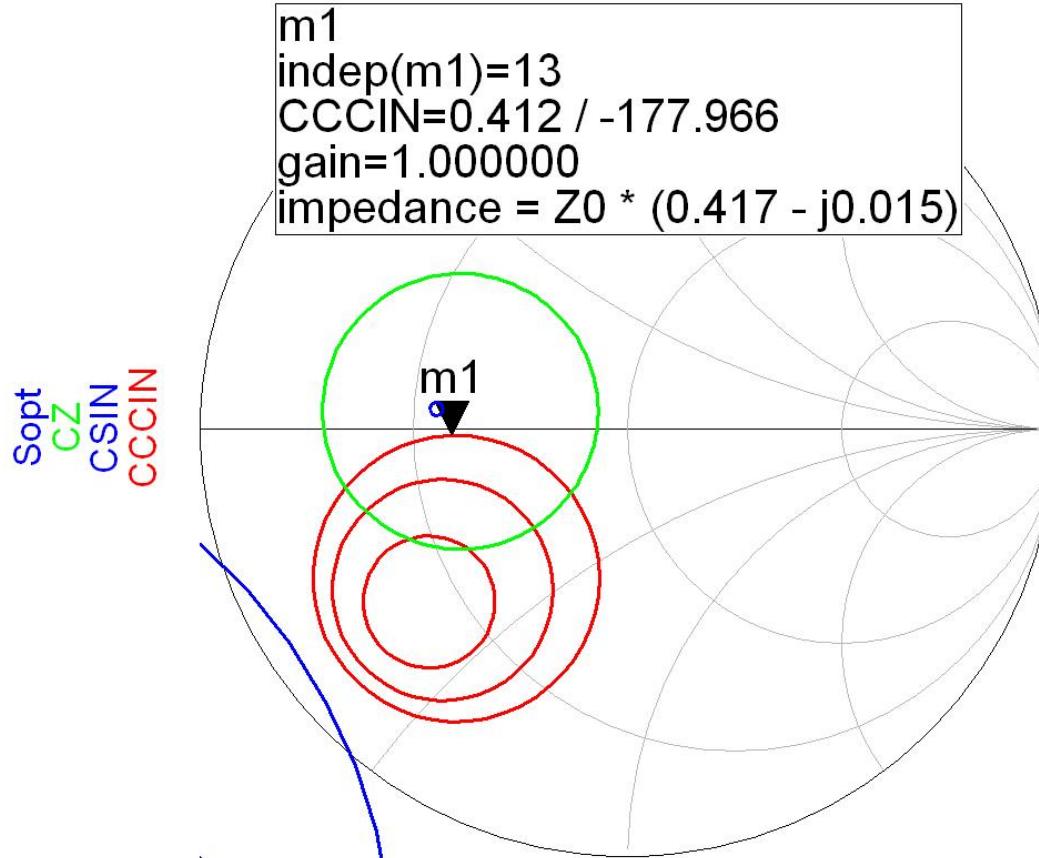
- In cazul particular prezent  $G_{L\max} = 0.21 \text{ dB}$ , amplificatorul ar putea functiona cu iesirea conectata direct la o sarcin de  $50\Omega$
- Absenta retelei de adaptare la iesire nu conduce la o pierdere importanta de castig, dar elimina posibilitatea ca prin reglaj sa se compenseze compromisul castig/zgomot introdus la intrare

# Adaptare la intrare



- Pentru reteaua de adaptare la intrare
  - CZ: 0.75dB
  - CCCIN: 1dB, 1.5dB, 2 dB
- Aleg (Q mic → banda largă) pozitia m1

# 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 intrare

## ■ Pozitia m1 de pe grafic

$$\Gamma_S = 0.412 \angle -178^\circ$$

$$|\Gamma_S| = 0.412; \quad \varphi = -178^\circ$$

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

$$\text{Im}[y_S(\theta)] = \frac{\mp 2 \cdot |\Gamma_S|}{\sqrt{1 - |\Gamma_S|^2}}$$

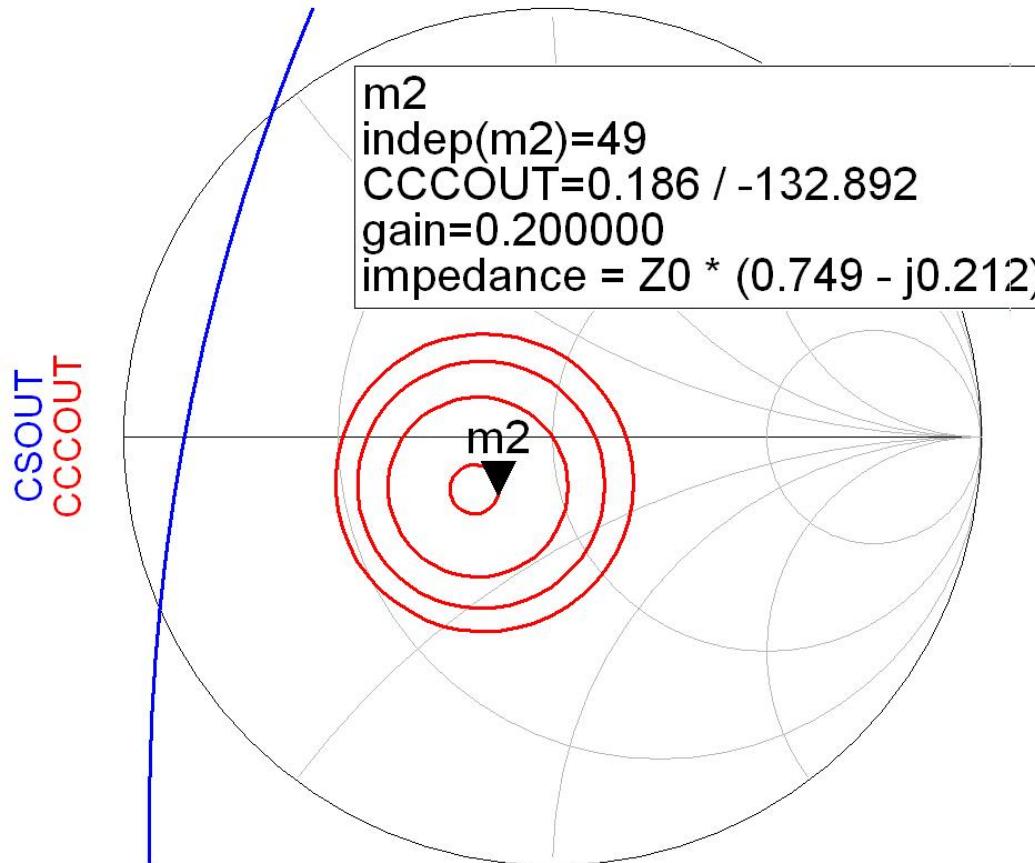
$$\cos(\varphi + 2\theta) = -0.412 \Rightarrow (\varphi + 2\theta) = \pm 114.33^\circ$$

---

$$(\varphi + 2\theta) = \begin{cases} +114.33^\circ \\ -114.33^\circ \end{cases} \quad \theta = \begin{cases} 146.2^\circ \\ 31.8^\circ \end{cases} \quad \text{Im}[y_S(\theta)] = \begin{cases} -0.904 \\ +0.904 \end{cases} \quad \theta_{sp} = \begin{cases} 137.9^\circ \\ 42.1^\circ \end{cases}$$

---

# 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)

# Adaptare la ieșire

## ■ Pozitia m2 de pe grafic

$$\Gamma_L = 0.186 \angle -132.9^\circ$$

$$|\Gamma_L| = 0.186; \quad \varphi = -132.9^\circ$$

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

$$\text{Im}[y_L(\theta)] = \frac{-2 \cdot |\Gamma_L|}{\sqrt{1 - |\Gamma_L|^2}} = -0.379$$

$$\cos(\varphi + 2\theta) = -0.186 \Rightarrow (\varphi + 2\theta) = \pm 100.72^\circ$$

---

$$(\varphi + 2\theta) = \begin{cases} +100.72^\circ \\ -100.72^\circ \end{cases} \quad \theta = \begin{cases} 116.8^\circ \\ 16.1^\circ \end{cases} \quad \text{Im}[y_L(\theta)] = \begin{cases} -0.379 \\ +0.379 \end{cases} \quad \theta_{sp} = \begin{cases} 159.3^\circ \\ 20.7^\circ \end{cases}$$

---

# LNA

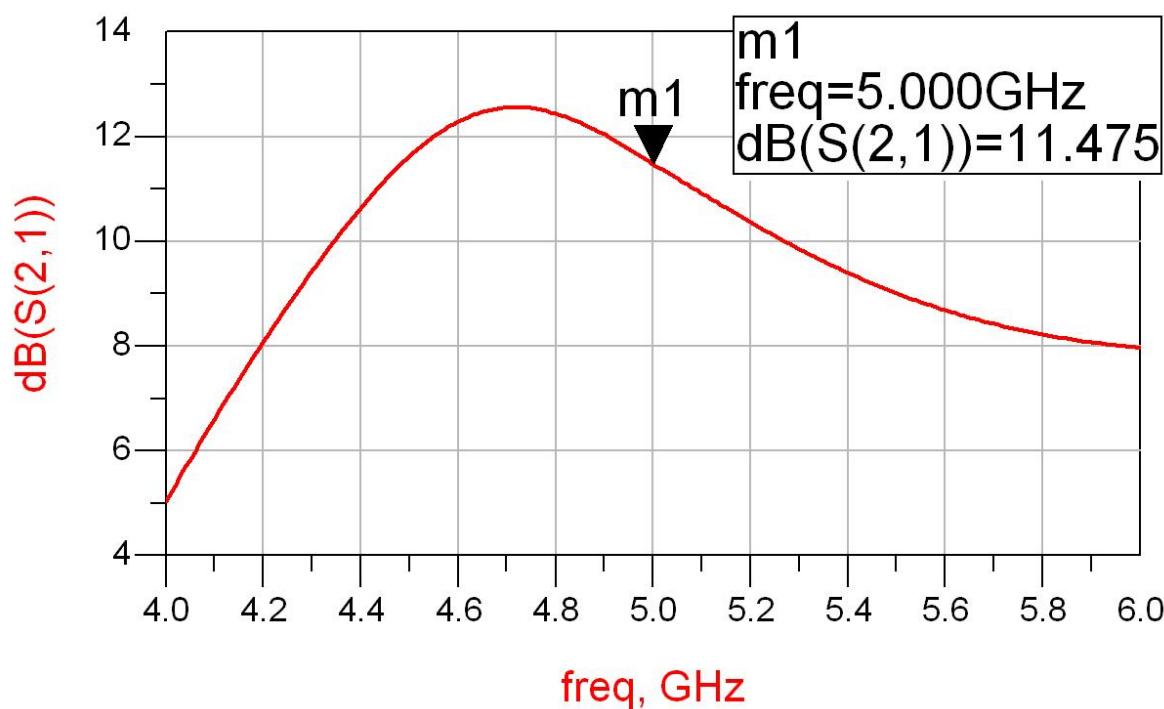
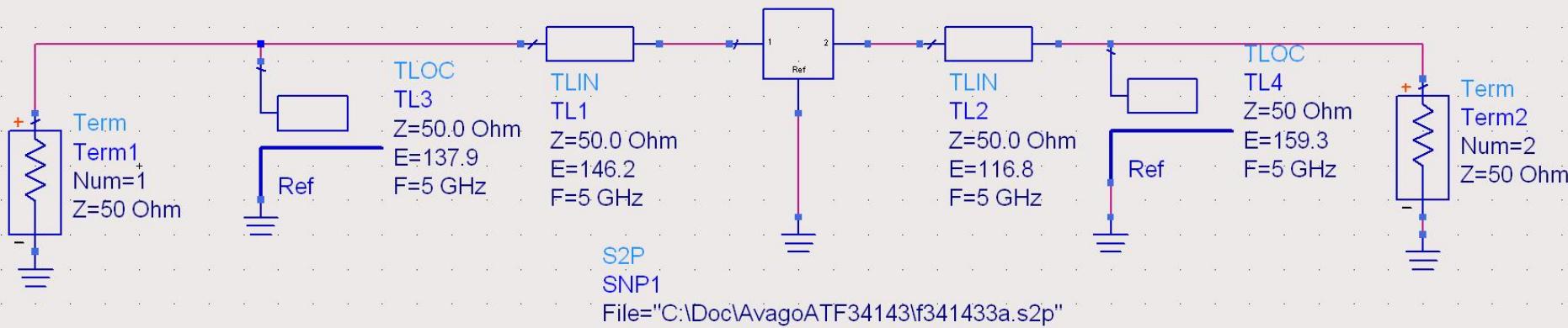
- Se estimeaza obtinerea unui castig (in ipoteza unilaterală,  $\pm 0.9$  dB)

$$G_T[\text{dB}] = G_S[\text{dB}] + G_0[\text{dB}] + G_L[\text{dB}]$$

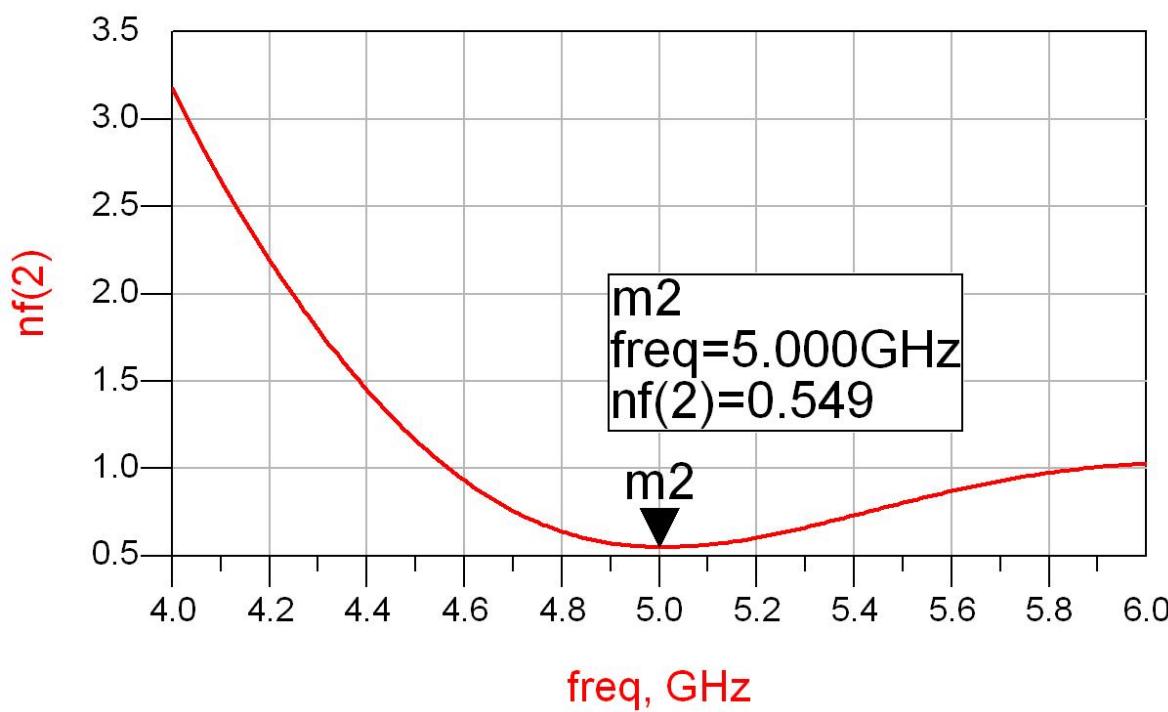
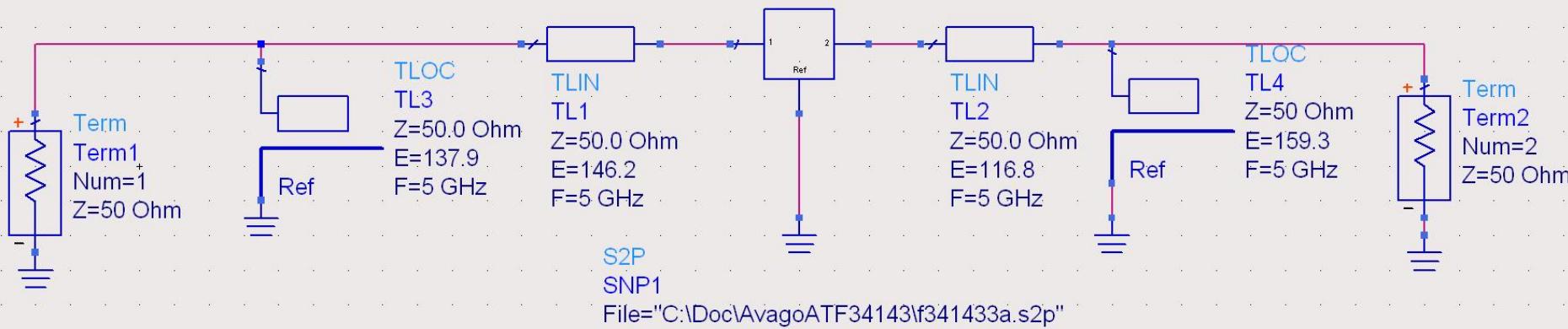
$$G_T[\text{dB}] = 1 \text{ dB} + 10 \text{ dB} + 0.2 \text{ dB} = 11.2 \text{ dB}$$

- Se estimeaza obtinerea unui factor de zgomot sub 0.75 dB (destul de apropiat de minim  $\sim 0.6$  dB)

# ADS



# ADS

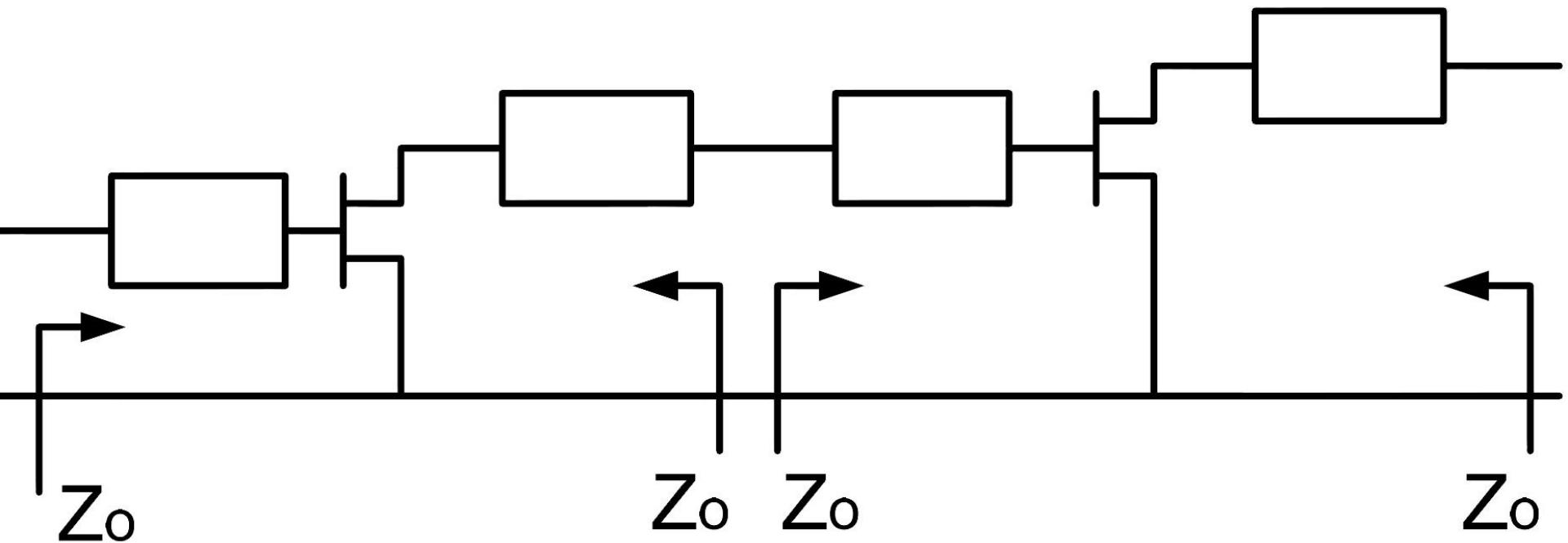


# Amplificatoare in cascada

- Daca e necesar un castig mai mare decat cel care poate fi oferit de un singur tranzistor
- Se utilizeaza formula lui Friis pentru a imparti necesarul de:
  - castig
  - zgomot
- pe cele doua etaje individuale

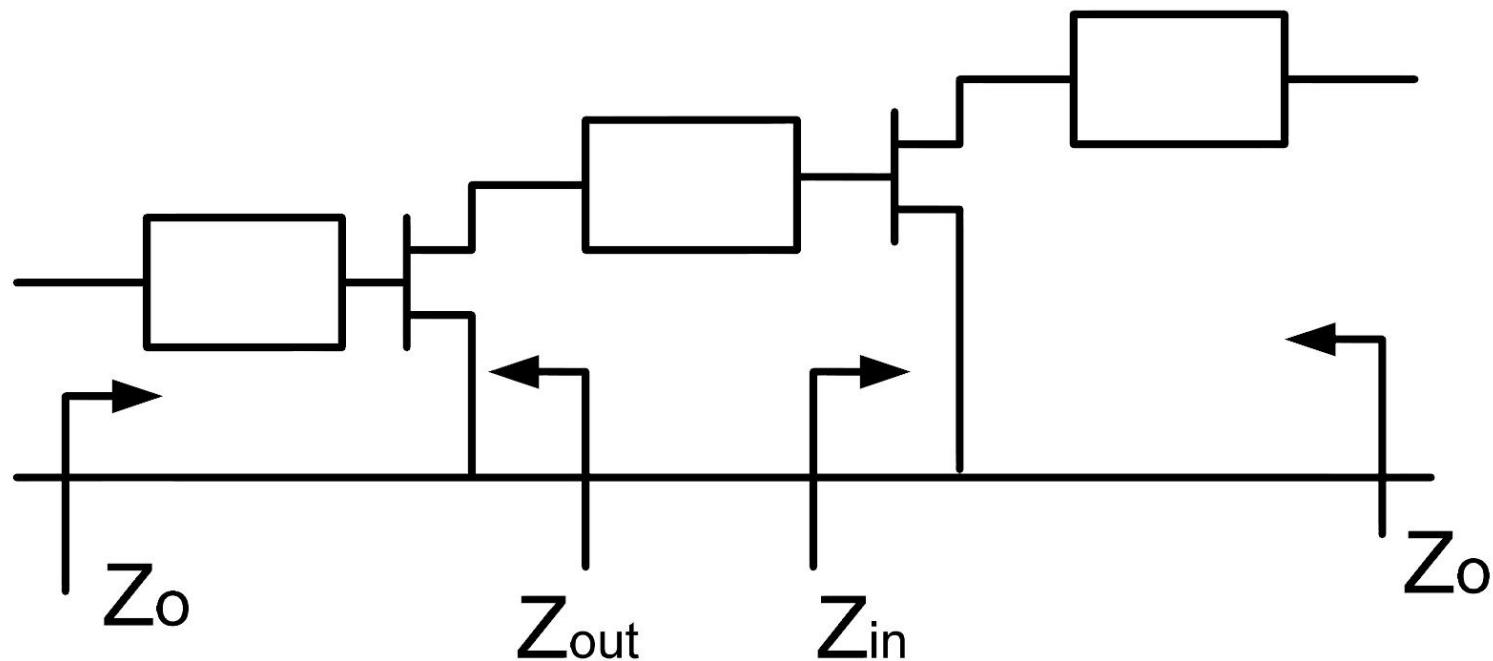
# Amplificatoare in cascada

- Adaptarea inter-etaje se poate projecța în două moduri:
  - adaptarea fiecarui etaj spre un  $\Gamma = \omega$  intermediar



# Amplificatoare in cascada

- Adaptarea inter-etaje se poate projecța în două moduri:
  - adaptarea unui etaj spre  $\Gamma$  necesar pentru celalalt



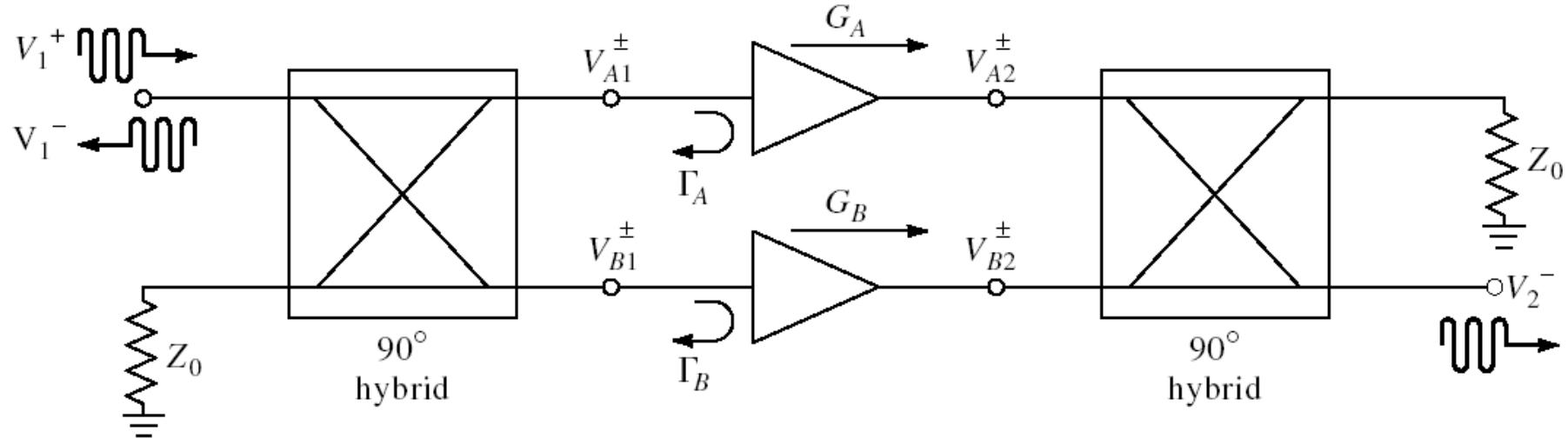
Amplificatoare de banda largă

# **Amplificatoare de microunde**

# Amplificatoare de banda largă

- Se pot obține prin un număr de tehnici de proiectare
  1. Retele de adaptare care să compenseze scaderea castigului cu frecventa
  2. Retele de adaptare rezistive
  3. Reactie negativa
  4. Amplificatoare echilibratе
  5. Amplificatoare distribuite
  6. Amplificatoare diferențiale

# Amplificatoare echilibrate



- 2 Amplificatoare (identice) cu două cuploare hibride 3 dB / 90° la intrare și ieșire

$$S_{21} = \frac{-j}{2} \cdot (G_A + G_B)$$

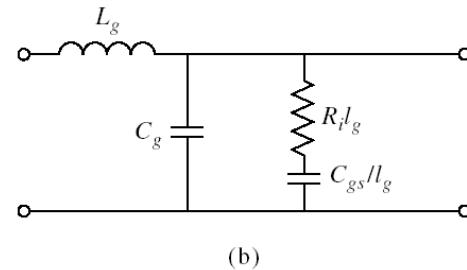
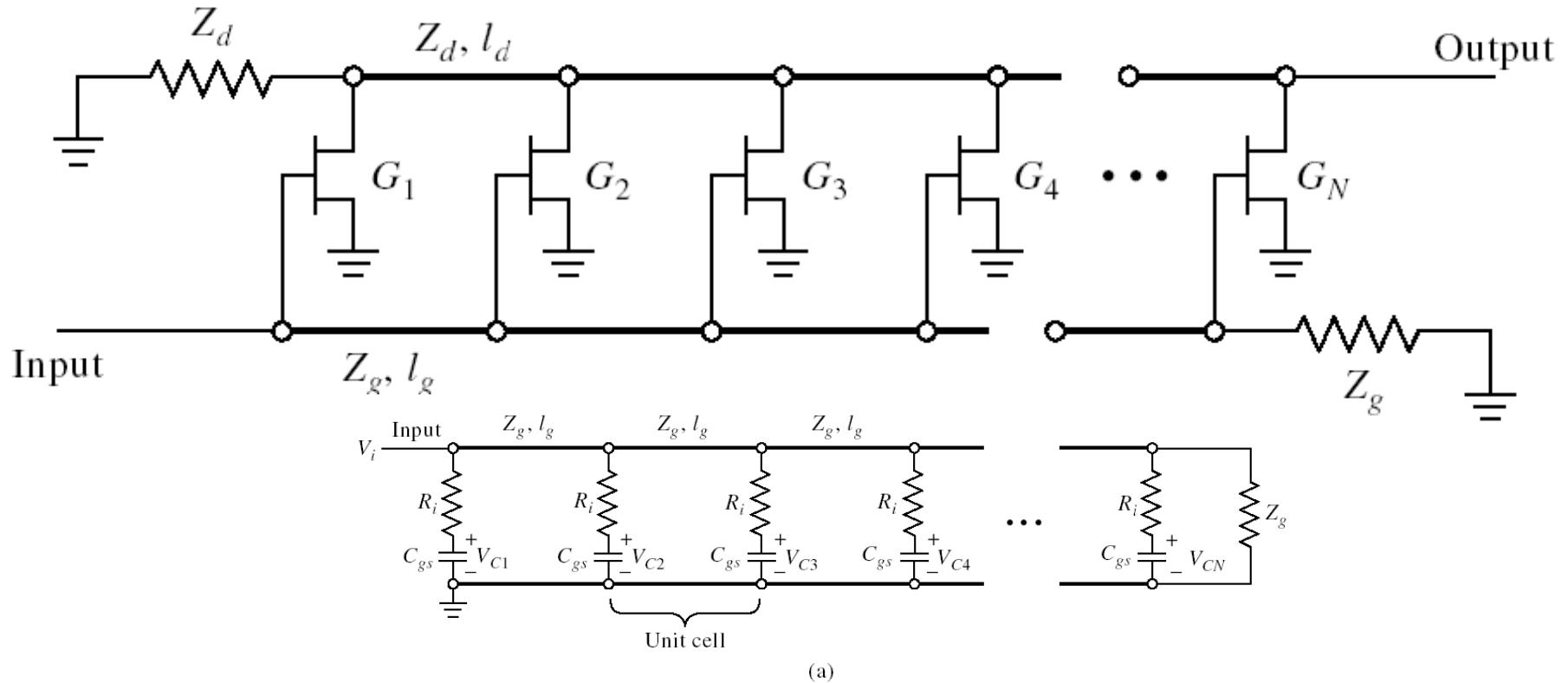
$$S_{11} = \frac{1}{2} \cdot (\Gamma_A - \Gamma_B)$$

$$F = \frac{1}{2} \cdot (F_A + F_B)$$

$$S_{21}|_{A=B} = -j \cdot G$$

$$S_{11}|_{A=B} = 0$$

# Amplificatoare distribuite



# Amplificatoare distribuite

- Conditia de sincronizare
  - intarzierea pe liniile de intrare (grila) egala cu cea de pe liniile de iesire (drena)

$$\gamma_g = \alpha_g + j \cdot \beta_g \quad \gamma_d = \alpha_d + j \cdot \beta_d \quad \beta_g \cdot l_g = \beta_d \cdot l_d$$

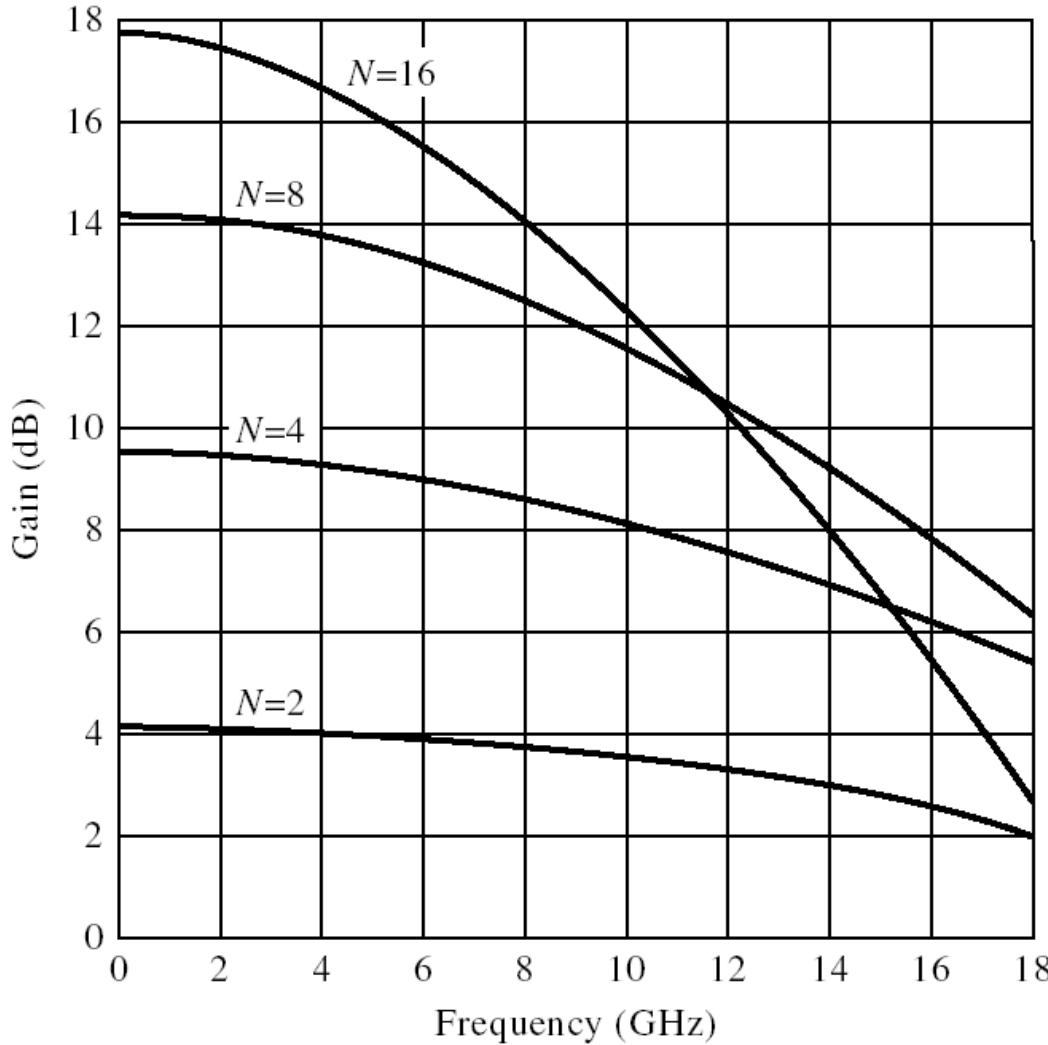
- Castigul de putere

$$G = \frac{g_m^2 \cdot Z_d \cdot Z_g}{4} \cdot \frac{\left( e^{-N \cdot \alpha_g \cdot l_g} - e^{-N \cdot \alpha_d \cdot l_d} \right)^2}{\left( e^{-\alpha_g \cdot l_g} - e^{-\alpha_d \cdot l_d} \right)^2}$$

- Castigul de putere fara pierderi

$$G = \frac{g_m^2 \cdot Z_d \cdot Z_g \cdot N^2}{4}$$

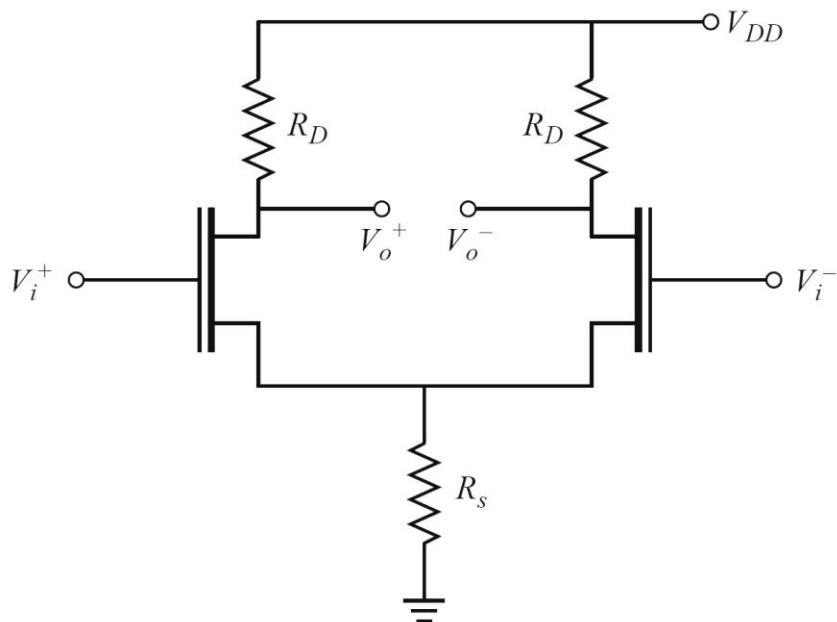
# Amplificatoare distribuite



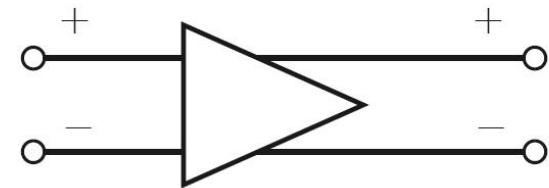
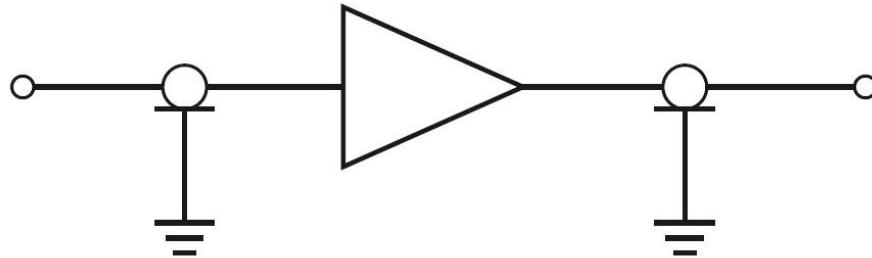
$$N_{opt} = \frac{\ln(\alpha_g \cdot l_g) - \ln(\alpha_d \cdot l_d)}{\alpha_g \cdot l_g - \alpha_d \cdot l_d}$$

# Amplificatoare diferențiale

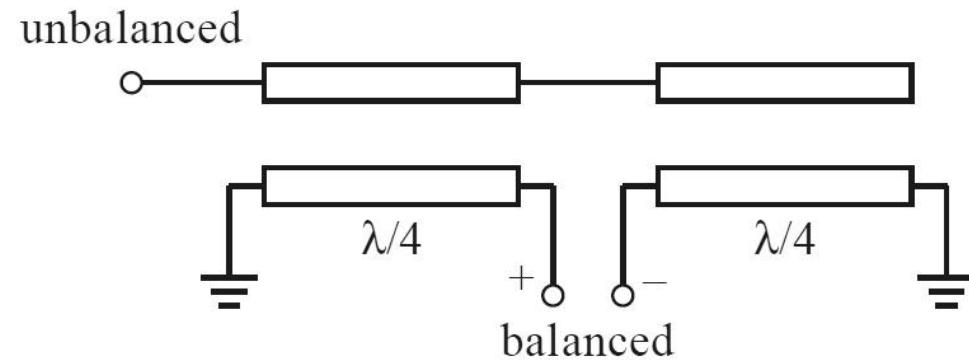
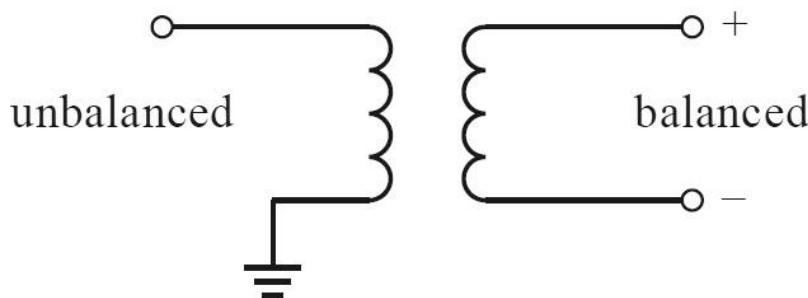
- Capacitatile de intrare în cele două tranzistoare în conexiune diferențială apar conectate în serie
- Se dublează astfel frecvența unitată



# Amplificatoare diferențiale



- Se utilizeaza structuri de circuit care sa faca conversia de la dispozitivele unipolare la cele diferențiale
  - cuploare hibride 3dB /  $180^\circ$
  - "balun" (balanced - unbalanced)



# Contact

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